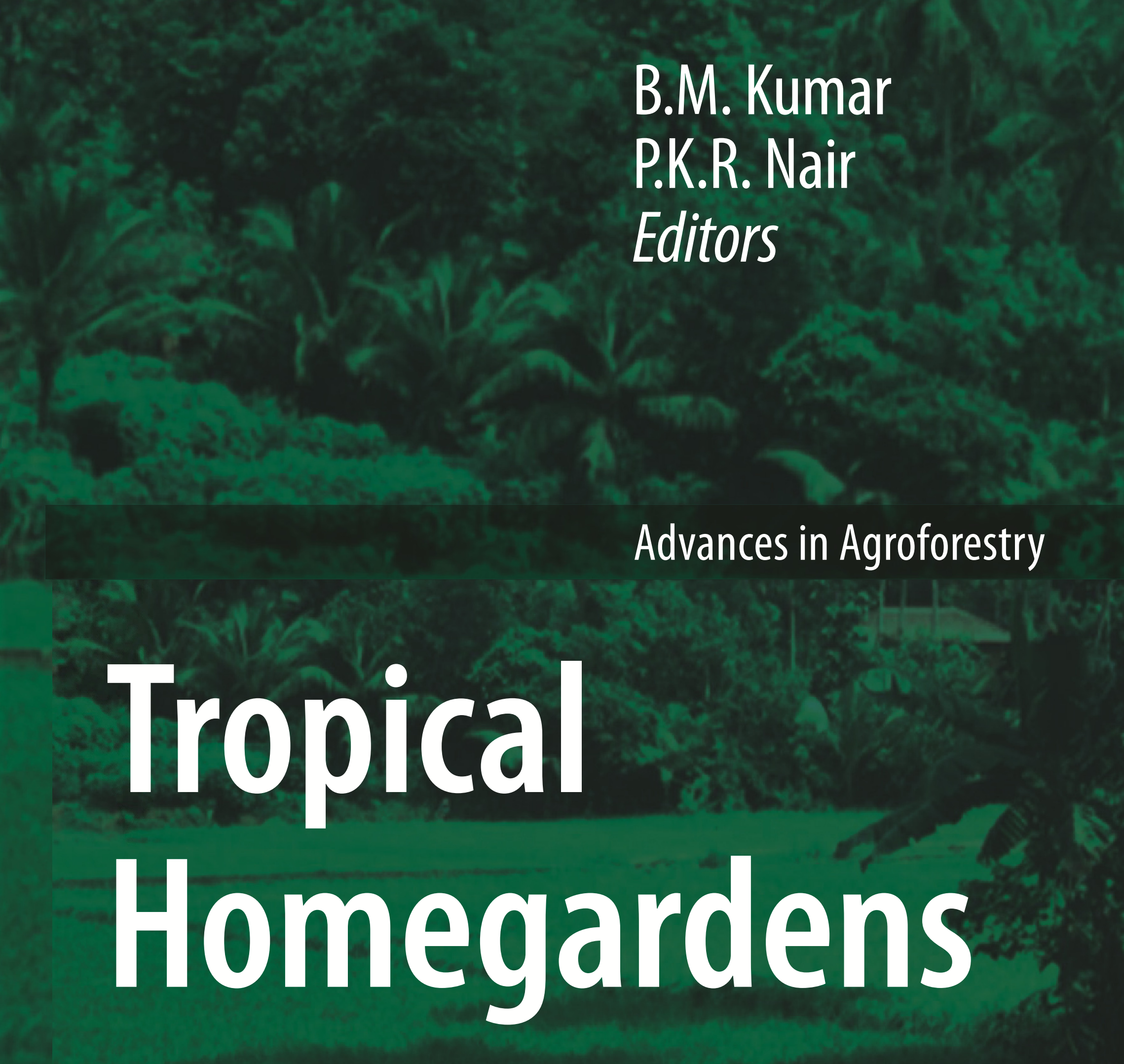

B.M. Kumar
P.K.R. Nair
Editors

Advances in Agroforestry

Tropical Homegardens

A Time-Tested Example of Sustainable Agroforestry

Springer

Tropical Homegardens

Advances in Agroforestry

Volume 3

Series Editor:

P.K.R. Nair
School of Forest Resources and Conservation,
University of Florida, Gainesville, Florida, U.S.A.

Aims and Scope

Agroforestry, the purposeful growing of trees and crops in interacting combinations, began to attain prominence in the late 1970s, when the international scientific community embraced its potentials in the tropics and recognized it as a practice in search of science. During the 1990s, the relevance of agroforestry for solving problems related to deterioration of family farms, increased soil erosion, surface and ground water pollution, and decreased biodiversity was recognized in the industrialized nations too. Thus, agroforestry is now receiving increasing attention as a sustainable land-management option the world over because of its ecological, economic, and social attributes. Consequently, the knowledge-base of agroforestry is being expanded at a rapid rate as illustrated by the increasing number and quality of scientific publications of various forms on different aspects of agroforestry.

Making full and efficient use of this upsurge in scientific agroforestry is both a challenge and an opportunity to the agroforestry scientific community. In order to help prepare themselves better for facing the challenge and seizing the opportunity, agoroforestry scientists need access to synthesized information on multi-dimensional aspects of scientific agroforesty.

The aim of this new book-series, *Advances in Agroforestry*, is to offer state-of-the art synthesis of research results and evaluations relating to different aspects of agroforestry. Its scope is broad enough to encompass any and all aspects of agroforestry research and development. Contributions are welcome as well as solicited from competent authors on any aspect of agroforestry. Volumes in the series will consist of reference books, subject-specific monographs, peer-reviewed publications out of conferences, comprehensive evaluations of specific projects, and other book-length compilations of scientific and professional merit and relevance to the science and practice of agroforestry worldwide.

The titles published in this series are listed at the end of this volume.

Tropical Homegardens

A Time-Tested Example of Sustainable Agroforestry

Edited by

B.M. Kumar

Kerala Agricultural University, India

and

P.K.R. Nair

University of Florida, Gainesville, FL, U.S.A.

Springer

A C.I.P. Catalogue record for this book is available from the Library of Congress.

ISBN-10 1-4020-4947-1 (HB)
ISBN-13 978-1-4020-4947-7 (HB)
ISBN-10 1-4020-4948-X (e-book)
ISBN-13 978-1-4020-4948-4 (e-book)

Published by Springer,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

www.springer.com

Printed on acid-free paper

Printed in the Netherlands.

CONTENTS

List of Contributors vii
Chapter Reviewers xi
Preface xiii

Introduction 1
P.K.R. Nair and B.M. Kumar

Section 1: Historical and Regional Perspectives

Diversity and change in homegarden cultivation in Indonesia 13
K.F. Wiersum

Urban and homegarden agroforestry in the Pacific islands: Current status and future prospects 25
R.R. Thaman, C.R. Elevitch, and J. Kennedy

Amazonian homegardens: Their ethnohistory and potential contribution to agroforestry development 43
R.P. Miller, J.W. Penn, Jr., and J. van Leeuwen

Homegardens of Mesoamerica: Biodiversity, food security, and nutrient management 61
F. Montagnini

Section 2: Structure, Function, and Dynamics of Homegardens

Homegarden dynamics in Kerala, India 87
A. Peyre, A. Guidal, K.F. Wiersum, and F. Bongers

Structure and dynamics of coconut-based agroforestry systems in Melanesia: A case study from the Vanuatu archipelago 105
N. Lamanda, E. Malézieux, and P. Martin

Diversity and dynamics in homegardens of southern Ethiopia 123
Tesfaye Abebe, K.F. Wiersum, F. Bongers, and F. Sterck

Homegarden plant diversity in relation to remoteness from urban centers: A case study from the Peruvian Amazon region 143
A. Wezel and J. Ohl

Gender and social dynamics in swidden and homegardens in Latin America 159
P.L. Howard

Section 3: Some New Thrust Areas

Carbon sequestration potential of tropical homegardens 185
B.M. Kumar

Medicinal plants in tropical homegardens 205
M.R. Rao and B.R. Rajeswara Rao

Commercialization of homegardens in an Indonesian village: Vegetation composition and functional changes 233
O.S. Abdoellah, H.Y. Hadikusumah, K. Takeuchi, S. Okubo, and Parikesit

Transpiration characteristics of some homegarden tree species in Central Sri Lanka 251
W.A.J.M. de Costa, K.S.P. Amaratunga, and R.S. Udumullage

Ecology versus economics in tropical multistrata agroforests 269
E. Torquebiau and E. Penot

Financial analysis of homegardens: A case study from Kerala state, India 283
S. Mohan, J.R.R. Alavalapati, and P.K.R. Nair

Section 4: Future of Homegardens

The role of homegardens in agroforestry development: Lessons from Tomé-Açu, a Japanese-Brazilian settlement in the Amazon 299
M. Yamada and H.M.L. Osaqui

Urban homegardens and allotment gardens for sustainable livelihoods: Management strategies and institutional environments 317
A.W. Drescher, R.J. Holmer, and D.L. Iaquinta

Are tropical homegardens sustainable? Some evidence from Central Sulawesi, Indonesia 339
K. Kehlenbeck and B.L. Maass

Whither Homegardens? 355
P.K.R. Nair

Subject Index 371

LIST OF CONTRIBUTORS

Abdoellah O.S.
Institute of Ecology and Department of Anthropology, Padjadjaran University, Bandung, Indonesia; E-mail <ecology@melsa.net.id> or <oekan@unpad.ac.id>

Alavalapati J.R.R.
School of Forest Resources and Conservation, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611, USA; E-mail <janaki@ufl. edu>

Amaratunga K.S.P.
Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peredeniya 20400, Sri Lanka; E-mail <amarathunga@ucdavis.edu>

Bongers F.
Forest Ecology and Management group, Wageningen University, The Netherlands; E-mail <Frans.Bongers@wur.nl>

De Costa W.A.J.M.
Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peredeniya 20400, Sri Lanka; E-mail <janendrad@yahoo.com>

Drescher A.W.
Albert-Ludwigs-Universität, Freiburg, Germany; E-mail <axel.drescher@sonne.uni-freiburg.de>

Elevitch C.R.
Agroforestry Net Inc., Holualoa, Hawai‘i 96725, USA; E-mail <cre@agroforestry.net>

Guidal A.
Forest and Nature Conservation Policy group, Wageningen University, The Netherlands (present address: GERES-CFSP #45 St.606, Toulkok, PO Box 2528, Phnom Penh-3, Cambodia); E-mail <a.guidal@online.com.kh>

Hadikusumah H.Y.
Institute of Ecology and Department of Biology, Padjadjaran University, Bandung, Indonesia; E-mail <ecology@unpad.ac.id>

Holmer R.J.
Xavier University College of Agriculture, Cagayan de Oro, The Philippines; E-mail <puvep@philcom.ph>

Howard P.L.
Department of Social Sciences, Wageningen University, Hollandseweg 1, 6706 KN Wageningen, the Netherlands; E-mail <Patricia.Howard@wur.nl>

Iaquinta D.L.,
Nebraska Wesleyan University, Lincoln, Nebraska, USA; E-mail <dli@nebrwesleyan.edu>

Kehlenbeck K.
Institute for Crop and Animal Production in the Tropics, Georg-August-University, Grisebachstr. 6, D-37077 Göttingen, Germany; E-mail <katja_kehlenbeck@yahoo.de>

Kennedy J.
Research School of Pacific and Asian Studies, Australian National University, Canberra, Australia; E-mail <jkennedy@coombs.anu.edu.au>

Kumar B.M.
College of Forestry, Kerala Agricultural University, Thrissur 680656, Kerala, India; E-mail <bmkumar53@yahoo.co.uk>

Lamanda N.
CIRAD UMR SYSTEM, TA 80/ 01, Avenue Agropolis, 34 398 Montpellier Cedex 5, France; E-mail <nathalie.lamanda@cirad.fr> or <nlamanda@yahoo.fr>

Maass B.L.
Institute for Crop and Animal Production in the Tropics, Georg-August-University, Göttingen, Grisebachstr. 6, D-37077 Göttingen, Germany; E-mail <bmaass@gwdg.de>

Malézieux E.
CIRAD UMR SYSTEM, TA 80/ 01, Avenue Agropolis, 34 398 Montpellier Cedex 5, France; E-mail <eric.malezieux@cirad.fr>

Martin P.
INA P-G département AGER, bâtiment EGER BP 01 78850 Thiverval-Grignon, France; E-mail <pmartin@inapg.inra.fr>

Miller R.P.
Instituto Olhar Etnográfico, SHIN CA 5 Conj. J Bl. B, Sala 105, Brasília-DF 71505, Brazil; E-mail <robert_safs@yahoo.com.br>

Mohan S.
CREST-RESSACA, Texas A&M University, MSC 213, 700 University Blvd, Kingsville, TX 78363, USA; E-mail <SMohan@eng.tamuk.edu>

Montagnini F.
Yale University, School of Forestry and Environmental Studies, 370 Prospect St., New Haven, CT 06511, USA; E-mail <florencia.montagnini@yale.edu>

Nair P.K.R.
School of Forest Resources and Conservation, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611, USA; E-mail <pknair@ufl.edu>

Ohl J.
School of Biological Sciences, University of East Anglia, Norwich NR4 7TJ, United Kingdom; E-mail <JuliaOhl@gmx.de>

Okubo S.
Department of Ecosystem Studies, Graduate School of Agricultural and Life Sciences, University of Tokyo, Japan; E-mail <aokubos@mail.ecc.u-tokyo.ac.jp>

Osaqui H.M.L.
Division of International Environmental and Agricultural Science, Graduate School of Agriculture, Tokyo University of Agriculture and Technology, 3-5-8 Saiwaichō, Fuchū-shi, Tōkyō 183-8509 Japan; E-mail <osaki@cksonline.net>

Parikesit
Institute of Ecology and Department of Biology, Padjadjaran University, Bandung, Indonesia; E-mail <parikesit@unpad.ac.id>

Penn J. W. Jr.
Grand Valley State University, 1155 Au Sable Hall, Allendale, MI, 49401, USA; e-mail <pennji@gvsu.edu>

Penot E.
CIRAD TERA, TA 60/ 15 – 34398 Montpellier CX5 – France; E-mail <eric.penot@ cirad.fr>

Peyre A.
Forest and Nature Conservation Policy group, Wageningen University, The Netherlands (present address: 50 Avenue Henri GINOUX 92 120 Mont Rouge, France); E-mail <adrien_peyre@hotmail.com> or <adrien_peyre@yahoo.com>

Rajeswara Rao B.R.
Central Institute of Medicinal and Aromatic Plants (CIMAP) Resource Centre, Boduppal, Uppal P.O. Hyderabad 500 039, India; E-mail <brrrao1@rediffmail. com>.

Rao M.R.
Plot No. 11, ICRISAT Colony (Phase-I), Brig. Syed Road, Manovikasnagar (P.O.), Secunderabad–500 009, India; E-mail <mekarao@sol.net.in>

Sterck F.
Forest Ecology and Management group, Wageningen University, The Netherlands; E-mail <Frank.Sterck@wur.nl>

Takeuchi K.
Department of Ecosystem Studies, Graduate School of Agricultural and Life Sciences, University of Tokyo, Japan

Tesfaye Abebe
Debub University, Awassa College of Agriculture, Ethiopia; E-mail <tesfayeabe@ yahoo.com>

Thaman R.R.
The University of the South Pacific, Suva, Fiji Islands; 1487; E-mail <thaman_r@ usp.ac.fj>

Torquebiau E.,
CIRAD TERA, TA 60/15 – 34398 Montpellier CX5, France; E-mail <emmanuel. torquebiau@cirad.fr> or <torquebiau@cirad.fr>

Udumullage R.S.
Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peredeniya 20400, Sri Lanka

van Leeuwen J.
Instituto Nacional de Pesquisas da Amazônia – INPA, Manaus, Amazonas, Brazil; E-mail <leeuwen@vivax.com.br>

Wezel A.
Institute of Landscape and Plant Ecology (320), University of Hohenheim, 70593 Stuttgart, Germany; E-mail <alexanderwezel@tiscali.de>

Wiersum K.F.
Forest and Nature Conservation Policy group, Wageningen University, The Netherlands; E-mail <freerk.wiersum@wur.nl>

Yamada M.
Division of International Environmental and Agricultural Science, Graduate School of Agriculture, Tokyo University of Agriculture and Technology, 3-5-8 Saiwaichō, Fuchū-shi, Tōkyō 183-8509 Japan; E-mail <masaakiy@cc.tuat.ac.jp>

CHAPTER REVIEWERS

Abdoellah, O.S, Padjadjaran University, Bandung, Indonesia

Allen, S.C., University of Florida, USA

Becker, Brian, University of Florida, USA

Bellow, John G., COAPS-Florida State University, USA

Bourdeix, Roland, CIRAD, France

Campilan, Dindo, CIP-Users' Perspectives with Agricultural Research and Development, The Philippines

Clement, C.R., National Research Institute for the Amazon (INPA), Brazil

De Costa, W.A.J.M., University of Peradeniya, Sri Lanka

De Zoysa, Mangala, University of Ruhuna, Kamburupitiya, Sri Lanka

Depommier, Denis, CIRAD-Forêt, Montpellier, France

Doolittle, A.A., Yale University, USA

Fleischman, Forrest, Forest Service Employees for Environmental Ethics, Eugene, USA

Geethakutty, P.S., Kerala Agricultural University, Thrissur, India

Jose, S., University of Florida, USA

Kallarackal, J., Kerala Forest Research Institute, India

Maass, B.L., Georg-August-University, Goettingen, Germany

Miller, R.P., Instituto Olhar Etnográfico, Brazil

Mohan, S., Texas A&M University, USA

Montagnini, Florencia, Yale University, USA

Muraleedharan, P.K., Kerala Forest Research Institute, India

Nair, V.D., University of Florida, USA

Palada, Manuel C., Asian Vegetable Research and Development Centre, Taiwan

Penot, Eric, CIRAD TERA, Montpellier, France

Puri, S., Indira Gandhi Agricultural University, Raipur, India

Rao, J.M., University of Florida, USA

Rao, M.R., Secunderabad, India

Russell, A.E., Iowa State University, USA

Schroth, G., Conservation International, Washington, USA

Torquebiau, E., CIRAD TERA, Montpellier, France

Wiersum, K.F., Wageningen University, The Netherlands

Yamada, Masaaki, Tokyo University of Agriculture and Technology, Japan

PREFACE

Tropical homegardens are a topic of discussion in most agroforestry conferences especially those covering humid tropical lowlands, but publications on this topic are scattered in the literature; comprehensive books and reports focused on it are rare. The motivation for this book was the desire to address that deficiency, following a session on Tropical Homegardens at the 1st World Congress of Agroforestry, Orlando, Florida, USA in June – July 2004 (http://conference.ifas.ufl.edu/wca). The initial idea was to bring out a publication based on the presentations at the Congress session; but consequent to enthusiastic responses from the professional community, the scope of the book was broadened to make it more comprehensive than a conference publication.

As it turned out, only five chapters out of the total 20 in the book are based on presentations at the above Congress session. Three chapters are adaptations from papers that have recently been published (or have been accepted for publication) in *Agroforestry Systems* journal on issues that are important from the point of comprehensiveness of the book. Seven of these eight chapters are research articles and are presented in the conventional research-publication format (Introduction, Materials and Methods, Results, and Discussion); they present a glimpse of the nature of current research in homegardens. All other chapters are review and synthesis of current state of knowledge on homegarden issues from all three developing continents (Africa, Asia, and Latin America & the Caribbean). The chapters are organized into five sections (Historical and Regional Perspectives; Structure, Function, and Dynamics; Some New Thrust Areas; and Future of Homegardens); each section contains a mix of research and review articles. We believe that these 20 chapters represent the state-of-the-art of tropical homegardens today.

The expeditious publication of the book would not have been possible without the cooperation and dedication of the authors and reviewers. All chapters were rigorously peer-reviewed. We thank the reviewers (see the list attached) for their insightful comments and critical suggestions, which helped to enhance the quality of the chapters. The authors too have been a very pleasant and professional group to work with; we greatly appreciate their cooperation and understanding in putting up with our requests for repeated revisions within very short and strict time schedules. Once again, we sincerely thank all the authors and reviewers for their splendid cooperation. Special thanks go to Dr. Michael Bannister, who did an excellent job of reading through the manuscripts and scrutinizing the literature citations.

B. Mohan Kumar, Thrissur, Kerala, India

February 2006 P. K. R. Nair, Gainesville, Florida, USA

CHAPTER 1

INTRODUCTION

P.K.R. NAIR[1] AND B.M. KUMAR[2]

[1]School of Forest Resources and Conservation, University of Florida, Gainesville, FL 32611, USA; E-mail: <pknair@ufl.edu>. [2]College of Forestry, Kerala Agricultural University, Thrissur 680656, Kerala, India; E-mail: <bmkumar53@yahoo.co.uk>

1. THE CONCEPT OF HOMEGARDEN

It is rather customary that any writing on homegardens starts with a "definition" of the term. The first drafts of several chapters in this book were no exception. This indicates that there is no universally accepted "definition" of the term and therefore the authors feel compelled to make their perception clear. An examination of the various "definitions" used or suggested by various authors (of chapters of this book as well as other recent homegarden literature) shows that they all revolve around the basic concept that has been around for at least the past 20 years, i.e., since the "early literature" on the subject (Wiersum, 1982; Brownrigg, 1985; Fernandes and Nair, 1986; Soemarwoto, 1987): *homegardens represent intimate, multistory combinations of various trees and crops, sometimes in association with domestic animals, around the homestead*. This concept has been developed around the rural settings and subsistence economy under which most homegardens exist(ed). But, as some chapters in this book describe, the practice of homegardening is now being extended to urban settings (Drescher et al., 2006; Thaman et al., 2006) as well as with a commercial orientation (Abdoellah et al., 2006; Yamada and Osaqui, 2006).

Even before the advent of such new trends as urban and commercial homegardens, the lack of clear-cut distinctions between various stages in the continuum from shifting cultivation to high-intensity multistrata systems and the various terms used in different parts of the world to denote the different systems has often created confusion in the use of the term homegarden and its underlying concept. The confusion is compounded by the fact that in many parts of the world, especially

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 1-10.

in the New World, swidden farming such as the milpa of Mesoamerica evolve over a period of time into full-fledged homegardens consisting of mature fruit trees and various other types of woody perennials and the typical multistrata canopy configurations. In such situations, it is unclear where the swidden ends and homegarden begins – and often they co-exist. Yet another cause of confusion is the term itself: homegarden. Even for most agricultural professionals who are either not familiar with or are not appreciative of agroforestry practices, what we write as one word 'homegarden' sounds as two words 'home' and 'garden' sending the signal that the reference is to ornamental gardening around homes. While ornamentals are very much a part of homegardens in many societies, homegardens, in our concept, are not just *home gardens* of strictly ornamental nature.

As we explained in our recent paper (Kumar and Nair, 2004), we use the term homegardens (and homegardening) to refer to farming systems variously described in English language as agroforestry homegardens, household or homestead farms, compound farms, backyard gardens, village forest gardens, dooryard gardens and house gardens. Some local names such as *Talun-Kebun* and *Pekarangan* that are used for various types of homegarden systems of Java (Indonesia), *Shamba* and *Chagga* in East Africa, and *Huertos Familiares* of Central America, have also attained international popularity because of the excellent examples of the systems they represent (Nair, 1993). In spite of the emergence of homegardening as a practice outside their "traditional" habitat into urban and commercial settings, the underlying concept of homegardens remains the same as before "intimate, multistory combinations of various trees and crops, sometimes in association with domestic animals, around homesteads." Intimate plant associations of trees and crops and consequent multistory canopy configuration are essential to this concept. Equally important in this concept is the *home* around which most *homegardens* are maintained; but in some situations, multistory tree gardens (such as the *Talun* or *Kebun* of Indonesia: Wiersum, 1982) that are not in physical proximity to homes but receive the same level of constant attention from the owners' household and have similar structural and functional attributes as other homegarden units located near homes are also considered as homegardens.

2. GENESIS AND GLOBAL DISTRIBUTION OF HOMEGARDENS

Tracing the history of homegardening, Kumar and Nair (2004) describe it as the oldest land use activity next only to shifting cultivation that has evolved through generations of gradual intensification of cropping in response to increasing human pressure and the corresponding shortage of arable lands. The Javanese homegardens of Indonesia and the Kerala homegardens of India – the two oft-cited examples – have reportedly evolved over centuries of cultural and biological transformations and they represent the accrued wisdom and insights of farmers who have interacted with environment, without access to exogenous inputs, capital, or scientific skills. Wiersum (2006) mentions that the origin of homegardening in Southeast Asia has been associated with fishing communities living in the moist tropical regions *ca* 13 000 to 9000 B.C. Implying the predominance of homegardens in ancient India, *Vatsyayana* in his great book of Hindu aesthetics – *Kamasutra*, written *ca* 300 to 400 AD, describe house gardens as a source of green vegetables, fig trees (*Ficus* spp.), mustard (*Brassica* spp.) and many other vegetables (*c.f.* Randhawa, 1980). Ibn Battuta in his travelogue (1325 – 1354) also wrote that the densely populated and intensively cultivated landscape with coconut (*Cocos nucifera*), black pepper (*Piper nigrum*), ginger (*Zingiber officinale*), sugarcane (*Saccharum officinarum*), pulses (grain legumes) and the like surrounding the houses formed a distinctive feature of the Malabar coast of Kerala (Randhawa, 1980). In both Java and Kerala, homegardening has been a way of life for centuries and is still critical to the local subsistence economy and food security (Kumar and Nair, 2004). This is true of several other Old World homegardens as well (e.g., the Chagga of Mt. Kilimanjaro in East Africa: Fernandes et al., 1984; Soini, 2005).

In spite, or perhaps because, of the pre-historic origin of the practice, accurate data on the extent of area under homegardens are not available. Estimating the area of homegardens is beset with several problems (Kumar, 2006). A major one is the lack of distinct boundaries or demarcation between homegardens and other cultivated agricultural fields. As Tesfaye Abebe et al. (2006) point out; most homegardens studies are focused on gardens that constitute a component of a farming system consisting of cultivated fields away from homes complemented by the homegardens surrounding residential houses. In those situations, it is difficult to determine where homegardens end and other cultivated fields begin. Added to this problem is the "commodity-centric" approach to recording land use statistics: statistics are prepared and presented for specific (single) crops and commodities. In most cases, the area is listed under the most conspicuous or visible crop (e.g., fruit trees, coconut palms, and other trees that occupy the upper stratum of multistoried homegarden system) and the lower-story crops are seldom reported – and, often the reporting forms do not allow entries to be made of such mixed stands. Thus, homegardens are a "non-entity" for agricultural statistics and land revenue records.

In spite of these difficulties, some efforts have been made in compiling statistics on the spread of homegardens. Such estimates include 5.13 million ha of land under *pekarangans* in Indonesia, 0.54 million ha under homesteads in Bangladesh, 1.05 million ha in Sri Lanka, and 1.44 million ha in Kerala, India (Kumar, 2006). Christanty (1990) reported that more than 70% of all households in the Philippines maintained homegardens; but the extent of area occupied by them was not reported. Area statistics of homegardens are also not available from a number of other parts of the world although the prevalence of the practice – indeed predominance in many situations – has been reported from various parts of the tropics as several chapters in this volume also attest to. In an attempt to present a global distribution of homegardens, we selected 135 entries from the CABI Abstracts for the period from 1990 to 2003 for which geographical locations are either mentioned or can be deduced; these included: Africa 21, Europe (Catalonia, Austria, etc.) 10, Central and South America 23, South Asia 45, Southeast Asia 30, other parts of Asia 2, Pacific islands 4. Based on these reports, supplemented with available statistics from other sources (e.g., reports on agricultural censuses) as well as personal experiences and observations of the authors, we have attempted a "Homegarden Map of the World" as presented in Fig. 1. The presentation only means that homegardens are present in

Explanation of Figure 1.

The global distribution of homegardens. This attempt is based on the geographical distribution of 135 selected studies (the specific geographical locations of which are reported or can be deduced) from the CABI abstracts for the period from 1990 to 2003, including Africa (21 studies), Europe: Catalonia, Austria, and others (10), Central and South America (23), South Asia (45), Southeast Asia (30), other parts of Asia (2), and Pacific Islands (4), supplemented with available statistics from other sources (e.g., reports on agricultural censuses) and authors' experiences/observations. Differing shade intensities in the figure represent high, moderate, and low frequency of occurrence of homegardens. We have used 'High' for areas where the frequency of occurrence in the CABI abstracts is more than 20 and/or if other databases (Statistical Yearbook 2000, Bangladesh Bureau of Statistics; Statistical Yearbook of Indonesia 2000, *Badan Pusat Statistik*; Census of Agriculture – Sri Lanka 2002. Agricultural holdings, extent under major crops and livestock statistics by district and DS/AGA division—based on operator's residence: small holding sector, Colombo; Land Resources of Kerala State 1995, Kerala State Land Use Board; see Kumar, 2006 for full citations) report that more than 50% of all households maintain homegardens, 'Medium' for 10 to 20 mentions in CABI abstracts or 25 to 50% of the households maintain homegardens according to the other reports listed above, and 'Low' for all those cases where presence of homegardens has been reported in one or more ways but at levels below the above limits. "Apparently present" is the term used to denote regions where homegardens are said to be abundant based on the authors' personal observations and/or communications from other sources, but on which published (accessible) information, especially on their area statistics, is limited or absent; such regions include tropical and subtropical parts of China, and some such other regions in Asia and Africa. The presentation only means that homegardens are present in the regions as indicated; it does not imply that homegardens are the only or the major land use system in any of these regions.

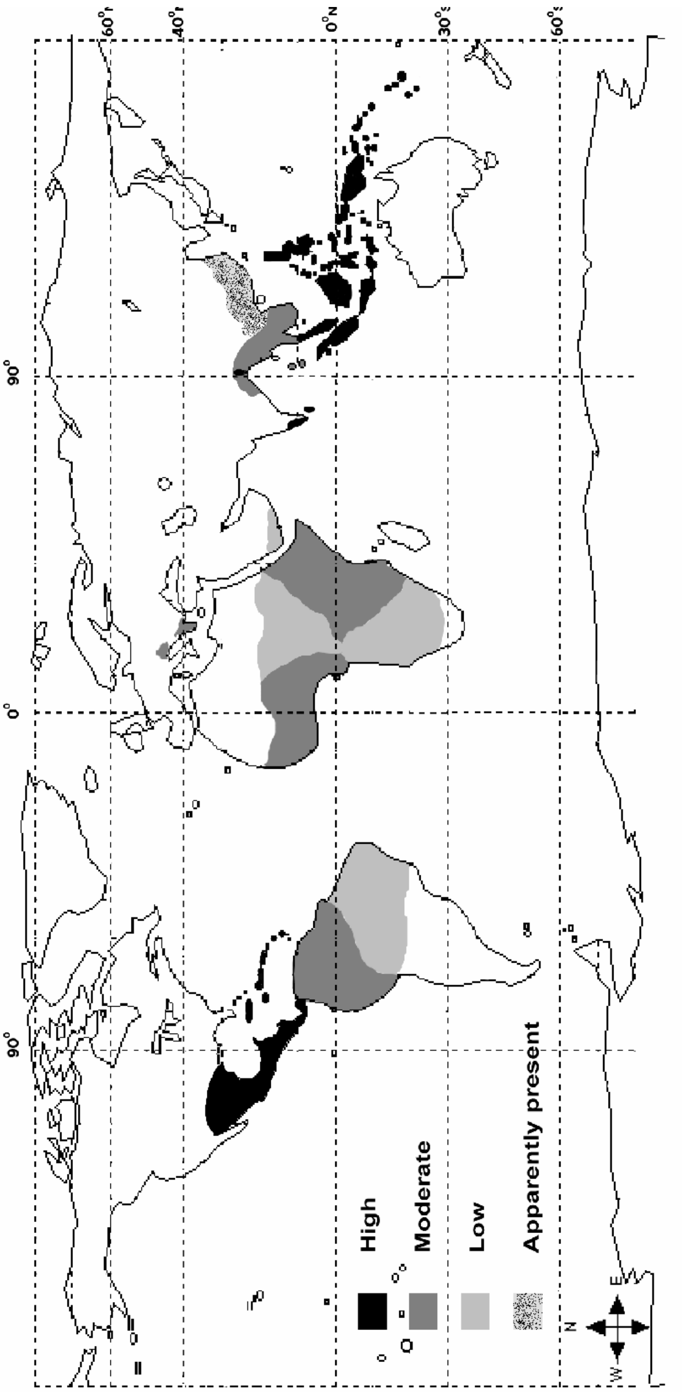

Figure 1. *The global distribution of homegardens (see description on the left hand side, p. 4).*

the regions as indicated; it does not imply that homegardens are the only or major land use system in any of these regions.

Based on the above, it is reasonable to assume that homegardens are most popular in the tropics, but can also be found between 40^{o}N and 30^{o}S latitudes. South- and Southeast Asia, the Pacific islands, East- and West Africa, and Mesoamerica are the regions where largest concentrations of homegardens can be found. Homegardens are also reportedly very popular in tropical and subtropical parts of China; however, other than general descriptions of the systems (e.g., Zhaohua et al., 1991; Wenhua, 2001), practically no information could be gathered on their area statistics. The Mediterranean region of Catalonia (Agelet et al., 2000) and southern Africa (High and Shackleton, 2000) also are reported to have homegardens. In terms of ecological distribution, the highest concentrations of homegardens are in the humid and subhumid tropics, but they are also common in other ecological regions, especially the tropical highlands of Asia, Africa, and Mesoamerica (Nair, 1989). Clearly, our understanding about the spread of homegardens is incomplete; more efforts are needed to compile these statistics at local, regional, national, and global levels.

Although homegardens are known as a predominantly tropical ‘phenomenon’, homegardening – or, conceptually similar practices – exist outside the tropical zone as well. For instance, Gold and Hannover (1987) and Herzog (1998) describe fruit-tree based agroforestry systems in North America and Europe, respectively. Vogl and Vogl-Lukasser (2003) reported that homegardens were typical elements of the mosaic of agroecosystems in the mountainous Alpine region of Austria. *Streuobst* (fruit trees grown on agricultural lands with crops or pasture as understorey), a traditional practice in Europe that has been on the decline since around 1930s, is now receiving increasing attention and acceptance among the general public and promoted by nongovernmental and conservation agencies. Although the fruit-tree based agroforestry systems are strictly not homegardening, such systems occasionally involve homegardening, and their socio-cultural, ecological, and aesthetic values often exceed their economic values. Based on an extensive survey and interview with practitioners of African-American gardening traditions in the rural southern United States, Westmacott (1992) traced the principal functions and features of African-American yards and gardens. During slavery, the gardens were used primarily to grow life-sustaining crops and vegetables, and the yard of a crowded cabin was often the only place where the slave family could assert some measure of independence and perhaps find some degree of spiritual refreshment. Since slavery, working the garden for the survival of the family has become less urgent, but there seems to be a revival of appreciation of their recreational, social, and other uses. For example, the gardeners are now finding pleasure in growing flowers and produce and deriving satisfaction from agrarian life-style, self-reliance, and private ownership. Through historical research, field observations, and oral interviews, Westmacott (1992) traces the West African roots of this gardening tradition and elucidates how the African-American community manipulated the garden space to their best advantage – something very similar to the motivations of subsistence gardeners in well-established homegardens in other parts of the world (Fig. 1).

Related to the above-mentioned "African-American Yards and Gardens" of the southern United States is the increasing interest in hobby farming and weekend gardening that is getting popular in many urban and rapidly urbanizing societies in both industrialized and developing nations. Drescher et al. (2006) describe the urban homegardens and some of the operational and institutional issues related to them from a number of locations around the world. In a survey of agroforestry practices and opportunities in southeastern United States, Workman et al. (2003) identified several "special applications" of agroforestry such as use of fruit trees combined with gardens, ponds, and as bee forage and so-called patio gardens as an increasingly popular activity especially among immigrant Latin American communities. Thus, although homegardening as a major land use practice is most widespread in thickly populated tropical regions, the concept is being adopted in other geographical regions as well to a limited extent.

3. COMPLEXITY OF HOMEGARDENS

Species diversity is one factor that is common to all homegardens, and this point has been well brought out in homegarden literature time and again. Indeed, authors tend to get nostalgic about describing how diverse the plant communities in homegardens are and rather adamant about including elaborate species lists in their papers on homegardens to the extent that many seem to consider that a paper on any aspect of homegarden is incomplete without a species list! Interestingly, most of the plants that are listed in most such publications are the same irrespective of the geographical regions from where they are reported (see Nair, 2006). As various analyses and summary reports have repeatedly indicated (e.g., Kumar and Nair, 2004), food plants (food crops and fruit trees) are the most common species in most homegardens throughout the world. This underscores the fact that food- and nutritional security is the primary role of homegardens – again, a point well recognized in homegarden literature right from the "early" years (e.g., Brownrigg, 1985; Fernandes and Nair, 1986). Next in importance to food crops are cash crops, and with increasing trend toward commercialization, the interest in such crops is likely to only increase.

We recognize that complexity by itself may not be a desirable attribute in land use systems that are (also) expected to fulfill production objectives. Being located on the "prime land" around homesteads and receiving utmost managerial attention of the homeowners all the time, farmers have high expectations of productivity from homegardens. After all, farmers decide on the species to be planted and retained in the homegardens based on the utilitarian value of the species. Species complexity in homegardens is therefore not a natural phenomenon, but a result of deliberate attempts and meticulous selection and management by farmers to provide the products they consider are important for their subsistence and livelihood. Species complexity in homegardens is thus a manmade feature, unlike in natural systems. This distinction is seldom recognized in comparisons involving ecological indices of species diversity of homegardens, several of which have lately been reported (see Nair, 2006).

Furthermore, it is likely that the extreme structural complexity and diversity may be a "bane" of the homegardens in a sense. Each homegarden is a unique land use entity in terms of component arrangement, organization, and management, and it reflects the personal preferences of its owner. This frustrates the development community that seeks out "replicable models"; this is presumably the main reason why homegardens have not received adequate attention in the development paradigms around the world.

4. HOMEGARDENS IN THE CONTEXT OF CONTEMPORARY LAND USE ISSUES

Today land use systems are challenged as never before with mounting concerns of environment and ethics on the one hand and pressures of economic development on the other. Production and economic issues that reigned supreme as ultimate goals in agricultural and forestry development activities during the past few decades are slowly yielding to environmental, societal, and social issues. Sustainability – meeting today's needs without compromising the ability of future generations to satisfy their needs – is a key issue in all land use activities today. Central to this concept is the urge to achieve a balance between ecological preservation, economic vitality, and social justice. Land use systems today are thus evaluated based not only on their ability to fulfill any single objective such as production of a preferred commodity, but also on how best they fulfill the sustainability criteria. Contemporary issues that dominate the discussions in this context include natural-resource use in perpetuity, biodiversity conservation, gender equity, social justice, environmental integrity, appreciation of indigenous knowledge, preservation of cultural heritage, and so on.

While systematic studies on the role of homegardens in many of these contemporary issues have not been done, there is a long-held belief and intuition that homegardens score very high on most – perhaps all – of these so-called "intangible" benefits. Logic, circumstantial evidences, and limited empirical results that are available support these conjectures; but certainly more convincing evidence based on rigorous research is needed. Several chapters in this book point in this direction and provide the framework for formulating future research plans.

REFERENCES

Abdoellah O.S., Hadikusumah H.Y., Takeuchi K., Okubo S. and Parikesit. 2006. Commercialization of homegardens in an Indonesian village: vegetation composition and functional changes. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 233 – 250. Springer Science, Dordrecht.

Agelet A., Angels B.M. and Valles J. 2000. Homegardens and their role as a main source of medicinal plants in mountain regions of Catalonia (Iberian Peninsula). Econ Bot 54: 295 – 309.

Brownrigg L. 1985. Home Gardening in International Development: What the literature shows. The League for International Food Education, Washington, DC, 330p.

Christanty L. 1990. Homegardens in tropical Asia with special reference to Indonesia. In: Landauer K. and Brazil M. (eds), Tropical home gardens, pp 9 – 20. United Nations University Press, Tokyo.

Drescher A.W., Holmer R.J. and Iaquinta D.L. 2006. Urban homegardens and allotment gardens for sustainable livelihoods: management strategies and institutional environments. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 317 – 338. Springer Science, Dordrecht.

Fernandes E.C.M. and Nair P.K.R. 1986. An evaluation of the structure and function of tropical homegardens. Agric Syst 21: 279 – 310.

Fernandes E.C.M., O'Kting'ati A. and Maghembe J. 1984. Chagga homegardens: a multistory agroforestry cropping system on Mt. Kilimanjaro, northern Tanzania. Agroforest Syst 2: 73 – 86.

Gold M.A. and Hanover J.W. 1987. Agroforestry systems of the temperate zone. Agroforest Syst 5: 109 – 21.

Herzog F. 1998. *Streuobst*: a traditional agroforestry system as a model for agroforestry development in temperate Europe. Agroforest Syst 42: 61 – 80.

High C. and Shackleton C.M. 2000. The comparative value of wild and domestic plants in homegardens of a South African rural village. Agroforest Syst 48: 141 – 156.

Kumar B.M. 2006. Carbon sequestration potential of tropical homegardens. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 185 – 204. Springer Science, Dordrecht.

Kumar B.M. and Nair P.K.R. 2004. The enigma of tropical homegardens. Agroforest Syst 61: 135 – 152.

Nair P.K.R. (ed.). 1989. Agroforestry systems in the tropics. Kluwer, Dordrecht, 664p.

Nair P.K.R. 1993. An introduction to agroforestry. Kluwer, Dordrecht, 499p.

Nair P.K.R. 2006. Wither homegardens? In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 355 – 370. Springer Science, Dordrecht.

Randhawa M.S. 1980. The history of Indian agriculture, vol. 2, pp 67 – 68 and 414 – 415. Indian Council of Agricultural Research, New Delhi.

Soemarwoto O. 1987. Homegardens: a traditional agroforestry system with a promising future. In: Steppler H.A. and Nair P.K.R. (eds), Agroforestry: A decade of development, pp 157 – 170. ICRAF, Nairobi.

Soini E. 2005. Changing livelihoods on the slopes of Mt. Kilimanjaro, Tanzania: challenges and opportunities in the Chagga homegarden system. Agroforest Syst 64: 157 – 167.

Tesfaye Abebe, Wiersum, K.F., Bongers, F. and Sterck, F. 2006. Diversity and dynamics in homegardens of southern Ethiopia. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 123 – 142. Springer Science, Dordrecht.

Thaman R.R., Elevitch C.R. and Kennedy J. 2006. Urban and homegarden agroforestry in the Pacific islands: current status and future prospects. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 25 – 41. Springer Science, Dordrecht.

Vogl C.R. and Vogl-Lukasser B. 2003. Tradition, dynamics and sustainability of plant species composition and management in homegardens on organic and non-organic small scale farms in Alpine Eastern Tyrol, Austria. Biol Agric Hortic 21: 349 – 366.

Wenhua L. (ed.). 2001. Integrated farming systems at different scales. In: Agro-ecological farming systems in China, Chapter 12, pp 201 – 252. UNESCO Man and Biosphere Series 26, Partheon Publishing, New York.

Westmacott R.N. 1992. African-American gardens and yards in the rural south. University of Tennessee Press, Knoxville, TN, 198p.

Wiersum K.F. 1982. Tree gardening and taungya in Java: Examples of agroforestry techniques in the humid tropics. Agroforest Syst 1: 53 – 70.

Wiersum K.F. 2006. Diversity and change in homegarden cultivation in Indonesia. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 13 – 24. Springer Science, Dordrecht.

Workman S.W., Bannister M.E. and Nair P.K.R. 2003. Agroforestry potential in the southeastern United States: Perceptions of landowners and extension professionals. Agroforest Syst 59: 73 – 83.

Yamada M. and Osaqui H.M.L. 2006. The role of homegardens for agroforestry development: Lessons from Tomé-Açu, a Japanese-Brazilian settlement in the Amazon. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 299 – 316. Springer Science, Dordrecht.

Zhaohua Z., Mantang C., Shiji W. and Youxu J. (eds). 1991. Agroforestry systems in China. Chinese Academy of Forestry, Beijing, and International Development Research Centre, Singapore, 216p.

SECTION 1

HISTORICAL AND REGIONAL PERSPECTIVES

CHAPTER 2

DIVERSITY AND CHANGE IN HOMEGARDEN CULTIVATION IN INDONESIA

K.F. WIERSUM

Forest and Nature Conservation Policy group, Department of Environmental Sciences, Wageningen University, The Netherlands;
E-mail: <freerk.wiersum@wur.nl>

Keywords: Homegarden dynamics, Rural transformations, Social sustainability.

Abstract. Homegardens have been described as traditional agroforestry systems that are ecologically and socially sustainable. The concept of social sustainability has two dimensions: positive role to present livelihood conditions and ability to respond to socioeconomic changes. The dynamics of homegardens and its repercussions on social sustainability have received relatively little research attention. On the basis of results of extensive studies in Java and other parts of Indonesia, this article summarizes the historic and recent developments in the homegardening context. The structure and composition of homegardens depend both on their position in the overall farming system and on livelihood strategies of the managers. Rural transformations result in changes in livelihoods and farming systems, and have impacts on homegarden function and composition. The opinions of various authors on homegarden dynamics range from positive to negative; the former consider that changes in homegarden features are associated with socio-professional changes of villagers and the rural-urban interface, while the latter view these changes as indicative of the demise of a traditional system and argue for its revitalization. These different opinions represent different norms in assessing social sustainability of homegardens and differences in value judgments on the ideal structure of homegardens.

1. INTRODUCTION

Homegardening has been hypothesized as being the oldest form of agriculture in Southeast Asia. Its origin has been associated with fishing communities living in the

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 13–24.

moist tropical region of Southeast Asia during 13 000 to 9000 B.C. In these regions an assured supply of fish and shells allowed fixed settlements and a relatively high population density, while the fertile soils along rivers and coasts favored cultivation (Sauer, 1969). As happened also in other regions (Miller et al., 2006), homegardening probably started as a spontaneous growth of plants from leftovers of products brought to the camps of the hunter/gatherers. Gradually, the accidental propagation became more deliberate with valuable species being planted to facilitate their use. At first such cultivation probably involved vegetative propagation techniques and only later seeding was introduced (Sauer, 1969). The earliest evidence of garden cultivation dates back to at least 3000 B.C. (Soemarwoto, 1987).

From these pre-historic and probably scattered origins, homegardens has gradually spread to many humid regions in South- and Southeast Asia including Java (Indonesia), the Philippines, Thailand, Sri Lanka, India and Bangladesh. For instance, according to Randhawa (1980), travelers already described homegardens with coconut (*Cocos nucifera*), black pepper (*Piper nigrum*), ginger (*Zingiber officinale*), sugarcane (*Saccharum officinarum*) and pulses (grain legumes) in Kerala, India, in the early 14th century, while Michon (1983) mentions that tree gardening systems were already common on the Indonesian island of Java in the tenth century AD. In all these regions, homegardening is almost always practiced in combination with other types of land use. The original association with gathering and fishing was gradually extended to shifting cultivation and permanent cropping. In the most widely studied homegarden systems in South- and Southeast Asia such as in Java (Soemarwoto, 1987), Kerala (Nair and Sreedharan, 1986; Kumar et al., 1994), and Sri Lanka (Jacob and Alles, 1987; McConnell, 1992), gardening is combined with permanent field cultivation often in the form of wetland rice (*Oryza sativa*) production. These regions with good farming conditions and relatively high population densities contributed to optimal development of the complementary system of staple food cultivation in open fields and supplementary diversified homegarden production for self-sufficiency and trade.

Since the recognition of agroforestry as a type of land use worthy of research and development, homegardens have been considered as an excellent example of a traditionally developed agroforestry system with good promise for the future (Soemarwoto, 1984; Hochegger, 1998; Gajaseni and Gajaseni, 1999). Much attention has been given to analyzing the structure and function of tropical homegardens and describing their features in respect to both ecological and socioeconomic sustainability (Torquebiau, 1992; Kumar and Nair, 2004). Regarding socioeconomic sustainability, these studies focused specifically on the roles of homegardens within the livelihood systems of rural producers. A commonly perceived indicator of homegardens' socioeconomic sustainability is the fact that homegardens typically contribute towards nutritional security, energy needs and income generation even under conditions of high population densities (Kumar and Nair, 2004). Recently it has been remarked, however, that the concept of socioeconomic sustainability should not only be related to the homegardens' function in the present livelihood conditions, but also to their ability to adjust to socioeconomic changes (Peyre et al., 2006). At present, many rural areas are undergoing major transformations involving diversification of rural livelihood strategies (Ellis, 1998; Ashley and Maxwell, 2001). Due to commercialization, cultivation systems are becoming more specialized on the one hand, and rural people are increasingly employed in non-primary production activities on the other. As a result, in many rural areas, farming systems in general, and homegardens in particular, are changing. Kumar and Nair (2004) have even posed the question as to whether homegardens are becoming extinct. This illustrates that the notion of socioeconomic sustainability of homegardens should be interpreted as referring not only to their ability to contribute towards the livelihood needs of traditional rural dwellers, but also to their ability to adjust to the process of rural change.

In contrast to studies on homegarden diversity, relatively little attention has been given to assessing the dynamics of homegardens. It seems that, since many studies in the past have been focused on ascertaining factors that explain the ecological stability of homegardens (Kumar and Nair, 2004), the concept of sustainability has mainly been attributed as referring to stability in an ecological sense, and that the concept of socioeconomic sustainability was by association interpreted as referring to livelihood stability. Only recently have the dynamics of homegardens been receiving some attention. In some studies, the traditional homegarden structure and composition is taken as ideal, and changes such as loss in some of the traditional species and structure are discussed in terms of homegardens becoming extinct (Kumar and Nair, 2004) and needing revitalization (Parikesit et al., 2004), while some other studies have tried to relate the various types of dynamics in homegarden structure and composition to the process of rural transformations (Michon and Mary, 1994; Peyre et al., 2006).

This review will assess the dynamics of homegarden development in Indonesia, focusing specifically on Java. First, it will describe the historic developments of homegardens on Java. Next, using data from both Java and Sulawesi, it will summarize the factors that impact on the structure and composition of homegardens and describe how under the influence of these factors different types of homegardens have evolved. On the basis of these data, the main trends in changing homegarden structure and composition will be summarized.

2. THE DEVELOPMENT OF HOMEGARDENS IN JAVA

The first studies on tropical homegardens in Southeast Asia that were started in the late 1940s in Java, Indonesia (Terra, 1953a; 1953b) remained relatively unnoticed for several years. For example, even in the 1970s it was noted that, in contrast to the open-field land use systems, homegardens had hardly yet been subject to detailed study (Stoler, 1978). This situation changed in the late 1970s when a series of new homegarden studies were initiated in Java (Soemarwoto, 1987; Soemarwoto and Conway, 1991). The Javanese experiences formed an important source of information when in the 1980s the potential of homegardens to contribute towards increasing food production and reducing malnutrition in tropical countries received greater international interest (Niñez, 1984; Brownrigg, 1985). This international interest in homegardens was further stimulated by the recognition of homegardens as a typical example of a multistoried agroforestry system (Nair and Sreedharan, 1986; Jacob and Alles, 1987). The first international conference on tropical homegardens organized in Java in 1985 (Landauer and Brazil, 1990) is a testament to the leading role of the homegarden research in Java during that period.

The extensive research on Javanese homegardens has contributed significantly to the present understanding of the structure and function of tropical homegardens. The Javanese homegardens demonstrate the typical functions of homegardens as summarized by Kumar and Nair (2004): they yield products with high nutritional value (proteins, vitamins, and minerals), medicinal plants and spices, firewood, and sometimes a1so forage crops and construction wood; all these products are used to supplement the staple food crops that are usually produced in open-field cultivation systems. Normally, the homegarden products provide a small, continuous flow of these supplementary products for subsistence and a possible small surplus for sale through local markets. In times of sudden necessities (unfavorable climatic conditions or social necessities like marriage), higher production and marketing levels may be attained (Wiersum, 1982).

In many homegarden studies (Kumar and Nair, 2004), these gardens have been described as a distinct agroforestry system with a set of generic features. Relatively little attention has been given to studying the diversity within homegardens as well as their relation to the surrounding land use systems. Moreover, in addition to homegardens, other types of tree gardening systems consisting of a mixture of several cultivated fruit- and other trees and crops exist (Wiersum, 2004), and the distinction between homegardens and other types of tree gardening systems is not straightforward. In Java, Terra (1953a; 1953b) originally differentiated three different types (see also Wiersum, 1982; Soemarwoto, 1984; Christanty et al., 1986):

- The homegarden (*pekarangan*): fenced-in gardens, surrounding individual houses, planted with fruit- and other trees, vegetable herbs and annual crops. Historically they are associated with wetland rice fields and more recently also with dry fields. They occurred in regions with individual land-ownership. Typically these homegardens occur in Central Java and are inhabited by the Javanese people.
- The tree garden (*kebun* or *talun*): mixed tree plantations on communal lands surrounding villages with dense clusters of houses, sometimes also at some distance from the villages. These plots are not inhabited and they are historically associated with shifting cultivation. They occur in regions with communally owned land. Mostly they are found in West Java and are inhabited by the Sundanese people. These tree gardens are much less tended than homegardens and often include more wild trees than present in the homegardens.
- Clumps of fruit- or other trees planted on abandoned shifting cultivation sites. Such plantings could denote a right of priority of these lands for the people who planted the trees in an area of otherwise communal land ownership.

As demonstrated by the characterizations, the tree gardening systems in Java normally forms a sub-set of an integrated farming system (Terra, 1958), which also comprises annually cultivated fields used for the production of staple, high calorific foods such as rice, maize (*Zea mays*) and cassava (*Manihot esculenta*). Consequently, the structure and function of homegardens significantly depends on the nature of the overall farming system.

Over the ages, gradual changes have taken place in these systems (Soemarwoto, 1984). The most important was perhaps the extension of the Javanese culture and subsequent spread of homegardens. For instance, in the eighteenth century, the *pekarangan* system was already practiced in West Java, where it partly replaced the *talun* system of the Sundanese (Michon, 1983). Also, gradually communal lands were divided among individual landowners, who by building houses in such individual tree gardens, converted them to homegardens. In other tree gardens, annual crops were introduced and management became more intensive. Also shifting cultivation virtually disappeared and in areas with clumps of planted trees on fallow lands, a conversion to tree gardens took place. According to Wiersum (1982), in the early 1980s it was possible to distinguish the following three types of tree gardening:

- Homegardens (*pekarangan*): a land use form on private lands surrounding individual houses with a definite fence, in which several tree species are cultivated together with annual and perennial crops, often including small livestock.
- Mixed gardens (*kebun campuran*): a land use form on private lands outside the village, which is dominated by planted perennial crops, mostly trees, under which annual crops are cultivated.
- Forest gardens (*talun*, *kebun*): a land use form on private lands outside the village in which planted and sometimes spontaneously grown trees and sometimes additional perennial crops occur.

The *pekarangan* is often considered as a typical prototype for homegardens. But as illustrated by the diversity of tree gardening system in Java, the distinction between homegardens and other types of tree-gardening systems is often diffuse and may be related more to location than to vegetation structure[1]. Moreover, homegarden structure may gradually change with time.

3. DIVERSITY IN HOMEGARDEN STRUCTURE AND COMPOSITION

The diversity in tropical homegardens types is not only illustrated by the historic developments in tree gardening systems, but also by the existing variation in homegarden structure and composition. Several homegarden studies in Java have assessed what factors impact on the homegarden structure and composition as well as function. Karyono (1990) demonstrated that homegarden composition was affected both by geographic conditions and their role in the farming systems. Compared to lowlands, homegardens in highland areas have lower plant diversity and simpler species composition. Also a different pattern of species composition exists in homegardens associated with irrigated rice production as opposed to those associated with dry-land agriculture: fruit species are dominant in the former, and food crops in the latter. Stoler (1978) also emphasized the relation between garden composition (as well as management intensity) and other components of the farming system. Households with sufficient croplands to produce rice to cover basic staple food requirements cultivated more commercial fruit trees than households who could not meet staple food requirements from croplands and hence had to cultivate more subsistence crops in the homegardens. Christanty (1990) differentiated urban and rural homegardens, and mentioned that these could be further classified depending on:

- The dominant plant species grown, e.g., fruit, vegetable, or flower species, and
- The main function of the homegarden, e.g., subsistence garden, kitchen garden, market garden, plant nursery garden, and aesthetic garden.

Soemarwoto (1984) added that in rural areas homegardens have important social functions through the provision of gifts in the form of fruits, leaves or products for religious or medicinal purposes. In urban areas this social function diminishes whereas their aesthetic function increases with ornamentals replacing food crops. Michon and Mary (1994) and Abdoellah et al. (2006) described that, in addition to urbanization, the rise of a market economy profoundly influences the homegarden function resulting in an increase in commercial crops. Abdoellah (1990) reported that the effect of various cultures (Javanese or Sundanese) was often still reflected in the structure of homegardens: for example, vegetables and ornamentals were often more common in Sundanese homegardens.

Also in the Indonesian island of Sulawesi different types of homegardens have been reported. For example, Kehlenbeck and Maass (2004) described four home-garden types distinguished by differences in garden age and size, and the level of diversity:

1. Small, moderately old, species- and tree-poor spice gardens
2. Medium-sized, old, species-rich fruit tree gardens
3. Large, rather young, species- and tree-poor gardens of transmigrant families
4. Diverse assemblages of rather old, individual gardens with very high crop diversity.

According to Terra (1958), the typical Javanese landscape with irrigated rice fields, dry croplands and mixed gardens was already common in this region in the 1950s. The types 2 and 4 mentioned above may reflect this traditional situation. But as illustrated by type 3, recently the area is becoming further settled by trans-migrants from Java. These transmigrants do not only open up new agricultural lands, but also establish homegardens around their new settlements. Such homegarden development takes time. Often, at first essential food crops are grown and only gradually supplementary crops are introduced. Other factors influencing home-garden structure are related to differences in access to markets and availability of garden products in the market. Moreover, the composition is found to be influenced by official homegarden development programs (Kehlenbeck and Maass, 2006).

In other studies on Asian homegardens too, several geographic and socio-economic factors have been found to influence the homegarden structure and composition (e.g., Kumar et al., 1994; John and Nair, 1999; Peyre et al., 2006). Table 1 summarizes the various factors that have been reported to impact on homegarden composition. As illustrated in this table, notably livelihood conditions are an important factor influencing the structure and composition of homegardens. Livelihood conditions are reflected in both the farming system and the socioeconomic status of households. For poor people, homegardens may form the only land available to them for primary production, and consequently they are likely to serve partly for production of essential staple foods rather than only for supplementary crop production. On the other hand, for affluent people living in urbanized areas and having access to non-farm incomes, homegardens may not any longer form a part of a farming system, but function only as an ornamental area around the living quarters. Thus, not only the overall livelihood conditions, but also specific socioeconomic variables such as access to land or off-farm labor opportunities impact the homegarden structure and composition. Generally, a decrease in the availability of land results in intensification of cultivation and the inclusion of more annual crops. Also, when alternative income opportunities are present, cultivation is "extensified" (and more ornamentals are included near urban areas). Where better marketing opportunities exist (near cities), specialization in fruit production may take place.

Table 1. *Factors impacting structure and composition of homegardens with special reference to Indonesian homegardens.*

Factors	*Conditions*	*Examples and remarks*
Geographic location	Urban versus rural location	Urban homegardens often smaller and more aesthetic oriented
Environmental conditions	Climate conditions	Variation in annual crops cultivated only in favorable climatic seasons is mostly less pronounced than in permanent crops that have to be adapted to variable climatic conditions over much larger periods
	Soil conditions	With decreasing soil fertility crop diversity tends to decrease and the effect of competition by trees on understorey becomes more pronounced. Dense tree gardens occur mostly on volcanic soils, while on tertiary soils tree gardens are more open
Role in farming systems	Degree of complementarity to open field cultivation systems	If homegardens are the only land asset more inclusion of staple food crops
	Established versus incipient farming system	Incipient gardens first dominated by annual crops, with time increased incorporation tree crops
Socioeconomic conditions of the household	Wealth status	With increased wealth increased importance of commercial and aesthetic plants
	Access to markets	Commercial crops stimulated by good market access
	Access to off-farm employment	In case of access to financially lucrative employment decreased importance commercial crops
	Gender-related issues	Gardens of female-headed households often more household use oriented
Cultural factors	Food preferences	Cultural preferences in respect to consumption of vegetables and spices

Up to a certain level, the cultivation of homegardens can respond well to changes in socioeconomic conditions by means of intensification of cultivation, shifting the ratio of perennials to annuals and sometimes domestic animals, and a certain degree of specialization in crops. But major differences in socioeconomic status are reflected in homegardens having a clearly different composition. It is possible to differentiate various types of homegardens in respect to their role in the household economics (Table 2).

Table 2. *Different types of homegardens in relation of household economics.*

Homegarden type	*Characteristics*
Survival gardens	Gardens form single component farming system of otherwise landless rural people
	Combined production of staple food crops and complementary crops
Subsistence gardens	Part of multi-component farming system in conjunction with permanent or shifting field production
	Complementary system to open-field staple food cultivation systems
	Provision of daily supply of vegetables, herbs, spices and fruits for household needs and occasional sale
Market gardens	Specialized farming system or part of multi-component farming system
	Cultivation of cash crops with possible complementary production of household products
Budget gardens	Gardens of households with economic bases in rural or urban employment; family needs are mostly purchased from the market
	Cultivation of 'hobby' products for household consumption and ornamentals

Source: Adapted from Niñez (1984).

4. HOMEGARDEN DYNAMICS

Many of the factors that impinge on homegarden structure and composition change with time, and it is therefore logical to infer that the homegarden structure and composition change whenever socioeconomic factors change (e.g., Peyre et al., 2006; Abdoellah et al., 2006). Such changes often reflect the general processes of rural changes and may involve several aspects of rural transformations. Areas that used to be remote are increasingly being incorporated into the national economy with traditional land use systems such as shifting cultivation gradually becoming transferred to more permanent cropping systems. Remote areas may also be actively opened up for migrants. In Indonesia the transmigration from the densely populated island of Java to other islands is actively stimulated, and as a result the typical Javanese homegarden is being introduced in new regions. Moreover, in many rural areas the (semi)subsistence household economies of former times are increasingly becoming more commercially oriented. In others, urban life-styles are developing and the household dependence on primary production is changing to include activities in the manufacturing or service and trade sectors. In some places, these dynamics are intensive; in others they take place more gradually. Depending on the nature and intensity of rural changes, the developments in structure and composition as well as functions of homegardens may show different trends (Table 3).

Table 3. *Main trends in homegarden development.*

Main trends	*Consequences*
Extension in area	
Extension of housing due to population growth	Prevalence of (bi)annual food crops in newly established gardens
Extension to new areas due to change in farming systems, e.g., from shifting cultivation to permanent cultivation	Young homegardens have not yet reached full diversity
Extension to new areas due to migration	Extension of homegarden to new areas with adaptation to different land use systems than in area of origin
Changing structure and composition	
Adaptation of gardens to new food habits and changing household needs or new agronomic practices	Gradual change in structure and composition including incorporation of new species
Increasing commercialization • Decreasing importance subsistence production • Increasing commercial production	Decreasing importance of supplementary production Increasing specialization on either vegetable, spices or fruit tree production
Increasing role of aesthetic function garden	Increase in ornamental plants

5. CONCLUSIONS

Homegardens have often been described as a sustainable agroforestry system with positive ecological and socioeconomic features. While several studies have explicitly highlighted homegardens as traditional systems, relatively little attention has been given to studies on the dynamics of homegardens under influence of rural transformations. Nonetheless, several studies have demonstrated that homegarden function and composition depends greatly on socioeconomic conditions as well as household livelihood strategies. In this context, not only different types of homegarden systems can be recognized, but also different pathways of homegarden development can be identified. The changes in homegarden function and composition have been interpreted differently by various authors. Some argue that although the traditional homegardens have gradually lost their original ecological and economic features, they still are a major asset for the modernization of village economy and society. The changes in homegarden features are associated with socio-professional changes of villagers and reflect a search for a new balance in the relationship between cities and villages. Other authors take a more negative point of view of the dynamics in tree gardening systems; they view the changes under influences of rural dynamics as the disappearance of a traditional system and propose measures to revitalize such traditional tree gardening systems. These different and somewhat opposing views on the trends in homegarden function and composition represent different norms in assessing social sustainability of homegardens and differences in value judgments on the ideal structure of homegardens.

ENDNOTE

1. The international literature on tropical homegardens is often ambivalent on whether homegardens are characterized by structure or location.

REFERENCES

Abdoellah O.S. 1990. Homegardens in West Java and their future development. In: Landauer K. and Brazil M. (eds), Tropical home gardens, pp 69 – 79. United Nations University Press, Tokyo.

Abdoellah O.S., Hadikusumah H.Y., Takeuchi K., Okubo S. and Parikesit 2006. Commercialization of homegardens in an Indonesian village: vegetation composition and functional changes. Agroforest Syst (in press).

Ashley C. and Maxwell S. 2001. Rethinking rural development. Dev Policy Rev 19: 395 – 425.

Brownrigg L. 1985. Home gardening in international development: What literature shows? The League for International Food Education, Washington, DC, 330p.

Christanty L. 1990. Homegardens in tropical Asia with special reference to Indonesia. In: Landauer K. and Brazil M. (eds), Tropical home gardens, pp 9 – 20. United Nations University Press, Tokyo.

Christanty L., Abdoellah O.S., Marten G.G. and Iskander J. 1986. Traditional agroforestry in West Java: the *pekarangan* (homegarden) and *kebun-talun* (annual-perennial rotation) cropping system. In: Marten G.G. (ed.), Traditional agriculture in South East Asia, pp 132 – 158. Westview Press, Boulder, CO.

Ellis F. 1998. Household strategies and rural livelihood diversification. J Dev Stud 35: 1 – 38.

Gajaseni J. and Gajaseni N. 1999. Ecological rationalities of the traditional homegarden system in the Chao Phraya Basin, Thailand. Agroforest Syst 46: 3 – 23.

Hochegger K. 1998. Farming like the forest: traditional homegarden systems in Sri Lanka. Tropical agroecology. Margraf Verlag, Weikersheim, 203p.

Jacob V.J. and Alles W.S. 1987. The Kandyan gardens of Sri Lanka. Agroforest Syst 5: 123 – 137.

John J. and Nair M.A. 1999. Socio-economic characteristics of homestead farming in south Kerala. J. Trop Agric 37: 107 – 109.

Karyono 1990. Homegardens in Java: their structure and function. In: Landauer K. and Brazil M. (eds), Tropical home gardens, pp 138-146. United Nations University Press, Tokyo.

Kehlenbeck K. and Maass B.L. 2004. Crop diversity and classification of homegardens in Central Sulawesi, Indonesia. Agroforest Syst 63: 53 – 62.

Kehlenbeck K. and Maass B.L. 2006. Are tropical homegardens sustainable? Some evidence from Central Sulawesi, Indonesia. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 339 – 354. Springer Science, Dordrecht.

Kumar B.M. and Nair P.K.R. 2004. The enigma of tropical homegardens. Agroforest Syst 61: 135 – 152.

Kumar B.M., George S.J. and Chinnamani S. 1994. Diversity, structure and standing stock of wood in homegardens of Kerala in peninsular India. Agroforest Syst 25: 243 – 262.

Landauer K. and Brazil M. (eds) 1990. Tropical home gardens. United Nations University Press, Tokyo, 257p.

McConnell D.J. 1992. The forest-garden farms of Kandy, Sri Lanka. Farm systems management Series No. 3, FAO, Rome, 117p.

Michon G. 1983. Village-forest-gardens in West Java. In: Huxley P.A. (ed.), Plant research and agroforestry, pp 13 – 24. ICRAF, Nairobi.

Michon G. and Mary F. 1994. Conversion of traditional village gardens and new economic strategies of rural households in the area of Bogor, Indonesia. Agroforest Syst 25: 31 – 58.

Miller R.P., Penn, Jr. J.W. and Leeuwen J. van. 2006. Amazonian homegardens: their ethnohistory and potential contribution to agroforestry development In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 43 – 60. Springer Science, Dordrecht.

Nair M.A. and Sreedharan C. 1986. Agroforestry farming systems in the homesteads of Kerala, southern India. Agroforest Syst 4: 339 – 363.

Niñez V.K. 1984. Household gardens: theoretical considerations on an old survival strategy. Potatoes in Food Systems Research Series Report No. 1. International Potato Center, Lima, Peru, 41p.

Parikesit, Takeuchi K., Tsunekawa A. and Abdoellah O.S. 2004. *Kebon tatangkalan*: a disappearing agroforest in the Upper Citarum watershed, West Java, Indonesia. Agroforest Syst 63: 171 – 182.

Peyre A., Guidal A., Wiersum K.F. and Bongers F. 2006. Dynamics of homegarden structure and function in Kerala, India. Agroforest Syst 66: 101 – 115.

Randhawa M.S. 1980. The history of Indian agriculture. Vol. 2, pp 414 – 415. Indian Council of Agricultural Research, New Delhi.

Sauer C.O. 1969. Agricultural origins and dispersals (2nd ed.). M.I.T. Press, New York. 175p.

Soemarwoto O. 1984. The Javanese rural ecosystem. In: Rambo A.T. and Sajise P.E. (eds), An introduction to human ecology research on agricultural systems in Southeast Asia, pp 254 – 287. University of Philippines, College, Los Banos.

Soemarwoto O. 1987. Homegardens: a traditional agroforestry system with a promising future. In: Steppler H.A. and Nair P.K.R. (eds), Agroforestry: A decade of development, pp 157 – 170. ICRAF, Nairobi.

Soemarowoto O. and Conway G.R. 1991. The Javanese homegarden. J Farming Syst Res Extn 2: 95 – 118.

Stoler A. 1978. Garden use and household economy in rural Java. Bull Indonesian Econ Stud 14: 85 – 101.

Terra G.J.A. 1953a. Mixed-garden horticulture in Java. Malaysian J Trop Geogr 1: 33 – 43.

Terra G.J.A. 1953b. The distribution of mixed gardening on Java. Landbouw (Indonesia) 25: 163 – 203.

Terra G.J.A. 1958. Farm systems in South-east Asia. Neth J Agric Sci 6: 157 – 182.

Torquebiau E. 1992. Are tropical agroforestry homegardens sustainable? Agric Ecosyst Environ 41: 189 – 207.

Wiersum K.F. 1982. Tree gardening and *taungya* on Java: examples of agroforestry techniques in the humid tropics. Agroforest Syst 1: 53 – 70.

Wiersum K.F. 2004. Forest gardens as an 'intermediate' land use system in the nature-culture continuum: characteristics and future potential. Agroforest Syst 61: 123 – 134.

CHAPTER 3

URBAN AND HOMEGARDEN AGROFORESTRY IN THE PACIFIC ISLANDS: CURRENT STATUS AND FUTURE PROSPECTS

R.R. THAMAN[1], C.R. ELEVITCH[2], AND J. KENNEDY[3]

[1]The University of the South Pacific, Suva, Fiji Islands; 148; E-mail: <thaman_r@usp.ac.fj>. [2]Agroforestry.net, Holualoa, Hawai'i. [3]Research School of Pacific and Asian Studies, Australian National University, Canberra, Australia

Keywords: Agrodeforestation, Food security, Nutrition, Sustainability, Traditional agroforestry.

Abstract. Pacific islanders traditionally had abundant, predominantly rural, agroforestry systems that provided a wide array of products for meeting the necessities of life, and conducive environments for the rich Pacific island cultures. In recent years, however, increasing urbanization and accompanying removal of trees and perennial agroforests ("agrodeforestation") have resulted in the breakdown of these traditional agroforestry systems, accompanied by increasing economic, cultural, nutritional, and environmental problems, particularly in the urban areas. A critical analysis of the nature and future prospects of the urban and homegarden agroforestry systems in these rapidly urbanizing islands suggests that intensification and enrichment of these systems could serve as an important foundation for sustainable development. In addition to addressing the nutrition-related health problems, food security, poverty alleviation, and trade deficits, these systems also help protect and enrich the cultural traditions of Pacific peoples who are increasingly out-migrating from rural areas and embracing urban living.

1. INTRODUCTION

Pacific island countries have historically been resource self-reliant because of their relative geographic isolation. Their traditional land- and sea-based economies,

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 25–41.

cultures, and isolation from major markets forced island communities to develop sustainable land use systems such as agroforestry and freshwater and marine fishery production systems. Today, however, the small island states of the Pacific Ocean are rapidly urbanizing and increasingly large populations no longer have access to traditional agricultural and wildland holdings. Moreover, trees are disappearing from both rural and urban areas, a process referred to as "agrodeforestation" (Thaman, 1992). Studies in the Ha'ppai Islands of Tonga, for example, showed that about 100 traditionally important trees or shrubs, all integral components of the traditional Tongan bush-fallow agroforestry, were reported to be endangered or in short supply. These included 28 large wild trees, 32 large cultivated trees, 19 wild small trees or shrubs, and 24 planted small trees and shrubs (Thaman et al., 2001). Species most commonly mentioned were multipurpose trees valued for medicine, fruit, firewood, construction purposes, and fragrant plants used for body ornamentation and perfume. Foremost among the reasons for the loss of tree cover was the failure to plant or replant trees in general, as well as changing land-management practices that included indiscriminate felling, clearing and burning, and the increasing use of the plow. These practices have caused a gradual shift away from the traditional mixed agroforestry systems in which fruit trees and other culturally useful trees, such as coconut (*Cocos nucifera*), breadfruit (*Artocarpus altilis*), traditional banana and plantain clones (*Musa* spp.), citrus (*Citrus* spp.), Malay apple (*Syzygium malaccense*) and Polynesian vi-apple (*Spondias dulcis*) were dominant, to monocultural production of commodities. Spread of tall grass species such as guinea grass (*Panicum maximum*) and the impact of grazing animals and other domesticated livestock made regeneration of trees particularly difficult (Thaman et al., 2001).

Today, most Pacific island countries are increasingly dependent on imported food, fossil fuels, medicines, and other industrial products to satisfy the basic needs, with the result that they experience negative balance of payment situations. Food security has become a major concern in all of the independent island states[1]. Disappearance of forests and agroforests, which traditionally provided these products and services, may partially explain this increasing dependence on imported foods and fuels (Thaman, 1988). The people of the Pacific islands also have high rates of nutrition-related, non-communicable diseases, such as diabetes, cardiovascular disease, hypertension, hyperuricemia and gout, obesity, iron deficiency anemia, and dental diseases (Parkinson, 1982; Thaman, 1982; Coyne, 2000)—with rates of obesity as high as 75% reported in Nauru, Samoa, the Cook Islands, Tonga, and French Polynesia. The main factor for most of these diseases has been the shift in the food habits from traditional "healthy" foods to processed, imported "unhealthy" foods (Curtis, 2004).

Experience from the region as well as elsewhere suggests that the promotion of urban and homegarden agroforestry may provide culturally appropriate and cost-effective means of addressing both urban agrodeforestation, and many of the economic, cultural, nutritional and environmental problems arising out of urbanization and globalization (Thaman and Clarke, 1993; Thaman, 2002; Lamanda et al., 2006). It can also help to address indirectly many emerging environmental problems, such as climate change and associated sea-level rise, coastal erosion, pollution, and loss of native trees and biodiversity. In this scenario, this chapter assesses the status and future prospects of urban and homegarden agroforestry in the Pacific islands.

This chapter is based on the authors' extensive experience in the region as well as inventories of urban and homegardens in Papua New Guinea (PNG), Fiji, Tonga, Kiribati, and Nauru during the 1970s and 1980s (Thaman, 1983; 1987), together with subsequent studies in these countries, and in New Caledonia, Solomon Islands, Vanuatu, Samoa, Niue, the Cook Islands, Tuvalu, French Polynesia, Hawai'i, the Marshall Islands, and Palau (Thaman, 1995).

1.1. Homegardens

Homegardens are a ubiquitous feature of the Pacific island landscapes, from the very densely populated urban areas in atoll microstates, such as South Tarawa, Kiribati, Fogafale Islet on Funafuti Atoll, Tuvalu, and RETA in northeast Majuro Atoll in the Marshall Islands to rural villages and plantations in areas of low population density in Fiji, Vanuatu, and Papua New Guinea. Even in areas not known for agricultural diversity, such as Kiribati, Tuvalu, the Marshall Islands, and Nauru, homegardens contain a wide range of food trees, non-tree staple and supplementary food plants, medicinal plants, and other non-food trees and plants of cultural and economic importance (Table 1). Homegarden surveys in these localities have indicated the cultivation of 33 to 114 species or distinct types of food plants in these localities (Thaman, 1995). In Palau, where women are responsible for most gardening, homegardens with a diversity of food trees and extensive multispecies, taro-dominated agroforests are found throughout the main towns and in areas surrounding villages.

Table 1. *Number of species and distinct varieties of food plants found in surveys of homegardens systems in different Pacific islands.*

Crop types	*Number of species/varieties in different Pacific islands*					
	PNG	*Fiji*	*Tonga*	*Kiribati*	*Nauru*	*Location*[1]
Non-tree staples	7	10	8	6	5	8
Non-tree supplementary	48	65	44	35	14	41
Food trees[2]	30	39	27	20	14	16
Total	85	114	79	61	33	65

Source: Thaman (1995); [1]Location, a contract worker settlement in Nauru; [2]The totals for Papua New Guinea and Nauru, where banana clones and *Citrus* spp., respectively, were not differentiated, would have been slightly higher for tree crops if these differentiations had been made).

In addition to the food plants, many useful non-food plants were also found in the homegardens. Examples include important "handicraft plants" such as *Pandanus*, the leaves of which are processed to make mats, thatching, baskets, hats and a wide range of other plaited ware; paper mulberry (*Broussonetia papyrifera*), the treated bast fiber of which is used for bark cloth (*tapa*); and sources of dyes such as annatto (*Bixa orellana*) and Java cedar (*Bischofia javanica*). There may also be multipurpose trees such as *Leucaena leucocephala*, a wide range of medicinal plants, plus countless other plants of considerable technological, economic, social, ecological, and ornamental values (Table 2; Fig. 1).

***Table 2**. Significant plant species of urban and rural Pacific island homegardens and underdeveloped urban and periurban open areas.*

a. Homegardens

Category	*Species*
Staple root crops	*Alocasia macrorrhiza* (giant taro) *Colocasia esculenta* (taro) *Cyrtosperma chamissonis* (giant swamp taro) *Dioscorea alata* (greater yam) *Dioscorea esculenta* (sweet yam) *Ipomoea batatas* (sweet potato) *Manihot esculenta* (cassava) *Xanthosoma* spp. (tannia or cocoyam)
Supplementary food crops	*Abelmoschus esculentus* (okra) *Abelmoschus manihot* (hibiscus spinach) *Allium* spp. (bunching onions) *Amaranthus* spp. (amaranth spinach) *Ananas comosus* (pineapple) *Arachis hypogaea* (peanuts) *Brassica chinensis*, *B. juncea* and *B. oleracea* vars. (cabbages, including Chinese, mustard and English or head cabbages) *Cajanus cajan* (pigeon pea) *Citrullus lanatus* (watermelon) *Coccinea grandis* (ivy gourd) *Colocasia esculenta* (taro leaf spinach) *Cucumis melo* var. *cantalupensis* (cantaloupe or rock melon) *Cucumis sativus* (cucumber) *Cucurbita pepo* (pumpkin) *Luffa acutangula* (angled loofah or ridgegourd) *Luffa cylindrica* (sponge gourd) *Momordica charantia* (bitter gourd) *Passiflora edulis* (passionfruit) *Phaseolus, Psophocarpus* and *Vigna* spp. (beans and other legumes) *Saccharum officinarum* (sugarcane) *Solanum lycopersicon* (tomato) *Solanum melongena* (eggplant) *Xanthosoma* spp. (taro leaf spinach) *Zea mays* (corn)

Fruit and nut yielding trees	*Annona* spp. (soursop and sweetsop) *Artocarpus altilis* and *A. camansi* (breadfruit and breadnut) *Carica papaya* (papaya) *Citrus aurantifolia* (limes), *C. aurantium* (sour orange), *C. limon* and *C. medica* x *limon* (lemon), *C. maxima* (pummelo), *C. mitis* (calamondin), *C. reticulata* (tangerine and mandarin orange), and *C. sinensis* (orange) *Cocos nucifera* (coconut) *Ficus* spp. (fig trees) *Inocarpus fagifer* (Tahitian chestnut) *Mangifera indica* (mango) *Musa* cultivars (banana and plantains) *Pandanus* spp. (edible pandanus) *Persea americana* (avocado) *Pometia pinnata* (oceanic litchi) *Psidium guajava* (guava) *Spondias dulcis* (vi apple) *Syzygium aqueum* (water apple) *Syzygium malaccense* (Malay apple) *Terminalia catappa* (beach almond)
Spice plants and social beverage and stimulant plants	*Areca catechu* (betel nut palms) *Capsicum frutescens* and *C. annum* cvs (chili) *Coriandrum sativum* (coriander) *Cymbopogon citratus* (lemon grass) *Mentha* spp. (mint) *Piper betle* (betel vine) *Piper methysticum* (*kava*) *Zingiber officinale* (ginger)
Non-food plants	*Cananga odorata* (*ylang-ylang*) *Fagraea berteroana* (*pua*) *Gardenia taitensis* (Tahitian gardenia) *Guettarda speciosa* (*guettarda*) *Pandanus* spp. (pandanus cultivars) *Pimenta racemosa* (bay rum) *Plumeria obtusa* and *P. rubra* (*frangipani*)

b. Undeveloped open areas

Staple root crops	*Colocasia esculenta* (taro) *Dioscorea esculenta* (sweet yam) *Ipomoea batatas* (sweet potato) *Manihot esculenta* (cassava) *Xanthosoma* spp. (tannia or cocoyam)

Table 2 (cont.)

Category	*Species*
Fruit and nut yielding trees	*Artocarpus altilis* (breadfruit)
	Carica papaya (papaya)
	Citrus spp. (citrus)
	Cocos nucifera (coconut)
	Mangifera indica (mango)
	Musa cultivars (banana and plantains)
	Pometia pinnata (oceanic litchi)
	Psidium guajava (guava)
	Syzygium spp.
	Terminalia catappa (beach almond)
Non-food plants	*Bischofia javanica* (*koka*)
	Cassia and *Senna* spp. (shower trees)
	Casuarina spp.
	Delonix regia (flamboyant)
	Erythrina variegata (coral tree)
	Eucalyptus spp.
	Ficus spp. (banyans)
	Gliricidia sepium (*madre de cacao*)
	Hibiscus rosa-sinensis
	Hibiscus tiliaceus (beach hibiscus)
	Lagerstroemia speciosa (pride of India)
	Leucaena leucocephala
	Macaranga spp.
	Morinda citrifolia (*noni*)
	Plumeria obtuse and *P. rubra* (*frangipani*)
	Polyscias spp. (hedge panax)
	Samanea saman (rain tree)
	Spathodea campanulata (African tulip tree)

Source: Based on Thaman (1983, 1987, 1995, 2002); Levett (1992, 1996); Levett and Uvano (1992). Categories such as 'supplementary food crops' and 'spice plants and social beverage and stimulant plants' were clearly absent in the undeveloped open areas.

Homegardens also contain a great diversity of cultivars of important food and handicraft plants. As stressed by Soemarwoto et al. (1985) in their study of Javanese homegardens, true plant diversity is far greater than indicated by the numbers of species, since many species are represented by numerous cultivars. In Tonga, for example, there are numerous distinct breadfruit cultivars, the most common of which include *ma'ofala*, *maopo*, *puou*, *loutoko*, *kea* and *'aveloloa*. There is similarly great cultivar diversity among other tree crops such as coconuts, banana, mango (*Mangifera indica*), pandanus (*Pandanus* spp.), papaya (*Carica papaya*), and especially among the traditional staple root crops such as yams (*Dioscorea* spp.), taros (*Colocasia esculenta*, *Alocasia macrorrhiza* and *Xanthosoma* spp.), and sweet potato (*Ipomoea batatas*), all of which add economic, ecological, and nutritional stability to the urban gardening systems. "Tree gardens" in the settlements in Yap, in the Federated States of Micronesia, for example, had 21 coconut cultivars, 28 breadfruit cultivars, and 37 banana cultivars (Falanruw, 1995). Similar cultivar diversity is found in the taro (*Colocasia esculenta*)-dominated agroforestry gardens in and around the main town of Koror and villages in Palau. Throughout Papua New Guinea, tree crops continue to provide a crucial component of the diverse subsistence agricultural systems of the rural population, with high cultivar diversity of many species such as bananas, breadfruit, pandanus, and many indigenous fruit and nut trees. This diversity is retained despite the addition of newly introduced high-yielding cultivars[2].

Figure 1. *Homegarden in downtown Apia, Samoa includes numerous useful tree species including the fast-growing timber tree poumuli (* Flueggea flexuosa*), fruit trees such as coconut (*Cocos nucifera*) and breadfruit (*Artocarpus altilis*), as well as many ornamentals (Photo: R. R. Thaman).*

Countless species, commonly overlooked as "weeds," are important components of homegardens (Soemarwoto et al., 1985). Homegardeners have many uses for spontaneously propagating plants as medicines, fuel, fodder, mulch, roofing, fish poisons, toothbrushes, and food. "Weeds" such as *Amaranthus* spp., black nightshade (*Solanum americanum*), purslane (*Portulaca oleracea*), water spinach (*Ipomoea aquatica*), and fetid sea holly (*Eryngium foetidum*), for example, are important potherbs in Fiji and are often sold in the municipal market of Suva

(Thaman, 1976/77), and almost all grass species are used for fodder if domestic animals are kept.

1.2. Urban agroforestry gardens apart from homegardens

Cultivation outside homegardens on undeveloped land (i.e., land without residences, buildings, or for other uses such as playing fields, parks, etc.) is very widespread in the Pacific island urban areas. These urban and periurban gardens also develop into agroforestry systems, and are important sources of food (including leaves, fruits, and nuts) and other products such as timber, fence posts, fuelwood, handicraft and light construction materials, medicines, and flowers (Table 2). Such areas include road frontages, empty lots, riverbanks and valleys, rights-of-way for proposed or existing paths and roads, and open land in general including hillsides and swamplands. Both subsistence and limited commercial production are attempted in these urban and periurban agroforestry gardens (Fig. 2).

Figure 2. *Periurban mixed planting with fruits, timber, medicinal, and staple crops on 'Upolu island', Samoa. Species include coconut (*Cocos nucifera*), breadfruit (*Artocarpus altilis*), poumuli (* Flueggea flexuosa*), bananas and plantains (* Musa *spp.), and noni (* Morinda citrifolia*). Note yam vine (* Dioscorea *sp.) trellised onto breadfruit tree on left (Photo: C. Elevitch).*

In the suburbs of Port Moresby, PNG, sampled in the 1970s, more than one-third of all households had "gardens" on other lands in addition to their homegardens. The distinction here is in the location of these gardens with respect to homes: while homegardens are located surrounding homes, these "other gardens" are not physically close to the homes. Kilakila villagers, who were then largely original inhabitants of the area, had particularly large tracts of urban savanna lands, and all households had, in addition to their homegardens, up to four "bush" gardens averaging 1135 m^2 located on urban lands within 3 km of the center of Kilakila. With the expansion of the Port Moresby population from 124 000 in 1980 to over 250 000 in 2000 (National Statistical Office of Papua New Guinea, 2000; Allen et al., 2002), such large urban gardens can no longer exist, although no detailed follow-up study has been undertaken.

Open hillsides within Port Moresby support a distinctive system of agriculture based on wet season plantings dominated by sweet potato, along with cassava (*Manihot esculenta*), banana, taro (*Colocasia* and *Xanthosoma* spp.), hibiscus spinach (*Abelmoschus manihot*), Chinese cabbage (*Brassica chinensis*), corn (*Zea mays*), cucumber (*Cucumis sativus*), passionfruit (*Passiflora* spp.), peanut (*Arachis hypogaea*), pineapple (*Ananas comosus*), pumpkin (*Cucurbita pepo*), snake or long bean (*Vigna unguiculata* subsp. *sesquipedalis*), bunching onion (*Allium* spp.), sugarcane (*Saccharum officinarum*), tomato (*Solanum lycopersicon*) and watermelon (*Citrullus lanatus*). Tree crops include breadfruit, coconut, mandarin and sweet oranges (*Citrus reticulata* and *C. sinensis*), mango and papaya. Practiced by urban migrants who rent the gardened land from local traditional landowners, this system differs from the surrounding agriculture of rural people in that the grassland fallow period is shorter, and drains are dug across the slope, with soil heaped behind them into long beds. These gardens are even less well studied than Port Moresby's homegardens (Allen et al., 2002), and they periodically attract public criticism in local newspapers, as a cause of erosion and smoke pollution.

In Suva, Fiji, about 20% of all households surveyed in the late 1970s cultivated "unused" open lands. It has been estimated that in the 30 km^2 Suva Peninsula, approximately 5 km^2 which represents more than 70% of the area not under swamp or mangrove – is still under this type of cultivation (Thaman, 1995). Planting is done along road frontage in about 20% of all households despite the City Council regulations forbidding such practices, and the practice seems to have intensified recently in parts of Suva.

In Tonga, Kiribati, and Nauru, there is little undeveloped "urban" land. However, in a number of cases, the Tongans planted entire adjacent unoccupied "town allotments" with sweet potato, taro, tannia (*Xanthosoma* spp.), and a mixture of trees, or with traditional mixed yam gardens, where yams, giant taro (*Cyrtosperma chamissonis*), plantains (*Musa* spp.), and taro are intercropped, usually among or under coconuts and other trees (Thaman, 1978). There is virtually no open land in urban Kiribati, but in Nauru, some Chinese, Tuvaluan and I-Kiribati (nationals of Kiribati) contract laborers plant food gardens near the Nauru Phosphate Corporation's workshops on the phosphate-rich central plateau and in the swampy areas surrounding landlocked Buada Lagoon. In Tuvaluan and I-Kiribati gardens, coconuts and banana clones were dominant.

1.3. Animal husbandry

Small-scale animal husbandry, although playing a minor role compared with plant food production, is also an important activity in urban and rural homegardens. In Port Moresby suburbs studied in the 1970s, animal keeping was minimal, with 11 of 79 households keeping pigs, chickens, or ducks and a few households keeping tethered cows or goats. More recently, there are a few reports of urban household pigs, and of raising pigs on food wastes at the city dump (Hide, 2003), but there has been no recent detailed study. Pigs were not kept in Suva, but in Tonga over half of all sample households kept tethered or penned pigs, and almost two-thirds kept chickens or ducks. In most cases, poultry were penned or tethered at night and allowed to roam around during the day, and pigs and other larger animals were generally tethered or penned at all times. In Kiribati, Tuvalu and Nauru, pigs and chickens are also kept on home allotments. In Nauru, there was a large communal pig rearing area along the beach in Denigomodu District. In Betio, the most heavily populated area of South Tarawa, there was a large communal pig rearing area with individualized pens, established by the local town council, under coconuts, breadfruit, and other trees. In Tuvalu, pigs are kept near the main urban village along the airport runway on the seaside of the main Fogafale Islet, where they are fed with kitchen wastes and mangrove leaves. In general, homegardens in rural areas also have animals which are penned, tethered, or sometimes free ranging – particularly chickens around houses, which also serve to control cockroaches and other insects.

Apart from kitchen waste, the main feed for pigs and chickens in most areas is coconut kernel. In Tonga, goats and pigs are commonly fed the leaves of *Leucaena leucocephala*, *Pisonia grandis*, and *Erythrina variegata*, while "living edible pens" (pens with edible living fencing) for poultry and pigs are made of these same species, plus others such as *Hibiscus tiliaceus* and *Polyscias* spp., all of which are easily pruned or pollarded to provide fodder. On open lands, horses, cattle, and goats are commonly tethered to trees, which also give them shade. Small animal pens that are commonly constructed of coconut logs, bamboo, *Leucaena*, or other local timber are also found occasionally. In rural homegardens, pigs, goats, and even cattle in Fiji, are stall-fed, or rotationally tethered to trees or fence posts where they can graze or browse.

On the negative side, grazing animals and pigs seem to accelerate agrodeforestation in urban areas through browsing or trampling effects. Once established, however, trees and animals co-exist well, except where browsing goats eat the bark of trees. Cattle, in fact, seem to enhance the establishment and spread of guava (*Psidium guajava*), which although an important fruit, medicinal, and fuelwood source, has become a noxious pasture weed in many areas. Another serious problem related to pig keeping in urban areas is the effect of high-nutrient waste runoff on the nearby shore coral reefs. Nutrient-enriched water favors the growth of algae and phytoplankton over the growth and maintenance of coral reefs, which require clear, nutrient-poor waters. In the rural outer islands of Ha'ppai in Tonga, free-ranging pigs were seen as one of the major constraints to expanded homegardening and the planting of trees in rural villages (Thaman et al., 2001).

1.4. Ethnic basis of garden composition

The most common plants of Pacific island homegardens tend to be traditionally important native plants or pre-European (aboriginal) introductions, except where the gardeners are from immigrant populations. For example, the Indian population of Fiji prefers species such as eggplant (*Solanum melongena*), okra (*Abelmoschus esculentus*), *Amaranthus* spp., pulses and cucurbits, and tree crops such as jackfruit (*Artocarpus heterophyllus*), tamarind (*Tamarindus indicus*), mango, *Citrus* spp., curry leaf (*Murraya koenigii*), Sebesten plum (*Cordia dichotoma*), horseradish or drumstick tree (*Moringa oleifera*), and the spiritually and medicinally important neem tree (*Azadirachta indica*).

Similarly in a study of 150 urban lots in Hawai'i, where the native population is small relative to the immigrant population of Japanese, Chinese, Filipino, European and North American origin, plants introduced after European contact dominated the homegardens (Ikagawa, 1994). Of the 42 genera present in more than 10% of Honolulu gardens, only two were introduced by Hawaiians, *ti* (*Cordyline fruticosa*) and *Musa* spp. A strong preference for ornamental landscapes and the strong money-based economy and culture presumably explain the relative lack of edible, culinary, and medicinal plants in Hawaiian homegardens.

In Port Moresby and most other PNG urban areas and plantation or mining settlements, where there are high percentages of immigrants from other areas of PNG, homegardens reflect the great diversity of species, cultivars and cultivation practices arising from the cultural and ecological diversity for which the country is famous. This diversity is evident in the gardens of settlers on the oil palm (*Elaeis guineensis*) projects of West New Britain (Benjamin, 1985) and Milne Bay Province. In Port Moresby, urban migrants often have preferences to traditional crops of their native habitats that may be unsuited to the local soils or climate. Examples include struggling sago palms (*Metroxylon sagu*), and the small potherb *Rungia klossii*, lovingly nurtured to coax a second crop of leaves from cuttings brought from the highlands. Similarly, Trobriand islanders, attached to the social values of their crops, have transferred competitive yam growing to Port Moresby (Battaglia, 1985).

Despite the dominance of these traditional crops, there is also a great range of more recently introduced crops, such as temperate vegetables, pineapple, papaya, avocado (*Persea americana*), guava, and improved citrus varieties and banana clones, as well as cassava, which is a ubiquitous staple in most Pacific island towns (Thaman and Thomas, 1985). In fact, Pacific homegardens seem to have been, and will probably continue to be, one of the most effective avenues for the introduction and acceptance of new plant species. The introduction of *chaya* or tree spinach (*Cnidoscolus chayamansa*) into homegardens in urban South Tarawa and elsewhere, mentioned above, is an excellent example.

1.5. Spatial arrangement of components in the homegardens

There is great diversity in the spatial distribution of food crops and their area. Whereas some households have only a few scattered fruit trees and vegetables, many cultivate food crops on over 50% of the total area of their property. In Port Moresby, for example, in Morata and Gerehu suburbs, recently settled in the mid-1970s, an average of approximately 40% of 450 m^2 allotments were then under food crops. Similarly, in some cases in Nuku'alofa, up to 75% of 500 to 1000 m^2 allotments were under food cultivation, primarily root crops (such as yam, taro, tannia, cassava, and sweet potato) and banana among scattered trees (Thaman, 1995). Trees gradually become dominant in long-settled areas as cash incomes increase, and tree seedlings mature and increasingly shade garden areas. Nevertheless, in suburbs such as Gerehu, where trees have matured, socioeconomic status has risen. Although and the contribution to household economies that homegardens provide has declined, gardening continues to be important (Levett, 1996).

Ornamentals are commonly planted closest to the home, often in front yards, as well as in containers on front porches. Medicinal plants, sacred or fragrant plants, and other culturally valuable, common multipurpose plants, are scattered amongst the food plants and ornamentals. In gardens of the indigenous Nauruans (who as a result of phosphate mining royalties, have historically had high per capita incomes), ornamental, aromatic and medicinal plants dominate, along with the ubiquitous coconut, edible pandanus, some bananas, and breadfruit. At the Location contract worker settlement in Nauru, where people live in multistory tenements, and where family gardening is limited to no more than 15 to 30 m^2, most families have only a few plants. The gardens of Tuvaluans and I-Kiribati who live as contract workers in Nauru often consist of juvenile tree seedlings, staple root crops, or a single coconut palm or stand of bananas. In the gardens of Chinese (mostly recruited from Hong Kong) and Filipinos, the emphasis is on intensive vegetable gardening, often in containers, reflecting a more intensive system than that was practiced by most indigenous Pacific island peoples. In Kiribati and Tonga, however, recent emphasis has been placed by the government and non-governmental organizations on more intensive types of gardening: in Kiribati, using hydroponic and deep mulching techniques because of the highly infertile calcareous and sandy soils there. In Kiribati, where vitamin A deficiency-induced night blindness and xerophthalmia have become problems, the planting and consumption of the vitamin-rich leaves of two native tree species: *noni* (*Morinda citrifolia*) and *Pisonia grandis*, and more recently *chaya* have been encouraged in urban areas (Thaman, 1995).

1.6. Trends toward agrodeforestation

Despite the current importance of gardening on open urban and periurban land, these areas have been severely affected by deforestation and agrodeforestation (Thaman, 1992). Increasing population, poverty, and need for firewood, expansion of squatter settlements, lack of legislation controlling tree removal, increasing dependence on root crops such as cassava and sweet potatoes, and the loss of knowledge on the importance of trees in the context of a rapidly urbanizing Pacific have led to the increasing elimination of trees from urban landscapes throughout the islands (Thaman, 2002). In rural areas, promotion of a wide range of export cash crops (e.g., coconut, banana, cacao [*Theobroma cacao*], sugarcane, coffee [*Coffea* spp.], ginger [*Zingiber officinale*], and butter pumpkin [*Curcurbita maxima*]) has led to the clearing of diverse agroforests. This has been particularly serious in Tonga, where rapid expansion in the export of pumpkins to Japan has led to increasing use of the plow and clearance of multipurpose trees from agricultural holdings[3]. The Southeast Asian homegardens also experience a similar situation with varying degrees of commercialization (Abdoellah et al., 2006). When clearing land for short-term crops, trees in traditional agroforests used to be severely pruned or pollarded, but not killed, so they would regenerate after the crops have been harvested. However, in recent times they are commonly bulldozed, ploughed, deliberately killed with herbicides, or burned to make way for cash crops or for urban expansion.

1.7. Constraints and limitations to homegardening

Homegardeners face a number of problems in maintaining their traditional agroforests. These include poor soils, cost, and availability of land and water, insufficient time and labor, agricultural thefts, lack of planting materials, and lack of government assistance (Thaman, 1995). For example, drought is a major problem in Port Moresby, which has a 7-month dry season and has suffered prolonged droughts during the recent *El Niño* events. Gardeners must contend with the increasing unreliability of the overstretched, reticulated, water supply system and the failure of community faucets, regulations against the use of water for gardening purposes, and lack of alternative water supplies (Vasey, 1990). Restrictions on the use of water in gardens are also imposed during periods of extended droughts in Fiji. The atolls are also periodically affected by prolonged droughts, which commonly lead to the death of a significant proportion of the breadfruit, citrus, and other trees and food plants that are only marginally suited to the atoll environment[4].

Urban gardeners commonly have to contend with infertile, poor soils, such as the rocky or stony Lithosols of Port Moresby, the shallow soils that overlie a marl substrate in Suva, hydromorphic soils in low-lying areas, and the notoriously infertile, calcimorphic atoll soils of Kiribati, Tuvalu, and the Marshall Islands. Continual cropping on small urban plots also leads to declining fertility and loss of soil structure, unless ameliorative measures are taken (Thaman, 1995). Both water shortage and poor soils, however, often make trees a more attractive proposition than short-term ground crops, which require water and higher soil fertility.

Insufficient land and insecurity of tenure are problems in most areas. More than half of all households in Suva, Fiji, said land shortage was a problem (Thaman, 1983). Insecurity of tenure, especially in Suva, where a number of people had short-term leases or were squatters, seems to be a major problem and a strong disincentive to homegardens and the protection of trees. City Council regulations, although not strictly upheld, have also been considered a disincentive; and have discouraged cultivation of ground crops and trees along road frontages, and the keeping of pigs, goats, cows, and horses within the city limits. Other problems for gardeners include: plant diseases, insects, snails, birds, rats, dogs, mongooses, and noxious weeds; theft of produce, especially of banana bunches and tree fruits; insufficient time; high costs of poultry feed and fertilizer; predation of firewood and deforestation on undeveloped urban and periurban lands where most low-income families still depend on firewood to cook their meals; boundary problems with respect to ownership of crops; and neighbors' unfavorable response to gardening or livestock rearing (Thaman, 1995).

In Port Moresby, hillside gardening has once again become the focus of criticism, on the grounds that it causes environmental damage, to the point that, in 2005, the Prime Minister promised publicly a legislation to ban it (Quartermain, 2005). Constraints to expanded homegardening are the greatest in Kiribati, Tuvalu, the Marshall Island, and Nauru, where extremely poor soils, limited water availability, and very high population densities, especially in South Tarawa and at Location, Nauru, are serious problems. Among the indigenous Nauruans, who are considered to be 100% urbanized, extremely high per capita incomes from phosphate royalties in the past and a resulting overdependence on imported foods seem to be the major disincentive to urban food gardening. The problem is complicated in Funafuti, where the soil from over half of the highest quality land on the main urban islet of Fogafale was excavated during World War II to build a runway, leaving only soil-less "borrow pits" of no agricultural utility.

1.8. Future prospects of urban and homegarden agroforestry

The importance of urban and homegarden agroforestry and its implications for planning are not clearly understood by most planners and policymakers in the Pacific islands because of a lack of quantitative data on its nature, extent, and cultural and ecological significance. There is little sign of a continuation of the interest once shown by some city planners and administrators. For example, the Port Moresby Housing Commission's survey of urban gardening in the early 1970s and the studies by the Committee on Food Supplies of the Solomon Islands (1974) of the production of major staple crops (primarily sweet potato) in Honiara stressed the need to increase production per capita in both rural and urban areas. Fitzroy (1981) pointed out the correlation between vitamin deficiencies in "urbanized" people without garden plots in Honiara. Although further studies stressing the importance of urban and homegardens have been conducted since the mid-1970s, there is still a need for more information on the problems faced by gardeners, such as crops that do best under conditions of increasing pressure on land and deteriorating soils, best practices in terms of soil conservation and improvement, successful models for promoting urban and homegardening, and, models for the propagation and distribution of desirable cultivars of particularly useful plants.

Nevertheless, there are some hopeful signs in favor of urban and homegarden agroforestry in the region. Among these are the continued efforts supporting the spread of kitchen gardening ("supsup" gardens) in Solomon Islands (Jansen et al., 2001), recognition by the National Agricultural Research Institute and other bodies in Papua New Guinea of the continuing importance of urban gardening and the need for remediation of erosion problems (Quartermain, 2005), and the international Slow Food movement[5], which promotes the appreciation of locally-grown food, and is gaining ground in Hawai'i.

It has been recognized that urban and homegarden garden agroforestry could help to prevent and alleviate poverty, reduce the alarming incidence of nutritional disorders and nutrition-related, non-communicable diseases, promote greater food security, reduce dependence on inferior imported medicines, fuels, ornamentation, handicrafts and other products and address environmental problems such as coastal erosion and pollution, loss of biodiversity and urban agrodeforestation (Thaman, 1988). These practices can also stem the loss of traditional ethnobiodiversity (e.g., the uses, knowledge, beliefs, management systems, and languages; Thaman, 2004) of which trees, forests and tree-rich agroforestry systems constitutes a dominant component. Particular emphasis must be placed on the protection and enhancement of existing urban and homegarden agroforestry systems. Preserving and improving existing systems is an appropriate and cost-effective means of fostering the use of trees within the fabric of a rapidly urbanizing and homegarden-oriented Pacific island landscape.

ACKNOWLEDGEMENTS

We thank the countless Pacific island urban and homegarden agroforesters and gardeners, both male and female, who have shared knowledge of their plants and technologies and allowed us to spend time with them in their agroforests over the past decades. Many thanks also to Robin Hide for his generous help in writing this article.

ENDNOTES

1. Bourke R.M., Allen M.G. and Salisbury J.G. 2001. Food security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference, ACIAR Proceedings 99. ACIAR, Canberra, Australia, 892p.
2. Kennedy J. and Clarke W.C. 2004. Cultivated landscapes of the southwest Pacific. RMAP Working Paper 50. Resource Management in Asia–Pacific Program, Research School of Pacific and Asian Studies, Australian National University, 47p.
3. Thaman R.R. 2004. *'Akau, poto mo e'ofa fonua: Ko e makatu'unga 'o e tukufakaholo* (Trees, arboreal diversity and ethnobiodiversity: An agroforestry action plan for sustainable development in the Kingdom of Tonga). Technical Report 2004/04. Institute of Applied Science, University of the South Pacific, Suva, Fiji, 128p.
4. Thaman R.R. 2004. Cool spots under threat: The conservation status of atoll biodiversity and ethno-biodiversity in the Pacific Islands. In: Lee K.J. and Tsai H.-M. (eds), Changing islands–changing worlds: Proceedings of Islands of the World VIII, pp 60–64. International Small Islands Studies Association (ISISA), Sydney, Australia.
5. <www.slowfood.com> last accessed: January 2006.

REFERENCES

Abdoellah O.S., Hadikusumah H.Y., Takeuchi K., Okubo and Parikesit, 2006. Commercialization of homegardens in an Indonesian village: vegetation composition and functional changes. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 233 – 250. Springer Science, Dordrecht.

Allen B.J., Nen T., Bourke R.M., Hide R.L., Fritsch D., Grau R., Hobsbawn P, and Lyon S. 2002. Central Province: Text Summaries, maps, code lists and village identification. Agricultural Systems of Papua New Guinea. Working Paper 15. Revised edition. Department of Human Geography, Research School of Pacific and Asian Studies, The Australian National University, Canberra, Australia, 152p.

Battaglia D. 1985. Bringing home to Moresby: Urban gardening and ethnic pride among Trobriand Islanders in the national capital. IASER Special Publication 11. Institute of Applied Social and Economic Research, Port Moresby, Papua New Guinea, 53p.

Benjamin C. 1985. Some food market influences of a large-scale smallholder development in the West New Britain area of Papua New Guinea. Papua New Guinea J Agric Forest Fisher 33(3–4): 133 –141.

Committee on Food Supplies (BSIP). 1974. Food and self-reliance: report of the Committee on Food Supplies. Government House, Honiara, Solomon Islands, 68p.

Coyne T. 2000. Lifestyle diseases in Pacific communities. Technical Paper 219. Secretariat of the Pacific Community, Noumea, New Caledonia, 331p.

Curtis M. 2004. The obesity epidemic in the Pacific Islands. J Dev Social Transfor 1: 37 – 42.

Falanruw M.C. 1995. The Yapese agricultural system. PhD thesis. University of the South Pacific, Suva, Fiji, 386p.

Fitzroy G.J. 1981. Commentary: Influence of development factors on nutritional patterns in the Solomon Islands. Ecol Food Nutr 10: 87 – 119.

Hide R. 2003. Pig husbandry in New Guinea. A literature review and bibliography. ACIAR Monograph 108. ACIAR, Canberra, Australia, 291p.

Ikagawa T. 1994. Residential gardens in urban Honolulu, Hawaii: neighborhood, ethnicity and ornamental plants. PhD thesis. University of Hawai i at Manoa, Honolulu, 208p.

Jansen T., Kotali C. and Pitavavini G. 2001. Improving household food security in Lauru, Solomon Islands, through grass roots extension, kitchen gardens and nutrition education. In: Bourke R.M., Allen M.G., and Salisbury J.G. (eds), Food security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference, pp 509–515. ACIAR Proceedings 99, ACIAR, Canberra, Australia.

Lamanda N., Malézieux E. and Martin P. 2006. Structure and dynamics of coconut-based agroforestry systems in Melanesia: a case study from Vanuatu archipelago. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 105 – 121. Springer Science, Dordrecht.

Levett M.P. 1992. Urban gardening in Port Moresby: A survey of the suburb of Gerehu. Yagl-Ambu, Papua New Guinea J Soc Sci Hum 16(3): 47 – 68.

Levett M.P. 1996. Fresh food production and marketing: national and Port Moresby perspectives. In: Gladman J., Mowbray D., and Duguman J. (eds), From Rio to Rai: Environment and development in Papua New Guinea up to 2000 and beyond: A quarter of next to nothing. Papers from the 20th Waigani Seminar Vol. 3, University of Papua New Guinea, Port Moresby, 302p.

Levett M.P. and Uvano M. 1992. Urban gardening in Port Moresby: A survey of the suburbs of Morata and Waigani. Yagl-Ambu, Papua New Guinea J Soc Sci Hum 16(3): 69 – 91.

National Statistical Office of Papua New Guinea. http://www.nso.gov.pg/2000_Census (last accessed: January 2006).

Parkinson S.V. 1982. Nutrition in the south Pacific—past and present. J Food Nutr 39(3): 121 –125.

Quartermain A. 2005. Food for thought. Nari Nius, Newsletter of the Papua New Guinea National Agric Res Inst 8(1): 9.

Soemarwoto O.M., Karyono I., Soekar, Tadiredia W.M. and Raman A. 1985. The Javanese homegarden as an integrated agro-ecosystem. Food Nutr. Bull. 7(3): 44 – 47.

Thaman R.R. 1976/77. Plant resources of the Suva Municipal Market, Fiji. Ethnomedicine IV 1/2 (1976/77): 23 – 62.

Thaman R.R. 1978. Cooperative yam gardens: An adaptation of a traditional agricultural system to serve the needs of the developing Tongan market economy. In: Fisk E.K. (ed.), The adaptation of traditional agriculture, pp 116–130. Development Studies Center Monograph No. 11. Australian National University, Canberra.

Thaman R.R. 1982. Deterioration of traditional food systems, increasing malnutrition and food dependency in the Pacific Islands. J Food Nutr 39(3): 109 – 121.

Thaman R.R. 1983. Urban gardening in Fiji: A direct means for sustainable national development. Proc Fiji Soc 13: 1 – 27.

Thaman R.R. 1987. Urban agroforestry: The Pacific islands and beyond. Unasylva 39(55): 2 – 13.

Thaman R.R. 1988. Environmental issues in the Pacific Islands: Constraints to sustainable island development. Pacific Issues 1, pp 1 – 77. Pacific Circle Consortium, Woden, Canberra, Australia.

Thaman R.R. 1992. Agrodeforestation as a major threat to sustainable development. In: Thistlethwaite R. and Votaw G. (eds), Environment and development: A Pacific Island perspective, pp 194–195. Asian Development Bank, Manila and South Pacific Regional Environment Programme, Apia, Samoa.

Thaman R.R. 1995. Urban food gardening in the Pacific Islands: A basis for food security in rapidly urbanising small-island states. Habitat Int 19: 209 – 224.

Thaman R.R. 2002. Trees outside forests as a foundation for sustainable development in the small island developing states of the Pacific Ocean. Int For Rev 4: 268 – 276.

Thaman R.R. 2004. Sustaining culture and biodiversity in Pacific Islands with local and indigenous knowledge. Pac Ecologist (7&8): 43 – 48.

Thaman R.R. and Clarke W.C. 1993. Pacific island agroforestry: Functional and utilitarian diversity. In: Clarke W.C. and Thaman R.R. (eds), Pacific Island agroforestry: Systems for sustainability, pp 17–33. United Nations University Press, Tokyo.

Thaman R.R. and Thomas P.M. 1985. Cassava and change in Pacific Island food systems. In: Cattle D.J. and Schwerin K.H. (eds), Food energy in tropical ecosystems, pp 191–228. Gordon & Breach, New York.

Thaman R.R., Eritaia B. and Fakaʻosi S. 2001. Community-based biodiversity surveys and conservation action plans as tools for nature conservation in the Pacific Islands: Lessons learned from Fiji, Tonga and Kiribati (Melanesia, Polynesia and Micronesia). In: Miller S. and Sim J. (eds), Tools for conservation: 6th South Pacific Conference on Nature Conservation & Protected Areas (29 September – 3 October 1997), Pohnpei, Federated States of Micronesia. Volume 3: Conference papers, pp 225 – 285. South Pacific Regional Environment Programme, Apia, Samoa.

Vasey D.E. 1990. On estimating the net social and economic value of urban home gardens. In: Landauer K. and Brazil M. (eds), Tropical home gardens, pp 203–213. United Nations University Press, Tokyo.

CHAPTER 4

AMAZONIAN HOMEGARDENS: THEIR ETHNOHISTORY AND POTENTIAL CONTRIBUTION TO AGROFORESTRY DEVELOPMENT

R.P. MILLER[1], J.W. PENN, JR.[2], AND J. VAN LEEUWEN[3]

[1]Instituto Olhar Etnográfico, SHIN CA 5 Conj. J Bl. B, Sala 105, Brasília-DF 71505, Brazil; E-mail: <robert_safs@yahoo.com.br>. [2]Grand Valley State University, 1155 Au Sable Hall, Allendale, MI, 49401, USA. [3]Instituto Nacional de Pesquisas da Amazônia – INPA, Manaus, Amazonas, Brazil

Keywords: *Caboclo*, Fruit tree domestication, Indigenous knowledge, *Ribereño.*

Abstract. This chapter reviews how homegardens and a number of other traditional agricultural practices survived the aftermath of European conquest of Amazonia. The historical development of homegardens in Amazonia began with the evolution of agriculture and domestication of trees in prehistoric times, followed by the development of cultural complexes along the Amazon River and its main tributaries. These traditional societies, characterized by rich material culture and well-developed agricultural systems, were decimated by the combination of epidemics, wars and slavery that accompanied the European conquest. Yet, the homegardens survived in Amazonia, and today they represent the reorganization of the original indigenous practices within the context of the upheaval and changes brought by colonization and market economies, including the incorporation of introduced Asian fruit trees. Although homegardens near urban centers may provide income, in rural areas they are important chiefly for household subsistence. They are often the focus of experimentation with new tree species and cultivation techniques, and thus have the potential to contribute to the development of other agroforestry systems, and to extension efforts that seek alternatives for agricultural development in Amazonia.

1. INTRODUCTION

The local and regional diversity of Amazonian homegardens is best understood by studying their origins and how they have been influenced by the socioeconomic and

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 43–60.

cultural forces that have shaped social organization and subsistence practices in the region, from prehistoric times to the present. This historical development begins with the evolution of agriculture and the domestication of trees in prehistoric times, followed by the emergence of complex cultures or chiefdoms along the main rivers, described by the first European explorers as exhibiting elaborate material culture and agricultural systems (Carvajal, 1542; Acuña, 1639). Although European conquest subsequently decimated these societies through a combination of epidemics, wars and slavery, as this chapter will show, a number of their agricultural practices, including homegardens, survived.

The *traditional* (i.e., prior to any interventions by research/extension agencies) homegardens of Amazonia represent a dynamic equilibrium of these original indigenous practices with the new social order and scenario created by the process of colonization. Included in this process was the incorporation of many Asian fruit trees introduced by the Europeans. The culture of traditional river-edge inhabitants, known as *caboclos* (in Brazil) or *ribereños* (in Peru) represents the fusion and synthesis resulting from this historical process, and homegardens today are an integral part of life throughout Amazonia.

Some of these homegardens and their ethnoecology have been formally described in many scientific publications (Denevan and Padoch, 1987; Padoch and de Jong, 1991; Smith, 1996; 1999; Coomes and Burt, 1997; Lamont et al., 1999; Denevan, 2002; Coomes and Ban, 2004), including some dissertations (Bahri, 1992), Annals of the Brazilian Agroforestry Congresses, and other such records (e.g., Miller, 1994; van Leeuwen and Gomes, 1995; Rosa et al., 1998a; 1998b; 1998c). Although a portion of this literature limits its scope to descriptions or lists of species found in the homegardens, some of these evaluate the factors determining choice of species, their management, and how proximity of markets influence these (e.g., Lamont et al., 1999). Based on this body of literature, and the personal experience of the authors in Amazonia, this chapter will attempt to reach some general conclusions as to the historical and cultural importance of homegardens, and how this can be linked to the underlying processes of the relationship between humans and cultivated trees. An understanding of this relationship is essential for evaluating the potential contribution of homegardens to extension efforts that seek alternatives for agricultural development in Amazonia, and some suggestions will be made along this line.

2. ETHNOHISTORY OF HOMEGARDENS IN AMAZONIA

2.1. Pre-historical development of agriculture and homegardens in Amazonia

Archeological evidence from the lowland neotropics in Colombia, Ecuador, Peru, and Mesoamerica indicates that between 10 000 and 8600 b.p. (before present) horticulture emphasizing both native tubers and seed plants was taking place outside Amazonia (Piperno and Pearsall, 1998; Piperno et al., 2000; Smith, 2001). However, in a site in Rondônia, in western Brazilian Amazonia, where human occupation by hunter-gatherers dates back to 9000 b.p., vestiges of agricultural activity, in the form of processing utensils, only begin to appear around 4500 b.p. (Miller, 1992). Lathrap (1977) argues that the earliest agriculture in Amazonia was probably adjacent to dwellings, along or near rivers in forests that did not require frequent clearing. At some moment, native fruit trees were domesticated and incorporated into these prehistoric agricultural systems. This process may have occurred initially through the 'dump heap' (*sensu* Anderson, 1952) or incidental route to domestication, when seeds of edible fruits collected in the forest were discarded near dwellings. Although little information is available on the sequence of domestication for neotropical tree crops, it is likely that this was concurrent with the domestication of root-crops, as the maintenance of gardens near dwellings would have provided an ideal location for the discarded seeds of useful tree species to germinate and grow. The recognition and management of such 'volunteers' would have been the first step along the road to their domestication.

By 3000 to 2000 b.p., agricultural development made possible the existence of larger villages of many hectares on the middle and lower Orinoco River in Venezuela, and by 2000 years ago, large, socially stratified chiefdoms were thriving along the principal rivers of Amazonia. There is evidence of crop domestication and diffusion from this period of Amazonian history. For example, Salick (1992) has found that the domestication and exchange of cocona (*Solanum sessiliflorum*), common to Western Amazonian homegardens today, may have begun as long as 2000 years before present. When the first European explorers arrived in Amazonia in the 16th century, large population complexes, exhibiting an elaborate material culture and ceremonial art, occupied the margins of the main rivers, with links to surrounding regions through extensive trade networks (Roosevelt, 1994). From the description by Jesuit friar Gaspar de Carvajal, in his account of the first European exploration of Amazon in 1541–`42, we know that part of this cultural development consisted of agricultural systems based on a great variety of cultivated plants, including fruit trees, and the storage of various foods such as cassava (*Manihot esculenta*), maize (*Zea mays*), dried fish, and penned river turtles (Carvajal, 1542). Although the existence of some sort of homegarden is clear in these historical accounts, little detail is provided on the nature of these indigenous agroforestry systems. Carvajal, for example, mentions only that "much fruit of all kinds" was found in one village, and that fruit trees were planted on either sides of the road leading to another village (Carvajal, 1542). In all, at least 138 species of plants are thought to have been under cultivation or management at the time of European arrival in Amazonia, of which 68% were trees or woody perennials (Clement, 1999a). Besides the species mentioned in historical accounts, it is possible that in pre-Columbian times many more species were also cultivated, or were in a state of incipient domestication. A number of commonly cultivated Amazonian fruit trees have the characteristics of long periods of selection and genetic improvement. Clement (1989; 1999b) suggests the existence of a pre-Columbian center of crop diversity in Western Amazonia, based on the genetic diversity of fruit tree domesticates. In terms of their manipulation of plant resources, pre-Columbian cultures in Amazonia appear to have operated along a gradient of domestication, with plants fully domesticated and reliant on human care for their dispersal and survival at one extreme, as is the case of the peach palm (*Bactris gasipaes*). At the other extreme of this gradient were those wild plants that may be found in greater than normal concentrations around ancient village sites, as a result of agricultural clearing and burning, with the possible favoring of their regeneration, but which do not exhibit any apparent genetic differentiation from their wild counterparts. Between these extremes are found a number of interesting and useful plants, suggesting that an active process of genetic selection and domestication was taking place in pre-Columbian Amazonia. An example of how this process may have occurred (and continues to occur) is described by Schroth et al. (2004), for the palm *Astrocaryum tucuma* in the Manaus region. Nevertheless, for the most part, the continuing domestication of wild species was truncated by the European conquest.

In less than 200 years after the events described in Carvajal's report (Carvajal, 1542), the great chiefdoms along the Amazon had succumbed to epidemics of imported diseases such as smallpox and measles, wars, and enslavement. Their sophisticated culture and political and trade networks collapsed, and large stretches of the Amazon River and its tributaries were totally deserted (Daniel, 1776).

Despite the decimation of native Amazonian populations that occurred during European conquest, with an ensuing loss of agrobiodiversity, many elements of their agricultural and agroforestry systems survived and can be seen among the modern tribal groups. The agroforestry practices of some of the tribal peoples in Amazonia, reviewed in Miller and Nair (2006), range from the cultivation of fruit trees and other useful plants around dwellings (homegardens), to the incorporation of trees in agricultural fields and fallows, which may involve practices such as actively planting or managing useful tree species or sparing seedlings that regenerate naturally. The homegarden of fruit trees, condiments and medicinal plants may grade into a belt of fruit trees surrounding a village, fruit trees interspersed with field crops, orchards of mixed fruit trees, and fallows of forest species enriched with fruit trees – these last mentioned configurations having been termed "swidden-fallow agroforestry" (Denevan and Padoch, 1987; Denevan, 2002). Although there are exceptions, as in the case of tribes with a very rudimentary agriculture, for the most part, homegardens can be considered as an important component of the subsistence technologies and cultural knowledge of Amazonian tribes.

Whether the specific cultivation methods employed by contemporary indigenous groups are the same as those of their pre-colonial ancestors is a difficult question to answer. Nevertheless, it is probable that the agroforestry systems practiced by indigenous peoples as well as the *caboclos* and *ribereños* are direct descendants of the systems in existence prior to European arrival, with the addition of a number of exotic species of fruit trees. This contribution of exotic species introduced by Europeans is discussed in the context of the ethnohistory of *caboclo* and *ribereño* culture, the subject of the following section.

2.2. Ethnohistory of caboclo *and* ribereño *culture and homegardens in Amazonia*

Although the use of the term *caboclo* has been criticized due to its negative social connotations (Lima, 1999), it is difficult to substitute, as it encompasses both colloquial as well as academic meanings in Brazil, and is a broad descriptor of a regional form of life and natural resource use. While modern-day tribal groups of

Amazonia in most cases represent the fragments of populations and cultures that escaped to survive and regroup following the colonial holocaust, *caboclo* society in Brazil or *ribereño* society in Peru and their cultures are the result of the fusion of the remnants of the native populations, decimated during colonization, with European and African racial and cultural elements (Padoch and Pinedo-Vasquez, 2001; Ribeiro, 1997). In this process, agricultural, social, economic, and belief systems were reconfigured and reconstructed upon an existing knowledge base of ecological systems and subsistence practices, with the addition of new tools and technologies. Key players in this process were the Catholic missionaries in Amazonia. As allies to the colonial economic system, they had a major role in providing an ideology for the domination of the native populations and their transformation into a labor force. Along with the forts, missions were fundamental elements in guaranteeing the domination of the region by the Portuguese from 1650 – 1750, and allowing the functioning of commerce (Alves-Filho et al., 2005).

Despite the superiority of Portuguese armaments, the native peoples did not submit easily to Portuguese attempts to enslave or otherwise conscript them as agricultural workers growing subsistence and commercial crops, collectors of forest products (such as cacao, *Theobroma cacao*), in the construction of public works, and other forms of labor, without which the colonial economy in Brazil would have collapsed (Alves-Filho et al., 2005). In response, they waged war, rebelled in villages and missions, deserted from royal services, massacred when possible their enemies, and even made peace treaties when convenient (Santos, 2002). Elsewhere in Amazonia, natives also put up fierce resistance, lasting well into the republican period of the former Spanish colonies, especially in Peru and Colombia (San Ramon, 1994; Stanfield, 1998; Rios, 2001).

The search for cacao using Indian labor, primarily from stands of wild or feral trees, motivated the Portuguese to range far upriver, leading Portuguese incursions west into Spanish territory (now Peru) to kidnap Indians on the Marañon River during 1686 – 1723 (Edmundson, 1922). By 1730, cacao had become the region's dominant export, remaining so for more than a century (Alden, 1976; Hemming, 1987). Cacao gathering expeditions had ceased by 1750 and cacao was being cultivated in plantations along the Amazon. Farmers grew seedlings on raised beds for a year, and then transplanted them into their cassava fields, where banana plants (*Musa* sp.) had been previously planted to provide shade. Native fruit trees, along with introduced species, such as orange (*Citrus sinensis*) and avocado (*Persea americana*), were also interplanted with cacao, as it was known that cacao produced better in shade (Daniel, 1776). Cacao appears to have been an important, if not the principal, economic element of the agroforestry systems of that time. By the mid-1800s, another exotic species, coffee (*Coffea arabica*), was one of the main agricultural exports of the region, along with cotton (*Gossypium* sp.), cacao, guaraná (*Paulinia cupana*), and tobacco (*Nicotiana tabacum*) (Amazonas, 1852).

By 1875, the rising demand for rubber, an important material for the Industrial Revolution, led to an economic boom in Amazonia. Rubber, extracted from the forest tree *Hevea brasiliensis*, had by 1880 become the third most important export in Brazil and Peru (Stanfield, 1998; Homma, 2003). The *caboclo* population, concentrated on the Amazon and Solimões Rivers, spread out through the entire basin in search of rubber trees. A mixture of *caboclo*, *mestizo*, European, and indigenous (tribal) gatherers tapped the forests of Peru, Colombia, and Bolivia; and Manaus, Belém, and Iquitos grew into the principal commerce centers along the Amazon River. The boom attracted many migrants as well as absorbing the local labor force, with the result that agricultural production in Amazonia dropped sharply (Ribeiro, 1997; Stanfield, 1998). The rubber boom also brought disastrous consequences to the remaining forest tribes, as rubber tappers penetrated even the most distant headwaters. The atrocities committed against the Indians and their conscription as forced labor were so widespread that they attracted international attention (Renard-Casevitz, 1992; Stanfield, 1998). With the drop in agricultural production, food prices soared. Tribal societies involved in the trade could do little farming, suffered from severe hunger, and often lost their lands to rubber tappers (Stanfield, 1998). Where they survived, homegardens undoubtedly played a key role in providing food for rural inhabitants, regardless of their ethnicity.

The crash in rubber prices returned Amazonia to the state of an economic backwater by the end of the First World War (Homma, 2003). Indigenous knowledge, so important to the European and *mestizo* efforts to cultivate and exploit the most economically lucrative resources of the region, lay dying in the form of abandoned fields across the wide swaths of Amazon basin. According to Denevan (2002), homegardens in Amazonia became less important and poorly developed after the arrival of Europeans, mostly because indigenous villages changed their locations much more frequently than they did in the past, yet another consequence of this tragic history.

2.3. Transformation of traditional agriculture during colonial times

Although the Portuguese introduced a number of new crops to Amazonia, such as sugarcane (*Saccharum officinarum*), indigo (*Indigofera indica*), and rice (*Oryza sativa*), as well as domestic animals, indigenous agricultural practices remained the basis for subsistence, and they were also adapted for the production of commercial crops such as cacao. At the same time that technology guaranteed Portuguese military superiority, agricultural technology in the form of steel tools resulted in the transformation of indigenous practices, with stone axes and digging sticks being substituted by steel axes, machetes, hoes and brush hooks. Where previously large trees were ringed with stone axes and left to dry slowly, and saplings were bludgeoned over (Daniel, 1776), steel tools greatly reduced the labor expended in agricultural clearing, with the result that what is considered today as "slash-and-burn" agriculture probably is quite different from what was practiced in pre-European Amazonia. Pre-Columbian agriculture most likely had greater affinity with slash-mulch systems, as fires used to prepare fields would have been much less intense, and ringed trees would slowly drop a layer of leaves over the field. The initial difficulty in opening fields out of forest probably led to a longer use of cleared areas, through complex polycultures and crop sequences, including trees. A more extended use of fields may have been possible due to the input of organic matter from the slowly dying original vegetation.

Catholic missions were in part responsible for the introduction of new technologies and agricultural practices. The Jesuit missions in particular were generally well-managed enterprises that exported a part of their production. Persuading natives to leave their villages and move to these missions involved a number of strategies, besides force, including convincing them that epidemics of introduced European diseases were caused by the insalubrities of their village sites. In some cases, life in a mission was the only alternative to being attacked and enslaved by colonists.

Life in the missions brought together individuals of separate tribes, with different languages and cultures, for the compulsory adoption of the body of beliefs and customs of the colonizer. The cultural result was a patchwork of beliefs, the syncretism of shamanism with a vague observance of Catholic saints and holidays, the base for a "folk Catholicism," incorporating various native practices and beliefs and the colonial influences of the Portuguese, as well as African slaves (Ribeiro, 1997; Maués, 2001). Some of these beliefs are associated with a variety of magical/medicinal plants (e.g., pião roxo, *Jatropha gossypiifolia*) often cultivated in modern homegardens, and which along with ornamentals, are often seen even in diminutive front yards in cities such as Manaus.

A characteristic of European colonization of Amazonia was the introduction of a number of exotic fruit trees. In 1662, Mauricio Heriarte (in Huber, 1904) described Belém as cheerful and full of fruit trees such as oranges, limes (*Citrus aurantifolia*), sweet limes (*Citrus limetta*) and biribás (*Rollinia mucosa*). The introduction of mango (*Mangifera indica*) to Belém in 1780 is credited to the Genovese architect Antonio Landi, who brought seeds from Bahia, the capital of Brazil until 1763. The Portuguese Crown officially sponsored a number of plant introductions from its eastern colonies of Goa (India) and Macau (China) and the establishment of a botanical garden in Belém (Dean, 1995). In 1808, in retaliation for the invasion of Portugal by France, the Portuguese invaded French Guiana and were able to take advantage of the collection of useful plants cultivated in Cayenne's botanical garden. By the time Cayenne was returned to the French in 1818, a number of tropical species had been sent to Belém, along with unspecified European fruit trees that had been acclimated in Cayenne (Holanda, 1965). Coffee was another introduced tree crop that soon proved lucrative for Brazil by the 1800s. Coffee germplasm was introduced to Belém in 1727 by Sargeant-Major Francisco de Mello Palheta, who transported five coffee seedlings and a handful of seeds from Cayenne. The first sample of coffee grown in Pará was sent to Lisbon in 1732, and two years later in 1734, 45 tons were shipped (Homma, 2003).

By the mid-19th century, exotic fruit trees had been fully incorporated into homegardens along the Amazon. Traveling on the Amazon between Óbidos and Manaus in 1849, the British naturalist Henry Walter Bates described homegardens with banana, papaya (*Carica papaya*), mango, orange, lemon (*Citrus* sp.), guava (*Psidium guajava*), avocado (*Persea americana*), abiu (*Pouteria caimito*), genipap (*Genipa americana*), and biribá, as well as coffee shrubs growing under the shade of the fruit trees (Bates, 1863). Ten years later, French traveler Robert Avé-Lallemant recorded a variety of fruit trees growing near houses on the outskirts of Belém: banana, mango, jackfruit (*Artocarpus heterophyllus*), various Annonaceae, orange trees, coffee, as well as the giant granadilla or maracujá-açu (*Passiflora quadrangularis*). Surrounding the dwellings of Indians near Cametá, Pará, he found native calabash trees (*Crescentia cujete*) and orange trees competing with mango, and the native açaí (*Euterpe oleracea*) and bacaba (*Oenocarpus bacaba*) palms. The presence of various Annonaceae, the bacuri (*Platonia insignis*) and brazilnut (*Bertholletia excelsa*) trees was also noted. Besides the homegarden, other tree species were cultivated as commercial crops, and income sources for these households came from "extensive stands of cacao" and rubber trees. Continuing up the Amazon to Santarém, he found many cacao and orange groves, as well as concentrations of the native tucumã palm (*Astrocaryum vulgare*), highly appreciated for the edible mesocarp of its fruits (Avé-Lallemant, 1859).

In Peru, coffee, mango and avocado germplasm entered the Amazon Basin from both the east and west. Avocado entered Peru and the Peruvian Amazon well before the arrival of the Spaniards, while coffee and mango cultivars in Amazonia were introduced from either direction. Accounts from early explorers suggest most mango germplasm came from coastal Peru. Besides Asian species, the Spaniards also brought plant species from and via Central America and the Caribbean. Thus, we might expect common crops of the colonial era such as bananas, beans (*Phaseolus vulgaris*), citrus, or sugarcane in the Peruvian Amazon to have diverse origins even soon after their introduction to the region. Explorers such as Eduard Poeppig, who studied the upper Amazon in 1829-31, have found that much of the cassava germplasm in Peru came from downriver in Brazil, while banana germplasm as far downriver as Manaus, Brazil, often came from Peru (Poeppig, 2003).

By no means, however, was the cultivation of trees limited to the traditional pattern of homegardens or commodity crops. Some homegarden species were creatively adapted to other uses, as is the case of the yellow mombin (*Spondias mombin*; Smith, 1999) and the calabash tree for live fences in the *várzea* (floodplain) region. Similarly, other species that were not previously cultivated, such as the munguba (*Pseudobombax munguba*), a common tree of the *várzea*, were enrolled to mark property boundaries on floodplain ranches. Species such as the rubber tree were added as economic elements, as a small rubber boom during World War II led to a renewed interest in this crop, and a low level of tapping continued even after the war.

2.4. The caboclo *and* ribereño *in the regional economy*

While colonization caused the demise and/or slow absorption of the indigenous tribal populations, a new hybrid society of non-tribal peoples was on the rise. The *caboclos* of Brazilian Amazonia are of mixed descent, as well as the remnants of the acculturated tribes. Similarly, the *ribereños* in Peru are of mixed European and Amerindian descent. Despite the persistent use of the term in the literature, these rural inhabitants do not actually call themselves "ribereños." They most often refer to themselves in occupational or class terms such as *pescador* (fisherman) or *chacarero*, as *chacra* is the common name for the plots of land they farm (Penn, 2004). Researchers point to the Cocama-Cocamilla tribal origins of *ribereños* in Peru, but *ribereños* have diverse origins, and it is not advisable to generalize about their ethnicity. The origin and ethnicity of the Cocama-Cocamilla themselves is still poorly understood (Cabral, 1995).

Although very similar to the original native populations in terms of their ecological adaptations and subsistence practices, the *caboclos* in Brazil were very different socially (Ribeiro, 1997). Historically, they have been embedded in an agricultural and extractive economy, trading raw materials and products collected from the forests and rivers, or grown in their fields, for the manufactured items and tools necessary for their subsistence. For the most part, there was an ample supply of land for the harvest of extractive products and for fields, under communal tenure or belonging to absentee owners and defunct rubber estates. In recent decades, however, this situation has changed as development of a different form has reached Amazonia, with the construction of roads shifting the economic axes away from rivers and floodplains to the *terra firme*, where human occupation has been characterized by a moving frontier of logging, ranching, and agricultural colonization, that leaves in its wake a landscape dominated by pasture and to a lesser extent swidden agriculture. As rights to land have become more disputed, homegardens have taken on another socioeconomic function, with the presence of cultivated trees used as proof of land tenure and property rights.

3. HOMEGARDENS IN PRESENT-DAY *CABOCLO* AND *RIBEREÑO* SOCIETIES

Homegardens in Amazonia are variously referred to in folk denomination as “huertos” or “jardíns” (in Peru), and “quintais” (yards) or “sítios” (homesteads) in Brazil, as well as “pomares caseiros” (home orchards) or “miscelânea” by researchers. They combine native species with fruit trees introduced from other parts of the globe during European colonization, as well as more recent introductions. In a survey of 33 upland homegardens across the Brazilian Amazon, Smith (1996) found a total of 77 tree species, of which 46% are indigenous to Amazonia, and 27% are from the Old World. In a study of 51 homegardens in Peru (Lamont et al., 1999) at least 30 of the 161 species found were exotics, including nine tree species. In the three villages (two of the Yagua tribe and one *ribereño*), the two most common species in all 51 gardens were of Asian origin (i.e., mango and banana).

The importance of homegardens is chiefly the domestic supply of fruits, condiments, medicines, craft materials, and shade. Near urban centers, however, they may become part of both subsistence and income-earning strategies through the production of marketable fruits. How farmers manage the composition of their homegardens in order to influence production and income generation has been little studied, but it appears that there is a ubiquitous stock of species valued for domestic consumption, while others are cultivated specifically as income-earners. Homegardens near Iquitos, Peru, may cultivate native palms for use in the handicraft business (Lamont et al., 1999), or exotic species such as taperibá (*Spondias dulcis*) for their prized fruits. In the Colombian Amazon, lulo (*Solanum sessiliflorum*) is common in homegardens to supply the markets of Leticia, while the market for fruit from the ocoró tree (*Rheedia* spp.) makes it popular in homegardens near Santa Cruz, Bolivia (J. Penn, pers. obs.).

Amazonian homegardens are very diverse in terms of size and number of species, both on a local level, with properties in the same community exhibiting very different assemblages, as well as on a regional level. While some of these differences can be explained, it becomes clear that there is no such thing as a "typical" homegarden, only trends or patterns. The 21 homegardens studied by Padoch and de Jong (1991) in the community of Santa Rosa, 150 km upstream from Iquitos, generally covered between 300 to 700 m^2, the size of a usual house lot in that community. However, the range in size was from 67 to 7322 m^2. Outlying houses had larger gardens, but this was not always the case. A typical pattern observed in many parts of Amazonia is for houses to be located in the central area of the community, where school, church, meeting hall, soccer field, and television are normally found. These hamlets can be part of planned "agrovilas" of colonization projects, or spontaneously formed communities (often based on kin ties) that group together in order to be attended by municipal services such as schools, health posts, or power generators. In these cases agricultural fields are located at a distance, and some sort of homegarden may be found surrounding the shelter used for processing the cassava crop.

Homegardens in Amazonia also must be studied in the context of how dynamism and change affect the economic, social, and cultural aspects of *caboclo* and *ribereño* societies. A community of 60 households near Iquitos, Peru, whose homegardens were studied by Coomes and Burt (1997), for example, was originally founded as an agricultural estate for the production of sugarcane, rum, and fuelwood, and subsequently was divided up among the former workers in 1971 as an act of agrarian reform. In the community studied by Padoch and de Jong (1991), also near Iquitos, life histories of the adults were found to typically include several long economic migrations and many changes of residence. Lamont et al. (1999) found that the intermarriage of *ribereños* within families of the Yagua tribe was associated with declining use of homegardens in Peru, indicating that researchers need to examine the resilience of these agricultural systems to social and cultural change.

Further study is needed to determine the extent to which differences in homegarden size and diversity are random, a product of local processes of sociocultural development and germplasm accession, or whether they reflect changes in management choice with regard to cash and energy flows and the perceived functions of the homegardens. In some cases, traditional homegardens may be eliminated to make place for more profitable plantations, if agricultural land (space) increases in value, as has been observed in the region near Manaus. If the farmer has the means to invest in a profitable crop, the homegarden can be eliminated to plant papaya (*Carica papaya*) or passionfruit (*Passiflora edulis*), or if still closer to Manaus, to plant horticultural crops (e.g., okra, *Abelmoschus esculentus*). This happens especially on better soils, such as anthropogenic black earths or the *várzea alta*, the higher part of the floodplain or natural levee that accompanies the Solimões and Amazonas rivers (J. van Leeuwen, pers. obs.). Penn (2004; 2006) found that homegardens in Peru were being planted with camu camu trees (*Myrciaria dubia*) by *ribereños* anxious to participate in a regional development program that promoted the cultivation of this species, extremely rich in vitamin C.

A category of Amazonian homegardens originating from rubber-cacao plantations, in which an upper stratum of rubber tree canopies is combined with a lower stratum of cacao, frequently is found on the *várzea alta* of the rivers Solimões, Amazonas, and Madeira. The cacao and rubber trees of this two-layer system are always quite old (J. van Leeuwen, pers. obs.). On the Ilha de Careiro, cacao and rubber were planted at the beginning of the twentieth century when production of these two commodities was much more profitable, but planting no longer occurs (Bahri, 1993). On the Ilha de Careiro and elsewhere many cases can be seen of the gradual substitution of cacao and rubber by other fruit trees, with the result that the plantation develops into a multispecies homegarden (Bahri, 1992; 1993). These examples indicate that homegardens can have a long history, in the sense that present day species composition does not necessarily closely reflect current economic scenarios. This is the case in Central Amazonia, where *várzea* homegardens may contain rubber trees that have not been tapped for many years. Although the presence of species that presently have little economic contribution may simply result from low levels of management, and not a conscious effort of conservation, their maintenance may also be part of risk-avoidance strategies. Poor farmers will generally refuse to cut a tree if it is thought that it might be useful at some moment in the future (J. van Leeuwen, pers. obs., based on work with small farmers in Mozambique and the Amazon).

Differing time horizons and expectations of farmers with regard to local market demands, land tenure and property size all can influence the configuration of homegardens and other agroforestry systems. Access to the markets of larger urban centers represents an important economic factor that comes into play. Studies by Rosa et al. (1998a; 1998b) near the state capitals Macapá (Amapá), and Belém (Pará), Brazil, for example, found that small livestock can have considerable economic importance as components of the homegarden system. In properties averaging 90 ha near Macapá, although more than 50% of the chickens, ducks, and pigs raised was consumed by the household, weekly revenue from livestock averaged R$ 35, a value greater than that obtained from the sale of fruits such as açaí, bananas, mangos, limes, and cupuaçu (*Theobroma grandiflorum*), which averaged R$ 20/week [the real (R$) was approximately equal to the US dollar at that time and is now exchanged at R$ 2.3 per US$]. Nevertheless, a good portion of the feed for these animals was said to come from homegarden fruits. In a survey of 20 households near Belém, where property size averaged 1.7 ha, it was found that families consumed 69% of the fruits, 100% of the medicinals, 85% of the vegetables, and 85% of the livestock, with the remainder being sold (Rosa et al., 1998c). Conversely, livestock can destroy homegardens, and make it impossible to maintain or restart a homegarden. The introduction of water buffalo near Iquitos has greatly reduced the number of homegardens where these animals are present (J. Penn, pers. obs.).

4. HOMEGARDEN MANAGEMENT IN AMAZONIA

According to Lathrap (1977), the maintenance of homegardens and clean yards around the dwellings of indigenous communities creates a domesticated microcosm out of the surrounding wild forest, otherwise the abode of spirits and other dangers.

In Waimiri Atroari villages in Central Amazonia, this zone is used by small children, who both forage and play at activities such as shooting lizards with toy bows and arrows (R. Miller, pers. obs.). Although the extent to which Lathrap's cosmological interpretation of the significance of homegardens can be applied to *caboclo* and *ribereño* societies may be limited, the maintenance of a *terreiro*, or *patio* (bare-earth yard) often swept daily, is a ubiquitous feature of rural homes in Amazonia, and serves to reduce hiding places for snakes and insects. The size of this yard is typically about 500 m^2 (20 x 25 m) and may often be larger. The exact limit of the *terreiro*, however, may depend on the time and labor available for weeding. Beyond the *terreiro*, the divide between the homegarden of planted trees and neighboring second growth may not be clearly distinguishable. These fluctuating boundaries between the bare earth yard, the homegarden, and encroaching second growth vegetation are important in permitting the establishment and recruitment of volunteer seedlings of useful trees. Discarded or fallen seeds will germinate in the shelter of leaf litter and undergrowth, and resulting seedlings may be spared by the observant farmer during periodic weeding. This process was noted by Huber (1904), who was probably the first to make specific mention of the ease with which even introduced species of fruit trees in Amazonia become sub-spontaneous, germinating from discarded seeds in the more fertile soil around dwellings. This "spontaneous" aspect of homegardens is in fact an important form of management. Near Iquitos, for example, Padoch and de Jong (1991) found homegardens to be a "combination of trees left from pre-existing fallows or forests, deliberately planted vegetation, spontaneously occurring useful forest plants, species transplanted from the forest, seeds germinating from the forest," resulting in mosaics of different-age vegetation. They also found that 14% of the plants identified as "non-cultivated" were useful and had been selected for in previous weeding operations. This process, also important for outlying fields, fits into what Wiersum (1996) described as the "second stage of domestication," and is suggestive of how trees may have been incorporated into agricultural systems in Amazonia during the past millennia. Some species will simply regenerate more easily than others in these environments. This is a major reason why *Rheedia*, *Genipa*, and *Inga* species are so common in homegardens along the Peruvian Amazon (Penn, 2006).

Areas beyond the yard that are not kept "clean" provide a dumping ground for assorted household and garden wastes, which besides being important as sources of seeds and forage for domestic fowl, can also represent significant nutrient additions. Over millennial time scales in Amazonia, humans have generated patches of higher fertility around their dwellings by concentrating nutrients obtained from surrounding terrestrial and aquatic ecosystems, resulting in anthropogenic "black earths" (Lehmann et al., 2004). Data from a hunting study with the Waimiri Atroari tribe in Central Amazonia (Mazurek, 2001) indicates that an average-size village of 50 people discards approximately 1.5 Mg of bones of game animals every year. Bones represent a significant contribution of calcium and phosphorus, which complement the other nutrient elements found in other forms of household wastes. Although redirecting nutrients can be a conscious practice, such as when farmers place cassava peelings at the foot of selected fruit trees as fertilizer, for the most part, the nutrient peak around dwellings that greatly benefits homegardens is an unconscious practice. Nevertheless, in the case of Waimiri Atroari villages, the zone of greater fertility is explored for the initial establishment of a belt of fruit trees around the communal dwelling, which then expands outward concentrically (Miller, 1994).

5. IMPORTANCE OF HOMEGARDENS FOR AGROFORESTRY DEVELOPMENT IN AMAZONIA

Throughout history, Amazonian farmers were subjected to exploitation as forces of colonization and trade penetrated the region. They have suffered immensely and have often been dispossessed of their traditional lands, but have shown a remarkable ability to adapt to new environments and socioeconomic scenarios. During this period, their homegardens have changed in many ways. Asian species soon became common in homegardens after the Conquests, and are an increasingly common part of these cultural landscapes. Among the various configurations of agroforestry systems, such as tree/crop combinations in fields, orchards of mixed fruit trees, and enriched fallows, homegardens represent the most widespread agroforestry practice employed by farmers in Amazonia today.

Although farmers near urban centers sell homegarden products (Lamont et al., 1999) as well as livestock (principally fowl) raised in and around homegardens, their overall contribution for domestic consumption is probably more important. In this regard, homegardens represent a robust and time-tested technology, employed by the traditional inhabitants of Amazonia, whether indigenous tribes or *caboclos* and *ribereños*, and from the point of view of food security, they may be of great value on agricultural colonization frontiers, where farmers face a difficult struggle to establish themselves and their families.

Originally managed for subsistence according to ethnic practices, homegardens are now increasingly important for farmer experimentation with commercial crops. As the locus of experimentation with new tree species and cultivation techniques, homegardens have the potential to contribute to the development of other agroforestry systems, and may expand into more commercial groves, as discussed by Penn (2004) on the new camu camu industry in Peru, and Yamada and Osaqui (2006) concerning the farmers of Japanese descent in Tomé-açu, Pará, Brazil. The homegarden can function as a “staging area” for testing new species and storing, safeguarding, and multiplying germplasm for transfer to and between fields (Coomes and Ban, 2004). In this manner, the homegarden can be an integral component of the larger agricultural system of the property as well as a key node in the local network of agrobiodiversity, if one considers the exchange of plant genetic resources between households in a community.

The historical study of the course of development of homegardens as a basic unit of interaction between humans and trees holds lessons relevant to the present-day scenario of advancing deforestation, in which agroforestry is ascribed a potential role in developing more sustainable land use. While the technologies or practices involved in expanding agroforestry systems out to fields are not necessarily those employed in homegardens, they entail similar concepts such as tree culture, nutrient cycling, and permanent soil cover, among others, and in this respect, homegardens could be considered as a conceptual core for agroforestry development. The basic units of information that farmers need to develop new models of agroforestry systems are in essence the knowledge of tree species, as to their behavior and interaction with other species. Homegardens, where trees can more easily be cared for and observed, offer optimal locations for the introduction and evaluation of new species.

Nevertheless, in any given community, members will exhibit different levels of perception and relationship with plants, varying from the "green thumbs" to those whose interest in plants goes little beyond their daily needs. In the past, such plant lovers were most likely responsible for the domestication of useful species, and today, they are the experimenters and innovators who generate new technologies by acute observation and the ability to create heuristic models of the behavior, growth, and interactions of the various components of their agroforestry systems. This is a very personal and human process of plant management, which mixes personality traits and life histories, and cannot simply be replicated or substituted by research agencies! The complexity of this social/agronomic interface may explain why homegardens appear to elude science, as Nair (2001) remarked.

Making the leap from growing fruit trees around houses for domestic consumption to planting trees in fields for production of fruit, timber, and other products, nonetheless, requires dealing with an entirely different set of constraints. The main constraints to further developing homegardens or expanding them out to fields for greater productivity and income generation are the lack of adequate germplasm, risk of accidental fires, survival of seedlings in the dry season and soil fertility (Smith et al., 1995; Smith et al., 1996; Smith et al., 1998; Miller, 2001). There may also be a need to modify the configuration of species and management practices observed in traditional systems to meet increased nutrient exports and labor requirements, as well as market demands. At present, commercial products obtained from early stages of agroforestry systems are mostly fruits, and marketing such products, especially processed pulps, requires facilities most farmers cannot afford to have by themselves, while farmers' associations lack the entrepreneurial and managerial expertise to run such installations. This factor has led many innovative agroforestry projects dependent on pulp processing facilities down the path to failure (Penn, 2004).

Despite the official interest in agroforestry, due to the immensity of the Amazon region, extension services have been unable to meet the growing demands for technical assistance. This scenario implies that if agroforestry is to fulfill its promise of providing an alternative and more sustainable form of land use in Amazonia, extension efforts need to break out of traditional paradigms and the mold of commodity-based systems to interact with farmers on a different level of knowledge. The traditional socio-cultural practices involved in acquiring and testing new germplasm, as seen in homegardens, must be included in rural development projects, and stimulated by creative new approaches, with farmers viewed as partners and experimenters in the development and domestication of new generations of tree crops. In this partnership, a major role for extension should be to help provide the necessary germplasm and information.

Surrogate homegardens, based at rural schools, where interesting germplasm can be tested and multiplied for access by frontier farmers, while at the same time improving nutrition for their children, are one suggestion to increase the spread and efficiency of extension services. With homegardens as a conceptual core, this form of agroforestry extension should be accompanied by other initiatives and small-scale experiments to improve the productivity of subsistence crops, through the use of green manures, polycultures, and management of organic matter, among other practices. Although this proposal appears to be simple, existing experiences in a similar vein must be identified and studied to know if it can work and how to make it work.

ACKNOWLEDGEMENTS

Portions of this paper were adapted from Miller and Nair (2006). Charles Clement provided valuable comments on an early version of this chapter. We also thank the comments and suggestions of three anonymous reviewers.

REFERENCES

Acuña C. 1639. Novo descobrimento do Grande Rio das Amazonas. Agir, Rio de Janeiro [reprinted 1994], 179p.

Alden D. 1976. The significance of cacao production in the Amazon Region during the late Colonial period: an essay in comparative economic history. Proc Am Philos Soc 120: 103 – 135.

Alves Filho A., Souza Jr. J.A. and Bezerra Neto J. M. 2005. Pontos de história da Amazônia Vol. 1 Paka-Tatu, Belém, 208p.

Amazonas L.S.A. 1852. Dicionário Topográfico, Historico, Descritivo do Alto Amazonas. Facsimile ed., Grafima, Manaus [reprinted 1984], 208p.

Anderson E. 1952. Plants, man and life. Little, Brown, Boston, 245p.

Avé-Lallemant R. 1859. No Rio Amazonas. EDUSP, São Paulo [reprinted 1980], 288p.

Bahri S. 1992. L'Agroforesterie, une alternative pour le développement de la plaine alluviale de l'Amazone – L'exemple de l'île de Careiro. PhD dissertation, Université de Montpellier II. Montpellier, 277p.

Bahri S. 1993. Les systèmes agroforestiers de l'île de Careiro. Amazoniana 12: 551 – 563.

Bates H.W. 1863. The naturalist on the river Amazons. University of California Press, Berkeley [reprinted 1988], 465p.

Cabral A.S. 1995. Contact-induced language change in western Amazonia: The non-genetic origin of the Kokama language. PhD dissertation. University of Pittsburg, Pittsburg, 415p.

Carvajal G. 1542. The Discovery of the Amazon. AMS Press, New York [reprinted 1970], 467p.

Clement C.R. 1989. A center of crop genetic diversity in western Amazonia: a new hypothesis of indigenous fruit-crop distribution. BioScience 39: 624 – 631.

Clement C.R. 1999a. 1492 and the loss of Amazonian crop genetic resources. I. The relation between domestication and human population decline. Econ Bot 53: 188 – 202.

Clement C.R. 1999b. 1492 and the loss of Amazonian crop genetic resources. II. Crop biogeography at contact. Econ Bot 53: 203 – 216.

Coomes O.T. and Ban N. 2004. Cultivated plant species diversity in a home garden of an Amazonian peasant village in northeastern Peru. Econ Bot 58: 420 – 434.

Coomes O.T. and Burt, G.J. 1997. Indigenous market-oriented agroforestry: dissecting local diversity in western Amazonia. Agroforest Syst 37: 27 – 44.

Daniel J. 1776. Tesouro descoberto no Rio Amazonas. Contraponto, Rio de Janeiro (2 vol.) [reprinted 2004], 1219p.

Dean W. 1995. With broadax and firebrand: the destruction of the Brazilian Atlantic forest. University of California, Berkeley, 482p.

Denevan W.M. 2002. Cultivated landscapes of native Amazonia and the Andes. Oxford University Press, Oxford, 395p.

Denevan W.M. and Padoch C. 1987. Swidden-fallow agroforestry in the Peruvian Amazon. Advances in Economic Botany 5, New York Botanical Garden, Bronx, 112p.

Edmundson G. 1922. Journal of the travels and labors of Father Samuel Fritz in the River Amazons between 1686 and 1723. Hakluyt Society, London, Second Series, No. 51, 164p.

Hemming J. 1987. Amazon frontier: The defeat of the Brazilian Indians. Harvard University Press, Cambridge, MA, 647p.

Holanda S.B. 1965. Historia Geral da Civilização Brasileira. Tomo 2 – O Brasil Monárquico. DIFEL, São Paulo, 415p.

Homma A.K.O. 2003. História da agricultura na Amazônia: da era pré-colombiana ao terceiro milênio. Embrapa Informação Tecnológica, Brasília, 274p.

Huber J. 1904. Notas sobre a patria e distribuição geographica das arvores fructiferas do Pará, pp 375 – 406. Boletim Museu Goeldi Historia Natural e Ethnographia. Tomo IV.

Lamont S.R., Eshbaugh W.H. and Greenberg A.M. 1999. Species composition, diversity, and use of homegardens among three Amazonian villages. Econ Bot 53: 312 – 326.

Lathrap D.W. 1977. Our father the cayman, our mother the gourd: Spinden revisited, or a unitary model for the emergence of agriculture in the New World. In: Reed C.A. (ed.), Origins of agriculture, pp. 713 – 751. Mouton, The Hague.

Lehmann J., Kern D.C., Glaser B. and Woods W.I. 2004. Amazonian dark earths: origin, properties and management. Kluwer, Dordrecht, 523p.

Lima D.M. 1999. A construção histórica do termo caboclo. Novos Cadernos NAEA 2: 5 – 32.

Maués R.H. 2001. Um aspecto da diversidade cultural do caboclo amazônico: a religião. In: Vieira I.C.G., Silva J.M.C., Oren D.C. and D'Incao M.A. (eds), Diversidade biológica e cultural da Amazônia, pp. 253-272. Museu Paraense Emílio Goeldi, Belém.

Mazurek R.R.S. 2001. Kinja txi taka nukwa myrykwase: fishing and hunting among the Waimiri Atroari Indians from Central Amazonia. PhD dissertation, University of Illinois, Chicago, 115p.

Miller E.T. 1992. Arqueologia nos empreendimentos hidrelétricos da Eletronorte; resultados preliminares. Eletronorte, Brasília, 93p.

Miller R.P. 1994. Estudo da fruticultura tradicional dos índios Waimiri-Atroari: Base para a extensão agroflorestal. Anais I Congresso Brasileiro de Sistemas Agroflorestais 2: 449 – 462, Embrapa-CNPF, Colombo.

Miller R.P. 2001. Extractive forest products and agroforestry on an agricultural frontier: A case study with the *Parakanã* tribe of the trans-Amazon region, Pará, Brazil. PhD dissertation. University of Florida, Gainesville, 227p.

Miller R.P. and Nair P.K.R. 2006. Indigenous agroforestry systems in Amazonia: from prehistory to today. Agroforest Syst 66: 151 – 164.

Nair P.K.R. 2001. Do tropical homegardens elude science, or is it the other way around? Agroforest Syst 53: 239 – 245.

Padoch C. and de Jong W. 1991. The house gardens of Santa Rosa: diversity and variability in an Amazonian agricultural system. Econ Bot 45: 166 – 175.

Padoch C. and Pinedo-Vasquez M. 2001. Resource management in Amazonia: *Caboclo* and *ribereño* traditions. In: Maffi L. (ed.), On biocultural diversity: Linking language, knowledge, and the environment, pp. 364-378. Smithsonian Institution press, Washington, DC, 578p.

Penn J.W. Jr. 2004. Another boom for Amazonia? Socioeconomic and environmental implications of the new camu camu industry in Peru. PhD dissertation, University of Florida, Gainesville, 298p.

Penn J.W. Jr. 2006. The cultivation of camu camu (*Myrciaria dubia*): A tree planting programme in the Peruvian Amazon. Forests Trees Livelihoods 16: 85 – 101.

Piperno D.R. and Pearsall D.M. 1998. The origins of agriculture in the lowland Neotropics. Academic Press, San Diego, 400p.

Piperno D.R., Ranere A.J., Holst I. and Hansell P. 2000. Starch grains reveal early root crop horticulture in the Panamanian tropical forest. Nature 407: 894 – 897.

Poeppig E. 2003. Viaje al Perú y al Río Amazonas, 1827-1832. CETA, Iquitos, 435p.

Renard-Casevitz F.-M. 1992. História Kampa, memória Ashaninca. In: Cunha M.C. (ed.), História dos índios no Brasil. Companhia das Letras, pp 197 – 212. Sec. Municipal de Cultura, São Paulo.

Ribeiro D. 1997. O povo brasileiro: a formação e o sentido do Brasil. Companhia das Letras, São Paulo, 476p.

Rios M.C. 2001. Historia de la Amazonía Peruana. Periodos: Independencia y república. Editora Selva, Iquitos, 322p.

Roosevelt A.C. 1994. Amazonian anthropology: strategy for a new synthesis. In: Roosevelt A.C. (ed.), Amazonian Indians from prehistory to present: Anthropological perspectives, pp 1 – 29. University of Arizona Press, Tucson.

Rosa L.S., Cruz H.d.S., Tourinho M.M. and Ramos C.A.P. 1998a. Aspectos estruturais e funcionais dos quintais agroflorestais localizados nas várzeas da costa amapaense. II Congresso Brasileiro em Sistemas Agroflorestais – Resumos Expandidos, pp 164 – 166. Embrapa, Belém.

Rosa L.S., Cruz H.d.S., Tourinho M.M. and Ramos C.A.P. 1998b. Caracterização dos quintais agroflorestais localizados nas várzeas do estuário amazônico. II Congresso Brasileiro em Sistemas Agroflorestais – Resumos Expandidos, pp 161 – 163. Embrapa, Belém.

Rosa L.S., Da Silva L.C.B., Melo A.C.G. and Cabral W.d.S. 1998c. Avaliação e diversificação de quintais agroflorestais na comunidade de Murinim – Benfica, Município de Benevides - Pará. II Congresso Brasileiro em Sistemas Agroflorestais – Resumos Expandidos, pp 167 – 169. Embrapa, Belém.

Salick J. 1992. Crop domestication and the evolutionary ecology of cocona (*Solanum sessiliflorum* Dunal). Evol Biol 26: 247 – 285.

San Ramon J.S. 1994. Perfiles históricos de la Amazonia Peruana. CETA-CAAAP-IIAP, Iquitos, Perú. 274p.

Santos F.J. 2002. Além da conquista: guerras e rebeliões na Amazônia pombalina. Editora da Universidade do Amazonas, Manaus, 239p.

Schroth G., Mota M.S.S., Lopes R. and Freitas A.F. 2004. Extractive use, management, and in situ domestication of a weedy palm, *Astrocaryum tucuma*, in the Central Amazon. For Ecol Manag 202: 161 – 179.

Smith B.D. 2001. Documenting plant domestication: the consilience of biological and archeological approaches. Proc Nat Acad Sci 98: 1324 – 1326.

Smith N.J.H. 1996. Home gardens as a springboard for agroforestry development in Amazonia. Int Tree Crops J 9:11 – 30.

Smith N.J.H. 1999. The Amazon river forest: a natural history of plants, animals, and people. Oxford University Press, New York, 208p.

Smith N.J.H., Dubois J., Current D.L.E. and Clement C. 1998. Agroforestry experiences in the Brazilian Amazon: constraints and opportunities. Pilot program to conserve the Brazilian rainforest. World Bank, Brasília, 80p.

Smith N.J.H., Falesi I.C., Alvim P.d.T. and Serrão E.A.S. 1996. Agroforestry trajectories among smallholders in the Brazilian Amazon: innovation and resiliency in pioneer and older settled areas. Ecol Econ 18: 15 – 27.

Smith N.J.H., Fik T.J., Alvim P.d.T., Falesi I.C. and Serrão E.A.S. 1995. Agroforestry developments and potential in the Brazilian Amazon. Land Degrad Rehabil 6: 251 – 263.

Stanfield M.E. 1998. Red rubber, bleeding trees: Violence, slavery, and empire in northwest Amazonia, 1850-1933. University of New Mexico Press, Albuquerque, 270p.

Van Leeuwen J. and Gomes J.B. 1995. O pomar caseiro na região de Manaus, Amazonas, um importante sistema agroflorestal tradicional. Actas II Encontro da Sociedade Brasileira de Sistemas de Produção, Londrina, PR, 21-23/nov/95, pp 180 – 189. IAPAR, Londrina (http://www.inpa.gov.br/cpca/johannes/joha-pomar.html; last accessed: February 5, 2006).

Wiersum K.F. 1996. Domestication of valuable tree species in agroforestry systems: evolutionary stages from gathering to breeding. In: Leakey R.B., Temu A.B., Melnyk M., and Vantomme P. (eds), Domestication and commercialization of non-timber forest products, pp 147 – 158. FAO, Rome.

Yamada M. and Osaqui H.M.L. 2006. The role of homegardens in agroforestry development: lessons from Tomé-Açu, a Japanese-Brazilian settlement in the Amazon. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 299 – 316. Springer Science, Dordrecht.

CHAPTER 5

HOMEGARDENS OF MESOAMERICA: BIODIVERSITY, FOOD SECURITY, AND NUTRIENT MANAGEMENT

F. MONTAGNINI

Yale University, School of Forestry and Environmental Studies, 370 Prospect St., New Haven, CT 06511, USA; E-mail: <florencia.montagnini@yale.edu>

Keywords: Mayan culture, Nutritional value, Rural development, Structural complexity.

Abstract. The region of Mesoamerica is densely populated and it suffers from poverty and malnutrition both in urban and rural areas. It is home to the Mayan civilization that practiced sustainable agricultural systems, involving many native crops and soil conservation strategies, for centuries. The homegardens, which provide the household with a basic food source as well as high value products to generate cash income are important in Mesoamerica, and are often used as tools in development projects that promote food security, especially in the poorest areas of Mesoamerica. The Mesoamerican homegardens are quite diverse in vertical and horizontal structure and species composition. Both exotic and native plants are used, with emphasis on fruit trees. Domestic animals, especially chickens and pigs, add protein to a diet that is generally protein-deficient. Many indigenous communities (descendants of the ancient Maya) still manage these homegardens using techniques that include residue management and ash deposition, thus enhancing nutrient recycling and conservation. Carbon sequestration may be important due to the efficient capture of solar radiation in the multi-layered homegardens, although its global or regional importance is minimal due to the relatively small area under the homegarden system. Management strategies that promote nutrient recycling and maintain high species diversity should be encouraged to ensure sustainability of homegardens in the region.

1. INTRODUCTION

A vast area of what is known today as Mesoamerica was the home of the Mayan civilization. The remnants of Mayan culture are concentrated in southern Mexico,

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 61–84.

Guatemala, and Belize. The Mayan people are known to have practiced sustainable agricultural systems for centuries, cultivating a wide variety of native crops and applying indigenous knowledge on nutrient cycling and soil conservation (De Clerck and Negreros-Castillo, 2000; Benjamin et al., 2001). In regions such as the Tehuacán-Cuicatlán Valley in Central Mexico, human cultures have a history of nearly 10 000 years and at present several indigenous ethnic groups continue to follow cultural traditions in plant gathering and cultivation (González-Soberanis and Casas, 2004). The long history of interactions between human cultures and plant diversity has created a substantial body of traditional knowledge on the myriad uses of plants. The existence of nearly 1200 plant species utilized by local peoples for different purposes, most of them native wild plants, has been documented; many of these species are obtained through gathering, but several species are also under silvicultural management (Casas et al., 2001; González-Soberanis and Casas, 2004).

This rich tradition of sustainable agricultural practices in Mesoamerica justifies an extensive study of homegardens in the region. Several types of homegardens are practiced in the region by the descendants of Maya in present-day Mexico, Guatemala, Belize, and Honduras, by other indigenous groups, and by people of Hispanic descent in Nicaragua, El Salvador, Costa Rica, and Panama. Traditional agroecosystems, which include 'forest gardens' or 'homegardens,' contain combinations of trees with an understorey of annual and perennial crops and sometimes livestock. Villagers live within or adjacent to their gardens and maintain them over many generations. In present-day Mayan towns in the Yucatán Peninsula of Mexico, this type of forest gardens covers about 10% of the region's forested area (Noble and Dirzo, 1997). Small, scattered forest or agroforests can provide local or regional environmental services such as conservation of biodiversity (Guindon, 1996; Harvey and Haber, 1999). Thus, the practice of homegardens can meet forest conservation needs in regions where deforestation and population growth are constant threats, as is the case in much of the Mesoamerican region.

As in other regions of the neotropics, such as Amazonia (Miller et al., 2006), present-day homegardens of Mesoamerica represent the reorganization of original indigenous practices as a result of the changes brought by colonization, among which the most outstanding feature was the incorporation of non-native fruit trees and crops. Today, homegardens are of vital importance to the local subsistence economy and food security in the region, especially in regions that still carry the influence of Mayan culture (De Clerck and Negreros-Castillo, 2000; Méndez et al., 2001; Zaldívar et al., 2002; Wezel and Bender, 2003; Blanckaert et al., 2004; González-Soberanis and Casas, 2004).

This chapter describes the characteristics of homegardens in Mesoamerica, with emphasis on biodiversity, their importance in sustaining food security in rural areas, and their role in nutrient cycling. Information is presented on indigenous systems that have been practiced by descendants of the ancient Maya for many centuries in regions of Mexico, Belize, and Guatemala, as well as on systems currently being practiced in regions beyond the Mayan influence such as in Nicaragua, El Salvador, Honduras, Costa Rica, and Panama.

2. GENERAL ECOLOGICAL AND SOCIOECONOMIC CHARACTERISTICS OF MESOAMERICA

Culturally Mesoamerica joins the present-day middle and south Mexico, Belize, Guatemala, parts of Honduras, and El Salvador (Fig. 1). Geographically, the other three countries of Central America (Nicaragua, Costa Rica, and Panama) are also included in the region. Most geographers consider Central America to be part of the North American continent; however, they do not consider Mexico to be a part of Central America. The Caribbean islands are often considered separately from Mesoamerica because they are culturally very diverse. For the purposes of this chapter an example is drawn from Cuba, a country with a Hispanic tradition as rich as many of the countries of Mesoamerica, and with similar ecological and economic conditions.

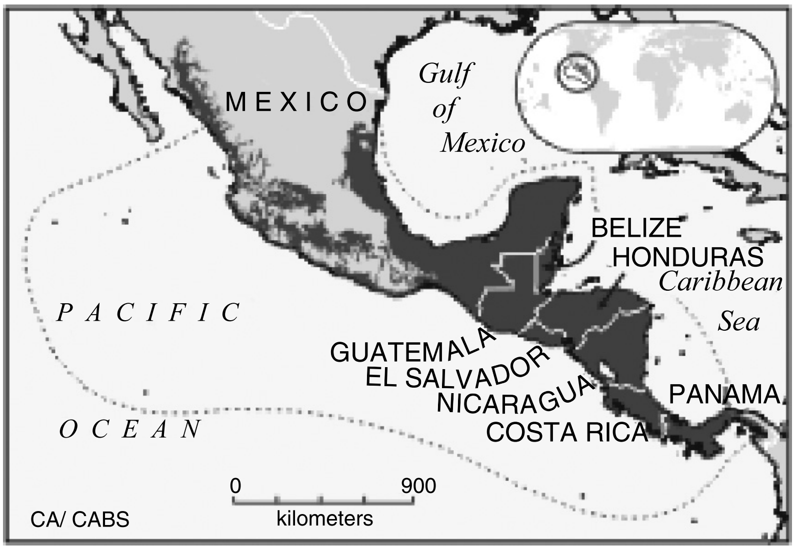

Figure 1. *Map of Mesoamerica (source: www.biodiversityhotspots/mesoamerica/; last accessed: January 2006).*

2.1. Ecological setting

The climate, vegetation, and soils of Mesoamerica are very heterogeneous given the latitudinal expanse of the region and its montane relief. This results in high ecological heterogeneity that gives room to a whole variety of agricultural systems. The climate ranges from mild temperate-subtropical in north-central Mexico and Guatemala, to tropical in the rest of Central America (Richards, 1996). There is a general pattern of a more humid climate (annual precipitation 3000 to 5000 mm) along the eastern or Caribbean side due to the influence of the humidity brought by the trade winds. Winds reach the central volcanic mountain range in the region, cause rains on the Atlantic side, and quickly lose much of their humidity. Consequently, most of the Pacific watersheds are drier with annual precipitation ranging from 300 to 2000 mm yr^{-1} and a marked dry season (November through April). The vegetation follows the climatic pattern ranging from subtropical and tropical rainforest in the Caribbean lowlands to dry forests and savannas in the Pacific watersheds (Richards, 1996).

The soil types cover a whole array from older, less fertile Oxisols and Ultisols (US Soil Taxonomy System), to younger Andosols and Inceptisols, especially in areas affected by past or present volcanic activity and in alluvial zones. Several other types of soils can be found due to the varied climatic and topographic conditions of the region (Sanchez, 1976; De Las Salas, 1987). In general, due to the recent volcanic influence, the soils of the region are relatively younger and more fertile than many soils of other regions of Latin America, such as the Amazon Basin.

The Mesoamerican region comprises an area with diverse plant and animal life. The varied topography, geology, vegetation, and drainage patterns within the region result in a rich array of vegetation types and animal communities. More than 24 000 plant species, 521 mammal species, 1193 bird species, 685 reptile species, and 460 amphibian species have been identified within Mesoamerica, many of which are endemic to the region[1]. Moreover, Mesoamerica is the third most biologically diverse region in the world; Myers et al. (2000) identified it as one of the world's 25 biological hotspots. Covering an estimated 0.5% of the world's terrestrial surface, it is home to roughly 7 to 10% of the world's plant and animal species (Harvey et al., 2005). Several trees that are currently planted worldwide in agroforestry combinations, such as *Leucaena leucocephala*, *Gliricidia sepium*, and some species of *Acacia* and *Mimosa*, have their centers of origin and diversity in Mesoamerica (NAS, 1979; 1980; Dommergues, 1987). Mesoamerican homegardens, in addition to meeting the immediate alimentary and economic needs of the people, also act as repositories of local biodiversity as they include a dynamic mixture of native and useful species.

2.2. Cultural setting

The region of Mesoamerica is culturally and socioeconomically diverse, sharing certain characteristics such as a strong Spanish colonial influence (with the exception of Belize) and a strong dependence on agriculture and natural resources (Harvey et al., 2005). In parts of Mesoamerica (southern Mexico, northern Guatemala, and Belize) homegardens and other types of agriculture carry the influence of ancient traditions from the indigenous Mayan groups that lived in this region prior to the arrival of European conquerors.

Several studies have reported and discussed sustainable land use practices that were used by the Maya, including terracing, using soil algae or wetland soil to enrich upland garden plots, and other soil conservation strategies (Barrera et al., 1977; Turner and Harrison, 1981; Beach and Dunning, 1995; Fedick and Morrison, 2004). Archaeological evidence of the use of homegardens by the ancient Maya include the location of residential sites within prime agricultural land, strategic placement of households to allow for gardening space, the addition of soil amendments as indicated by nutrient enrichment within house lots, and the distribution of tools in the vicinity of residences (Fedick and Morrison, 2004).

The decline of the Maya civilization (~700 BC to 800 AD) has been attributed in part to complex economic, political, and social changes that led people to change their traditional sustainable agricultural practices to less diverse agricultural systems (Barrera et al., 1977; Turner and Harrison, 1981; Atran, 1993; Atran et al., 1999). A set of political and ecological factors apparently led some Maya groups such as the lowland Maya of Petén, Guatemala, to reject a diverse swidden-fallow management strategy for a more simple 'milpa' or shifting agricultural system that provided fewer forest products. This led to a less diverse agricultural landscape and a less diverse biological landscape (Atran, 1993; Steinberg, 1998; Atran et al., 1999). The milpa system consisted of 2 to 5 ha plots that were cut and burnt, and cultivated mainly with maize (*Zea mays*). In the traditional system, after a few harvests the plots were left to regenerate with a long fallow cycle, leaving tree species time to mature and bear fruits (15 to 40 years).

At present, many Maya groups such as the Mopan of Belize have shortened the fallow periods to about 5 years. With such a short fallow cycle, the vegetation regenerating in the milpas is much less diverse than in the traditional Mayan systems, with only a few useful species of shrubs and palms (Steinberg, 1998). However, some authors argue that only the most sophisticated and intensive type of Maya agriculture collapsed, while the oldest, simplest, and most ecologically stable type is still being practiced (Atran, 1993). The milpa system – as practiced today – with dispersed fruit trees and vegetable crops and livestock has the attributes of a productive homegarden.

2.3. Socioeconomic conditions

With a total land area of almost 2.5 million km^2 and a total population size of almost 140 million people, Mesoamerica is one of the most densely populated regions of not only Latin America but also the entire world (Harvey et al., 2005). The current population of Central America is approximately 38 million people, of which about 20% are indigenous (Harvey et al., 2005). With a yearly growth rate of about 2.6%, the population is expected to double within the next 25 years. The overall population density of the region is 56 people per km^2, with a range from 296 people per km^2 in El Salvador to just 11 in Belize (Table 1).

Despite its recent economic growth, Central America remains one of the world's poorest regions. About 50% of the population is poor (i.e., unable to cover basic needs such as nutrition and housing) and 23% is extremely poor (i.e., not able to cover even daily basic nutrition; Harvey et al., 2005). Particularly striking are the cases of Honduras and Guatemala with poverty levels of 74.5% and 78.5%, respectively (Harvey et al., 2005). The region's poverty has led to the massive exploitation of its natural resources. Large areas of forest have been cut down and burnt for firewood, used in the production of paper, and cleared for agricultural uses. Despite an equal distribution of population between rural and urban areas, rural populations are considerably poorer than their urban counterparts (Harvey et al., 2005).

Mesoamerica has diverse ecological, cultural, and socioeconomic conditions that have given origin to varied agricultural systems. The prevalent conditions of rural poverty and associated malnutrition call for the need of agricultural systems that can help fulfill urgent household needs. Homegardens, whose main function is to provide the household with a basic food source and marketable products, are extremely important—given the socioeconomic conditions prevalent today in Mesoamerica.

Table 1. *Area,population size and population density of Mesoamerica.*

Country	*Area (km^2)*	*Population size*	*Population density (no./km^2)*
Mexico	1,964,375	101,879,000	52
Nicaragua	131,847	4,918,000	37
Honduras	112,520	6,406,000	57
Guatemala	108,917	12,974,000	119
Panama	75,536	2,846,000	38
Costa Rica	51,113	3,773,000	74
Belize	22,965	256,000	11
El Salvador	21,046	6,238,000	296
Total	2,488,319	139,290,000	56

***Source*:** Data update 2001 estimates, http://www.globalgeografia.com/north_america/nam_sup.htm (last accessed: January 2006).

3. COMPOSITION AND STRUCTURE OF HOMEGARDENS IN MESOAMERICA

As in other regions worldwide, the structure and composition of homegardens in Mesoamerica are quite complex. A full spectrum of homegarden practices can be found in different locations of Mesoamerica, ranging from near complete domination of woody perennials to homegardens where trees may account for less than 20% of the annual productivity. Plant composition in homegardens of Mesoamerica is influenced by access to water, owners' economic activities, labor availability, traditional social organization, modernization processes, and economic development (Blanckaert et al., 2004). In general, plant species composition within the homegardens is the result of continuous selection in which the family usually favors the planting of fruit trees with high productivity (Caballero, 1992).

Most homegardens of Mesoamerica consist of several vertical and horizontal strata in which plants are arranged according to their adaptability to the existing light conditions and nutrient resources (Fig. 2). The number of individual plants per stratum, however, varies among homegardens; older, more mature homegardens display more developed tree strata. Some homegardens resemble agricultural fields with an emphasis on herbaceous and low shrub strata, with a greater focus on agricultural crop production. Others have more trees, with architecture similar to that of the native forests of the region (Gillespie et al., 1993; De Clerck and Negreros-Castillo, 2000; Méndez et al., 2001; Zaldívar et al., 2002; Blanckaert et al., 2004).

Figure 2. *Most homegardens of Mesoamerica consist of several vertical and horizontal strata, with plants arranged according to their adaptability to light and nutrient resources. A homegarden in Siquirres, in the Caribbean lowlands of Costa Rica showing vertical stratification with peach palm (* Bactris gasipaes*) in the top layer (right), coconut palms (*Cocos nucifera*) and plantains or bananas (* Musa *spp.) in the lower tree strata (left), sugarcane (*Saccharum officinarum*), and other herbaceous crops in the herb layer (Photo: R. González).*

3.1. Vertical stratification

The vertically stratified homegardens are potentially more productive on an area basis since they can capture more resources and exhibit tighter nutrient cycling, than those without a stratified arrangement. For example, in a study of four homegardens in the Petén, Guatemala, Gillespie et al. (1993) reported high structural complexity, with full canopy closure in the layers within the canopy. The garden architecture made efficient use of light and space, with intensive management for food and fuel production. The development of homegardens in the area utilized existing trees, leaving the most useful as residuals after thinning, and inserting other desirable trees and shrubs in the understorey and open space. This strategy seemed to maximize light use, according to results of measurements of incident radiation at different canopy levels reported by Gillespie et al. (1993).

In most Mesoamerican homegardens, each stratum contains plant species that belong to a characteristic life form, much like in a native forest of the same region. In homegardens of the Zona Maya of Quintana Roo, Yucatán Península, Mexico, there were six strata: low herbs, low shrubs, tall shrubs, fruit trees, timber trees, and a stratum with vines (De Clerck and Negreros-Castillo, 2000). These authors studied the species composition of each stratum, and concluded that in these systems the efficient use of space and resources maximized the production of food, timber, medicinal plants, and non-timber products to cover the farmers' needs. They suggested that these systems (or analogs of these in terms of structure and composition) could be managed in a manner that protects the natural resource base of the region.

3.2. Plant species composition

The species composition of the homegardens in Quintana Roo analyzed by De Clerck and Negreros-Castillo (2000) was much like others in Mesoamerica and in other regions of Latin America as well, with a mixture of native and exotic species in each stratum fulfilling the farmers' needs. The herbaceous stratum (0 to 0.5 m tall) was comprised of herbs and creepers such as basil (*Ocimum basilicum*), squash (*Cucurbita* spp.), and sweet potatoes (*Ipomoea batatas*), containing an average of 14% of all species in the homegarden. The low shrub stratum (0.5 to 1.5 m tall) contained annual and perennial herbaceous plants such as tomatoes (*Lycopersicum esculentum*), maize or corn (*Zea mays*), ruda (*Ruta chalapensis*), and included several shade-tolerant species such as cassava (*Manihot esculenta*), ginger (*Zingiber officinale*), pineapple (*Ananas comosus*), and taro (*Colocasia esculenta*). The low shrub stratum contained 12% and the tall shrub stratum contained 15% of the total number of species of the homegardens. The low tree stratum was dominated by fruit trees, most frequently by *Citrus* spp., and contained 41% of the total number of species; this stratum was often dominant in the absence of the fifth stratum (tall trees). The presence of the tall tree stratum, with 15% of the species, was an indicator of the maturity of homegardens. It was composed of several species of palms, tall fruit trees such as mango (*Mangifera indica*) and avocado (*Persea americana*), and timber trees. The vine stratum started at ground level and rose up to the top of the canopy, with 4% of the total number of species, composed mainly of tuber-forming vines such as sweet potatoes and several species of yams (*Dioscorea* spp.). Many epiphytic species were found on trees and shrubs (De Clerck and Negreros-Castillo, 2000).

This complex horizontal and vertical structure allows for a variety of agricultural crops and tree products that are consumed in the household and sold in the local markets. Multistrata agroforests combining agricultural crops with high-value timber species, as described in the above example, can provide farmers with long- and short-term revenue with harvest distributed throughout the year.

In a study of homegardens located in eastern Cuba, Wezel and Bender (2003) found that species composition and structure were similar to "typical" homegardens of other regions in Mesoamerica. The top layer (3 to 10 m) consisted mostly of trees such as avocado, coconut (*Cocos nucifera*), mango, and breadfruit (*Artocarpus communis*). In the middle layer (1 to 3 m), smaller trees like guava (*Psidium guajava*), soursop (*Annona muricata*), orange (*Citrus sinensis*), or papaya (*Carica papaya*) were found together with bananas and plantains (*Musa* spp.), sugarcane (*Saccharum officinarum*), pigeon pea (*Cajanus cajan*), and climber yam (*Dioscorea* spp.). In the ground layer (0 to 1 m), different vegetables, spices, and medicinal plants were cultivated while others grew spontaneously.

3.3. Horizontal structure

The horizontal structure of homegardens shows interesting patterns, governed by the uses/functions of the different plant species. For example, ornamental plants are often found in linear patterns around the house. They are also found along the roadside of the garden, reflecting their aesthetic purpose as well as their use for the delineation of property or sections thereof (Blanckaert et al., 2004). In general, edible plants are found a little farther away from the house, mostly in small groups to facilitate management such as weeding or pruning. In semiarid environments such as south-central Mexico (Blanckaert et al., 2004), central Nicaragua (Méndez et al., 2001), and in the Baitiriqui region of Cuba (Wezel and Bender, 2003), irrigation is frequently used. In these cases, edible plants are located downhill from the house and in close proximity to it so that they can be watered using the wastewater recycled from domestic uses. Medicinal plants are often found still farther away than ornamental or edible plants (Blanckaert et al., 2004). Homegardens are also important for providing additional living and working space to supplement small household structures (Lok, 1998).

In an effort to organize and systematize the study of this very complex type of agroecosystem, many authors have used statistical procedures to group descriptive characteristics of homegardens. For example, cluster analysis, correspondence analysis, and diversity indices have been used by several authors to explain the patterns of variations in floristic composition of the homegardens (Méndez et al., 2001; Zaldívar et al., 2002; Blanckaert et al., 2004). These procedures help in the description of the characteristics of the specific homegardens under study such as explaining differences in species diversity among homegardens of different settlements or localities in a region.

4. PLANT SPECIES DIVERSITY IN HOMEGARDENS OF MESOAMERICA

Results of several studies indicate that homegardens of Mesoamerica are rich in biodiversity, and need to be considered for *in situ* conservation and development programs. Table 2 shows a summary of studies on plant biodiversity in homegardens of different geographic regions of Mesoamerica. Several of the studies shown in Table 2 emphasize tree and shrub species and their uses and relevance for forest conservation, while others focus on the variety of plant species of all life forms and

Table 2. *Examples of studies on plant diversity of homegardens in Mesoamerica.*

Location	*Climate*	*Number of homegardens studied*	*Number of plant species*	*Source*
Tehuacán-Cuicatlán Valley, Puebla, south-central Mexico	semiarid to arid	30	233 (66% ornamental, 30% edible, 9% medicinal)	Blanckaert et al., 2004
Tixpeual and Tixcacaltuyub, Yucatán, Mexico	tropical humid lowland	not available	301 trees and shrubs (70% medicinal, 40% apiculture, 30% edible, 17% fuel, 19% building, 12% timber)	Rico-Gray et al., 1991
Tropical forests of nine states, south-southeast Mexico	tropical humid lowland	not available	278	Toledo et al., 1995
Totonac community in Coxquihui, Veracruz, Mexico	warm, subhumid, low elevation	40	223	Del Angel-Perez and Mendoza, 2004
Zona Maya of Quintana Roo, Yucatán Peninsula, Mexico	tropical humid lowland	78	80	De Clerck and Negreros Castillo, 2000
Maya community of San Jose, Toledo district, Belize	tropical humid lowland	18	164	Levasseur and Oliver, 2000
El Camalote, Copán, SW Honduras near the border with Guatemala	montane wet	10	253 (91 trees, 42 shrubs 90 herbs, 24 lianas, 2 palms, 2 mushrooms)	House and Ochoa, 1998

Nicoya, SW Costa Rica	tropical seasonal lowland wet	12	289 (63 varieties)	Lok et al., 1998
Five life zones (*sensu* Holdridge, 1987) of Costa Rica	tropical subhumid to humid	225	236 (excluding ornamentals)	Price, 1989
Eastern Costa Rica	wet tropical	45	133	Price, 1989
Talamanca, S. Costa Rica	wet tropical	83	46 cultivated species	Zaldivar et al., 2002
Coto Brus, S. Costa Rica	wet tropical	55	27 cultivated species	Zaldivar et al., 2002
Masaya, Nicaragua	semiarid to arid	20	334	Mendez et al., 2001
Eastern Cuba	semiarid	31	101	Wezel and Bender, 2003

their role in sustaining local livelihood needs. In a region with such broad geographic diversity as Mesoamerica, diversity of plants found in homegardens is expected to vary according to latitude, elevation, and rainfall. These trends are not evident from the data shown in Table 2, as similar numbers of species are reported for wet and for semiarid to arid locations. The number of species reported by the authors depends on the number of homegardens studied, types of species that were emphasized, size of the homegardens studied, reliance of homegardens for subsistence needs, and the traditional uses of the plants, among other factors as discussed below.

A number of the studies shown in Table 2 also emphasize plant uses and management. For example, in Yucatán, Mexico, Rico-Gray et al. (1991) reported the uses of trees and shrubs from the tropical deciduous forests by the Yucatecan Maya. Despite the lack of important timber species in these forests, the authors conclude that management could lead to sustainable production of honey, deer, and building materials for houses. In homegardens of the Tehuacán-Cuicatlán Valley in Puebla, Mexico (Table 2), plants were categorized into three main groups: cultivated (68%), protected (10%), or spared (22%) (Blanckaert et al., 2004). Cultivated plants are those that are sown or planted by the owner. Protected plants are those that are encouraged by the farmer, whether they are transplanted from zones outside the garden or grow spontaneously in the garden. The farmer may choose to protect or encourage the plant, for example, by supporting it or attaching it to a solid structure, or by putting stones around the plant. Spared plants are those that spontaneously grow in the garden and are not removed (Blanckaert et al., 2004).

The high diversity in plant species and uses reported by Blanckaert et al. (2004) were found at 1217 m above sea level with a climate classified as semiarid to arid (total annual precipitation 395 mm). Theoretically, these conditions would place the region at the low end of the spectrum of potential plant species diversity. The most represented plant families were Cactaceae, Araceae, Liliaceae, Solanaceae, and Crassulaceae, reflecting the climatic characteristics as well as the preferences of the local farmers. Members of both Cactaceae and Solanaceae families in the homegardens are important edible plants. For instance, nopal (*Opuntia* spp. and other species of Cactaceae), chilli (*Capsicum* spp.), and tomato (*Lycopersicum esculentum*) (Solanaceae) are important ingredients of the Mexican diet.

A possible explanation for the relatively large diversity of plants found in dry locations was advanced by Price (1989), who studied the characteristics of homegardens in five different ecological regions of Costa Rica (Table 2). The author found that homegardens were most important in regions of dry tropical forests because socioeconomic conditions were more difficult than in other regions of the country, making people rely more on homegardens for self-sustenance. In a semiarid region in eastern Cuba, Wezel and Bender (2003) also reported the importance of homegardens and their high species diversity (Table 2), with about 50% of the species consisting of fruit trees.

Locally, plant diversity of homegardens can also be influenced by size of the homegardens. For example, in Nicoya, Costa Rica, Lok et al. (1998) found that the size of homegardens ranged from 0.1 to 1.4 ha with an average of 0.5 ha (Table 2). The smallest homegardens considered in the study had the highest diversity, with

205 to 745 species and an average of 348 species per ha. In contrast, the larger homegardens had only an average of 96 species per ha, with less variability among gardens in comparison to the smaller homegardens that exhibited higher variability in species diversity.

4.1. Importance for species domestication and conservation

The high plant species diversity of homegardens in Mesoamerica makes them an important resource for ethnobotanical studies. Since many species in homegardens are encouraged or cultivated, the process of domestication of useful species has long taken place in homegardens. This is true for homegardens in other regions of the neotropics where they are intensely managed and crops are carefully selected for specific purposes. For example, the homegardens of Japanese emigrants in the Tomé-Açu settlement in Pará, in the eastern Amazon region of Brazil, have served as "banks" of potential crop species that had been gathered and closely observed by the family members (Yamada and Osaqui, 2006). The homegardens of Tomé-Açu functioned as individual validation facilities for farmers making decisions about planting new crops in their farms. Farmers also used homegardens for improvement and propagation of nursery stock.

Several studies shown in Table 2 emphasize the role of homegardens as sites for domestication and preservation of useful species (Toledo et al., 1995; House and Ochoa, 1998; González-Soberanis and Casas, 2004, among others). In El Camalote, Copán (Honduras), House and Ochoa (1998) found several introduced species along with native species that belonged to natural forests of the region, and they stressed the importance of homegardens as genetic banks of ancient crops and as a research field for new varieties and cultivars. The diversity of traditional vegetables in the homegardens studied by these authors was outstanding, with many species that are also present in Guatemala and Mexico but that are absent in other parts of Honduras. They cite examples of several vegetables and fruits that today are almost exclusively found in the homegardens. Such is the case of the chayo (*Cnidoscolus chaymansa*), a popular green vegetable in Camalote (similar to spinach) but almost absent in the rest of Honduras. They also cite other unique species of vegetables and fruits that, again, are found only in the homegardens of Honduras and Guatemala.

Other examples of domestication of crop species can be found in regions such as the Tehuacán-Cuicatlán valley in central Mexico, where the Maya cultures have a history of over 10 000 years (González-Soberanis and Casas, 2004). These authors studied the management and domestication of a fruit of the Sapotaceae family, the tempesquistle (*Sideroxylon palmei*). This fruit is consumed and commercialized in large quantities in the villages studied. Apparently, management of this species in homegardens has resulted in larger, better quality fruits than those of the wild populations, demonstrating the importance of domestication of plant species by the owners and managers of homegardens. This is a good example of a process of selection by local farmers that may be true for many other species in other homegarden settings too.

Homegardens may have other positive effects on biodiversity, as they can serve as local refuges for plants and animals that otherwise may be threatened by human or natural disturbances. For example, Griffith (2000) reported that during the 1998 fires in Petén, Guatemala, homegardens and other agroforestry systems might have served as critical refuges for many forest species. Apparently, agroforestry farms attracted birds by virtue of their complex structure – similar to that of intact forest patches – they harbor insects, provide nesting sites, and offer protection from predators (Griffith, 2000). They were also attracted by the cultivated fruit trees, which may have provided some of the only food sources in the region after fire destroyed most of the surrounding vegetation. Homegardens, thus, can provide additional services as buffers for protecting local biodiversity in times of stress.

5. SIGNIFICANCE FOR HOUSEHOLD FOOD SECURITY

Homegardens can enhance food security in several ways, most importantly through: (1) direct access to a diversity of nutritionally rich foods, (2) increased purchasing power from savings on food bills and income from sale of garden products, and (3) fall-back food provision during periods of temporary food scarcity. In many parts of the world, homegardens supplement food supply for people, but in some cases, homegardens can yield basic staples, when they are large enough to plant sufficient quantities of tubers or cereals (Eibl et al., 2000; Wezel and Bender, 2003). In this regard, homegardens fulfill a very important social function, especially in a region like Mesoamerica where poverty and malnutrition co-exist. For example, in the Maya community of San Jose, Belize, traditional agroforestry systems including milpa, cacao (*Theobroma cacao*) under trees, and homegardens almost entirely meet the family needs for food and wood, and generate 62% of family income (Levasseur and Oliver, 2000).

In contrast to other types of agroforestry and other productions systems, homegardens are very important for supplying the household with food products year-round (Budowski, 1990; Lok, 1998; Eibl et al., 2000). Their principal goal is not to optimize production, as it could be in the rest of the farm, but to guarantee a minimum supply of different food products at all times of the year, functioning as a buffer in times of low income and food scarcity. Often, high value products from homegardens can be sold to purchase staple foods during periods of scarcity. In Central America, women play an important role in the management, maintenance, and sale of homegarden food products (Lok, 1998; Howard, 2006).

5.1. Edible plant species

As seen in the previous sections, homegardens in Mesoamerica are planted with a variety of species used for various purposes, including food, medicinal, ornamental, timber, construction, crafts, among others (Zaldívar et al., 2002) . In addition to their use for self-sustenance, many studies have indicated that the potential for cash sales from homegardens is highly important in their composition and management. Frequently, excess homegarden production is given away to relatives working in urban areas, thereby supporting food security in both urban and rural areas.

The importance of homegardens for household food security becomes greater in more extreme situations of poverty and isolation. In present day Cuba, homegarden products have contributed additional food to the basic provision such as bread, oil, flour, meat, and other products sold cheaply in government stores. After 1989, when the Soviet Union collapsed and dropped aid to Cuba, the economic situation worsened and food distribution declined precipitously. As it was imperative to find alternative sources of food supplies, farmers intensified homegarden production in order to feed their families (Wezel and Bender, 2003).

Similar situations of low income and little assistance by government programs are common in several countries of Mesoamerica. In Nicaragua, one of the poorest countries of Central America, Méndez et al. (2001) found that families in Masaya obtained at least 40 different plant products from their homegardens (Table 2), as well as the benefit of space for working on handicrafts (a major source of income in Masaya), and socializing. People enjoyed meeting their neighbors and visitors in the homegarden because it was a pleasant area of their homes. Although dependence on homegardens varied according to specific conditions, they seemed to be a consistent, flexible resource used to meet a diversity of needs, although their main function was always to provide edible products for household consumption.

Although Costa Rica probably has the best conditions of Mesoamerica in terms of average per capita income and social welfare programs, rural poverty and malnutrition persist there, especially among some indigenous groups living in remote areas. Chibchan Amerindians (Bribris, Cabecares and Guaymis) who live in reserves located in Talamanca and Coto Brus, in the south-central part of Costa Rica, practice slash-and-burn agriculture, and maintain polyculture fields or homegardens adjacent to their dwellings with a high diversity of plants (Zaldívar et al., 2002; Table 2). Both Bribris and Cabecares have lived in territories within the Talamanca Reserve for centuries, while the Guaymi migrated about 60 years ago from their ancestral territories in Panama. Most edible crops common to all settlements studied by Zaldívar et al. (2002) were native to the region, with the exception of plantains and bananas, 'manzana de agua' (water apple, *Syzygium malaccense*), oranges and mangoes. In other regions of Costa Rica also, homegardens are important for supplying food; they also serve as a buffer in times of harvest failures or economic depressions (Price, 1989).

In the Chiriquí province of Panama, Lok and Samaniego (1998) found that among the Ngöbe (or Guaymi) indigenous populations, the homegarden was the system that provided the largest cash income and number of edible products for household consumption when compared with other farm activities. They studied 10 farms with an average size of 6.7 ha each, of which about half a hectare was dedicated to homegardens. The Ngöbe grow annual food crops in plots where they also grow "fire-hardy" trees. These plots provide the basic food needs of the family (rice, maize, and beans) during much of the year. In the homegardens they grow about 100 plant species, of which 75 are woody species (trees, shrubs, and palms). Among the woody species most of them are fruit trees, including oranges, guayabas, avocados, and coconuts. Fruits are harvested for household consumption, and often are the sole source of food for the family in times of scarcity. Fruits are also a source of food for wildlife, especially birds that the Ngöbe hunt for food. About 80% of land inhabited by the Ngöbe is of low productivity and is not suitable for commercial production of basic grains, as soils are low in organic matter and high in aluminium content. The cultivation of homegardens is one alternative that the Ngöbe families have successfully used to offset such edaphic constraints and/or to alleviate the problem of food shortage.

5.2. Domestic animals

Domestic animals are frequently found in the homegardens of Mesoamerica and Cuba. For example, in the Maya community of San Jose, Belize, poultry and pigs were found in about 80% of the households (Levasseur and Olivier, 2000). Likewise, in the Totonac backyard homegardens of Veracruz, Mexico, pigs, chickens, and small livestock were common (Del Angel-Perez and Mendoza, 2004). In a survey of 80 homegardens in the dry and humid regions of Costa Rica, Nicaragua, and Honduras, Wieman and Leal (1998) also noted chickens in 79% of the homegardens, pigs in 49%, and ducks in 10% of the households. In Cuba, animals such as pigs, sheep, chickens, and to a lesser extent ducks, rabbits, and turkeys abound in the homegardens (Wezel and Bender, 2003). Larger farm animals such as sheep, goats, and cows are often kept tethered on the nearby roadsides to permit grazing, or sometimes kept in small-fenced paddocks next to the house (C. Munford, pers. comm., October 2005).

Small animals, in particular, represent a source of production of low-cost protein in homegardens, especially for the low-income households (Wieman and Leal, 1998). Several small animals such as chickens, ducks, and rabbits also provide B-complex vitamins and minerals such as iron, calcium, and phosphorus. The small sizes of these animals also make their care and management, besides meat preparation (slaughtering, skinning, and cooking) relatively easy. Yet another advantage is the ease of selling the animals and their products in the local markets and their year-round production, unlike the orchard plant products which can be seasonal (Del Angel Pérez and Mendoza, 2004).

Chickens are particularly important in the homegardens of the developing countries worldwide, primarily for their ability to generate cash income from the production of eggs, meat, and chicken manure. They also contribute to biological pest control by preying on insects and grubs, and facilitating household waste recycling. In the Totonac backyard homegardens of Veracruz, Mexico, chickens roamed free in about half of homegardens surveyed, although they are often penned at night (Del Angel-Perez and Mendoza, 2004). The families in Central America also consumed most of the chicken meat and eggs produced by them. In contrast, duck meat is not as much appreciated, as ducks are often considered pets. Overall, the home-raised livestock has high priority among the Totonac farmers, presumably because of the high value of these animals in the open market.

Similarly, pigs are an important source of meat, despite the seasonality of production, mostly coinciding with festivities or special occasions. In the home-gardens studied by Wieman and Leal (1998), an average of seven pigs were found in the larger homegardens of Limón, Costa Rica and Paraíso, Honduras, and a smaller number in the smaller-sized homegardens of Masaya, Nicaragua. Ornamental plant nurseries, wherever present, deterred pig husbandry because of the potential damage to nursery plants.

In general, local breeds of animals with high resistance to pests and diseases are used, and women take care of the animals (Lok and Samaniego, 1998). Whenever the domestic animals are likely to interfere with the cultivation of plants within the homegardens, they are enclosed or tied up. In the orchards dominated by trees, pigs and chickens roam freely, suggesting that the farmers disregard the understorey vegetation, while backyards in town often have animals in cages or in enclosed quarters to protect ornamental, medicinal, condiment, and ritual plants.

5.3. Promotion of homegardens in food security and development projects

Homegardens have long been used as a tool to promote household food security in many regions of the world, and especially as part of many educational and dissemination efforts by international aid agencies, local governments and non-government organizations (NGOs). For example, FAO has produced materials for their training package '*Improving Nutrition through Homegardening*' (FAO 2001), featuring homegardens for food security in many regions of the world, including specific projects in Nicaragua, El Salvador, and Honduras. In Nicaragua, government subsidies, in combination with international aid, have been used for decades to promote homegardens as a means to guarantee basic household food security. For example, the Plan Alimentario Nacional (National Food Plan) with financial support from foreign-aid and local logistic and technical support from NGOs working in the region, has distributed seeds, working tools, and cooking utensils to families in need, mostly from the rural areas of semiarid regions (El Nuevo Diario, Managua, Nicaragua, April 3, 2002). Similar promotion of homegardens to alleviate poverty and ensure basic food supply in rural and urban areas is underway in Panama and El Salvador, again supported by local NGOs and international assistance (e.g., Food Safety Program in Tacuba, El Salvador, sponsored by World Vision, Canada). In Nicaragua, the Peace Corps of the USA established the Food Security Program after Hurricane Mitch in 1998, while other organizations such as the Red Cross integrated homegarden projects into larger ones directed to address the post-Mitch needs including natural disaster mitigation efforts (D. Craven, pers. comm., October 2005).

In several locations of Mesoamerica, homegardens are often grown and managed as part of the communal development efforts. For example, in Diriamba, Nicaragua, community homegardens form part of a larger development program (POSAF, Program for Agroforestry Development and Environment) funded by the World Bank (Piotto et al., 2004). Similarly, in El Salvador and Nicaragua, homegardens are components of community development efforts in coffee cooperatives. They are assisted by local NGOs working on rural development and biodiversity conservation (Méndez and Bacon, 2005).

6. NUTRIENT CYCLING

Efficient nutrient cycling is a key to the ecological sustainability of traditional homegardens, and species and structural diversity are critical to maintaining it through optimum use and transfer of carbon, water, and nutrients. Many traditional homegardens in Mesoamerica have survived for centuries despite many ecological, social, and political changes, justifying the claim that they are a sustainable land use system (e.g., the Maya homegardens of Yucatán Peninsula; Caballero, 1992). However, this cannot be generalized to all systems practiced by traditional peoples of the region. A comparison of land use and land clearing by Maya descendants and Hispanic populations in the Sierra de Lacandón National Park in Petén, Guatemala, is a case in point; not only agricultural land use by these two groups is very similar but also the impacts on land clearing are comparable (Carr, 2004). Population pressure and changes in other socioeconomic conditions thus strongly influence nutrient management and recycling, affecting the sustainability of homegardens. Yet many traditional societies retain the conventional wisdom on sustainable land management.

In a study conducted in the northwestern and north-central regions of the Yucatán Peninsula of Mexico, Benjamin et al. (2001) hypothesized that Mayan farmers have been choosing tree associations and garden structures that maximize productivity and optimize nutrient cycling of the homegardens. At present, however, the Maya have ceased to use many of their earlier technologies that improved production, e.g., using raised beds and muck. Nevertheless, 'modern' Mayan homegardens still maintain relatively high yields using technologies of nutrient recycling such as mulching for residue management and fertilization (Benjamin et al., 2001). Soils in the region are very thin and contain rocks and calcium carbonates due to the shallow limestone bedrock. Low annual precipitation results in depleted surface and ground water resources, making large-scale irrigation a non-viable option. Benjamin et al. (2001) also noted that the Maya recognize appropriate tree species for such sites and know their growth characteristics; they also have the knowledge on appropriate nutrient management practices, which are applied in the design and management of homegardens. Irrigation timing, pruning, addition of ash to soils, and composting are some of the practices that Maya farmers use to enhance tree growth and survival, resulting in high fruit production with less investment in leaf biomass.

Sweeping and burning of litter in homegardens results in the export of substantial amounts of nutrients, decreasing the effectiveness of nutrient cycling. Ash is recycled in the homegardens, although not uniformly. However, soils had high concentrations of organic matter. If litter were not removed, potential nitrogen contributions from litter to the homegardens would be very high (Benjamin et al., 2001).

Nutrient addition through the litter of nitrogen-fixing species is also a practice used in many homegardens in Mesoamerica. The Maya communities of San Jose, Belize, use the litter of *Gliricidia sepium*, a tree species native to Mesoamerica, to fertilize their homegardens (Levasseur and Oliver, 2000). In addition, practices that are aimed to controlling soil erosion also contribute to nutrient recycling through soil and nutrient conservation. The Totonacs in Coxquihui, Veracruz, Mexico, perceive soil loss as the most serious hazard to their traditional homegardens, and therefore, have sought to control erosion by retaining a continuous canopy cover, and using litter for mulching among other soil conservation practices (Del Angel-Pérez and Mendoza, 2004).

The small size of homegardens allows for the application of intensive management practices that can improve nutrient recycling and lead to higher productivity. In Tacuba, El Salvador, farmers often open small trenches (about 30 cm deep, few meters long, and set perpendicular to the direction of the slope) in their homegardens (Fig. 3). They drop household residues as well as prunings and other organic materials in the trenches. This avoids losses of residues that otherwise could be washed down the slope during the rains. They change the location of the trenches in the area of the homegarden so that eventually residues are recycled all over the homegarden area (pers. obs.).

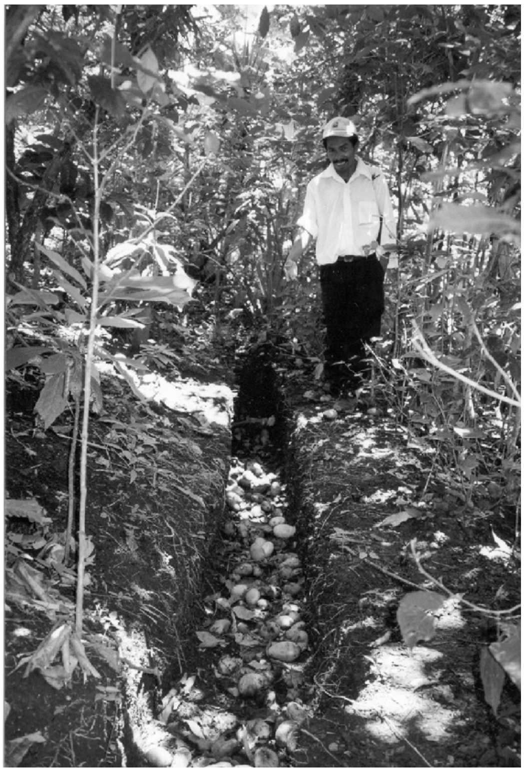

Figure 3. *Recycling of household residue in homegardens in Tacuba, El Salvador. Farmers dig small trenches set perpendicular to the direction of the slope, where they deposit household residues, prunings and other organic material, to avoid losses of residues down the slope.*

Manure of small animals is valuable as a nutrient source for the homegardens. This may be a localized effect as chickens or pigs often wander free in portions of the homegarden and their manure falls near cultivated plants. It can also be part of a specific management strategy, as chicken manure in regions of Costa Rica is used to fertilize small patches planted with corn that is used to feed the chickens as well as other animals of the homegarden (author's pers. obs.).

Vermiculture, or growing earthworms in worm boxes to use the castings for fertilizing homegarden soils, is used in many parts of Central America to increase the productivity of vegetable gardens and fruit trees. The high production of worm castings by certain earthworm species (e.g., the red Californian earthworm, *Allophora caliginosa*) is a source of cheap fertilizer for staple crops such as corn and sorghum (*Sorghum bicolor*). In rural areas of Nicaragua, some families sell the worm castings as organic manure (D. Craven, pers. comm., November 2005).

As mentioned above, in Mesoamerica the traditional agricultural knowledge existing in many regions that still carry the influence of ancient Mayan indigenous peoples includes management practices that improve nutrient cycling. Some management practices can be redirected or improved to optimize plant productivity in homegardens. Improved litter management and knowledge of the relative nutrient content of the litter from different species when used as mulch or compost may be one avenue for improving both water and nutrient cycling and homegarden production. Composting of homegarden litter, instead of burning it, would augment the amounts of nutrients recycled in the system. Water retention, by adding organic matter via compost, would help to improve water availability for plants, especially important in homegardens located in subhumid and semiarid regions of Mesoamerica.

Long-rotation production systems such as agroforests and homegardens can also sequester sizeable quantities of carbon in plant biomass and in long-lasting wood products (Albrecht and Kandji, 2003; Montagnini and Nair, 2004; Kumar, 2006). Many of the traditional homegardens already described share ecological characteristics and management practices that make them efficient in the use of solar radiation and carbon, and allow high levels of productivity. Soil carbon sequestration constitutes another realistic option achievable in homegardens.

7. CONCLUSIONS

The region of Mesoamerica suffers from social and environmental problems due to overpopulation and rural poverty. Under such conditions, homegardens have traditionally fulfilled and still provide an important function in terms of ensuring a basic food supply for the family. This is especially important in the remote areas such as in indigenous reserves or in other rural settings in the relatively more impoverished countries of the region.

Mesoamerican homegardens are quite diverse, with a complex vertical and horizontal structure that includes plants for food, ornamental, medicinal and other purposes. Mesoamerican homegardens are important reservoirs of local biodiversity and have a prominent role in the domestication of useful species.

Domestic animals in homegardens of Mesoamerica contribute to increased food security. Animal manure also contributes to nutrient recycling. The inclusion of domestic animals in homegardens is vital to ensure a more sustained protein supply. However, they require an investment for the care and management of animals that would be relatively large for the poor, rural households.

Mesoamerica was the home of the ancient Maya civilization, whose descendants still practice sustainable agriculture and manage homegardens in ways that increase the efficiency of the capture of solar radiation, increase productivity and improve nutrient cycling. Soil organic matter in homegardens can be increased by several practices of residue management. It is important that such sustainable management practices be retained to ensure homegarden sustainability. Homegardens of Mesoamerica also contribute to environmental services such as carbon sequestration, even though globally their role may be minimal due to their small land area.

ACKNOWLEDGEMENTS

Dylan Craven, Philip Marshall, Quint Newcomer, and Tatsuhiro Ohkubo provided useful comments and insights to this manuscript. Dylan Craven also helped with the literature review and editing.

ENDNOTE

1. CCAD (Comisión Centroamericana de Ambiente y Desarrollo). 2003. Estado del Sistema Centroamericano de Areas Protegidas: informe de síntesis regional. Comisión Centroamericana de Ambiente y Desarrollo (Central American Comisión for Environment and Development). San José, Costa Rica. 33p.

REFERENCES

Albrecht A. and Kandji S.T. 2003. Carbon sequestration in tropical agroforestry systems. Agric Ecosyst and Environ 99: 15 – 27.

Atran S. 1993. Itza Maya tropical agroforestry. Curr Anthropol 34: 633 – 700.

Atran S., Medin D., Ross N., Lynch E., Coley J., Ucan Ek' E., and Vapnarsky V. 1999. Folk ecology and commons management in Maya lowlands. Proc Natl Acad Sci USA 96: 7598 – 7603.

Barrera A., Gómez-Pompa A., and Vázquez-Yanes C. 1977. El manejo de las selvas por los Mayas: sus implicaciones silvícolas y agrícolas. Biotica 2(2): 47 – 61.

Beach T. and Dunning N.P. 1995. Ancient Maya terracing and modern conservation in the Peten rain forest of Guatemala. J Soil Water Conservation 50: 138 – 145.

Benjamin T.J., Montañez P.I., Jiménez J.J.M. and Gillespie A.R. 2001. Carbon, water and nutrient flux in Maya homegardens in the Yucatán Península of Mexico. Agroforest Syst 53: 103 – 11.

Blanckaert I., Swennen R.L., Paredes Flores M., Rosas López R., and Lira Saade R. 2004. Floristic composition, plant uses and management practices in homegardens of San Rafael Coxcatlán, Valley of Tehuacán, Mexico. J Arid Environ 57: 39 – 62.

Budowski G. 1990. Home gardens in Tropical America: a review. In: Landauer K. and Brazil M. (eds), Tropical home gardens, pp 3 – 8. United Nations University, Tokyo.

Caballero J. 1992. Maya homegardens: past, present and future. Ethnoecologica 1(1): 35 – 54.
Carr, D.L. 2004. Ladino and Q'eqchi Maya land use and land clearing in the Sierra de Lacandon National Park, Peten, Guatemala. Agric Hum Values 21: 67 – 76.
Casas A., Valiente-Baunet A., Viveros J.L., Dávila P., Lira R., Caballero J., Cortés L., and Rodríguez I. 2001. Plant resources of the Tehuacán Valley, Mexico. Econ Bot 55: 129 – 166.
De Clerck F.A.J. and Negreros-Castillo P. 2000. Plant species of traditional homegardens of Mexico as analogs for multistrata agroforests. Agroforest Syst 48: 303 – 317.
Del Angel-Perez A.L. and Mendoza M.A. 2004. Totonac homegardens and natural resources in Veracruz, Mexico. Agric Hum Values 21: 329 – 346.
De Las Salas G. 1987. Suelos y ecosistemas forestales con énfasis en América tropical. Instituto Interamericano de Cooperación para la Agricultura (IICA), San José, 479p.
Dommergues Y.R. 1987. The role of biological nitrogen fixation in agroforestry. In: Steppler H.A. and Nair P.K.R. (eds), Agroforestry: A decade of development, pp 245 – 272. ICRAF, Nairobi.
Eibl B., Fernández R., Kozarik J.C., Lupi A., Montagnini F. and Nozzi D. 2000. Agroforestry systems with *Ilex paraguariensis* (American Holly or yerba mate) and native timber trees on small farms in Misiones, Argentina. Agroforest Syst 48: 1 – 8.
Food and Agriculture Organization (FAO) 2001. Improving nutrition through home gardening. A training package for preparing field workers in Southeast Asia. Food and Agriculture Organization of the United Nations, Rome, 171p.
Fedick S.L. and Morrison B.A. 2004. Ancient use and manipulation of landscape in the Yalahau region of the northern Maya lowlands. Agric Hum Values 21: 207 – 219.
Gillespie A.R., Knudson D.M. and Geilfus F. 1993. The structure of four home gardens in the Peten, Guatemala. Agroforest Syst 24: 157 – 170.
González-Soberanis C. and Casas A. 2004. Traditional management and domestication of tempesquistle, *Sideroxylon palmeri* (Sapotaceae) in the Tehuacan-Cuicatlán Valley, Central México. J Arid Environ 59: 245 – 258.
Griffith D.M. 2000. Agroforestry: a refuge for tropical biodiversity after fire. Conserv Biol 14: 325 – 326.
Guindon C. 1996. The importance of forest fragments to the maintenance of regional biodiversity in Costa Rica. In: Schelhas J. and Greenberg R. (eds), Forest patches in tropical landscapes, pp 168 – 186. Island Press, Washington, D.C.
Harvey C.A. and Haber W.H. 1999. Remnant trees and the conservation of biodiversity in Costa Rican pastures. Agroforest Syst 44: 37 – 68.
Harvey C., Alpizar F., Chacón M. and Madrigal R. 2005. Assessing linkages between agriculture and biodiversity in Central America. Historical overview and future perspectives. Mesoamerican and Caribbean region, Conservation Science Program. The Nature Conservancy (TNC), San José, 138p.
Holdridge L.R. 1987. Ecología basada en Zona*s* de Vida. Instituto Interamericano de Cooperación para la Agricultura (IICA), San José, 216p.
House P.H. and Ochoa L. 1998. La diversidad de especies útiles en diez huertos en la aldea de Camalote, Honduras. In: Lok R. (ed.), Huertos caseros tradicionales de América Central: características, beneficios e importancia, desde un enfoque multidisciplinario, pp 61 – 84. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba.
Howard P.L. 2006. Gender and social dynamics in swidden and homegardens in Latin America In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 159 – 182. Springer Science, Dordrecht.
Kumar B.M. 2006. Carbon sequestration potential of tropical homegardens In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 185 – 204. Springer Science, Dordrecht.

Levasseur V. and Olivier A. 2000. The farming system and traditional agroforestry systems in the Maya community of San Jose, Belize. Agroforest Syst 49: 275 – 288.
Lok R. 1998. El huerto casero tropical tradicional en América Central. In: Lok R. (ed.), Huertos caseros tradicionales de América Central: características, beneficios e importancia, desde un enfoque multidisciplinario, pp 7 – 28. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba.
Lok R. and Samaniego G. 1998. La valorización sociocultural del huerto y del café con árboles entre la población Ngöbe de Chiriquí, Panamá. In: Lok R. (ed.), Huertos caseros tradicionales de América Central: características, beneficios e importancia, desde un enfoque multidisciplinario, pp 185 – 213. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba.
Lok R., Wieman A. and Kass D. 1998. Influencia de las características del sitio y el acceso al agua en huertos de la Península de Nicoya, Costa Rica. In: Lok R. (ed.), Huertos caseros tradicionales de América Central: características, beneficios e importancia, desde un enfoque multidisciplinario, pp. 29 – 59. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba.
Méndez V.E. and Bacon C. 2005. Medios de vida y conservación de la biodiversidad arbórea: las experiencias de las cooperativas cafetaleras en El Salvador y Nicaragua. LEISA Revista de Agroecologia 20 (4): 27 – 30.
Méndez V.E., Lok R. and Somarriba E. 2001. Interdisciplinary analysis of homegardens in Nicaragua: micro-zonation, plant use and socioeconomic importance. Agroforest Syst 51: 85 – 96.
Miller R.P., Penn Jr. J.W. and van Leeuwen J. 2006. Amazonian homegardens: their ethnohistory and potential contribution to agroforestry development. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 43 – 60. Springer Science, Dordrecht.
Montagnini F. and Nair P.K.R. 2004. Carbon sequestration: An under-exploited environmental benefit of agroforestry systems. Agroforest Syst 61: 281 – 295.
Myers N., Mittermeier R.A., Mittermeier C.G., da Fonseca G.A.B. and Kent J. 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853 – 858.
National Academy of Sciences (NAS). 1979. Tropical legumes: Resources for the future. Board of Science and Technology for International Development, National Research Council, Washington, DC, 332p.
National Academy of Sciences (NAS). 1980. Firewood crops. Shrubs and tree species for energy production. Board of Science and Technology for International Development, National Research Council, Washington, DC, 236p.
Noble I.R and Dirzo R. 1997. Forests as human-dominated ecosystems. Science 277: 522 – 525.
Piotto, D., Montagnini F., Kanninen M., Ugalde L. and Viquez E. 2004. Forest plantations in Costa Rica and Nicaragua: performance of species and preferences of farmers. J Sustainable For 18: 59 – 77.
Price N.W. 1989. The tropical mixed garden in Costa Rica. PhD Thesis. University of British Columbia, Vancouver, 403p.
Rico-Gray V., Chemas A. and Mandujano S. 1991. Uses of tropical deciduous forest species by the Yucatecan Maya. Agroforest Syst 14 (2): 149 – 161.
Richards P.W. 1996. The tropical rainforest: An ecological study (2nd ed.). Cambridge University Press, London, 450p.
Sanchez P.A. 1976. Properties and management of soils in the tropics. John Wiley and Sons, New York, 618p.

Steinberg M.K. 1998. Political ecology and cultural change: impacts on swidden-fallow agroforestry practices among the Mopan Maya in southern Belize. Prof Geogr 50: 407 – 417.

Toledo V.M., Batis A.I., Becerra R. Martinez E. and Ramos C.H. 1995. The useful forest: quantitative ethnobotany of the indigenous groups of the humid tropics of Mexico. Interciencia 20: 177 – 187.

Turner II B.L. and Harrison P.D. 1981. Prehistoric raised-field agriculture in the Maya lowlands. Science 213: 399 – 405.

Wezel A. and Bender S. 2003. Plant species diversity of homegardens of Cuba and its significance for household food supply. Agroforest Syst 57: 39 – 49.

Wieman A. and Leal D. 1998. La cría de animales menores en los huertos caseros. In: Lok R. (ed.), Huertos caseros tradicionales de América Central: características, beneficios e importancia, desde un enfoque multidisciplinario, pp 85 – 115. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba.

Yamada M. and Osaqui H.M.L. 2006. The role of homegardens for agroforestry development: lessons from a Japanese-Brazilian settlement in the Amazon. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 299 – 316. Springer Science, Dordrecht.

Zaldivar M.E., Rocha O.J., Castro E. and Barrantes R. 2002. Species diversity of edible plants grown in homegardens of Chibchan Amerindians from Costa Rica. Hum Ecol 30: 301 – 316.

SECTION 2

STRUCTURE, FUNCTION, AND DYNAMICS OF HOMEGARDENS

CHAPTER 6

HOMEGARDEN DYNAMICS IN KERALA, INDIA

A. PEYRE[1,2], A. GUIDAL[1,2], K.F. WIERSUM[2]*, AND F. BONGERS[1]

*[1]Forest Ecology and Forest Management group and [2]Forest and Nature Conservation Policy group, Wageningen University, The Netherlands; *E-mail: <freerk.wiersum@wur.nl>*

Note: Adapted from: Peyre A., Guidal A., Wiersum K.F. and Bongers F. 2006. Dynamics of homegarden structure and function in Kerala, India. *Agroforestry Systems* 66: 101 – 115.

Keywords: Biodiversity, Functional differentiation, Multispecies systems, Social adaptability, Socioeconomic change.

Abstract. Homegardens in Kerala, India, have long been important multipurpose agroforestry systems that combine ecological and socioeconomic sustainability. These traditional homegardens, however, are subject to changes consequent to various on-going socioeconomic transformations. The study of structural and functional dynamics of homegardens offers an opportunity to understand the trends in socioeconomic sustainability in relation to their ecological sustainability. These dynamics were studied in a survey of 30 homegardens. Based on a cluster analysis of tree/shrub species density and a subsequent grouping using homegarden size, six homegarden types were differentiated, and these were assessed for structural, functional, and managerial characteristics, besides their dynamics. Four development stages of homegardens were found along a gradient from traditional to modern homegardens. Fifty percent of the homegardens still displayed traditional features, whereas 33% incorporated modern practices. The process of modernization includes a decrease of the tree/shrub diversity, a gradual concentration on a limited number of cash crop species, an increase of ornamental plants, a gradual homogenization of homegarden structure and an increased use of external inputs. A traditional homegarden combining multispecies composition and intensive management practices could, however, offer an alternative development path to modern homegardens in adapting homegardens to changing socioeconomic conditions.

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 87–103.

1. INTRODUCTION

Homegardens are recognized worldwide as an epitome of a sustainable agroforestry system (Torquebiau, 1992; Kumar and Nair, 2004). From a system-dynamics point of view, the concept of sustainability includes two main dimensions (Wiersum, 1995): ecological sustainability (in the sense of keeping within ecological stability domains) and social sustainability (in the sense of adjusting to social dynamics). Most studies on sustainability of homegardens have been focused on ecological sustainability, while social sustainability has been given much less systematic attention (Torquebiau, 1992; Kumar and Nair, 2004). Social sustainability may relate either to the social acceptability of homegardens within the livelihood systems of rural producers or to the ability of homegardens to adjust to socioeconomic changes. The structure and composition of homegardens can well be adjusted to various livelihood conditions such as size of landholdings, role of homegardens within the overall farming-system and degree of commercialization. However, homegardens are not static, but have evolved over centuries; thanks to adaptive abilities of farmers in responding to changing rural and livelihood conditions (Wiersum, 2006). Traditionally, the homegardens mainly served to produce vegetables, fruits and other crops, which supplemented the staple food crops produced on open croplands. With the advent of commercialization, often an increase in selected cash crops such as coconut (*Cocos nucifera*) or rubber (*Hevea brasiliensis*) has been observed. The shift from subsistence agriculture to market economy often implies drastic structural and functional modifications, including a homogenization of the homegarden structure and use of external inputs (Kumar and Nair, 2004).

Several authors have voiced concern that these developments result in the loss of relevance of the homegardens and threaten their future development. Recently the question was even raised whether the homegardens are becoming irrelevant or even extinct (Kumar and Nair, 2004). The expressed fears that the traditional, diverse and ecologically sustainable homegardens will gradually dissolve into monospecific agricultural systems with uncertain sustainability are in stark contrast to the earlier ideas on homegardens as having a promising future (Soemarwoto, 1987). The maintenance of multispecies and multistrata agroforests is deemed worthwhile because of the growing interest in developing multifunctional land use systems, which contribute not only to production objectives, but also to the objectives of biodiversity and environmental conservation. In order to maintain the positive characteristics of the traditional homegardens it is therefore necessary to develop improved homegardens that counterbalance the ongoing trend of homogenization.

In order to better understand whether there is scope for such an alternative development path, and whether it is possible to adapt homegarden systems to the changing rural conditions while still maintaining the positive features of the traditional homegardens, it is necessary to study the trends in homegarden dynamics in detail. Up until the present, most homegarden studies have focused mainly on species inventories or system description (Nair, 2001) and still little attention has been given to their structural and functional evolution. In the past, differences between homegardens were mostly described based on characteristics such as size, structure (vertical stratification, diversity indices) or socioeconomic factors (level of inputs, subsistence/commercial production). Only recently, studies have been undertaken to systematically classify the structure of homegardens using analytical methods such as cluster analysis common to vegetation science (Leiva et al., 2002; Quiroz et al., 2002; Mendez et al., 2001; Tesfaye Abebe, 2005). These methods offer good opportunities for obtaining a systematic insight into different types of homegardens. The further evaluation of these different types in respect to socioeconomic conditions, under which they evolved, can provide useful insights into the development trends of homegardens.

Homegardens have traditionally been managed and adopted by farmers rather than through agroforestry research (Nair, 2001). Consequently, an interesting question is whether all farmers are following similar homegarden development trends, or whether farmers are following different pathways in maintaining their homegardens. The recent advances in using statistical methods for classification of homegarden systems provides a good basis for assessing whether there exist differences in homegarden types and evaluating whether different types follow different development trends.

Based on these considerations, the present study was undertaken with the objective of assessing the nature of dynamics of homegarden characteristics. It focused on the following questions:

1. What different types of homegarden are present in the study area and what are their characteristics?
2. What changes in homegarden structure, function, and management characteristics took place during the past decade?
3. What conclusion can be drawn regarding the position of the different homegarden types on an evolutionary axis?

2. MATERIALS AND METHODS

2.1. Study site

The study was conducted in Palakkad district, Kerala, India, which is one of the tropical regions where concerns about the future of homegardens have been raised[1]. In this region, the value of homegardens as multipurpose production systems combining ecological and socioeconomic sustainability is well-recognized (Nair and Sreedharan, 1986; Jose and Shanmugaratnam, 1993; Kumar et al., 1994). Various authors have voiced concern that socioeconomic changes and related adoption of modern managerial systems cause a negative conversion process of homegardens in this region (Jose and Shanmugaratnam, 1993; John and Nair, 1999). Several government development programs want to assist the farmers to raise their cash incomes and therefore promote the conversion of homegardens towards cash-cropping systems by providing loans and subsidies for rubber or other cash-crop cultivation. Moreover, government controls on timber production discourage the growing of timber in homegardens.

In view of these developments, Kerala offers a good opportunity to study the development trends in agroforestry systems. The case study was carried out in two *panchayaths* (administrative units: Mundur and Puduparyaram) of Palakkad district in central Kerala. The region is characterized by a tropical humid climate with a monsoonal pattern of rainfall. The topography is rolling to hilly and main soil types are Dystric Nitosols (FAO, 1977).

2.2. Data collection

Within the two study *panchayaths*, a stratified sample of 30 farm households was selected. The sample was stratified according to total landholding size, i.e., small (< 1 ha; n = 10), medium (1 to 2 ha; n = 10) and large (> 2 ha; n = 10). The households were selected based on information from a local rural development organization (Integrated Rural Technology Centre, Mundur, Palakkad) and from referrals of initial respondents.

In the homegardens of each household, a detailed survey of the composition and management practices was made. The survey consisted of an inventory of tree and shrub species and a count of all individuals per species. Only presence was recorded for herbs and (bi)-annuals. The species were classified according to their use into the categories: fruits and nuts, staple food, beverages and stimulants, spices, timber and firewood, medicinal products, religious plants, ornamentals, multipurpose species with more than four uses, and others. Rubber was the only species used exclusively as a cash crop and classified as such. During the survey, information was also collected on the management practices for individual species based on the approach developed by Wiersum and Slingerland[2]. In this approach, five main practices are distinguished: controlled utilization, protection, and maintenance, stimulation of desired products, regeneration, and interface management. The first four categories represent an increasing input of human energy per unit of land (Wiersum, 1997). Additional information concerning the homegarden size, the overall strategy in homegardens orientation (subsistence or commercial) and management inputs was collected using structured interviews. In these interviews, additional information was collected on changes in homegarden structure and management during the preceding ten years. This concerned both changes in homegarden composition and spatial arrangements (including homegarden size) as well as in management practices (changes in vegetation structure, production characteristics, and chemical input use).

2.3. Data processing and analysis

A hierarchical cluster analysis was applied for classification of the 30 homegardens using tree/shrub species density (number of individuals per species per unit area) as the main variable. Chi-square was used as distance or similarity measure and between-group average linkage method. Nine clusters were distinguished of which five consisted of only one homegarden each. Those five "single" clusters were reclassified based on homegarden size into two new types. Thus, a group of four small homegardens and a "group" of one big homegarden emerged. These six homegarden types were assessed with respect to their structural, functional and management characteristics as well as dynamics.

Structural characteristics: Four parameters were used to assess the structural attributes: homegarden size (land area including the house), total density of trees per homegarden, and species richness and evenness (except for species that could not be counted)—computed using Shannon's and Simpson's diversity indices (following Huston, 1994). Since only three of the six types had a sufficient number of homegardens, statistical analysis was only applied to differences among these homegarden types. Differences were tested using ANOVA for all the parameters except for number of species and tree density, as populations were not normally distributed even after transformation. In this case, a non-parametric Kruskall and Wallis test was applied.

Functional characteristics: Two parameters were used to assess the functional characteristics: the proportions of mean number of trees per use-category and the differentiation in home- or cash-orientation in production. Relative contribution of each use group was calculated and compared within each homegarden type. Annual staple food crops and 'other' crops were not included in this analysis; coconut and rubber were treated as separate categories in view of their high value according to both farmers' opinions and actual situation.

Management characteristics: Management was characterized in respect to management intensity, spatial arrangement, and use of inputs. Assessment of the management intensity was based on a detailed assessment of the management practices for the seven most common and preferred species: rubber, coconut, arecanut (*Areca catechu*), mango (*Mangifera indica*), jackfruit (*Artocarpus heterophyllus*), teak (*Tectona grandis*) and neem (*Azadirachta indica*). It was characterized on a comparative scale according to the technique of Wiersum and Slingerland[2]. The characterization of management inputs was based on an assessment of the internal and external inputs applied in cultivating the seven tree species.

Homegarden dynamics: The dynamics of each homegarden type were qualitatively assessed according to the changes in homegarden size, vegetation structure (introduction of new species, changes in respect to ornamental and medicinal plants, and changes in spatial arrangements), and production characteristics (change of homegarden orientation and evolution of chemical input use).

The data were analyzed using the statistical package SPSS 10.0 (SPSS Inc.). Based on structure, functions, management, and dynamics, the different homegarden types were arranged along a gradient from *traditional* to *modern* homegardens.

3. RESULTS

3.1. Distinction in homegarden types

Based on the cluster analysis using a dissimilarity index of 12.2 as a cut-off point, the 30 selected homegardens were categorized into nine clusters with different patterns of tree/shrub species density (Fig. 1). As five clusters consisted of only one

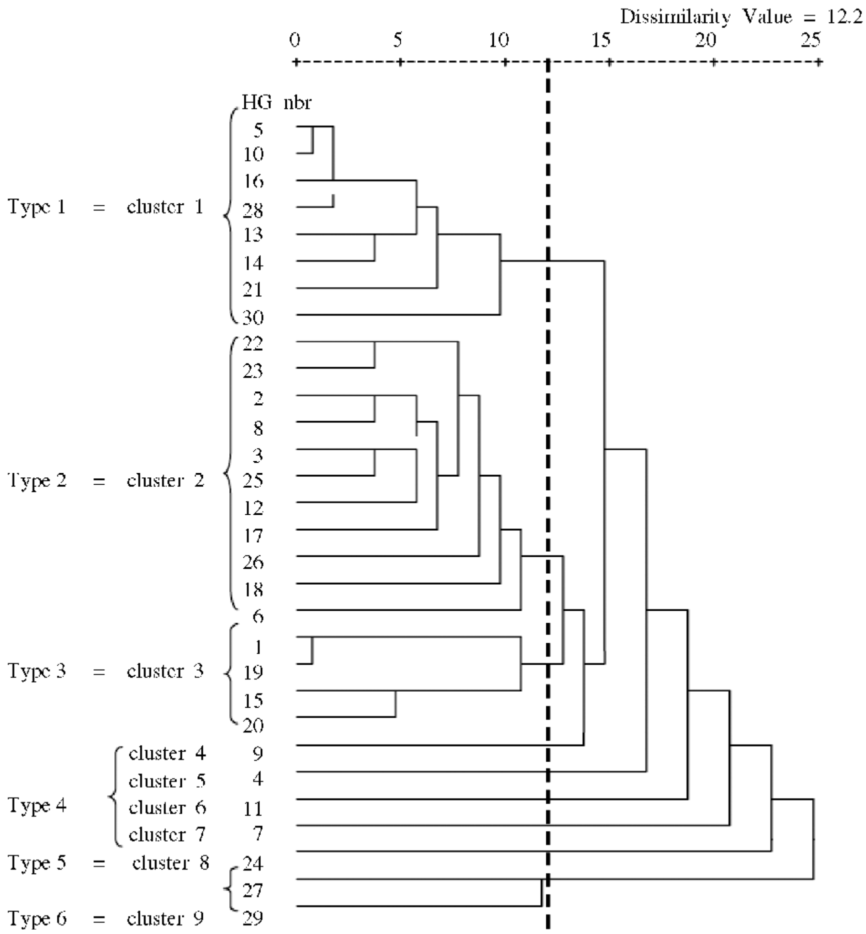

Figure 1. *Hierarchical classification of 30 homegardens in Kerala, India.*

homegarden each, a qualitative assessment was made to further delineate different homegarden types. Four clusters (clusters 4, 5, 6 and 7) which were similar in respect of their very small size (0.12 to 0.2 ha) were combined. Cluster 8 was maintained as a specific type due to its large size (0.81 ha) and specific structure. Consequently, the nine clusters were regrouped into six homegarden types for further analysis (Fig. 1).

3.2. Structural characteristics

The different homegarden types showed important variations in all their structural characteristics except for the number of species (Table 1). Although the average number of species in the various homegarden types ranged from 17 to 51, in types 1, 2, 4, and 6, the average number of species per homegarden were relatively similar. Types 2, 3, and 4 are small homegardens, whereas types 5, 6, and 1 are much larger. Types 1, 2, and 3 have a much lower tree density than types 4, 5, and 6. Types 1, 3, and 6 have lower species diversities (higher Simpson and lower Shannon indices) compared to types 2, 4, and 5. Finally, types 1 and 6 have lower evenness values than the other garden types. This indicates that in these homegarden types, production is oriented toward fewer species compared to types 2, 4, and 5. Further statistical tests were applied on types 1, 2, and 3 (Table 1). Type 1 is significantly larger than types 2 and 3. The three types are significantly different in respect to their number of species, but have similar tree/shrub densities per homegarden. Concerning the diversity indices, type 1 is statistically less diverse and has a lower evenness compared to type 2. Type 3 is intermediate.

***Table 1**. The structural characteristics of six homegarden types, Kerala, India.*

Attributes	*Homegarden types*						*Tests*		
	1 (n = 8)	*2 (n = 11)*	*3 (n = 4)*	*4 (n = 4)*	*5 (n = 1)*	*6 (n = 2)*	*Type*	*F/Chi²*	*P*
Homegarden size (ha)	0.72[a] (0.117)	0.40[b] (0.076)	0.24[b] (0.057)	0.14 (0.020)	0.81 (na)	1.01 (0.200)	A	4.04	0.034
Number of species	27.1 (3.47)	28.7 (1.33)	17.7 (3.09)	27.5 (3.77)	51.0 (na)	24.0 (3.00)	KW	6.14	0.046
Density (No./ha)	555.5[a] (57.99)	449.0[a] (54.9)	621.3[a] (128.9)	1105.8 (137.7)	1671.6 (na)	1387.9 (46.6)	KW	2.74	0.254
Simpson's index	0.35[a] (0.077)	0.08[b] (0.007)	0.20[ab] (0.028)	0.09 (0.015)	0.09 (na)	0.51 (0.068)	A	9.33	0.001
Shannon's index	0.79[a] (0.108)	1.24[b] (0.020)	0.89[a] (0.092)	1.21 (0.076)	1.32 (na)	0.50 (0.087)	A	13.18	0.001
Evenness	0.56[a] (0.060)	0.86[b] (0.013)	0.72[b] (0.052)	0.84 (0.018)	0.77 (na)	0.36 (0.049)	A	16.65	0.001

Values in parentheses represent the standard error (na = not applicable).
Values with different letters among homegardens are significantly different.
Tests: A = ANOVA, KW = Kruskall Wallis; F value for ANOVA, Chi-square values for Kruskall & Wallis tests and P = probability level of significance.

In general, there is a tendency that with an increase in size of homegardens [from type 4 (very small) to types 2 and 3 (small) to type 1 (medium) and type 6 (very big)], there is an increase in the Simpson's diversity index, a decrease in the Shannon's diversity, and a decrease in the evenness index. Only homegarden type 5 does not fit into this pattern; this big homegarden has a low Simpson's diversity index, a high Shannon's diversity index, and a high evenness index.

3.3. Functional characteristics

The various homegarden types differ in functional characteristics (Fig. 2). A range from five to nine use-categories was present in the homegarden types. Fruits and nuts, spices, timber, and coconut, are present in all homegarden types. In two types, only one use group consists of more than 50% of all trees: rubber in type 1 and beverage in type 6. The relatively less important use categories are the ones of religious, medicinal, and multipurpose trees.

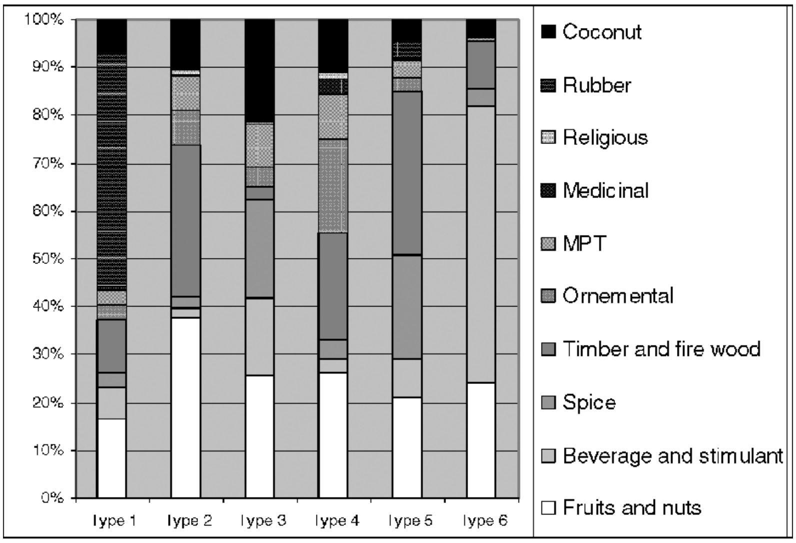

Figure 2. *Functional characteristics of six different homegarden types, Kerala, India (% of number of individuals in each functional use group).*

The different types of homegardens can be arranged along a gradient from predominately single commodity production to intensive multiple cropping. Type 1 is predominantly focused on rubber production, types 3 and 4 are characterized by a mixture of fruit trees and coconuts, type 6 had a mixture of fruit trees and beverage crops with some additional spices and timber trees, type 2 was a mixture of coconut, fruit trees, and timber trees, and type 5 by an intensive mixture of timber trees, spices, fruit trees, and beverage crops. These characteristics are related to the differences in whether farmers are oriented toward cash income generation or home consumption. Farmers managing type 1 and 6 are cash-oriented as reflected by the dominance of rubber and beverage producing crops or stimulant producing trees respectively. In these gardens, cash crops represent more than half of the total number of trees. Also the farmer managing homegarden 5 is cash-production oriented, but in this case there is no clear dominance of any crop. The managers of homegarden type 3 are focused on both cash income generation (coconuts) and subsistence production (fruits). The homegarden types 2 and 4 are both home consumption oriented. These homegardens are small in contrast to the cash-oriented types 5 and 6, which are larger in size. The garden type 1 with highest production specialization in rubber production is of medium size.

3.4. Management characteristics

Most management practices concern the manipulation of the tree environment rather than the tree itself. Sanitary pruning, rejuvenation pruning, canopy pruning to increase light penetration and cutting low branches are seldom, whereas weeding, fertilization, and crop spacing are more common (Table 2). In particular, cash crops are subjected to a variety of management practices. The most intensively managed species are coconut, rubber and arecanut; their cultivation includes use of chemical fertilizers and insecticides, systematic weeding, organic fertilization, and row arrangement of trees. They are also relatively often protected from competitors and are the only crops that receive watering. Fruit trees and neem receive less attention (selective weeding, some application of organic manures). The valuable timber species, teak receives no particular attention to increase its productivity.

The different homegarden types can be arranged along a gradient of management intensity. The small-sized types 4 and 2 are on one end of this gradient characterized by low to medium management with a concentration on internal inputs and with random arrangement of trees. On the other extreme of the gradient, the medium- to big sized homegarden types 1, 5, and 6 are subject to a more intensive management with use of both internal and external inputs such as chemical fertilizers, insecticides and purchased seedlings. In this case, row planting is dominant. The small-sized type 3 has intermediate characteristics, with only a medium intensity of management, but with a dominant spatial arrangement in row. In summary, the smaller homegarden types are managed at a lower intensity than the larger ones, but their production is more diverse. Type 5 has the distinctive feature of being a large garden with very intensive management but low use of external inputs; this homegarden is oriented at multiple-production.

3.5. Homegarden dynamics

During the past decade, there has been hardly any change in homegarden size. However, several changes in the structure and function occurred; these varied for the different homegarden types (Table 3). Spices (black pepper or *Piper nigrum*) and ornamental species are the only use categories that have been introduced in all homegarden types except in types 5 and 3 where they were already present.

Table 2. *Management practices of seven common species in different homegarden types.*

Species/management				*HG types*					
				1	*2*	*3*	*4*	*5*	*6*
RUBBER			presence	8/8	0/11	0/4	0/4	1/1	0/2
	Management		latex tapping	8	-	-	-	1	-
			weeding	6	-	-	-	1	-
			removing competition	4	-	-	-	0	-
			sanitary pruning	0	-	-	-	1	-
			cut low branches	0	-	-	-	1	-
			spatial arrangement	2	-	-	-	2	-
	Inputs	Int	organic fertilization	8	-	-	-	1	-
		Ext	bought seedlings	7	-	-	-	1	-
			chemicals	8	-	-	-	0	-
COCONUT			presence	8/8	11/11	4/4	4/4	1/1	2/2
	Management		nut harvesting	8	11	4	4	1	2
			weeding	8	6	3	0	1	2
			watering	0	4	2	2	0	2
			ringing	8	9	4	0	0	2
			sanitary pruning	0	0	0	0	1	0
			removing competition	4	6	2	0	0	0
			leaf harvesting	0	5	2	0	0	2
			canopy prunings	0	0	0	0	1	0
			spatial arrangement	2	2	2	2	2	2
	Inputs	Int	organic fertilization	7	10	4	3	1	2
			mulching	8	10	4	3	0	1
			seeding	0	0	0	0	0	2
			nursery	0	0	2	0	0	1
		Ext	bought seedlings	5	7	2	4	1	0
			chemicals	5	0	2	0	1	0
ARECANUT			presence	3/8	1/11	4/4	0/4	0/1	2/2
	Management		nut harvesting	3	1	4	-	-	2
			weeding	3	1	0	-	-	2
			watering	2	0	0	-	-	2
			ringing	3	1	2	-	-	1
			sanitary pruning	0	0	0	-	-	1
			removing competition	0	0	0	-	-	1
			spatial arrangement	2	2	1/2	-	-	1/2
	Inputs	Int	organic fertilization	3	1	3	-	-	2
			mulching	2	0	2	-	-	0
			seeding	2	0	0	-	-	1
			nursery	0	0	1	-	-	1
		Ext	bought seedlings	0	1	0	-	-	1
			chemicals	2	0	0	-	-	0

Species/management				*H G types*					
				1	*2*	*3*	*4*	*5*	*6*
MANGO	presence			7/8	11/11	4/4	4/4	1/1	2/2
	Management		fruit harvesting	7	11	4	4	1	2
			sanitary pruning	2	5	2	0	1	1
			rejuvenation pruning	0	0	0	0	1	0
			canopy pruning	0	0	0	0	1	0
			lopping	2	2	2	0	1	0
			weeding	0	0	0	0	1	0
			cutting low branches	0	0	0	0	1	0
			spatial arrangement	4	4	4	4	4	4
	Inputs	Int	organic fertilization	0	0	0	0	1	0
			seeding	3	3	0	0	0	0
			nursery	0	3	3	0	1	0
			protecting natural regeneration	0	0	0	2	0	1
			plant cuttings	0	0	0	0	0	1
		Ext	bought seedlings	3	5	0	3	0	0
			chemicals	0	3	0	0	0	0
JACKFRUIT	presence			8/8	10/11	4/4	3/4	1/1	2/2
	Management		fruit harvesting	8	10	4	3	1	2
			sanitary pruning	3	3	2	0	1	1
			rejuvenation pruning	0	0	0	0	1	0
			canopy pruning	0	0	0	0	1	0
			lopping	0	2	0	0	1	0
			weeding	0	0	0	0	1	0
			cutting low branches	0	2	0	0	1	0
			spatial arrangement	4	4	4	4	4	4
	Inputs	Int	organic fertilization	0	0	0	0	1	0
			seeding	4	5	0	2	0	1
			nursery	0	0	0	0	1	0
			protecting natural regeneration	2	0	2	0	0	1
		Ext	bought seedlings	0	0	0	0	0	0
			wildings	0	3	0	0	0	0
TEAK	presence			6/8	10/11	1/4	3/4	1/1	2/2
	Management		sanitary pruning	2	2	0	0	1	2
			rejuvenation pruning	0	0	0	0	1	0
			canopy pruning	0	0	0	0	1	0
			lopping	3	2	0	0	1	2
			weeding	0	2	0	0	1	1
			cutting low branches	0	0	0	0	1	1
			coppicing	0	0	0	0	1	1
			spatial arrangement	4	4	1	4	4	1/4
	Inputs	Int	organic fertilization	0	2	0	0	1	0
			nursery	0	2	0	0	1	1
			protecting natural regeneration	4	3	0	2	0	0
		Ext	bought seedlings	4	3	1	0	0	1

Table 2 (cont.)

Species/management				*HG types*					
				1	*2*	*3*	*4*	*5*	*6*
NEEM			presence	5/8	5/11	0/4	2/4	1/1	0/2
	Management		leaf harvesting	3	5	-	0	1	-
			sanitary pruning	0	2	-	0	1	-
			rejuvenation pruning	0	0	-	0	1	-
			lopping	0	0	-	0	1	-
			cutting low branches	0	0	-	0	1	-
			spatial arrangement	1	4	4	4	1/4	4
	Inputs	Int	organic fertilization	0	0	-	0	1	-
			nursery	0	0	-	0	1	-
			protecting natural regeneration	5	3	-	1	0	-
		Ext	bought seedlings	0	0	-	1	0	-

Presence: a/b a = number of homegardens studied; b = number of homegardens with species; (-) tree is not present; HG = homegardens, Int = internal, Ext = external; Legend for spatial arrangements: 1 = borders, 2 = rows, 3 = strips, 4 = scattered.

Ornamentals are usually cultivated around and in front of the house and along the paths. Black pepper is usually associated with palm trees in order to benefit from their soil management and inputs. Some farmers reported difficulties to harvest the palm nuts without damaging the pepper vines. Also some other support trees such as *Erythrina* spp. were introduced. In five out of the six homegarden types, fruit trees have also been introduced. They are usually cultivated close to the house, except for big trees such as mango or jackfruit or when planted in a large-scale. Another change concerns the medicinal plants. In the homegarden types 1, 5, and 6, many farmers have partially removed the medicinal species.

Few structural and functional changes have occurred in types 2 and 4, especially when compared to types 1 and 6. The large majority (93%) of the homegardens of types 2 and 4 are still subsistence-oriented, just as they were 10 years ago. Crop introductions do not concentrate on any specific species or use and are of low intensity (less than 50 individuals per species). These homegardens have preserved the traditional features; they still have a multistoried structure, high diversity and low dependency on external inputs. In contrast, 60% of farmers managing types 1 and 6 have shifted to a cash strategy with a modernized management oriented toward a few cash crops such as rubber, arecanut, and coffee. The introduction of these commercial crops resulted in important structural and functional changes. The canopy became less stratified and species diversity was reduced, notably in respect to species producing fruits and nuts, timber, and medicines. This caused a reduction in the multiple functions of homegardens. This change was most dominant in case of increased rubber cultivation, as this species is always grown as a monoculture. Coconut and arecanut are often still intercropped. Moreover, 70% of the farmers increased their use of chemical inputs.

No clear pattern could be deduced concerning the dynamics of the homegarden types 3 and 5. Although the production pattern of type 3 changed, its vegetation structure did not undergo any fundamental modification and the predominant spatial arrangement of trees remained in rows. The owner of type 5 follows a long-term cash strategy oriented toward timber production. The farmer has been able to follow the market demand by introducing more rubber and arecanut trees. However, these introductions did not affect the structural characteristics and vegetation structure.

Table 3. *Species introductions and changes in spatial arrangements in the period 1993 – 2003 in six homegarden types, Kerala, India.*

Garden types	*Introduced uses/species*	*Rate of introduction*	*Spatial arrangements of trees*	
			10 years ago	*Nowadays*
Type 4	Spices (pepper)	low	random	random
	Fruits (*Citrus,*	low		
	guava)	low		
	Beverage (coffee)	low		
	Ornamentals			
Type 2	Spices (pepper)	low	random	random
	Fruits (*Citrus*,	low		
	guava, *Annona*,			
	papaya)	low		
	Ornamentals			
Type 3	Spices (pepper)	low	row	row
	Fruits (guava, jack,	low		
	cashew, papaya)			
Type 5	Beverage (arecanut)	low	partly	partly
	Cash (rubber)	low	random,	random,
	Ornamentals	low	partly rows	partly rows
Type 6	Timber (teak)	low	random	row
	Ornamentals	low		
	Beverage (arecanut,	high		
	coffee)	high		
	Spices (pepper)	high		
	Fruits (banana)			
Type 1	Spices (pepper)	low	random	row
	Fruits (guava,	low		
	Citrus)	low		
	Ornamentals	high		
	Cash (rubber)			

Low = less than 50 individuals introduced in total; High = more than 50 individuals introduced in total.

3.6. Classification of homegarden types on an evolutionary axis

Based on their structural and functional characteristics and dynamics, the different homegarden types can be arranged along a gradient from *traditional* to *modernized* homegardens (Table 4). The homegarden types 2 and 4 are relatively small and have a high diversity and a random arrangement of trees. Few changes occurred during the past decade and the traditional features of homegardens have been preserved (high diversity, multi-storied canopy, and multi-production). These homegardens are oriented toward subsistence production and few products are sold. The management practices are predominantly based on internal inputs, although in type 2 some external inputs are also used. Based on these characteristics, they can be characterized as *traditional* homegardens. These traditional homegardens can be contrasted with homegarden types 1 and 6, which can be characterized as "modern." In these *modern* homegarden types, farmers have adopted a cash-orientation and have introduced several new management practices. In these relatively big homegardens the production became oriented at a few cash crops which are systematically arranged in rows. In the case of rubber, part of the homegarden is even transformed into single species plantation. Also, the use of external inputs (purchased seedling, chemical fertilizers, and insecticides) has increased.

Table 4. *Ordination of homegarden types along a gradient from traditional to modernized homegarden, Kerala, India.*

HG categories	*Type (s)*	*No. of HGs*	*Size*	*Orientation*	*Nature of production*	*Tree/shrub diversity*
Traditional	2,4	15	(very) small	home	multiple	high
Adapted traditional	6	1	big	cash	multiple	high
Incipient modern	3	4	small	home and cash	multiple	medium
Modern	5,1	10	medium to very big	cash	mono	low

HG = homegardens.

Type 3 can be considered as *incipient modern* type as it shares both traditional and modern characteristics. This homegarden type consists of small homegardens with medium diversity, and involves a low management intensity that depends predominantly on external inputs. Although type 5 is characterized by its cash orientation including introduction of new cash crops such as rubber and systematic spacing of trees, it still maintains the multispecies composition of the traditional homegardens. The garden is very intensively managed, but mostly with internal inputs by using organic fertilization and mulching for soil management and by regenerating trees by protecting natural regeneration, seeding, and using local plant material such as plant cuttings. Thus, although this homegarden was adapted to the modern cash economy, it maintained several characteristics of the traditional homegardens.

4. DISCUSSION AND CONCLUSIONS

This study shows that homegardens should not be considered as being static. Rather, their composition and management are gradually evolving in response to the socioeconomic dynamics. Only 50% of all respondents still followed traditional homegarden management practices, whereas 33% of all respondents have adopted modern practices by increasingly moving towards concentrated cash crop production and use of external inputs. Traditional homegardens were mostly of small size, while modern homegardens are much larger. This parameter should not be interpreted as the only, or main, feature influencing the development path of homegardens. Other factors, such as the role of the homegarden in the overall farming system and the degree to which a household has access to off-farm employment and income (Wiersum, 2006) might be of more importance. Unfortunately, these factors could not be taken into account in the present study.

Our data reinforce the general fears regarding the loss of traditional characteristics of homegardens and their gradual demise into cash crop production systems (Kumar and Nair, 2004). Because of the rise of market economy, agriculture in Palakkad region of Kerala is currently struggling to find new intensification strategies. Although traditional Kerala homegardens are reputed to be sustainable in both biophysical and socioeconomic terms, they do gradually change from a traditional type to a more modern one. This process of modernization often brings with it a decrease of the tree/shrub diversity, a gradual concentration on a limited number of cash-crop species, gradual homogenization of homegarden structure and increased use of external inputs.

Interestingly, however, one farmer in our sample had combined an increased orientation at cash crop production with the maintenance of a high species diversity and use of internal rather than external inputs. This example shows that there is no single uniform trend towards the modernization of homegardens in Kerala, but that alternative pathways exist. Moreover, this example also shows that traditional ecological features ensuring ecological sustainability of homegardens could still be maintained in modernized homegardens. This suggests that it might be possible to identify new development policies that aim at optimal combination of ecological and productive features of the homegardens rather than optimizing only cash crop production.

Although the study was focused on ascertaining trends in tree composition resulting from the process of commercialization, other trends influencing the composition of the homegarden vegetation were also observed (Wiersum, 2006). These included an increase in the use of ornamental plants and an increase in staple food production. The trend in gradual replacement of functional plants to ornamentals has also been observed in cases where people became richer. The gradual increase in staple food production was specifically found in cases where homegardens were the last remaining farming unit of poor households. Unfortunately, little attention has been given towards systematically studying under which set of conditions these different trends in homegarden development occur, to what extent they are interrelated, how they are related towards changes in livelihood conditions, and what their impact on biodiversity is.

Our study further shows that it is incorrect to assume a uniform development pattern for all homegardens, rather different pathways in homegarden development may co-exist. At present rural areas are subject to many socioeconomic changes (Ashley and Maxwell, 2001). The notion of homegardens being sustainable needs therefore to be specified in respect to ecological and social sustainability. Whereas the concept of ecological sustainability is time-independent, the concept of social sustainability includes the notion of agroforestry systems adjusting in a timely fashion to changing rural conditions. With respect to the potential of traditional agroforestry systems such as homegardens, the focus in assessing social sustainability should not only be on the question of whether the system fits into the traditional farming and livelihood systems, but also on the question of whether these agroforestry systems can be adjusted to modern rural conditions while still maintaining their features of ecological sustainability. Our study shows that research based on detailed assessments of the actual dynamics in the features of traditional agroforestry systems is rewarding. Such studies may indicate that different developments trajectories are being followed. The understanding of these development pathways and the factors involved offers good scope for the identification of options for further modification of agroforestry systems.

ACKNOWLEDGEMENTS

The fieldwork for this research was accommodated by the Integrated Rural Technology Center, Mundur, Palakkad, Kerala. Dr. Unnikrishnan provided valuable background information and important assistance to the organization of the survey. Additional information on the status of homegardens was provided by Dr. B. Mohan Kumar, Kerala Agricultural University, Dr. S. Sankar, Kerala Forest Research Institute and M/s. K.P. Ouseph and M. Shetty of the Kerala Forest Department.

ENDNOTES

1. The trends in homegarden structure and composition in the research area were discussed in an International workshop on agroforestry and natural resource management, organized in 2002 by the Centre for Rural Development and Appropriate Technology, Cochin University of Science and Technology, in association with the Integrated Rural Technology Center, Mundur, Palakkad, Kerala, India.
2. Wiersum K.F. and Slingerland M. 1996. Use and management of two multipurpose tree species (*Parkia biglobosa* and *Detarium microcarpum*) in agrisilvopastoral land use systems in Burkina Faso. Wageningen Agricultural University, Antenne sahelienne. Document de projet No. 41.

REFERENCES

Ashley C. and Maxwell S. 2001. Rethinking rural development. Dev Pol Rev 19: 395 – 425.

FAO. 1977. FAO-UNESCO Soil Map of the World 1:5000000. Volume VII, South Asia. UNESCO, Paris.

Huston M.A. 1994. Biological diversity. The coexistence of species on changing landscapes. Cambridge University Press. 681p.

John J. and Nair M.A. 1999. Socio-economic characteristics of homestead farming in south Kerala. J Trop Agric 37: 107 – 109.

Jose D. and Shanmugaratnam N. 1993. Traditional homegardens of Kerala, a sustainable human ecosystem. Agroforest Syst 24: 203 –213.

Kumar B.M. and Nair P.K.R. 2004. The enigma of tropical homegardens. Agroforest Syst 61: 135 – 152.

Kumar B.M., George S.J. and Chinnamani S. 1994. Diversity, structure and standing stock of wood in the homegardens of Kerala in peninsular India. Agroforest Syst 25: 243 –262.

Leiva J.M., Azurdia C., Ovanda W., Lopez E. and Ayala H. 2002. Contributions of homegardens to in situ conservation in traditional farming systems – Guatemalan component. In: Watson J.W. and Eyzaguirre P.B. (eds), Homegardens and in situ conservation of plant genetic resources in farming systems. Proceedings of the Second International homegarden workshop, Witzenhausen, Germany, pp 56 – 72. International Plant Genetic Resources Institute, Rome.

Méndez V.E., Lok R., and Somarriba E. 2001. Interdisciplinairy analysis of homegardens in Nicaragua: micro-zonation, plant use and socioeconomic importance. Agroforest Syst 51: 85 – 96.

Nair M.A. and Sreedharan C. 1986. Agroforestry farming systems in the homesteads of Kerala, southern India. Agroforest Syst 4: 339 – 363.

Nair P.K.R. 2001. Do tropical homegardens elude science, or is it the other way around? Agroforest Syst 53: 239 – 245.

Quiroz C., Gutierrez M., Rodriguez D., Perez D., Ynfante J., Gamez J., Perez de Fernandez T., Marques A. and Pacheco W. 2002. Homegardens and in situ conservation of agrobio-diversity – Venezuelan component. In: Watson J.W. and Eyzaguirre P.B. (eds), Homegardens and in situ conservation of plant genetic resources in farming systems. Proceedings of the Second International homegarden workshop, Witzenhausen, Germany, pp 73 – 82. International Plant Genetic Resources Institute, Rome.

Soemarwoto O., 1987. Homegardens: a traditional agroforestry system with a promising future. In: Steppler H.A. and Nair P.K.R. (eds), Agroforestry, a decade of development, pp 157 – 172. ICRAF, Nairobi.

Tesfaye Abebe 2005. Diversity in homegarden agroforestry systems of southern Ethiopia. Wageningen University, the Netherlands, Tropical Resource Management Paper No. 59, 143p.

Torquebiau E. 1992. Are tropical agroforestry homegardens sustainable? Agric Ecosyst Environ 41: 189 – 207.

Wiersum K.F. 1995. 200 years of sustainability in forestry: lessons from history. Environ Manage 19: 321 – 329.

Wiersum K.F. 1997. Indigenous exploitation and management of tropical forest resources: an evolutionary continuum in forest – people interactions. Agric Ecosyst Environ 63: 1 – 16.

Wiersum K.F. 2006. Diversity and change in homegarden cultivation in Indonesia. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 13 – 24. Springer Science, Dordrecht.

CHAPTER 7

STRUCTURE AND DYNAMICS OF COCONUT-BASED AGROFORESTRY SYSTEMS IN MELANESIA: A CASE STUDY FROM THE VANUATU ARCHIPELAGO

N. LAMANDA[1]*, E. MALÉZIEUX[1], AND P. MARTIN[2]

*[1]CIRAD UMR SYSTEM, Agro M, Bâtiment 27, 2 place viala, 34060 Montpellier, France; *E-mail: <nathalie.lamanda@cirad.fr>. [2]INA P-G département AGER, bâtiment EGER BP 01, 78850 Thiverval-Grignon, France*

Keywords: *Cocos nucifera*, Cropping system dynamics, Melanesian agriculture, Vegetation structure analysis.

Abstract. Coconut (*Cocos nucifera*)-based agroforestry systems hold promise as a sustainable land use activity in the Melanesian islands, where food dependency on foreign sources and land shortages are increasing dramatically. This chapter describes the dynamics of these smallholder production systems in the Malo Island of northern Vanuatu (Melanesia), where a dual economy operates in which resources are dedicated to both subsistence and commercial production. The floristic elements found in the coconut plantations were typical of those described in the humid tropical homegardens elsewhere, with an average of 12 tree species per plot. Mean Shannon Weaver index was 1.57 with the vertical profile of vegetation having one-to-five strata. Although the coconut palms dominate these production systems, in certain cases other trees may dominate it. Situations in coconut plots evolve throughout the development phase of the palms. Based on that, five types of smallholder coconut-based agroforestry systems were recognized, which falls into two main evolutionary patterns: (1) a perennial occupation of the cultivated land by coconut trees, because of coconut replanting, and (2) a gradual return to tree fallow in which the coconut palms gradually disappear because of changes in the complex multistrata vegetation.

1. INTRODUCTION

In the Melanesian archipelago of Vanuatu, about 80% of the estimated 0.2 million population lives in rural areas and are involved in agriculture (Labouisse, 2004). The

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 105–121.

traditional farming systems are shifting cultivation with long fallows (food gardens) and cultivation of coconut palms (*Cocos nucifera*) with a mixture of other species. The coconut palm incidentally is known as the "tree of life" in the Pacific islands because of its multiple uses. The staple food crops in the multistory food gardens include root and tuber crops, for example, yam (*Dioscorea* spp.) and taro (*Colocasia esculenta*), often closely associated with other species such as banana (*Musa* spp.), island cabbage (*Abelmoschus* spp.), or cassava (*Manihot esculenta*) and numerous tree species (*Artocarpus altilis*, *Barringtonia edulis*, etc.). Some farmers also undertake pig breeding, mainly due to social considerations (Bonnemaison, 1996).

During the 20th century, however, development of large "coconut estates" by the Europeans became a dominant land use activity and was rapidly followed by the evolution of a large number of smallholder plantations that substantially altered the indigenous farming systems in Vanuatu (Barrau, 1955; Clarke and Thaman, 1993; Bonnemaison, 1996). In particular, such coconut plantations became dominant in the northern islands of the archipelago where the agroclimatic conditions and market opportunities were ideally suited for coconut production. Furthermore, over a period of time, the intercropped, smallholder food gardens, with young coconut trees planted after bush or tree fallow clearing (Weightman, 1989) have evolved into complex farming systems in which coconut is associated with numerous other species and/or cattle grazing. Because of the development of coconut plantations, often on the best agricultural lands, food gardens were pushed farther from villages and onto the marginal lands (Clarke and Thaman, 1993; Bonnemaison, 1996). Concomitantly, forests or old tree-fallows were also converted into gardens and coconut plantations.

At present about 60% of the cultivated area in Vanuatu is occupied by coconut plantations and copra production is still the major source of income for the northern Vanuatu's rural population, despite the downward trend in copra prices worldwide during the past decade (Labouisse, 2004). With an increasing population that may double over the next 30 years, food dependency on external sources and pressure on natural resources may increase, and farmers and agricultural extension services are expressing concern about how to improve the current cropping systems. As a result, a diagnosis of the performance and sustainability of the existing situations in the coconut farms is needed in order to manage and prepare for the intensification of these systems. Moreover, the existing situations are the result of mixed species vegetation developing in plots managed with farmers' practices, and are, in turn dependent on local agro-ecological conditions. This chapter analyzes the dynamics of these complex coconut-based land use systems and the evolution of its vegetation structure over time.

2. MATERIALS AND METHODS

2.1. Study area and selection of sample plots

The study site was situated on Malo Island (15°40'S, 167°10'E) in northern Vanuatu that has a dual economy, in which resources are dedicated to both subsistence and commercial production (Allen, 2000). Malo Island, which covers about 180 km², is located southeast of the Santo Island, 20 km from Luganville (Santo Island), the second-ranking urban center of the archipelago (Fig. 1). This island, with its highly fertile soils and an equatorial climate tempered by oceanic influence (Quantin, 1982), offers optimum conditions for coconut cultivation (IRHO, 1969). Coincidentally, copra production is the main source of income to the inhabitants.

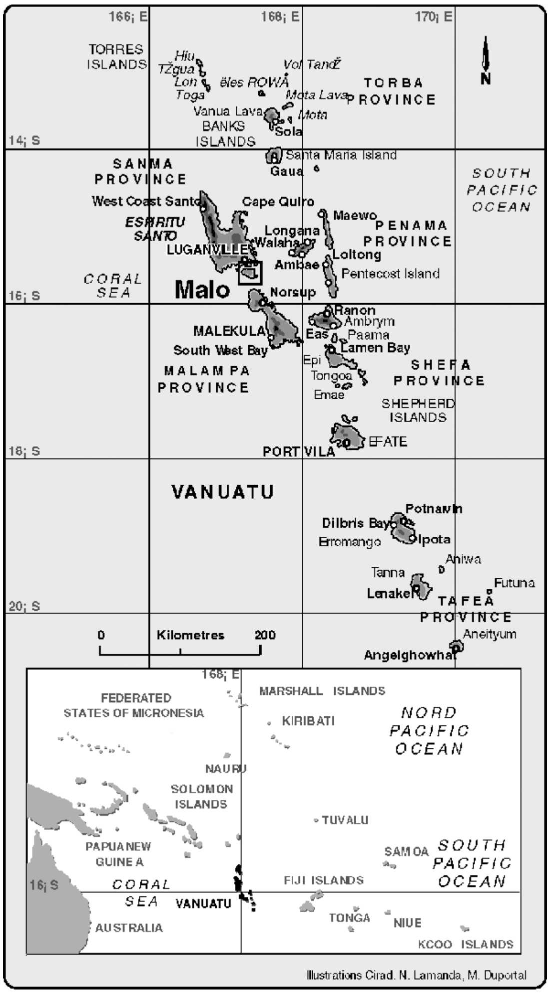

Figure 1. *Location of the study area, Malo Island, Vanuatu.*

The experimental approach involved characterizing the structure and dynamics of the smallholder coconut-based agroforestry systems. It consisted of four steps: (1) selection of sample plots representing the diverse situations existing in the study area; (2) description of the selected plots that included a farmer survey and plot observations; (3) classification and grouping of the monitored plots according to their vegetation structure; and (4) correlation studies to gain insights into the temporal dynamics of the cropping systems.

Malo island was first stratified according to its biophysical and socioeconomic characteristics (soil type, climate, and market opportunity) using a participatory mapping technique (Caron, 1997). The bibliographical data (Quantin, 1982; Weightman, 1989; Allen, 2000) were supplemented with historical data gathered through interviews of the local chiefs, farmers, and extension officers, chosen for their knowledge of Malo and its agriculture. Soil and climate characteristics, population density and origin, roads and marketing areas were also mapped on the basis of these bibliographical and interview data.

By linking the historical aspects and the biophysical characteristics of Malo (Lamanda et al., 2004), two distinct production areas were identified: the western area and the central eastern area. A native population and heterogeneous biophysical conditions characterize the western area. The predominant soil types are coral limestone in the coastal region and clay soils on the hills. In this area, the households are nested within villages and the farm fields of each family are scattered over large areas (i.e., the fields are often more than half an hour's walk from the household). Infrastructures are also concentrated in the villages, including the main dispensary, markets and roads and a rapid sea-link with the second-ranking town of the archipelago (Luganville) where most of the harvested produce are marketed. The central eastern area is characterized by a population essentially composed of migrants from other islands, and with more homogeneous soil characteristics (clay soils with good agronomic potential). The habitat is scattered and the coconut plots are located around the houses. Subsistence food gardens are also cultivated, sometimes far from the household depending on land availability. The population density is lower than that in the western area with estimates[1] of 250 inhabitants per km^2 in Avunatari, the main village of the western area, and 15 inhabitants per km^2 in the central eastern area during 1997.

In the main villages of each production area, farmers were interviewed in order to select the sample plots. The objective was to produce a sample that captures the diversity of situations existing in the coconut plots of Malo Island (i.e., different stages of development of coconut and/or different intercropping situations). We defined a *plot* in this study by evaluating the vegetation structure and stage of development of the coconut palms; accordingly, two or more plots could be distinguished within a farmer's field. The fieldwork was carried out in 2002 – '03 when 191 coconut plots were sampled and described. These plots (116 plots in the western area and 75 in the central eastern area) represented different stages of coconut development over an 85-year period and involved different species associations.

2.2. Description of the selected plots

A farmers' survey was conducted in each selected plot in order to assess the management history of the plots from coconut pre-planting to the present. The survey covered aspects such as when and how the plantation was established (biological material, original planting patterns, how fallow was destroyed, or used: e.g., forest or tree fallow), what are the changes in associated vegetation types, e.g., presence of food gardens or cacao (*Theobroma cacao*) trees, when coconut palms began to produce, present management of the plots, and its evolution through time.

The plots were located and their area was calculated using a geographical positioning system (GPS) when the canopy provided a clear signal; otherwise, direct measurements were used. All tree and crop species present in each plot were identified and grouped according to their nature and uses. Density was calculated by counting the individuals (i) on three sub-plots of size 900 m^2 each for species regularly planted such as coconut and cacao, and (ii) on the total plot area for other species. Species richness (number of species) and the Shannon Weaver index of species diversity (Krebs, 1985) were calculated collectively and separately for trees and other species.

Horizontal distribution of species was assessed visually and the planting pattern of coconut and cacao evaluated using a *0* (no visible planting pattern) to +++ (systematic pattern) scale. The distance between rows and trees in a row was measured for 10 coconut and cacao trees each in order to assess the planting pattern. Location of the large trees was determined using GPS. The vertical differentiation of the vegetation profile was first assessed visually and then supplemented by height measurements obtained for all tree species with individuals taller than 1.5 m.

2.3. Classification of the monitored plots

Structural groups (or vegetation types) were constructed based on the responses to a hierarchical set of questions concerning vegetation structure in the plot: (1) major species in the plot, (2) extent of species diversity, (3) horizontal distribution of major species and species groups, (4) vertical differentiation of the vegetation (canopy) profile, (5) status of the major species in the vegetation profile, and (6) dominant species or species groups. Many of these structural parameters, however, showed a continuous gradation; consequently, the structural groups identified in the classification scheme also constituted a continuum.

2.4. Dynamics of coconut-based agroforestry systems

A matrix of 'cropping situations' that combined the structural groups vs. time was constructed in order to position the situations described in the coconut plots in a temporal scheme. Time was represented by the development stages of coconut trees. Based on literature reference and the information provided by the farmers, four distinct stages of development of the coconut palms were recognized: (1) juvenile stage (0 to 7 years), (2) low productive stage (8 to 15 years), (3) productive stage (16 to about 60 years), and (4) senescent stage (over 60 years).

All monitored plots were then positioned in the matrix according to the structural groups and the development stages of the palms, which was crosschecked through farmer survey, especially about the date of plantation. The cropping situations were then linked to the management histories of the plots, and expressed as a succession of cropping situations during coconut development representing its temporal dynamics. A 'cropping situation' defined by the intersection in the matrix of a structural group and a development stage could be represented by different plots.

3. RESULTS

3.1. Vegetation structure of coconut plots

Vegetation characteristics of the experimental area are presented in Table 1. The major tree species found are coconut and cacao. Mean density of coconut palms in the smallholder plantations was 148 trees per ha, which is close to the 143 trees per ha recommended by local extension services. Density ranged from 11 to 744 palms per ha, and higher densities were common especially when two generations of coconut palms coexisted in the same plot. Mean density for cacao was 209 trees per ha, with a maximum of 1053, which was indeed less than the density recommended by the extension services (1111 cacao trees intercropped with 143 coconuts per ha). Mean size of the coconut plots was 1 ha (range 0.01 to 4 ha) and the smallest plots were mainly the food gardens associated with juvenile coconut palms.

Table 1. *Vegetation characteristics of coconut plots on Malo Island (Vanuatu).*

Vegetation characteristics	*Mean*	*Min*	*Max*
Number of species	15	4	40
Number of tree species	12	0	28
Number of semi-perennial herbs	3	0	12
Shannon Weaver index (total)	1.57	0.14	2.81
Shannon Weaver index (trees)	1.5	0	2.88
Shannon Weaver index (semi-perennial herbs)	0.61	0	1.94
Coconut planting density (all generations; no. per ha)	164	11	744
Coconut planting density (number per ha)	148	0	457
Number of tree species per ha (coconut and cocoa not included)	223	3	2733
Ratio of coconut palms-to-total tree species	0.5	0.05	0.99
Cacao tree planting density (number per ha)	209	0	1053
Age of first generation coconut palms (years)	35	planting	84
Coconut field area (ha)	1	0.01	4

In addition to the two main species mentioned, 90 other useful species were identified in the monitored plots (a list of conspicuous species with their local names and uses are given in Appendix I). According to their habit and uses, the species were grouped as 'trees' (49 species mainly with fruit trees such as *Mangifera indica* or *Barringtonia edulis* and/or timber trees such as *Hibiscus tiliaceus* or *Pometia pinnata*) and 'semi-perennial food crop species' (41 species). The mean number of cultivated species per plot was 16, with a minimum of four and a maximum of 40 species (Table 1). The most represented species were fruit trees such as *Artocarpus altilis*, *B. edulis* and *M. indica*, found in 68, 60, and 55% of the monitored plots respectively. Semi-perennial food crops such as *Musa* spp., *Carica papaya*, *Xanthosoma sagittifolium,* and *Dioscorea nummularia* were also frequently intercropped along with coconuts (in about 40% of the monitored plots).

The number of trees intercropped with coconut showed a wide range (3 to 2733 trees per ha); consequently, the proportion of coconut palms relative to other tree species was highly variable. Indeed, the ratio of the coconut tree density to the density of other tree species ranged from 0.05 to 0.99 (with a mean of 0.5), which illustrates the high floristic diversity of the coconut plots (Table 1). Consistent with this, the Shannon Weaver index collectively for tree and crop species ranged from 0.14 to 2.81 (mean =1.57). Furthermore, species diversity was higher for trees than for the semi-perennial food crops (mean Shannon Weaver index of 1.50 for trees and 0.60 for food crops). The extent of mixing food crops also varied substantially, with situations ranging from plots cropped with juvenile coconuts along with mixed food gardens, to plots in which only a few taro or banana plants were grown.

3.2. Horizontal and vertical structure of vegetation

Theoretically, the horizontal distribution of a species could be 'systematic' (with a repeated pattern), 'distorted' (if altered by the death or cutting down of certain individuals in the systematic pattern), 'random' (without any definite pattern), or 'patchy' (presence of groups or clusters; Fig. 2). Our observations indicate that the horizontal distribution of coconut and cacao trees in the sample plots was mostly systematic or distorted. This is because the coconut trees were mostly planted in a square pattern with a mean distance of 7.7 m between trees (CV = 14.5%). Likewise, the cacao trees were interplanted between the coconut rows with a mean distance of 5.3 m between cacao trees (extension recommendations are 9 m for coconuts and 3 m for intercropped cacao). The horizontal distribution of other trees was mostly random, without any clear geometrical arrangement. Semi-perennial food crop species mainly had a patchy distribution pattern either on the boundaries or between tree species depending on species and their cultivation requirements. For instance, strong yam (*Dioscorea nummularia*) was often found close to large trees that provided supports for the vines, while banana plants were clustered in pure or mixed stands.

As regards to vertical organization of the components, a multistrata arrangement with one-to-five strata depending on the number and architecture of the tree species was discernible. Coconut palms often formed the dominant component, but were sometimes dominated, especially when they were young and/or before the fallow clearing. Complex situations in which coconuts were both dominant and dominated were also noted when forest trees (dominant) were combined with food crops (dominated). Natural regeneration of tree/shrub species constituted the lower strata along with the food crop species. When cattle grazing under coconut and fruit trees was practiced, the naturally regenerating tree/shrub species of interest were protected by the farmers.

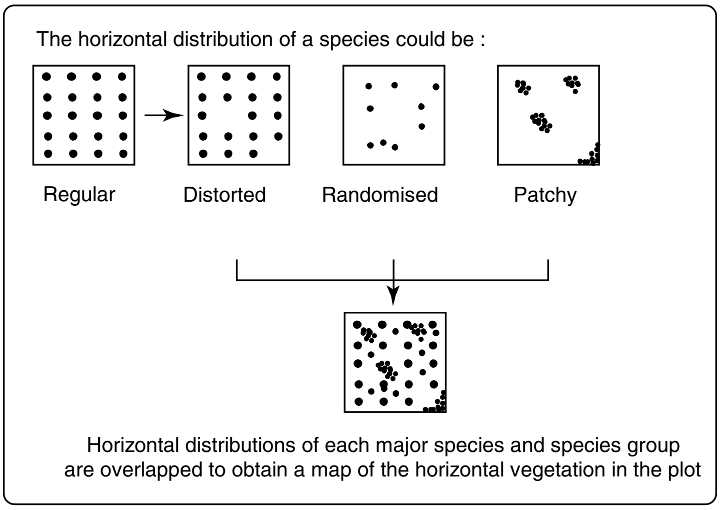

Figure 2. *Different types of horizontal vegetation distribution on Malo Island, Vanuatu.*

3.3. Structural groups

The monitored plots were finally classified into 14 structural groups (Fig. 3) and their principal attributes are summarized in Table 2. Similar structural groups were observed both in the western and central eastern areas and for the sole coconut and coconut+cacao systems. However, four structural groups not described on Malo but existing on other Vanuatu islands were also included in the classification scheme for the sake of comprehensiveness; these include the coconut estates where the palm was cultivated as a single species, possibly intercropped with cacao or associated with cattle grazing (I_{0A}, I_{0B}, II_{0A}, II_{0B}; Fig. 3). In contrast to these, the smallholder plots were generally characterized by significant species diversity.

3.4. Temporal dynamics of coconut-based cropping systems

Five coconut-based agroforestry systems were identified and the dynamics of their vegetation structure during coconut development phases were reconstructed (Fig. 4). Different structural groups can be noted for a given stage in the coconut cycle. Productive coconut plots could also be classified into several structural groups, thus illustrating the profound variability in vegetation structure and farmers' practices associated with coconut production in Malo Island (Fig. 5).

The evolutionary pathway starts as a system involving fruit trees, coconut palms, and food gardens planted together in a tree fallow that has been selectively managed.

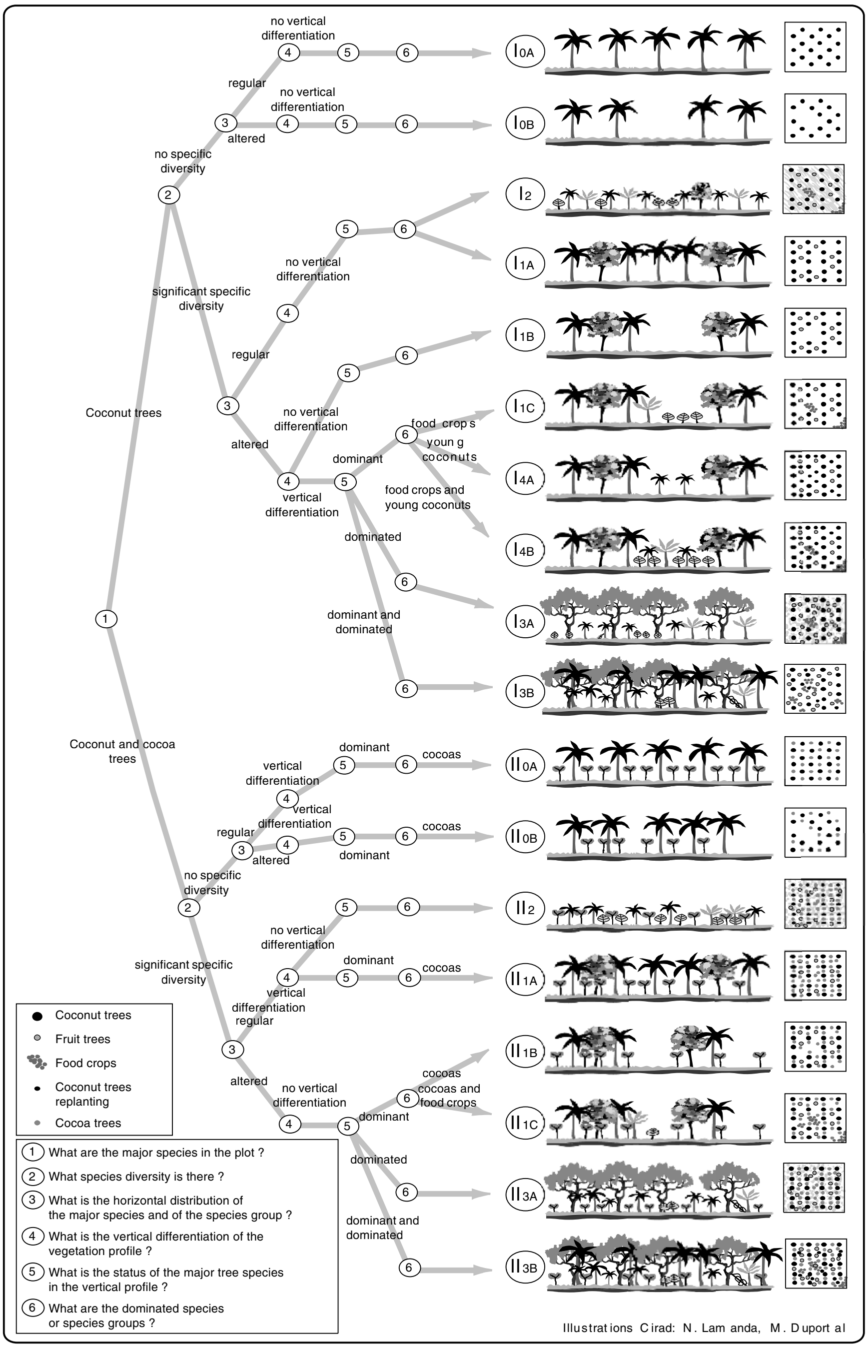

***Figure 3.** Classification of coconut plots for Malo (Vanuatu) in structural groups.*

Table 2. *Characteristics of structural groups for Malo Island (Vanuatu).*

Structural groups	*Monitored plots (no.)*	*Structural attributes of vegetation*											
		Number of tree species per plot		*Number of semi-perennial crop species per plot*		*Shannon Weaver index*		*Coconut tree density (no. per ha)*		*Cacao tree density (no. per ha)*		*Tree density other than coconut and cocoa (no. per ha)*	
		mean	*CV%*	*mean*	*CV%*	*mean*	*CV%*	*mean*	*CV%*	*mean*	*CV%*	*mean*	*CV%*
I_{1A}	22	13	33	1	251	1.13	48.8	165	29	0	469	81	163
I_{1B}	41	12	29	0	-	1.35	42.6	126	30	1	384	120	134
I_{1C}	19	15	27	5	45	2.01	23.3	107	26	5	436	244	99
I_2	15	9	57	5	78	1.66	24.1	218	50	11	190	129	54
I_{3A}	17	9	51	7	42	1.58	26.6	210	57	3	141	206	84
I_{3B}	10	7	23	1	218	1.36	33.5	332	56	0	0	1017	77
I_{4A}	4	13	13	2	141	1.31	39.6	240	100	0	0	108	60
I_{4B}	4	14	38	8	29	1.86	27.7	198	81	1	200	60	76
II_{1A}	6	15	40	2	92	1.44	46.3	144	26	280	87	167	165
II_{1B}	5	17	34	1	100	1.49	23.1	150	29	128	49	51	35
II_{1C}	12	17	30	5	64	2.03	22.9	134	32	249	90	172	55
II_2	8	15	45	3	77	1.62	39.1	197	33	125	187	198	52
II_{3A}	14	11	38	6	47	1.74	29.4	131	63	332	88	341	103
II_{3B}	11	14	42	5	47	1.92	21.6	150	56	173	97	366	91

As the palms attain the bearing stage, cattle is introduced into the plantation and grazed until the coconut trees become senescent (cropping system *I*). With the coconut palms becoming still older (~60 years) and that their planting pattern gets distorted, food crops are introduced and/or a new generation of coconut trees interplanted along with the first generation palms. Cacao might also be intercropped along with coconuts at the beginning. However, as the cacao trees die eventually, cattle might be introduced into the plantation, and this system (System *III*) then evolves like the previous one; alternately food crops can be inter-planted (System *IV*).

When the tree fallows are not managed, however, the coconut palms would be dominated by other woody perennial components (systems *II* and *V* where cacao was intercropped with coconut). 'Key situations' of these systems, corresponding to the trajectories for the juvenile coconut stage are I_{3A}, I_2, II_{3A} and II_2 (Fig. 4). Moreover, at the beginning of the senescent stage if gaps arise between coconut trees through altered planting patterns, it could be utilized in different ways (I_{1B} and II_{1B}).

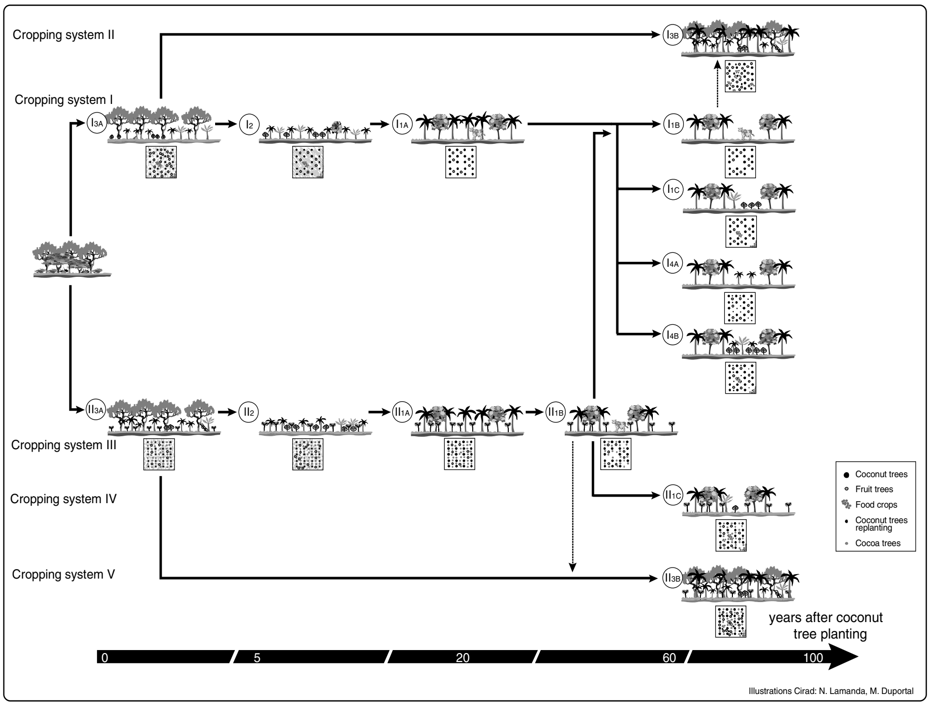

Figure 4. *Temporal dynamics of coconut-based agroforestry systems on Malo Island, Vanuatu.*

4. DISCUSSION

The coconut plots on Malo Island had species diversity levels close to those noted in the multistrata agroforestry systems of the humid tropics, i.e., an average number of 12 tree species per plot with a mean Shannon Weaver index of 1.57 (for a complete review of the reported floristic elements in homegardens see Kumar and Nair, 2004).

Figure 5. *Some structural groups described on Malo Island (Vanuatu) [I_{1A}: Systematic planting of coconut trees (++) and no vertical differentiation of the vegetation profile; mixtures of coconut palms (*Cocos nucifera*),* Mangifera indica *and* Hibiscus tilaceus *can, however, be seen in the rear end. I_{3B}: Coconut plots with significant species diversity. Distorted planning pattern and a vertical differentiation of the vegetation profile where coconut trees are dominant (e.g., a first generation of coconut trees dominates a younger generation and* Annona *spp. at the first level of the picture) and dominated (mainly by forest trees). I_{1C}: Coconut trees with a significant species diversity. Distorted planning pattern and a vertical differentiation of the vegetation profile. Food crops such as* Musa *spp. constitute the lower stratum of the vegetation profile].*

A vertical stratification involving one to five strata is also characteristic of the structure of homegardens, one of the most common agroforestry systems in the tropics (Fernandes and Nair, 1986; Kumar and Nair, 2004). The vegetation structure reported for the smallholder coconut plots on Malo Island is similar to that described for many smallholder coconut production systems in other locations, e.g., cattle grazing in the Pacific islands (Nair, 1983; Clarke and Thaman, 1993), multistory mixed species systems involving coconut and another cash crop such as cacao, or with food crops in South Asia, and in particular in India (for a comprehensive review of the agroforestry systems with coconut, see Nair, 1979; 1983; 1989).

The situation of coconut plots was, however, not static and evolved throughout its development phases. We discerned five dynamic phases for the smallholder coconut-based agroforestry systems that corresponded to five major trajectories (Fig. 4) from which two evolutionary patterns could be deduced. First, a perennial occupation of the cultivated land by the coconut palms, because of coconut replanting in cropping systems *I*, *III* and *IV*. In these systems, the tree fallows gradually evolved into situations with one-to-three strata and a new coconut stand could be established in the original pattern after about 60 years of coconut cultivation. Second, a gradual return to tree fallows where coconut trees could gradually disappear because of the evolution of complex multistrata vegetation in which other tree species dominate (coconut-based agroforestry systems *II* and *V*). This pattern of evolution could lead to a new cultivation cycle depending on the agroecological impacts (especially on soil fertility) and fallow duration (e.g., the food gardens).

The smallholder coconut-based agroforestry systems have various economic/ social functions too: (1) generating cash flow by copra and/or cocoa production, which incidentally, is the main source of income for most Maloese, (2) contribution to food security by producing fruits, nuts, leaves, roots, etc., that are a substantial source of food supply – and some of which have high nutritional value, thus adding to the nutritional security, (3) an inheritance pattern with plantations being passed down to the children, (4) a social function with copra harvesting by a working group called '*kompagny*", and (5) a cultural role with the production of decorative, medicinal/'magic' species. Cattle grazing in coconut plots is also associated with (1) generation of cash income, (2) food production that constituted an important source of animal proteins, (3) a social function with cattle slaughtered for marriage and funeral ceremonies, (4) weed control and (5) a nutrient recycling function, e.g., grazing and nutrient addition through dung and urine.

In addition, the coconut-based agroforestry systems provide for ecological functions such as carbon sequestration (see Kumar, 2006); efforts to quantify this substantial potential of the plantations of Vanuatu are currently underway. Yet another advantage is *in situ* agrobiodiversity conservation, especially the high intra-specific variability and genetic diversity at plot level. For instance, seven named *types* of coconut trees were reported per ha of the smallholder plantations in Vanua Lava, another northern island of Vanuatu (Caillon, 2005). And a wide variety of breadfruit (*Artocarpus altilis*) is also cultivated in Vanuatu (~132 types; Walter, 1989).

Cultivating food crops in coconut gardens also might reduce the impact on tree fallows or forests by reducing the rate at which these are being cleared for food production. Furthermore, it represents a sustainable way of intensifying the current cropping practices. That is, with only 25% of the light and space being used by the coconut palms, resources are often under-exploited in mature coconut plantations. Intercropping might be the best option for effectively utilizing these resources (Nair, 1979; 1983). In the current context of Melanesian agriculture (with land shortages and a downward trend in the profitability of copra production), agroforestry, thus, appears to be a very attractive option for intensification of the smallholder coconut production systems, and in particular, the old plantations. Nowadays, in the western area of Malo, where there are land shortages due to human pressure, food crops such as banana, papaya, island cabbage, or strong yam are already being introduced on the farm boundaries, or in the distorted planting patterns of coconut trees in the older (~60 year-old) plantations (I_{IC} in Figs. 3, 4 and 5). This situation, which is found at the senescent stage of coconut palms and in areas with high human population pressure, may constitute an innovation and a valid alternative to current land use problems.

More intensive use of the older coconut plantations is possible by intercropping food crops or species with high economic value such as vanilla (*Vanilla planifolia*), that are adapted to the level of resources usually available under the canopy of the coconut palms. These species can provide a significant source of income or food. Moreover, food crops can be sold in the local markets that offer considerable potential for development and expansion due to the increase in urban populations. In isolated areas such as Melanesian islands, however, developing the production of species with high economic potential should be linked to niche-marketing opportunities and extension facilities to certify the quality attributes/organic origin of the produce.

Existing smallholder copra production systems are also more complex than the large European coconut estates. Yet the development of copra production has led to a simplification of the pre-existing smallholder systems, a phenomenon called agrodeforestation (Clarke and Thaman, 1993), which had dramatic consequences on many Pacific islands. Therefore, it should be accompanied by another process of agroforestation, to avoid environmental disasters.

6. FUTURE DIRECTIONS

Characterizing the existing smallholder coconut-based agroforestry systems and their dynamics constitutes the first step towards evaluating their agro-ecological and agro-economical potentials, which is required to guide the future of these systems. Key situations, such as those where food crops are reintroduced into the coconut plots, are currently being studied to assess the possibility of more intensive use of the old coconut plantations. In particular, soil fertility levels (with organic matter indicators) and light availability in the vegetation profile and root occupation are being measured to estimate the degree to which various biophysical resources are used. Future studies should also take into account differences in soil fertility due to topographic differences (coral limestone in coastal area versus clay soils on hills), and economic evaluation of the coconut-based agroforestry systems to ensure that they match the farmers' goals.

ACKNOWLEDGEMENTS

We are grateful to the Vanuatu Research and Training Centre (VARTC) and the Vanuatu Agriculture Extension Services and the Farming Support Association (FSA) for their logistical support and cooperation. We would also like to express our gratitude to the Maloese farmers for their warm welcome and infinite patience.

ENDNOTE

1. Allen M.G. 2001. Change and continuity: Land use and agriculture on Malo Island, Vanuatu. Master of science. Australian National University, Canberra, 201p.

REFERENCES

Allen M. 2000. Subsistence or Cash Cropping ? Food Security on Malo Island, Vanuatu. In: Bourke R., Salisbury M.G., and Allen J.C. (eds), Food security for Papua New Guinea - Proceedings of Papua New Guinea food and nutrition 2000 Conference, pp 100 – 111. ACIAR Proceeding. PNG University of Technology, Canberra.

Barrau J. 1955. L'agriculture vivrière mélanésienne. Commission du Pacifique Sud. Nouméa, 206p.

Bonnemaison J. 1996. Gens de Pirogues et Gens de la Terre- Les fondements géographiques d'une identité, l'archipel du Vanuatu- Livre 1. Orstom (eds). Paris, 460p.

Caillon S. 2005. Pour une conservation dynamique de l'agrobiodiversité: gestion locale de la diversité variétale d'un arbre "des Blancs" (cocotier, *Cocos nucifera* L.) et d'une plante "des ancêtres" (taro, *Colocasia esculenta* (L.) Schott) au Vanuatu. Doctorat, Géographie, Université d'Orléans, Orléans, 789p.

Caron P. 1997. Le zonage régional à dire d'acteurs. Connaître, représenter, planifier, agir, une méthodologie expérimentée dans le Nordeste du Brésil. In: Quelle géographie au CIRAD? Montpellier 10: 145 – 156.

Clarke W.C. and Thaman R.R. (eds). 1993. Agroforestry in the Pacific Islands: systems for sustainability. United Nation University, Tokyo, 297p.

Fernandes E.C.M. and Nair P.K.R. 1986. An evaluation of the structure and function of tropical homegardens. Agroforest Syst 21: 279 – 310.

Institut de Recherches des Huiles (IRHO) 1969. Accroissement de la production de coprah aux Nouvelles Hébrides. Institut de Recherches des Huiles et Oléagineux (IRHO), Paris, 154p.

Krebs C.J. 1985. Ecology: the experimental analysis of distribution and abundance. Harper and Row Publisher, New York, 686p.

Kumar B.M. 2006. Carbon sequestration potential of tropical homegardens. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 185 – 204. Springer Science, Dordrecht.

Kumar B.M. and Nair P.K.R. 2004. The enigma of tropical homegardens. Agroforest Syst 61: 135 – 152.

Labouisse J-P. 2004. Systèmes agraires et économie du cocotier au Vanuatu: historique et perspectives. Journal de la Société des Océanistes (CNRS-Musée de l'Homme), Paris, 118: 11 – 33.

Lamanda N., Malézieux E. et Martin P. 2004. Organisation spatiale et dynamique des systèmes de culture à base de cocotiers (*Cocos nucifera* L.) dans une île mélanésienne. Cahiers Agricultures 6: 459 – 467.

Nair P.K.R. 1979. Intensive multiple cropping with coconuts in India. Paul Parey, Berlin/Hamburg, 148p.
Nair P.K.R. 1983. Agroforestry with coconuts and other tropical plantation crops. In: Huxley P.A. (ed.), Plant research and agroforestry, pp 79 – 102. ICRAF, Nairobi.
Nair P.K.R. (ed.). 1989. Agroforestry systems in the tropics. Kluwer, Dordrecht, 664p.
Quantin P. 1982. Atlas des sols et de quelques données du milieu naturel: Atlas and exploratory notes. Orstom (eds), Paris, 37p.
Walter A. 1989. Notes sur les cultivars d'arbres à pain à Vanuatu. Journal de la Société des Océanistes (CNRS-Musée de l'Homme), Paris, 1/ 2: 3 – 18.
Weightman B. 1989. Agriculture in Vanuatu: An historical review. The British Friends of Vanuatu, Cheam, 320p.

APPENDIX 1

List of local, scientific names and uses of the conspicuous species reported in coconut plots on Malo Island, Vanuatu.

List of conspicuous species		*Uses*						
Scientific name	*Local name (bishlama)*	*Sold*	*Food*	*Timber*	*Fuel*	*Used every day*	*Eaten by animals*	*Magic and medicinal uses*
Abelmoschus manihot	aeland kappish	⊕	⊕					
Ananas comosus	pineapple	⊕	⊕					
Annona spp.	korrosol	⊕	⊕		⊕			⊕
Artocarpus altilis	breadfruit	⊕	⊕	⊕		⊕		⊕
Barringtonia edulis	navele	⊕	⊕		⊕			⊕
Canarium indicum	nangaie	⊕	⊕	⊕	⊕			⊕
Carica papaya	paw paw	⊕	⊕				⊕	⊕
Citrus grandis	pomelos	⊕	⊕		⊕			
Citrus limon	lemon	⊕	⊕		⊕	⊕		
Citrus reticulata	mandarine	⊕	⊕		⊕			
Dioscorea spp.	soft yam	⊕	⊕					⊕
Discorea nummularia	strong yam	⊕	⊕					
Erythrina variegata	narara					⊕		⊕
Helicona indica	leaf lap lap	⊕				⊕		
Hibiscus tiliaceus	bourrao		⊕	⊕	⊕	⊕	⊕	⊕
Inocarpus fagiferus	namambé	⊕	⊕					⊕
Macaranga spp.	navenue			⊕	⊕	⊕		⊕
Mangifera indica	mango	⊕	⊕				⊕	
Manihot esculenta	manioc	⊕	⊕					
Metroxylon warburghii	natangora	⊕		⊕				⊕
Musa spp.	banana	⊕	⊕			⊕		⊕
Pometia pinnata	nandao	⊕	⊕	⊕	⊕			⊕

Psidium guajava	guava	⊕	⊕						⊕
Saccharum officinarum	sugarcane	⊕	⊕						
Spondias dulis	naos	⊕	⊕						⊕
Vanilla planifolia/tahitensis	vanilla	⊕							
Xanthosoma sagittifolium	taro Fiji	⊕	⊕						⊕

CHAPTER 8

DIVERSITY AND DYNAMICS IN HOMEGARDENS OF SOUTHERN ETHIOPIA

TESFAYE ABEBE[1], K.F. WIERSUM[2]*, F. BONGERS[3] AND F. STERCK[3]

*[1]Debub University, Awassa College of Agriculture, Ethiopia. [2]Forest and Nature Conservation Policy group, and [3]Forest Ecology and Management group, Wageningen University, The Netherlands; *E-mail: <freerk.wiersum@wur.nl>*

Keywords: Adaptability, Species composition, Socioeconomic change, Sustainability**.**

Abstract. Most homegarden studies have focused on Asia, where homegardens constitute a component of a spatially separated farming system consisting of cultivated fields with staple food and/or commercial crops away from homes complemented by the homegardens with supplementary crops such as fruits and vegetables surrounding residential houses. In the highlands of East and Central Africa, another type of homegarden is found in the form of an integrated farming system within itself and without additional cultivated fields. In these 'integral' homegardens, not only supplementary crops such as fruits and vegetables, but also staple food crops and cash crops are grown. The enset (*Enset ventricosum*) and coffee (*Coffea arabica*) homegarden system in southern Ethiopia is a typical example of such integral homegardens. An assessment of 144 of these homegardens was made to gain insights into their structure and vegetation composition and the relation between composition and geographic and socioeconomic factors. Four specific garden types are identified, which vary in commercial crop composition and diversity. These variations are related to farm size and access to roads and markets, and illustrate the dynamic character of homegardens. Overall, the diversity of the integral homegarden system seems to be somewhat lower than that of the 'complementary' homegarden systems in Asia, probably due to the inclusion of light demanding staple food crops and a relatively large number of commercial crops. The dynamic pathways of the integral homegarden systems because of commercialization appear similar to reported trends in the 'complementary' homegarden systems in Asia. Although the composition of the homegardens is influenced by socioeconomic dynamics, overall the Ethiopian homegardens can be characterized as being ecologically and socioeconomically sustainable. This can be attributed not only to species diversity but also to the presence of two keystone species—coffee and enset.

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 123–142.

1. INTRODUCTION

Homegardens have commonly been characterized as biodiverse and sustainable land use systems (Soemarwoto, 1987; Torquebiau, 1992; Kumar and Nair, 2004). Recently, it has been acknowledged that this does not mean that the structure and composition of homegardens should be assumed as being stable (Kumar and Nair, 2004). From an ecological point of view, the production processes are not necessarily negatively affected by changes in vegetation structure and composition, if the nutrient cycling processes, hydrological conditions, and synergetic relations are not compromised. From a social point of view, the concept of sustainability incorporates the notion of adaptation to social change (Peyre et al., 2006). Similar to any land use system, homegardens are faced with constant pressure of change brought about by demographic, economic, technological, and social dynamics, and they are constantly adapted to changing livelihoods. Several studies in Asia indicate that with commercialization, often a gradual change from subsistence to commercial crops occurs in homegardens, while the crop diversity decreases (Michon and Mary, 1994; Kumar and Nair, 2004; Peyre et al., 2006; Abdoellah et al., 2006).

Most homegardens studies are focused on gardens that constitute a component of a spatially separated farming system consisting of cultivated fields away from homes complemented by the homegardens surrounding residential houses. In such multi-locational farming systems, homegarden production is mostly supplementary to the staple food production and mainly focuses on vegetables, fruits, and condiments (Wiersum, 2006; Soemarwoto, 1987; Hoogerbrugge and Fresco, 1993). The notion of tropical homegardens as components of integrated farming systems, which also include cultivated fields for staple food production, prevails in much of the homegarden literature. These 'complementary' homegardens typically consist of small (0.01 to 1 ha) plots around houses with a more or less randomly organized cropping pattern. A part of the garden may be devoted to ornamentals or tree crops. As these homegardens complement other components of the overall farming system, crop diversity and homegarden dynamics are influenced by the nature and characteristics of the other components of the overall farming system (Stoler, 1978; Karyono, 1990). However, in the highlands of East and Central Africa, a somewhat different type of homegardens exists in the form of an integrated farming system within itself without additional cultivated fields (Tesfaye Abebe, 2005). These 'integral' homegardens consist of medium-scale (0.4 to ~3 ha) multipurpose farm fields around homes that form the principal means of livelihood for the households. In these gardens, not only supplementary crops such as vegetables, fruits, condiments, and/or medicinal crops, but also staple food crops and cash crops are cultivated. The motivating factor for this multiplicity of species is that farmers have no or very little additional land devoted to specialized types of production, for instance cereals. Consequently, these homegardens function as a total rather than a partial farming system. Most of the homegardens in the highlands of East Africa belong to this category (Fernandes et al., 1984; Okigbo, 1990; Oduol and Aluma, 1990; Rugalema et al., 1994; Tesfaye Abebe, 2005). They have been much less intensively studied than the 'complementary' homegardens of Asia. An interesting question is whether the diversity and dynamics as observed in the 'complementary' homegardens are also present in these 'integral' homegardens. This question is examined in this chapter by analyzing the structure and composition of the homegardens of southern Ethiopia as an example.

2. HOMEGARDENS IN SOUTHERN ETHIOPIA

The traditional agroforestry homegardens of southern Ethiopia are located at altitudes of 1500 to 2300 m above sea level where moisture and temperature conditions are favorable for agriculture. These gardens are popularly known as 'enset-coffee homegardens' after the two major perennial crops dominating this system (Fig. 1; Tesfaye Abebe, 2005). Enset [*Enset ventricosum* (Welw.) Cheesman], sometimes called false-banana, is a multipurpose crop that provides subsistence food for about 10 million people in Ethiopia (Bezuneh and Feleke, 1966; Desalegn Rahmato, 1995; Almaz Negash, 2001). Because of the possibility to harvest this perennial crop in times of famine, it has been termed as a 'tree against

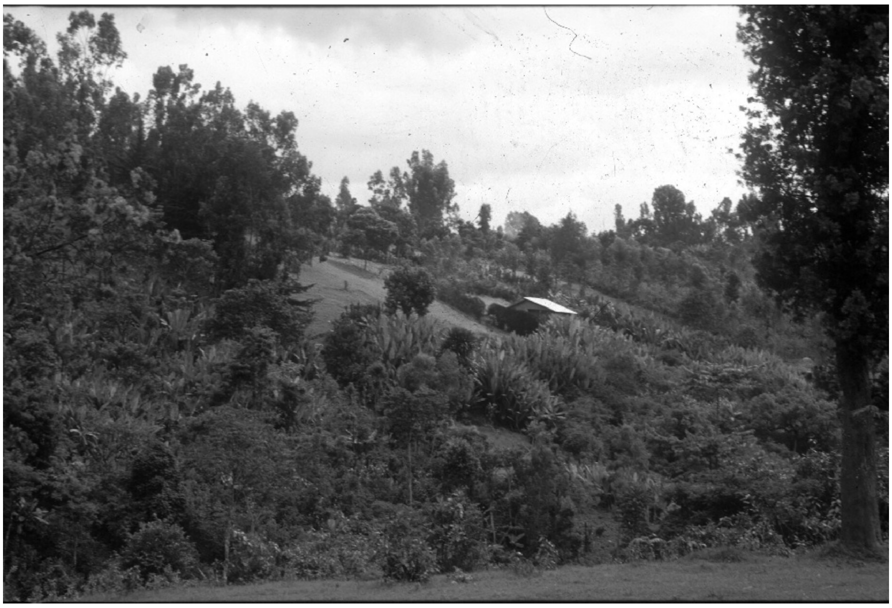

Figure 1. *Coffee (*Coffea arabica*)-enset (*Enset ventricosum*) homegarden in southern Ethiopia. This 'integral' homegarden is not leveled as usual in Asian homegardens (Photo: Tesfaye Abebe).*

hunger' (Brandt et al., 1997). Coffee (*Coffea arabica*) is also a native crop, which is not only grown for household use, but also as a cash crop. Other components of this agroforestry system include roots and tubers, fruits, vegetables, cereals, spices, and other crops such as the stimulant chat (*Chata edulis*). Moreover, livestock is kept in the gardens and different tree species are grown to serve productive as well as ecological functions. Structurally, the gardens resemble the coffee-banana agroforestry systems of Uganda (Oduol and Aluma, 1990) and northern Tanzania (Fernandes et al., 1984; Rugalema et al., 1994; Soini, 2005) with enset taking the position of banana.

The enset-coffee homegardens have for centuries supported very dense populations in the mid-altitude highlands of southern Ethiopia (Kippie Kanshie, 2002). Although some studies have been made on the system (Westphal, 1975; Okigbo, 1990; Tessema Chekun, 1997; Zemede Asfaw and Zerihun Woldu, 1997), still only limited information is available about the (variations in) diversity and composition as well as the dynamics of the system. For instance, the gardens have been mostly described as being predominantly subsistence-based, although the presence of coffee and chat is indicative of the fact – and the authors' experiences support this – that these gardens are also used for commercial production.

3. RESEARCH ON STRUCTURE AND COMPOSITION OF SOUTHERN ETHIOPIAN HOMEGARDENS

In order to assess the structure and composition of the enset-coffee homegardens as well as the main factors influencing them, a study was conducted in the Sidama

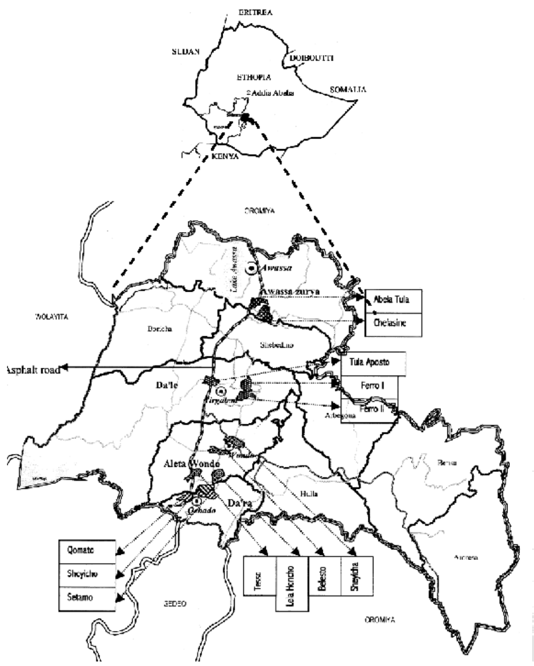

Figure 2. *Map of Sidama administrative zone (southern Ethiopia) showing the study areas with location of selected* woredas *(or districts) and names of selected Peasant Associations within each* woreda.

administrative region of southern Ethiopia during 1999 to 2002 (Tesfaye Abebe, 2005). This region is one of the most densely populated areas of the country with a population density of 320 persons km^{-2}. The most important agroecological zone in the area is locally known as *Gammoje* (Sidama) or *Woyna-Dega* (Amharic). This zone is situated between 1500 and 2300 m above sea level, and characterized by a moist to subhumid warm subtropical climate with average annual rainfall of 1000 to 1800 mm, and a mean temperature of 15 to 20^{o}C. The dominant soils are Eutric Nitosols (corresponding to Alfisols in the USDA soil taxonomy). Within this zone, detailed data on homegarden composition were collected from 144 homegardens located in 12 different Peasant Associations (PA = smallest Ethiopian administrative unit) distributed over four *Woredas* or districts (Fig. 2). The administrative units were selected purposefully in order to systematically cover the range of geographic conditions in the study area; and, within each administrative unit, the homegardens were selected randomly. For each homegarden, data were collected on the size and layout and all species (except spontaneously grown weeds) were inventoried and enumerated. Through farmer's interviews, data were also collected on physical and socioeconomic characteristics of the farms, such as altitude, distance to markets and roads (physical data collection in the field), and on household characteristics such as family size, labor force, age and educational status. The interviews also served to collect data on the production of various crops and their market prices. Tesfaye Abebe (2005) gives further details on that.

4. STRUCTURE AND COMPOSITION OF HOMEGARDENS IN SIDAMA REGION

4.1. Structure

The size of the 144 selected homegardens varied from 0.18 to 7.46 ha with a mean size of 0.90 ha. These homegarden holdings included residential areas and specialized grazing areas (with mean share of 14% of the holding size), cultivated lands (mean 82%), and sometimes some specialized woodlots (average 4%; Fig. 3). A major variable influencing plot size was the wealth status of the households with average values of 0.55, 1.46 and 2.75 ha for poor, middle income, and rich farmers (according to the local Peasant Association classification) respectively. Coffee and enset dominate in over 50% of the homegarden area, while the other crops occupy much smaller areas. Cash crops such as chat, sweet potato (*Ipomoea batatas*) and pineapple (*Ananas comosus*) often are grown in special zones.

Within the homegardens, the vegetation structure was not uniform; often zones distinguished by specific crop combinations were found. For instance, zones dominated by coffee mixed with fruit and other trees, enset, and miscellaneous auxiliary crops; zones dominated by enset mixed with vegetables and miscellaneous trees; zones with maize (*Zea mays*) mixed with other food crops; zones with cash crops such as chat; and residential and grazing zones. The diversity of homegardens can, therefore, not only be assessed based on species composition, but also of the area share of main crop components.

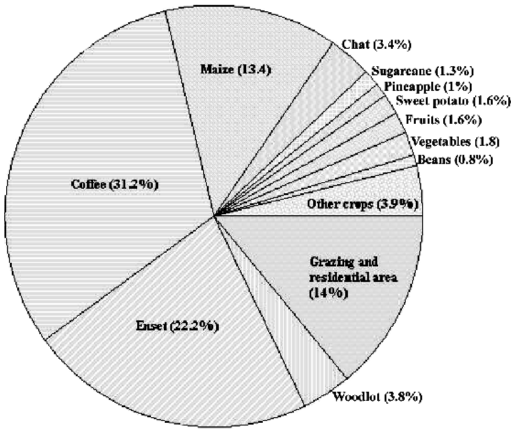

Figure 3. *Mean area share of major homegarden components in Sidama administrative zone, southern Ethiopia.*

4.2. Species composition

Overall, 198 species of cultivated crops (78) and trees (120) were recorded from the 144 homegardens in four *woredas*. Within each *woreda*, the total number of plant species present in homegardens varied from 84 to 159 (Table 1) demonstrating significant intra-regional variations. The mean number of plant species per homegarden was 37, with values ranging from 15 to 78. Appendix 1 gives an overview of the recorded crop species. In addition to species diversity, a high level of genetic diversity was found with respect to the two major crops, enset and coffee, being represented by 42 and 24 cultivars respectively. Homegardens also included seven livestock species: cattle, goats, sheep, donkeys, horses, mules, and poultry (mainly chicken).

Homegarden composition can also be characterized by the diversity of functional crop types. Besides miscellaneous tree species, 10 functional groups of plants were recognized: fruit crops (24%), root and tuber crops (16%), vegetables (15%), stimulant crops (10%), cereals (9%), pulses (6%), spices and condiments (5%), oil crops (3%), medicinal crops (3%), and miscellaneous crops (9%). Each functional crop type was represented by 3 to 15 species. Cereals and root/tuber crops provide carbohydrate-rich staple foods; fruits, vegetables, pulses, spices/condiments, and medicinal crops mostly yield supplementary food and household products; the stimulants and oil crops mostly serve as cash crops. Miscellaneous tree species provide fuel- and construction wood and serve as shade trees. This combination of different functions of crops, coupled with the presence of livestock in the homegardens, illustrates its character of forming an integrated farming system.

Table 1. *Number of crop, tree, and livestock species in the homegardens of four woredas in southern Ethiopia.*

Woreda (n)	*Crop species*	*Tree species*	*Total useful plant species*	*Livestock species*
Dara (36)	56	72	128	5
Aleta Wondo (48)	64	95	159	6
Dale (36)	57	94	151	5
Awassa Zurya (24)	33	51	84	6
Overall combined	78	120	198	7

n = number of homegardens sampled.

4.3. Homegarden types

In addition to species composition, the extent of area under major crops varied significantly among different geographic zones. Four homegarden types could be

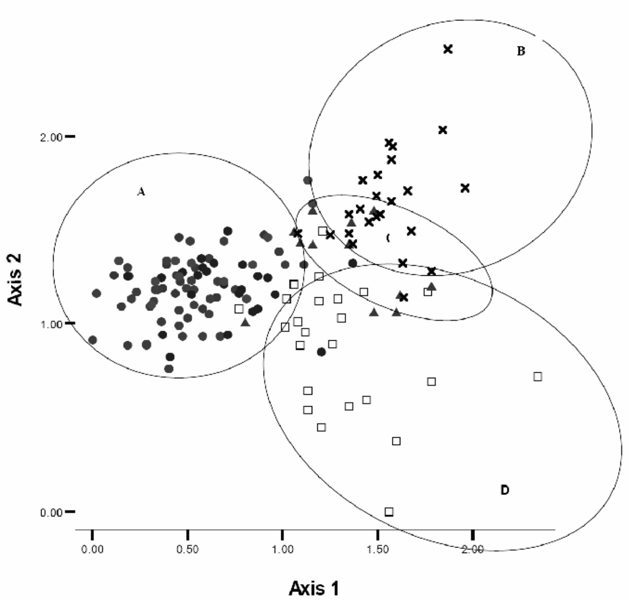

Figure 4. *Detrended correspondence analysis (DCA) scatter plots of tree composition of the farms. The four homegarden types are indicated with different symbols and indicated by a different letter, and are spatially separated. A, Type 1 Enset-coffee-maize type; B, Type 2 Enset-chat-maize-coffee type; C, Type 3 Enset-coffee-sweet potato type; D, Type 4 Enset-coffee-maize-chat-pineapple type.*

identified based on the extent of area under major crops in different PAs (Tesfaye Abebe, 2005). This comparative deductive assessment of crop data for the four types is compared with the results of a Detrended Correspondence Analysis of tree species present in the homegardens. DCA reduces the multidimensional space of a species-abundance matrix into a two-dimensional one. We used DCA as implemented in CANOCO[1]. The first axis represents the main variation in species composition, the second axis the main variation once the first axis variation is removed. The homegarden types are indicated in the DCA graph (Fig. 4). The spatial separation of the homegarden types in the graph indicates that the two methods (deductive assessment of crop data and DCA of tree species data) resulted in a similar categorization into four homegarden types having the following characteristics (see Tables 2 and 3):

1. The enset-coffee-maize type. In a large part of the research area (almost 60% of all inventoried homegardens), the homegardens belong to this original type in which coffee and enset dominate on about 75% of the farmland. In addition, maize is grown on about 10% of the land. As reflected by their high wood volume, trees form an important component in the system (Appendix I). Species diversity is relatively high with a mean of 41 cultivated crop and tree species. These homegardens are predominantly subsistence-oriented with enset and maize serving as main staple food crops and coffee serving as a cash crop. The overall financial value (based on production amounts and market values) of the combined annual yields amount to Birr 5084 ha^{-1}, which is relatively low (1 Birr ~ 0.1 US$).
2. The enset-coffee-maize-sweet potato type is present in 8% of all sampled homegardens. It is even more subsistence-oriented than the first homegarden type. The share of the staple crop enset is relatively lower than in type 1. Instead, farmers produce mainly maize and sweet potato as staple foods. The proportion of land devoted to coffee as a cash crop is much lower than in type 1. Some farmers are cultivating eucalyptus (*Eucalyptus* spp.) as an alternative cash crop. This homegarden type has the highest species richness (43) of crops and trees. The overall financial value of the annual yields was lowest with Birr 4362 ha^{-1}.
3. The enset-chat-maize-coffee type is found in 16% of all sampled homegardens. It is much more cash-oriented than the types 1 and 2. Staple food production dominates in 56% of the land with maize occupying more land than enset production. The importance of coffee as a cash crop is low, and chat has taken over this role. The diversity of plant species is relatively low, however, the number of livestock per farm is the highest (3.4) of all types. This can be attributed to the higher farm income of farmers (overall annual financial value of all crops = Birr 6802 ha^{-1}) which enables them to buy cows and feed them to produce milk for home consumption and the market.
4. The enset-coffee-maize-chat-pineapple type was represented in 8% of all sampled homegardens. This homegarden type accommodates a relatively balanced proportion of the different major crops. This garden type has the lowest area share of grazing and housing lands, and the highest proportion of croplands, where enset production dominates. The staple food crops enset,

maize, and sweet potato occupy 41% of the land area against 46% for the cash crops. In addition to coffee and chat, pineapple is an important cash crop. Species diversity of this type is relatively low, but higher than in type 3. The overall financial value of all crop annual yields is high with Birr 6809/ha.

***Table 2**. Area share of main crops in different homegarden types of four woredas in southern Ethiopia.*

Homegarden type (n)	*Area coverage of different crops[1] (%)*						
	enset	*coffee*	*maize*	*chat*	*sweet potato*	*pine-apple*	*others*
Enset-coffee-maize (84)	29.1	46.5	10.5	0.6	1.2	0.3	12.2
Enset-coffee-maize-sweet potato (12)	17.2	27.2	33.0	0.8	10.6	0	11.2
Enset-chat-maize-coffee (24)	24.8	13.7	31.6	19.8	1.4	0	8.7
Enset-coffee-maize-pineapple and chat (24)	23.5	31.1	12.2	6.5	5.3	8.5	13.1
Mean	26.4	36.6	16.4	4.5	2.6	1.6	11.9

n=number of homegardens sampled. [1]Percentage area coverage of different crops was calculated considering the crop areas only. That is, residential and grazing areas and separate woodlots were not included in the calculation. Overall area share including these are shown in Fig. 3.

***Table 3.** Composition of different homegarden types of four woredas in southern Ethiopia.*

Homegarden types (n)	*Number of crop and tree species*		*Number of livestock species*		*Number of livestock (TLU ha^{-1})*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Enset-coffee-maize (84)	41^a	12.3	2.3^a	0.9	2.1^b	1.9
Enset-coffee-maize-sweet potato (12)	43^a	12.2	2.0^a	0.4	1.9^b	1.0
Enset-chat-maize-coffee (24)	25^b	5.6	2.1^a	0.7	3.4^a	3.6
Enset-coffee-maize-chat-pineapple (24)	30^b	7.9	2.2^a	0.6	1.7^b	1.6
Mean	37	12.0	2.2	0.8	2.2	2.2
F test (*p*)	< 0.001		ns		< 0.05	

n = number of homegardens sampled; SD = standard deviation; TLU = tropical livestock unit; ns = not significant. Homegarden types with different letters differ significantly (F test and Duncan's Multiple Range test, $p < 0.05$); *p* = probability level of significance.

4.4. Factors influencing presence of different homegarden types

The different types of homegardens were not evenly distributed over *woredas* (Tesfaye Abebe, 2005): type 2 was found in only one PA of Dale *woreda*, type 3 was found in Awasa Zurya *woreda* only, type 4 was found in one PA in Dara and in one PA in Aleta Wondo. Type 1 was most extensively found, in three *woredas*. This indicates that the presence of different homegarden types cannot be explained by variation in physical conditions only; but socioeconomic conditions might account for a significant extent of such variations. For instance, the homegardens of type 1 are located far from major roads, while homegardens of type 4 have good access to roads, which facilitates the sale of homegarden products. Homegarden type 3 is located in areas with a very high population density, which necessitated an increase in staple food production (e.g., maize). The impact of several ecological and socioeconomic factors on homegarden composition was further tested by means of multiple step-wise regressions between crop and tree diversity and possible explanative factors. The factors that were included in this analysis were: altitude and slope of the farm, farm size, farm labor force, involvement in off-farm activities and distance to major roads and markets (Tesfaye Abebe, 2005). Among these, the following two factors emerged as the most important determinants of homegarden diversity (Table 4).

Farm size: Although a decrease in farm size was not significantly correlated with overall crop diversity, it negatively affected the relative proportion of a homegarden covered by cash crops, indicating how smallholders give priority to produce food crops rather than cash crops. Also, species richness of trees and livestock decreased with decreasing farm size. Small landholders grew the same number of crop species as the large holders; but with increasing land size, farmers increased the number of tree species. The density of dominant native timber and multipurpose species such as *Podocarpus falcatus*, *Cordia africana* and *Milletia ferruginea* also decreased with decreasing farm size, while that of fast-growing eucalyptus increased because of the need for wood for home consumption as well as for income generation.

Access to major roads: Although access to highways did not significantly correlate with overall crop diversity, it affected significantly the area share of the major crops. The share of annual crops, mainly maize, increased at the expense of enset. Also the importance of the new cash crops chat and pineapple increased, while the traditional cash crop coffee declined. Proximity to major roads also negatively affected the richness in tree species. The share of native and multipurpose trees declined with increased road access, but the share of eucalyptus increased. This reflects the ability of eucalypts to grow fast and produce wood for consumption as well as income generation.

These two factors are, however, not static, but depend on socioeconomic development. They can logically be related to the processes of population growth and commercialization. It can, therefore, be concluded that under the current local conditions, these two developments have a major impact on the dynamics in homegarden structure and composition. In respect to the first factor, it should be remembered that agroforestry homegardens of southern Ethiopia already carry a very dense population of 300 to 600 persons per km^2. Its high growth rate (2.2%) is likely to increase the fragmentation of farmlands. The resulting increasingly smaller farms may lead to a reduction of the perennial crop and tree components as well as livestock. Regarding commercialization, it appears that the access to road networks often results in a gradually greater emphasis on commercial crops and crop specialization in homegardens. Consequently, the share of the perennial crops and native tree species tend to decline with proximity to highways and, hence, access to markets.

***Table 4**. Multiple linear regression of species richness and number of livestock on physical and socioeconomic environments of homegardens in southern Ethiopia.*

Factors	*Species richness*			*No. of livestock (TLU)*
	Crops	*Trees*	*Live-stock*	
Physical environment				
Altitude (1520 – 2040 m above sea level)	ns	ns	ns	0.19*
Slope (0 – 45%)	ns	0.14*	ns	ns
Socioeconomic environment				
Distance to markets (0.04 – 6.0 km)	0.17*	ns	ns	ns
Distance to highway (0.02 – 26 km)	ns	0.35***	0.17*	ns
Farm size (0.18 – 7.46 ha)	ns	0.42***	0.28***	0.48***
Farm labor force (2 – 12)	0.18*	ns	ns	ns
Population density (2 – 35 inhabitants/ha of farmland)	–0.20*	–0.17*	ns	ns
Involvement in off-farm work (yes/no)	ns	0.14*	ns	ns

Parenthetical values under "factors" denote the range for each parameter. R^2 values species richness of crops, trees and livestock were 0.15, 0.53 and 0.11 respectively and that of TLU was 0.48; * = $p < 0.05$; ** = $p < 0.01$; *** = $p<0.001$; TLU = tropical livestock unit.

5. COMPARISON WITH OTHER HOMEGARDEN STUDIES

With an average of 37 plant species per garden (excluding "weeds" and ornamentals), the Sidama homegardens are less rich in species compared to other tropical homegardens, notably those located in humid lowlands and mid-altitudes (Table 5). The latter represent the 'complementary' type of homegardens that have a supplementary role to other components of the family's whole farm system. But species diversity of the Sidama homegardens is higher than that reported from other homegarden systems in the East African highlands (Table 5) which also represent the 'integral' type as described here. Thus, it seems that species diversity in the 'integral' homegarden systems is somewhat lower than that in the 'complementary' type. The less intensive multiple crop combinations in 'integral' versus 'complementary' systems can be explained by the incorporation of light demanding staple food crops and cash crops (e.g., maize and chat). However, other aspects play a role here as well. In the first place, the differences in lowland/highland location may impact species diversity with humid lowland homegardens having more biodiversity than highland homegarden systems (Wiersum, 2006). In the second place, one should take care in comparing the diversity figures, because of differences in the types of plant species considered. Some reports considered all plant species including ornamentals and sometimes weeds. For instance, Mendez et al. (2001) reported a total of 324 plant species in the homegardens of Nicaragua, out of which 180 (56%) were ornamentals. Likewise, 219 plant species occurred in one village in West Java and 60 (27%) were ornamentals. As mentioned earlier, in the present study only deliberately grown crops and trees were recorded. Due to such differences in inventory, broad comparisons of species diversity in homegardens in agroecologically and socioeconomically different regions have several drawbacks, and should be considered as providing only indicative information.

Table 5. *Species richness of selected homegardens in the tropics.*

Ecological zone	*Location*	*Total no. of plant species*	*Average no. of plants per homegarden*	*Sources*
Humid lowlands	West Java, Indonesia	219 (60 ornamentals)	56	Soemarwoto (1987); Soemarwoto and Conway (1991)
	Quintanana Roo, Mexico	150 useful plants	39	De Clerck and Castillo (2000)
	Nicaragua	324 (180 ornamentals)	70 (22–106)	Mendez et al. (2001)
	Santa Rosa , Peruvian Amazon	168	35 (18–74)	Padoch and De Jong (1991)
Humid lowlands to mid altitudes	Kandy, Sri Lanka	125 (93 usable)	46 (37–65)	Perera and Rajapakse, 1991
	Kerala, India	127 woody species	22	Kumar et al. (1994)
Highlands	Chagga, Tanzania	111 (58 woody and 53 herbs)	na	Fernandes et al. (1984)
	Bukoba, Tanzania	57	na	Rugalema et al. (1994)
	Wolayita and Gurage, southern Ethiopia	60	14.4	Zemede-Asfaw and Zerihun-Woldu (1997)
	Sidama, southern Ethiopia	198 crop and tree species	37 (15–78)	Tesfaye Abebe (2005)

na = not available.

Regarding the pattern in changing homegarden composition in the Sidama region in relation to decreasing plot size and commercialization respectively, similar trends have also been observed in 'complementary' homegarden systems (Kumar and Nair, 2004; Peyre et al., 2006; Wiersum, 2006). For the 'integral' Chagga homegardens in Tanzania, changing livelihoods due to dynamics in socioeconomic conditions as well as market prices for garden products are reported to affect the composition of the gardens (Soini, 2005). We hypothesize that these trends are stronger in the 'integral' homegarden system compared to the 'complementary' type because the former essentially incorporates cash crops, while this is not necessarily the case in the latter.

6. IMPLICATIONS OF HOMEGARDEN COMPOSITION AND DYNAMICS FOR SUSTAINABILITY

The description of the homegardens in southern Ethiopia illustrates that their structural characteristics are similar to the general features of tropical homegardens. The multispecies composition is often considered as a basic feature contributing to sustainability (Kumar and Nair, 2004). However, the presence of different types of homegardens illustrates that the homegarden composition is not always similar, but that it varies in response to socioeconomic differences and changes. Thus, when considering the sustainability of homegardens, a differentiation between ecological sustainability and socioeconomic sustainability seems warranted (Peyre et al., 2006).

6.1. Homegarden composition and ecological sustainability

Many studies have discussed the relation between species diversity in homegardens and their ecological sustainability (Soemarwoto, 1987; Torquebiau, 1992; Kumar and Nair, 2004). In the case of the Sidama homegardens, the presence of animal species is also a noteworthy phenomenon. Although such presence has been noted in several studies (e.g., Soemarwoto, 1987; Okafor and Fernandes, 1987), the animal component of homegardens is often neglected. However, our data demonstrate that livestock form an important component of the system (see also the Mesoamerican gardens described by Montagnini, 2006). In addition to their economic contribution by fulfilling various functions such as providing food in the form of milk and meat, traction and transport, they also play an important ecological role providing manure for the improvement of soil fertility and crop productivity. The animals contribute towards the maintenance of a closed nutrient cycling system with minimum dependence on external inputs such as fertilizers. The plant species diversity contributes toward the maintenance of animals. For instance, in the dry season, when fodder grass is in short supply, the animals are fed with immature thinned-out plants and leaves of enset, banana and other plants, as well as crop residues.

Thus, within the Sidama homegardens not only the diversity in crop species and related multilayered vegetation system, but also the inclusion of animals in the system contributes toward their ecological sustainability. Moreover, the gardens also demonstrate that the stability of the system should not exclusively be related to its diversity, but can also be attributed, at least in part, to the specific characteristics of the two main components: enset and coffee. As an evergreen perennial crop, enset gives a permanent shade to understorey crops, including coffee. Soil management is facilitated by the use of enset residues as a mulching material. Coffee is an ideal complementary crop to enset. Not only is it architecturally and ecologically compatible with enset, but the harvest of both enset and coffee involve only selected plant parts and do not involve major export of soil nutrients. Thus, enset and coffee can be considered as keystone species contributing to ecological sustainability of the system. In ecological studies, the role of keystone species in maintaining ecosystem stability has received some attention (Mills et al., 1993; Khanina, 1998), but the notion of keystone species has still received little attention in agroforestry research.

6.2. Homegarden composition and socioeconomic sustainability

The maintenance of high species diversity in the Sidama homegardens also contributes to socioeconomic stability. As in other homegarden systems, the diversity of crop, tree, and livestock species with different uses and production cycles enables year-round production of different products, reduces risk of production failure, allows spreading of labor-use and flexibility, and enables efficient cycling of locally available resources, thus reducing dependence on external inputs (Kumar and Nair, 2004). In addition, the Sidama homegardens also incorporate several specific features in respect to socioeconomic sustainability. They not only have high species diversity, but also a high diversity in functional crop types; notable is the presence of both staple food crops and cash crops in addition to the more usual supplementary homegarden crops. The basic food crops (enset and maize), which are rich in carbohydrates, are supplemented by pulses, vegetables, fruits, and animal products that provide proteins, fats, and vitamins, and by trees that provide resources for construction and household energy. Also cash crops are incorporated in the homegarden, not only coffee, but also chat and pineapple. The proportion of subsistence and cash crops is often adjusted to meet the household requirements. Moreover, the spreading of risk from crop failures is not only facilitated by the crop diversity, but also by the inclusion of enset. The flexibility in harvesting enset for staple food production has been indicated as one of the main reasons why the Southern Highlands are relatively free of hunger (Desalegn Rahmato, 1995; Brandt et al., 1997).

Thus, similar to the ecological sustainability, the socioeconomic sustainability cannot only be explained by species diversity, but also by the specific features of the two key species enset and coffee. Enset is both a food crop and a provider of different products such as fiber and fodder. It is therefore ideally suited to low-external input agricultural production systems, while its high productivity and multiple functions provide sustenance for a very dense population which is often two to three times higher than that in the cereal-based systems found in other parts of Ethiopia. Moreover, due to its perennial production cycle, enset can serve well as an excellent drought-relief crop. Coffee serves as a main cash crop supplementing the mainly subsistence-oriented enset production. The combined production allows for a good safety net in times of crop or market failures. Also, processing and marketing of coffee creates employment for many people. Consequently, not only from an ecological point of view, but also from a socioeconomic point of view, coffee and enset can be considered as keystone species.

6.3. Impact of system dynamics on sustainability

Even if the Sidama homegardens can be characterized as being sustainable, this does not mean that they do not change. The system is affected by decreasing farm size resulting from population growth and increased commercialization. The shift from the traditional enset-coffee systems towards inclusion of other food and cash crops has diversified the diet and increased household incomes. But the expansion of open-field food crops, such as maize and sweet potato, and of monocultural cash crops, such as chat and pineapple, are not only causing a gradual loss of species diversity and tree biomass, but also a gradual decrease in the dominance of the two key species enset and coffee. This results in a gradual reduction of the ecological benefits of these integrated and complex systems, e.g., by decreasing soil cover and thus increasing erosion hazards, as well as a reduction of the keystone enset species serving as 'a tree against hunger' in favor of quickly producing cash crops. Although the hazards of such changes in vegetation structure and composition could potentially be offset by more intensive management practices including use of external inputs, in case that no proper adaptive management activities are undertaken this may threaten the long-term sustainability of the homegardens. In view of the call for stimulating new development of forest-analogous land use systems combining production and biodiversity conservation (Wiersum, 2004), attempts should be made to integrate new crops into the existing multistory systems without affecting its biodiverse nature and without losing essential keystone species.

7. CONCLUSIONS

The enset-coffee homegarden system can be considered as an integral homegarden system as it forms a spatially delineated farming system in contrast to the more commonly studied homegarden systems that are spatially complementary to cultivated fields and have a supplementary role to the overall family farming system. Nonetheless, both types of systems have several common features. The diversity of crops that are predominantly perennial in nature, with high diversity of trees and the presence of livestock allow a multitude of ecological interactions among the homegarden components and allow ecological sustainability. Moreover, the species richness combined with presence of different functional crop groups permit a balanced year-round production of both subsistence and cash crops.

The enset-coffee homegarden systems also have some characteristics that are different from those of the more common spatially integrated (or supplementary) homegarden systems. Due to the absence of additional fields for staple food production or cash crop cultivation, the enset-coffee systems form a sort of "complete" farming system, producing a much higher proportion of basic food and cash crops than in the 'complementary' homegarden systems. The system is characterized by the presence of two crops, enset and coffee, which are keystone species, due to their important economic and ecological roles. The large number of varieties of both species reflects their great importance in the system. The combination of these two, mutually compatible, native perennial crops and their dominance in the systems are essential features of these homegardens.

In a similar manner as reported on complementary homegarden systems, the recent developments in land use systems resulted from increasing commercialization and continuing population growth affects the enset-coffee homegarden system. The growing population requiring basic foods has resulted in a gradual replacement of enset by annual staple food crops. The advent of commercialization has resulted in the development of new lucrative cash crops such as chat and pineapple requiring monoculture-cropping practices. These patterns have led to the decline in the areas of enset, coffee, and other trees. The decline in the share of these perennial components and their replacement particularly with annual crops could reduce some of the multiple benefits derived from these integrated and complex traditional systems, but the impact of such changes on long-term sustainability of the system is speculative, at best.

Within homegarden studies, little attention has been given to differences in homegarden structure and function in relation to their position either in the overall farming system or to the role of keystone species in respect to the sustainability of these systems. As demonstrated by the features of the Sidama homegarden systems, these aspects deserve further research attention.

ENDNOTE

1. Ter Braak C.J.F. and Smilauer P. 1998. CANOCO reference manual and user's guide to CANOCO for Windows: Software for canonical community ordination (version 4). Centre for Biometry, CPRO-DLO, Wageningen, 351p.

REFERENCES

Abdoellah O.S., Hadikusumah H.Y., Takeuchi K., Okubo S. and Parikesit. 2006. Commercialization of homegardens in an Indonesian village: vegetation composition and functional changes. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 233 – 250. Springer Science, Dordrecht.

Almaz Negash. 2001. Diversity and conservation of enset (*Enset ventricosum* (Welw.) Cheesman) and its relation to household food and livelihood security in southwestern Ethiopia. PhD dissertation, Wageningen University, Wageningen, 247p.

Bezuneh T. and Feleke A. 1966. The production and utilization of the genus *Ensete* in Ethiopia. Econ Bot 20: 65 – 70.

Brandt S.A., Spring A., Hiebsch C., McCabe J.T., Endale Tabogie, Mulugeta Diro, Gizachew Wolde Michael, Gebre Yntiso, Masyoshi Shigeta and Shiferaw Tesfaye. 1997. The tree against hunger. American Association for the Advancement of Science, Washington, DC, 56p.

De Clerck F.A.J. and Negreros-Castillo P. 2000. Plant species of traditional Mayan homegardens of Mexico as analogs for Multistrata agoforests. Agroforest Syst 48: 303 – 317.

Desalegn Rahmato 1995. Resilience and vulnerability: Enset agriculture in southern Ethiopia. J Ethiopian Stud 28: 23 – 51.

Fernandes E.C.M., Oktingati A. and Maghembe J. 1984. The Chagga homegardens: a multistoryed agroforestry cropping system on Mt. Kilimanjaro, Northern Tanzania. Agroforest Syst 2: 73 – 86.

Hoogerbrugge I.D. and Fresco L.O. 1993. Homegarden systems: Agricultural characteristics and challenges. International Institute for Environment and Development, Gatekeeper series no. 39, London, 23p.

Karyono 1990. Homegardens in Java: their structure and function. In: Landauer K. and Brazil M. (eds), Tropical home gardens, pp 138 – 146. United Nations University Press, Tokyo.

Khanina L. 1998. Determining keystone species. Conservation Ecology 2(2):R2 [online]: URL:http:// www.consecol.org/Journal/vol2/iss2/resp2 (last accessed: December 21, 2005).

Kippie Kanshie T. 2002. Five thousand years of sustainability? A case study on Gedeo land use. PhD dissertation, Wageningen University, Wageningen, 295p.

Kumar B.M. and Nair P.K.R. 2004. The enigma of tropical homegardens. Agroforest Syst 61: 135 – 152.

Kumar B.M, George S.J. and Chinnamani S. 1994. Diversity, structure and standing stock of wood in the homegardens of Kerala in peninsular India. Agroforest Syst 25: 243 – 262.

Mendez V.E., Kok L. and Somarriba E. 2001. Interdisciplinary analysis of homegardens in Nicaragua: micro-zonation, plant use, and socioeconomic importance. Agroforest Syst 51: 85 – 96

Michon G. and Mary F. 1994. Conversion of traditional village gardens and new economic strategies of rural households in the area of Bogor, Indonesia. Agroforest Syst 25: 31 – 58.

Mills L.S., Soule M.E. and Doak D.F. 1993. The keystone-species concept in ecology and conservation. BioScience 43: 219 – 224.

Montagnini F. 2006. Homegardens of Mesoamerica: biodiversity, food security, and nutrient management. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 61 – 84. Springer Science, Dordrecht.

Oduol P.A. and Aluma J.R.W. 1990. The banana (*Musa* spp.)-*Coffea robusta*: traditional agroforestry system of Uganda. Agroforest Syst 11: 213 – 226.

Okafor J.C. and Fernandes E.C.M. 1987. Compound farms of southeastern Nigeria: A predominant agroforestry homegarden system with crops and small livestock. Agroforest Syst 5: 153 – 168.

Okigbo B.N. 1990. Homegardens in tropical Africa. In: Landauer K. and Brazil M. (eds), Tropical home gardens, pp 21 – 40. United Nations University Press, Tokyo.

Padoch C. and Jong W. de 1991. The house gardens of Santa Rosa: Diversity and variability in an Amazonian agricultural system. Econ Bot 45: 166 –175.

Perera A.H. and Rajapakse R.M.N. 1991. A baseline study of Kandian forest gardens of Sri Lanka: structure, composition and utilization. For Ecol Manag 45: 269 – 280.

Peyre A., Guidal A., Wiersum K.F. and Bongers F. 2006. Homegarden dynamics in Kerala, India. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 87 – 103. Springer Science, Dordrecht.

Rugalema G.H., Okting'ati A. and Johnson F.H. 1994. The homegarden agroforestry systems of Bukoba district, Northwestern Tanzania. 1. Farming systems analysis. Agroforest Syst 26: 53 – 64.

Soemarwoto O. 1987. Homegardens: A traditional agroforestry system with a promising future. In: Steppler H.A. and Nair P.K.R. (eds), Agroforestry: A decade of development, pp 157 – 170. International Council for Research in Agroforestry, Nairobi.

Soemarwoto O. and Conway G.R. 1991. The Javanese homegarden. J Farming Syst Res Extn 2: 95-118.
Soini E. 2005. Changing livelihoods on the slopes of Mt. Kilimanjaro, Tanzania: challenges and opportunities in the Chagga homegarden system. Agroforest Syst 64: 157 – 167.
Stoler A. 1978. Garden use and household economy in rural Java. Bull Indonesian Econ Stud 14: 85 – 101.
Tesemma Chekun 1997. The culture of coffee in Ethiopia. Agroforest Today 9: 19 – 21.
Tesfaye Abebe 2005. Diversity in homegarden agroforestry systems of southern Ethiopia. Wageningen University, the Netherlands, Tropical Resource Management Paper No. 59, 143p.
Torquebiau E. 1992. Are tropical agroforestry homegardens sustainable? Agric Ecosyst Environ 41: 189 – 207.
Westphal E. 1975. Agricultural Systems in Ethiopia. Centre for Agricultural Publication and Documentation, Wageningen, 278p.
Wiersum K.F. 2004. Forest gardens as an 'intermediate' land use system in the nature-culture continuum: characteristics and future potential. Agroforest Syst 61: 123 – 134.
Wiersum K.F. 2006. Diversity and change in homegarden cultivation in Indonesia. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 13 – 24. Springer Science, Dordrecht.
Zemede Asfaw and Zerihun Woldu 1997. Crop associations of homegardens in Welayita and Gurage in southern Ethiopia. Sinet: Ethiopian J Sci 20: 73 – 90.

APPENDIX I

List of crop species in Sidama homegardens listed under their main functional crop group, sorted by frequency (% of homegardens in which the species is found, out of a total of 144).

Scientific name	*Family*	*English common name*	*Frequency (%)*
Roots and tubers			
Enset ventricosum (Welw.) Cheesman	Musaceae	enset, false	100
Dioscorea alata L.	Dioscoreaceae	yam	59
Colocasia esculenta (L.) Schoot	Araceae	taro	51
Ipomoea batatas (L.) Lam.	Convolvulaceae	sweet potato	42
Manihot esculenta Cranz.	Euphorbiaceae	cassava	8
Solanum tuberosum L.	Solanaceae	potato	6
Beta vulgaris L.	Chenopodiaceae	beet root	5
Daucus carota L.	Apiaceae	carrot	2
Dioscorea bulbifera L.	Dioscoreaceae	aerial yam	1
Vegetables			
Brassica integrifolia (West.) O.E.	Brassicaceae	kale	99
Cucurbita pepo L.	Cucurbitaceae	pumpkin	83
Capsicum frutescens L.	Solanaceae	hot pepper	43
Brassica oleraceae L.	Brassicaceae	Ethiopian kale	33
Lycopersicon esculenta L.	Solanaceae	tomato	16

Capsicum annuum L.	Solanaceae	chilly	12
Solanum villosum L.	Solanaceae	African	9
Allium cepa L.	Alliaceae	shallot	3
Brassica oleracea L. var. *capitata*	Brassicaceae	cabbage	3
Lactuca sativa L.	Asteraceae	head lettuce	2
Allium porrum L.	Alliaceae	leek	2
Allium sativum L.	Alliaceae	garlic	1
Pulses			
Phaseolus vulgaris L.	Fabaceae	common bean	99
Phaseolus lunatus L.	Fabaceae	lima bean	30
Vicia faba L.	Fabaceae	faba bean	3
Pisum sativum L.	Fabaceae	pea	2
Cajanus cajan (L.). Mill.	Fabaceae	pigeon pea	2
Cereals			
Zea mays L.	Poaceae	maize	100
Sorghum bicolor (L.) Moench	Poaceae	sorghum	31
Eragrostis tef (Zucc.) Trotter	Poaceae	tef	6
Hordeum vulgare L.	Poaceae	barley	2
Triticum sativum L.	Poaceae	wheat	2
Fruits			
Persea americana Mill.	Lauraceae	avocado	88
Musa paradisiaca L.	Musaceae	banana	83
Psidium guajava L.	Myrtaceae	guava	43
Citrus sinensis (L.) Osbeck	Rutaceae	sweet orange	38
Casimora edulis La Llave & Lex.	Rutaceae	white sapota	29
Ananas comosus (L.) Merr.	Bromeliaceae	pine apple	24
Prunus persica (L.) Batsch	Rosaceae	peach	15
Carica papaya L.	Caricaceae	papaya	15
Passiflora edulis Sims.	Passifloraceae	passion fruit	13
Annona reticulata L.	Annonaceae	bullock’s heart	11
Mangifera indica L.	Anacardiaceae	mango	8
Cyphomandra betacea (Cav.) Sendt.	Solanaceae	tree tomato	8
Fragaria vesca L.	Rosaceae	strawberry	5
Citrus aurantifolia (Christm.) Swingle	Rutaceae	lime	4
Punica granatum L.	Punicaceae	pomegranate	1
Stimulants			
Coffea arabica L.	Rubiaceae	coffee	100
Chata edulis (Vahl.) Forssk. ex Endl.	Celastraceae	khat	57
Nicotiana tabacum L.	Solanaceae	tobacco	8
Spices and condiments			
Capsicum frutescens L.	Solanaceae	hot pepper	43
Ruta chalepensis L.	Rutaceae	rue	17

Appendix 1 (contd.)

Capsicum annuum L.	Solanaceae	chilly	12
Afromomum korarima (Braun) Jansen	Zingiberaceae	false cardamom	6
Zingiber officinale L.	Zingiberaceae	ginger	3
Rosmarinus offwinalis L.	Lamiaceae	rosemary	3
Ocimum basilicum L.	Lamiaceae	sweet basil	3
Lippia adonensis Hochst. ex Walp.	Verbenaceae		3
Piper nigrum L.	Piperaceae	black pepper	1
Nigella sativa L.	Ranunculaceae	black cumin	1
Oil crops			
Ricinus communis L.	Euphorbiaceae	castor	43
Brassica carnata A. Br.	Brassicaceae	Ethiopian mustard	19
Arachis hypogaea L.	Fabaceae	ground nut	9
Carthamus tinctorius L.	Asteraceae	safflower	3
Linum usitatissimum L.	Linaceae	linseed	1
Medicinal plants			
Ocimum gratissimum L.	Lamiaceae		13
Foeniculum vulgare Mill.	Apiaceae	fennel	2
Otostegia integrifolia Benth.	Lamiaceae		1
Artemisia absinthium L.	Asteraceae	absinthe	1
Fragrance plants			
Ocimum gratissimum L.	Lamiaceae		13
Lippia adoensis Hochst. ex Walp	Verbenaceae		12
Cymbopogon citratus (DC.) Stapf.	Poaceae	lemon grass	1
Other crops			
Rhamnus prinoides L'herit	Rhamnaceae	rhamnus	70
Saccharum officinarum L.	Poaceae	sugarcane	54
Lagenaria siceraria (Mol.) Stardl.	Cucurbitaceae	bottle gourd	5
Agave sisalana Perr.	Agavaceae	sisal	4
Gossypium herbaceum L.	Malvaceae	cotton	2
Sorghum dochna (Forsk.) Snowden	Poaceae	sweet stalk sorghum	1
Pennisetum purpureum Schumach[1]	Poaceae	elephant grass	12
Chloris gayana Kunth[1]	Poaceae	Rhodes grass	2
Desmodium unicinatum (Jacq.) DC[1]	Leguminoseae	desmodium	1

[1]introduced forage crop.

CHAPTER 9

HOMEGARDEN PLANT DIVERSITY IN RELATION TO REMOTENESS FROM URBAN CENTERS: A CASE STUDY FROM THE PERUVIAN AMAZON REGION

A. WEZEL[1] AND J. OHL[2]

[1]Institute of Landscape and Plant Ecology (320), University of Hohenheim, 70593 Stuttgart, Germany; E-mail: <alexanderwezel@tiscali.de>. [2]School of Biological Sciences, University of East Anglia, Norwich NR4 7TJ, United Kingdom

Note: Adapted from: Wezel A. and Ohl J. 2005. Does remoteness from urban centres influence plant diversity in homegardens and swidden fields: a case study from the Matsiguenka in the Amazonian rainforest of Peru. *Agroforestry Systems* 65: 241 – 251.

Keywords: Floodplains, Indigenous people, Manu National Park, Shifting cultivation, Slash and burn, Swidden agriculture

Abstract. Swidden cultivation is the traditional agricultural system in most parts of the Amazonian rainforest, and in many situations swiddens lead to the establishment of homegardens. In a remote area of the Manu National Park, Peru, such a system was investigated in two indigenous Matsiguenka communities for diversity of cultivated plants on swidden fields and in homegardens. The cultivated plants were identified from two to four plots per field in 46 fields in a total of 126 survey plots and 19 homegardens. Altogether 71 species were found in the homegardens and 25 in the swidden fields. Cassava (*Manihot esculenta*) was dominant in the cultivated fields, whereas fruit trees such as peach palm (*Bactris gasipaes*), guava (*Psidium guajava*), and *Inga edulis*; and cotton (*Gossypium barbadense*) and a medicinal plant (*Cyperus* sp.) predominated more than 75% of the homegardens. Species diversity increased steadily with age (length of cultivation) of the swidden fields. Diversity of species cultivated in the homegardens was low compared to other studies reported from the Amazon. This seemed to be due to remoteness from urban areas, relative isolation and consequently little interaction of the farmers with outside communities, and easy availability of plant products from nearby forests. Although these findings appear to contradict the premise that subsistence farming in such remote areas encourages farmers to produce a broad variety of species and, therefore, remoteness from urban centers increases species richness on farms; the extent to which the situation is impacted by easy availability of plant products from nearby forests, however, was not investigated in this study. In contrast to the homegardens, swidden fields in this study did not show any difference in species richness compared to other reported studies.

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 143–158.

1. INTRODUCTION

The indigenous agricultural system in most parts of the Amazonian rainforest is based on swidden cultivation (also known as slash-and-burn or shifting cultivation; Dufour, 1990). Besides cropping on swidden fields and cultivation of plants in homegardens, other activities of resource use such as hunting, fishing, and forest extraction are employed by rural peoples in the Amazonian floodplains and on the *terra firme* (elevated river terraces or hills).

In a basic swidden cultivation cycle, the first step is to select a new field site in primary or secondary forest areas (Thrupp et al., 1997). The forests are then cleared and burnt, and different crops planted. Cropping is normally abandoned after 2 to 3 years because of declining yields, partly due to increasing weed pressure. Finally, secondary forests develop on the fallowed fields and might be cleared again after several years. Analyses of different swidden systems in the Peruvian and Colombian Amazon including lists of plant species cultivated on swidden fields were reported by various authors previously (e.g., Johnson, 1983; Hiraoka, 1986; 1989; Eden and Andrade, 1987; Salick, 1989; Dufour, 1990; Coomes and Burt, 1997). In most such systems, cassava (*Manihot esculenta*) is the main crop during the first three years. In some cases, this is followed by another 2 to 3 years of plantain and banana (*Musa* spp.) production. Finally, the fields are fallowed (often called swidden fallows) when forest regrowth takes place, although fruit trees and other tree species still occupy the sites (e.g., Hiraoka, 1986; 1989).

In systems with permanent or semi-permanent settlements, different plants are cultivated around the dwelling units. These homegardens are generally characterized by different vegetation strata (trees, shrubs and herbs) composed of annual and perennial agricultural crops and small livestock within the house compounds (Fernandez and Nair, 1986). Normally, the whole tree-crop-animal unit is intensively managed by family labor. Homegarden systems around the world have been comprehensively analyzed and summarized by Kumar and Nair (2004). In Peru, homegardens in the villages on the Amazonian floodplains have been investigated by Padoch and de Jong (1991) and Lamont et al. (1999), and those in the upland locations (upper Amazon) by Salick (1989). Works[1] described the homegardens of a small but steadily growing town in the Alto Mayo region of upper Amazon.

Ohl (2004) analyzed the traditional economic system as well as the influences of new economic activities of two indigenous communities in a remote area in the Peruvian Amazon. Among other things, that study focused on the extent of changes currently taking place and its implications for sustainable resource use in the Manu National Park. The research of the broader project included an investigation on different aspects such as the socioeconomic situation of the households, land use practices, hunting and fishing activities as well as health care issues. This chapter focuses on the plant aspects of this broad study: plants cultivated on fields and in homegardens for meeting the basic food needs of the indigenous population, and the diversity as well as similarities among such plants in the two communities. The results were used to examine if remoteness from the urban centers increases plant diversity in homegardens and swidden fields, as often reported in the literature.

2. STUDY AREA

The study area is located in the lowland part of the Manu National Park in south-eastern Peru (Fig. 1). The National Park comprises an area of about 1.72 million ha. The area studied within the National Park receives 2000 – 2500 mm annual precipitation[2]. The average annual temperature is around 23°C. Two seasons are distinguished: a dry period from May to September and a rainy period from October to April. The vegetation is characterized by different types of tropical lowland rainforests on both periodically inundated alluvial plains (*varzea*) and on more elevated river terraces or hills (*terra firme*). Predominant soil types are Fluvisols and Gleysols (according to FAO classification) on the alluvial plains and Cambisols, Luvisols, and Acrisols on river terraces and on the hilly terrain[3].

This region is also the most sparsely populated area[4] of Peru with 0.1 persons/km². Two Matsiguenka communities in the Fitzcarrald district of the Manu province were selected for the study following several visits to them during 2000 – 2002; the community Tayakome (123 people) is located at 11°43.8' S/71°38.8' W (368 m altitude) and Yomibato (183 people) at 11°48' S/71°54.4' W (419 m altitude). Both are remote locations that can be reached only by boat on the river Manu, taking 1 to 4 days from Boca Manu, the nearest important settlement. Besides Tayakome and Yomibato, a third, smaller settlement of colonists from the Andes exists in the Manu National Park.

2.1. Matsiguenka villages

The two selected villages are relatively new communities founded in 1968 (Tayakome) and 1978 (Yomibato). A few decades ago, the Matsiguenka were mainly semi-nomadic hunter-gatherers, who used various sites along their treks to cultivate food crops (Johnson, 1989). After establishing permanent settlements, most people started to practice slash-and-burn, hunting, and fishing around their villages. Nevertheless, there are still some people, mainly in Yomibato, who wander around, moving between two or three distant huts spending a week or two in each, for successful hunting. In general, every household consists an average of 5.9 persons in Tayakome and 6.1 in Yomibato (range: 4 to 26 members per household in both villages: a household is defined as a group of people eating regularly together in one house), who actively cultivate 2.0 fields (a 'field' in this context is an area of land cleared in the primary or secondary forest for cropping) in Tayakome (0.73 ha) and 1.8 fields in Yomibato (0.92 ha). The cropping period for a single field varies normally between 2 to 3 years during which cassava is mainly cultivated. In the third and fourth years, the swiddeners mostly harvest species such as plantains /bananas or papaya (*Carica papaya*), which were planted in the first year. After that, they return every now and then to the swidden fallows to collect mainly fruits from previously planted trees.

The Matsiguenka often cultivate different crops in homegardens around their houses. Some chickens and ducks are also kept. Eggs are sometimes used, but their meat is only consumed in case of food shortage. Hunting trips are made only by

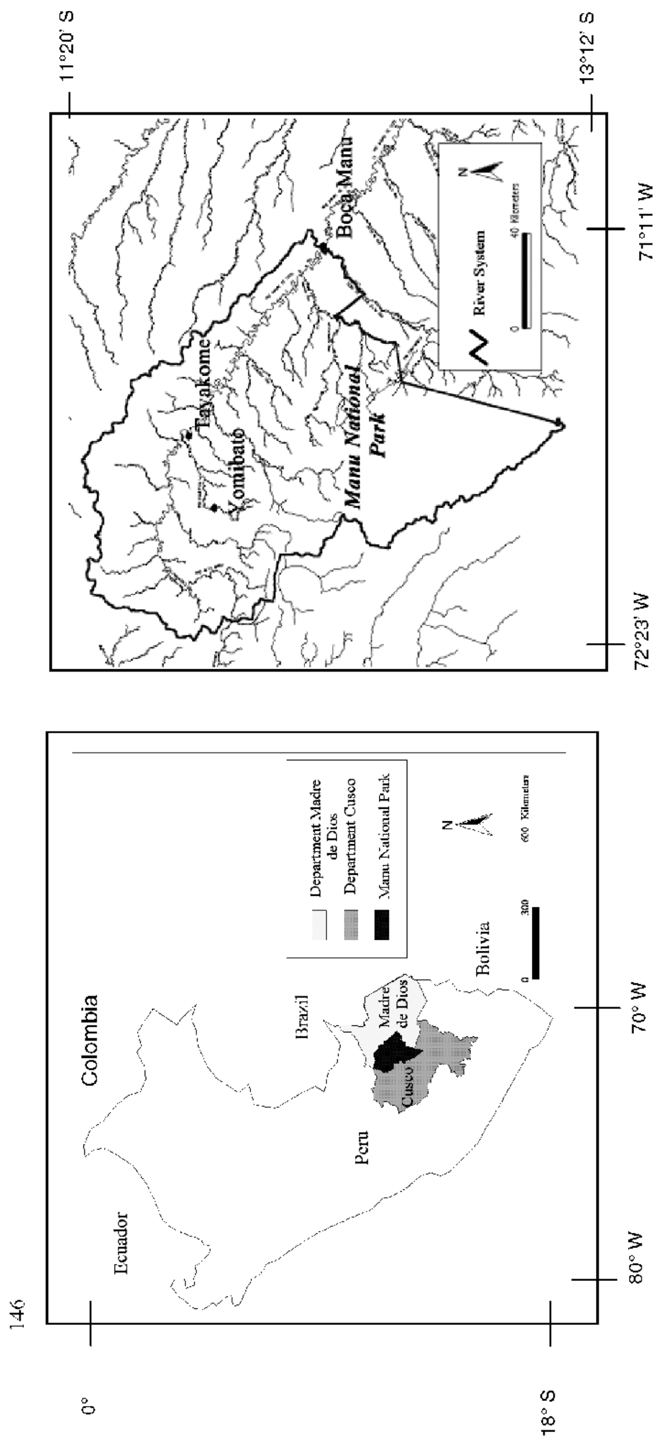

Figure 1. *Location of the Manu National Park in Peru and the two villages studied.*

men, mainly during the rainy season. Fishing is the main activity in the dry season when rivers are low. In addition, joint fishing is done in small rivers using fish poison.

3. METHODS

Cultivated plants were counted from 2 to 4 plots per field in a total of 46 fields in both communities; each plot was 5 x 10 m in size. There were a total of 126 survey plots in 1 to 2 year-old fields, implying that if the distribution of cultivated plants in the field appeared to be homogeneous, two plots were randomly selected and four if the distribution was non-homogeneous. Cultivated plants were counted in 19 homegardens as well, and were organized into functional groups according to their preferred uses. Ornamental plants and timber species were not included in this study.

Normally the homegardens are located within a zone of 5 to 25 m around the houses. The boundaries of most homegardens were quite evident because of the regular weeding that takes place within this zone. In few cases, however, it was difficult to distinguish between homegardens and the adjacent fields. Three age classes were recognized for the homegardens: young = up to 2 years since establishment; medium-old = 3 to 10 years; and old = more than 10 years.

Plants which could not be directly identified were collected in a field herbarium. Local names provided by the owners were referenced to corresponding scientific names following Brack Egg (1999), and in few cases with the help of Shepard and Chicchón (2001) and Baer (1984). The collected plant samples were then verified with the help of botanists from the Universities of Cusco and Lima. Scientific plant names follow Brack Egg (1999).

The similarity of species composition of fields and homegardens between the two communities was calculated using the Sørensen coefficient of similarity (Müller-Dombois and Ellenberg, 1974), according to the formula (2A/B+C) x 100 (where A = number of species common to two villages; B = total number of species in village 1 and C = total number of species in village 2). For the comparison of species composition between fields and homegardens within each community also the same formula was used (where A = number of species common in fields and homegardens; B = total number of species in fields and C = total number of species in homegardens).

4. RESULTS

4.1. Swidden fields

The dominant crop cultivated by the Matsiguenka on all fields is cassava (for details see Wezel and Ohl, 2005). It is consumed daily and used frequently to brew cassava beer. In Tayakome, 19 different cassava varieties were cultivated, and as many as 56 in Yomibato. Other important plants included plantains/bananas and maize (*Zea mays*). Plants such as sugarcane (*Saccharum officinarum*), sweet potato (*Ipomoea batatas*), *Lonchocarpus* sp. (used as fish poison), papaya and cush-cush yam (*Dioscorea trifida*) were also cultivated, but less frequently; pineapple (*Ananas comosus*) and guava (*Psidium guajava*) were grown only occasionally.

.

Furthermore, some species such as plantains/bananas, sugarcane, *Lonchocarpus* sp. and cotton (*Gossypium barbadense*) were found much more frequently in the second year of cultivation than the first. By contrast, maize is only planted during the first year. Maize, sugarcane, sweet potato, and papaya are cultivated generally more often in Tayakome than in Yomibato. In total, 25 species of crops were found in the study villages, with 21 in each village; besides, 18 and 24 species were found in one- and two-year-old swidden fields respectively. Species composition of the fields was comparable between the study villages with 81% similarity (Sørensen's coefficient).

4.2. Homegardens

In Matsiguenka homegardens, fruit trees such as peach palm (*Bactris gasipaes*), guava, and *Inga edulis*; cotton and a medicinal plant (*Cyperus* sp.) predominated more than 75% of the observations (Table 1). Other fruit-producing trees and shrubs such as cashew (*Anacardium occidentale*), *Pouteria caimito*, mango (*Mangifera indica*), papaya, plantains/bananas, lemon (*Citrus limon*) and orange (*C. sinensis*) were also frequent with an occurrence of over 50%. Tubers such as cassava and *Xanthosoma poeppigii*, as well as pineapple and sugarcane were also noted on 50% of the gardens. One homegarden had many medicinal plants (but only some could be identified). Guava, *Inga edulis*, and *Pouteria caimito* were the most frequent tree species in the homegardens.

Papaya, cassava, and pineapple were most frequent in young homegardens and their frequency decreased with age (Table 1). By contrast, *Inga edulis*, *Pouteria caimito*, orange, *Genipa americana*, mandarin (*Citrus reticulata*) and *Crescentia cujete* were found more often in the older homegardens. Out of 71 species found in all homegardens studied, 25 species, not considering medicinal plants, were cultivated in young homegardens, 27 in medium-aged and 50 species in old homegardens. For medicinal plants, the numbers were 26, 29 and 66 species, respectively. Eighteen species were found only in old homegardens. The almost exclusive occurrence of medicinal plants in the category of 'old homegardens' might be related to the fact that they were mainly found in one homegarden whose owner had a broad knowledge of the medicinal uses of such plants. The average number of species per garden increased with age: 14 in young, 16 in medium, and 20 in old homegardens.

On an average, 18 species of plants were found in the homegardens of the two villages (range: 7 to 31). In both communities, the homegardeners mostly cultivated the same species, although a few disparate species with low occurrences (e.g., coconut palms, *Cocos nucifera*, with less than 15% occurrence) were noted. This is also reflected in the Sørensen coefficients of similarity, which showed that 75% of the species were similar in both villages when medicinal plants were excluded, and 65% when they were included.

Similarity of species between swidden fields and homegardens was 46% for both Yomibato (46% without medicinal plants) and Tayakome (54% without medicinal plants). Plants cultivated widely in swidden fields and homegardens were cassava, plantain/banana and, to a lesser extent, sugarcane.

Table 1. *Cultivated plants in homegardens of the Matsiguenka in the Amazonian rainforest of Peru.*

Functional groups/species	*Occurrence (%) in different age classes of homegardens*[1]			*Matsiguenka name*	*Local name*	*English name*	*Family*
	Young (n = 3)	*Medium (n = 4)*	*Old (n = 12)*				
Fruit trees[2]							
Bactris gasipaes	67	100	92	kuri	pijuayo, chonta	peach palm	Arecaceae
Psidium guajava	100	75	92	komashki	guava	guava	Mirtaceae
Inga edulis	67	75	92	intsipa	guallaba, pakay		Mimosaceae
Anacardium occidentale	67	75	67	kasho	marañon	cashew	Anacaridaceae
Carica papaya	100	50	58	tinti	papaya	papaya	Caricaceae
Pouteria caimito	0	25	83	segorikashi	caimito		Sapotaceae
Mangifera indica	0	75	67	manko	mango	mango	Anacaridaceae
Musa paradisiaca[3]	33	75	50	parianti	platano	plantain/banana	Musaceae
Citrus limon	33	75	58	irimoki	limon	lemon	Rutaceae
Citrus sinensis	0	50	67	naranka	naranja	orange	Rutaceae

Table 1 (cont.)

Functional groups/species	*Occurrence (%) in different age classes of homegardens*[1]			*Matsiguenka name*	*Local name*	*English name*	*Family*
	Young (n = 3)	*Medium (n = 4)*	*Old (n = 12)*				
Persea americana	33	0	58	tsivi, inchatoki	palta	avocado	Lauraceae
Genipa americana	0	25	58	ana	huito		Rubiaceae
Citrus reticulate	0	25	58	tasharina	mandarina	mandarin	Rutaceae
Annona chirimola	67	0	50	tsirimoito	chirimoya	cherimoya	Anonaceae
Mauritia flexuosa	33	50	25	koshiki, achoariki	aguaje		Arecaceae
Crescentia cujete	0	25	50	pajo, pamoko	calabaza	tree gourd	Bignoniaceae
Citrus limetta	0	0	50	lima[4]	lima	sweet lime	Rutaceae
Artocarpus altilis	0	50	25	pan de arbol[4]	pan de arbol	breadfruit	Moraceae
Attalea phalerata	0	25	25	tsigaro	chapaja		Arecaceae
Inga sp.	0	0	25	intsipa orompiano	pacay "colombiano"		Mimosaceae
Citrus grandis	0	0	17	toronja[4]	pomela, toronja	pummelo	Rutaceae
Cocos nucifera	0	0	17	koko	coco	coconut palm	Palmae
Oenocarpus bataua	0	0	17	sega(ki)	ungurahui		Arecaceae
Solanum sessiliflorum	0	0	17	kokona	cokona		Solanaceae
Bactris sp.	0	0	8	manataroki	chontilla		Arecaceae

Tubers							
Manihot esculenta	100	75	42	sekatsi	yuca	cassava	Euphorbiaceae
Xanthosoma poeppigii	33	25	67	tsanaro	uncucha	cocoyam	Araceae
Calathea allouia	33	0	25	shonaki	dale-dale	Guinea arrowroot	Marantaceae
Dioscorea trifida	33	0	17	magona	sacha papa	cush-cush yam	Dioscoreaceae
Pachyrhizus ahipa	0	0	8	poi	ashipa	yam bean	Fabaceae
Ischnosiphon killipii	0	0	8	shirina	sachaoca		Marantaceae
Ipomea batatas[5]	0	0	8	koriti	camote	sweet potato	Convolvulaceae
Vegetables and pulses							
Capsicum pubescens	33	0	17	tsitikana	aji		Solanaceae
Lycopersicon cf. *peruvianum*	33	0	0	tomate[4]	tomate	tomato	Solanaceae
Cyclanthera pedata	33	0	0	iritsima poreatsiri	caihua	wild cucumber	Cucurbitaceae
Cucurbita moschata	0	50	0	kemi	zapallo	seminole pumpkin	Cucurbitaceae
Solanum mommosum	0	25	8	ivoniaro	nuña huaca		Solanaceae
Cajanus cajan	0	0	8	ivinkoki	poroto de palo	pigeonpea	Fabaceae
Capsicum annuum	0	0	8	masekagana	aji	chili	Solanaceae
Lablab niger	0	0	8	tsitstita	poroto	hyacinth bean	Fabaceae

Table 1 (cont.)

Functional groups/species	*Occurrence (%) in different age classes of homegardens*[1]			*Matsiguenka name*	*Local name*	*English name*	*Family*
	Young (n = 3)	*Medium (n = 4)*	*Old (n = 12)*				
Others							
Gossypium barbadense	100	75	75	ampei	algodon	cotton	Malvaceae
Ananas comosus	100	75	50	tsirianti	piña	pineapple	Bromeliaceae
Saccharum officinarum	67	75	42	impongo	caña azugar	sugarcane	Poaceae
Bixa orellana	33	100	33	potsoti	achiote	annato	Bixaceae
Banisteriopsis sp.	33	75	25	kamarampi	ayahuasca		Malpighiaceae
Lonchocarpus sp.	33	25	25	kogi, shimaaro, komo	barbasco		Fabaceae
Brugmansia sp.	33	0	25	saaro, jayapa, kepigari	toé		Solanaceae
Gynerium sagittatum	0	25	8	chakopi	caña de flecha	arrow cane	Poaceae
Nicotiana tabacum	33	0	0	seri	tabaco	tobacco	Solanaceae
Cedrela odorata	0	0	8	santaviri, santari	cedro		Meliaceae
Curcuma longa	0	0	8	porikano	palillo	curcuma	Zingiberaceae

Hymenaea courbaril	0	0	8	koveni	azucar huayo	Caesalpinaceae
Miconia sp.	0	0	8	savotaroki		Melastomataceae
Crescentia sp.	0	25	0	oeshinta, pamoko		Bignoniaceae
Medicinal plants[6]						
Cyperus sp.	100	100	67	ivenkiki	piri piri	Cyperaceae
Jatropha gossypiifolia	0	0	25	piñon	piñon negro	Euphorbiaceae
Eryngium foetidum	0	0	8	sacha culantro	sacha culantro	Apiaceae
Plukenetia volubilis	0	0	8	mani	sachamani	Euphorbiaceae
Justicia pectoralis	0	0	8	viriorioshi		Acanthaceae
Cordia nodosa	0	0	8	matiagiroki		Boraginaceae
Martinella obovata	0	0	8	pocharo		Bignoniaceae
Eleutherine bulbosa	0	0	8	kapirokotapini	yahuar piri-piri	Iridaceae

[1] Young: 0 to 2 years, Medium: 3 to 10 years, Old: >10 years; [2] Inclusive of *Musa paradisiaca* and *Carica papaya*; [3] No distinction was between plantains and bananas. Anyhow, plantains were reported to be mainly cultivated; [4] The Matsiguenka use the common name as they have no own name for this species; [5] In few cases it might be a second *Ipomoea* species; [6] Additionally, nine different plants said to possess medicinal value were noted in the homegardens; but they could not be identified other than by their local names and are, therefore, not reported.

5. DISCUSSION

5.1. Remoteness of homegardens and richness of cultivated species

One question that is discussed in homegarden studies is the relation between species richness and distance to urban markets (Fernandez and Nair, 1986; Padoch and de Jong, 1991; Lamont et al., 1999). Often it is mentioned that urban-market pressure results in decreased total species diversity in the homegardens, whereas subsistence farmers in remote areas are compelled to produce diverse products and, therefore, species diversity increases in remote areas (but see: Lamont et al., 1999).

In the present study, differences in total species numbers between homegardens of the two study villages were small, ranging from 49 in Yomibato to 58 in Tayakome. These numbers, however, were lower than the species richness reported by Lamont et al. (1999) from north-east Peru, where they documented 104, 111, and 125 different species in three villages located 3 to 10 hours away by boat ride from the nearest urban center. Padoch and de Jong (1991), however, recorded as many as 168 species in the homegardens of another de-tribalised and market-influenced village in north-east Peru. It needs to be noted that Lamont et al. (1999) included species for construction in their analysis, whereas Padoch and de Jong (1991) included species for construction as well as ornamental plants; *albeit* their numbers were relatively low. The remoteness of the villages and ethnical differences seem to be important in determining total species richness. For example, in the village with the highest species number, residents included former members and descendants of at least four tribal groups as well as a few families who trace their ancestry to Europe (Padoch and de Jong, 1991). Peoples of mixed European and Amazonian ancestry live in the village with 125 homegarden species (Lamont et al., 1999). The other two villages are considered native communities although peoples of mixed ancestry have migrated to one of these villages over the years. Similar results are mentioned by Works[1] with more than 120 different species in the homegardens of Moyobamba. This town is a steadily growing urban center in the upper Amazon area where many newcomers settled in recent decades. In contrast, the Mastiguenka communities are native, without mixture of different tribes and located most remotely from the urban centers. The Matsiguenka homegardens can thus be characterized as relatively "pristine" with fewer cultivated plants. This seems to be similar to the situation of the Andoke and Witoto Indians in the Colombian Amazon, who cultivate only 33 species in their homegardens (Eden and Andrade, 1987). The contact of the Andoke and Witoto Indians with the outside world is relatively limited and local production is largely subsistence-oriented. Although the Matsiguenka exchange cultivated plants with other Matsiguenka communities, they are presently not able to sell any plant products from homegardens in the urban market because of remoteness and transportation problems. This could be a disincentive for planting many commercial species. Although Matsiguenka communities rely on subsistence production, they do not cultivate a broad variety of different species. Furthermore, these communities are of relatively recent origin, having been founded only in 1968 (Tayakome) and 1978 (Yomibato). The Matsiguenka still collect many products from the forest including medicinal plants. This seems to be the reason why only few medicinal plants were found in most homegardens. About 55% of the medicinal plants that were noted in this study were found in one single homegarden whose owner is a traditional healer and he planted medicinal plants from the forest as well as from other places in his homegarden.

In the present study, 25 species were found in the one-and two-year-old swidden fields, 21 in each village. Johnson (1983) reported 26 species in his random samples. For young swiddens in the Colombian Amazon, Eden and Andrade (1987) recorded a total of 38 cultivated species, with an average of 12 per field, and Dufour (1990) reported nine different crops per field – but that could be because only four plots were studied. Contrary to the situation in the homegardens, however, differences in species numbers in the swidden fields were relatively small and factors such as remoteness did not seem to have an influence. This might be due to the fact that in swidden fields the most common crops and fruit trees are cultivated, whereas in homegardens, factors such as remoteness and cultural difference play a much more important role in species selection.

5.2. Frequently cultivated species in the homegardens and swidden fields

Many plants found in the Matsiguenka homegardens with high frequency are also typical plants of homegardens throughout the tropics in the world, e.g., plantains/ bananas, guava, mango, avocado (*Persea americana*), papaya, *Citrus* spp., breadfruit (*Artocarpus altilis*), cassava, and sugarcane (Jensen, 1993; De Clerck and Negreros-Castillo, 2000; Méndez et al., 2001; Wezel and Bender, 2003). By contrast, coconut palms, which are planted very frequently in the homegardens worldwide, are rarely found in Matsiguenka homegardens, except for a few young trees in Tayakome. Instead, the peach palm is cultivated in 89% of the gardens analyzed. This species is a domesticated natural hybrid of different native Amazonian palms (Brack Egg, 1999). Another frequently planted tree is *Inga edulis*, also a domesticated species in the tropical America. Both species have been reported from the homegardens of Latin America (Peru: Padoch and de Jong, 1991; Lamont et al., 1999; Colombia: Eden and Andrade, 1987; Brazil: Smith, 1996; Costa Rica: Zaldivar et al., 2002), although homegardens elsewhere seldom contain these species (Brazil, 1990). Other native plants which are most frequently cultivated in Mastiguenka homegardens and cultivated worldwide at present include cashew and guava, the latter having its origin in Peru itself (Brack Egg, 1999).

Plant species found in the swidden fields of Matsiguenka are also reported from other areas of the Peruvian Amazon. For example, Johnson (1983) reported that cassava, maize, cocoyam (*Xanthosoma* sp.), pineapple, cotton, sugarcane, papaya and yam (*Dioscorea* sp.) are frequently planted crops of young Matsiguenka fields. In general, the most frequently planted crop that dominates the swiddens is cassava (Eden and Andrade, 1987; Dufour, 1990).

5.3. Changes in species richness

The longer an area of land is used by the Matsiguenka, the more different will be the plant species cultivated. For instance, species diversity increased steadily from 18 and 24 species on one-and two-year-old fields to 26, 29, and 66 species in young, medium-old, and old homegardens, respectively. Some species such as maize, *Calathea allouia*, *Dioclea virgata*, *Citrullus lanatus*, and tobacco (*Nicotiana tabacum*) are only cultivated in swidden fields, and not in the homegardens. In contrast, many tree species, e.g., *Citrus* spp., *Pouteria caimito*, mango and avocado, are solely observed in the homegardens. The tree species present in fields are *Lonchocarpus* sp., peach palm, guava, *Inga edulis*, and cashew. These species except *Lonchocarpus* sp. are the most common ones in homegardens too and they all are native to Amazonia.

Typical plants reported by the Matsiguenka to be harvested on the old abandoned fields are peach palm, avocado, *Lonchocarpus* sp., sugarcane and plantains/bananas. On such abandoned sites in other parts of Amazon, often described as the *agroforest* stage, preference for harvested species is, however, different, except for peach palm and plantains/bananas. Hiraoka (1986; 1989) described that peach palms and plantains/bananas as well as *Inga edulis*, star apple (*Chrysophyllum caimito*), Brazil nut (*Bertholletia excelsa*), and *Poraqueiba sericea* are still used in the floodplains of Peruvian Amazon. In the Colombian Amazon, *Inga edulis*, *Theobroma bicolor*, breadfruit, *Poraqueiba sericea*, *Pourouma cercropiifolia*, and the West Indian locust (*Hymenaea courbaril*) are cultivated (Dufour, 1990).

5.4. The swidden cultivation system in Manu

Before the Matsiguenka settled in communities, they used to move their fields and huts around in the rainforest area of the Manu. The swidden process typically involved clearing a patch of rainforest for cultivation (2 to 4 years), building the huts in the center of the field, and cultivation of mainly cassava in the first two years. They also used to plant some trees in a very simple form of homegardens around the huts. Once the field is abandoned, they move to a new field, and build a new hut. However, every now and then, they return to the old fields to harvest plantains /bananas or papaya. Some of the homegardens investigated in this study also originated in this manner. Presently, however, most homegardens are created anew – around scattered huts of the villages. Although this swidden cultivation system is very similar to the traditional one, the difference is that the Matsiguenka now cultivate fields within a certain range of the village – without having to move through the forests. They also re-establish new fields on fallows within a short period of time. As calculated for Yomibato, 29% of the field areas cultivated in 2000 or 2001 are located within formerly cultivated fallow areas (Ohl, 2004). About 28% of these fields were established on 2 to 10 year fallows, 38% on 10 to 14 year fallows and 34% on 14 to 21 year fallows. However, most fields (71% field area) were created by clearing primary forests or very old fallows of at least 26 years. On satellite images these differences could not be clearly seen; but it seems that mainly primary forests have been cleared for establishing the new fields.

6. CONCLUSIONS

The diversity of species cultivated by the Matsiguenka communities in homegardens is relatively low as compared to results of other studies reported from the rainforests of Amazon. Relative isolation from other communities and remoteness from urban areas seem to be the most important reasons for this low diversity. These findings are somewhat contrary to the often perceived notion that remoteness from urban centers increases species richness because subsistence production is based on a broad variety of species. Furthermore, these communities are still able to extract several plant products from the surrounding forests, and the impact of this factor on the observed low species diversity in homegardens was not investigated in this study.

ACKNOWLEDGMENTS

We thank E. Mannigel, H. Ohl and G. Shepard very much for their corrections and comments on the manuscript. The fieldwork of this study was financed by the Tropical Ecology Support Program of the GTZ, Germany.

ENDNOTES

1. Works M.A. 1990. Dooryard gardens in Moyobamba, Peru. Focus (Summer 1990): 12 – 17.
2. CTAR (Consejo Transitorio de Administracíon Regional, Madre de Dios), Parque Nacional del Manu and IMA (Instituto de Manejo de Agua y Medio Ambiente) 1998. Propuesta de ordenamientio territorial de la provincia del Manu - Resumen ejectivo oficina de proramcíon y planeamiente ambiental – Unidad de estudios. Cusco, Peru, 231p.
3. CTAR (Consejo Transitorio de Administracíon Regional, Madre de Dios) and IIAP (Instituto de Investigacíon de la Amazonia Peruana) 2000. Zonificacíon Ecologica Economica de la Region Madre de Dios, Medio Fisico II, Puerto Maldorado, Peru, 156p.
4. Instituto Nacional de Estadistica e Informatica 2003. Censos – informacíon distrital. www.inei.gob.pe. (last accessed: December 2005).

REFERENCES

Baer G. 1984. Die Religion der Matsiguenka - Ost-Peru. Wepf & Co. AG Verlag, Basel, 516p.

Brack Egg A. 1999. Diccionario enciclopédico de plantas útiles del Perú. CBC, Cuzco, 550p.

Brazil M.A. 1990. A list of herbaceous and woody plants grown in home gardens world-wide. In: Landauer K. and Brazil M. (eds), Tropical home gardens, pp 214 – 230. United Nations University Press, Tokyo.

Coomes O.T. and Burt G.J. 1997. Indigenous market-oriented agroforestry: dissecting local diversity in western Amazonia. Agroforest Syst 37: 27 – 44.

De Clerck F.A.J. and Negreros-Castillo P. 2000. Plant species of traditional Mayan homegardens of Mexico as analogs for multistrata agroforests. Agroforest Syst 48: 303 – 317.

Dufour D.L.1990. Use of tropical rainforest by native Amazonians. BioScience 40: 652 – 659.

Eden M.J. and Andrade A. 1987. Ecological aspects of swidden cultivation among the Andoke and Witoto Indians of the Colombian Amazon. Hum Ecol 15: 339 – 359.

Fernandes E.C.M. and Nair P.K.R. 1986. An evaluation of the structure and functions of tropical homegardens. Agric Syst 21: 279 – 310.

Hiraoka M. 1986. Zonation of *Mestizo* riverine farming systems in northeast Peru. Natl Geogr Res 2: 354 – 371.

Hiraoka M. 1989. Agricultural systems of the floodplains of the Peruvian Amazon. In: Browder J.G. (ed.), Fragile lands of Latin America: Strategies for sustainable development, pp 75 – 101. Westview Press, Boulder, CO.

Jensen M. 1993. Soil conditions, vegetation structure and biomass of a Javanese homegarden. Agroforest Syst 24: 171 – 186.

Johnson A. 1983. Machiguenka gardens. In: Hames R.B. and Vickers W.T. (eds), Adaptive responses of native Amazonians, pp 29 – 63. Academic Press, New York.

Johnson A. 1989. How the Machiguenga manage resources: Conservation or exploitation of nature. In: Posey D.A. and Balee W. (eds), Resource management in Amazonia: Indigenous and folk strategies, pp 213 – 223. New York Botanical Society, New York.

Kumar B.M. and Nair P.K.R. 2004. The enigma of tropical homegardens. Agroforest Syst 61: 135 – 152.

Lamont S.R., Eshbaugh W.H. and Greenberg A.M. 1999. Species composition, diversity, and use of homegardens among three Amazonian villages. Econ Bot 53: 312 – 326.

Méndez V.E., Lok R. and Somarriba E. 2001. Interdisciplinary analysis of homegardens in Nicaragua: micro-zonation, plant use and socio-economic importance. Agroforest Syst 51: 85 – 96.

Müller-Dombois D. and Ellenberg H. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, New York, 547p.

Ohl J. 2004. Die Ökonomie der Matsiguenka im Nationalpark Manu, Peru – Tourismus als Chance für eine nachhaltige Entwicklung? PhD thesis. University of Greifswald, Germany (on CD-ROM).

Padoch C. and de Jong W. 1991. The house gardens of Santa Rosa: diversity and variability in an Amazonian agricultural system. Econ Bot 45: 166 – 175.

Salick J. 1989. Ecological basis of Amuesha agriculture, Peruvian upper Amazon. Adv Econ Bot 7: 189 – 212.

Shepard G.H.J. and Chicchón A. 2001. Resource use and ecology of the Matsiguenka of the eastern slopes of the Cordillera de Vilcabamba, Peru. In: Alonso L.E., Alonso A., Schulenberg T.S., and Dallmeier F. (eds), Rapid assessment program, pp 163 – 174. Smithsonian Institution/Monitoring and Assessment of Biodiversity Program, Washington D.C.

Smith N.J.H. 1996. Home gardens as a springboard for agroforestry development in Amazonia. Int Tree Crops J 9: 11 – 30.

Thrupp L.A., Hecht S. and Browder J. 1997. The diversity and dynamics of shifting cultivation: myths, realities, and policy implications. World Resources Institute, Washington D.C. 49p.

Wezel A. and Bender S. 2003. Plant species diversity of homegardens of Cuba and its significance for household food supply. Agroforest Syst 57: 39 – 49.

Wezel A. and Ohl J. 2005. Does remoteness from urban centres influence plant diversity in homegardens and swidden fields: a case study from the Matsiguenka in the Amazonian rainforest of Peru. Agroforest Syst 65: 241 – 251.

Zaldivar M.E., Rocha O.J., Castro E. and Barrantes R. 2002. Species diversity of edible plants grown in homegardens of Chibchan Amerindian from Costa Rica. Hum Ecol 30: 301 – 316.

CHAPTER 10

GENDER AND SOCIAL DYNAMICS IN SWIDDEN AND HOMEGARDENS IN LATIN AMERICA

P.L. HOWARD

Department of Social Sciences, Wageningen University, Hollandseweg 1, 6706 KN Wageningen, the Netherlands; E-mail: <Patricia.Howard@wur.nl>

Keywords: Gender relations, Social structures, Women's status.

Abstract. Structure, composition, and functions of homegardens are said to be closely related to the social structure of households, but this issue is not often researched. An analysis of the literature on swidden and homegardens in Latin America shows that such interrelationships become transparent when examining the gender division of labor, gendered access to garden resources including land, trees, and other plants, and gendered control over subsistence and cash crops and income derived from them. Social status related to gardening, gendered knowledge distribution and transmission, and social dynamics leading to change in gardening and gardens are also important parameters in this matrix. A review of 39 Latin American case studies dealing with swidden or homegardens revealed that women are by far the prominent garden managers across its sub-regions. Aside from the multiple material benefits provided by gardens, other drivers that tend to ensure that women will strive to maintain them include their emotional and spiritual values and the positive social status that productive and beautiful gardens confer. Homegardening is a 'respectable' way for women to contribute to subsistence production and manifest specialized knowledge and skills without competing with men. However, commercialization may be undermining both women's control and the benefits they derive from homegardening as well as the complex structure and function of homegardens.

1. INTRODUCTION

Past research on homegardens shows that the composition, structure, and functions of gardens are interrelated with their economic, social, and cultural functions (see for example Wiersum, 2006). However, the social dimensions of homegardens have only rarely been researched in-depth. Social factors influencing swidden and homegardens

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 159–182.

have not been discussed in any depth in the agroforestry literature in Latin America. It is particularly by examining gender relations within swidden and homegardens that the complex interrelationships between social structures and gardens as land use systems become transparent. Examining gender relationships is also of great importance since, across most of Latin America, swidden and homegardening are largely women's domains, and homegardens may help to mitigate the inequalities between the sexes that are evident across the region.

This chapter is based on a review of the literature on swidden and homegardens in Latin America (that which is published in English as well as the little available to the author in Spanish) that reported sex-disaggregated information. Eight cases were found that focus on homegardens within Mayan production systems in Mesoamerica, whereas 12 cases refer to non-Mayan indigenous or mestizo (mixed Indian-Spanish descent) populations in the same region. In South America, 14 cases were found that deal with Amazonian Amerindian populations and swidden gardens, whereas only five cases were found that focus on homegardens among non-Amerindian South American populations, four of which are also in the Amazon basin. While swidden gardens and homegardens are distinct land use systems, they are both agroforestry systems that are rich in species diversity, possessing "sophisticated spatial structures and dynamics" and manifesting sustained yields (Michon, 1983). Further, while there has been very little study of homegardens among Amazonian Amerindians (for reasons for this see Heckler, 2001), there is a rich literature on swidden gardening.

It must be recognized that a thorough comparative effort would require a substantially richer bibliographical underpinning. Further, the information provided in the 39 case studies that are reviewed here is very uneven and hence often difficult to compare. Thus, in analyzing this literature, the emphasis is on setting out certain similarities and identifying some of the potential explanatory factors in order to illustrate the nature and complexity of homegardens as social systems and of gender relations in swidden and homegardening, and to begin to relate these to the structure, composition, and functions of these gardens as agroecological systems. Finally, it is acknowledged that the 39 case studies analyzed herein do not cover the full spectrum of gardens across the sub-regions, or its ethnic, racial, and indigenous groups, and therefore the results can only be generalized within the limits of the study.

2. THE GENDER DIVISION OF LABOR IN GARDENING IN LATIN AMERICA

The gender division of labor not only provides many insights into how households organize homegarden production; it also highlights how contributions and responsibilities of individuals differ according to their positions within the household, which is very important for understanding the incentives, opportunities, and constraints that they confront when managing homegardens and how such individual factors influence homegarden structure, composition and functions. Many studies across the world seek to analyze the household division of labor in homegardens by sex and age, principally with the aim of understanding how production is organized. Some studies conceptualize and measure the division of labor in terms of tasks, where the breakdown may be gross or fine, e.g., land preparation, planting material procurement, varietal selection, planting, weeding, water management and irrigation, soil management, pest management, and harvesting. Others present the division of labor in relation to specific types of crops (e.g., medicinals, vegetables, spices, trees), to specific species (e.g., coffee [*Coffea* spp.], manioc [cassava, *Manihot esculenta*]), or to specific varieties (e.g., red maize [*Zea mays*] used for rituals, versus white maize used for daily consumption). Other relevant factors include the amount of time required and the timing and intensity of work, and the relation between homegarden work and individuals' other labor obligations and physical mobility. Yet another way it is approached is in terms of the division of decision-making responsibilities (e.g., for location and design of the garden, selection and arrangement of species, cultural practices, destination of output). Divisions of labor are also sometimes discussed in relation to physical spaces such as zones within gardens or gardens in different locations that are considered to 'belong' to particular persons. Irrespective of how it is measured, the division of labor is based on cultural associations between sex, age, and kinship relations (e.g., senior male, wife, daughter-in-law) and obligations that people with such "social identities" (Boster, 1985a) have to provide particular resources for the household or for themselves, as well as the differential access to resources (land, labor, capital, markets, livestock, knowledge, and skills) that is related to these obligations. These cultural associations are rooted in cosmologies ('world views'; understandings of the universe and human beings' place in it) and related concepts of what is appropriate behavior for people of different social identities, which at least for the past generation have been undergoing rapid change nearly across the region.

In general, homegardening studies in Latin American still do not mention the gender division of labor, and those that do often present only one of the possible indicators without specifying why that particular indicator was chosen. Who provides information about the gender division of labor is also an issue. Lerch (1999) pointed out that men and women gave very different answers when asked who was mainly responsible for the homegarden: men said that both were responsible whereas women said that they themselves were responsible. In fact, women were most observed working in homegardens. Dufour (1981) also reported that Tukanoan men in her study site in the Colombian Amazon insisted on representing their households to outsiders and socially it was not acknowledged that women are knowledgeable about plants; however, she found that the plant knowledge of men and women of the same social status did not differ significantly. Such problems affect much more than only data on the gender division of labor – getting the informants 'right' is necessary to avoid all sorts of research bias, but particularly bias about women's work and knowledge around plants (Howard, 2003).

Table 1 presents the reported sex of the 'main gardener' (exclusively women, mainly women, or both men and women together) across the 39 cases, disaggregated by sub-region. Reporting the sex of the 'main gardener' does not mean that the other sex is not involved – even where it is indicated that "only women" are responsible, men may occasionally "help out" and, where "mainly women" garden, men often take on certain tasks or manage certain crops. In those case studies where men were reported to be the "only" or "main" gardeners, this was in relation to a minority of the households studied.

2.1. Mayan Mesoamerica

Geographically, Mesoamerica includes the seven countries of Central America as well as Mexico. Culturally it "joins present day middle and south Mexico, Belize, Guatemala and parts of Honduras and El Salvador," much of which was historically dominated by the Mayan civilization (see Montagnini, 2006). As Montagnini indicates, homegardens are a complex and much-studied feature of the traditional land use system among the Mayan people, which have evolved in conjunction with a particular system of shifting cultivation and bush fallow (milpa) agricultural production that is organized around the 'milpa triad': maize, beans (*Phaseolus coccineus*, *P. polyanthus*, *P. vulgaris*) and squash (*Curcurbita moschata*, *C. argyrosperma*, *C. pepo*). In all but one (Murray, 2001) of the Mayan homegarden studies reviewed, it was found that women were the exclusive or main homegarden managers, although children and other household members might provide labor. For Mayan populations, the milpa, which provides the bulk of subsistence staples and cash crops, is "symbolically the male domain and is the source of male prestige" (Stavrakis, 1979; Greenberg, 1996; Murray, 2001; Lope Alzina, 2006). Women often provide 'additional' or seasonal labor for milpa production, but it is considered improper for women to be seen in the milpa without the company of males, a proscription which is enforced by social sanctions, gossip, and even the threat of witchcraft (e.g., Murray, 2001). On the other hand, homegardens (*solares*, *huertos*, *patxokon na*) are perceived as female domains or spaces where a great diversity of vegetables, condiments, ornamentals, medicinals, and other utilitarian or ritualistic plants are maintained along with most useful trees, and where women are primary decision-makers (Benjamin, 2000; Patterson, 2000). When men are involved, this is either related to particular tasks such as land clearing, tree pruning and thinning, construction of structures and fences and chopping undesirable growth (Benjamin, 2000; Patterson, 2000), or to specific species or crops. Men also use homegardens as experimental stations and *in situ* gene banks for crop diversity - for example, in a case study site in the Yucatan, Mexico, men use homegardens to test new maize varieties and preserve traditional varieties that they do not wish to plant in their fields (Lope Alzina, 2006). Trees and tree crops may be of particular concern to Mayan men especially when these have commercial value (Patterson, 2000), but they are usually principally women's responsibility (Gillespie et al., 2004) because they fall within the physical space of the homegarden.

In one case, in Belize among the Kekchi Maya, the interrelationship between the gender division of labor, production spaces, crops, and conceptions about what is appropriate behavior for women was shown to have an effect on the species diversity and size of different types of gardens. Women manage homegardens and 'milpa gardens'. The latter are established after milpa fields are left fallow and are generally much larger than homegardens (Patterson, 2000). Women maintain

Table 1. *Sex of the "Main Gardener" in the 39 homegardens across Latin America.*

Sex of the "main gardener"	*Number and percentage of cases, countries, and literature citations for different sub-region/ethnic groups*											
	Mayan Mesoamerica			*Non-Mayan Mesoamerica*			*Amazonian Amerindian*			*Non-Amerindian S.A*		
	#	%	Country (literature reference)	#	%	Country (literature reference)	#	%	Country (literature reference)	#	%	Country (literature reference)
Women only [i]	4	50	Belize (35), Guatemala (18), Mexico (12, 14)	3	25	Belize (28); Mexico (6, 13)	5	35.7	Brazil (30); Colombia (17, 38); Peru (1); Venezuela (16)	2	30	Brazil (34); Ecuador (11)
Mainly women	3	37.5	Belize (29), Mexico (5, 22)	3	25	Honduras (9), Mexico (3, 24)	6	42.9	Colombia (10), Ecuador (8, 36), Peru (7), Venezuela (15, 37)	3	70	Brazil (23, 39), Peru (20)

Table 1 (cont.)

Men and women	1	12.5	Mexico (26)	6	50	Costa Rica (27); Guatemala (31); Honduras (21); Mexico (19); Nicaragua (25); Panama (33)	3	21.5	Brazil (4), Peru (2, 32).	0	0
Total	8			12			14			5	

[1] Men may 'help' or not, but their labor is otherwise not systematically involved.

Literature citations and countries of the case studies.

1. Aikman, 1999 (Peru); 2. Alexiades, 1999 (Peru); 3. Angel Perez et al., 2004 (Mexico); 4. Baleé, 1994 (Brazil); 5. Benjamin, 2000 (Mexico); 6. Blanckeart et al., 2004 (Mexico); 7. Boster, 1985a (Peru); 8. Descola, 1994 (Ecuador); 9. Doxon, 1988 (Honduras); 10. Dufour, 1981 (Colombia); 11. Finerman and Sackett, 2003 (Ecuador); 12. Gillespie, et al., 2004 (Mexico); 13. Govers, 1997 (Mexico); 14. Greenberg, 1996 (Mexico); 15. Heckler, 2004 (Venezuela); 16. Hoffmann, 1993 (Venezuela); 17. Irvine, 1987 (Colombia); 18. Keys, 1999 (Guatemala); 19. Lazos Chavero and Alvarez Buylla, 1988 (Mexico); 20. Lerch, 1999 (Peru); 21. Lok (endnote 1; Honduras); 22. Lope Alzina, 2006 (Mexico); 23. Madaleno, 2000 (Brazil); 24. Martin, 1996 (Mexico); 25. Mendez et al., 2001 (Nicaragua); 26. Murray, 2001 (Mexico); 27. Ochoa et al. (endnote 2; Costa Rica); 28. Palacio, 1980 (Belize); 29. Patterson, 2000 (Belize); 30. Posey, 1984 (Brazil); 31. Ruonavaara, 1996 (Guatemala); 32. Salick, 1997 (Peru); 33. Samaniego and Lok (endnote 3; Panama); 34. Sereni Murrieta and Winklerprins, 2003 (Brazil); 35. Stavrakis, 1979 (Belize); 36. Uzendoski, 2004 (Ecuador); 37.Veth and Reinders (endnote 4; Venezuela); 38. Wilson, 1997 (Colombia); 39. Winklerprins, 2002 (Brazil).

milpa gardens because of constraints in terms of soil quality, animal predation, and lack of space in homegardens. It was found that women who cultivate a large number of edible crops and herbs in their homegardens are those whose husbands are frequently away for considerable periods, during which time women rarely if ever travel to milpa gardens. Women whose husbands do not leave the village cultivate larger milpa gardens and maintain fewer species in their homegardens. In another case, in a Mayan community in the Yucatan (Lope Alzina, 2006) where communal land has become available within city limits, people use it as a second, non-traditional gardening space. Men and women share labor and decision-making to a much greater extent and women are allowed to work in these gardens unaccompanied by men, even though these gardens are organized as a kind of "miniature milpa," containing the traditional milpa staple crop triad. Thus, gendered norms appear to be more flexible when people work outside of the traditional production system, and such flexibility also affects the structure, composition, and functions of homegardens.

2.2. Non-Mayan Mesoamerica

In the division of labor among non-Mayan Mesoamerican populations, men are typically responsible for field crop and cattle production and women for homegardening and small livestock (usually pigs and chickens). The staple crops produced across much of Mesoamerica are similar to those produced in the Mayan milpa: especially maize and beans are prominent. The exception is presented by the one case study on the Garifuna (Palacio, 1980) which is a Black Carib population in which women are the main crop producers. Eleven of the studies presented information on the "main gardeners" – in six of these cases, women are reported to be exclusive or principal gardeners, whereas in the other five cases homegardens are managed by both sexes. The main differences with the Mayan division of labor in terms of men's participation appears to be that men are involved in homegardening principally in relation to crops with high commercial value, especially tree crops [e.g., citrus (*Citrus* spp.) and coffee], and there are more cases where men use homegardens to test exotic crops that they wish to introduce into agricultural production (Angel Peréz and Mendoza, 2004; endnotes 2 and 3). Homegardens may also be considered in general as women's spaces in non-Mayan Mesoamerica and the restrictions on women's work in milpas appear to be strict (Govers, 1997; Roquas, 2002).

2.3. Amazonian Amerindians and swidden gardening

Nearly all Amazonian Amerindian societies have traditionally depended for their livelihoods on a combination of hunting, fishing, gathering, and gardening activities, where men hunt and fish and women are responsible for gardening, although these relations are changing mainly due to commercialization (Knauft, 1997; Heckler, 2004). Amazonian Amerindians often have highly complex land use systems that combine multiple types of swidden gardens (including fallow field gardening) and homegardening to provision themselves with starchy staples, particularly manioc (both bitter and sweet varieties), which are complemented especially by plantain and banana (*Musa* spp.), yam and sweet potato (*Dioscorea* spp.), taro (*Colocasia esculenta*), vegetables, fruits and medicinals. The complexity of their agroforestry systems and social organization has made them the subject of much in-depth research.

In all but three of the 14 case studies on Amazonian swidden gardens that were reviewed, women were the exclusive or principal gardeners. In one case, among the Ese Eja in Peru (Alexiades, 1999), there is also an age division of labor that gives a more prominent role to older men in gardening than in other Amazonian Amerindian cases, mainly due to the fact that certain cultivars are associated with malevolent spirits that may harm fetuses and infants, which effectively prohibits women of childbearing age from cultivating or consuming them. In another case, among the Ka'apor in the Eastern Amazon of Brazil (Baleé, 1994), men invest a slightly greater amount of time in swidden gardening than women, and neither sex invests much time in homegardening. However, men's involvement in swidden gardening over much of Amerindian Amazonia is often restricted mainly to clearing undergrowth and felling trees for new gardens, whereas all other tasks are left to women (Posey, 1984; Hoffman, 1993; Descola, 1994). In some cases it is reported that men assist in garden maintenance (Hoffman, 1993; Uzendoski, 2004), particularly among Guyanese groups where the gender division of labor is less rigid – for example, among the Piaroa of Venezuela, men are reported to help in weeding, harvesting and carrying crops from swidden gardens (Heckler, 2004).

The gender division of labor is not only reflected in tasks associated with gardening – it is also often strongly related to crops as well as to physical spaces, associations which are embedded within cosmology and concepts of masculinity and femininity that are in turn related to prestige and to complementarities and conflicts between the sexes. Manioc is by far the most important crop across Amazonian Amerindian cultures, and it is strongly culturally associated with women – in only two cases (Baleé, 1994; Salick, 1997) was it found that men had a substantial role in manioc cultivation and in one of these (Salick, 1997) it was reported that this probably represented a deviation from the traditional division of labor due to labor shortages. Manioc and manioc beer figure importantly not only in the diet, but as well in ritual and exchange. The highly complex cosmology associated with women, manioc, and gardening is discussed in relation to the Achuar (Descola, 1994) and the Warua[4].

Apart from tubers, other crop-sex associations are also quite evident. Among the Ka'apor (Baleé, 1994), both men and women plant manioc, but women are exclusively responsible for planting cotton (*Gossypium* spp.), Indian shot (*Canna indica*), job's tears (*Coix lacryma jobi*) and pipiriwa (*Cyperus corymbosus*), which are used only by women for textiles or for body ornamentation. Only men plant maize. Among the Piaroa, it is also men who plant maize, and they exclusively plant tobacco (*Nicotiana tabacum*) (Heckler, 2004). In fact, Amazonian Amerindian men are often strongly linked to particular species and have exclusive power to manage these species – among the Achuar, only men may plant botanical fish poisons since "if these were to be handled by women, they would lose their effectiveness"

(Descola, 1994). Achuar men are also predominantly associated with hallucinogens, tobacco, maize, and bananas, which are only planted outside the main swidden garden around the edges of the house yard. This reveals yet another aspect of the gender division of labor. Women's swidden gardens are out-of-bounds to men since they are "the only absolutely female space in the Achuar social topography, the only place where women truly exercise a material and symbolic hegemony" (Descola, 1994). Uzendoski (2004) also noted the very strong association between physical production spaces and gender among the Napo Runa of the Ecuadorian Amazon, who see the forest (*sacha*) as masculine while gardens (*chagra*) are seen as mainly feminine.

2.4. Non-Amerindian South America

Few case studies were found that focus on homegardening in non-Amerindian South American societies and that discuss the gender division of labor. Four out of the five studies reviewed deal with the Amazonian region but not with Amerindian populations, whereas only one was found that relates to the Andes (Finerman and Sackett, 2003).

All five cases reported that women are the exclusive or principal gardeners in the majority of the households that were investigated. However, in three of these cases, a number of households were found where men were main gardeners, although those households were in the minority. In the case of three villages in rural Amazonian Peru (Lerch, 1999), in those households where men were the main gardeners, it was clear that women were also involved in the work. In the two urban cases in Para State, Brazil, 70% of the urban growers in Belém were women, whereas in Santarém, 67% of the homegardens were maintained by women (Madaleno, 2000; Winklerprins, 2002). On Ituqi Island, also in Para State, among a *Caboclo* population (mixed Brazilian Amerindian and European or African ancestry), homegardens are said to be the "unquestionable domain of women" (Sereni Murrieta and Winklerprins, 2003). In the Ecuadorian Andes, Finerman and Sackett (2003) also found that women are unquestionably the heads of gardens. These gardens are "medicine cabinets" (one contained 194 species of which 132 were medicinals and on average nearly 70% of species in homegardens were used for medicine), where lay medicine is clearly defined as a female domain.

The case studies reviewed above demonstrate that the gender division of labor can be viewed in multiple ways – as a division of tasks or responsibilities, of crops, or of resources or physical domains, and typically as a combination of these. Regardless of how it is viewed, it is related to culturally established norms of behavior that often have their roots in cosmology and that clearly differ according to ethnicity and tribal affiliation. What is considered appropriate behavior for women differs strongly between Amerindian and non-Amerindian populations insofar as women have primary responsibility for staple crop production in many Amerindian societies. Yet they are excluded from such production over much of Latin America, where instead they are responsible for a myriad of so-called 'minor' crops, particularly those with cultural, culinary, and medicinal values that are typically produced in homegardens. In both cases, the responsibility for swidden and homegardens, and *ipso facto* for the skills, resources, knowledge, and biological diversity that are entailed, falls mainly to women.

3. GENDER AND ACCESS TO GARDEN RESOURCES

From the foregoing discussion, it appears that the gender division of labor is closely related to men and women's differential access to homegarden resources, especially land, trees, and other plants. Terms of access and rights to these resources are more complex and significant than most case studies suggest and have significant consequences for garden structure, composition and functions, for the investments made and benefits derived from gardening, and for the distribution of such benefits between households and among household members.

As is the case with property rights of all types, rights to swidden and homegarden resources are also differentiated by sex. Variations in homegarden resource access according to sex that are found in the case studies are summarized in Table 2. This table includes only a subset of the total number of case studies reviewed since the majority did not provide sufficient sex-disaggregated information about resource access.

Table 2. *Patterns of gendered access to garden resources[i] in the 39 case studies across Latin America.*

Agricultural land ownership[ii]	*Agricultural land usufruct*	*Garden land ownership[ii]*	*Garden land usufruct*	*Garden tree ownership[iii]*	*Garden plant ownership[iii]*	*Countries (literature references: see Table 1 for author details)*
MF	M	MF	F	F	F	Ecuador (11)
M	M	M	MF	MF	MF	Belize (29) Mexico (5, 12, 22)
M	M	M	MF	M	F	Costa Rica (27) Mexico (3, 19) Panama (21, 33)
-	-	M	M‖F	M‖F	M‖F	Ecuador (8)

Note: ‖ signifies physically separate; M = male; F = female.
[i] Includes only cases where gendered resource access and control were discussed.
[ii] Where there is no private ownership, this means customary control over land allocation.
[iii] May be explicit, or may be inferred from the case studies.

Although homegardens in Latin America are nearly by definition small (generally considerably less than 1 ha and at times only a dozen square meters), land is obviously still a crucial production factor, and homegarden land can be even more productive on a per hectare basis than agricultural land[3]. Irrespective of the sex of the main gardener, it is reported that poorer households have greater difficulty obtaining access to land for homegardening and greater difficulties meeting household needs from gardens when they do have access. For these people, lack of tenure security represents the greatest threat since many occupy land illegally, especially in urban or urbanizing areas (Madaleno, 2000; Finerman and Sackett, 2003). Lower land access is reported to prevent cultivation of species that require substantial amounts of space (Doxon, 1988). As well, tree planting and security of land tenure are often interrelated since tree planting often creates rights to land or, conversely, only landowners may plant trees (Bruce and Fortmann, 1988). Thus, tree and land tenure may affect composition and structure through the number and type of trees planted in homegardens and through garden size.

It is normally presumed that whoever owns or formally controls homegarden land will control homegarden production, but this is certainly not so in the case studies reviewed here. Deere and Leon (2001) show that male land ownership and control predominate over most of Mesoamerica and non-Amerindian South America, which is confirmed by the homegarden studies that report such information: in only one case was it said that men and women jointly own land (Finerman and Sackett, 2003). Generally, it is men who have the ultimate right to dispose of land, although decision-making may be joint as Patterson (2000) showed for Mayan homegardens in Belize. In all homegardening cases, women appear to obtain informal usufruct rights to homegarden land from their husbands. Among populations where there is no clear concept of land ownership, such as among many swidden horticulturalists, 'spaces' are frequently gendered and gardens may be considered strongly or weakly as 'women's spaces'. Generally, men formally control swidden garden land and allocate it to women (Descola, 1994; Goldman, 1963; Posey, 1984). However, neither of these phenomenon is pervasive – for example, "The Cubeo always speaks of a particular manioc plot as belonging to a woman, the only instance of individual possession of land in Cubeo society" (Thompson, 1977).

Only two studies were found that elucidate why or how it is that women gain which type of usufruct rights to homegarden land that men control (Descola, 1994; Lope Alzina, 2006), and these discuss how such rights are influenced by negotiations between men and women. Among the polygamous Achuar of Amazonian Ecuador (Descola, 1994), each co-wife must cultivate her own garden plot. Men divide plots that they have cleared and assign them to each co-wife by planting rows of banana. The size of the garden is negotiated: while both men and women wish to have large gardens, women consider their access to labor for weeding and negotiate with their husbands considering this constraint. It is also notable that once each co-wife's patch "has been materially marked out under male authority, the garden finally becomes the closed area of a purely female praxis." Still, it is clear that women have strong obligations to produce manioc beer for the men who provide them with land.

Access to homegarden land must be very important for those Latin American women who lack access to other land to cultivate, particularly when women are able to use this land in a way that is highly productive and to make most decisions regarding its use and management. The fact that women obtain land through their husbands implies that divorce or separation may deprive them of access altogether, and men can also ultimately decide to use such land in other ways, which is discussed further below.

Land is not the only resource that is crucial to homegardening. Agrobiodiversity is also a major resource and rights to trees and other plants cannot simply be assumed to pertain to those who control the land. What appears to be most common in the cases reviewed is that men may grow specific homegarden crops of their own, but most homegarden species belong to women. Within this, a relatively consistent pattern is discernable in relation to trees, since trees are often related to male ownership (Bruce and Fortmann, 1988) and tree tenure also differs from "plant tenure" (Howard and Nabanoga, 2006). In the Mayan cases, tree ownership does not appear to be clearly related to either men or women and women generally plant and manage trees in homegardens (Benjamin, 2000; Gillespie et al., 2004). Nevertheless, in the Mayan case that reported that trees provide cash crops, men also participate in their management and use (Patterson, 2000). In many non-Mayan Mesoamerican communities, however, it appears that men make decisions about trees and control income from them, particularly when they have high commercial value (Lazos Chavero and Alvarez Buylla, 1988; endnotes 2 and 3).

One case provides insights into the relationship between land tenure, tree tenure, and cosmology. Samaniego and Lok[3] report that, among the Ngöbe in Panama, women attribute greatest importance to homegardening while men value tree (especially coffee) production most highly. Land is generally communally owned, but the person that plants a tree becomes the owner of the land upon which the tree is planted. The head of a household will bury the placenta pertaining to every newborn and plant a tree on that site, and only the head knows the tree species and the site. The well-being of the tree and of the person whose birth the tree marked are directly interrelated, so household heads should always be consulted regarding the management of trees in homegardens.

Aside from trees, women may have exclusive rights to plants growing in homegardens and their husbands or other household members may have no right to harvest or otherwise destroy these plants without their permission. Finerman and Sackett (2003) reported that, in their study village in the Ecuadorian Andes, men and women jointly own land and animals. Men make most decisions concerning farmland and cattle, while households and homegardens are women's domains, both in terms of management and of rights to the plants growing therein. Anyone wishing to have access to a plant in a woman's garden must ask her permission. Dufour (1981) observed that, among the Tukanoan Indians of the Colombian Northwest Amazon, women often plant manioc in a section of another woman's garden. This highlights the fact that there are myriad social relations and subtle social norms about property in land and in plants that are related to factors other than "ownership": other homegarden research shows that even a person who "owns" or manages trees or plants in a homegarden might not have exclusive rights to them (Howard and Nabanoga, 2006).

Lok[1] provided an example that demonstrates how rights to plants and trees may be circumscribed depending upon the species and upon who controls the zone in which they are planted, as well as how gendered rights to homegarden resources affect their structure and composition. She researched homegardens in a Mestizo (mixed Spanish-Indian) community in north central Honduras and found 253 useful plant species in a sample of 10 gardens, with an average 60 species per garden distributed in nine management zones that could be discriminated by examining vertical strata, geophysical characteristics and "gender access or responsibility." Women have responsibility for particular zones, such as the residential zone where ornamentals, vegetables, and medicinal plants are produced, as well as tree and plant nurseries. Men are in charge of the coffee zone, which provides much shade for vegetables and medicinal plants that women plant within it, but men simply 'tolerate' these plants and eliminate them without their wives' permission if they see fit in order to plant more coffee. Lok[1] concluded that the study of management zones "makes it possible to relate agroecological variables to social and economic ones, which is of great importance in homegarden analysis." It is clear that one factor in this analysis is gendered rights to homegarden trees, plants and zones.

4. GENDER AND COMMODITY PRODUCTION IN HOMEGARDENING

Both the gender division of labor in homegardening and gendered rights to homegarden resources appear to be related to the control over income generated through cash crops. In the author's experience with rural homegardens in Honduras, Nicaragua and El Salvador from 1982 – 1990, women use such income to pay for school fees, pharmaceuticals and medical services, and as "pocket money" for making daily purchases of food and other goods to meet household needs. Homegarden produce is available in small quantities year-round, so it is unsurprising that women are responsible both for such small daily purchases and for the production that provides the income for these purchases. The cases reviewed suggest that, when women market homegarden produce, they do so nearly exclusively in local markets, and the amount of income generated is generally quite small in relation to total household income. However, the amount generated can certainly be more substantial, as several homegarden studies across the globe attest. Finerman and Sackett (2003) reported that, in the Andes of Ecuador, women sell sufficient surplus from their homegardens to contribute to household income and improve their own status.

Table 3 presents an overview of the gender division of labor in relation to the production of subsistence crops, of crops that are marketed on a small-scale, and of high-value crops or crops marketed on a larger scale for those case studies that provided information (15 of the 39 reviewed). It shows that women are more likely to manage crops destined principally for subsistence (in 80% of the cases) or for sale in small quantities in local markets (in 88%). As cash cropping occurs on a larger scale or high value crops are produced, men's involvement and control are much more evident (86%).

The associations between women and subsistence production are quite strong, as are the associations between women and medicinals, spices, condiments, and ornamentals. A typical example is found in Angel Peréz and Mendoza (2004) in relation to a traditional Totonac community in Veracruz, Mexico. They reported that women manage culturally important plants (for subsistence, ritualistic, and medicinal purposes) and are responsible for backyard gardens and orchards, whereas men use homegardens to test and adapt exotic plants that they later introduce into commercial field crop production. Patterson (2000) found a similar pattern among the Kekchi Maya in Belize where homegarden cash crops have recently increased in number and are mainly introduced by male heads.

Table 3. *Responsibility for subsistence and cash crop production in homegardens by sex*[i] *in 15 case studies across Latin America.*

Subsistence	*Small scale marketing*	*Major or high value cash crops*	*Countries (literature references: see Table 1 for author details)*
F	-	M	Belize (29), Honduras (21), Mexico (3[ii], 26), Panama (33)
MF	M		Mexico (Alvarez Buylla et al., 1989)[iii]
F	F	-	Guatemala (18), Ecuador (11), Mexico (6, 13, 14, 22), Venezuela (16)
MF	-	M	Costa Rica 27)
MF	-	MF	Nicaragua (25)
12 80.0%	7 87.5%	0 0.0%	Total cases and percent of women in them
3 20.0%	0 0.0%	1 14.3%	Total cases and percent of both men and women
0 0.0%	1 12.5%	6 85.7%	Total cases and percent of men
15	8	7	Total cases

[i]Includes only cases where some garden produce is reported to be sold.
[ii]Men experiment with cash crops destined eventually for agricultural fields.
[iii]Implicit. Men manage fruit trees, and only citrus is sold in small quantities.
M = male; F = female.

Given the strong influence of women's decision-making in homegardening across most of the cases in Latin America, it is interesting to examine whether commodity production plays a role in the gender division of labor in homegardens that are managed by both men and women. Table 4 presents the cross-tabulation of the 10 cases where data on the sex of the main gardener and the production of major market crops were both reported. In five of the six cases where both men and women share responsibility for homegardening, men produce major or high value cash crops in homegardens and, in one case, both men and women produce them. In only one case was it reported that, while men and women are main gardeners, no major or high value cash crops are produced; in another two cases, women are the main homegardeners but men manage high value crops. It is important to note that all of these cases refer to the Mesoamerican context: the South American cases presented insufficient data.

A few studies have discussed what occurs in terms of shifting responsibilities for, and benefits from, homegardening when it begins to generate substantial amounts of cash income or cash crops are introduced, even in contexts where homegardening is culturally strongly associated with women. Murray (2001) reported that, among the highland Maya of Chiapas, Mexico, people are quite dependent on the cash economy. Men emigrate and secure paid jobs, and much cash crop production occurs in homegardens where chemical inputs are also used. Commercial flower production is one of the activities that men have integrated into traditional homegardens. The strong integration into the market economy has undermined women's economic and decision-making power in these households and gardens. As homegarden production becomes more lucrative or more market-oriented, women's roles in them as managers, sellers, and earners of cash income appear to shift. Other studies report that commercialization may have negative effects with respect to agrobiodiversity and household food security. For example, Baleé (1994) reported that, in the eastern Amazon of Brazil, agricultural extensionists encouraged the production of rice as a cash crop. The result was that the space for traditional crops such as foods, spices, and other utilitarian plants was reduced to the point that these crops are no longer found in swiddens in these villages, which would obviously have a substantial impact on women.

Table 4. *Cross-tabulation of sex of the main gardener and responsibility for major or high value cash crops in 10 case studies across Latin America*[i].

Sex of main gardener	*Subsistence*	*Major or high value cash crops*	*Countries (literature references: see Table 1 for author details)*
Men and women	Men and women	-	Mexico (19)
Women	Women	Men	Belize (29), Mexico (3)[ii]
Men and women		Men	Costa Rica (27), Honduras (21), Mexico (26), Panama (33)
Men and women		Men and women	Nicaragua (25)

[i] Ruonavaara (1996 – Guatemala) reported that both women and men manage homegardens and also reported small-scale marketing, but did not report who was responsible.
[ii] Men only experiment with cash crops destined eventually for agricultural fields.

Commercialization may leave women's gardening responsibilities intact but may create other shifts that affect the composition and structure of homegardens and therefore agrobiodiversity and dietary composition. In Ecuador, dependency on global markets caused an economic crisis when the nation's economy collapsed in the late 1990s. Residents of the village that Finerman and Sackett (2003) studied in the Andes have lost property and been forced to emigrate, so that "increasing number of homegardens lie abandoned by absentee landowners, or are plowed under to make way for cash crops that have done little, thus far, to ease the financial burdens of the owners."

Women are not necessarily marginalized when homegardens increase in economic importance; rather, both women and homegardens may provide a buffer against the worst effects of economic or environmental crisis affecting men's agricultural production. Greenberg (1996) reported that, due to decreasing viability of men's agricultural production in rural areas of the Yucatan Peninsula, families have migrated to the tourist resort of Quintana Roo in search of wage labor. Men no longer engage in agricultural production, but women maintain traditional homegardens and agrobiodiversity in this urban setting, and homegardens generate cash for these families in many ways. Still, there may be other negative implications of shifting gender roles: this change in gender domains may partly account for social problems and men's excessive drinking.

Yet other trade-offs for women and their households must be considered, since production for subsistence and for cash income generation are certainly not the only measures of the value that homegardens provide. As many authors point out, homegardens are often sources of non-monetary exchange values through gift-giving and reciprocal exchange. These are very important especially to women gardeners as sources both of material goods and of status and social autonomy.

5. SOCIAL STATUS, GENDER, AND GARDENS

Much of the research that has been done on homegardens has emphasized the economic and ecological functions and benefits of homegardening and has stressed these as principal reasons for their creation and maintenance, without examining in any depth other ways in which homegardens provide social or material advantages for their owners. Even so, several of the articles reviewed acknowledge the social status that is associated with homegardening, especially with having a particularly large, beautiful or genetically diverse garden. As Sereni Murrieta and Winklerprins (2003) noted, a homegarden "says much about its keeper."

The same also appears to be true of swidden gardening. Descola's (1994) work highlighted how researchers often mistakenly assume that the diversity that swidden gardeners create or maintain is due to ecological or economic motivations rather than to status-seeking behavior. At the same time, he showed how gardening may increase women's status in the eyes of men. For the Achuar, it is a "point of honor" for women to cultivate large swidden gardens. The garden diversity evident, particularly in tubers, cannot be attributed to nutritional or culinary needs since "men - whose attitude openly encourages their wives' agronomic capacities - recognize by taste alone only a very low proportion of the varieties of manioc, yams, or sweet potatoes." Nor can it be attributed to the need to reduce species-specific diseases since only one serious manioc disease is recognized, and only a few plants are usually affected. Rather, "a woman who successfully grows a rich pallet of plants thereby demonstrates her competence as a gardener and fully assumes the main social role ascribed to women by proving her agronomic virtuosity" (Descola, 1994).

Finerman and Sackett (2003) found in the Ecuadorian Andes that people observe each other's homegardens and deduce information about the owners' wealth status, occupation and market orientation, as well as health status. The abundance and diversity of a garden is an important source of status for women who develop reputations as skilled gardeners whom people continually approach for planting materials, for advice and to exchange produce. Women boast about their homegardens and about the independence these afford. Yet the implications of homegardening for women's status are not only related to their production capacities; they are also clearly linked to the roles women are expected to perform as family caretakers and as representatives of their households. Homegardens reveal:

> the extent of the owner's commitment to family well-being . . The presence of a garden rich in . . [medicinal plants] epitomizes her exertions on behalf of kin, and her proficiency as primary health provider; a spacious and productive garden filled with medicinal plants suggests that the family, too, is prosperous and fit . . Gardens themselves [are] a manifestation of the community's most deeply held values: autonomy, status, religious piety, and personal investment in family. . A garden demonstrates a woman's freedom from dependence on products from neighbors and commercial vendors; her fiscal standing evidenced by her ability to expend valuable land on a garden; her faith displayed by a sacrifice of resources to adorn the church; and her industriousness and devotion to family exhibited by her investment in plant cultivation (Finerman and Sackett, 2003).

It is clear that the status provided through gardening is not confined to gardens' visible characteristics or the skills of their owners. Many studies show that garden produce that is not consumed is much more commonly given as gifts or exchanged with others rather than sold in markets, and most homegarden studies also report that the vast majority of garden planting materials that are not self-provisioned are acquired through gifts and exchange (Blanckaert et al., 2004), predominantly between women (Boster, 1985b; Alvarez Buylla et al., 1989; Hoffman, 1993; Greenberg, 1996; Lerch, 1999; Patterson, 2000; Ruonavaara, 1996; Finerman and Sackett, 2003; Sereni Murrieta and Winklerprins, 2003). Such exchanges are not only important in terms of the garden products or planting materials that gardeners access – they are just as important as a means to create and maintain social networks. Gift giving and exchange of planting materials often help Mayan women maintain kinship and neighborly ties with people in distant places (Greenberg, 1996) and provide additional opportunities to accumulate knowledge (Patterson, 2000). Likewise, Finerman and Sackett (2003) referred to women's plant "borrowing" in the Andes as an important basis for household exchanges, which are most common among female relatives and close friends. Lerch (1999) researched homegarden plant diversity and exchange in the Amazon where networks for exchange of indigenous planting material have been strong historically. In the villages she studied, reciprocal exchange among neighbors (who might also be kin) was the most important source of plant material acquisition, and households with high plant diversity exchanged plants at a higher rate.

Among Amazonia Amerindians, male prestige is often related to ceremonial exchange of food products such as manioc beer (Descola, 1994; Heckler, 2004; Thompson, 1977). Women may also gain prestige as producers of the crops that men exchange as occurs among the Cubeo (Goldman, 1963), the Achuar (Descola, 1994) and the Piaroa (Heckler, 2004). Among Piaroa groups, women manioc cultivators can assert themselves as agronomic experts, which is evident in the great diversity of manioc cultivars they produce. They create alliances by exchanging this diversity, as well as by processing manioc in "processing parties" which are events of "communality and congeniality" in which women gain prestige as hard workers and food providers (Heckler, 2004).

To the degree that women's status is positively affected by their homegardening activities, their status may erode as homegardening itself declines. Stavrakis (1979) noted in the villages that she studied in Belize how kitchen gardens lost prestige as people began to reject local fruits and vegetables in favor of imported varieties, and gardens became obsolete. "As the garden loses its social value, so naturally do women's gardening activities." Aikman (1999) and Hoffman (1993) argue that women's traditional knowledge and management of local crop diversity that they maintain in home or swidden gardens may become valueless, and their high social status turn to social stigma, as such knowledge and production become increasingly associated with poverty and backwardness.

6. KNOWLEDGE AND GENDER IN HOMEGARDENING

The status derived from gardening is in part due to the knowledge and skills that are necessary to create and maintain them. Depending on the degree to which gardening knowledge is specialized, it will be unevenly distributed and this distribution will reflect factors such as age, sex roles, and differential 'opportunities to learn' (Boster, 1985a). That gardening knowledge is specialized is widely reported in the literature reviewed. To the degree that the species diversity in homegardening is greater than in agricultural fields, this implies greater breadth of ethnobotanical and agronomic knowledge than what is common in agricultural production. Further, because so many species and varieties are intercropped in homegardens, knowledge of plant associations is also likely to be greater. Such associations are also very likely to be related to microclimates that are created within homegardens and that do not exist elsewhere, which "enables: (i) the growing of varieties with different climatic requirements . . . (ii) the elaboration of a management calendar independent of the climatic functions, and (iii) the experimentation with new varieties" (Alvarez Buylla et al., 1989; endnote 1).

When Benjamin (2000) examined Mayan cultural homegarden practices in depth, she found that women homegardeners' knowledge is based on "principles" that maximize micro-environmental conditions for successful plant propagation, which are passed on across generations. Similarly, Gillespie et al. (2004) found that Mayan women's management of Ramón trees (*Brosimum alicastrum*), a dry-season forage source found in all homegardens in their study area in the Yucatan, is based upon an intimate knowledge of environmental factors that are taken into account when propagating the species, where their management techniques were found to increase growth very substantially.

Gardening knowledge is not confined to agroecology and agronomy. Garden planning for subsistence purposes must combine an understanding of vegetative cycles, of perishability and processing and storage characteristics, and of timing and quantity of demand, including the needs for ingredients for specific dishes and/or medicines and substitutability of those ingredients (Lope Alzina, 2006), and of the need to meet nutritional and medicinal requirements of households whose composition also changes over time. Finerman and Sackett (2003) showed that the composition of homegardens in their study area closely reflects the stage in the life cycle, where the medicinals produced reflect in part the specific needs of young families or elderly household members. Several other researchers confirm that homegardens provide the basis for acquiring much environmental, agronomic, cultural and other knowledge related to plants and plant uses (Alvarez Buylla et al., 1989; Angel Peréz and Mendoza, 2004; Greenberg, 1996).

Indigenous knowledge associated with gardening is also related to plants as cultural capital, where individual plants take on social meaning. For example, Sereni Murrieta and Winklerprins (2003) found that women were able to relate the history of many individual plants, their origins, utility, and their status as a gift, a symbol of someone's affection or a commemoration of an event (see also Finerman and Sackett, 2003). Much ritualistic knowledge may also be entailed in gardening as Descola's (1994) work on the Achuar amply testifies.

It can therefore be presumed that knowledge entailed in managing complex gardens takes a considerable part of a lifetime to accrue, involves considerable hands-on experience and trial and error (experimentation), and entails continual exchange of information. It is clear that, across the region, women are more often homegardening specialists; as principle knowledge holders, it can be hypothesized that it is also women who are primarily responsible for the transmission of homegardening knowledge. In other words, homegardening knowledge and knowledge transmission are largely gender-related.

There is ample testimony to gendered gardening knowledge in the literature reviewed in this chapter. In one case where women are nearly exclusively responsible for homegardening, it was reported that "men generally disavow any knowledge of homegardening, deferring to their wives for even basic information about gardens and their products" (Finerman and Sackett, 2003). In another such case, Descola (1994) came to an even more dramatic conclusion: Achuar men "are . . . totally incapable of replacing their wives if the need arises, and moreover have no desire to do so. When a man no longer has any woman (mother, wife, sister, or daughter) to cultivate his garden and prepare his food, he has no choice but to kill himself."

However, it is more common that both men and women have homegardening knowledge and that the division of such knowledge reflects the nature of their involvement. Such a conclusion is born out by an unusual study[2] that researched gendered species knowledge in 23 households in the Nicoya Peninsula of Costa Rica, where both women and their husbands participate in homegardening. The 13 homegarden species most frequently used were selected: four exclusively for medicinal use, five for medicinal and food use, and four exclusively for food. The results showed that women's knowledge of medicinal plants was always higher than men's. Regarding food plants, only for *Musa* spp. (plantains and bananas) did the knowledge between men and women differ significantly, where men had greater knowledge than women. The authors related these findings to the gender division of labor where women were responsible for health care and food preparation and men for cash crop production, and six out of nine of the food items studied had commercial values.

It is also important to stress that gardening knowledge, like ethnobotanical or ethnobiological knowledge in general, varies not only between men and women, but as well according to factors such as kinship, age, social class, ethnicity, specialization, and personal propensity (Howard, 2003). As Greenberg (1996) reported among the Maya of Quintana Roo, Mexico, “There are individual differences in the intensity of peoples’ interests in plants and their cultivation.”

When examining knowledge transmission networks and processes of knowledge erosion, the influence of kinship and age also comes to the fore. Knowledge transmission is a dynamic and continual process since household circumstances and ecological and economic conditions change continually, and homegardens must be adapted to such changes. In this, women and their social networks play a predominant role. Several authors show that homegardening knowledge is transmitted largely among women and then principally among closely related kin (Boster, 1985a; Descola, 1994; Greenberg, 1996; Keys, 1999; Patterson, 2000). Children’s labor in homegardening is so common that it is not surprising that much general knowledge is transmitted to them as they work under the supervision of their mothers. Keys (1999), whose research specifically focused on homegarden knowledge transmission among the Kaqchikel Maya of Guatemala, showed how homegardens act as veritable classrooms for both girls and boys where women teach children how to use farm tools and to cultivate and manage crops. What boys learn is not only applicable to the homegarden. Keys observed that boys have already learned the basic concepts of cultivation before they accompany their fathers to the milpa. Not only cultivation techniques, but as well knowledge about the use of plants for food, medicine and handicrafts, are transmitted from mother to child through homegardens. Patterson (2000), working within Mayan communities in Belize, showed that it was often not only mothers, but also other female relatives, who formed key knowledge transmission networks. All gardeners interviewed stated that they acquired environmental and homegarden management knowledge from older female family members, whereas 94% said they also acquired environmental knowledge from “other” female family members including younger sisters and more distant relations. The process of knowledge transmission begins at age five or six when girls accompany their female relatives to gardens where they learn to identify, water, and harvest or collect plants and to tend small animals. Hoffman (1993) found that not only was gardening knowledge transmitted between mothers and daughters: plant material as well as knowledge, material, skills and practices were often part of a “package” of cultural and physical capital that flows among women and between women and their offspring. Boster (1985b) also reported this for women Aguaruna manioc cultivators in northern Peru.

Some homegarden researchers remark that homegarden knowledge is eroding or is likely to erode in the near future. They provide several reasons for this, some of which are gender-specific. One is cultural erosion: as young people assimilate into a dominant culture through education and migration, they learn less about plants and homegardening (Angel Peréz and Mendoza, 2004). Benjamin (2000) cites emigration among Mayan youth as the main risk. Keys (1999) pointed out that particularly young Guatemalan women are affected by off-farm employment in textile factories, which leaves them no time for homegardening, and Hoffman (1993) stressed not only off-farm employment, but also migration and participation in formal educational systems that denigrate women’s traditional gardening practices, which leads to loss of knowledge.

7. CONCLUSIONS

Many women in Latin America contribute to subsistence and to meeting the cash needs of their families but usually do so in ways that are not permitted to be predominant or very visible. Swidden gardening and other work that Amazonian Amerindian women perform accord them social status and prestige. Although men mainly clear and allocate swidden garden land to women, women have strong if not exclusive claims to most swidden garden resources. Many Mayan and mestizo women are far less likely than men to own property, and are generally not permitted to engage in agricultural production or to generate substantial amounts of income. Still, as 'acceptable' social and environmental spaces where domesticity is centered and esteemed, homegardens offer these women sources of authority, autonomy, status, social networks and visible 'public' spaces of recognition without challenging male dominance. Homegardens are clearly essential to women: they fit in well with their domestic duties, labor patterns, productive decision-making spheres, aesthetic sensibilities, and cultural roles. Through gardening, women develop great knowledge and proficiency in relation to the plant world and to the environment, which permits them to shape and manage these to meet the needs of their households. In addition to utilitarian or monetary values, homegarden species have deeper, spiritual emotional, and symbolic meaning for women whose spaces and relations are circumscribed by historically and culturally-specific phenomena that relegate them to subordinate positions; they are also assertions (and continual reassertions) of women's importance, contributions and the continuity of traditions and identity that they bring to their societies, families and communities. In this, homegardens serve men as much as they serve women. They permit women to contribute to family subsistence, status, and identity in ways that are 'respectable'.

Women can more readily enter markets where they do not compete with men or when they do not earn so much income that they challenge men's economic predominance. Beyond this, they also appear to be able to negotiate change with husbands and other family members based upon their authority as garden managers. The terms of such negotiations may be restrictive, but they may also afford women the ability to meet their own particularistic needs, and may contribute positively to their status and increase their ability to "have a greater say" in the management of their households and communities. On the other hand, this does not negate the fact that women's command over homegarden resources is tenuous and likely to shift as commercialization increases, and they may also lose access altogether in the case of separation or divorce. Homegardening may also be seen as a source, or a continuing reminder, of women's subordinate status, and change processes may leave them bereft of control over or access to homegarden resources.

Threats to homegardening are many – as are the driving forces to maintain them that are mentioned above. Commoditization, the decreasing status of local agrobiodiversity in human consumption and health due to acculturation, urbanization which draws youth away from primary production, and formal education that denigrates 'traditional', 'peasant' or 'indigenous' ways of life, can all be major threats since they subvert many of the dynamics that have maintained the value of homegardens – diversity, independence and autonomy, cultural identity, local adaptability, home- and needs-centeredness, and multi-value production. Many of these threats at the same time may offer women greater formal equality and autonomy. But it is likely that women will attempt to negotiate the trade-offs between such potential gains and losses – as ample literature on homegardens among urban migrant populations attests, women are very likely to continue to exert every effort to create, maintain and manage the most socially and agroecologically complex systems known to the region.

ENDNOTES

1. Lok R. 2001. A better understanding of traditional homegardens through the use of locally defined management zones. Indigenous Knowledge and Development Monitor 9: 14 – 18.
2. Ochoa L., Fassaert C., Somarriba E. and Schlonvoight A. 1998. Conocimiento de mujeres y hombres sobre las especies de uso medicinal y alimenticio en huertos caseros de Nicoya, Costa Rica. Agroforestería en las Américas 5: 17 – 18, 7 – 11.
3. Samaniego G. and Lok R. 1998. Valor de la percepción y del conocimiento local de indígenas Ngöbe, en Chiriqui, Panamá. Agroforestería en las Américas 5: 17 – 18, 12 – 16.
4. Veth B. and Reinders M. 1995. Planten zijn als mensen: genezen met medicinale planten bij de Warao en Wayana in de Guyana's. Indigo 3(5): 4 – 7.

REFERENCES

Aikman S. 1999. Schooling and development: Eroding Amazon women's knowledge and diversity. In: Heward C. and Bunwaree P. (eds), Gender, education and development: Beyond access to empowerment, pp. 99 – 153. Zed Press, London.

Alexiades M.N. 1999. Ethnobotany of the Ese Eja: Plants, health and change in an Amazonian Society (Plant Medicinals). PhD dissertation, City University of New York. University Microfilms International, Ann Arbor, Michigan.

Alvarez Buylla M., Lazos Chavero M.A. and García Barrios J.R. 1989. Homegardens of a humid tropical region in South East Mexico: An example of an agroforestry cropping system in a recently established community. Agroforest Syst 8: 133 – 156.

Angel Peréz, A. del and Mendoza B., M.A. 2004. Totonac homegardens and natural resources in Veracruz, Mexico. Agric Hum Val 21: 329 – 346.

Baleé W.L. 1994. Footprints of the forest: Ka'apor ethnobotany–The historical ecology of plant utilization by an Amazonian people. Columbia University Press, New York pp. 50 – 60; 158.

Benjamin T.J. 2000. Maya cultural practices in Yucatecan homegardens: An ecophysiological perspective. PhD dissertation, Purdue University. University Microfilms International, Ann Arbor, Michigan.

Blanckaert I., Swennen R.L., Paredes Flores M., Rosas Lopez R. and Lira Saade R. 2004. Floristic composition, plant uses and management practices in homegardens of San Rafael Coxcatlán, Valley of Tehuacán-Cuicatlán, Mexico. J. Arid Env 57: 39 – 62.

Boster J.S. 1985a. Requiem for the omniscient informant: there's life in the old girl yet. In: Dougherty J. (ed.), Directions in cognitive anthropology, pp. 177 – 198. University of Illinois Press, Champaign, Illinois.

Boster J.S. 1985b. Selection for perceptual distinctiveness: Evidence from Aguaruna cultivars of *Manihot esculenta*. Econ Bot 39: 310 –325.

Bruce J. and Fortmann L. 1988. Why land tenure and tree tenure matter: Some fuel for thought. In: Fortmann L. and Bruce J.W. (eds), Whose trees? Proprietary dimensions of forestry, pp 1 – 9. Westview Press, Boulder and London.

Deere C.D. and Leon M. 2001. Empowering women: Land and property rights in Latin America. University of Pittsburgh Press, Pittsburgh pp. 264 – 291.

Descola P. 1994. In the society of nature: A native ecology in Amazonia, pp 93 – 212. Cambridge University Press, Cambridge.

Doxon L.E. 1988. Diversity, distribution and use of edible and ornamental plants in homegardens in Honduras. PhD Dissertation, Kansas State University. University Microfilms International, Ann Arbor, Michigan.

Dufour D.L. 1981. Household variation in energy flow in a population of tropical forest horticulturalists. PhD dissertation. State University of New York at Binghamton. University Microfilms International, Ann Arbor, Michigan.

Finerman R. and Sackett R. 2003. Using homegardens to decipher health and healing in the Andes. Med Anth Quart 17: 459 – 482.

Gillespie A.R., Bocanegra Ferguson D.M. and Jiménez Osornio J.J. 2004. The propagation of Ramón (*Brosimum alicastrum* Sw.; Moraceae) in Mayan homegardens of the Yucatan peninsula of Mexico. New Forests 27: 25 – 38.

Goldman I. 1963. The Cubeo: Indians of the North-west Amazon. University of Illinois Press, Champaign, Illinois.

Govers C. 1997. Agriculture, cosmology and the gender division of labour in a Totonac highland village (Mexico). In: de Bruijn M. and van den Hombergh H. (eds), Gender and land use: Diversity in environmental practices, pp. 27 – 47. Thela Publishers, Amsterdam.

Greenberg L.S. 1996. You are What you eat: ethnicity and change in Yucatec immigrant house lots, Quintana Roo, Mexico. PhD dissertation, University of Wisconsin-Madison. University Microfilms International, Ann Arbor, Michigan.

Heckler S.L. 2001. The ethnobotany of the Piaroa: Analysis of an Amazonian people in transition. PhD dissertation, Cornell University. University Microfilms International, Ann Arbor, Michigan.

Heckler S.L. 2004. Tedium and creativity: The valorization of manioc cultivation and Piaroa women. J Roy Anth Inst 10: 241 – 259.

Hoffman S.D. 1993. Subsistence in transition: Indigenous Agriculture in Amazonas, Venezuela. PhD Dissertation, University of California Berkeley. University Microfilms International, Ann Arbor, Michigan.

Howard P. 2003. Women and plants: An exploration. In: Howard P. (ed.), Women and plants: Gender relations in biodiversity management and conservation, pp. 1 – 47. Zed Press and Palgrave Macmillan, London and New York.

Howard P. and Nabanoga G. 2006. Are there customary rights to plants? An inquiry among the Baganda (Uganda), with special attention to gender. World Devel (in press).

Irvine D. 1987. Resource Management by the Runa Indians of the Ecuadorian Amazon. PhD dissertation, Stanford University. University Microfilms International, Ann Arbor, Michigan.

Keys E. 1999. Kaqchikel gardens: Women, children, and multiple roles of gardens among the Maya of Highland Guatemala. Yearb Conf Lat Am Geogr 25: 89 – 10.

Knauft B.M. 1997. Gender identity, political economy and modernity in Melanesia and Amazonia. J Roy Anth Inst 3: 233 – 259.

Lazos Chavero E. and Alvarez Buylla M. 1988. Ethnobotany in a tropical-humid region: The homegardens of Balzapote, Veracruz, Mexico. J Ethnobio 8: 45 – 79.

Lerch N.C. 1999. Homegardens, cultivated plant diversity, and exchange of planting material in the Pacaya-Samiria National reserve area, Northeastern Peruvian Amazon. Masters thesis, McGill University. University Microfilms International, Ann Arbor, Michigan.

Lope Alzina D. 2006. Gendered production spaces and crop varietal selection: a case study in Yucatan, Mexico. Sing. J. Trop. Geog (in press).

Madaleno I. 2000. Urban agriculture in Belém, Brazil. Cities 17: 73 – 77.

Martin G.J. 1996. Comparative ethnobotany of the Chinantec and Mixe of the Sierra Norte, Oaxaca, Mexico. PhD dissertation, University of California, Berkeley. University Microfilms International, Ann Arbor, Michigan.

Mendez V.E., Lok R. and Somarriba E. 2001. Interdisciplinary analysis of homegardens in Nicaragua: Micro-zonation, plant use and socioeconomic importance. Agroforest Syst 51: 85 – 96.

Michon G. 1983. Village forest gardens in West Java. In: Huxley P.A. (ed.), Plant research and agroforestry, pp. 13 – 24. International Centre for Research in Agroforestry, Nairobi, Kenya.

Montagnini F. 2006. Status of homegardens in Mesoamerica In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp. 61–84. Springer Science, Dordrecht..

Murray S.J. 2001. Plants in the 'Patxokon Na': Tzotzil Maya homegardens in the highlands of Southeastern Mexico. PhD dissertation, Wayne State University. University Microfilms International, Ann Arbor, Michigan.

Palacio J. 1980. Food and social relations in a Garifuna village (Belize). PhD dissertation, University of California at Berkeley. University Microfilms International, Ann Arbor, Michigan.

Patterson M.L. 2000. Agroforestry in Belize: Maya homegardens in San Lucas. Masters thesis, University of Alberta. University Microfilms International, Ann Arbor, Michigan.

Posey D.A. 1984. A preliminary report on diversified management of tropical forest by the Kayapó Indians of the Brazilian Amazon. In: Prance G.T. and Kallunki J.A. (eds), Ethnobotany in the neotropics: Proceedings. Ethnobotany in the Neotropics Symposium, Society for Economic Botany (13-14 June 1983), Oxford, Ohio. Adv Econ Bot 1: 112 – 126. New York Botanical Garden, New York.

Roquas E. 2002. Stacked law. Land, property and conflict in Honduras. PhD dissertation, Wageningen University. Rozenberg Publishers. Amsterdam.

Ruonavaara D.L. 1996. Traditional household gardens of the Petén, Guatemala. Masters thesis, Michigan State University. University Microfilms International, Ann Arbor, Michigan.

Salick J. 1997. Subsistence and the single woman among the *Amuesha* of the Upper Amazon, Peru. In: Sachs C. (ed.), Women working the environment, pp. 139 – 153. Taylor and Francis, Washington DC.

Sereni Murrieta R.S. and Winklerprins A. 2003. Flowers of water: Homegardens and gender roles in a riverine *Caboclo* community in the lower Amazon, Brazil. Cult Agri 25: 35 – 47.

Stavrakis O. 1979. The effects of agricultural change upon social relations in a village in Northern Belize, Central America. PhD dissertation, University of Minnesota. University Microfilms International, Ann Arbor, Michigan.

Thompson S. 1977. Women, horticulture, and society in tropical America. Am Anthrop 79: 908 – 910.

Uzendoski M.A. 2004. Manioc beer and meat: Value, reproduction and cosmic substance among the Napo Runa of the Ecuadorian Amazon. J Roy Anth Inst 10: 883 – 902.

Wiersum K.F. 2006. Diversity and change in homegarden cultivation in Indonesia. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp. 13 – 24. Springer Science, Dordrecht.

Wilson W.M. 1997. Why bitter cassava (*Manihot esculenta* Crantz)? Productivity and perception of cassava in a Tukanoan Indian settlement in the Northwest Amazon (Colombia). PhD dissertation, University of Colorado at Boulder. University Microfilms International, Ann Arbor, Michigan.

Winklerprins A. 2002. House-lot gardens in Santarém, Pará, Brazil: linking rural with urban. Urb Ecosyst 6: 43 – 65.

SECTION 3

SOME NEW THRUST AREAS

CHAPTER 11

CARBON SEQUESTRATION POTENTIAL OF TROPICAL HOMEGARDENS

B.M. KUMAR

Department of Silviculture and Agroforestry, College of Forestry, Kerala Agricultural University, Thrissur 680656, Kerala, India; E-mail: <bmkumar53@yahoo.co.uk>

Keywords: Carbon stocks, Multistrata systems, Net primary productivity, Soil organic matter.

Abstract. This chapter examines the premise that tropical homegardens have a special role in carbon (C) sequestration because of their ability for carbon storage in the standing biomass, soil, and the wood products. In doing so, it analyzes the potential for C storage in homegardens and the role of homegardens in reducing CO_2 concentration in the atmosphere. Lack of reliable inventories/estimates and uncertainties in the estimation of C sequestration potential of homegardens present formidable difficulties in the analysis. Nevertheless, available information indicates that homegardening has a higher potential to sequester C compared to monospecific production systems, and the costs are lower than emission reduction or sequestration by other means. Indeed, the C sequestration potential of homegardens that mimic the structure and diversity of mature evergreen forest formations is comparable to that of such forest stands. Although experimental evidence suggests that species diversity does not necessarily mean high C sequestration, complementary or compensatory gains in resource acquisition, possibility of biological N_2 fixation and the relatively low herbivory pressure, may explain this high C sequestration ability of homegardens. Extension of homegardens into more lands and adaptive management of the existing gardens offer scope for enhanced C sequestration and economic gains.

1. INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) Special Report on Land Use, Land Use Change and Forestry (LULUCF) suggests that the average annual accounted carbon stock changes in the first commitment period (2008–2012), resulting from afforestation and reforestation, would be between 197 and 584 Tg C year^{-1} (Watson et al., 2000). Agroforestry, including the homegarden, plays a cardinal role in this respect—net changes in global C stocks are estimated to be 26

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 185–204.

Tg C year^{-1} for better agroforest management and 390 Tg (million tons) C year^{-1} for agroforestry-related land use changes in 2010 (Watson et al., 2000). Information relating to this substantial, but under-exploited potential of agroforestry as a carbon sequestration strategy has been recently reviewed by Albrecht and Kandji (2003) and Montagnini and Nair (2004). This chapter is a follow up to these reports, with the objective of examining the role of tropical homegardens as a mechanism for carbon sequestration, on which presently little or no concrete information exists. Furthermore, an attempt is made to examine carbon restitution (above- and belowground) as a function of species richness in homegardens, using biomass productivity as a 'proxy' of carbon sequestration by comparing several woody perennial-based polycultures.

2. EXTENT OF HOMEGARDENING

Although homegardens are an age-old practice in many parts of the tropics and even other parts of the world (Kumar and Nair, 2004; Nair and Kumar, 2006), only limited data are available on their extent and distribution. The available information suggests that Indonesian homegardens or *pekarangan* cover about 5.13 million ha of land, of which 1.74 million ha are in Java[1]. Homesteads cover about 0.54 million ha in Bangladesh[2] and 1.05 million ha in Sri Lanka[3] (which constitutes about 60% of the land holdings <8 ha). In Kerala, India, there are about 5.4 million predominantly small operational holdings (average size: 0.33 ha) covering a total area of 1.8 million ha[4]; about 80% of these are apparently homegardens (http://www.kerala.gov.in/dept_agri/schemes2.htm; last accessed: November 2005). Furthermore, a survey of 330 small, medium, and large farms in Thrissur district of Kerala indicated that about 74% of the cultivated lands fall under the homegarden system (Kumar, unpublished data). Thus, Kerala state has an estimated 4.32 million homegardens covering about 1.33 million ha of land. Likewise, in the Philippines over 70% of all households maintained homegardens (Christanty, 1990).

Although Montagnini (2006) argues that the global or regional importance of Mesoamerican homegardens is minimal due to their relatively small area, the South and Southeast Asian gardens seemingly have a much wider coverage and make up a substantial part of the cropped area. There are, however, considerable variations in species composition and site characteristics and, therefore, biomass and C accumulation among the different homegarden regions. Much of the homegardens are also under threat of extinction due to urbanization, fragmentation of holdings, and development of single-commodity production systems (Kumar and Nair, 2004).

3. HOMEGARDENS AS A POTENTIAL SINK FOR ATMOSPHERIC CO_2

Removal of carbon dioxide (CO_2) from atmosphere through photosynthesis and its eventual storage in biomass and soil as organic matter or secondary carbonates have, of late, received considerable scientific attention (Watson et al., 2000; FAO, 2004). Agroforestry can help reduce atmospheric CO_2 levels via three main mechanisms (Montagnini and Nair, 2004): *carbon sequestration* (creating new stocks in growing trees and soil for which a high rate of net primary production, NPP, usually greater than 2000 g C m^{-2} yr^{-1}, is imperative; Kaye et al., 2000), *carbon conservation* (easing of anthropogenic pressure on existing stocks of C in forests through conservation and management efforts), and *carbon substitution* (substitution of energy demand materials by renewable natural resources, fuelwood production, increased conversion of biomass into durable wood products for use in place of energy-intensive materials; Kürsten, 2000).

While most agroforestry systems are important in respect to one or the other mechanisms mentioned above (Ruark et al., 2003), the homegardens perhaps are unique in that all three mechanisms are relevant; i.e., they sequester C in biomass and soil, reduce fossil-fuel burning by promoting woodfuel production, help in the conservation of C stocks in existing forests by alleviating the pressure on natural forests and ensure greater synergy with the Convention on Biological Diversity (CBD). Moreover, there is no complete removal of biomass from the homegardens (Gajaseni and Gajaseni, 1999), signifying the permanence of the system. While lack of stability or permanence of the C sequestered being a major concern in LULUCF C sequestration projects (UNFCCC, 2002), the homegarden system is remarkably resilient. Additionally, C storage can last for decades if boles, stems or branches are processed in any form of long-lasting products (Roy, 1999) and the homegarden system has reasonable prospects in that respect too (Kumar et al., 1994).

Available reports and case studies on biomass production/carbon sequestration potential of tropical homegardens are summarized in Table 1, and are compared with other tropical land use systems. One particular problem, however, is the profound age-related variations in the C stocks of different land use activities. Although Tomich et al. (2002) suggested that time-averaged C stocks (e.g., half the system's C stock at its maximum age or rotation length) will be appropriate to compare C stocks of different land use systems on a scale that adjusts C stocks of the systems to their ages, adequate information on this aspect is not available in many case studies. Notwithstanding such intrinsic variability and assuming that homegardens are "steady-state systems" (Kumar and Nair, 2004), Table 1 is an attempt to compare different systems. As expected, the multi-layered woody perennial dominated systems have higher C sequestration potentials than other comparable systems. For example, the Javanese and Sumatran homegardens accumulated C in the range of 55.8 to 162.7 Mg ha^{-1} [19 Sumatran homegardens of 12 to 17 years age (Roshetko et al., 2002) and a Javanese garden of undefined age (Jensen, 1993)], which is considerably greater than monocultures of annual crops, most woodlots and simple agroforests (with one dominant species such as oil palm, cacao or coffee). Likewise, the data show that a shift from single-crop production systems to multistrata systems increased the C sequestration potential. For example, conversion of all "sun-coffee" to "shade coffee" systems in Sumatra increased average landscape level C stocks by an estimated 10 Mg C ha^{-1} during a 20-year period (van Noordwijk et al., 2002). Monospecific woodlots also accumulate substantial C in their biomass – which is, however, dependent on the species, site, and management (Table 1).

In certain cases, the aboveground C in homegardens is on par with the C stocks reported for similar-aged secondary forests (e.g., Jensen, 1993); but lower than that

Table 1. *Carbon uptake rates and carbon stocks of prominent land use systems in the tropics[1].*

Land use practice	*Duration [years]*	*C uptake [Mg C ha^{-1} yr^{-1}]*	*C stocks [Mg C ha^{-1}]*	*Remarks and source*
Primary and logged forest	Unknown	0	192 to 276	Sum of above-and below-ground C; summary of 116 sites within different land uses before and after slash and burn from Brazil, Cameroon, Indonesia and Peru (time averaged system C stocks; Sanchez, 2000)
Cropping after slash and burn	2	–76 to –112	39 to 52	As above
Crops/bush fallow	4	2 to 4	32 to 36	As above
Tall secondary forest fallows	23	5 to 9	95 to 142	As above
Complex agroforests	25 to 40	2 to 4	65 to 118	As above
Simple agroforests	15	5 to 9	65 to 92	As above
Pastures, *Imperata* grasslands	4 to 12	–0.2 to –0.6	27 to 31	As above
Indonesian homegardens, Sumatra	13.4	-	107.2 ± 37.2 [range: 55.8 to 162.7]	Sum of aboveground, litter, herbs, soil and roots (35.3, 2.0, 0.3, 60.8 and 8.8 Mg C ha^{-1} respectively; Roshetko et al., 2002)
Javanese homegarden, Legokole	-	-	63	Total biomass (including 4.4 Mg ha^{-1} of ground litter; Jensen 1993) were converted to carbon stocks by multiplying with 0.5

Forest remnants, Lampung, Indonesia	-	-	262	Time averaged total C stock above –0.3m in the soil (van Noordwijk et al., 2002)
Shade-coffee, Lampung, Indonesia	-	-	82	As above
Sun-coffee (monoculture), Lampung, Indonesia	-	-	52	As above
Monospecific stands of *Casuarina equisetifolia, Eucalyptus robusta* and *Luecaena leucocephala,* Puerto Rico	4	-	128.3, 115.7 and 116.9 respectively	Sum of aboveground, litter, herbs, soil and root C; unplanted control had 83.2 Mg C ha^{-1} (Parrotta, 1999)
Woodlots of *Acacia auriculiformis, Ailanthus triphysa, Artocarpus heterophyllus, Artocarpus hirsutus, Casuarina equisetifolia, Emblica officinalis, Leucaena leucocephala, Paraserianthes falcataria and Pterocarpus marsupium,* Kerala, India	8.8	-	26.3 to 178.4	Sum of bole, branch, foliage, roots (Kumar et al., 1998) and detrital C (Jamaludheen and Kumar, 1999): converted to carbon stocks by multiplying with 0.5
Amazonian forests: *Terra firme*, Tall Caatinga and Tall Bana forests	Unknown	-	152, 178 and 155 respectively	Above + belowground C (Cuevas and Medina 1986)

Table 1 (cont.)

Land use practice	*Duration [years]*	*C uptake [Mg C ha^{-1} y^{-1}]*	*C stocks [Mg C ha^{-1}]*	*Remarks and source*
Natural forests, Jambi, Indonesia	120	-	500	Aboveground C: (cited from Roshetko et al., 2002)
Central American lowland forests	Unknown		146	Average for six forest types (above + belowground: 114 + 32 Mg ha^{-1}); Sanford and Cuevas (1996)
Mature agroforests, Sumatra	30	-	101	Aboveground C: Roshetko et al. (2002)
Secondary forests, Sumatra	30	-	86	As above
Young agroforests, Sumatra	9	-	14	As above
Cassava, Sumatra	0.3	-	0.5	As above
Cordia alliodora + cacao, Turrialba, Costa Rica	initial 5 10		98 (soil) 156.6 213.8	Perennial C stock [i.e., soil + tree + cacao (cacao branches and stems), tree stems, estimated 85% of roots (coarse root proportion), and *Cordia* branches)]; Beer et al. (1990) cited in Montagnini and Nair (2004)

Erythrina poeppigiana + cacao, Turrialba, Costa Rica	initial	115	As above; except for *Cordia* branches
	5	159.8	
	10	220.8	
Mature forests, Mekoe, Cameroon	Unknown	270	Biomass (sum of tree, understorey, litter and roots; Duguma et al., 2001) converted to carbon stocks by multiplying with 0.5
Cacao agroforests, Mekoe, Cameroon	26	152	As above
Tectona grandis plantation, Panama	20	120.2	Sum of above (104.5 Mg ha^{-1}) and belowground C (15.7 Mg ha^{-1}); Kraenzel et al. (2003)
Food crop fields, Mekoe, Cameroon	-	43	Biomass (sum of tree[2], understorey, and roots; Duguma et al., 2001) converted to carbon stocks by multiplying with 0.5

[1]Also, see Schroeder (1994) who estimated the average carbon storage by agroforestry practices as 9, 21, 50, and 63 Mg C ha^{-1} for semiarid, subhumid, humid, and temperate regions and Albrecht and Kandji (2003) who reported a value between 12 and 228 Mg C ha^{-1} with a median value of 95 Mg ha^{-1}.
[2]When land was cleared, indigenous fruit, medicinal and timber trees (e.g., *Ricinodendron heudelotii*, *Cola nitida*, *Voacanga africana*, *Triplochiton sclerozylon* etc.) were deliberately retained.

accumulated by the mature forests in the region (114 to 500 Mg aboveground C ha^{-1} Table 1). Indeed, the homegardens resemble young secondary forests in structure and biomass accumulation and may be considered as a human-made forest kept in a permanent early successional state with considerable productive potential. Consistent with this, in a study on Kerala homegardens, Kumar et al. (1994) showed that the average standing stock of commercial timber ranged from 6.6 to 50.8 m^3 ha^{-1}. Overall, the data presented shows that the homegardens that mimic the structure and diversity of mature evergreen forest formations (Fig. 1) rank very close to mature forests in their biomass C storage potential (Table 2). This observation is based, however, on a few datasets, and should be followed up with more rigorous studies.

Figure 1. *Diversity, multistrata canopy structure, and various functional groups of food, fuel, fruit and nut yielding plants in a Kerala homegarden [coconut palms (*Cocos nucifera*), areca or betel nut palms (*Areca catechu*), jackfruit tree (*Artocarpus heterophyllus*), black pepper vines (*Piper nigrum*), plantains (*Musa *spp.) and the like].*

3.1. Uncertainties in estimating homegarden C stocks

Since net ecosystem productivity generally reflects the overall gain or loss of terrestrial C pools (Nair and Nair, 2003), larger C sinks are probable when croplands (input-intensive production systems) are converted into homegardens (*sensu*

.

Houghton and Goodale, 2004) than simple agroforests/plantations. Information on the actual rate of change in homegarden coverage and the spatial and temporal heterogeneity in C stocks are, however, not available. Lack of such data at the landscape-level particularly hampers our understanding of the potential of homegarden systems to sequester C and its eventual use in C sink projects, which is a situation that is common to most agroforestry systems (Montagnini and Nair, 2004).

Yet another challenge is the difficulty in estimating tree biomass itself. Despite the fact that most trees accumulate C in their wood, precise estimates on the C sequestration potential of several tropical trees are not available (Roshetko et al., 2002). Aboveground biomass is usually estimated with general regression equations developed for trees in the natural forests. However, the size of individual tree canopies in a forest and in an open agroforestry setting could be variable, as the trees in some agroforestry systems have more space and access to light. In addition, the crown and root architecture and tree management practices are different; the resultant variations in structure could probably result in erroneous estimates.

A more important technical issue is the definition of a standard set of methods and procedures for the inventory and monitoring of C stocks in current and potential land use and management approaches (FAO, 2004). Differing interpretations of source and sink category or other definitions, use of simplified representations with "averaged" values and uncertainties in the basic processes leading to emissions and/or removals further complicate the matter (de Jong, 2001). In addition, to estimate the effects of harvest on homegarden C stocks, accurate information on three items is required: pre-harvest biomass, the fraction of this biomass harvested or damaged, and the fraction of the harvested biomass removed; much of these are not available, making estimation of the C sequestration potential of homegardens at the landscape-level a difficult issue.

4. PLANT DIVERSITY IN HOMEGARDENS AND C SEQUESTRATION

High biodiversity is an intrinsic property of the homegardens (Kumar and Nair, 2004), which presumably favors greater NPP (Vandermeer, 1989) and higher C sequestration potential than monospecific production systems. This could be because diverse assemblages (Fig. 2) have a greater likelihood of containing species with strong responses to resources compared to species-poor assemblages (Tilman et al., 1997). The inference that diversity leads to greater NPP and thus stability of ecosystems, however, is the subject of an ongoing debate in ecology (McCann, 2000). That is, although homegardens and other multistrata systems are assumed to promote NPP and improve the soil and biomass C sequestration (Table 2), often doubts are expressed concerning the productive capacities of species mixtures (FAO, 1992; Wedin and Tilman, 1993). In particular, asymmetric competition (resource acquisition at differential rates; Wedin and Tilman, 1993) and thereby resource pre-emption by the dominant component of a competing mixture may retard their productive potential.

***Table 2**. Summary of the relative attributes of a land use continuum in the tropics.*

Attributes	*Types of land use system*					
	Intensive monoculture		*Polyculture*		*Secondary forests*	*Mature forests*
	Annual crops	*Perennial crops/ plantations*	*Simple agroforests*[9]	*Homegardens and complex multistrata systems*		
C stocks[1]						
Aboveground	low	low-high[8]	low-high	medium-high	medium-high	very high
Soil	low	low-high	low-high	medium-high	medium-high	very high
Fossil fuel inputs/subsidies (C costs)[2]	high	medium-high	low-medium	low	zero	zero
Ecosystem services[3]	low	low-medium	low-high	medium-high	high	very high
Diversity[3]	low	low	medium	high	very high	very high
Herbivory pressure[4]	high	high	medium	low	low	very low
Loss rate of soil C (decomposition)[5]	high-very high	medium	medium	low-medium	low-medium	low
Nutrient outputs[6] (leaching/other losses)	high	medium	medium	low	low	very low
Soil biota[7]	low	low	medium	high	high	very high

Explanatory Notes.

[1]Low (<30 Mg C ha^{-1}), medium (31 to 80 Mg C ha^{-1}); high (81 to 120 Mg C ha^{-1}) and very high (>121 Mg C ha^{-1}); upper limits represent the midpoints of the range of values reported by Sanchez (2000) for pastures, simple agroforests and complex agroforests rounded to the nearest multiple of 10 (see Table 1).

[2]Annual/perennial crops are usually fertilized, irrigated, and managed with heavy doses of plant protection chemicals; agroforestry in general is less input intensive and for homegardens, in particular, little or no chemical inputs are used, while the natural systems are self-nourished.

[3]Agricultural intensification (e.g., large-scale use of agricultural chemicals) reduces diversity and abundance of biota; for example, the bees, which render pollination services (Kremen et al., 2002).

[4]The natural enemy complex of crop pests/pathogens is generally low in intensive monospecific production systems than in polycultures; consequently, the herbivory pressure is much lower in the natural and woody perennial-based mixtures (Keenan et al., 1995; Ball et al., 1995; Jactel et al., 2005).

[5]Soil organic matter (SOM), a keystone component of the ecosystem (*sensu* Swift et al., 2004), is related to the quantity and variability of plant litter inputs. Higher floristic diversity generally ensures greater litter heterogeneity (Hättenschwiler et al., 2005) and the "species-rich" systems generally have a greater chance of maintaining soil organic matter relations than the "species-poor" ones (Russell et al., 2004).

[6]Loss of perennial vegetation leads to erosion, reduced soil quality, and low productivity (Singh et al., 1992; Vinod et al., 2003).

[7]Greater organic matter fluxes in woody perennial-based systems favor soil biota (Vohland and Schroth, 1999; Kumar and Nair, 2004).

[8]Wherever ranges are mentioned, it denotes variations because of stand age, species, management and/stage of succession.

[9]with one dominant species such as oil palm, cacao, coffee and the like.

The implicit assumption in studies reporting the positive "mixture effect," however, is that one or more of the components improve the environment (facilitative production principle; Vandermeer, 1989) and/or share site resources harmoniously. The contribution of biologically fixed N_2 to the associated non-N_2 fixing component is particularly relevant in this respect. Legumes in general are thought to be soil improvers—and may promote the growth and productivity of components in such systems (Kaye et al., 2000); yet there is no agreement on the role of woody legumes in promoting growth and NPP of associated woody non-legume components. Lack of consistent impacts of the legume components in experimental mixtures (Parrotta, 1999; Gathumbi et al., 2004), can be explained based on species, site attributes—especially soil N content and soil management, ensuring the availability of appropriate rhizobial strains and maintenance of conditions suitable for their multiplication.

In certain cases, productivity has been linked to site quality; for example, higher productivity for mixtures on nutrient-poor sites (Montagnini et al., 1995). Furthermore, there are considerable variations in the C sequestration potential of individual gardens and species, implying both within- and between- garden variations (Table 1). Yet, no comparative accounts on homegarden productivity as a function of its floristic attributes could be found. Issues such as what contributes to the superior performance of multistrata systems and homegardens also have not been adequately addressed. Such an analysis, however, is relevant to the CBD to which land use change, agriculture and forestry activities recognized by the Kyoto Protocol are closely linked. Aside from the ecological benefits of biological diversity conservation and improved site fertility, species mixtures offer greater resistance to insect infestation or disease outbreak (Table 2). A recent review, based on a meta-analysis of more than 50 field experiments, which contrasted pure stand vs. mixed stand of the same tree species, demonstrated a significant increase in insect pest damage in single-species stands (Jactel et al., 2005).

It is probable that the relative superiority is dependent on species/circumstances, and is not amenable to sweeping generalizations; i.e., the effect may be positive, negative, or neutral. Ideally, in a mixture, the components should exploit different vertical layers—both above- and belowground—which signifies greater resource utilization efficiency. This idea, however, pre-supposes that species with divergent growth characteristics, be mixed for optimizing resource capture (Kumar et al., 2001; Gathumbi et al., 2002). An interesting aspect of belowground resource use, however, is that the proximity of species/individuals often favors competitive downward displacement of tree roots (Kumar and Divakara, 2001). That is, in certain cases, species may develop vertically stratified root systems, and this spatial segregation of the roots of associated plants may abate possible inter specific competition in species-mixtures (Divakara et al., 2001). By extension, in home-gardens, depending upon the nature of associated tree components, a greater potential to capture the lower leaching nutrients and accomplishing on-site nutrient conservation is probable (safety-net mechanism). Therefore, if planned with consideration for each species' growth characteristics, mixed stands and home-gardens could, theoretically, be more productive than single species stands and would probably sequester more C.

.

5. PRODUCTIVITY UNDER RISING ATMOSPHERIC CO_2 LEVELS

Although it is now clear that high CO_2 emission levels (Houghton, 1995) will have several adverse fallouts, indications are that the elevated CO_2 may increase plant photosynthesis and NPP to some extent (Mingkui and Woodard, 1998). Given that the capacity of the photosynthetic machinery of C_3 plants remains unsaturated at current concentrations of close to 370 ppm of CO_2 (Körner, 2003), this seems reasonable too (but see Luo et al., 2004). Some experimental evidences also suggest that plant diversity and composition influence the enhancement of biomass and C acquisition in ecosystems subjected to elevated atmospheric CO_2 concentrations. For instance, Reich et al. (2001) reported that biomass accumulation was greater in species-rich than in species-poor experimental populations under conditions of CO_2 and N fertilization. By extension, homegardens, which are inherently species-rich, may trap progressively greater quantities of atmospheric CO_2 under rising levels of this gas. In view of the limited nature and range of the experimental studies reported (mostly from temperate regions and none on tropical homegardens), however, it is difficult to draw firm generalizations on the effects of enriched CO_2 levels on C sequestration, especially in the tropics.

6. SOIL CARBON SEQUESTRATION

More than half of the C assimilated by woody perennials is eventually transported belowground via root growth and organic matter turnover processes (e.g., fine root dynamics, rhizodeposition, and litter dynamics), making soil organic carbon (SOC) a significant pool of terrestrial C (~2500 Pg C globally; Lal, 2004). In view of the great diversity and abundance of woody perennial components, it is perhaps reasonable to assume that the magnitude of such processes will be greater in homegardens compared to other systems (Gajaseni and Gajaseni, 1999; Kumar and Nair, 2004). Judicious management of plant residues as it is often practiced in homegardens also can contribute to increases in soil organic matter content (Montagnini, 2006). There is, however, great variation among homegardens in this respect. For instance, Roshetko et al. (2002) found that SOC of Indonesian homegardens ranged between 10.4 to 103.7 Mg C ha^{-1}.

The C stored within the soil may increase and under certain conditions biomass production also increases, augmenting C inputs (root biomass, litter and prunings) into the soil (*sensu* Lal et al., 1998). Consistent with this, Russell (2002) noted that total SOC may increase directly with basal area of the trees included in the system. Both inputs and decomposition rates are, however, strongly affected by a host of factors (Lal et al., 1998) including climate change (Schimel et al., 2000). Warmer temperatures generally accelerate litter decomposition. However, in view of the possible stimulatory effects of rising atmospheric CO_2 levels on photosynthetic production and the associated greater litterfall production rates, the effects are seemingly more complex (Kumar et al., 2005).

Soil organisms such as microflora (bacteria, fungi, actinomycetes and algae), mesofauna (mites, collembola, micro-arthropods and enchytraeid worms), microfauna (protozoa, nematodes and mites) and macrofauna (earthworms, spiders, slaters, centipedes, larvae, molluscs, etc.) fulfill a wide range of ecosystem services that underpin C sequestration and eventually the sustainability of the homegarden system (Table 2). However, as on many other aspects of belowground diversity, few data are available on the composition of soil biota or its determinants in the homegardens. This is partly because soil research in multistrata agroforestry systems poses methodological difficulties. Owing to variations in soil microenvironment, profound intra-garden variations in soil biotic activity are also probable.

7. CARBON SEQUESTRATION PROGRAMS AND LIVELIHOOD SECURITY OF RURAL PEOPLE

The Kyoto Protocol, the main instrument of the United Nations Framework Convention on Climate Change (UNFCCC), has set up the Clean Development Mechanism (CDM) concept as a cost-effective process to reduce rural poverty by extending payments to low-income farmers who provide carbon storage through land use systems[5]. Projects under the CDMs usually have the dual mandate of reducing greenhouse gas emissions and contributing to sustainable development. Implicit in this are, trade-offs between carbon sequestration, local social development, economic well-being and access to resources, and other aspects of environmental changes. Moreover, C storage through agroforestry is less costly (range \$1–69/Mg C, median \$13/Mg C) than through other CO_2 mitigating options such as pure tree-based systems, carbon dioxide capture and storage or emission reduction (Albrecht and Kandji, 2003). It allows investors in developed countries to receive carbon credits in exchange for greenhouse gas emission reductions, whilst the developing countries where such investments are made, receive investments. There are many examples of how payment for environmental services to farmers can be made, while implementing mitigation projects (Brown et al., 2004; Montagnini and Nair, 2004). Carbon finance projects, thus, could transcend the existing barriers in resource mobilization for sustainable development of the developing countries.

Although a number of such projects have been initiated as pilot activities around the globe, in alliance with non-governmental or development agencies, none of these as of date, are on tropical homegardens, implying that the potential of homegardens as a strategy for carbon sequestration has not yet been fully recognized, let alone exploited. Yet, the homegarden system offers considerable scope to improve biomass accumulation, and overcome "excess problems" (i.e., ameliorating "soil sickness" through mechanisms such as phytoremediation). Three pathways could be explored to promote externalities in agroforestry, in general, and homegarden systems, in particular. These are:

- "Bringing more land under homegardens": More land should be brought under agroforestry, resulting in more C sequestered in the landscape. There are already plenty of degraded lands available in most developing countries. For example, an estimated 1900 million ha of land is affected by soil degradation worldwide; of these, the largest area (around 747 million ha) is in the Asian region (van Lynden and Oldeman, 1997); India alone has an estimated 130 million ha of degraded lands[6]. The bottom line is that degraded sites could be molded into reasonably productive systems by appropriate policy and/or management interventions. For example, the indigenous Mayan groups have survived the extreme conditions by developing the multistrata homegardens over the karst topography, formed by limestone bedrock, and limited amounts of precipitation (Benjamin et al., 2001).

- Intensification: More C can be sequestered per unit of land by improving efficiency of production through the choice of optimal species combinations and/or appropriate stand management practices, on which little scientific information exists, however. Moreover, restoring soil C triggers soil quality improvements (Lal, 2004). Multistrata stands and polycultures such as homegardens not only increase C sinks in soil and vegetation but also improve agricultural productivity and livelihood security, and are thought to be one step closer in the transformation of barren landscapes to "perpetually natural looking forests"—clearly a "win-win" situation (FAO, 2004).
- Conservation: Ensuring long-term stability and sustainability—if such polycultures at least partially alleviate the anthropogenic pressure on natural forests— improves biodiversity conservation and reduce fossil fuel consumption. Many such traditional land use systems are, however, experiencing severe strains (Kumar and Nair, 2004), especially in the backdrop of technological changes; and to preserve them, appropriate land use policies/managerial interventions are needed.

8. CONCLUSIONS

Under the Kyoto Protocol, one clear strategy for mitigating the increase in atmospheric CO_2 is to expand the size of the terrestrial C sink, using trees on agricultural lands as "biological scrubbers." The magnitude of such C sequestration may, however, be dependent on the nature and extent of agroforestry system involved, and its structure and function, which in turn, are dependent on species composition and system management. Apparently, the homegardens have a special role in such abatement processes. Overall, they occupy the penultimate position in a tropical land use continuum ranging from annual crops to mature forests (Table 2). In particular, aspects such as higher biomass production potential and the return of a greater proportion of plant materials to the soil to increase its C stock compared to other agroforestry systems have been adequately demonstrated. In addition, they ensure "carbon permanence," which the "carbon contracts" require, farmers to adopt; maintain sustainability and exploit the synergies between CBD and the Kyoto Protocol.

One of the major constraints in employing homegardens to provide environmental benefits, however, is the lack of quantitative data on such potential advantages. Nevertheless, in view of the substantial coverage of homegardens in some geographical regions (e.g., south and southeast Asia) and especially if effective policies to promote such land use systems are implemented especially for degraded lands, they could become large carbon sinks; and the mitigation costs are probably lower than what is required for emission source controls. Indeed, the traditional knowledge has shown that the homegarden system is ideally suited for regions characterized by highly weathered soils with relatively lower nutrient endowments as in the lateritic soils of Kerala and the karst deposits of Yucatán Peninsula. On a final note, science and natural resource policy should recognize the work of local people who still maintain agroecosystems with high agrobiodiversity as part of their culture, lifestyle, or practice.

ENDNOTES

1. Badan Pusat Statistik (BPS) 2000. Statistical yearbook of Indonesia 2000, Jakarta, 590p.
2. Bangladesh Bureau of Statistics (BBS) 2001. Statistical yearbook 2000. Ministry of Planning, Government of People's Republic of Bangladesh, Dhaka, 452p.
3. Department of Census and Statistics (DCS) 2003. Census of agriculture – Sri Lanka 2002. Agricultural holdings, extent under major crops and livestock statistics by district and DS/AGA division: based on operator's residence—small holding sector. Preliminary Release– No. 2, P.O. Box 563, Colombo, 62p (www.statistics.gov.lk). Last accessed: November 2005.
4. Kerala State Land Use Board (KSLUB) 1995. Land resources of Kerala State. Thiruvananthapuram, Kerala, 209p.
5. Smith J. and Scherr S.J. 2002. Forest Carbon and local livelihoods: assessment of opportunities and policy recommendations. CIFOR Occasional Paper 37, Centre for International Forestry Research, Jakarta, 45p.
6. Indian Council of Forestry Research and Education (ICFRE) 2000. Forestry statistics—2000. Directorate of Statistics, Indian Council of Forestry Research and Education, Dehra Dun, pp 55.

REFERENCES

Albrecht A. and Kandji S.T. 2003. Carbon sequestration in tropical agroforestry systems. Agric Ecosyst Environ 99: 15 – 27.

Ball J.B., Wormald T.J. and Russo L. 1995. Experience with mixed and single species plantations. Commonwealth For Rev 74: 301 – 305.

Beer J., Bonnemann A., Chavez W., Fassbender H.W., Imbach A.C. and Martel I. 1990. Modelling agroforestry systems of cacao (*Theobroma cacao*) with laurel (*Cordia alliodora*) or poro (*Erythrina poeppigiana*) in Costa Rica. V. Productivity indices, organic material models and sustainability over ten years. Agroforest Syst 12: 229 – 249.

Benjamin T.J., Montanez P.I. Jimenex J.J.M. and Gillespie A.R. 2001. Carbon, water and nutrient flux in Maya homegardens in the Yucatan peninsula of Mexico. Agroforest Syst 53: 103 – 111.

Brown K., Adger W. N., Boyd E., Corbera-Elizalde E. and Shackley S. 2004. How do CDM projects contribute to sustainable development? Tyndall Centre Technical Report No. 16. University of East Anglia, Norwich, UK, 54p. http://www.tyndall.ac.uk/publications/tech_reports/tech_reports.shtml (last accessed: December 2005).

Christanty L. 1990. Homegardens in tropical Asia with special reference to Indonesia. In Landauer K. and Brazil M. (eds), Tropical home gardens, pp. 9 – 20. United Nations University Press, Tokyo.

Cuevas E. and Medina E. 1986. Nutrient dynamics within Amazonian forests. 1. Nutrient flux in fine litterfall and efficiency of nutrient utilization. Oecologia 68: 466 – 472.
de Jong B.H.J. 2001. Uncertainties in estimating the potential for carbon mitigation of forest management. For Ecol Manag 154: 85 – 104.
Divakara B.N., Kumar B.M., Balachandran P.V. and Kamalam N.V. 2001. Bamboo hedgerow systems in Kerala, India: root distribution and competition with trees for phosphorus. Agroforest Syst 51: 189 – 200.
Duguma B., Gockowski J. and Bakala J. 2001. Smallholder cacao (*Theobroma cacao* Linn.) cultivation in agroforestry systems of West and Central Africa: challenges and opportunities. Agroforest Syst 51: 177 – 188.
FAO. 2004. Assessing carbon stocks and modelling win–win scenarios of carbon sequestration through land use changes. Food and Agriculture Organization of the United Nations, Rome, 156p.
FAO. 1992. Mixed and pure forest plantations in the tropics and sub-tropics. FAO Forestry Paper 103, Food and Agriculture Organization of the United Nations, Rome, 152p.
Gajaseni J. and Gajaseni N. 1999. Ecological rationalities of the traditional homegarden system in the Chao Phraya Basin, Thailand. Agroforest Syst 46: 3 – 23.
Gathumbi S.M., Cadisch G. and Giller K.E. 2004. Improved fallows: effects of species interaction on growth and productivity in monoculture and mixed stands. For Ecol Manag 187: 267 – 280.
Gathumbi S.M., Ndufa J.K., Giller K.E. and Cadisch G. 2002. Do species mixtures increase above- and belowground resource capturing in woody and herbaceous tropical legumes? Agron J 94: 518 – 526.
Hättenschwiler S., Tiunov A.V. and Scheu S. 2005. Biodiversity and litter decomposition in terrestrial ecosystems. Ann Rev Ecol Evol Syst 36: 191 – 218.
Houghton J.T. 1995. Determining emissions of carbon from land: a global strategy. In: Murai S. (ed.), Toward global planning of sustainable use of the earth, pp 59 – 76. Elsevier, Amsterdam.
Houghton R.A. and Goodale C.L. 2004. Effects of land use change on the carbon balance of terrestrial ecosystems. Ecosystems and land use change. Geophys Monogr Ser 153: 85 – 98.
Jactel H., Brockerhoff E. and Duelli P. 2005. A test of the biodiversity–stability theory: meta-analysis of tree species diversity effects on insect pest infestations, and re-examination of responsible factors. In: Scherer-Lorenzen M., Körner Ch., and Schulze E.-D. (eds), Forest diversity and function: Temperate and Boreal Systems. Ecological Studies, Vol. 176. pp 235 – 262. Springer-Verlag, Berlin, Heidelberg.
Jamaludheen V. and Kumar B.M. 1999. Litter of nine multipurpose trees in Kerala, India- variations in the amount, quality, decay rates and release of nutrients. For Ecol Manag 115: 1 – 11.
Jensen M. 1993. Soil conditions, vegetation structure and biomass of a Javanese homegarden. Agroforest Syst 24: 171 – 186.
Kaye J.P., Resh C.S., Kaye M.W. and Chimner R.A. 2000. Nutrient and carbon dynamics in a replacement series of *Eucalyptus* and *Albizia* trees. Ecology 81: 3267 – 3273.
Keenan R., Lamb D. and Sexton G. 1995. Experience with mixed species rainforest plantations in North Queensland. Commonwealth For Rev 74: 315 – 321.
Körner C. 2003. Carbon limitation in trees. J Ecol 91: 4 – 17.
Kraenzel M., Castillo A., Moore, T. and Potvin C. 2003. Carbon storage of harvest –age teak (*Tectona grandis*) plantations, Panama. For Ecol Manag 173: 213 – 225.
Kremen C., Williams N.M. and Thorp R.W. 2002. Crop pollination from native bees at risk from agricultural intensification. Proc Natl Acad Sci 99: 16812 – 16816.

Kumar B.M. and Divakara B.N. 2001. Proximity, clump size and root distribution pattern in bamboo: A case study of *Bambusa arundinacea* (Retz.) Willd., Poaceae, in the Ultisols of Kerala, India. J Bamboo Rattan 1: 43 – 58.

Kumar B.M. and Nair P.K.R. 2004. The enigma of tropical homegardens. Agroforest Syst 61: 135 – 152.

Kumar B.M, George S.J. and Chinnamani S. 1994. Diversity, structure, and standing stock of wood in the homegardens of Kerala in peninsular India. Agroforest Syst 25: 243 – 262.

Kumar B.M., George S.J., Jamaludheen V. and Suresh T.K. 1998. Comparison of biomass production, tree allometry and nutrient use efficiency of multipurpose trees grown in wood lot and silvopastoral experiments in Kerala, India. For Ecol Manag 112: 145 – 163.

Kumar B.M., Haibara K. and Toda H. 2005. Does plant litter become more recalcitrant under elevated atmospheric CO_2 levels? Global Environ Res 9: 83-91.

Kumar B.M., Thomas J. and Fisher R.F. 2001. *Ailanthus triphysa* at different density and fertilizer levels in Kerala, India: tree growth, light transmittance, and understorey ginger yield. Agroforest Syst 52: 133 – 144.

Kürsten E. 2000. Fuelwood production in agroforestry systems for sustainable land use and CO_2 mitigation. Ecol Eng 16: 69 – 72.

Lal R. 2004. Soil carbon sequestration impacts on global change and food security. Science 304: 1623 – 1627.

Lal R., Kimble J.M., Follett R.F. and Stewart B.A. 1998. Soil Processes and the Carbon Cycle. CRC Press LLC, MA, 609p.

Luo Y., Su Bo, Currie W.S., Dukes J.S., Finzi A., Hartwig U., Hungate B., McMurtrie R.E., Oren R., Parton W.J., Pataki D.E., Shaw, M.R., Zak D.R. and Field C.B. 2004. Progressive nitrogen limitation of ecosystem responses to rising atmospheric carbon dioxide. BioScience 54: 731 – 739.

McCann K.S. 2000. The diversity-stability debate. Nature 405: 228 – 233.

Mingkui C. and Woodard F.I. 1998. Dynamic responses of terrestrial ecosystem carbon cycling to global climatic change. Nature 393: 249 – 252.

Montagnini F. 2006. Status of homegardens in Mesoamerica. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 61 – 84. Springer Science, Dordrecht.

Montagnini F. and Nair P.K.R. 2004 Carbon sequestration: an underexploited environmental benefit of agroforestry systems. Agroforest Syst 61: 281 – 295.

Montagnini F., Gonzalez E., Porras C. and Rheingans R. 1995. Mixed and pure forest plantations in the humid neotropics: a comparison of early growth, pest damage, and establishment costs. Commonwealth For Rev 74: 306 – 314.

Nair P.K.R. and Kumar B.M. 2006. Introduction. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 1 – 10. Springer Science, Dordrecht.

Nair P.K.R. and Nair V.D. 2003. Carbon storage in North American agroforestry systems. In: Kimble J., Heath L.S., Birdsey R.A., and Lal R. (eds), The potential of U.S. forest soils to sequester carbon and mitigate the greenhouse effect, pp 333 – 346. CRC Press, Boca Raton, FL.

Parrotta J.A. 1999. Productivity, nutrient cycling and succession in single- and mixed-species stands of *Casuarina equisetifolia*, *Eucalyptus robusta* and *Leucaena leucocephala* in Puerto Rico. For Ecol Manag 124: 45 – 77.

Reich P.B., Knops J., Tilman D., Craine J., Ellsworth D. Tjoelker M., Lee T., Wedin D., Naem S., Bahauddin D., Hendrey G., Jose S., Wrage K., Goth J. and Bengston W. 2001. Plant diversity enhances ecosystem responses to elevated CO_2 and nitrogen deposition. Nature 410: 809 – 812.

Roshetko M., Delaney M., Hairiah K. and Purnomosidhi P. 2002. Carbon stocks in Indonesian homegarden systems: Can smallholder systems be targeted for increased carbon storage? Am J Alt Agr 17: 125 – 137.

Roy C. 1999. Options techniques et socio-économiques des émissions de CO_2 et d'augmentation des stocks de carbone. CR Acad Agric. France 85: 311 – 320.

Ruark G.A., Schoeneberger M.M. and Nair P.K.R. 2003. Agroforestry–Helping to Achieve Sustainable Forest Management. UNFF (United Nations Forum for Forests) Intersessional Experts Meeting on the Role of Planted Forests in Sustainable Forest Management, New Zealand (24 – 30 March 2003). www.maf.govt.nz/unff-planted-forestry-meeting (last accessed: July 2005).

Russell A.E. 2002. Relationships between crop-species diversity and soil characteristics in southwest Indian agroecosystems Agric Ecosyst Environ 92: 235 – 249.

Russell A.E., Cambardella C.A., Ewel J.J. and Parkin T.B. 2004. Species, rotation, and life form diversity effects on soil carbon in experimental tropical ecosystems. Ecol Appl 14: 47 – 60.

Sanchez P.A. 2000. Linking climate change research with food security and poverty reduction in the tropics. Agric Ecosyst Environ 82: 371 – 383.

Sanford R.L. and Cuevas E. 1996. Root growth and rhizosphere interactions in tropical forests. In: Mulkey S., Chazdon R.L., and Smith A.P. (eds), Tropical forest plant ecophysiology, pp 268 – 300. Chapman and Hall, New York.

Schimel D., Melillo J., Tian H., McGuire A.D., Kicklighter D., Kittel T., Rosenbloom N., Running S., Thornton P., Ojima D., Parton W., Kelly R., Sykes M., Neilson R. and Rizzo B. 2000. Contribution of increasing CO_2 and climate to carbon storage by ecosystems in the United States. Science 287: 2004 – 2006.

Schroeder P. 1994. Carbon storage benefits of agroforestry systems. Agroforest Syst 27: 89 – 97.

Singh G., Babu R., Narain P., Bhushan L.S. and Abrol I.P. 1992. Soil erosion rates in India. J Soil Water Conserv 47 (1): 97 – 99.

Swift M.J., Izac A.-M.N. and van Noordwijk M. 2004. Biodiversity and ecosystem services in agricultural landscapes—are we asking the right questions? Agric Ecosyst Environ 104: 113 – 134.

Tilman D., Lehman C.L. and Thomson K.T. 1997. Plant diversity and ecosystem productivity: theoretical considerations. Proc Natl Acad Sci USA 94: 1857 – 1861.

Tomich T.P., de Foresta H., Dennis R., Ketterings Q., Murdiyarso D., Palm C., Stolle F., and van Noordwijk M. 2002. Carbon offsets for conservation and development in Indonesia? Am Alt Agr 17: 125 – 137.

UNFCCC 2002. Activities implemented jointly under the pilot phase. Sixth synthesis report. Subsidiary Body for Scientific and Technological Advice. FCCC/SBSTA/2002/8. United Nations Framework Convention on Climate Change, Bonn 5p (http://unfccc.int/resource/docs/2002/sbsta/08. pdf; last accessed: December 2005).

van Lynden G.W.J. and Oldeman L.R. 1997. The Assessment of the Status of Human-Induced Soil Degradation in South and Southeast Asia. International Soil Reference and Information Centre, Wageningen, 35p.

van Noordwijk M., Rahayu S., Hairiah K., Wulan Y.C., Farida A. and Verbist B. 2002. Carbon stock assessment for a forest-to- coffee conversion landscape in Sumber-Jaya (Lampung, Indonesia): from allometric equations to land use change analysis. Science in China Series C-Life Sciences 45: 75 – 86 Suppl. S Oct 2002. Science in China Press, Beijing.

Vandermeer J. 1989. The Ecology of Intercropping. Cambridge University Press, Cambridge, 249p.

Vinod V.R., Syed Anwarulla M. and Vishwanth D.P. 2003. Run off and soil loss under different land use systems in the Western Ghats of Karnataka. Indian J Soil Conserv 31: 131 – 138.

Vohland K. and Schroth G. 1999. Distribution patterns of the litter macrofauna in agroforestry and monoculture plantations in central Amazonia as affected by plant species and management. Applied Soil Ecol 13: 57 – 68.

Watson R.T., Noble I.R., Bolin B., Ravindranath N.H., Verardo D.J. and Dokken D.J. (eds). 2000. Intergovernmental Panel on Climate Change (IPCC). Land use, land use change, and forestry. A special report of the Intergovernmental Panel on Climate Change. Cambridge University Press, 377p.

Wedin D. and Tilman D. 1993. Competition among grasses along a nitrogen gradient: initial conditions and mechanisms of competition. Ecol Monogr 63: 199 – 229.

CHAPTER 12

MEDICINAL PLANTS IN TROPICAL HOMEGARDENS

M.R. RAO[1] AND B.R. RAJESWARA RAO[2]

[1]*Former ICRAF Scientist; Current address: Plot No. 11, ICRISAT Colony (Phase-I), Brig. Syed Road, Manovikasnagar (P.O.), Secunderabad 500 009, India; E-mail: <mekarao@sol.net.in>.* [2]*Central Institute of Medicinal and Aromatic Plants (CIMAP) Resource Centre, Boduppal, Uppal P.O., Hyderabad 500 039, India*

Keywords: Aromatic plants, Bioprospecting, Indigenous knowledge, Phytochemicals, Traditional medicine, Value addition.

Abstract. Nearly 80% of the people living in developing countries depend on medicinal plants (MPs) for primary healthcare, and homegardens are an important source of production of these plants. Homegardens can fulfill the dual role of production and *in situ* conservation of MPs to overcome their dwindling supplies and threat of extinction from natural sources. MPs in homegardens are either deliberately cultivated or they come up spontaneously. They are an important constituent of homegardens, next only to food crops and fruit trees; yet their economic value is not fully recognized, let alone exploited. Homegardens offer an economically and socially viable option for large-scale production of phytochemicals from important MPs under organic cultivation. Promoting organic production of selected commercially valuable species of MPs through homegardening can, thus, augment the farmers' income, enhance rural employment opportunities, and help reduce migration of rural youth to urban centers in search of jobs. Research is needed to improve the existing germplasm, introduce suitable commercial MPs in different agroecosystems, and develop cultivation and processing techniques to increase yield and improve product quality, and exploit indigenous knowledge and market opportunities.

1. INTRODUCTION

Humans depended on certain plants for healthcare since time immemorial. Centuries of experimentation on the use of plants or products derived from them has led to the development of indigenous systems of medicine that are still respected and used in many societies. Plants have been a source of medicines for humans and livestock and pesticides to protect crops from certain pests and diseases. In India, over 200 types of vegetable drugs were in use during the *Vedic* period (3700 – 2000 BC). *Charak Samhita* (600 BC) mentioned 1270 medicinal plants (MPs), while *Sushruta*

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 205–232.

Samhita (450 BC) and Vagbhatta's *Astangahridaya* (342 BC) mention about 1100 and 1150 MPs, respectively (Chadha and Gupta, 1995). America, Arabia, China, Egypt, Greece, Mexico, and many other countries in Europe and Asia too recorded the use of MPs (Principe, 1991). Furthermore, about 1800 species of MPs are reported to be used in the traditional Indian medical system of *Ayurveda*, 750 species in *Unani* or *Tib*, 500 species in *Siddha*, 400 species in the Tibetan medicine and 5000 species in the Chinese medicine. Traditional medical systems in Japan, Korea (*Kampo* system), Indonesia (*Jamu* system), South Africa (*Julu* system), Bhutan (*Gso-ba-rig-pa*), Sri Lanka (*Deshiya Chikitsa*), and Malaysia (Malay herbal medicine) also recorded a number of MPs and their uses (Principe, 1991).

An estimated 14 to 28% of the 422 000 plants occurring on earth had been used by human cultures for medicinal purposes at one time or another (Farnsworth and Soejarto, 1991). Approximately 80% of the people in developing countries rely even today mainly on traditional medicines for humans (FAO, 1996) as well as domestic animals, a major portion of which are extracts of medicinal plants or their active principles. More than 6500 species of such medicinal plants have been identified in Asia, 1900 species in tropical America and 1300 species in north-west Amazon (Farnsworth and Soejarto, 1991). Global trade in plant-based drugs was estimated at US$ 100 billion, of which traditional medicines using medicinal plants accounted for 60 billion (WHO, 2004). In addition, trade[1] in herbal teas, drug adjuncts, dietary foods etc. (sold over the counter) was estimated at US$ 5 billion in 1997. India has approximately 150 000 practitioners of traditional systems of medicine, 10 000 licensed pharmacies manufacturing plant-based drugs. The trade in medicinal herbs in India was estimated at US$ 1 billion (EXIM Bank, 2003) and the country exports medicinal herbs worth US$ 287 million annually[2].

Most of the medicinal plants (70 to 90%) have traditionally been collected from forests and natural habitats. Indiscriminate extraction over years not only reduced their supplies but also endangered some of these valuable species. The growing demand for plant-derived drugs both in modern and traditional systems of medicine[3] further exacerbated the problem in many natural habitats. This has led to the extinction of about 75 species between 1600 and 1900 and a similar number in a short span between 1900 and 1970 (Principe, 1991; Rao, 1999). It is feared that if this trend continues, about 60 000 species will become extinct in the next century (Principe, 1991). Considering the economic importance of medicinal plants, there is an urgent need to systematically cultivate them to exploit their full potential and to save them from extinction. MPs can be cultivated like any other crop(s) in different systems including agroforestry – in forest plantations, homegardens, as intercrops between trees, and as components of multistrata systems (Rao et al., 2004). This chapter reviews the status of medicinal plants in tropical homegardens and examines the scope for improving their relative contribution to the economy of rural families.

2. MEDICINAL PLANTS IN HOMEGARDENS

Homegardens being one of the earliest forms of agroforestry practiced in the tropics (Kumar and Nair, 2004), it is only logical to be expected that MPs have been an essential component of these production systems (Tables 1 and 2). Indeed, the homegardens make a substantial contribution to the supply of MPs, which may be traded or consumed locally by the family or community (Albuquerique and Andrade, 2002). There is, however, no reliable data on the extent of homegardens in different countries (see Nair and Kumar, 2006), yields of medicinal plants, or products extracted and sold at national and international levels. Majority of MPs in homegardens are herbs/vines/climbers and they together with vegetables and spices generally constitute the lower layer (0 – 1 m), unless they are vines and climbers. Additionally, a number of homegarden shrub and tree species also have medicinal value and they constitute the second (1 – 3 m) and upper (>10 m) layers respectively (Wezel and Bender, 2003). Some species that grow spontaneously in homegardens may possess medicinal value which may or may not be recognized and used. For example, in Chiriqui, Panama, the Ngöbe community utilizes the land fallowed for soil fertility replenishment as a source of MPs (Samaniego and Lok, 1998). Nearly half of the 41 weed species found in the homegardens of Central Sulawesi, Indonesia, possess medicinal value (Kehlenbeck and Maass, 2005). In India, seasonal weeds such as *Phyllanthus amarus*, *Boerhaavia diffusa*, *Achyranthus aspera*, *Tribulus terrestris*, *Sida cordifolia*, and *Aerva lanata* that occur both in cultivated fields (including homegardens) and wild are collected for medicinal purposes (Rao et al., 1999).

2.1. Relative importance of MPs in homegardens

While some components in the homegardens have exclusive medicinal value, others are multipurpose species combining medicinal value with food, ornamental, fiber, and spice values. For example, in the Kandyan homegardens of Sri Lanka, 30% of the total 125 species found were exclusively mentioned for medicinal uses and 12% combined medicinal with other uses. Among the medicinal species, trees constituted 7%, shrubs 5%, herbs 15%, and creepers 3% of the total species (Perera and Rajapakse, 1991). Homegardens in Bukoba district in northwestern Tanzania contained species that were said to be used exclusively for medicine (*Baphiopsis* spp., *Cyperus dives*, *Leonotis nepetifolia*, *Vernonia amygdalina*, and *Solanum incanum*), those that combined medicine and fuelwood (*Senecio multicorymbosa* tree for medicines to cattle), medicine, fruit, and fuelwood (*Psidium guajava* and *Citrus limon*), and propping poles and medicine (*Ricinus communis*; Rugalema et al., 1994). The Chagga homegardens on Mt. Kilimanjaro in Tanzania were dominated by woody components; nearly 50% of the 111 species found in the region were trees, of which 30% were mentioned as medicines for humans and livestock (O'Kting'ati et al., 1984). Of the 77 useful plants (shrubs, vines, and forbs) found across 80 traditional Mayan homegardens in Quitana Roo, Mexico, nine were reported to have exclusive medicinal value and 26 species combined medicine, food, spice, and ornamental values (De Clerck and Negreros-Castillo, 2000). About 70% of 301 species in the forest and homegardens in the Yucatan, Mexico were classified for medicinal purpose; however, only 16 species were exclusively used for medicine and the rest had multiple uses (Rico-Gray et al., 1991).

Table 1. *Spices, condiments, and aromatic plants possessing medicinal value grown in tropical homegardens.*

Species	*Family*	*Part(s) used*	*Uses (for treatment of diseases/other applications mentioned)*	*Where grown?*
Trees				
Cinnamomum zeylanicum (cinnamom)	Lauraceae	bark	diarrhea, gastric debility, flatulence, nausea, vomiting, herbal tea	Sri Lanka, Indonesia, Madagascar, Brazil, Seychelles
Citrus aurantifolia (lime)	Rutaceae	fruit	source of vitamin C, cataract, bleeding gum, herbal tea, smallpox	Many countries in tropics
Syzygium aromaticum (clove)	Myrtacae	flower buds	carminative, antispasmodic, galacto purifier, antibacterial, appetizer, rubifacient	Southeast Asia , Sri Lanka, Tanzania, Brazil
Myristica fragrans (nutmeg)	Myristicaceae	seeds, aril	dyspepsia, diarrhea, hepatopathy, impotency, insomnia, cardiac disorders	Southeast Asia, Sri Lanka, West Indies
Murraya koenigii (curry leaf)	Rutaceae	leaves	carminative, skin diseases, anorexia, dyspepsia, flatulence, hair tonic, stomach ache	India
Tamarindus indica (tamarind)	Caesalpiniaceae	root, leaves, fruit pulp, seed	jaundice, scabies, smallpox, alcoholic intoxication, carminative, refrigerant	South Asia, East, and West Africa
Shrubs/herbs/grasses				
Allium sativum (garlic)	Liliaceae	bulb	antiperiodic, antibacterial, diuretic, skin diseases	throughout tropics

Allium cepa (onion)	Liliaceae	bulb	pulmonary phthisis, whooping cough, colic dyspepsia, reduces cholesterol	South and Southeast Asia, Spain, Brazil, Egypt
Capsicum annuum	Solanaceae	fruits	gout, arthritis, dyspepsia, hoarseness, flatulence	throughout tropics
Cymbopogon flexuosus, C. citratus (lemongrass)	Poaceae	leaves	source of vitamin A, leprosy, epilepsy, mosquito repellent, herbal tea	Mexico, Brazil, China, Haiti, South and Southeast Asia, Africa
Coriandrum sativum (coriander)	Apiaceae	fruit, leaf	colic, laxative, blood purifier, indigestion, sour throat	South and Southeast Asia
Cuminum cyminum (cumin)	Apiaceae	seed	dyspepsia, flatulence, diarrhea, skin diseases	East Asia, India
Curcuma longa (*C. domestica*) (turmeric)	Zingiberaceae	rhizome	antiseptic, skin allergies, viral hepatitis, anti-bacterial, wounds, anti-inflammatory, soar throat	South, Southeast, and East Asia
Elettaria cardamomum (small cardamom)	Zingiberaceae	fruit	nausea, indigestion, abdominal pains, bronchitis, respiratory infections	South and Southeast Asia
Kaempferia galanga (*candramula*)	Zingiberaceae	rhizomes, root-stock. leaves	digestive, vulnerary, anthelminthic, dyspepsia, leprosy, skin diseases, rheumatism, asthma, bronchitis, malaria, urolithiasis	India

Table 1 (cont.)

Species	*Family*	*Part(s) used*	*Uses(for treatment of diseases/other applications mentioned)*	*Where grown?*
Mentha arvensis (mint)	Labiatae	leaves	cough syrups, flavoring agent, expectorant, pain reliever	Mexico
Mentha piperita (mint)	Labiatae	leaves	flavoring agent	Mexico
Piper betle (betel vine)	Piperaceae	leaves	antiseptic, aphrodisiac, expectorant, bronchitis, rheumatism, stimulant, carminative, wounds	South and Southeast Asia
Piper nigrum (black pepper)	Piperaceae	dried berries	indigestion, chronic rheumatism, asthma, cough, throat complaints	Asia, Africa, Brazil
Trigonella foenum-graecum (fenugreek)	Fabaceae	seeds	anti-diabetic, flatulence, carminative, emollient, galactagogue	India, Middle East, Egypt, Morocco
Zingiber officinale (ginger)	Zingiberaceae	rhizome	asthma, skin diseases, de-worming, nausea, carminative, common colds	South and Southeast Asia, China, Nigeria

***Source*:** Padoch and De Jong (1991), Perera and Rajapakse (1991), Rugalema et al. (1994), Lamont et al. (1999), Rao et al. (1999), De Clerck and Negreros-Castillo (2000), Millat-e-Mustafa et al. (2002), and Wezel and Bender (2003).

Many of the economic species grown in homegardens possess complementary medicinal values. Such species may or may not be exploited commercially for their medicinal properties but are used locally within the family and community. For example, people in southeastern Nigeria uses a number of species that they grow in their compound farms—for purposes other than healthcare, for medicinal purposes (Okafor and Fernandes, 1987). Such species include *Cajanus cajan* (leaves for treating measles), *Carica papaya* (leaves for treating malaria), *Cola lipidota/ C. nitida/C. pachycarpa* (stimulant), *Kigelia africana* (bark for treating sores), *Jatropha curcas* (leaves for ringworm treatment), *Neubouldia laevis* (stem and roots medicinal), and *Invingia gabonensis* var. *gabonensis* (leaves and bark medicinal). Similarly, many plants are collected for medicinal uses from multistoried agroforestry systems in west Sumatra (Indonesia), although none was grown in the system consciously for that purpose (Michon et al., 1986). Majority of spices, a number of vegetables and ornamentals grown in homegardens also have medicinal uses (Table 1). The homegardens in Java and Sumatra were reported to contain 26 medicinal species and a similar number of spices (Kubota et al., 1992).

Agelet et al. (2000) made a detailed analysis of medicinal plants found in 155 homegardens in the mountain zones of Catalonia (north-eastern Iberian Peninsula, Spain). The gardens contained nine distinct categories of species: plants exclusively cultivated for medicinal purpose (23) mostly close to the house, the medicinal wild plants favored by homegarden structure and care (105), and seven kinds of horticultural plants with complementary medicinal values (117). There was, however, loss of about 56 taxa or 23% of the total over the years.

Despite the presence of many medicinal species in homegardens, only a few species stand out as economically important in any given region. The most frequently found species in 31 homegardens in three villages in Cuba, were *Jatropha gossypiifolia*, *Senna occidentalis*, *Xanthoxylum pistacifolium*, *Pluchea odorata*, and *Rhoeo spathacea* (Wezel and Bender, 2003). Common among species expressly cultivated for medicinal purpose in Catalan homegardens were *Tanacetum parthenium* – a plant used for intestinal antiseptic – and *Liliun candidum* for vulnerary use (Agelet et al., 2000). In the state of Kerala (India), *Kaempferia galanga* – which has been traditionally collected from forests, is now being commercially cultivated in the homegardens (Kumar et al., 2005) and as intercrop in orchard crops (Maheswarappa et al., 1998). Tribals living in the Eastern Ghats of Andhra Pradesh (India) have been growing *Piper longum* and *Curcuma angustifolia* extensively for medicinal purposes along with turmeric (*Curcuma longa*) using *Jatropha curcas* as a bio-fence in homegardens (K.P. Sastry, CIMAP Resource Centre, Hyderabad, pers. comm., July 2005). In the 'Dai homegardens' of Xishuangbanna province in China, the prominent medicinal species found were *Acanthopanax trifoliatus*, *Toona sinensis*, *Sapindus rarak*, *Tamarindus indica*, *Bryophyllum pinnatum*, *Euphorbia antiquorum,* and *Prunus persica* (Saint-Pierre, 1991). *Ammomum villosum*, which requires about 70% shade, is planted under forest cover after clearing the undergrowth and it yields 30 to 150 kg rhizomes ha^{-1} $year^{-1}$ depending on water resource availability. Homegardens even in an isolated Soqotra island in the Republic of Yemen despite containing on average 3.9 to 8.4 species per garden included medicinal plants such as *Aloe perryi*, *Jatropha unicostata*, and

Commiphora ornifolia (Ceccolini, 2002). This should indicate the importance given to MPs by rural people in the tropics.

Table 2. *Relative importance of medicinal species in relation to total species in tropical homegardens.*

Region/location	*Homegardens examined (no.)*	*Total and medicinal[a] species across gardens*	*Total and medicinal[a] species per garden*	*Reference*
Santa Rosa, Peruvian Amazon	21	168 (46)	18 to 74 (9.7)	Padoch and de Jong (1991)
Bukoba, North-western Tanzania	72	57 (10)	N/A	Rugalema et al. (1994)
Amazon, Northeastern Peru	51	161 (56)	N/A (9.5)	Lamont et al. (1999)
Catalonia, Iberian Peninsula, Spain	145	N/A (250)	N/A (30 to 60)	Agelet et al. (2000)
Congo (Zaire)	N/A	273 (74)	N/A	Mpoyi et al. (1994)
Masatepe, Nicaragua	1	98 (10)	N/A (10)	Viquez et al. (1994)
Floodplain Jamuna tributary, Bangladesh	17	125 (48)	N/A	Yoshino and Ando (1999)
Dhamrai, Bangladesh	243	N/A (71)	N/A	Millat-e-Mustafa et al. (2001)
Deltaic, dry land, hilly, and plain regions, Bangladesh	200	120 (31)	N/A	Millat-e-Mustafa et al. (2002)
Eastern Cuba	31	101 (39)	18 to 24 (4)	Wezel and Bender (2003)
Tixcacaltuyub and Tixpeual, Mexico	N/A	301 (152)	N/A	Rico-Gray et al. (1991)
Kerala, India	252	127 (25)	3 to 25	Kumar et al. (1994)
Kandy, Sri Lanka	50	125 (52)	37 to 65	Perera and Rajapakse (1991)
Central Sulavesi, Indonesia	30	149	28 to 37 (2.8)	Kehlenbeck and Maass (2005)

[a]Values in parentheses refer to medicinal species; N/A = information not available.

Immigrants from Southeast Asia to USA continued the tradition of growing many species in homegardens wherever they settled – for family use as well as for sale in the Asian markets. A survey of 59 gardens of Laotian Hmong settlers in the central Sacramento Valley, California, USA, revealed 59 taxa of which 38 had food value, 36 had medicinal value and a few others had uses like fiber and ornamental. Nineteen taxa had exclusive medicinal value, 15 combined food and medicine, and one or two combined medicinal, with ornamental or fiber uses. Many species that are categorized as being used for both food and medicine were primarily used for food seasoning or as additives (Corlett et al., 2003).

2.2. Diversity of MPs in homegardens

The species diversity including medicinal species in homegardens primarily depends on climate, altitude, socioeconomic and cultural factors, and nearness to markets. The diversity and density of plants generally increase with rainfall and elevation. In Venezuela, high diversity was positively correlated with age and remoteness of the garden, its use for subsistence, age of the farmer, and extent of participation of family labor in the activities of the garden (Mulas et al., 2004). In Bangladesh, species number decreased with increase in homegarden size and from deltaic region to dry region (Millat-e-Mustafa et al., 2002). Homegardens in West Java, Indonesia, contained the greatest diversity with an average number of 56 species per garden, the number of species being more in the wet season than in the dry season (Soemarwoto, 1987). In contrast, species composition of Cuban gardens differed across sites, especially in terms of medicinal plants, with gardens in the semiarid climate showing greater range than those in the humid region (Wezel and Bender, 2003). Medicinal plants were recognized as the second most important group next only to cash value species in Sri Lanka (Perera and Rajapakse, 1991) and Bangladesh (Millat-e-Mustafa et al., 2002), food crops in Peruvian Amazon (Padoch and de Jong, 1991) and fruits in Cuba (Wezel and Bender, 2003) and Peruvian Amazon (Lamont et al., 1999). Homegardens close to cities were noted to capitalize on their relatively easy access to market in exploiting medicinal/other plants (Padoch and de Jong, 1991; Drescher et al., 2006).

Aromatic species are less common compared to medicinal species in homegardens. Vetiver (*Vetiveria zizanioides*) cultivation was, however, observed in the homegardens of Kerala, India (Nair and Sreedharan, 1986) and the Chagga gardens on Mt. Kilmanjaro in Tanzania (Fernandes et al., 1984). Likewise, lemongrass (*Cymbopogon citratus*) was found in the homegardens of Thailand (Boonkird et al., 1984), Kerala (Nair and Sreedharan, 1986), and Nicaragua (Mendez et al., 2001), and citronella (*Cymbopogon nardus*) in the Kandyan homegardens of Sri Lanka (Perera and Rajapakse, 1991). Homegardens in Ethiopia also contained aromatic plants (Zemede and Ayele, 1995).

2.3. Uses of MPs grown in homegardens

The MPs grown in homegardens are used to treat a variety of ailments ranging from common colds, fevers, headache, snake bites, and digestive problems to infectious and complicated diseases (Tables 1, 3, and 4). Thus, we find species yielding curatives, preventives, placebos, palliatives, nutrition supplements, and energizers. Some of the species provide medicaments to treat livestock diseases, fish baits, and piscicides. Medicinal and aromatic species found in the homegardens are also used as biopesticides. For example, leaves of sacred basil (*Ocimum sanctum/ O. enuiflorum*) are traditionally used as a toxicant against insect pests in grain legume storage. Clove (*Syzygium aromaticum*) powder was found to cause adult mortality of bruchids (*Callosobruchus maculatus*; Rajapakse et al., 2002). Essential oils of citronella, *Eucalyptus citriodora*, and lemongrass are widely used as mosquito repellants. Parts of MPs used for medicinal purpose could be whole plants, young shoots, flowers, young leaves, stem, seed, bark, pods, rhizomes, bulbs, fruits, roots, and inflorescence depending on the species (see Tables 1, 3, and 4).

3. GENDER ISSUES AND MEDICINAL PLANTS

In many traditional societies, women are actively involved in the cultivation of food crops, while men are more concerned with the cash crops. This is true generally for Africa, the Ngöbe community of Panama (Samaniego and Lok, 1998), and the natives of Soqotra Island, Yemen (Ceccolini, 2002). Commercialization of certain products in the homegardens, however, reduced the diversity of species and income to women in a number of communities in Latin America (Howard, 2006). The proverbial reference to household treatment for common ailments, which generally are based on MPs as 'grandmother's remedies', perhaps indicates the understanding of women on these aspects. Women also may have as much role as men, if not more, in the cultivation of traditional medicinal plants, use, and sale of herbal products in village markets because of proximity. In Nicoya, Costa Rica, it was noted that although men and women had equal knowledge of the parts used, women had greater knowledge of medicinal species, the forms of preparation, and application than men (Ochea et al., 1999; Howard, 2006). In Tanzania, men harvest fuel and fodder trees, while women harvest fodder grasses and herbs (Fernandes et al., 1984). Understanding the role of women in homegardens in general and possible impact of introduction of high value medicinal plants in homegardens on gender equity and well-being of women within the family and society is important; yet, in-depth studies are lacking on these aspects.

4. SHADE TOLERANCE OF MEDICINAL PLANTS

Several MPs, especially those grown in homegardens, require or can tolerate overstorey shade. Ginger (*Zingiber officinale*) can withstand light interception by the overstorey up to 48% without experiencing appreciable yield reduction (Kumar et al., 2001). Yield and quality of galangal or *kacholam* (*Kaempferia galanga*) – a medicinal and aromatic oil-yielding herbs were, however, not affected by light interception levels by the upperstorey canopy up to 82% of the open (Kumar et al., 2005). In fact, rhizome yield of galangal as an intercrop in coconut garden was 6.1 Mg ha^{-1} compared with 4.8 Mg ha^{-1} in the open in Kerala, India. Essential oil and oleoresin contents were also greater in the rhizomes of the intercropped *kacholam* (Maheswarappa et al., 1998). Likewise, *Plumbago rosea*, *K. galanga,* and *Asparagus racemosus* performed better as intercrops in 20 year-old coconut

Table 3. *Multipurpose trees with medicinal uses grown in, or suitable for, homegardens.*

Latin name	*Family*	*Parts used*	*Medicinal uses (treatment of the diseases mentioned) and other applications*	*Where grown at present?*
Albizia lebbeck (siris tree)	Mimosaceae	flowers, seeds, bark	asthma, thoracic pain, skin diseases, leprosy, sprains, wounds, ulcers, neuralgia, night blindness, diarrhea	India, Africa
Alstonia scholaris/*A. boonei* (devil tree)	Apocynaceae	leaves, bark, milky exudates	asthma, bronchitis, leprosy, ulcers, fevers, tumors, cardiopathy, helminthiasis, debility, elephantiasis	India, Africa
Azadirachta indica (neem tree)	Meliaceae	leaves, sticks, flowers, seeds, oil, bark	bronchitis, diabetes, ulcers, haemorrhoides, skin diseases, tumors, syphilis, antiseptic, dandruff, contraception, dental care, insecticide	India, Africa
Bombax buonopozense (bombax)	Bombacaceae	leaves	antipyretic	Africa
Cinnamomum camphora/ C. parthenoxylon (camphor tree)	Lauraceae	leaves	fever, eruptions, measles, delirium, whooping cough, melancholia, chronic bronchitis, uterine pains, myalgia	India, China, Sri Lanka
Cedrela odorata (cedro)	Meliaceae	bark	snake bites, fever	Peru, Brazil, East Africa
Commiphora mukul (Indian bedellium tree)	Burseraceae	stem, leaves, gum, resin	rheumatic disorders, hyperchhloroesterolaemia	India
Croton lechleri (sangre de drago)	Euphorbiaceae	latex	swellings, gastric ulcers, contraception	Peru

Table 3 (cont.)

Latin name	*Family*	*Parts used*	*Medicinal uses (treatment of the diseases mentioned) and other applications*	*Where grown at present?*
Emblica officinalis (Indian gooseberry)	Euphorbiaceae	fruits	aging and general debility, acid-peptic diseases, hair loss, dyspepsia, laxative, cooling, diuretic, ulcers	India
Erythrina spp. (Indian coral tree)	Fabaceae	bark, leaves	sedative, vulnerary, lactogogue, collyrium, sterility in women, diabetes, dysentery, eye infections, insomnia, worms, joint pains, whooping cough	India, Africa
Eucalyptus citriodora (lemon-scented gum)	Myrtaceae	leaves	essential oil, perfumery, mosquito repellant	India, China
Eucalyptus spp.	Myrtaceae	leaves	essential oil, colds	India, China
Euterpe precatoria (*chonta*, *pana*)	Arecaceae	roots	diabetes, vaginal infections	Peru
Garcinia cola, *G. afzelii*, *G. efunctata*	Clusiaceae	branch sticks, seeds, fruits	anthelmenthic, cardiotonic, astringent, demulcent, emollient, antiobesity, dental care	India, Africa
Ginkgo biloba (ginkgo)	Ginkgoaceae	leaves, fruits	old-age problems, memory enhancer, general tonic, adaptogenic	China, Japan, other east Asian countries
Gliricidia sepium (Mexican lilac)	Fabaceae	leaves	insecticide	India, Africa
Hagenia abyssinica (*cusso*)	Rosaceae	flowers	anthelminthic, purgative	Africa
Jatropha curcas (furging tree)	Euphorbiaceae	leaves, stem, seeds, oil	laxative, lactogogue, leprosy, rheumatism, eczema, blisters, inflammations, ear-ache	India, Africa, China

Leucaena leucocephala (lead tree)	Mimosoideae	bark, root	emmengogue, ecbolic, depilatory, contraceptive	India, Africa, America
Madhuca longifolia (butternut tree)	Sapotaceae	bark, heartwood, flowers, seeds	inflammations, sprains, pruritus, epilepsy, strangury, verminasis, haemotysis, hepatopathy, dipsia, bronchitis, dermatopathy, cephalalgia, rheumatism, skin diseases	India
Maytenus macrocarpa (*chuchuhuasha*)	Celastraceae	bark	arthritis, diarrhea, stomach disorders, anemia	Peru
Melia volkensii, M. azadirach	Meliaceae	different parts	insecticide, anthelmintic, antiseptic, astringent, emetic, febrifuge, anti-rheumatic	India, Africa
Okoubaka aubrevillei (*oku*)	Octoknamaceae	bark	vomiting, influenza, infections, diarrhea, gastritis	Africa
Pausinystalia johimbe (*yohimbe*)	Rubiaceae	bark	male impotency, aphrodisiac, hypotensive, cardio tonic	Central Africa
Prunus africana	Rosaceae	bark	prostatitis	Central Africa
Saraca asoca (*ashoka*)	Caesalpiniaceae	bark, leaves, flowers, seeds	luecorrhoea, anthelmintic styptic, dyspepsia, ulcers, visceromegaly, pimples, cervical adenitis, vesicle calculi, haemorrhagic dysentery, diabetes	India
Terminalia arjuna	Combretaceae	bark, leaves, fruits	wounds, ear-ache, heart diseases, fractures, contusions, febrifuge, dysentery, diuretic, tonic, deobstruent, hypertension	India, Africa

Table 3 (cont.)

Latin name	*Family*	*Parts used*	*Medicinal uses (treatment of the diseases mentioned) and other applications*	*Where grown at present?*
Terminalia bellirica (beleric myrobalan)	Combretaceae	bark, fruits, gum	bronchitis, sore throat, biliousness, inflammations, strangury, asthma, astringent, dropsy, diarrhea, leprosy, gum purgative	India, Africa
Terminalia chebula (cherubulic myrobalan)	Combretaceae	fruits	asthma, soar throat, vomiting, hiccoughs, eye diseases, heart, and bladder diseases	India, Africa
Raphia hookeri (raphia palm)	Arecaceae	exudates	cosmetics, wine	Africa
Uncaria tomentosa (*uña de gato*)	Rubiaceae	bark	infections, cancer, gastritis, birth control, allergies	Peru, Brazil
Zanthoxylum rhoifolium	Rutaceae	leaves, fruits	chest infection, dental care, analgesic, antibacterial	Brazil, Columbia

***Source*:** Saint-Pierre (1991), Chadha and Gupta (1995), and Rao et al. (1999; 2004).

Table 4. *Shade-tolerant medicinal species of commercial potential that can be grown in homegardens.*

Latin name (common name)	*Family*	*Habit*	*Part(s) used*	*Uses (treatment of the diseases mentioned) and other applications*	*Where grown at present?*
Aconitum heterophyllum (monks hood)	Ranunculaceae	herb	tuberous root	astringent tonic, anti-diarrhea, dyspepsia, cough, alexitexic, anti-periodic, anthelmenthic, hemorrhoids, general debility	East Asia, Western Himalayas
Adhatoda zeylanica, *A. beddomei* (Malabar nut tree)	Acanthaceae	shrub	leaves, roots, stem bark	asthma, menorrhagia, psoriasis, chronic bronchitis, cough, body inflammation	India
Aloe vera, A. barbadensis (aloe)	Liliaceae	herb	leaves	health drink, burns, cuts, skin diseases, leprosy, piles, liver ailments, dysentery	Many countries
Alpinia galanga, *A. calcarata* (galangal)	Zingiberaceae	herb	rhizomes	asthma, bronchitis, hiccoughs, dyspepsia, diabetes, obesity, rheumatoid arthritis, stimulant, tonic	Malaysia, Indonesia
Ammomum villosum	Apiaceae	herb	fruit	stomachic, carminative, expectorant, tonic, antiemetic, antispasmodic	China
Andrographis paniculata (king of bitters)	Acanthaceae	herb	shoots	antipyretic, antiperiodic, anti-inflammatory, ulcers, bronchitis, skin diseases, intestinal worms, jaundice, leprosy, hemorrhoids	India
Asparagus racemosus, *A. adscendens* (asparagus)	Liliaceae	climber	tuberous roots	lactogogue, urinary and gynecological disorders, diseases of nervous system, hyperacidity, gastritis, cardiac debility, hypertension, oligospermea	India

Table 4 (cont.)

Latin name (common name)	*Family*	*Habit*	*Part(s) used*	*Uses (treatment of the diseases mentioned) and other applications*	*Where grown at present?*
Boerhaavia diffusa (hog weed)	Nyctaginaceae	creeping herb	whole plant	aphrodisiac, diuretic, cardiac disorders, stimulant, diaphoretic, anti-inflammatory, jaundice, anemia, general debility, myalgia, scabies, oedema	many tropical countries
Cassia senna, *C. acutifolia* (senna)	Caesalpiniaceae	shrub	leaves, pods	constipation, skin diseases	India, Sudan
Catharanthus roseus (periwinkle)	Apocynaceae	small shrub	leaves, roots	cancer therapy (leaves), hypertension (roots)	India, China, Central and South America
Centella asiatica (Indian pennywort/goticola)	Apiaceae	creeper	whole plant	memory enhancer, anxiety, neurosis, general debility, wound healing, leprosy, eczema, sporiasis	India
Chlorophytum borivilianum, C. tuberosum, C. arundinaceum (safed *musli*)	Liliaceae	herb	tubers	aphrodisiac, nervine tonic,	India
Costus speciosus	Zingiberaceae	shrub	rhizomes	contraception, aphrodisiac astringent, digestive, skin diseases, fevers	India
Curculigo orchioides (black *musli*)	Amaryllidaceae	herb	roots	erectile impotency, spermatorrhoea, general weakness, burning and fatigue piles, menorrhagia, jaundice	India
Curcuma angustifolia (arrow root)	Zingiberaceae	herb	tubers	anti-diarrheal, anti-dysenteric, coolant, health drink	India

Cymbopogon martinii var. *motia*	Poaceae	shrubby grass	flowering shoots	perfumery, flavoring, joint pains, galactogogue, febriluge, aromatherapy	South and Southeast Asia
Decalepis hamiltonii	Asclepiadaceae	twining straggler	tuberous roots	health drink, tonic, promotes digestion, cures fever	India
Dioscorea deltoides/ D. floribunda (medicinal yam)	Dioscoreaceae	tuberous twines	tubers	steroidal drugs, contraception, anthelmintic, leprosy	India
Gloriosa superba (glory lily)	Liliaceae	climbing herb	tuber, seeds	gout, polyploidy, rheumatism, abortifacient, chronic ulcers, piles, diarrhea, antiperiodic, anthelmintic, snake bites, scorpion stings, gonorrhea	India
Glycyrrhiza glabra (liquorice)	Fabaceae	shrub	roots	cough, general tonic, acid peptic disease anti-inflammatory, sweetener	India, China, Eurasia
Gymnema sylvestre (pepricola of the wood)	Asclepiadaceae	climbing shrub	leaves	antidiabetic, cardiac stimulant, eye diseases, diuretic	India
Hippophae rhamnoides (seabuckthorn)	Elaeagnaceae	shrub	berries	skin care, analgesic, antioxidant, antibacterial, anti-inflammatory, nutraceutical	USA, Canada, Europe, India
Holostemma adakodien (swallow wort/ring coronet)	Asclepiadaceae	climber	roots	opthalmopathy, fever, arthritis, cough, burning sensation, stomachalgia	India
Mucuna pruriens (velvet bean)	Fabaceae	climbing shrub	seeds	Parkinson's disease, anthelmintic, laxative, tonic for male virility, elephantiasis	many countries

Table 4 (cont.)

Latin name (common name)	*Family*	*Habit*	*Part(s) used*	*Uses (treatment of the diseases mentioned) and other applications*	*Where grown at present?*
Ocimum sanctum (sacred basil)	Lamiaceae	herb	flowering shoots	cold, cough, bronchospasm, general debility, stress disorders, skin infections, wounds, indigestion, nausea, essential oil in flavoring, perfumery	India, West Indies
Phyllanthus amarus	Euphorbiaceae	herb	whole plant	hepatoprotective, oedema, anorexia	many countries
Piper longum (long pepper)	Piperaceae	climbing shrub	fruit, stem, roots	bronchial asthma, throat infections, flatulence, dyspepsia, respiratory diseases, analgesic, carminative, sedative, insomnia, epilepsy, abortifacient	India
Plumbago zeylanica, P. rosea (white/red flowered lead wort)	Plumbaginaceae	herb	roots	acro-narcotic poison, abortifacient, rheumatic and paralytic affections, ulcers, leprosy, enlarged spleen, rubefacient, piles, skin diseases, leucoderma, syphilis, influenza	India
Pueraria tuberosa (Indian kudzu)	Fabaceae	large climber	tubers	arthritis, agalactia, cardiac debility, pharyngitis, leprosy, tuberculosis, spermatorrhoea	India
Rauvolfia serpentina, R. tetraphylla, R. vomitoria (serpentine root)	Apocynaceae	shrub	roots leaves	hypertension, insanity, insomnia, psychological disorders, epilepsy eczema, skin diseases opacities of cornea, psoriasis, snake and insect bites, toxic goiter, angina pectoris	India, Malaysia, Indonesia

Rosemarinus officinalis	Lamiaceae	herb	flowering shoot	perfumery, aromatherapy, digestive, nervine tonic, stimulates kidneys	Mediterranean region
Salvia officinalis (sage)	Lamiaceae	herb	leaves, oil	perfumery, digestive, nervine tonic, antiseptic, deodorant, diaphoretic	Mediterranean region
Stevia rebaudiana (stevia)	Asteraceae	herb	leaves	sweetener	Brazil, Japan, Paraguay, China, Indonesia, Thailand
Tinospora cordifolia (tinospora)	Menispermaceae	woody climber	stem	seminal weakness, urinary affections, tonic, fever, jaundice, syphilis, rheumatism, general debility, leprosy	India

Source: Saint-Pierre (1991), Rao et al. (1999), Chadha and Gupta (1995), and Kehlenbeck and Maass (2005).

plantations spaced at 7.5 x 7.5 m, and gave 69 to 97% higher net returns compared to sole crops. The performance of *Adhatoda beddomei* and *Holostemma adakodien*, however, was unaffected by the cropping systems (Kurien et al., 2003), implying that they could perform well under disparate cropping situations. Patchouli (*Pogostemon patchouli*), an important aromatic crop, is grown as an intercrop in the coconut gardens of India. Its biomass yield and quality of oil were better under shade than when grown in the open (E.V.S. Prakasa Rao, CIMAP Resource Centre, Bangalore, India, pers. comm., July 2005). Black musli or golden eye grass (*Curculigo orchioides*) planted at 10 x 10 cm spacing under 25% shade performed better than the crop in the open in terms of vegetative growth, rhizome yield, harvest index, and nutrient uptake[4].

Most of the medicinal plants harvested from forests are shade tolerant or prefer some degree of shade, so that they can be cultivated in the homegardens as well, provided they are adapted to the prevailing climatic and soil conditions. A number of medicinal and aromatic crops that are traditionally grown outside forests can also withstand some shade (Jha and Gupta, 1991; Nair et al., 1991) and such species too can be integrated into homegardens. Tables 3 and 4 list a number of species that can be promoted in the homegardens. Species requiring mild shade may be grown in the early years of newly established homegardens or in patches under partial shade, whereas those that withstand intense shade can be grown in ‘mature’ homegardens.

5. PROMOTING MEDICINAL CROPS IN HOMEGARDENS

With the future of homegardens themselves being uncertain (Kumar and Nair, 2004; Wiersum, 2006), its role in providing a steady supply of medicinal plants and other products is unclear. Consistent with this, some reports indicate a reduction in the supply of MPs from homegardens. For example, an analysis of the species composition of homegardens in West Java, Indonesia in 1980 and 1999 revealed that fruit trees and ornamentals constituted a high proportion of plant species in both the years. There was, however, a decrease in the number of useful species from 126 to 100 during the 1999 enumeration. The utilization of useful plants, except for fruit trees and plants for miscellaneous uses largely changed in the past 20 years especially in the case of vegetable, industrial, and ornamental plants (Kubota et al., 2002). In Catalonia, MPs declined because of the loss of original significance of certain species and death of people with particular knowledge on the cultural requirements of some plants (Agelet et al., 2000).

In spite of the above uncertainties, homegardens offer an opportunity to produce some high value medicinal crops and help smallholders earn additional incomes. For instance, in the Ba Vi National Park in northern Vietnam, the Dao people have taken up cultivation in the homegardens some of the 44 commercially important medicinal species identified in the area including *Alstonia scholaris*, *Cinnamomum zeylanicum, Tradescantia zebrine*, *Piper retrofractum,* and *Travesia palmatet* (On et al., 2001). *Ammomum villosum* in China (Saint-Pierre, 1991) and *Piper longum* and *Kaempferia galanga* in India (Kumar et al., 2005) are similarly grown for commercial purposes. In the Peruvian Amazon, younger generations were as keen as the older ones to add species potentially useful as medicine, food, cosmetics, and other items to their collections as well as gathering knowledge on such plants (Padoch and de Jong, 1991).

In the humid tropics, the active slash-and-burn agriculture (120 million ha), secondary forest fallow (203 million ha), logged forests (136 million ha), secondary forest fallows (203 million ha), *Imperata*-infested grasslands in Southeast Asia (40 million ha), and degraded pastures in the Amazon (10 million ha) present vast degraded and abandoned areas, some of which can be put under permanent crop production systems (Sanchez et al., 1994). Homegardens and multistrata systems are regarded as some of the best bet alternatives to slash-and burn system both for the newly cleared lands as well as to bring degraded lands into permanent production. In the uplands of northern Vietnam, the need for improved homegardens using medicinal crops, rattan, quality timber, and livestock was recognized to replace shifting cultivation and to prevent opium production (Tai et al., 1995). Homegardens have been taken up by smallholders in the re-settlement projects in Southeast Asia (e.g., Indonesia) and Amazon (e.g., Brazil). The native people and migrants in the course of developing their homegardens have used a wealth of plant materials including recently developed germplasm. A survey of 33 homegardens in the uplands and 18 in the floodplains of Brazilian Amazon revealed that a total of 77 and 80 commercially valuable perennial species respectively are present (Smith, 1996). These species included, in addition to those providing food, beverages, juices, nuts, oils, thatch, and wood, those that provided folk remedies such as *juca* (*Caesalpinia ferrea*), piao roxo (*Jatropha gossypiifolia*), yellow mombim or taperebá (*Spondias mombim*), fish bait (e.g., *Colossoma macropomum*, *C. bidens*, and *Brycon* sp), and piscicide (e.g., *Ichthyothere cunabi*). The species diversity was greater if medicinal, ornamental, and vegetable species meant mostly for family use were also considered. The number of such species in gardens ranged from 4 to 27. Homegardens established recently as alternatives to slash-and-burn agriculture in cleared forests or degraded lands, however, did not contain as many medicinal species as the traditional gardens. Similarly, recently established homegardens in southern Andaman, India did not contain medicinal plants (Pandey et al., 2002).

Official recognition of traditional medicine will promote growing of medicinal plants, which in turn would help farmers earn better price to their products and citizens to get healthcare at reduced costs. Homegardens and health resorts could also promote ecotourism or 'health tourism', as is happening in the Kerala state of India (www.ktdc.com and www.keralatourism.org; last accessed: December 2005). The social benefits include revival of local traditions and protection of traditional knowledge. It is possible to patent indigenous knowledge about medicinal plants and preparations of products so that the society associated with the development of such knowledge derive the economic benefits thereof. Patenting of the stress relieving properties of *Trichopus zeylanicus*, a medicinal plant used by the Kani tribals of Agasthyar hills in Kerala is worth mentioning in this context (TBGRI, 2003). Indeed, a share of the royalty paid by the firm, which commercialized the technology, has been passed on to the tribal community that possessed this knowledge as part of their traditions. Value-addition and product development at local level wherever possible would also increase the earnings of farmers as well as create rural employment to skilled people and reduce migration to cities.

6. MARKETING OF MEDICINAL PLANTS FROM HOMEGARDENS

Local markets may not be adequate in most cases to absorb all the commercially valuable MPs and offer an equitable price to the producer; prices offered at these markets are often only a small fraction of those at the national and international markets. Lack of organized market channels, poor infrastructure, and involvement of middlemen in the supply chain from farm to factory deprive the farmers of remunerative prices to their produce. Strategies that will promote marketing of MPs and offer competitive prices to farmers are needed; these include establishment of farmers' cooperatives, contract farming with 'buyback' arrangements by the industry, declaration of minimum support price to promising MPs, and subsidies to exporters of MPs as in other sectors. Examples of such proactive policies include development of a marketing network for *Piper longum* in Andhra Pradesh (India) and the intervention by government agencies in the case of *Ammomum villosum* in China, which encouraged large-scale cultivation of these MPs in homegardens. The Girijan Cooperatives in many Indian states also help the tribals living at forest margins to market non-wood forest products. Likewise, the Mayan farmers in the Yucatan region of Mexico have organized a cooperative project for the sale of aloe (*Aloe barbadensis*) and orange juice produced from forest gardens (Neugebauer and Mukul, 2000). Dabur India Ltd., a pharmaceutical company that makes herbal medicines, relies on contract farming for the supply of Indian gooseberry (*Emblica officinalis*), *Rauvolfia*, and *Piper longum*. Maintaining quality of the produce all through the supply chain is, however, very important to earn a premium price for which the farmers, transporters, and processors should be trained properly.

7. OUTLOOK AND RESEARCH NEEDS

Clearly, not all medicinal and aromatic plants found in the homegardens are used by people, and the relative importance of these plants to local societies also varies greatly from place to place. As a first step, therefore, priority species need to be identified based on their medicinal importance, ailments for which they are used, commercial value, cost effectiveness of alternate medicines, and the potential for synthesizing alternative compounds. Research efforts could then concentrate on a few priority species in terms of improving germplasm and developing agronomic techniques, particularly effective propagation techniques, and field establishment in homegardens and forest gardens. Sustainable harvesting methods have to be developed, especially for species harvested from the wild.

Basic research is needed on the response of important medicinal species that are, and can be grown, in the homegardens to variations in quantity and quality of light; and to determine the effects of varying light regimes and organic and inorganic sources of nutrients on yield and quality. Such information helps to develop appropriate canopy management practices for multistrata systems to facilitate the growth of understorey crops. The use of MPs is based on indigenous knowledge and customs passed down from generations; the principal chemical compounds in many of these plants and their curative properties and mode of action have not yet been elucidated properly. Such studies will give authenticity to the use of traditional medicines and help protect genuine herbalists from unscrupulous practitioners.

Globalization of agricultural trade under the World Trade Organization (WTO) regime brought with it several challenges and opportunities in the medicinal and aromatic plants sector too. The challenges include price competition, maintenance of quality, and scientific validation of claims for traditional medicines. The opportunities include global positioning of natural products obtained from medicinal plants, which have large demand. Bioprospecting for molecules of pharmaceutical or flavor/fragrance value from these plants and patenting of these molecules is going to be a future source of conflict between developed and developing countries. While the developed countries have the technology and fiscal resources, the developing countries in the tropics, where most of these MPs are grown, lack such resources. As a first step, therefore, tropical countries should make efforts to develop databases on MPs, indigenous medicinal practices, and herbal preparations in use. These will not only prevent loss of indigenous knowledge but also help promote the use of MPs. Documentation further helps native communities to protect their intellectual property rights on their genetic resources and indigenous knowledge systems and safeguard from biopiracy (Jose, 2004).

7.1. Processing of homegarden produced MPs

Medicinal and aromatic plants in homegardens can be produced at a lower cost compared to input intensive sole crops, as they benefit from common field operations and minimal use of chemical inputs. Organically produced MPs may also attract premium prices in the international markets. Processing and packaging of MPs at local level instead of selling the raw materials will further increase the value of the products and benefit the growers. Some typical value-addition practices are: (1) drying and powdering of relevant plant parts, (2) distillation of aromatic plants, (3) isolation of menthol crystals from mentha oil (*Mentha* spp.) following chilling and centrifuging, (4) pulverizing and encapsulation (e.g., peeled and dried tubers of *Chlorophytum borivilianum* in India), (5) preparation of herbal extracts, and (6) preparation of simple products such as incense sticks, perfumed candles, soaps, and herbal drugs. Powdering medicinal plant parts is the simplest activity, which can be taken up at the farm-level; e.g., tribals cultivating *Curcuma angustifolia* in Andhra Pradesh state, India, prepare a white powder from the tubers of this plant. Other processes may need establishment of facilities at village- or community-level as cottage industries. Nevertheless, it may increase profits to the farmers and generate employment to the local people. For instance, in Karnataka state of India, incense sticks are made mostly by women and children using plant-derived raw materials, adding value to these products and enhancing household incomes. Farmers have to be encouraged and trained, if necessary, to take such value-addition processes either individually or collectively at the farm- or village-level to realize better prices for their products. Good packaging, branding, organic labeling, and quality certification by authorized agencies for finished products will also increase the value of herbal medicines and its consumer acceptability.

8. CONCLUSIONS

Homegardens will continue to be an important land use system for the small-scale farmers in humid and subhumid tropics. They can be turned into future 'biofactories' for the production of commercially important phytochemicals. Furthermore, organically grown MPs can be an important income and employment generating village enterprise in many rural localities. Promotion of ecotourism to herbal/homegardens and health resorts catering to aromatherapy or herbal therapy will have its spin off in terms of additional income and rural employment. Training farmers in improved cultivation and processing practices, contract farming, and establishment of institutions that provide market information and ensure quality standards will go a long way in promoting MPs in the homegardens.

ACKNOWLEDGEMENTS

The authors sincerely thank Dr. J.S.K. Prasad, Central Research Institute for Dryland Agriculture (CRIDA), Santhoshnagar, Hyderabad 500 030, India, and Mr. Solomon G. Haile, School of Forest Resources and Conservation, University of Florida, Gainesville, Florida, USA for providing some useful literature in the course of preparing this paper.

ENDNOTES

1. World Bank stresses importance of coming phytomedicines. Newsletter of the Asian Network on Medicinal and Aromatic Plants. 23: 5 – 6 (1997).
2. DGCIS 2004. Monthly statistics of foreign trade of India. Annual report for 2003 – 2004 (Vol. 1). Exports including re-exports. Directorate General of Commercial Intelligence and Statistics, Ministry of Commerce, Kolkata.
3. Emerging trends in productivity of medicinal and aromatic plants. Newsletter of the Asian Network on Medicinal and Aromatic Plants. 18: 7 (1996).
4. Joy P.P., Savithri K.E., Mathew S. and Thomas J. 2005. Optimum shade and spacing for black musli (*Curculigo orchioides* Gaertn.). In: Book of Abstracts 'National seminar on achievements and opportunities in post-harvest management and value addition in roots and tuber crops', 19 – 20 July 2005, Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, p114.

REFERENCES

Agelet A., Bonet M.A. and Valles J. 2000. Homegardens and their role as a main source of medicinal plants in mountain regions of Catalonia (Iberian peninsula). Econ Bot 54: 295 – 309.

Albuquerique de U.P. and Andrade L. de H.C. 2002. Conhecimento botánico tradicional e conservação em uma área de caatinga no estado de Pernambuco, nordeste do Brasil. Acta Botanico do Brasil 16: 273 – 285.

Boonkird S.A., Fernandes E.C.M. and Nair P.K.R. 1984. Forest villages: an agroforestry approach to rehabilitating forest land degraded by shifting cultivation in Thailand. Agroforest Syst 2: 87 – 102.

Ceccolini L. 2002. The homegardens of Soqotra island, Yemen: an example of agroforestry approach to multiple land use in an isolated location. Agroforest Syst 56: 107 – 115.

Chadha K.L. and Gupta R. 1995. Medicinal and aromatic plants. Advances in horticulture (Vol 11). Malhotra Publishing House, New Delhi, 932p.

Corlett J.L., Dean E.A. and Grivetti L.E. 2003. Hmong gardens: Botanical diversity in an urban setting. Econ Bot 57: 365 – 379.

De Clerck F.A.J. and Negreros-Castillo P. 2000. Plant species of traditional Mayan homegardens of Mexico as analogs for multistrata agroforests. Agroforest Syst 48: 303 – 317.

Drescher A.W., Holmer R.J. and Iaquinta D.L. 2006. Urban homegardens and allotment gardens for sustainable livelihoods: Management strategies and institutional environments In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 317 – 338. Springer Science, Dordrecht.

EXIM Bank 2003. Export potential of Indian medicinal plants and products. Publication No. OP 98. Export and Import Bank of India (EXIM Bank), Mumbai, India (see also www.eximbankindia.com/publications; last accessed: October 9, 2005).

Farnsworth N.R. and Soejarto D.D. 1991. Global importance of medicinal plants. In: Akerele O., Heywood V., and Synge H. (eds), The conservation of medicinal plants, pp. 25 – 51. Cambridge University Press, Cambridge.

Fernandes E.C.M., O'kting'ati A. and Maghembe J.M. 1984.The Chagga homegardens: a multistoreyed cropping system on Mount Kilimanjaro (Northern Tanzania). Agroforest Syst 2: 73 – 86.

Food and Agricultural Organization (FAO) 1996. Forests, food and health. www.fao.org/forestry/site /28813/em (last accessed: October 10, 2005).

Howard P.L. 2006. Gender and social dynamics in swidden and homegardens in Latin America In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 159 – 182. Springer Science, Dordrecht.

Jha K.K. and Gupta C. 1991. Intercropping of medicinal plants with poplar and their phenology. Indian For 117: 535 – 544.

Jose R. 2004. US firm hijacks Kerala patent. www.huk.org/articles/0204/78.html (last accessed: October 10, 2005).

Kehlenbeck K. and Maass B.L. 2005. Crop diversity and classification of homegardens in Central Sulavesi, Indonesia. Agroforest Syst 63: 53 – 62.

Kubota N., Hadikusumah H.Y., Abdoellah O.S. and Sugiyama N. 2002. Changes in the performance of the homegardens in West Java for twenty years. 2. Changes in the utilization of cultivated plants in the homegardens. Jpn J Trop Agr 46: 152 – 161.

Kubota N., Shimamura K. and Ogo T. 1992. Useful plant species observed in homegardens, fields and local markets in Java and Sumatra islands. 2. Spice, medicinal, industrial and miscellaneous plants. Jpn J Trop Agr 36: 298 – 308.

Kumar B.M. and Nair P.K.R. 2004. The enigma of tropical homegardens. Agroforest Syst 61/62: 135 – 152.

Kumar B.M., George S.J. and Chinnamani S. 1994. Diversity, structure and standing stock of wood in the homegardens of Kerala in Peninsular India. Agroforest Syst 25: 243 – 262.

Kumar B.M., Kumar S.S., and Fisher R.F. 2005. Galangal growth and productivity related light transmission in single-strata, multistrata and no-over-canopy systems. J New Seeds 7: 111 – 126.

Kumar B.M., Thomas, J. and. Fisher, R.F. 2001. *Ailanthus triphysa* at different density and fertilizer levels in Kerala, India: tree growth, light transmission and understorey ginger yield. Agroforest Syst 52: 133 – 144.

Kurien A., Augustin A. and Nybe E.V. 2003. Economic analysis of resource-based cropping in selected medicinal species. In: Mathur A.K., Dwivedi S., Patra D.D., Bagchi G.D., Sangwan N.S., Sharma A., and Kanuja S.P.S. (eds), Proceedings of the first national interactive meet on medicinal and aromatic plants, pp. 47 – 49. Central Institute of Medicinal and Aromatic Plants, Luknow.

Lamont S.R., Eshbaugh W.H. and Greenberg A.M. 1999. Species composition, diversity and use of homegardens among three Amazonian villages. Econ Bot 53: 312 – 326.

Maheswarappa H.P., Hegde M.R, and Nanjappa M.V. 1998. Kacholum (*Kaempferia galanga*) – a potential medicinal-cum-aromatic crop for coconut gardens. Indian Coconut J (Cochin) 29 (5): 4 – 5.

Mendez V.E., Lok R. and Somarriba E. 2001. Interdisciplinary analysis of homegardens in Nicaragua: micro-zonation, plant use and socioeconomic importance. Agroforest Syst 51: 85 – 96.

Michon G., Mary F. and Bompard J. 1986. Multistoreyed agroforestry garden system in west Sumatra, Indonesia. Agroforest Syst 4: 315 – 338.

Millat-e-Mustafa M., Khodeja Begum, Mohammed-Al-Amin and Shafiul Alam Md. 2001. Medicinal plant resources of the traditional homegardens in Bangladesh. J Trop Med Plants 2: 99 – 106.

Millat-e-Mustafa M., Teklehaimanot Z. and Haruni A.K.O. 2002. Traditional uses of perennial homestead garden plants in Bangladesh. Forests Trees Livelihoods 12: 235 – 256.

Mpoyi K., Lukebakio N., Kapendo K. and Paulus J. 1994. Inventaire de la flore domestique des parcelles d'habitation. Cas de Kinshasa (Zaire). Revue de Mé et Pharmacopée Africaine 8(1): 55–66.

Mulas M.G., Quiroz C., Perez S. D.M., Rodriguez D., Perez T., Marques A. and Pacheco W. 2004. Conservacion in situ de diversas especies vegetales en 'conucos' (home gardens) in the states of Carabobo y Trujillo de Venezuela. Plant Gen Resour Newsl 137: 1 – 8.

Nair P.K.R. and Kumar B.M. 2006. Introduction. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 1 – 10. Springer Science, Dordrecht.

Nair M.A. and Sreedharan C. 1986. Agroforestry farming systems in the homesteads of Kerala, southern India. Agroforest Syst 4: 339 – 363.

Nair G.S., Sudhadevi P.K. and Kurian A. 1991. Introduction of medicinal and aromatic plants as intercrops in coconut plantations. In: Raychaudhuri S.P. (ed.), Recent advances in medicinal, aromatic and spice crops, pp 163 – 165. Today and Tomorrow's Printers & Publishers, New Delhi.

Neugebauer B. and Mukul Ek A. 2000. Trees for people – a Mayan strategy towards organic agriculture. In: Alfoldi T.T., Lockeretz W., and Niggli U. (eds), The world grows organic: Proceedings 13th International IFOAM scientific conference (28-31 August 2000), IFOAM, Basel, Switzerland, 428p.

Ochea L., Fassaert C., Somarriba E. and Schlonvoight A. 1999. Medicinal and food plants in Nicoya, Costa Rica: there are differences in what men know and women know. Agroforest Today 11: 1–2, 11 – 12.

Okafor J.C. and Fernandes E.C.M. 1987. The compound farms of southeastern Nigeria: a predominant agroforestry homegarden system with crops and small livestock. Agroforest Syst 5: 153 – 168.

O'Kting'ati A., Maghembe J.A., Fernandes E.C.M. and Weaver G.H. 1984. Plant species in the Kilimajaro agroforestry system. Agroforest Syst 2: 177 – 186.

On T.V., Quyen D., Bich L.D., Jones B., Wunder J., and Russel-Smith J. 2001. A survey of medicinal plants in Ba Vi National Park Vietnam: methodology and implications for conservation and sustainable use. Biol Conserv 97: 295 – 304.

Padoch C. and de Jong W. 1991. The house gardens of Santa Rosa: diversity and variability in an Amazonian agricultural system. Econ Bot 45: 166 – 175.

Pandey C.B., Kanak Lata, Venkatesh A., Medhi R.P. and Lata K. 2002. Homegardens: its structure and economic viability in South Andaman. Indian J Agroforest 4: 17 – 23.
Perera A.H. and Rajapakse R.M.N. 1991. A baseline study of Kandian forest gardens of Sri Lanka: structure, composition and utilization. For Ecol Manag 45: 269 – 280.
Principe P.P. 1991. Valuing the biodiversity of medicinal plants. In: Akeele O., Heywood V., and Synge H. (eds), The conservation of medicinal plants, pp 79 – 124. Cambridge University Press, Cambridge.
Rao B.R.R. 1999. Medicinal plants for dry areas. In: Singh R.P. and Osman M. (eds), Sustainable alternate land use systems for drylands, pp 139 – 156. Oriental Enterprises, Dehra Dun.
Rao M.R., Palada M.C. and Becker B.N. 2004. Medicinal and aromatic plants in agroforestry systems. Agroforest Syst 61/62: 107 – 122.
Rao P.S., Venkaiah K. and Padmaja R. 1999. Field guide on medicinal plants. Forest Department, Government of Andhra Pradesh, Hyderabad, India, 208p.
Rajapakse R., Rajapakse H.L. de Z. and Ratnasekera D. 2002. Effect of botanicals on oviposition, hatchability and mortality of *Callosobruchus maculatus* L. (Coleoptera: Bruchidae). Entomon 27: 93 – 98.
Rico-Gray V., Chemas A. and Mandujano S. 1991. Use of tropical deciduous forest species by the Yucatecan Maya. Agroforest Syst 14: 149 – 161.
Rugalema G.H., Okting'ati A. and Johnsen F.H. 1994. The homegarden agroforestry system of Bukoba district, Northwestern Tanzania. 1. Farming system analysis. Agroforest Syst 26: 53 – 64.
Saint-Pierre C. 1991. Evolution of agroforestry in the Xishuangbanna region of tropical China. Agroforest Syst 13:159 – 176.
Samaniego G. and Lok R. 1998. Valor de la percepcion y del conocimiento local de indigenas Ngöbe, en Chiriqui, Panama. Agroforesteria en las Americas 5 (17/18): 12 – 16.
Sanchez P.A., Woolmer P.L. and Palm C.A. 1994 Agroforestry approaches for rehabilitating degraded lands after tropical deforestation. In: Rehabilitation of degraded forest lands in the tropics: Technical approach. JIRCAS International Symposium Series No. 1, pp 108 – 119. Japan International Research Centre for Agriculture Research, Tsukuba, Ibaraki.
Smith N.J.H. 1996. Homegardens as a springboard for agroforestry development in Amazonia. Int Tree Crops J 9: 11 – 30.
Soemarwoto O. 1987. Homegardens: a traditional agroforestry system with a promising future. In: Steppler H.A. and Nair P.K.R. (eds), Agroforestry: A decade of development, pp 157 – 170. ICRAF, Nairobi.
Tai N.D., Nhan H.D., Yen N.T. and Cameron D.M. 1995. Socio-economic considerations in the planning of agroforestry systems for the acid uplands of northern Vietnam. In: Date R.A., Grundon N.J., Rayment G.E., and Probert M.E. (eds), Plant–soil interactions at low pH: Principles and management. Proceedings of the Third International Symposium (September 12–16, 1993), pp 697 – 702. Brisbane, Queensland.
Tropical Botanic Garden and Research Institute (TBGRI) 2003. TBGRI, Palode, Thiruvananthapuram, Kerala, www.tbgri.org/tbgri/patent/htm (last accessed: October 10, 2005).
Viquez E., Prado A., Onoro P., Solano R. and Solano A.R. 1994. Characterization of the tropical mixed garden 'La Asuncion', Masatepe, Nicaragua. Agroforesteria en las Americas 1(2): 5 – 9.
Wezel A. and Bender S. 2003. Plant species diversity of homegardens of Cuba and its significance for household food supply. Agroforest Syst 57: 39 – 49.
World Health Organization (WHO) 2004. www.WHO.int/entity/mediacentre/news/notes/2004/np3/en (last accessed: October 9, 2005)

Wiersum K.F. 2006. Diversity and change in homegarden cultivation in Indonesia. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 13 – 24. Springer Science, Dordrecht.
Yoshino K. and Ando K. 1999. Utilization of plant resources in homestead (*bari-bhiti*) in floodplain in Bangladesh. Japanese J Trop Agric 43: 306 – 318.
Zemede A. and Ayele N. 1995.Homegardens in Ethiopia: Characteristics and plant diversity. Sinet-An Ethiopian J Sci 18(2): 235 – 266.

CHAPTER 13

COMMERCIALIZATION OF HOMEGARDENS IN AN INDONESIAN VILLAGE: VEGETATION COMPOSITION AND FUNCTIONAL CHANGES

O.S. ABDOELLAH[1*], H.Y. HADIKUSUMAH[2], K. TAKEUCHI[3], S. OKUBO[3], AND PARIKESIT[2]

*[1]Institute of Ecology and Department of Anthropology and [2]Department of Biology, Padjadjaran University, Bandung, Indonesia. [3]Department of Ecosystem Studies, Graduate School of Agricultural and Life Sciences, University of Tokyo, Japan; * E-mail: <oekan@unpad.ac.id>*

Note: Adapted from: Abdoellah O.S., Hadikusumah H.Y., Takeuchi K., Okubo S. and Parikesit. 2006. Commercialization of homegardens in an Indonesian village: Vegetation composition and functional changes. *Agroforestry Systems* (in press).

Keywords: Agricultural transformation, Cash crops, Owner preferences, Plant diversity.

Abstract. With rapid development of Indonesia's agricultural sector in response to market pressures, homegardens and other traditional forms of agriculture are increasingly being transformed into income-generating enterprises through the introduction of cash crops. We examined the impact of this commercialization on the structure and function of homegardens in the upland area of the Citarum watershed, West Java, Indonesia, and analyzed the ecological, social, and economic implications of these changes. Results of a vegetation survey and a survey of 94 respondents indicated plant diversity in commercialized (intensively managed) homegardens decreased owing to the introduction of commercial crops. The change from subsistence to commercial farming was accompanied by decreased plant diversity, higher risks, higher external input use, increased instability, and reduced social equitability. The needs and preferences of the owners and market pressures were the main factors that triggered the development of intensive agriculture and increased the commercialization of homegardens. Commercialization adversely impacted the socio-cultural value that homegardens have traditionally provided to the society. Likewise, the long-term impacts and sustainability of commercial homegardens are also uncertain.

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 233–250.

1. INTRODUCTION

Traditional homegardens have received special attention in Indonesia since the 1970s, when the Institute of Ecology of Padjadjaran University discussed the role of these homegardens in rural development. Soemarwoto (1987) defined homegardens as a land surrounding houses in which the structure resembles that of a forest, combining the natural aspects of a forest with solutions to the socioeconomic and cultural needs of the people. Homegardens are centuries-old components of the rural ecosystems and are usually cultivated with a mixture of annual and perennial plants that can be harvested on a daily or seasonal basis.

The structure of homegardens, however, varies from place to place according to the local physical environment, ecological characteristics, and socioeconomic and cultural factors (Christanty et al., 1986; Abdoellah, 1990; Karyono, 1990; Ceccolini, 2002; Kumar and Nair, 2004). The high diversity of plant species in these homegardens and the mixture of annuals and perennials at different heights result in a complex horizontal and vertical structure. The multi-layered plant canopies prove to be beneficial in terms of the utilization of sunlight and in terms of water and soil conservation (Wiersum, 1982; Brownrigg, 1985; Torquebiau, 1992).

Homegardens have several functions: economic, social and cultural, esthetic, and ecological (Abdoellah, 1990; Soemarwoto and Conway, 1991; Wezel and Bender, 2003). In addition, the multiple uses of homegarden products contribute significantly to meeting the various needs (such as nutrition and income) of the households (Abdoellah and Marten, 1986; Christanty et al., 1986; Abdoellah, 1990; Karyono, 1990; Michon and Mary, 1994; Ceccolini, 2002; Blanckaert et al., 2004). Income derived from homegardens in West Java, for example, ranged from 6.6% to 55.7% of the family's total income (Soemarwoto, 1987). The diversity of plants in traditional homegardens is beneficial from the nutritional point of view as well. Many of the plants are important sources of non-food necessities such as fuelwood and building materials too (see Shanavas and Kumar, 2003).

Apart from their economic and ecological functions, rural homegardens also play important social roles (Abdoellah, 1990; Soemarwoto and Conway, 1991). For many rural people, the homegarden is an important place for socializing with family and neighbors. Many homegarden products also have social functions, since it is common for neighbors to let each other obtain such products freely. Many species are believed to have "magical" values or to serve as weather indicators. The homegarden is also an important status symbol; those who do not have their own homegardens and who must build their homes in another's homegarden are considered poor. In the light of these multiple functions, many authors have concluded that homegardens are sustainable production systems (Karyono, 1990; Soemarwoto and Conway, 1991; Ceccolini, 2002; Nair, 2001; Wezel and Bender, 2003; Blanckaert et al., 2004; Kumar and Nair, 2004).

However, during the rapid development of Indonesia's agricultural sector in response to market pressures, commercialization and the adoption of new technologies have been forcing major changes upon the agroecosystems, and homegardens are no exception to that general rule (Abdoellah et al., 2001; Kumar and Nair, 2004). Some villagers are already transforming their homegardens to meet the need for more cash as consumer goods become increasingly available. The introduction of commercial crops into this system to generate income is a potential source of structural and functional changes. Coincidentally, some homegardens have become dominated by few plant species; or have even become similar to monocultures. Examples include the gardens comprising of cash crops such as vegetables that are in high demand in urban markets.

We examined the impact of this commercialization on the structure and function of homegardens in Sukapura village in the upland area of Citarum watershed, West Java, Indonesia. We addressed the following key questions: Does commercialization of homegardens affect their structure? Does it affect their social and economic functions? The answers to these questions will increase our understanding of the homegardens in relation to the multidimensional socioeconomic, ecological, and cultural dynamics of the people in this region.

2. METHODS

2.1. Study site

The study was conducted in the Upper Citarum watershed, West Java, Indonesia during 2000 and 2001. With a total catchment area of approximately 6000 km^2, the watershed covers seven districts, and its main river, the Citarum, runs approximately 350 km northward from Mount Wayang to the Java Sea. This watershed, particularly in the upper part, has been experiencing rapid agricultural development since the 1970s (after the Green Revolution), which caused major changes in its agricultural landscape, with a strong trend towards homogenization.

Sukapura village, the study site, is located about 30 km southeast of Bandung Municipality and 20 km to the Majalaya sub-district, a center of the textile industry, in the Upper Citarum river basin. Most families in Sukapura depend on agriculture with little influence of urbanization. A major share of the total land area of the village (163.5 ha out of the administrative area of 187 ha) is devoted to agriculture consisting of cash crop gardens and mixed gardens. Being located at about 1250 m above sea level, the climate of the village is slightly cooler than in the lower part of the watershed and thus more suitable for cultivation of leafy vegetable such as Chinese cabbage (*Brassica sinensis*) and green onion (*Allium fistulosum*). The soil, which is an Andosol, volcanic in origin, is well drained and quite fertile. The village also has easy access, with an asphalt road, to nearby urban centers (Majalaya and Bandung), which allows the villagers to easily market their agricultural products. Because of these, cash crop cultivation in homegardens is nowadays quite common in this village. Thus, we considered Sukapura village as one of "typical" places that have the potential for homegarden commercialization.

2.2. Sampling design

We interviewed respondents by using a standard questionnaire. In addition, we conducted a vegetation survey to characterize the composition and structure of the homegardens.

Sample selection: We determined the required number of homegardens by the following formula of Lynch et al. (1974):

$$n = \frac{N Z^2 p(1-p)}{N d^2 + Z^2 p(1-p)}$$

Where
n = number of samples,
N = number of households in the study village,
Z = the value of the normal variable (1.96) for a confidence level of 0.95,
p = the highest possible proportion (0.5), and
d = the sampling error (0.1).

Using the above formula, we randomly selected 94 households out of 3433 for interviews and for our vegetation survey. This total number of households was based on data obtained from the village office. In fact, landlessness in the study village was very high (>50%). Based on preliminary interviews with the 94 landowners, we defined the homegardens as commercial (if more than half of the products from the homegarden were sold for cash) or non-commercial (if more than half of the products were consumed by the family). Fifty-nine homegardens were thus found to be non-commercial and 35 commercial homegardens. We also collected data on household profiles, including main occupation, income from the homegardens, resources used as inputs, and the presence or absence of livestock, fences, and *buruan* (places in front of the house used for socializing and as playgrounds) by conducting interviews and through direct observation. Regarding income, the data obtained on annual and currency bases (Indonesian Rupiah: IDR) were converted into the value equivalent to rice weight at the rate of 1250 IDR per kg rice, which was the average of selling rate for the variety being cultivated in the village during 2001.

Vegetation survey: For the vegetation survey, we recorded the following data: species name, number of individuals of each species per plot/farm, number of structural layers based on plant height, and the plant category based on the main use. Vegetables were categorized into cash crops (for sale) and subsistence foods (for own consumption). Land utilization in the homegardens for nursery for plants and for growing cash crops was also recorded.

To describe the dominance of a given species, we calculated the summed dominance ratio (SDR; Numata, 1966) for each species. This index was based on the density and frequency of the species. We also calculated plant diversity using the Shannon–Wiener diversity index and Pielou's evenness index (Magurran, 1988).

2.3. Data analysis

The vegetation and interview data for each homegarden were summarized, and the differences between commercial and non-commercial homegardens were compared using non-parametric tests in the SPSS for Windows software, Version 10.0 (SPSS

Inc., Chicago, Illinois, USA). The Mann–Whitney *U*-test was used for the number of species and individuals, diversity and evenness indexes, area of the homegarden, ownership of other agricultural land, and income from the homegarden. For a bivariate comparison between the types of homegardens and the presence or absence of fences, livestock, and *buruan*, the use or non-use of external inputs, and either off-farm activities or on-farm activities as the main occupation, the Chi-square test was used.

3. RESULTS

3.1. Structure of homegardens

The size of the homegardens averaged 341.73 m^2, but commercial homegardens were larger than the non-commercial gardens (Table 1). The correlation between the number of species and the size of the homegarden was, however, poor for both types (Fig. 1a). The number of individual plants tended to increase with increasing size of the commercial homegardens, but not for the non-commercial ones (Fig. 1b).

Table 1*. Plant diversity parameters in commercial and non-commercial homegardens in Sukapura village, West Java, Indonesia.*

Structural attributes	*Commercial homegardens (n = 35)*	*Non-commercial homegardens (n = 59)*
Area (m^2)		
Average	461.54	270.66
Range	120 – 2000	85 – 1400
Number of species		
Total	145	181
Average	15.71	15.37
Range	4 – 49	4 – 41
Number of all plants		
Total	42952	3893
Average	1227.20	65.98
Range	95 – 8388	6 – 159
Shannon–Wiener diversity index		
Average	1.11	2.03
Range	0.16 – 2.00	0.96 – 3.12
Pielou's evenness index		
Average	0.42	0.78
Range	0.07 – 0.86	0.39 – 0.95

The numbers of species and individual plants in the commercial and non-commercial homegardens are shown in Table 1. The total number of species found in both types of homegarden was 127 (out of 199 species; data not presented). There was no significant difference in the number of species per homegarden between the commercial and non-commercial gardens (Fig. 1a and Table 1); however, there was significant difference in the number of individuals between the two categories (*U*- test, $p < 0.01$; Fig. 1b and Table 1). Likewise, there was a positive relationship

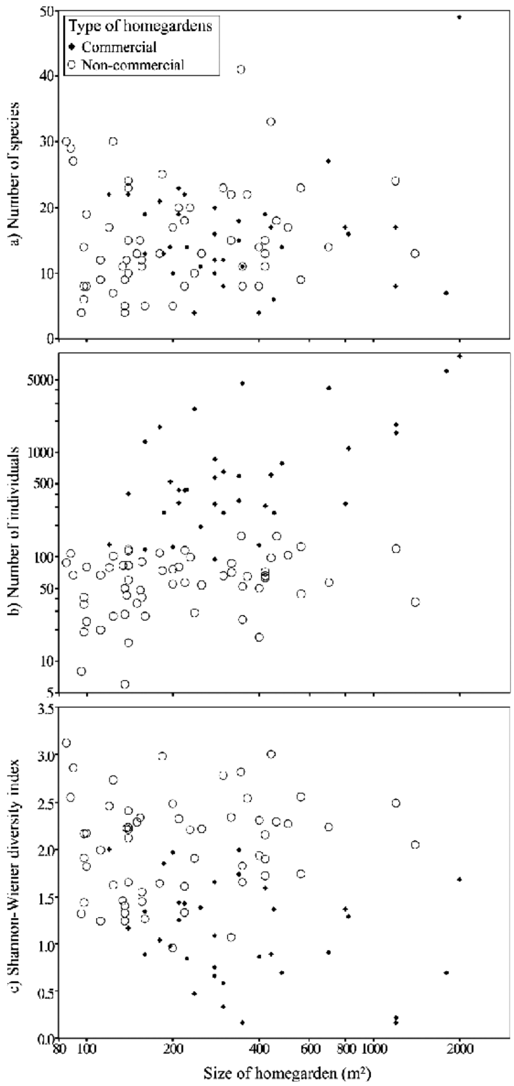

***Figure 1**. Relationship between the size of the homegarden and (a) the number of species, (b) the number of individuals planted, and (c) the Shannon–Wiener diversity index in Sukapura Village, West Java, Indonesia.*

between the number of individuals and area particularly in the commercial ones. A comparison of the area density (individuals/ha) between the two types of homegardens, showed that the average number in commercial ones was significantly higher than that in the non-commercial ones (27 154 and 3486 individuals/ha respectively; *U*-test, $p < 0.01$). The average Shannon–Wiener diversity and evenness indexes in commercial homegardens were significantly lower than that in the non-commercial homegardens (*U*-test, $p < 0.01$). The five most-dominant species in the commercial homegardens were vegetables (Table 2). Green onion (*Allium fistulosum*) had by far the highest SDR among these species. In the non-commercial homegardens *Duranta erecta* was dominant because of its use as a living hedge surrounding the homegardens. The numbers of species and their SDR values suggest that although the number of species did not differ significantly between homegarden types, the species distribution differed.

Table 2. *The five most-dominant species (based on the summed dominance ratio) in the commercial and non-commercial homegardens in Sukapura village, West Java, Indonesia.*

Type of homegarden and species rank order	*Dominant species*	*Relative density*	*Relative frequency*	*Summed dominance ratio*
Commercial				
1	*Allium fistulosum*	39.27	3.27	21.27
2	*Daucus carota*	12.15	2.00	7.07
3	*Ipomoea batatas*	10.48	2.00	6.24
4	*Brassica sinensis*	9.87	0.55	5.21
5	*Raphanus sativus*	8.38	0.36	4.37
Non-commercial				
1	*Duranta erecta*	15.75	3.64	9.69
2	*Manihot esculenta*	4.98	1.87	3.43
3	*Psidium guajava*	3.39	3.31	3.35
4	*Alternanthera philoxeroides*	4.44	1.43	2.94
5	*Musa paradisiaca*	3.06	2.32	2.69

Based on the main use of each species, we defined eight plant categories in all sampled homegardens: vegetable, ornamental, food, fruit, spice, medicinal, building material, and "other" (Table 3). In commercial homegardens, vegetables were dominant, whereas ornamental plants were dominant in the non-commercial gardens. Table 4 presents the proportion of individuals in each plant category as a function of the size of the homegarden and it shows that the proportion of vegetables was highest for all sizes of commercial homegardens. These figures suggest that villagers who used homegardens for commercial purposes did so regardless of the size of the gardens. In addition, 65% to 93% of the total area of the commercial homegardens was planted with vegetable crops (data not shown). In contrast, in the non-commercial homegardens, inedible ornamental plants were dominant (Table 3). The relative proportion of the number of individuals in each plant category did not seem to be related to the size of the homegarden, but ornamental plants occupied the highest percentage for all size categories (Table 4). Even though the average number of individuals of ornamental plants was not different between the commercial and non-commercial homegardens, there were pronounced variations in this respect concerning vegetables and food crops (Table 4).

Table 3. *Dominance ratios of the main categories of plants in commercial and non-commercial homegardens in Sukapura village, West Java, Indonesia.*

Plant category	*Summed dominance ratio*	
	Commercial	*Non-commercial*
Vegetable	44.30	9.61
Ornamental	23.63	56.51
Food	14.53	7.85
Fruit	11.30	16.76
Spice	1.80	3.06
Medicinal	1.35	2.46
Building	1.25	1.52
Other	1.84	2.23
Total	100.0	100.0

In terms of growth form, 88.6% of the individual plants in commercial homegardens occupied the first (ground) strata of the vegetation structure and were shorter than 1 m tall (Fig. 2). Of this, 90.1% comprised commercial crops such as *Allium fistulosum*, *D. carota*, *Ipomoea batatas*, *Brassica sinensis*, and *Raphanus sativus*. Figure 2a also indicates that the non-commercial homegardens kept the multistrata structure better than the commercial gardens.

3.2. Functions of homegardens

In general, homegarden functions depended on their species composition. In the commercial homegardens, the choice of species is determined largely by market demands. The number of respondents conducting off-farm activities as the main occupation was about 22% in the non-commercial category and about 11% for the commercial-homegarden owners; *albeit* the differences were not significant (Table 5; Chi-square test, $p = 0.20$). Moreover, based on the area of other agricultural lands owned by farmers, there was no difference between the types of the homegardens (U-test, $p > 0.05$; n = 31 for the commercial homegardens and n = 46 for the non-commercial class).

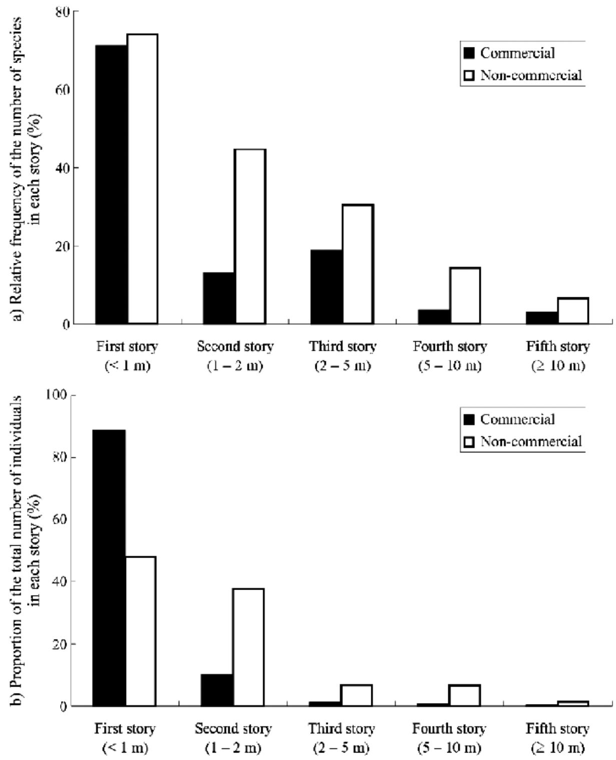

Figure 2. *Vertical structural differences between the commercial and non-commercial homegardens in Sukapura Village, West Java, Indonesia. (a) Relative proportion of the number of species in each story of the vegetation structure to the total number of species. (b) Proportion of the total number of individuals in each story.*

Table 5 also shows the income derived from homegardens. The annual income from commercial homegardens was significantly higher than that from non-commercial homegardens (14 553 versus 2467 kg rice equivalent per ha). It is interesting to note that income per unit area in each sample was almost similar among the commercial gardens, but it varied among the non-commercial homegardens. The actual income in each sample (kg rice per year) had a significant and positive correlation with the area of the gardens only for the commercial category (Table 6). It was also significantly correlated with the number of individuals of all species, as well as the numbers of vegetable species, timber species (producing building materials), and food plants in commercial homegardens (Table 6). Although there was significant correlation between the income (kg rice per year) and the number of plants in non-commercial homegardens, it was only correlated with the number of fruit- and food plants (Table 6). These results imply that the main sources of income in the commercial homegardens were commercial

***Table 4**. Proportion of the individual plants in each of the eight plant categories as a function of the size of the homegardens in Sukapura village, West Java, Indonesia.*

Type of homegardens and area classes	*n*	*Proportion of the number of individuals in each plant category (%)*							
		Vegetable	*Ornamental*	*Food*	*Fruit*	*Spices*	*Medicinal*	*Building material*	*Other*
Commercial									
< 100 m^2	0	–	–	–	–	–	–	–	–
101–200 m^2	7	45.9 (295)	23.2 (149)	25.6 (164)	1.5 (10)	0.6 (5)	0.2 (1)	0.0 (1)	3.0 (19)
201–300 m^2	11	69.9 (410)	7.2 (43)	18.3 (108)	3.1 (19)	0.4 (3)	0.7 (5)	0.2 (1)	0.2 (1)
301–400 m^2	5	81.8 (1061)	4.1 (54)	11.2 (145)	2.0 (26)	0.0 (1)	0.1 (1)	0.4 (6)	0.5 (7)
401–500 m^2	5	74.2 (313)	15.5 (66)	6.8 (29)	2.9 (13)	0.0 (1)	0.2 (1)	0.1 (1)	0.2 (1)
> 501 m^2	7	73.8 (2470)	2.3 (79)	22.6 (758)	0.8 (28)	0.0 (1)	0.0 (1)	0.4 (15)	0.0 (1)
Non-commercial									
< 100 m^2	7	11.5 (6)	66.9 (35)	1.1 (1)	16.1 (9)	2.2 (2)	0.3 (1)	0.3 (1)	1.6 (1)
101–200 m^2	24	5.3 (4)	60.3 (36)	12.4 (8)	15.5 (10)	0.8 (1)	1.2 (1)	2.1 (2)	2.4 (2)
201–300 m^2	8	13.6 (10)	62.2 (44)	10.1 (8)	6.7 (5)	1.6 (2)	4.2 (3)	1.1 (1)	0.5 (1)
301–400 m^2	7	5.9 (5)	57.5 (44)	14.3 (11)	16.4 (13)	2.5 (2)	1.0 (1)	0.4 (1)	2.1 (2)
401–500 m^2	7	16.4 (13)	46.6 (35)	19.3 (15)	7.4 (6)	4.2 (4)	4.0 (3)	0.6 (1)	1.5 (2)
> 501 m^2	6	7.6 (7)	66.6 (55)	1.0 (1)	12.1 (10)	10.5 (9)	0.6 (1)	1.6 (2)	0.0 (0)

n = number of homegardens; parenthetic values are the average number of individuals per homegarden.

Table 5. *Differences in socioeconomic data for the owners of commercial and non-commercial homegardens in Sukapura village, West Java, Indonesia.*

Socioeconomic attributes	*Type of homegarden*		*Statistical significance*[d]
	Commercial (n = 35)	*Non-commercial (n = 59)*	
Ownership[a] of agricultural lands (m^2)			
Paddy field	23.57 (0 – 700)	90.68 (0 – 2400)	NS
Crop field	881.20 (0 – 1000)	653.05 (0 – 6000)	NS
Mixed garden	116.00 (0 – 2100)	28.98 (0 – 840)	NS
Total agricultural lands (area)	1020.77 (0 – 11600)	772.71 (0 – 6000)	NS
Income from homegarden[b] (kg rice equivalent ha^{-1} yr^{-1})	14565 (13757 – 14960)	2467 (144 – 12318)	**
Off-farm activities as the main occupation[c]	4	13	NS
Use of external inputs in the homegarden[c]	33	16	**
Existence of fences around the homegarden[c]	29	13	**
Raising livestock in the homegarden[c]	7	42	**
Presence of *buruan* in the homegarden[c]	10	51	**

[a]Mean followed by range in parentheses (m^2).
[b]Mean followed by range in parentheses (kg rice equivalent ha^{-1} yr^{-1}).
[c]Number of respondents doing off-farm activities as the main occupation, using external inputs such as chemical fertilizers and pesticides in their homegardens, having fences around their homegardens, raising livestock in their homegardens and having a *buruan* in front of their homegardens.
[d]For comparing commercial and non-commercial homegardens, we used the Mann–Whitney U-test for the three types of ownership of agricultural lands and for income from the homegarden and Chi-square test—for external inputs, existence of fences and livestock, and presence of a *buruan*; ** $p < 0.01$; NS = no significant difference or correlation.

crops such as vegetables and timber species while in the non-commercial homegardens it was the fruit-producing species. This relatively higher income from the commercial homegardens reflected the change in function of homegardens from subsistence to commercial purposes. Based on our observation, the owners of commercial homegardens managed their homegardens much more intensively, for example, by routinely watering the homegarden plants and using external inputs such as chemical fertilizers and pesticides (Table 5). Thus, commercialization of the homegardens increased the demand for external inputs. Almost all respondents with commercial homegardens (94.3%) used these inputs to enhance crop yields and to protect crops from pests. There was a significant correlation between the use of external inputs and the type of homegarden: most commercial gardens used those inputs, while very few non-commercial gardens did.

Table 6. *Pearson's correlation coefficient between the annual income from the homegardens and some homegarden characteristics in Sukapura village, West Java, Indonesia.*

Homegarden characteristics	*Correlation coefficient to the annual income (kg rice equivalent yr^{-1})*	
	Commercial homegardens (n = 35)	*Non-commercial homegardens (n = 59)*
Size of homegarden	1.00**	–0.09
Number of individuals		
Total	0.77**	0.31*
Vegetable	0.72**	0.18
Ornament	0.11	0.04
Food	0.53**	0.26*
Fruit	0.14	0.29*
Spice	–0.21	0.24
Medicinal	–0.06	0.15
Building material	0.60**	0.05
Other	–0.15	–0.17

To protect the commercial homegardens, 82.9% owners established fences, although the fences did not completely enclose the homegardens. In contrast, 78% of the owners of non-commercial homegardens did not establish fences (Table 5). In addition, 80% of the owners of commercial homegardens did not raise animals such as chickens, goats, and sheep in their homegardens, partly because of lack of space to raise the animals and build livestock pens, and partly because of the desire to protect their cash crops from grazing animals. Conversely, 71.2% of the owners of non-commercial homegardens raised livestock, and this difference was significant. Furthermore, 71.4% of commercial homegardens lacked a *buruan* where children could play in front of the house. The main reason for the decision not to create a *buruan* was, again, the lack of space and the worry that the children might damage the crops. In contrast, 86.4% of the non-commercial homegardens had a *buruan*, and this difference was significant.

4. DISCUSSION

Although the average number of species present did not differ significantly between the types of homegardens and many species were planted in both types, floristic composition of commercial homegarden was characterized by an increasing number of individuals of cash crops (vegetables) and a significantly decreasing diversity index. Implicit in this is that owners of both types of homegardens desired variety in products for both self-consumption and for sale, but that the latter goal probably outweighed the former for the owners of commercial homegardens.

The total number of species found in all sampled homegardens in Sukapura did not differ from the results of the previous studies conducted in the lower part of the Citarum watershed. However, the dominant species in the present study (and especially those in the commercial homegardens) differed strongly from those of the previous studies. For example, in a study conducted by Chistanty et al. (1986), the homegardens greatly resembled the non-commercial homegardens of the present study, which were dominated by ornamental plants and had only few cash crops. This difference may have been strongly influenced by the specific needs and preferences of the landowners as well as by the different climatic and edaphic factors prevailing in the lower parts of the watershed. The fertile and well-drained soils and cooler climate of the upper watershed (present study) could have encouraged the local farmers to intensify the land use, including homegardening.

The low correlation between the number of species and size of the homegardens in the present study suggests that homegarden size is probably not the main factor that governs species diversity. Instead, the structure and composition of the homegardens depended most likely on the role of various species required to fulfill the owner’s cultural, nutritional, social, and economic needs. For example, the fact that *buruan* were far more common in the non-commercial homegardens suggests that these landowners gave a high priority to the social and cultural roles traditionally supported by homegardens.

Unlike in rural areas located at lower altitudes, the structure of the commercial homegardens in the present study was characterized by a more complex lower canopy, which, for example, was different from that described by Karyono (1990). In our study, some homegardens were dominated by only a few plant species that occupied the lower layers of the canopy structure, and some had even become monocultures, with the dominant species comprising cash crops such as vegetables that were usually found in the lowest layer (less than 1 m tall; 88.6% of the total). Interestingly, plants were more evenly distributed throughout the vertical structure of the non-commercial gardens. This indicates the presence of a multistrata canopy structure in most of these homegardens, as has been suggested by many others too (Karyono, 1990; Soemarwoto and Conway, 1991; Michon and Mary, 1994; Blanckaert et al., 2004). However, there were both inter-site and intra-site variations that complicate this inference. The specific needs and preferences of the owners were clearly important factors that influence the structure and the number of strata that were preserved or created in the homegardens (De Clerck and Negreros-Castillo, 2000).

Many authors have pointed out that the structural pattern of the vegetation cover is influenced by specific physical circumstances, ecological characteristics, economics, and social and cultural factors (Christanty et al., 1986; Abdoellah, 1990; Karyono, 1990; Soemarwoto and Conway, 1991; Wezel and Bender, 2003). Although the landowners in our study were living under similar biophysical conditions, the structural pattern of the vegetation cover differed between the commercial and non-commercial homegardens (Fig. 2). Given the high degree of variation among gardens (Tables 1 and 4), there was clearly no single "typical" homegarden. Although tree species taller than 10 m were found in both types of homegardens, they were clearly more common in the non-commercial category (Fig. 2). These tree species were grown by the owners of non-commercial homegardens without distinct spatial arrangements; these owners grew big trees in any part of the yard and on any side of the house. It is likely that the owners tried to make the better use of available space in their homegardens, besides, tree planting is an old custom aimed to fulfill subsistence needs and, to some extent, to provide a restful micro-environment around the house. Besides, as the non-commercial homegardens often function as spots for social activities, the presence of tree canopies providing shade may facilitate such activities. In contrast, the owners of commercial homegardens mostly planted such trees in the backyard areas to mark the border of their gardens. It was very rare to find a tall tree in front of or at the side of a house in a commercial homegarden where cash crops were planted. According to the owners, this was because growing a big tree would inhibit their ability to grow commercial vegetable crops due to excessive shading.

This difference suggests that the structural pattern of the vegetation in the homegardens was strongly influenced by the specific needs and preferences of the owners. We assumed that the owner whose main occupation was farming and who did not have much agricultural lands might commercialize his/her homegarden and vice-versa. However, there was no significant correlation between the commercialization of an owner's homegarden and ownership of other agricultural lands or the main occupation status (Table 5). Thus, the structure of the homegarden depended on the owner's management objectives as has been reported by several previous workers too (De Clerck and Negreros-Castillo, 2000; Mendez et al., 2001; Kumar and Nair, 2004).

Many authors, such as Abdoellah (1990) and Soemarwoto and Conway (1991), have also reported that the increased intensity of cultivation of homegardens and the domination of these homegardens by particular species has reduced the overall number of plant species. However, our study showed that the number of species did not change significantly because of commercialization, but that the diversity index did indeed decrease, most likely because of the greatly increased number of individuals of certain species (Table 1). One consequence of the rising demand for better vegetable crops is that the species evenness has decreased substantially. The increased reliance on a limited number of species is likely to increase the risk of pest and disease outbreaks, as has already occurred in the sweet orange (*Citrus nobilis*) and clove (*Syzygium aromaticum*) orchards of Java. Soemarwoto and Conway (1991) reported that these crops, which were being extensively introduced in the homegardens, were already being severely damaged by *Phyllosticta* spp. and by citrus vein phloem degeneration disease, respectively. Similar problems have also been reported by Ceccolini (2002) in the homegardens on Soqotra Island. This suggests that commercialization of homegardens may eventually create ecological instability, leading to an increased incidence of pests and diseases.

Furthermore, commercialization of homegardens by focusing on cash crops has resulted in only short-term improvements in farmers' incomes. It is, however, not certain whether the high initial levels of productivity can be sustained. Cash crops also require high-energy inputs in the form of fertilizers and pesticides (Abdoellah, 1990; Abdoellah et al., 2001). Our study confirmed that the use of these external inputs is significantly higher in the commercial gardens (Table 5), and that such increased use of chemical fertilizers and pesticides are inevitable for the commercial gardeners. Thus, although the gross income is higher, at least in the short term, net income will increasingly suffer and the long-term stability of this income is also uncertain, particularly for the products for which market demand fluctuates greatly. An additional consequence is the need for credit from banks and other sources of capital. Inadequate credit facilities in the public sector, however, have driven the villagers to unscrupulous middlemen and moneylenders, potentially leading to future changes in land ownership, and making the continued existence of somewhat autonomous homegardens doubtful. This seemed to reflect what has been stated by Michon and Mary (1994) that apart from high population density, major factors that threatened the existence of traditional homegardens in West Java were increased scarcity of agricultural lands, conflicts between commercial agriculture and traditional food production system, and development of a market economy.

Soemarwoto and Conway (1991) also stated that the income generated from the sale of homegarden products tended to be used for ceremonies and other forms of consumption. There is also a danger that the dietary role of homegardens in providing protein, vitamins, and minerals may be neglected or even lost (Abdoellah and Marten, 1986; Soemarwoto and Conway, 1991; Wezel and Bender, 2003; Blanckaert et al., 2004), because traditional vegetables with low commercial value but high nutritional value may be the first to disappear from the commercial homegardens. Furthermore, commercialization of these homegardens has led to a decline in animal husbandry, thereby eliminating another source of nutrition that might compensate for the loss of these vegetables. These factors, taken together, undoubtedly decrease the ecological and economic sustainability of the commercial homegarden production system.

Commercialization of homegardens has eliminated or reduced some of their multiple functions also. Traditionally, many products such as fruits, vegetables, and other useful plants were shared within the local communities (Abdoellah, 1990; Soemarwoto and Conway, 1991), thereby adding a unique social role to these homegardens (Kumar and Nair, 2004). Commercialization, however, has impeded this practice and has thus reduced the equitability of farming. Soemarwoto and Conway (1991) already pointed out that traditionally the Sundanese who live in this area have abided by the prospect of living harmoniously (*rukun*) with both relatives and other members of the community. Soemarwoto and Conway (1991) reported that an important way of expressing *rukun* was by offering useful homegarden products to relatives or neighbors daily, and particularly to the poor or unfortunate who needed this gift to survive, thereby maintaining, and strengthening social networks. Unfortunately, based on our interviews with several respondents, commercialization has decreased this sharing, even with relatives, and this has undermined the community's social linkages, particularly concerning the poor.

Commercialization of homegardens has forced more owners to establish fences around their homegardens (Table 5). Although these fences do not completely enclose the homegarden, they prevent people from entering or passing through freely, and force these people to request the owner's permission to enter. This represents an important negative change from the traditional free access, as there was originally no concept of trespassing (Soemarwoto and Conway, 1991). This access has been retained in many non-commercial homegardens, which still mostly lack fences (Table 5). Most owners of non-commercial homegardens feel that establishing a fence around a homegarden is socially inappropriate, and that the owners of completely fenced homegardens are "conceited" (Soemarwoto and Conway, 1991). Furthermore, commercialization of homegardens has significantly decreased the number of *buruans* (Table 5). Children can no longer play in front of a house that lacks a *buruan*, thereby removing an important location for socializing with family and neighbors. Even more seriously, the *buruan* has traditionally been a place for children to learn cultural and social values from their elders (Soemarwoto and Conway, 1991). As a result of decreasing the sharing of products from homegardens and disrupting the social networks that are encouraged by free passage through homegardens and the existence of *buruan*, the commercialization of homegardens has done serious damage to the social fabric of these communities.

5. CONCLUSIONS

Our results suggest that the homegardens of Sukapura village, in the Upper Citarum watershed of Indonesia, have changed dramatically over the past two decades. The ecological characteristics and social roles of these homegardens have been adversely affected, and the traditional system of sustainable agriculture that has kept people safe and well fed for centuries may no longer be sustainable without external inputs. Although income from commercialized homegardens has increased, these gardens have decreased plant diversity and evenness, heightened the ecological and financial risks to the owners, increased the requirements for external inputs such as fertilizers and pesticides, lowered community equitability, and increased overall instability.

To revitalize the traditional functions of homegardens, we must convince the owners that the complex vegetation structure of these homegardens is more advantageous in the long-term, than the simpler and less stable structures of the commercial homegardens. In order not to go to the dangerous extent of full commercialization, heavily relying on external inputs as occurring in the research site, efforts should be made to improve the economic functions of the homegardens by manipulating their species composition. To succeed in this endeavor, a detailed analysis of the plant associations in traditional homegardens is required. This will provide a better knowledge of the ecological and economic compatibility of various plant species. The perceptions of landowners related to the preferred plant species must also change to reflect these findings, leading to new planting patterns based on improved selection of species, based on both their ecological roles and economic potential. Improved homegarden designs should also consider integrating crop-based activities with animal husbandry, both of which are crucial "social capital" for sustaining traditional homegardens and permitting future development. Post-harvest technology related to the products of these homegardens should also be investigated so as to reveal opportunities to add value to the products and create jobs that generate income without undermining the sustainability of the homegardens. Finally, supportive regional land use planning and management policies must be developed to encourage landowners to maintain the structure and function of traditional homegardens.

ACKNOWLEDGMENTS

This research was supported by the Institute of Ecology and the Research Institute of Padjadjaran University, and the Core University Program in Applied Biosciences funded by the Japanese Society for the Promotion of Science and the Directorate General of Higher Education, Indonesian Ministry of Education and Culture (Grant-in-Aid for Scientific Research Category B #16405037, JSPS). The authors thank their students: Luppy Handinata, Deyna Handiyana, Dendi Muhamad, and Fazar R. Zulkarnaen, for assistance in fieldwork. This article was written while the first author was a visiting professor at the Laboratory of Landscape Ecology and Planning, Department of Ecosystem Studies, Graduate School of Agricultural and Life Sciences, University of Tokyo, Japan.

REFERENCES

Abdoellah O.S. 1990. Homegardens in Java and their future development. In: Landauer K. and Brazil M. (eds), Tropical home gardens, pp 69 – 79. United Nations University Press, Tokyo.

Abdoellah O.S. and Marten G.G. 1986. The complementary roles of homegardens, uplands fields, and rice fields for meeting nutritional needs in West Java. In: Marten G.G. (ed.), Traditional agriculture in Southeast Asia: A human ecology perspective, pp 293 – 325. West view Press, Boulder and London.

Abdoellah O.S., Takeuchi K., Parikesit, Gunawan B. and Hadikusumah H.Y. 2001. Structure and function of homegarden: revisited. In: Proceedings of First Seminar of JSPS-DGHE Core University Program in Applied Biosciences "Toward harmonisation between development and environmental conservation in biological production" (21–23 February 2001), pp 167–185. University of Tokyo, Tokyo.

Blanckaert I., Swennen R.L., Paredes Flores M., Rosas López R. and Lira Saade R. 2004. Floristic composition, plant uses and management practices in homegardens of San Rafael Coxcatlan, Valley of Tehuacan-Cuicatlan, Mexico. J Arid Environ 57: 179 – 202.

Brownrigg L. 1985. Home gardening in international development: what literature shows? The League for International Food Education, Washington, DC, 330p.

Ceccolini L. 2002. The homegardens of Soqotra islands, Yemen: an example of agroforestry approach to multiple land use in an isolated location. Agroforest Syst 56: 107 – 115.

Christanty L., Abdoellah O.S., Marten G. and Iskandar J. 1986. Traditional agroforestry in West Java: the *pekarangan* (homegarden) and *kebun-talun* (perennial/annual rotation)

cropping systems. In: Marten G.G. (ed.), Traditional agriculture in Southeast Asia: A human ecology perspective, pp 132 – 156. Westview Press, Boulder and London.
De Clerck, F.A.J. and Negreros-Castillo P. 2000. Plant species of traditional Mayan homegardens of Mexico as analogs for multistrata agroforests. Agroforest Syst 48: 303 – 317.
Karyono 1990. Home gardens in Java: their structure and function. In: Landauer K. and Brazil M. (eds), Tropical home gardens, pp 138 – 146. United Nations University Press, Tokyo.
Kumar B.M. and Nair P.K.R. 2004. The enigma of tropical homegardens. Agroforest Syst 61: 135 – 152.
Lynch F., Hollnsteiner M.R. and Corvar L.C. 1974. Data gathering by social survey. Trial edition. Social Science Council Inc., the Philippines, Quezon City, 227p.
Magurran E.A. 1988. Ecological diversity and its measurement. Princeton Univ. Press, New Jersey, 179p.
Mendez V.E., Lok R. and Sommarriba E. 2001. Interdisciplinary analysis of homegardens in Nicaragua: micro-zonation, plant use and socioeconomic importance. Agroforest Syst 51: 85 – 96.
Michon G. and Mary F. 1994. Conversion of traditional village gardens and new economic strategies of rural households in the area of Bogor, Indonesia. Agroforest Syst 25: 31 – 58.
Nair P.K.R. 2001. Do tropical homegardens elude science, or is it the other way around? Agroforest Syst 53: 239 – 245.
Numata M. 1966. Ecological judgment of grassland condition and trend. II: Judgment by floristic composition (in Japanese with English abstract). J Jpn Soc Grassland Sci 12: 29 – 36.
Shanavas A. and Kumar B.M. 2003. Fuelwood characteristics of tree species in homegardens of Kerala, India. Agroforest Syst 58: 11 – 24.
Soemarwoto O. 1987. Homegardens: a traditional agroforestry system with a promising future. In: Steppler H.A. and Nair P.K.R. (eds), Agroforestry: A decade of development, pp 157 – 170. ICRAF, Nairobi.
Soemarwoto O. and Conway G.R. 1991. The Javanese homegarden. J Farming Syst Res Extn 2: 95 – 118.
Torquebiau E. 1992. Are tropical homegardens sustainable? Agric Ecosyst Environ 41: 189 – 207.
Wezel A. and Bender S. 2003. Plant species diversity of homegardens of Cuba and its significance for household food supply. Agroforest Syst 57: 39 – 49.
Wiersum K.F. 1982. Tree gardening and *taungya* in Java: examples of agroforestry techniques in the humid tropics. Agroforest Syst 1: 53 – 70.

CHAPTER 14

TRANSPIRATION CHARACTERISTICS OF SOME HOMEGARDEN TREE SPECIES IN CENTRAL SRI LANKA

W.A.J.M. DE COSTA*, K.S.P. AMARATUNGA, AND R.S. UDUMULLAGE

*Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peredeniya 20400, Sri Lanka; *E-mail: <janendrad@yahoo.com>*

Keywords: *Artocarpus heterophyllus*, *Cedrela toona*, Radiation interception, Soil water deficit, *Swietenia macrophylla*, Vapor pressure deficit.

Abstract. Deep-rooted trees that dominate the multilayered homegardens (MHG) in Central Sri Lanka might adversely impact the catchment water yield because of their high transpiration rates. Our objectives were to quantify the water use of three representative tree species in an MHG and to identify the major determinants of transpiration. The species were *Artocarpus heterophyllus* (diameter at breast height, DBH = 40.5 cm), *Cedrela toona* (DBH = 9 cm) and *Swietenia macrophylla* (DBH = 3 cm) representing the upper, middle and lower canopy layers respectively of an MHG in the high-rainfall zone of central Sri Lanka. Transpiration was measured as trunk sap flow rate using thermal dissipation probes in *Artocarpus* and *Cedrela* and sap flow gauges in *Swietenia*. Measurements during a 72 h period, when soil moisture was not limiting, showed that sap flow of *Artocarpus* was significantly greater than those of *Cedrela* and *Swietenia*. Daily transpiration of *Cedrela* and *Swietenia* ranged from 19% to 27% of that in *Artocarpus* and it increased linearly with incident solar radiation and saturation vapor pressure deficit (VPD). Measurements during a 54-day rainless period also showed that *Artocarpus* and *Cedrela* had high transpiration rates despite reduced water availability in the top 1 m soil layer, indicating water extraction by roots from deeper horizons. Transpiration rate increased with increasing irradiance up to 13 MJ m^{-2} d^{-1} and with increasing VPD up to 0.8 kPa. Decreases in transpiration at irradiances and VPDs greater than the above values indicated that stomata had begun to exert significant control over water loss from the foliage canopy.

1. INTRODUCTION

Multi-layered homegardens (MHG) are a common agroforestry system, which covers a considerable part of the Central Province of Sri Lanka. It is the

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 251–267.

predominant land use system in the Kandy district of Central Sri Lanka, where this traditional system of perennial cropping has been practiced for several centuries, and hence known as the 'Kandyan forest gardens' (Jacob and Alles, 1987). The MHGs consist of a mixture of trees of varying heights, canopy spreads, life cycle durations, and uses. The high diversity of plants in a Kandyan MHG offers economic stability to farmers because of the wide range of economically important products obtained from them such as food, beverage and fruits, spices and timber[1].

The predominantly perennial vegetation in MHGs could absorb a significant amount of water from the soil through their deep root systems. This water is ultimately transpired from the foliage after it is translocated through the xylem system. Therefore, water use by MHGs forms an important consideration in the catchment water balance of the Central Province of Sri Lanka, which is the most important rainfall catchment on which much of the Sri Lankan agriculture and power generation depend on. Catchment water balance of this region thus exerts a critical influence on the national economy. Strong evidence available from different parts of the world suggests that high rates of transpiration by forests and other taller, perennial vegetation could lead to decreased water yields in rivers and reservoirs (Calder, 1996).

Following an analysis of 94 forest catchment experiments in different parts of the world across a range of climates, Bosch and Hewlett (1982) concluded that a 10% increase in forest cover would decrease annual water yield by 40 mm for *Pinus* and *Eucalytpus* and by 25 mm for deciduous hardwood forests. Although such reports generally predict reduced streamflow and ground water availability in areas planted with *Pinus* and *Eucalytpus*, it could be argued that such reductions may not occur in the humid tropics because of their high rainfall. This question has been frequently raised in Sri Lanka and based on limited and incomplete data[2,3], it was concluded that water use of forests and taller perennial vegetation in the Central Province was greater than that of grasslands and annual cropping systems. Quantification of water use of MHGs and determination of its impact on catchment water balance are difficult because of the complex and diverse vegetation structure of MHGs. The total water use of an MHG would be the sum of transpiration rates of different tree species whose canopies are arranged into different vertical layers (Jacob and Alles, 1987). As a first step in quantifying the total water use of MHGs, transpiration rates of a limited number of trees representing different vertical layers in the canopy structure was measured. Our specific objective was to relate the measured transpiration rates to the microenvironmental factors in the relevant canopy layers. Developing mechanistic relationships between transpiration and its driving environmental factors could pave the way to estimate water use of MHGs through an adequately comprehensive modeling approach.

Transpiration rates depend on soil water availability (Monteith, 1986; Jarvis and McNaughton, 1986; Wallace, 1996); and in the absence of soil water deficits it is primarily driven by microenvironmental factors such as incident solar radiation and vapour pressure deficit. With increasing soil water deficits, stomata may exert a significant control over transpiration by partial closure. Therefore, a secondary objective of our study was to see whether stomata could exert an appreciable control over water use of the MHGs during rainless periods of gradually increasing soil water deficits. Considering the widely predicted reductions in rainfall and water availability (McCarthy et al., 2001), this information would be relevant to the discussion on sustainability of MHGs.

2. MATERIALS AND METHODS

2.1. Experimental site

The study was conducted from June 2001 to February 2002 in a typical multilayered homegarden in Kandy (7°17'N, 80°40'E), in the central highlands of Sri Lanka. The site is in the mid-elevational (500 m above sea level), high rainfall (2000 mm yr^{-1}) zone, which is known as the Mid-country Wet Zone, WM_2, according to the classification of agro-ecological zones of Sri Lanka by Panabokke (1996), with a mean daily temperature in the range of 25 to 27°C and relative humidity between 70 to 90%.

This agro-ecological zone contains gently to steeply undulating terrain consisting of hills and valleys. Multilayered homegardens are located in the hills while the valleys are cultivated with lowland rice (*Oryza sativa*). Soil in the hills is deep and well-drained, dark reddish brown with a sandy clay loam texture; it is classified as 'Reddish Brown Latosolic Soils' according to the local classification (Panabokke, 1996), Dystric Cambisols by FAO/UNESCO and Typic Troporthents by USDA (Senarath and Dassanayake, 1999). Bulk density ranges from 1.50 x 10^3 to 1.60 x 10^3 kg m^{-3} and pH from 5.0 to 5.5 throughout the soil profile. Available water, i.e. soil water content between field capacity (–0.01 MPa of soil water potential) and permanent wilting point (–1.5 MPa) is 111.4 mm m^{-1}.

2.2. Composition of the homegarden

The area of the MHG selected for this study, including the house within, was 0.15 ha. The house was surrounded by vegetation consisting mainly of trees varying in heights, canopy spread and depth, trunk diameter and age. The woody perennials at the study site were enumerated by measuring their height and diameter at breast height (DBH). The probable age of trees was ascertained from the garden owner. The MHG had 56 trees belonging to 14 species (Table 1), most of which were of economic value providing food (*Artocarpus heterophyllus* and *Cocos nucifera*), beverages (*Coffea arabica*), fruits (*Mangifera indica* and *Persea americana*), spices (*Syzygium aromaticum* and *Myristica fragrans*), timber (*Swietenia macrophylla* and *Artocarpus heterophyllus*) and variety of other products and services.

The trees were categorized into three groups based on their canopy position: top layer (10 m or taller), middle layer (5 to 10 m), and bottom layer (less than 5 m). Three representative trees occupying these three vertical layers were selected for measuring transpiration rates. The species were *Artocarpus heterophyllus*, *Cedrela toona*, and *Swietenia macrophylla* representing the top, middle, and bottom layers, respectively. Main attributes of the three species are given in Table 1. The trees were located within a 15 m radial zone to avoid using excessively long wires conducting voltage signals from sapflow sensors and to have the data-logger in a central location. The trees were selected based on their characters at the time of transpiration measurement. For example, a sapling of *Swietenia* was selected to represent the bottom canopy layer because of its lower height. However, this does not imply that *Swietenia* always would occupy the lower canopy layer of MHGs. Among the several tree species occupying the top layer, *Artocarpus heterophyllus*, which is the most abundant species in Kandyan MHGs[4], was selected.

Table 1. *List of tree species in a multilayered homegarden in central Sri Lanka and their structural attributes.*

Sl. No	*Tree species*	*Height (m)*	*Canopy depth (m)*	*Canopy spread (m)*	*DBH (cm)*	*Probable age (yr)*
1	*Persea americana*	7.5	6	3.5	16	10
2	*Artocarpus heterophyllus*	15.5	14	14	55	40
3	*Gliricidia sepium*	13	11	3	14	27
4	*Persea americana*	11	6	5	18.5	10
5	*Mangifera indica*	12.5	8.5	5.5	17	10
6	*Cedrela toona*	8	4	1.5	8.5	8
7	*Persea americana*	13	10	4.5	25.5	11
8	*Swietenia macrophylla*	15	6	5	37	15
9	*Swietenia macrophylla*	15.5	9.5	6.5	46	15
10	*Cocos nucifera*	15	6	9.5	30	10
11	*Swietenia macrophylla*	1.9	1.3	0.9	1	3
12	*Cocos nucifera*	15	6	9	24.5	10
13	*Cocos nucifera*	14	5.75	9	28.5	10
14	*Cocos nucifera*	16	7	9	32	10
15	***Swietenia macrophylla***	**4**	**1.5**	**0.6**	**3.5**	**3**
16	*Alstonia macrophylla*	4	1.5	2	3	5
17	*Alstonia macrophylla*	9.5	7.5	4	9.5	2
18	*Persea americana*	9	7	4	15.5	5
19	***Artocarpus heterophyllus***	**15**	**13**	**10**	**40.5**	**25**
20	*Persea americana*	8.5	4	2	17	8
21	***Cedrela toona***	**8**	**1.9**	**2.8**	**9**	**8**
22	*Cedrela toona*	8.75	4.5	2.3	9.5	8
23	*Alstonia macrophylla*	8	3	4.2	7.5	5
24	*Michelia champaca*	13	8.5	5	18	10
25	*Swietenia macrophylla*	6.5	2.5	2	8	8
26	*Swietenia macrophylla*	6.5	2.5	3.5	10.5	8
27	*Swietenia macrophylla*	7	2.5	2.5	10	8
28	*Cedrela toona*	4.3	0.25	1.5	3	8

29	*Cedrela toona*	4.3	0.25	1	3.2	8
30	*Cedrela toona*	4	0.25	0.5	3	8
31	*Myristica fragrans*	4.3	1.7	1.4	3	8
32	*Michelia champaca*	13.5	7.5	6	30	8
33	*Alstonia macrophylla*	8	4.5	5	11	15
34	*Swietenia macrophylla*	7	4.3	2	7	8
35	*Swietenia macrophylla*	7	4	1.8	6.5	8
36	*Cedrela toona*	5	0.75	2	4	8
37	*Swietenia macrophylla*	7.5	5	3	11	8
38	*Swietenia macrophylla*	7.5	5	1.5	7.5	8
39	*Litsea iteadaphna*	7.5	6	5.5	22.2	15
40	*Michelia champaca*	14	6	4.7	16.5	10
41	*Cedrela toona*	10	*	*	7	8
42	*Caryota urens*	13	6.5	6	33.5	8
43	*Cocos nucifera*	14.5	5	9	30	10
44	*Cedrela toona*	13.5	0.5	2.8	3	8
45	*Syzygium aromaticum*	13	9.5	6	21.5	25
46	*Coffea arabica*	7.5	6.5	3.5	5.25	5
47	*Cocos nucifera*	14	6.5	9.5	27.5	10
48	*Persea americana*	8	5	5.5	15	6
49	*Gliricidia sepium*	7	6.5	3	6.5	15
50	*Duria zibethinus*	22	7	10.2	40	28
51	*Gliricidia sepium*	8	5	2	12	14
52	*Cocos nucifera*	13.5	5	4.5	22	28
53	*Alstonia macrophylla*	17	7	1.5	15	8
54	*Psidium guajava*	1.9	1.5	1.5	2	10
55	*Swietenia macrophylla*	1.9	1	1.2	1	3
56	*Cassia roxburghii*	23	1.2	7	45	40

Note: The trees selected for transpiration measurement are indicated in bold; DBH = diameter at breast height.

2.3. Measurement of transpiration rates of different trees

Among a variety of techniques available for measuring transpiration rates in trees, thermal methods (Swanson, 1994) involve measurement of the rate of heat flow in the xylem transpiration stream. Under steady-state conditions, the rate of xylem sap flow would be equal to the rate of transpiration of a tree (Van den Honert, 1948; Cowan, 1965). An added advantage of thermal methods is their ability to measure transpiration rates of individual trees, which is essential in a species mixture such as the MHG. In the present study, we used two thermal methods, thermal dissipation probes and stem sap flow gauges (Dynamax Inc, USA/Delta-T, UK), the former for *Artocarpus* (DBH = 40.5 cm) and *Cedrela* (DBH = 9 cm), and the latter for

Swietenia. Both instruments measure the rate of sap flow in the xylem, but the thermal dissipation probe (TDP) relates the rate of heat dissipation to sap flow rate through an empirical relationship, while the sap flow gauge directly calculates the rate of sap flow as the residual of an energy balance equation.

The TDP consisted of two 'needles', each 30 mm long and 1.2 mm in outer diameter, spaced 40 mm apart; these were inserted horizontally to the trunk at a height of 1.2 m above the ground. Both needles contained thermocouples to measure the average sap temperature. In addition, the upper needle contained a heating element, which was supplied with a constant input of energy (0.15 Js^{-1}) by a 12 V car battery through a voltage regulator (AVRD Dual Regulator, Delta-T Devices). As the lower un-heated needle measured the reference sap temperature, temperature difference (*dT*) between the two needles was determined by rate of heat dissipation due to sap flow. As such, *dT* was inversely related to sap velocity. It was measured and recorded as a voltage signal every 30 seconds, averaged every 5 minutes and stored in a DL2e data logger (Delta-T Devices). Equation 1 (Granier, 1985; 1987) was used to compute a dimensionless 'flow index' K as follows,

$$K = (dTm - dT)/dT \tag{1}$$

Where *dTm* is the maximum recorded value of *dT* at times of zero sap flow. In the present experiment, the maximum *dTm* values were recorded between midnight and 0400 h. Mean *dTm* during this four-hour period each day was taken as *dTm* for the respective day. *K* was related to the average sap velocity, *V*, in cm s^{-1}, by an empirical relationship of Granier (1985; 1987) as,

$$V = 0.0119\, K^{1.231} \tag{2}$$

This relationship, which did not differ significantly among tree species, was used in the present study. *V* was converted to sap flow rate, F_s, as,

$$F_s = A_s V \tag{3}$$

Where *As* is sap wood cross-sectional area, which was measured by taking several core samples using an increment borer on *Artocarpus* and *Cedrela* trees that were not being used for sap flow measurements. As recommended by the manufacturer (Dynamax), three thermal dissipation probes were used at different locations around the trunk of *Artocarpus* while two probes were used on *Cedrela*. Signals from different probes were averaged before sap flow calculations.

The Dynagage (SGB25-ws) consisted of a heating plate, 110 mm high and 28 mm in diameter, which was wrapped around the stem of sapling *Swietenia* at a height of 1.2 m above the ground. A constant, regulated power input (*Pin*) of 0.5 Js^{-1} was supplied to the heating plate. A set of precise electronic sensors attached to the gauge measured the radial heat transfer from the gauge to the ambient air (*Qr*) and axial heat fluxes through the trunk (Qv). The variable amount of heat carried by the sap flow (Qf) was calculated from an energy balance equation (Sakuratani, 1981; Baker and Van Bavel, 1987) as,

$$Qf = Pin - Qr - Qv \quad (4)$$

Qf can be converted to the sap flow rate (F) by dividing it with specific heat capacity of water (Cp) and sap temperature increase (dT) as,

$$F = (Pin - Qr - Qu - Qd)/(Cp\ dT) \quad (5)$$

Where Qu and Qd are the upward and downward components of the axial heat transfer (Qv). Voltage signals from sensors were recorded every 30 seconds, averaged every 5 minutes and stored in the data logger.

2.4. Measurement of environmental variables

Solar radiation incident on the canopies was measured by tube solarimeters installed at appropriate heights above and within the MHG. Relative humidity and air temperature at the top of the three selected trees were measured by solid-state sensors (TDK Inc., Hiroshima, Japan) installed at the respective heights. Output signals from all these sensors were recorded every 30 seconds, averaged every 5 minutes and stored in the data logger. Relative humidity (h) and air temperature (T_a) data were used to compute the saturation vapor pressure deficit (VPD) of air as,

$$VPD = e_{s(Ta)} - e \quad (6)$$

Where $e_{s(Ta)}$ is the saturation vapor pressure at air temperature T_a and e the actual vapor pressure. $e_{s(Ta)}$ was computed by an empirical equation developed by Tetens (1930) and adopted by Murray (1967) as,

$$e_{s(Ta)} = 0.611\ e^{[17.27\ [(T - 273)/(T - 36)]} \quad (7)$$

The actual vapor pressure (e) was calculated from measured relative humidity and $e_{s(Ta)}$ as,

$$e = (h\ e_{s(Ta)})/100 \quad (8)$$

Soil moisture content was measured gravimetrically at weekly intervals by taking samples at 20 cm depth intervals down to a maximum depth of 1 m. Soil moisture was measured at a point approximately equidistant from the three trees on which transpiration was being measured.

2.5. Computation of canopy conductance

Canopy conductance (g_c) is the overall stomatal conductance of the entire foliage canopy. It was computed by inverting a simplified version of the Penman-Monteith equation adopted for tall vegetation by Granier et al. (1996) as,

$$g_c = (F \lambda \gamma)/(\rho \; Cp \; D) \quad (9)$$

Where F is mean sap flow rate (kg m^{-2} s^{-1}), λ the latent heat of evaporation of water (J kg^{-1}), γ the psychrometer constant (kPa K^{-1}), ρ the density of air (kg m^{-3}), Cp the specific heat capacity of air (J kg^{-1} K^{-1}) and D the vapor pressure deficit of air (kPa). The measured daily total sap flow values obtained in kg $tree^{-1}d^{-1}$ were divided by tree leaf area and day length to convert them to F in kg $m^{-2}s^{-1}$. Therefore, g_c obtained from equation *9* were daily mean canopy conductance values.

2.6. Measurement of canopy area

Approximate leaf area of all three trees selected for sap flow measurements was computed by measuring area of a sample of 50 leaves representing a range of sizes and counting the number of branches, leaf cohorts, and leaf number per cohort as follows:

Approximate canopy area per tree = No. of branches per tree x mean no. of leaf cohorts per branch x mean no. of leaves per cohort x mean area per leaf (10)

Projected leaf area index (*LAI*) was computed as the ratio between approximate canopy area per tree and projected horizontal ground area covered by the tree canopy, assuming a circular canopy having a diameter equal to the measured canopy spread (Table 1).

2.7. Data analysis

Data on transpiration and environmental variables recorded at 5-minute intervals were plotted against time of the day to obtain their diurnal variation patterns. Regression analysis was used to obtain relationships between transpiration and environmental variables.

3. RESULTS

3.1. Short-term variations in tree transpiration rates and its determinants in the absence of soil water deficits

The data presented in Fig. 1a show the diurnal variation of sap flow rate over a 72-h period (from 23 to 25 June 2001) when the soil was fully saturated. All three species showed a similar pattern of sap flow, with the maximum rate being achieved from 1300 to 1500 h. Minimum sap flow rates were observed from midnight to 0400 h.

The very small rates of sap flow that were observed during the night were probably to replace the water that was lost during the daytime from water storage tissues (i.e., capacitors) surrounding the xylem vessels. *Artocarpus*, which occupied the upper canopy layer of the MHG, showed the highest sap flow rate. There was, however, no significant difference in sap flow rate between *Cedrela* (middle canopy) and *Swietenia* (sapling in the lower canopy). Furthermore, the highest sap velocity

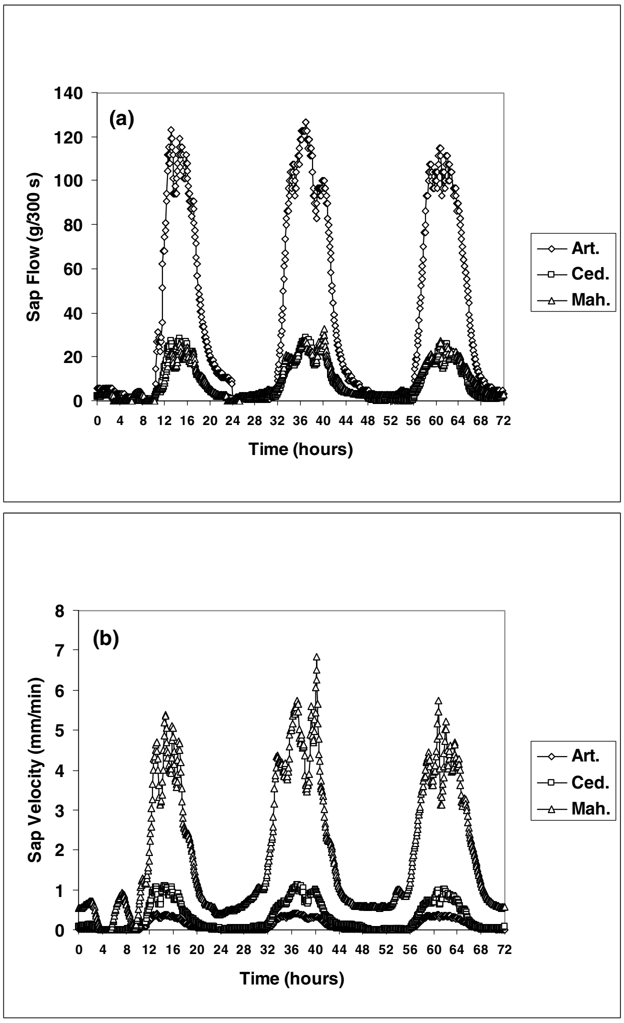

***Figure 1**. Diurnal variation of sap flow (a) and sap velocity (b) of three tree species representing different vertical layers in a multi-layered homegarden in central Sri Lanka during a 72 h measurement period of adequate soil water availability. Art.* – Artocarpus heterophyllus*; Ced.* – Cedrela toona*; Mah.* – Swietenia macrophylla.

was observed in *Swietenia* (Fig. 1b) while the lowest was noted in *Artocarpus*, with *Cedrela* having intermediate values. The respective sapwood cross-sectional areas for *Artocarpus*, *Cedrela* and *Swietenia* were 605, 51 and 9.6 cm^2. Hence, an inverse relationship between sap velocity and sapwood cross-sectional area can be deduced. This is because sap has to be translocated at a higher velocity to provide enough water to compensate for the transpirational losses in individuals having a lower sapwood cross-sectional area.

The upper canopy *Artocarpus* trees also received the highest irradiance (Fig. 2) during most of the day. However, irradiance on the upper canopy showed substantial short-term fluctuations because of partially cloudy weather. Middle canopy *Cedrela*

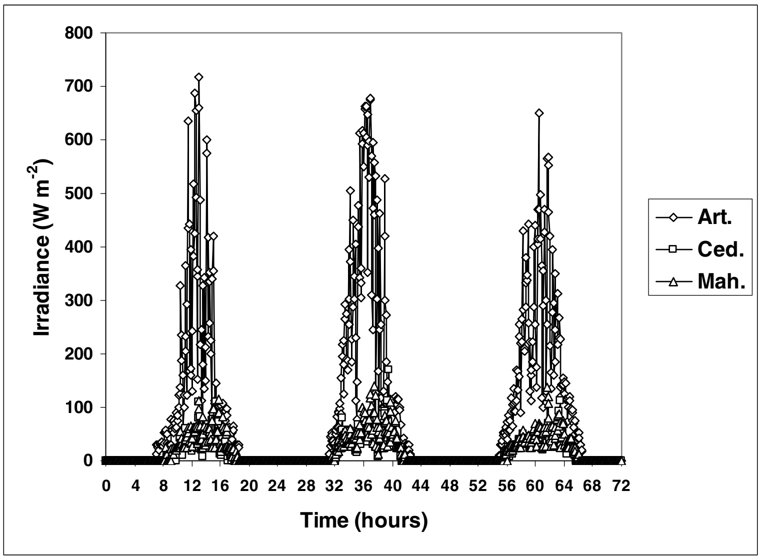

Figure 2*. Diurnal variation of incident radiation on canopies of three selected tree species in a multi-layered homegarden in central Sri Lanka during a selected 72 h measurement period.* Artocarpus heterophyllus *(Art.),* Cedrela toona *(Ced.), and* Swietenia macrophylla *(Mah.) represented the upper, middle, and lower layers of the homegarden.*

and lower canopy *Swietenia* received radiation, which was approximately similar to each other and less fluctuating compared to the upper canopy. Even the lower canopy *Swietenia* was exposed to direct sunlight during part of the day (from the direction of the house), which explains the similarity in irradiance level of the middle and lower canopies. When the data for the different canopy layers were pooled, there was, however, a clear linear relationship between transpiration and incident radiation on a daily basis (Fig. 3). Daily total transpiration of middle and lower canopy trees were 15 to 27% of that of upper canopy trees (Table 2).

Vapor pressure deficit above the MHG (i.e., near the upper canopy) was greater than that within it (data not shown), especially during daytime. However, the diurnal patterns of both were similar with maximum values around 1200 to 1400 h. Transpiration rates of trees representing all canopy layers increased with increasing VPD (Fig. 4). However, above a threshold VPD of about 0.8 kPa the increase of transpiration slowed down, because of decreasing stomatal conductance at higher VPD (data shown elsewhere).

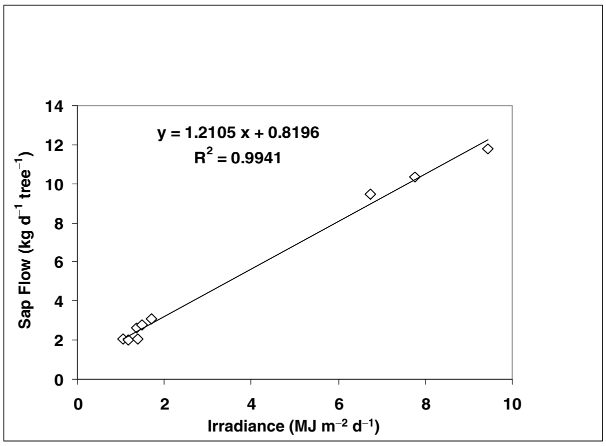

Figure 3*. Relationship between daily total sap flow of the three selected tree species and the daily total solar radiation incident on their respective foliage canopies during a 72 h measurement period.*

Table 2. *Daily totals of transpiration and incident radiation during a three-day period of adequate soil water availability (june 2001) in a multi-layered homegarden in central Sri Lanka.*

Species	*Transpiration (kg d^{-1} $tree^{-1}$)*			*Incident radiation (MJ m^{-2} d^{-1})*		
	23 Jun '01	*24 Jun '01*	*25 Jun '01*	*23 Jun '01*	*24 Jun '01*	*25 Jun '01*
Artocarpus heterophyllus	9.46	11.80	10.34	6.73	9.44	7.77
Cedrela toona	2.06 (0.22)	2.64 (0.22)	2.00 (0.19)	1.04 (0.16)	1.37 (0.15)	1.16 (0.15)
Swietenia macrophylla	2.04 (0.22)	3.10 (0.26)	2.77 (0.27)	1.38 (0.20)	1.71 (0.18)	1.49 (0.19)

Note: Fraction of the respective upper canopy value is given in parenthesis.

3.2. Medium-term variation of transpiration during a period of increasing soil water deficits

Daily transpiration rates of the upper canopy *Artocarpus* and middle canopy *Cedrela* were monitored during a two-month period of very little rainfall (25 Dec. 2001 to 20

Feb. 2002). Despite the gradual decrease of soil water content in the top 1 m of the soil, both trees continued to have high rates of transpiration (Fig. 5). This probably indicated that root systems of both tree species absorbed water from deeper layers of the soil profile during periods when the top soil was dry. Total transpiration of *Artocarpus* during the 54-day experimental period was 3881 kg tree^{-1}, with the daily transpiration ranging from 17.84 to 95.87 kg day^{-1} tree^{-1}. The corresponding values for *Cedrela* were 463 kg tree^{-1} and 0.64 to 21.60 kg day^{-1} tree^{-1}.

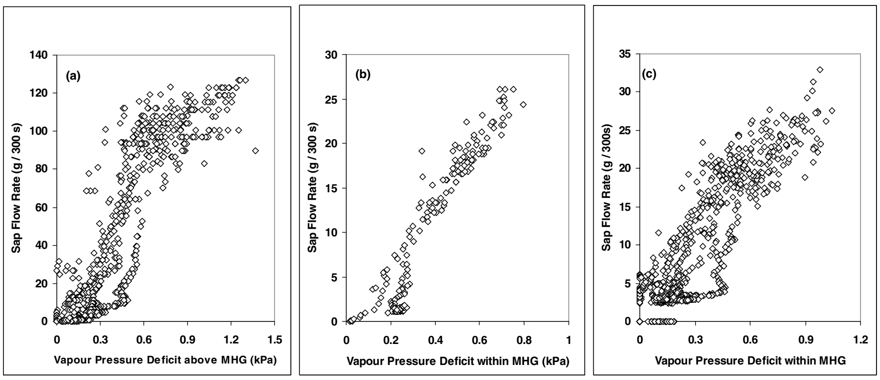

Figure 4. *Variation of sap flow rate with vapour pressure deficit in* Artocarpous heterophyllus *(a),* Cedrela toona *(b) and* Swietenia macrophylla *(c) in a central Sri Lankan homegarden during a selected 72 h measurement period.*

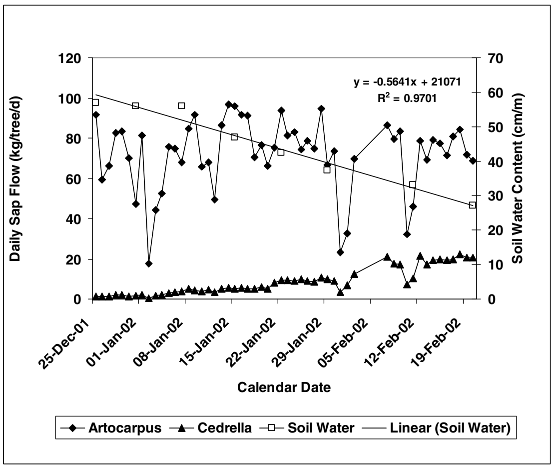

Figure 5. *Medium-term variation of daily sap flow of two selected upper- (*Artocarpus heterophyllus*) and middle canopy (*Cedrela toona*) trees in multi-layered homegarden in central Sri Lanka during a selected 54-day experimental period. Variation of soil water content in the top 1 m of the soil profile is also shown along with a fitted linear regression.*

The clear increase of daily transpiration in *Cedrela* was due to the significant increase of its projected LAI from 1.4 to 3.0 during the experimental period. In contrast, the projected LAI of *Artocarpus* was around 5.7 throughout. Medium-term fluctuations in sap flow of *Artocarpus* were closely related to fluctuations of daily total irradiance (Fig. 6a) and daily mean VPD (Fig. 6b). Transpiration of *Artocarpus* increased with increasing irradiance up to about 13 MJ m^{-2} d^{-1} and with increasing VPD up to about 0.8 kPa. The subsequent leveling-off and reduction was probably due to partial stomatal closure induced by higher VPD. This was confirmed by observed reduction of canopy conductance (g_c) with increasing vapor pressure deficits both on a daily basis (Fig. 7) and on a diurnal basis (data not shown).

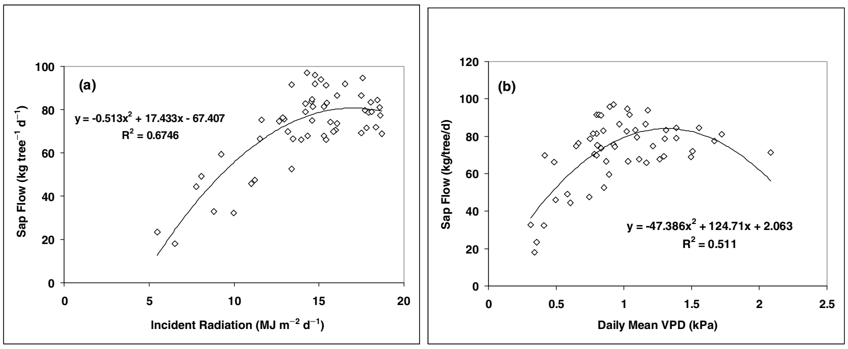

Figure 6. *Relationships between daily sap flow of upper canopy* Artocarpus heterophyllus *with daily total irradiance (a) and daily mean vapour pressure deficit (b) in a multi-layered homegarden in central Sri Lanka during a selected 54-day experimental period.*

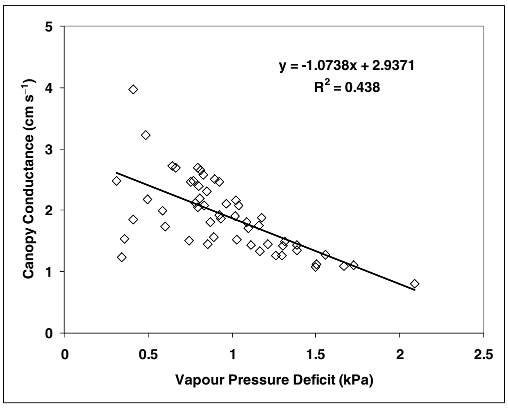

Figure 7. *Relationship between canopy conductance during the day time in upper canopy Artocarpus heterophyllus and vapour pressure deficit in a multi-layered homegarden in central Sri Lanka during a selected 54-day experimental period. The canopy conductance was estimated by inverting a simplified version of the Penman-Monteith equation.*

4. DISCUSSION

4.1. Water use of multi-layered homegardens and its determinants

Results of the present study clearly show that the taller trees occupying the upper canopy, which experience higher levels of incident radiation and vapour pressure deficits, dominate the total water use of MHGs. However, the contribution of trees occupying the middle and lower strata cannot be ignored. For instance, at the individual tree level, the combined transpiration of these two strata accounted for 30 to 33% of the total water use of the three strata (based on data in Table 2).

A linear increase in sap flow with incident solar radiation (Fig. 3) and vapour pressure deficit (Fig. 4) implies that these are the main drivers of transpiration in the MHG trees, irrespective of the level of water availability in the top 1 m of the soil. Furthermore, the linear relationship between transpiration and irradiance on a daily basis can be used to predict the daily transpiration rates of trees during periods of adequate soil water availability. The dependence of tree transpiration on VPD and irradiance is consistent with several other studies on a range of tree species (Granier and Loustau, 1994; Granier et al., 1996).

Decreasing sensitivity of transpiration rate to increasing VPD and irradiance, as shown by decreasing slopes of the relevant relationships above 0.8 kPa (Fig. 4a and Fig. 6b) and above 13 MJ m^{-2} d^{-1} (Fig. 6a), indicates some degree of stomatal control of transpiration. These observations suggest that canopy conductance decreases with increased VPD above 0.8 kPa, which was confirmed by the observed reduction in canopy conductance with increasing VPD (Fig. 7). This is in agreement with the findings of several other studies (Roberts et al., 1990; Granier et al., 1996; Hogg and Hurdle, 1997; Meinzer et al., 1997) on several tree species in different forest types. However, the high levels of daily transpiration observed during the prolonged rainless period (Fig. 5) show that the level of stomatal control observed was not strong enough to reduce transpiration substantially. It is probable that both *Artocarpus* and *Cedrela* had root systems that were deep enough to extract water from soil depths below 1 m.

4.2. Implications on sustainability of multi-layered homegardens in central Sri Lanka

The MHGs in the Central Province of Sri Lanka are generally found on deep soils with high potential for water storage. Presence of deep-rooted trees capable of absorbing water from the lower soil layers is, however, a matter of concern under certain circumstances—especially during the rainless periods. Although the Sri Lankan MHGs generally predominate the humid tropical climatic zone having well-distributed rainfall (~2000 mm yr^{-1}), the predicted drop in total rainfall and its increasingly non-uniform distribution in a future climate change scenario (McCarthy et al., 2001), is becoming a matter of concern. Perhaps this may be an overcautious scenario considering that the MHGs have sustained themselves for several centuries in areas with shallow soils and limited ground water resources. For example, the

Maya homegardens of the Yucatan Peninsula of Mexico (Benjamin et al., 2001) have provided sustainable livelihoods under rather harsh environmental conditions with limited water resources and soil nutrients. This could be yet another aspect of the 'mysteries' or the 'enigma' of tropical homegardens that defy the conventional scientific wisdom developed based on single-species systems (Nair, 2001; Kumar and Nair, 2004).

5. CONCLUSIONS AND DIRECTIONS FOR FURTHER RESEARCH

It is acknowledged that this study is based on a set of data, which is limited in several aspects. First, the transpiration measurements are not replicated and are based on only three trees out of 56 present in the 0.15 ha extent of the MHG. This was because of the practical difficulties involved in installing TDPs or sap flow gauges on an adequate number of trees and saplings and recording their output signals. Moreover, the highly uneven nature of tree distribution made replications difficult. For example, the two trees of *Artocarpus heterophyllus* were situated in the opposite parts of the MHG. We acknowledge that adequately replicated measurements of several tree species have to be done before making firm conclusions on the dynamics of transpiration in a highly complex vegetation system such as the MHGs.

Subject to the above limitations, the study suggests that water use of multi-layered homegardens of Central Sri Lanka is dominated by the upper canopy trees, with appreciable contributions from middle and lower canopy trees. Transpiration rates of MHGs are driven by incident radiation and vapour pressure deficit during periods of both adequate soil water availability and significant soil water deficits. Upper and middle canopy trees of MHGs maintain high rates of transpiration even during prolonged rainless periods by absorbing water from deeper soil layers. These findings should prompt concern on the impacts of high transpiration rates of MHGs on catchment water yield in a predicted future climate of reduced rainfall. We have not investigated the extent and depth of ground water availability. Despite the enormous practical difficulties involved, further in-depth studies are needed to quantify this impact at the catchment scale and to understand the ability of MHGs to sustain the livelihoods and ecosystem stability.

ACKNOWLEDGEMENTS

We thank the National Research Council of Sri Lanka for financial support (Research grant no. NRC-99-23) and Ms. M.R.H.L. Karunasinghe and Mr. P. Surenthran for help in the fieldwork. A special word of thanks should go to Mr. Tennakoon, the land owner of the homegarden in which this research was done for all support and cooperation.

ENDNOTES

1. McConnell D.G. and Dharmapala K.A.B. 1973. The economic structure of Kandyan Forest Farms. The Management Report No. 7, UNDP/FAO, Agricultural Diversification Project, Peradeniya, Sri Lanka.
2. Finlayson W. 1998. Effects of deforestation and of tree planting on the hydrology of the Upper Mahaweli catchment: A review of the published evidence. Environment and Forest Conservation Division, Mahaweli Authority of Sri Lanka, Polgolla.
3. Gunawardena E.R.N. 1998. Overview of the hydrology project. In: Gunasena H.P.M. (ed.), Proceedings of the final workshop: University of Peradeniya - Oxford Forestry Institute Link Project, July 1998, pp. 20 – 29. UP-OFI Link Project, Peradeniya.
4. Hitinayake H.M.G.S.B., De Costa W.A.J.M. and Jayaweera K.G.D. 1996. Food trees in multi-layered homegardens in different agro-ecological regions of Kandy district. In: Gunasena H.P.M. (ed.), Multipurpose trees for food security. Proceedings of the seventh regional workshop on multipurpose tree species, Kandy, Sri Lanka (24 – 26 October 1996), pp. 252 – 264. UP-OFI Link Project, Peradeniya.

REFERENCES

Baker J.M. and Van Bavel C.H.M. 1987. Measurement of mass flow of water in stems of herbaceous plants. Plant Cell Environ 10: 777 – 782.

Benjamin T.J., Montanez P.I., Jimenez J.J.M. and Gillespie A.R. 2001. Carbon, water and nutrient flux in Maya homegardens in the Yucatan peninsula of Mexico. Agroforest Syst 53: 103 – 111.

Bosch J.M. and Hewlett J.D. 1982. A review of catchment experiments to determine the effects of vegetation changes on water yield and evapotranspiration. J Hydrol 55: 3 – 23.

Calder I.R .1996. Water use by forests at the plot and catchment scale. Commonwealth For Rev 75: 19 – 30.

Cowan I.R. 1965. Transport of water in the soil-plant-atmosphere system. J Appl Ecol 2: 221 – 239.

Granier A. 1985. Une nouvelle methode pour la mesure du flux de seve brute dans le tronc des arbres. Ann For Sci 42: 81 – 88.

Granier A. 1987. Evaluation of transpiration in a Douglas-fir stand by means of sap flow measurements. Tree Physiol 3: 309 – 320.

Granier A. and Loustau D. 1994. Measuring and modeling the transpiration of a maritime pine canopy from sap-flow data. Agric For Meteorol 71: 61 – 81.

Granier A., Huc R. and Barigah S.T. 1996. Transpiration of natural rain forest and its dependence on climatic factors. Agric For Meteorol 78: 19 – 29.

Hogg E.H. and Hurdle P.A. 1997. Sap flow in trembling aspen: implications for stomatal responses to vapour pressure deficit. Tree Physiol 17: 501 – 509.

Jacob V.J. and Alles W.S. 1987. Kandyan gardens of Sri Lanka. Agroforest Syst 5: 123 – 137.

Jarvis P.G. and McNaughton K.G. 1986. Stomatal control of transpiration: scaling up from leaf to region. Adv Ecol Res 15: 1 – 49.

Kumar B.M. and Nair P.K.R. 2004. The enigma of tropical homegardens. Agroforest Syst 61/62: 135 – 152.

McCarthy J.J., Canziani O.F., Leary N.A., Dokken D.J. and White K.S. 2001. Climate change 2001: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, 1032p.

Meinzer F.C., Andrade J.L., Goldstein G., Holbrook N.M., Cavelier J. and Jackson P. 1997. Control of transpiration from the upper canopy of a tropical forest: the role of stomatal, boundary layer and hydraulic architecture components. Plant Cell Environ 20: 1242 – 1252.

Monteith J.L. 1986. How do crops manipulate water supply and demand? Phil Trans Royal Soc London, Ser A 316: 245 – 259.

Murray F.W. 1967. On the computation of saturation vapour pressure. J Appl Meteorol 6: 203 – 204.

Nair P.K.R. 2001. Do tropical homegardens elude science, or is it the other way around? Agroforest Syst 53: 239 – 245.

Panabokke C.R. 1996. Soils and Agro-ecological Environments of Sri Lanka. Natural Resources, Energy and Science Authority of Sri Lanka, Colombo, 220p.

Roberts J., Cabral O.M.R. and Aguiar L. de F. 1990. Stomatal and boundary layer conductances in Amazonian *Terra firme* rain forest. J Appl Ecol 27: 336 – 353.

Sakuratani T. 1981. A heat balance method for measuring water flux in the stem of intact plants. J Agric Meteorol 37: 9 – 17.

Senarath A. and Dassanayake A.R. 1999. Soils of the mid-country wet zone. In: Mapa R.B., Somasiri S., and Nagarajah S. (eds), Soils of the wet zone of Sri Lanka: Morphology, characterization and classification, pp. 92 – 121. Soil Science Society of Sri Lanka, Peradeniya.

Swanson R.H. 1994. Significant historical developments in thermal methods for measuring sap flow in trees. Agric For Meteorol 72: 113 – 132.

Tetens O. 1930. Uber einige meteorologische Begriffe. Zeitschrift Geophysic 6: 297 – 309.

Van den Honert T.H. 1948. Water transport in plants as a catenary process. Discuss Faraday Soc 3: 146 – 153.

Wallace J.S. 1996. The water balance of mixed tree-crop systems. In: Ong C.K. and Huxley P.A. (eds), Tree-crop interactions: A physiological approach, pp. 189 – 233. CAB International, Wallingford.

CHAPTER 15

ECOLOGY VERSUS ECONOMICS IN TROPICAL MULTISTRATA AGROFORESTS

E. TORQUEBIAU* AND E. PENOT

*CIRAD TERA, TA 60/15 – 34398, Montpellier CX5, France; *E-mail: <torquebiau@cirad.fr>*

Keywords: Environmental services, Externalities, Modeling, Risk buffering, Rubber.

Abstract. Homegardens and other multistrata agroforests are often described as ecologically sound, economically viable, and socially equitable land use activities. As in a majority of sustainable management situations, there are no widely accepted norms for a "perfect" combination of these attributes; what is often envisaged is a compromise among them. We argue that the development of ecological features of homegardens can be fostered by an "innovative" economic analysis. Performance of homegardens cannot be fully assessed by using conventional economic criteria and approaches such as yield, cost-benefit analysis, and net present value. Alternatively, if micro- and meso-level economic analyses (farming systems and upper level systems) are applied, the internalization of externalities such as agrobiodiversity management, carbon sink value, improved nutrient cycling or integrated pest management may turn homegardens into highly profitable ventures. Economic analysis methods should integrate risk buffering, outputs of mixtures of plants with different cycles, and allow to take into account farming strategies with long-term objectives as well as the patrimonial (asset inheritance) components. Additionally, the merits of homegardens in terms of subsistence food for families, flexibility in production, reduced external-input requirements, enhanced aesthetic-, landscape-, and societal values, should also be incorporated into such an analysis.

1. INTRODUCTION

In the realm of agroforestry, homegardens and other multistrata, multispecies associations occupy an odd place. They are the most elaborate manmade, tree-crop-animal associations, and as such the only agroforestry system which can claim a resemblance to natural forests; hence their alternative name "agroforests." Although

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 269–282.

these systems have been studied in several countries (Indonesia, Brazil, India, and Sri Lanka: see chapters in this volume), the fact remains that they are seldom advocated as a land use option in agricultural or forestry development paradigms.

Before pursuing further, a clarification on the use of the term homegardens versus other multistrata agroforestry systems is relevant. Both are multistrata combinations of trees and crops (sometimes with a livestock component). Homegardens are located next to human dwellings, managed for the production of subsistence items, and sometimes includes a cash objective. They are practiced on small parcels of land and are usually intensively managed. Not all multistrata agroforestry systems may, however, qualify as homegardens. Examples are the village-forests (village-forest-gardens), which are multistrata agroforestry systems developed on larger areas (at least a few ha per family) and managed mainly for cash income generation through the production of resins, jungle rubber, wood, fruits, etc. These are often considered as 'intermediates' between natural forests and tree-crop plantations (Wiersum, 2004). Neither can all agroforestry systems be called "agroforests." For example, the term does not cover agroforestry systems such as scattered trees on croplands, windbreaks, or woody hedgerows. As the term suggests, agroforests resemble forests and mimic their ecology (Michon and de Foresta, 1999; Wiersum, 2004). This resemblance is important in the context of the present chapter, as ecological and economic analyses applied to multistrata systems partly draw on their forest equivalents. Agroforest is thus the term used to represent both homegardens and other multistrata agroforestry systems and will hereafter be used in this chapter (instead of homegardens).

1.1. Attributes and spread of agroforests

Because of their resemblance to forests both physiognomically and ecologically, agroforests have a "good reputation." Most statements recognizing the quality of agroforests, including in recent papers, refer to their ecological attributes, in particular biodiversity conservation and the long-term benefits of soil fertility maintenance and water conservation (Gajaseni and Gajaseni, 1999; Kaya et al., 2002; Penot, 2001), even under harsh environments (e.g., the Soqotra Island of Yemen; Ceccolini, 2002). In some studies, the socioeconomic variables are taken into account (e.g., Mendez et al., 2001; Penot, 2003; Wezel and Bender, 2003) for analyzing the system's functions but most do not describe the socioeconomic attributes with the same rigor as that of the ecological variables. Some studies dealing with bio-economic modeling of agroforests are also restricted to the cropping system-level (e.g., Purnamasari et al., 2002). Issues such as labor needs and returns, investments and return-on-investments in the mid- and long-term, product benefits, and income generation might be described, but they are seldom presented as arguments for adoption, or even taken into account in the innovation process behind the adoption of agroforests. In other words, the overall advantages as well as positive externalities of agroforests are widely recognized but not properly valued. Direct benefits of agroforests at farm-level are generally underrated and more so at the community and landscape levels.

The only two economic variables which seem to provide convincing arguments are: (1) diversification linked with the spreading of risk, income and labor, and (2) income generation as a whole (e.g., Torquebiau, 1992; Mendez et al., 2001; Penot, 2003; Wezel and Bender, 2003; Wiersum, 2004). The large number of products of agroforests and their uses may explain the difficulty to go beyond mere description and quantify these in economic terms. Similarly, the links between diversification, risk buffering capacity and long-term economic and ecological sustainability have not been sufficiently taken into account so far. The role of risk and uncertainty has been studied in agroforestry adoption (Mercer, 2004) but not as an innovation process in itself.

Yet, tree homegardens cover significant land areas. For example, they occupy 20% of arable land of Java, Indonesia (Jensen, 1993). It has been shown that the economic functions of these "*pekarangans*" (see Wiersum, 2006) contribute to social equilibrium (Mary and Dury, 1997). A study of their patrimonial value demonstrated that durians (*Durio zibethinus*, a popular fruit tree) in these Javanese homegardens have a significant economic importance, both as a source of income and as an insurance mechanism in informal financial systems (Dury et al., 1997). There are more than 5 million homegardens in Kerala State, India (Kumar and Nair, 2004) – another homegarden 'hotspot'. Three million hectares of jungle rubber (*Hevea brasiliensis*-based agroforest) provide more than 50% of the total rubber production of Indonesia and there are another 2 million ha of various agroforests in Indonesia (Penot, 2001). Multistrata agroforests are also known in Brazil, Cameroon, Ghana, Nigeria, Tanzania, Sri Lanka, and other countries (Kumar and Nair, 2004). Agroforestry homegardens can also be observed in many tropical countries, both on agricultural frontiers and in stabilized agricultural landscapes. Although a worldwide estimation of the contribution of these cropping systems to agricultural production has not been made, it is now accepted that their contribution is far from negligible, be it in terms of traded products, fuelwood, subsistence crops, nutritional value, medicinal plants, timber, etc. If farmers worldwide have developed such systems, it is certainly not because they mimic the forests or foster biodiversity conservation—there must be something else as discussed hereunder.

1.2. Need for a specific economic analysis

We argue that there is an economic rationale explaining the importance of agroforests worldwide, but that this rationale is relatively complex to identify and measure. First, there is a well-known complementarity between direct sales of agroforestry products (timber, fruits, legumes, resins, nuts, rattan, medicinal products, etc.) and self-consumption by the garden owner, which leads to significant savings in the households' day-to-day expenses. Secondly, it has been shown that long-term patrimonial strategies are of utmost importance to farmers growing agroforests (Mary and Dury, 1997); yet, conventional economic analyses based on discounting rates hardly serve for such perennial, multi-component and multi-cycle systems, where future discounted values of tree products are difficult to anticipate and as such seldom taken into account by farmers in their planting choices (Torquebiau et al., 2002), unless the harvested products are easily marketable and they generate a net margin which covers replanting costs (e.g., clonal rubber). Finally, farmers also plant and tend agroforests for their social functions (land tenure, social status and living environment). So, while scientists have repeatedly said that agroforests are environmentally sound, that alone is probably not a major motivation for farmers.

The objective of this chapter is to try and show that the reason behind the "enigma of tropical homegardens" (Kumar and Nair, 2004) lies in elements of positive externalities, which are not accounted for in standard economic analyses, yet matter to the farmers and perhaps to other stakeholders (e.g., timber for sawmills). If agroforestry scientists want to convince farmers and policy makers that agroforests are more than just relics of the past and are worthy to be considered as land use options, then appropriate economic analyses of agroforests need to be done covering the ecological services (e.g., watershed protection, nutrient-cycling, carbon sink, bio-habitat functions, and biodiversity maintenance) as well as social, cultural and aesthetic values.

Following Coase (1960)'s analysis of social cost, we make a difference between "giving a value to a service" (potentially, but not automatically tradable) and "paying for a service" (which leads to the "who is going to pay" question). Taking into account (assigning a value to a service) or internalizing positive externalities (paying for a service) relate to resources or services that cannot be included in private accounting because they are public goods (e.g., landscape beauty, pollinating insects) or because they are preserved for future generations (e.g., biodiversity, soil resources). We argue here that such "global goods," considered as services to the community, need be taken into account not only by international negotiations such as discussions on climate change or biodiversity, but also in agricultural policies and incentives, and, as a consequence in the farmers' day-to-day decision-making processes.

One of the services that are likely to be taken into account in the future is the carbon sink function of the Clean Development Mechanism (CDM), as scheduled in the Kyoto Protocol. Rubber being the only tree crop (beside timber trees) eligible for CDMs, rubber-based and timber-based agroforests will theoretically be eligible. In such a case, their carbon sink service can be valued and considered in the trade or exchange of pollution rights (O.J. Cacho, pers. comm., 2002).

2. AGROFORESTS AS CROPPING SYSTEMS PROVIDING MISCELLANEOUS GOODS AND SERVICES

2.1. Multiple roles

Farmers worldwide, but especially those in the developing countries, do not focus only on agricultural production. They are concerned first and foremost about their family priorities and are seldom sensitive to global issues such as biodiversity conservation or carbon sequestration; they nevertheless contribute to a series of goods and services that are not always marketed or even recognized. This multi-functional role of agriculture is now recognized and promoted in some regions (e.g., Europe) in contrast to merely "production-oriented" agriculture. This has also led to the reduction in direct subsidies to production but subsidizing the environmental functions of farms.

Agroforests can fulfill this multi-functional role better than other farming systems because they have more positive externalities than other monocultures or simpler agroforestry systems. So they deserve a specific economic analysis taking into account both goods and environmental services as well as short- and long-term issues. Agroforests, homegardens in particular, combine perennial-based production with long-term strategies (e.g., resin, nuts, fruits, and timber production) and shorter-duration food crops (e.g., legumes, cassava – *Manihot esculenta*, and banana – *Musa* sp.) with a short-term perspective. Farming systems models can include components on externalities or services to analyze this multifunctional feature. It might, however, be easier to handle the benefits of some services such as biodiversity conservation at regional- or macro-level. While priority has so far been on plant biodiversity, some studies have shown the role of agroforests as wildlife buffer zones (Nyhus and Tilson, 2004).

Another important role is the generation of a "forest rent" as defined by Ruf (1987), i.e., the reduction of costs and risks of perennial plantation establishment – thanks to the forest's positive externalities such as soil quality, weed and pest control. This concept has been extended to agroforests by Penot (2001), who showed that agroforests did maintain (sometimes improve) the forest rent while conventional monoculture plantation crops such as cacao (*Theobroma cacao*), coffee (*Coffea* spp.), and oil palm (*Elaeis guineensis*) generally consumed (part of) it.

Agroforests have some constraints too, however. Since crop mixtures are the rule, some crops are favored while others are not; and agroforests may provide small quantities of a given crop that are not always saleable, except locally. Crops may also change with time; e.g., rice, maize or cassava may be initially intercropped with young trees but will not yield optimally under an increasing intensity of shade, which necessitates their replacement with shade tolerant crops (e.g., beans, some banana varieties). Similarly, rattan vines intercropped in rubber agroforests will not be harvested during peak rubber production but rather at the end of rubber trees' lifespan because rattan harvesting tends to damage tree canopies.

High reliance on manual labor and limited markets for specific products are other significant features in this respect. Delayed production (from large-sized trees) delays return on investment. Most farmers use non-improved plants and the quality can be variable, a potential problem for export of fruits, although there can also be a niche market for "organically grown" local varieties. However, some agroforests (e.g., rubber agroforestry systems) also rely on fertilizers and improved planting materials (e.g., rubber clones and grafted fruit trees).

Overall, agroforests are specific cropping systems, which display a range of specifications making them more difficult to analyze than the monocropping or even multiple cropping systems with annual crop associations. It can be argued that it is this lack of analysis that has hampered the efforts of agronomists and extension agents to promote agroforests and hindered research to reach beyond the descriptive studies and into the stage of analytical research.

3. SUSTAINABILITY OF AGROFORESTS

Sustainability of agroforests can be explained based on different factors and criteria. Ecological sustainability stems principally from biodiversity conservation, natural resource management (soil and water), the control of pollution (little or no use of agrochemicals) and phytoremediation. Against today's global change challenge, agroforests represent an important carbon sequestration potential (Kumar, 2006). Economic sustainability is based on the consideration that agroforests are able to provide in the long-run a stable and diversified source of income and are viewed as patrimonial assets (i.e., contributing to the long-term wealth and inheritance of the family; Mary and Dury, 1997). A large proportion of the local, traditional farming knowledge is related to agroforests. The risk buffering capacity of agroforests contributes to both ecological and economic sustainability. Social sustainability might be achieved through land tenure security linked to tree growing and preservation of community values. Institutional sustainability might be seen through the fact that agroforests can be individually or commonly managed. Table 1 summarizes some arguments that link agroforests with sustainability.

Table 1. *A summary of sustainability attributes of agroforests.*

Ecological	*Economic*	*Social and institutional*
- reduced soil erosion - high soil organic matter content - buffered soil moisture and temperature - closed nutrient cycling - improved soil physico-chemical properties - efficient use of light and water - high wild plant and animal biodiversity - use of endogenous resources - contribution to on-farm production of wood and fuel wood - high soil biotic activity - better scope for evolution and diversification of economic plants - differentiated vertical and horizontal management zones and related ecological niches - potential for organically grown products	- significant use of endogenous resources - high safety factor against marketing and seasonality hazards - reduced cash needs - high and diversified bio-physical outputs (plant and animal food, medicines, fibers, etc.) - socio-economic outputs diversified and distributed over time - balance between subsistence and cash income - building up of capital - boosting rural industries and employment - adjustment to varied contexts - yield stability - management flexibility (intensive vs. extensive) - economic resilience (value as "land reserve")	- reduced and flexible labor needs - contribution to nutritional security - contribution to community socialization - preservation of traditional knowledge - biodiversity linked to traditions and practices - key role of women - equitable distribution of products - land reserve function (for alternative landuses) - maintenance of access rights to common goods (e.g., fruits) - flexibility of ownership (private vs. communal)

Source: Adapted from Torquebiau (1992), Penot (2003), and Kumar and Nair (2004).

Kumar and Nair (2004) rightly point out that homegardens (i.e., not all agroforests) may be on the verge of extinction due to new trends in agrarian structure, high market-orientation, demographic pressure, land fragmentation, and cultural dynamics. In the face of such constraints, the ecological foundations of homegardens may not be sufficient to warrant their survival. However, Javanese homegardens keep their place and role with an average population density of more than 800 persons km^{-2}, and a strong market-orientation of agriculture (Wiersum, 2006). Presence of some high value crops (e.g., durian) may probably explain this. Interestingly, Java is not the only place where a positive correlation is observed between number of trees per unit area and human population density. Other examples include Kenya (Tiffen et al., 1994), Kerala (India) and Sri Lanka.

Often multistrata agroforests are also under the influence of changing economic factors. For instance, jungle rubber and damar (*Shorea javanica*) gardens of Indonesia are facing international price fluctuations (e.g., rubber price moving from 2 US \$ kg^{-1} in 1996, to 0.6 in 2001, and then back to 1.2 in 2004). Furthermore, diversification of local farming may be at the expense of traditional agroforests, e.g., massive investments in industrial crops such as oil palm. The recent push toward globalization impacts the traditional farming practices in a myriad of ways among which access to market and marketing procedures rank high. In Asia, for instance, most export products have long been linked with international prices (rubber, oil palm, coffee and cocoa). The commodity boards established in Africa in the 1970s to protect farmers from price volatility have failed to deliver the expected results and their relevance is now being questioned. Thus, globalization has a stronger impact on African farmers than their Asian counterparts, who used to adapt better to the international markets and price cycles. We suggest that agroforests play a role in this adaptability; yet new policies of decentralization and local governance, new rules for access to credit, projects or information may impact it. It is, however, speculative as to whether agroforests will be able to react to such changes more efficiently than conventional monocropping.

4. CHALLENGING THE REAL ECONOMIC IMPACT OF AGROFORESTS

The sustainability advantages of agroforests come from a trade-off between ecological and socioeconomic attributes. Conventional economic approaches may be inadequate for integrating these attributes in a comprehensive manner, because (1) farmers manage agroforests for a variety of objectives, (2) the ecological benefits are not internalized in existing analyses, and (3) some ecological attributes have no current market value.

Furthermore, if neoclassical economics are used to assess the performance of agroforests, the criteria of yield, cost-benefit analysis and net present value may end up giving agroforests poor ratings compared to conventional monocropping activities, because the analysis will exclude a series of agroforests' outputs, which are not traded in the market or insufficiently taken into account in farm economics; Indonesia's jungle rubber is a case in point. While it has been a major opportunity for poor farmers at the agricultural frontier for years, it is now becoming obsolete compared to clonal rubber monoculture, in terms of yields and labor productivity

(Penot, 2001). However, it is difficult to measure or assign economic values to intangible services and positive externalities. For instance, carbon sink values of tree crops and forests are currently available but no one can choose among various prices suggested by experts as long as carbon markets are not functional. Risk-buffering potential of agroforests, as in situations of climatic variations and commodity price volatility, also deserves to be measured. The key question behind this is: how to make a measurement of the agricultural sustainability of agroforests? Perhaps farm-system models used in farming system research could be a useful tool for such comparative assessments.

4.1. Farming system level approach

A pragmatic approach could be first to analyze at the household-level the cost saved by using products provided by agroforests for items that would otherwise need to have been purchased (e.g., building and fencing materials, food, medicines and raw materials for handicraft). Next, the accounting for environmental benefits might be performed at the household-level by compiling data over at least a year. Farming system modeling (e.g., with a software like "Olympe")[1] is useful to process data on production, value, cost of production and labor, in order to be able to compare returns to labor and gross margin per cropping systems at the farm-level. Olympe performs whole-farm analysis in terms of resources, land, labor and other opportunities. It is a simulation tool for farm management advice which includes a "hazard" module that takes into account uncertainties, externalities (both positive and negative), as well as scenario definition according to risks. It can also be run at the regional level and with farmers' groups. An analysis can be made in terms of income source, return to labor or investment, and linkage between strategic choices and production factor allocation, in order to assess the relative importance and real impact of cropping systems within the farming system. The combination of farm modeling with economic quantification, a historical perspective and the "contextualization" of farmers' decisions according to political, socioeconomic, non-market (ecological)- and market factors provide the explanatory factors of a given farming system. Typically, the software allows re-interpreting the role of agroforests, as cropping systems within a farming or regional system.

Under this approach, farmers' strategies on labor, capital and land use are analyzed holistically (i.e., at the level of all enterprises of a farm, and not only at the level of one or the other cropping system). This is crucial to detect the place of agroforests in the overall farming strategy, because agroforests seldom produce the main staple food (Michon and de Foresta, 1999), and are invariably one cropping system among others on a farm. This approach, developed for the rubber farmers of Indonesia[2], allows analyzing the diversification of opportunities for farmers facing an economic crisis and a political change that, in turn, can trigger significant changes in the social framework.

4.2. A social-ecological perspective

While a farming system approach can pave the way for a better understanding of agroforests' roles, there is also a need for a renewed approach to agroforest analysis which can deal with higher levels of complexity and translate their "social-ecological[3]" performance into economic performance. An apparently non-rational behavior that has been observed in Indonesia is the maintenance of old rubber agroforests along with economically very profitable oil palm plantations. One hypothesis was that agroforests would gradually leave the way for oil palm plantations. Social value (land control), possibilities of agroforest improvement (clonal rubber), and diversification strategies eventually may lead to a new development of improved rubber agroforests, which remain within the financial possibilities of local farmers with no access to credit, or even insufficient capital building capability. Meanwhile, whatever the important gains in return to labor and net margin provided by oil palm, agroforests have never disappeared – a proof of the value of such systems in a social perspective. Agroforests as "reserve land factor" or "long-term land control factor" might not have a direct value but do have an indirect value as a capital reproduction factor or as a potential expanding factor.

Patrimonial analysis based on the evolution of capital building and asset transmission could be used for agroforests considered as reserves of land which can be traded, and since large-sized trees constitute a strategy for the build-up of capital for further investment. Long-term multi-cycle analyses may provide a framework to understand the farmers' behavior and strategies. Economic analyses of mixtures of plants with different cycles can also be done through farming system modeling. Smoothening of long-term and patrimonial strategies (Mary and Dury, 1997; Torquebiau et al., 2002) may help taking into account the time factor and historical perspective (e.g., capital accumulation and building capacity). A multi-criteria analysis at both farm and community level is far more powerful than simple conventional cost-benefit analysis at cropping system level. Again, linking crucial social aspects (and their consequences in terms of use of production factors) with the economic analysis may provide a reliable framework that can take into account all cultural and non-merchantable aspects. Unfortunately, since methods for valuation of non-tangible social and cultural benefits of agroforestry are practically non-existent (Kumar and Nair, 2004), it is difficult to substantiate the above (Penot and Deheuvels, 2006); rather, it is a plea for future research on these issues.

4.3. Subsistence versus cash income generation

The merits of agroforests in terms of subsistence for families, flexibility in crop production or reduced external input requirements also need to be taken into account. The comparison between farms with and without agroforests may show the savings and impact on household's income. However, not all agroforests are food crop-based. Some agroforests are totally cash-oriented, e.g., rubber (jungle rubber), resin (damar agroforest), spices (e.g., cinnamon: *Cinnamomum zeylanicum*), fruits (durian) and timber-based agroforests.

The flexibility in crop and tree production in agroforests relates to the different phases with mature and immature periods of trees or crops. Therefore, it is essential to take into account the life cycle of plants to implement an economic analysis in the long run. Specific discounting rates may be necessary as cycles may extend up to 40 or 50 years. Different scenarios are necessary, as this may introduce bias in valuing products according to the discounting rates chosen. For instance, in tree crop-based agroforests, rubber or resin is produced for more than 30 years when annual and biennial crops are generally produced only in the first 3 to 6 years. Timber can be harvested only at the end of the agroforest's life-span. Therefore, if detailed data are available to obtain a reliable assessment of real income (including self-consumption), system comparison will be more valuable than absolute data (Penot, 2001).

4.4. Landscape amenity and social conviviality

The role of agroforests in providing services such as landscape beauty and aesthetics or social interaction or social status improvement has also to be incorporated in the assessment. It seems clear that in many situations, agroforests, and in particular, the non-private agroforests managed by local communities, and as such considered as public goods with limited and shared access (for fruits, timber etc.), have a social importance. The "Tembawang" of the Dayak people in Kalimantan (Indonesia) is a typical example. Besides being a reserve of forest products through "extractivism," when original forests will have disappeared, such agroforests generally include important social components such as graveyards or may play a role of protection through the maintenance of a "green belt" around the village. Even if there is no economic value to this service, its social value will be a compelling reason for the maintenance of such agroforests and generally prevent its destruction.

5. THE MICRO-ECONOMIC APPROACH

Obviously, many specific features of agroforests might not be purely valued as goods. Social values, long-term strategic value of land, and risk buffering are examples; yet they provide powerful incentives to advocate agroforest development. With farming system modeling and a prospective approach, it is possible to assess the effects on risks. A prospective analysis with scenarios can lead to identification of economic thresholds and boundaries[1,2] and enables the definition of an economic feasibility domain (or expected economic outputs), i.e., the range within which the system is economically viable.

If agroforests' benefits can be analyzed through market values of their products and services, then neo-classical environmental economics can be used and externalities can be included (or re-internalized) into the process of income generation. Growth or pollution costs and delay may be taken into account as negative externalities or constraints to further development. Environmental services (for example, carbon sequestration potential: Albrecht and Kandji, 2003; Montagnini and Nair, 2004; Kumar, 2006) can be valued according to a "system of values" recognized locally as relevant at a higher, community or provincial level. The real problem is, therefore, to see whether farmers can potentially or do really take benefit of externalities and positive advantages of agroforestry. The payment of environmental services as promoted by the RUPES project (South-Sumatra and Lampung provinces, Indonesia)[4] provides some evidence in this respect. Other examples include the potential of agroforestry to reach the millennium development goals (Garrity, 2004) and the application of the Kyoto mechanisms to rubber trees (Hamel and Eschbach, 2001). Research on rubber agroforestry in Indonesia (Lawrence, 1996) provides an important data-set on these issues.

In the context of most developing countries, huge income gaps due to strong social stratification, information asymmetry, high transaction costs and institutional failures have strong implications on local economies. Microeconomics allows accounting for environmental assets, complexity, and uncertainty, and involves stakeholder participation. When dealing with agroforests, benefits that relate to public goods or goods that cannot be given a market price because they are for future generations (e.g., biodiversity, landscape amenity, carbon sink and cultural and aesthetic values) need to be assessed through a new perspective. A multi-functional approach, similar to that developed by the Common Agricultural Policy for European farmers (Dévé, 2004), can provide ideas to take these externalities into account. New mechanisms such as the CDMs could be explored, in particular for global issues such as biodiversity conservation.

Agroforest attributes should also be considered in national accounting. Policy makers should acknowledge the fact that if resource depletion is taken into account through an environmental economics approach; agroforests will rank very high among land use options because they generate an "agroforest rent" which is much higher than the rent from conventional agriculture or other forms of resource exploitation (e.g., logging, mining the soil through excessive harvests). Farmers contributing to this resource rent could hence be given direct or, better, indirect incentives (e.g., tax exemption) to stimulate land use options, which contribute to such public goods for current and/or future generations.

To reach a status where agroforests could be recommended among other land use options, they need a reference framework, which takes into account these alternative economic analyses. Unfortunately, such analyses are lacking at present. In the meantime, multistrata agroforestry systems will continue being rejected or marginalized by conventional literature as not fitting into the mainstream economics and hence in development objectives. Be it for commercially oriented agroforests or subsistence oriented homegardens, a long-term perspective must be part of farmers' strategy. However, there is obviously a biased debate between short-term (economics) vs. long-term (ecology) issues. In both cases, farmers have developed long-term farming practices through a long haul innovation process that eventually takes into account economics through the risk buffering capacity of agroforests. In most cases, social organization is deeply linked with technical constraints in production, food reliance, income securing and, eventually, land control. There is a strong coherence between technical pathways and social systems (Penot, 2003). Customary laws take into account this important point and are generally able to adapt to changes. There is an economic strategy behind maintaining agroforestry practices that have proved to be able to secure production and maintain control on land. In other words, long-term economics are totally associated with ecology and sustainability. An appropriate economic analysis should actually take care of the long-term aspects. One main challenge for the immediate future, however, is to take further steps towards the internalization of externalities, providing a value to services through a multifunctional approach and giving value-added objectives to ecological criteria.

6. CONCLUSIONS

If an economic perspective with emphasis at local and regional level is applied to integrate positive externalities such as agrobiodiversity management, improved nutrient cycling, integrated pest management, ecological sustainability and services, decision-makers may be convinced that homegardens and agroforests are highly profitable ventures. If an "agroforest rent" approach is adopted, policy makers and development officers will see a long-term profitable investment in agroforests. Hopefully, this will lead to agroforests being given better consideration than at present in research and development programs worldwide. Furthermore, if agroforests are still a success-story with many farmers, it is obviously not because of biodiversity conservation. Other values such as social values, security, diversity, land control and reserve (including land and tree tenure) are probably important. There is also a need for a mechanism for the societal or community payment of those external and social benefits. A micro-economic analysis at the farming system level including all sources of income, cost-benefit per activity and return to labor, can explain such long-term strategies, provided they take into account the dynamics ("time effect") of perennial crops in homegardens and other agroforests.

Economic analysis methods using farming system modeling which integrate the outputs of mixtures of plants with different cycles and allow for the smoothening of long-term and patrimonial strategies are required to explain with accuracy what the farmers do and why they do so. Agroforests, despite their positive externalities and advantages are not a "panacea" but seem to be an ideal compromise between sustainability and risk spreading.

ACKNOWLEDGEMENTS

We acknowledge the useful comments by Stefano Farolfi, Anne Marie Izac, Patrice Levang, and three anonymous referees on an earlier version of the manuscript.

ENDNOTES

1. Penot E., Le Bars M., Deheuvels O., Le Grusse Ph. and Attonaty J.M. 2004. Farming systems modelling in tropical agriculture using the software "Olympe." ECOMOD Workshop, June 2004, Paris.
2. Penot E. and Hébraud C. 2003. Modélisation et analyse prospective des exploitations hévéicoles en Indonésie: Utilisation du logiciel Olympe pour la

définition de scénarios d'évolution en fonction de choix techniques et des aléas. Modélisation des exploitation agricoles: les multiples usages du logiciel Olympe. CIRAD Workshop, September 2003, Montpellier.

3. The term “social-ecological” implies an interactive system of equally important social and ecological parts, while the conventional “socio-ecological” has the simple connotation of an ecological system with some social aspects (Sayer and Campbell, 2004).
4. Van Noordwijk M., Chandler F.J. and Tomich T.P. 2004. An introduction to the conceptual basis of RUPES: rewarding upland poor for the environmental services they provide. ICRAF Southeast Asia, Bogor, 46p.

REFERENCES

Albrecht A. and Kandji S.T. 2003. Carbon sequestration in tropical agroforestry systems. Agric Ecosyst Environ 99: 15 – 27.

Ceccolini L. 2002. The homegardens of Soqotra island, Yemen: an example of agroforestry approach to multiple land use in an isolated location. Agroforest Syst 56: 107 – 115.

Coase R.H. 1960. The problem of social cost. J Law Econ 3: 1 – 44.

Dévé F. 2004. Major findings and conclusions on the role of agriculture. RAO Project of FAO, Phase 1. FAO, Rome, 18p.

Dury L., Vilcosqui L. and Mary F. 1997. Durian trees in Javanese homegardens: their importance in informal financial systems. Agroforest Syst 33: 215 – 230.

Gajaseni J. and Gajaseni N. 1999. Ecological rationalities of the traditional homegarden system in the Chao Phraya Basin, Thailand. Agroforest Syst 46: 3 – 23.

Garrity D.P. 2004. Agroforestry and the achievement of the millennium development goals. Agroforest Syst 61: 5 – 17.

Hamel O. and Eschbach J.M. 2001. Impact potentiel du MDP dans l’avenir des cultures pérennes: état des négociations internationales et analyse prospective à travers l'exemple de la filière de production du caoutchouc naturel. Oléagineux Corps Gras Lipides 8: 599 – 610.

Jensen M. 1993. Productivity and nutrient cycling of a Javanese homegarden. Agroforest Syst 24: 187 – 201.

Kaya M., Kammesheidt L. and Weidelt H.J. 2002. The forest garden system of Saparua island, Central Maluku, Indonesia, and its role in maintaining tree species diversity. Agroforest Syst 54: 225 – 234.

Kumar B.M. 2006. Carbon sequestration potential of tropical homegardens. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 185 – 204. Springer Science, Dordrecht.

Kumar B.M. and Nair P.K.R. 2004. The enigma of tropical homegardens. Agroforest Syst 61: 135 – 152.

Lawrence D.C. 1996. Trade-offs between rubber production and maintenance of diversity: the structure of rubber gardens in West Kalimantan, Indonesia. Agroforest Syst 34: 83 – 100.

Mary F. and Dury S. 1997. Les fonctions économiques méconnues des jardins villageois à Java-Ouest. Fruits 49: 141 – 150.

Mendez V.E., Lok R. and Somarriba E. 2001. Interdisciplinary analysis of homegardens in Nicaragua: mico-zonation, plant use and socioeconomic importance. Agroforest Syst 51: 85 – 96.

Mercer D.E. 2004. Adoption of agroforestry innovations in the tropics: a review. Agroforest Syst 61: 311 – 328.

Michon G. and de Foresta H. 1999. Agro-forests: incorporating a forest vision in agroforestry. In: Buck L.E., Lassoie J.P., and Fernandes E.C.M. (eds.) Agroforestry in sustainable agricultural systems, pp 381 – 406. CRC Press, Boca Raton, FL.

Montagnini F. and Nair P.K.R. 2004. Carbon sequestration: an underexploited environmental benefit of agroforestry systems. Agroforest Syst 61: 281 – 295.

Nyhus P. and Tilson R. 2004 Agroforestry, elephants and tigers: balancing conservation theory and practice in human dominated landscapes of Southeast Asia. Agric Ecosyst Environ 104: 87 – 97.

Penot E. 2001. Stratégies paysannes et évolution des savoirs: l'hévéaculture agro-forestière indonésienne. PhD Thesis, University of Montpellier, Faculty of Economics, France, 360p.

Penot E. 2003. Cohérence entre systèmes techniques et systèmes sociaux et territoires. Evolution des systèmes de production hévéicoles et gestion de la ressource foncière : le cas de la province de Ouest-Kalimantan, Indonésie. In: Dugué P. and Jouve P. (eds), Organisation spatiale et gestion des ressources et territoires ruraux, pp 60 – 68. UMR SAGERT (CIRAD – CNEARC - ENGREF), Montpellier.

Penot E. and Deheuvels O. (eds) 2006. Du système de culture à la petite région: Modélisation du fonctionnement de l'exploitation agricole, simulation et aide à la décision avec le logiciel Olympe. L'Harmattan, Paris (in press).

Purnamasari R., Cacho O. and Simmons P. 2002. Management strategies for Indonesian rubber production under yield and price uncertainty: a bio-economic analysis. Agroforest Syst 54: 121 – 135.

Ruf F. 1987. Eléments pour une théorie sur l'agriculture des régions tropicales humides: de la forêt, rente différentielle au cacaoyer, capital travail. Agron Trop 42: 218 – 232.

Sayer J. and Campbell B. 2004. The science of sustainable development: Local livelihoods and the global environment. Cambridge University Press, Cambridge, 268p.

Tiffen M., Mortimore M. and Gichuki F. 1994. More people less erosion: Environmental recovery in Kenya. John Wiley, London, 234p.

Torquebiau E. 1992. Are tropical agroforestry homegardens sustainable? Agric Ecosyst Environ 41: 189 – 207.

Torquebiau E., Mary F. and Sibelet N. 2002. Les associations agroforestières et leurs multiples enjeux. Bois et Forêts des Tropiques 271: 23 – 36.

Wezel A. and Bender S. 2003. Plant species diversity of homegardens of Cuba and its significance for household food supply. Agroforest Syst 57: 39 – 49.

Wiersum K.F. 2004. Forest gardens as an 'intermediate' land use system in the nature-culture continuum: Characteristics and future potential. Agroforest Syst 61: 123 – 134.

Wiersum K.F. 2006. Diversity and change in homegarden cultivation in Indonesia. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 13 – 24. Springer Science, Dordrecht.

CHAPTER 16

FINANCIAL ANALYSIS OF HOMEGARDENS: A CASE STUDY FROM KERALA STATE, INDIA

S. MOHAN*, J.R.R. ALAVALAPATI, AND P.K.R. NAIR

*School of Forest Resources and Conservation, University of Florida, Gainesville, FL 32611, USA; *Current Address: CREST-RESSACA, Texas A&M University, Kingsville, MSC 213, 700 University Blvd, Kingsville, TX 78363, USA; E-mail: <smohan@even.tamuk.edu>*

Keywords: Adaptive management, Economic utility, Non-monetary benefits, Resilience, Sensitivity analysis.

Abstract. Homegardens are touted as economically and biologically sustainable systems, but studies to quantify the economics of these gardens are limited. This study used inventories, survey information and market data to estimate the productivity of 75 homegardens in Thrissur district of Kerala state, India, and applied benefit-cost analysis to ascertain the current financial values of these systems. All homegardens were found to be economically profitable and also to be of better economic utility to the farmer than selling or leasing the land. Sensitivity analyses indicated that these systems were easily resilient to 10% shifts in the prices of hired labor and in the prices of the three most economically important crops: coconut (*Cocos nucifera*), arecanut (*Areca catechu*), and banana (*Musa* spp.). Profit value of the gardens tended to increase with holding size and with increasing years of cultivation. Labor hours (both household and hired) and gender of the decision-maker were not suitable predictors of profit. Intensity of profit generation was highest in the smaller gardens, thus perhaps indicating both adaptive management to land constraints, and the presence of other intangible benefits that might affect land management strategies.

1. INTRODUCTION

Homegardens are well developed agroforestry systems consisting of distinct assemblages of plants with or without livestock, intensively managed within the residential compound. Economic theories and methodologies relating to agroforestry

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 283–296.

systems are well documented (Alavalapati et al., 2004); however, rigorous field studies that apply these concepts to homegardens are rare (Nair, 2001). One of the major constraints to implementing some of these concepts stems back to an observation made by Scherr (1992) regarding the lack of guidelines for data collection and analysis. Preliminary economic analyses in Central America and the Caribbean have indicated that many agroforestry systems are profitable even at real discount rates of 20% or higher (Current et al., 1995), yet economic studies relating to homegardens are limited. The economic worth of homegardens is especially difficult to quantify due to three reasons: these systems have high, yet variable levels of biodiversity, making data collection time-intensive and error-prone; these systems provide some benefits that are designed to be of particular use to certain farmers only; and finally, these are established systems, some of which have existed for many hundreds of years, and the benefits realized in the past may not be accurately quantified because of the inadequate availability of data. Different methods of quantification of intangible benefits, which are outside the scope of this chapter, are now increasingly studied and might potentially, be used to address these non-market values.

Homegardens, although primarily used for subsistence purposes of the household, are increasingly being used to generate cash income (Christanty, 1990; Torquebiau, 1992; Mendez et al., 2001). They are also used to generate non-market benefits such as aesthetics, ornamentation, improved food quality, and nutritional security to the farmers (Karyono, 1990; Jose and Shanmugaratnam, 1993; Drescher, 1996). With the overall aim of using a combination of different methodologies to assess the current tangible financial status of existing homegardens and providing a set of guidelines for data collection and analysis, a study was carried out in Kerala, India (Mohan, 2004). This chapter forms a part of that investigation and deals with the cost-benefit analyses for one year, and sensitivity studies to ascertain the economic resilience of Kerala homegardens to market fluctuations. The net values of these gardens were also compared with other available economic alternatives.

2. METHODOLOGY

2.1. Study location, sampling and economic evaluation

The study was conducted in Thrissur District of central Kerala (between 10^{o} and 10^{o} 47’ N latitude, and 75^{o} 55’ and 76^{o} 54’ E longitude). Kerala is one of the southernmost states of India, with a coastline of approximately 600 km and a tropical monsoonal climate. Thrissur experiences an annual precipitation of approximately 2500 mm. Homegardens are the predominant form of agriculture in the district, along with rice (*Oryza sativa*) farming and commercial plantations of coconut (*Cocos nucifera*), arecanut or betel nut (*Areca catechu*) and bananas (*Musa* spp.). A wide variety of plants are grown in the homegardens including commercial crops such as coconut and arecanut, starchy foods such as cassava (*Manihot esculenta*), and a large number of vegetables and fruits.

Seventy-five homegardens of Thrissur district were randomly selected, and systematically (based on location) inventoried during October 2002 – February 2003. These homegardens were located in both rural and semi-urban areas. A comprehensive survey was administered and the productivity of all homegardens estimated. The values of the products were determined according to existing market prices (shadow prices for medicinal plants), and key decision-makers in the selected homegardens were interviewed.

The study was based on the premise that an analysis encompassing the steps summarized below would provide an adequate understanding of the economic value of these gardens in steady state (i.e., no natural calamities or extenuating circumstances that distinguished the year of study from other years).

- Accounting the costs and benefits for the farmer over a one-year period.
- Assessing the economic resilience of homegardens to market shifts in labor or crop price patterns by conducting sensitivity analyses.
- Comparing homegardens with other economic alternatives to evaluate the option that would provide optimal economic utility to the farmer.

Cost and benefit sources were determined based on the farmers' records, as well as inventory of the gardens. Plant productivity was based on both yield estimates[1] and farmer records. Market values were determined based on existing prices. Costs and benefits were assessed at the actual existing prices that the participating farmers encountered in markets. Many of the costs had already been incurred, such as one-time costs for building wells and for the initial preparation of land, but they were added to the total cost involved in maintaining the garden if incurred during the lifetime of the farmer who owned and farmed the property during the time of the study. The benefits realized from these costs are usually continuous and stretch over several years. Therefore, the yearly worth of these benefits was also added to the annual profits generated from these gardens.

2.2. Opportunity costs of land and household labor

The land tenure and ownership system in Kerala makes land a very valuable commodity in an increasingly land-deprived social system. Furthermore, the land occupied by the homegarden almost always houses the residential building, and these homes are usually inherited by the next generation. Therefore, it is unlikely that a homegarden will be sold on its own, without the residential building. However, in order to avoid inflating the financial worth of these systems while adhering to the observed social and cultural norms of the land, the opportunity costs of land were assigned values equivalent to the rate at which farmers were able to lease out all or part of the land. This rent rate was calculated to be an average of Rupees 12 350 (~ $262) per ha per year (one US $ = ~ Rupees 47, October 2003).

Opportunity cost of household labor (OCHL) was calculated as a function of time as *OCHL= f (t*labor rate)*, where *t* is time spent in the garden. If the daily rate for a hired male laborer in a particular area was Rupees 70, and the owner/farmer put in an average of four hours work in the garden per day, the household labor costs were calculated to be Rupees 35(30) = 1050 (~ $22) per month.

2.3. Components of the annual financial cycle of Kerala homegardens

Based on farmer surveys and farm inventories, Table 1 presents the inputs and outputs that are the main components of the annual finances of a typical Kerala homegarden in steady state. Inputs were determined as any monetary contribution to the annual economic cycle of the garden and were generally found to comprise of human labor, seeds, organic and chemical fertilizers, hired labor, one-time costs such as barn maintenance and equipment (if incurred during the year of study), and the associated transportation costs. Some of the associated maintenance costs included transportation of products to markets, de-husking of coconuts, and the harvesting of coconuts, areca nut, and other market products. Except for transportation, these tasks were usually performed by hired labor. The farmers sometimes employed a system called *karar* (contract), in which the commercial produce is leased either in part or full to a buyer, who would undertake all associated tasks, such as harvesting, transporting and selling, after paying a fixed sum of money to the owner. Such local barter systems might exist in other geographic locations around the world, and any financial analysis should take into account these individual practices and the social and cultural factors that influence these decisions. The tangible benefits derived from the garden also included products for market sale, milk and other livestock products, and goods used for household consumption such as food, firewood and medicinal plants.

Table 1. *Components of the annual finances of a typical homegarden in steady state in Thrissur district, Kerala, India.*

Inputs	*Outputs*
Fertilizers	Household products
Seeds and seedlings	Market products
Animal feed	Animal products (milk, meat, dairy)
One-time expenses	Long-term benefits (timber)
Maintenance operations	Medicinal plants
Land cost	
Household labor	

Note: Intangible benefits (e.g., shade, aesthetics, and ornamentation) have not been quantified in this study.

All economically important species were inventoried and the production over the period of one year was estimated based on farmer reports. The economic inventory included medicinal plants that might or might not have been used by the farmer during the course of one-year, but were present in the garden because the gardeners considered them essential. The values of these medicinal species were included in those instances where the farmer had occasion to utilize a medicinal plant, by using a shadow pricing mechanism of estimating the cost involved in obtaining a similar benefit elsewhere.

Economic theory argues that the highest social utility is attained when producers adopt practices generating the highest rates of return to all available resources, including all costs and benefits (Scherr, 1992). Economic planners also prefer investment in those activities yielding the highest rates of return to total resources or total labor used. However, the adoption decision for farmers is more complicated, especially in the case of homegardens where they reside within the confines of the agricultural property. These decisions may be influenced by a desire to maximize utility of family labor, returns to land, or even nutritional security. Two alternatives to homegarden cultivation have been considered in this study in order to understand the extent to which the farmer-needs and desires affect the pure cash flow into the homegarden system: *Option I*, entails selling the entire property and the house (assuming that selling the property without the house might prove to be improbable in the case of Kerala state) and *Option II*, in which the homegarden land is leased to another farmer, while the owner resides in the same house. Both options would allow the decision-making farmer to seek employment (work as agricultural laborer) elsewhere, assuming there is a steady demand for labor; yet they would have to pay to attain all benefits from the homegarden. Option 1 would also require that the farmer seek out an alternate residence.

2.4. Analysis

The collected data were analyzed using the basic economic methods of benefits and costs comparison, i.e., *net financial worth (NFW)* = $B_r - C_r$, where, B = benefits, C = costs, and r = year of study. For this, the homegarden products were categorized as having one of the three levels of economic utility; *primary utility*: those that are essential to the household, e.g., cassava, coconuts, and banana; *secondary utility*: those that are not absolutely essential but without which the household might suffer from nutritional deficiencies or other losses, e.g., gourd vegetables, amaranth (*Amaranthus* spp.), and medicinal plants; and *tertiary utility*: those that are grown primarily for personal pleasure, e.g., ornamental plants and flowers, e.g., roses (*Rosa* spp.). Some plants are grown for both decorative and medicinal purposes, e.g., the shoe flower plant (*Hibiscus* spp.). The value of primary utility plants was quantified, and the value of the secondary category including medicinals was estimated using shadow pricing; the tertiary category provides mainly intangible benefits. All tree and shrub species found in the homegardens are listed in Appendix I.

The sensitivity analyses were conducted by adding a 10% increment to the price of hired labor, and reduction of 10% in market prices of coconut, arecanut and banana, which are the main market crops in Kerala. Data were analyzed using the statistical software, *Statistica*. Various statistical procedures utilized in the analysis included analysis of variance (ANOVA) to compare characteristics of different size categories of homegardens, *t*-tests for comparison of means assuming unequal variances, and multivariate regression analyses to determine the predictors of homegarden profitability.

3. RESULTS

The 75 gardens included in this study had a mean landholding size (excluding the residential area) of 0.34 ha (± 0.03; median = 0.26 ha). The smallest garden was 0.01 ha in extent, and the largest, 1.0 ha. Although homegardens greater than 1 ha was initially included in the data collection as part of the random sampling scheme, they were subsequently excluded from the analysis because they were deemed to be very large farms that showed more characteristics of sole cropping than that of traditional homegardening. The gardens included in the study were also subdivided into four groups (*small*: ≤ 0.26 ha; *medium*: 0.26 to 0.52 ha; *large*: 0.52 to 0.78 ha and *commercial*: 0.78 to 1.0 ha). Following this, there were 24 small, 14 medium-sized, 10 large, and 27 commercial gardens.

3.1. Economic values of homegardens and annual economic profit

The existing financial worth of all the surveyed gardens, estimated based on the quantitative values of costs and benefits experienced in the year of study, is presented in Table 2. All 75 homegardens generated a positive economic value for the year 2001 – ‘02. Intensity of cultivation as indicated by the generation of profit per unit area (mean profit/m^2 of homegarden) calculated for the four holding-size categories was highest for the small gardens. While the commercial gardens yielded an average profit of Rupees 40.61/m^2, the small gardens yielded more than double the average profit at more than Rupees 84/m^2. Implicit in this is that the intensity of production is much greater in the smaller gardens, despite net production being higher in the larger gardens.

Table 2. *Mean financial value of homegardens for 2002 – ‘03 based on the benefits and costs of 75 gardens surveyed in Thrissur district, Kerala, India.*

Size of homegarden	*Mean financial value (Rupees)*[1]	*Mean financial value including opportunity costs of land and labor (Rupees)*	*Intensity of profit generation*[2]	
			Mean profit/m[2] *(Rupees/ year)*	*Standard error*
Small (≤0.26 ha, n = 24)	62261	46284	84.28[a]	10.72
Medium (≤0.52 ha, n = 14)	157524	132759	68.80[b]	9.61
Large (≤0.78 ha, n = 10)	256639	225116	76.64[a]	11.48
Commercial (≤1.0 ha, n = 27)	275967	214899	40.6[c]	4.15

[1]Financial worth measured in Rupees (1.00 $US ~ Rs. 47, October 2003).

[2]Intensity refers to the mean profit generated per m^2 of cultivated area in the homegarden. Superscripts (*a*, *b*, and *c*) following a value indicate significant changes in means at α = 0.05 in *t*-tests assuming unequal variances.

3.2. Economic importance of homegarden species

The most important contributors to the economic profit generated by homegardens were coconut, arecanut and banana (both cooking and dessert varieties), but the distribution of profit varied across garden sizes (Fig. 1). The other economically important categories in the homegarden were dairy, cashew (*Anacardium occidentale*), spice trees such as nutmeg (*Myristica fragrans*), and vanilla (*Vanilla planifolia*) (data not presented). Household needs consumed a significant percentage of the products (more than 50%) in the smaller gardens, while the larger and commercial gardeners invested most in the commercial production of coconut and arecanut (Fig. 1).

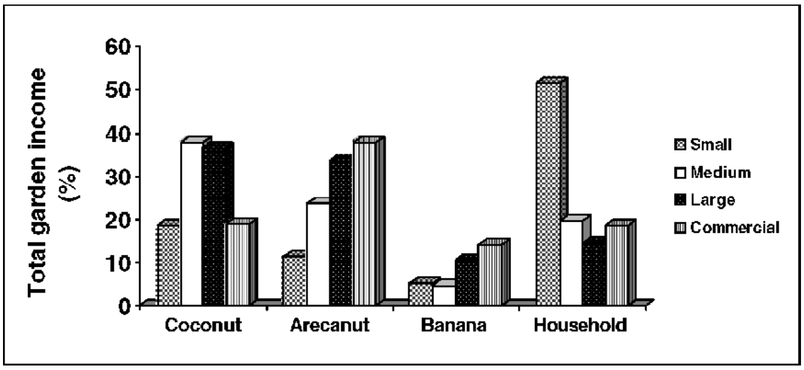

Figure 1. *Contribution of three crop categories and household use to total profit generated by different size classes of homegardens in Thrissur district, Kerala, India. The holding sizes are: small: ≤0.26 ha; medium: 0.26 to 0.52 ha; large: 0.52 to 0.78 ha, and commercial: 0.78 to 1.0 ha.*

3.3. Sensitivity analyses

Sensitivity analyses are important when evaluating economic benefits, in order to ascertain the extent to which agricultural systems are susceptible to shifts in the prices of labor and market products. A majority of the households surveyed (96%) reported that the prices of hired labor to be the most restrictive aspect of managing these systems, and coconut, arecanut and banana are the most economically important crops. A comparison of the data in Table 3 indicates the changes in net value of the gardens when the labor prices are increased by 10%, and the market prices of coconut, arecanut, and banana are reduced by 10%. Some of the gardens that cultivated rubber trees (*Hevea brasiliensis*) as a component were also very dependent on it; but rubber was mainly found in the larger gardens, mostly as a sole crop. Hence, it was excluded from the sensitivity analysis.

The results indicate very low changes in annual profit value across all classes of homegardens, ranging from 0.24% to 2.46%. The only statistically significant difference across means was the effect of raised arecanut prices in the commercial gardens, which ranged from 2.46% for commercial gardens to 0.81% for the small gardens.

***Table 3**. Sensitivity analysis to ascertain the economic resilience of homegardens to price fluctuations in labor and price of three economically significant crops.*

Sensitive categories	*Percent response in financial worth (based upon a 10% change in price)*			
	Small	*Medium*	*Large*	*Commercial*
P (hired labor)	0.28	1.12	0.24	0.31
P (coconut)	1.0	2.0	2.8	1.0
P (arecanut)	0.81	1.65	2.21	2.46*
P (banana)	0.42	0.35	0.74	0.92

P = existing market price; *significant at $\alpha = 0.05$ in comparisons involving small (n = 24), medium (n = 14), large (n = 10), and commercial (n = 27) using *t*-test assuming unequal variances.

3.4. What factors affect the financial value of homegardens?

The multivariate regression model developed to predict the effects of various factors on the financial values of the surveyed homegardens is as follows and its statistical parameters are given in Table 4.

$$\textit{Financial worth of homegarden} = 4.61 + 0.007(x_1) + 0.003(x_2)$$

Where x_1 = land area in m^2 and x_2 = number of years in cultivation.

***Table 4**. Coefficients, standard error and probability level of significance of the predictors of homegarden's economic worth in Thrissur district in Kerala, India.*

Parameter	*B*	*Standard error of B*	*p values*
Intercept	4.61	0.073	0.000
Land holding size (m^2)	0.007	0.056	< 0.005
Age of garden (years)	0.003	0.001	0.017

Adj. R^2 = 0.447; standard error = 0.319.

The model indicates that the financial value of Kerala homegardens increases with increasing land holding size and with an increase in the number of years of cultivation, although both are only modest predictors of profit. The number of hours of household or hired labor and gender of the decision-maker in the household were, however, not significant predictors ($p \geq 1.00$) of net profitability. Biophysical aspects such as soil quality and availability of water might contribute to the financial value of these gardens, but such effects need to be investigated further.

3.5. Economic alternatives to homegardens

Two possible alternatives were considered when comparing the economic rationale behind homegarden cultivation to other forms of investment. The first assigned alternative for a farmer was to sell the land, with the house and all associated crops and benefits, invest the capital in a bank at 6% compound interest rate (average prevailing rate at the time of study) and to live in a comparable neighborhood with a similar quality of life. The second option was to lease the land and all associated benefits to other farmers. Both alternatives and their profit values for all size classes of homegardens at the end of the investment year are considered in Table 5. The non-monetary benefits, however, were not quantified.

***Table 5**. Comparison of homegarden finances to two alternate forms of economic investment[1] for small, medium, large and commercial holdings in Thrissur district, Kerala, India.*

Variables	*Finances from gardens and two alternate land use options (Rupees)*		
	Garden[2]	*Lease*[3]	*Bank*[4]
a. Mean 'small' homegarden (n = 24)			
Land	0	1086	22012
Labor	0	7250	7250
Living expense	0	(20000)	(20000)
Rent	0	0	(15000)
Transportation	0	(500)	(500)
Incidentals	0	(800)	(800)
Homegarden costs	(7548)	0	0
Benefits	65519	0	0
Net income	57971	(12964)	(7038)
b. Mean 'medium' homegarden (n = 14)			
Land	0	2552	61329
Labor	0	14914	14914
Living expense	0	(22000)	(22000)
Rent	0	0	(15000)
Transportation	0	(500)	(500)
Incidentals	0	(800)	(800)
Homegarden costs	(12399)	0	0
Benefits	174912	0	0
Net income	162513	(5834)	37943

Table 5 (contd.)

Variables	*Finances from gardens and two alternate land use options (Rupees)*		
	Garden[2]	*Lease*[3]	*Bank*[4]
c. Mean 'large' homegarden (n = 10)			
Land	0	4240	101760
Labor	0	11880	11880
Living expense	0	(22000)	(22000)
Rent			(15000)
Transportation	0	(500)	(500)
Incidentals	0	(800)	(800)
Homegarden costs	(12307)	0	0
Benefits	237158	0	0
Net income	224851	(7180)	75340
d. Mean 'commercial' homegarden (n = 27)			
Land	0	8250	201370
Labor	0	17862	17862
Living expense	0	(24000)	(24000)
Rent			(15000)
Transportation	0	(500)	(500)
Incidentals	0	(800)	(800)
Homegarden costs	(17302)	0	0
Benefits	275524	0	0
Net income	258222	812	178932

[1]Estimated for a homegarden of mean size in each size category; [2]maintained as homegardens; [3]lease option and the lease values were based on existing rent rate of Rupees 12 350 per ha. [4]capital invested in a bank at 6% compound interest rate; parenthetical values are costs.

Living costs were estimated based on a two-month survey of expenses incurred by four urban and rural households with no attached homegardens. All household expenses, not including meat, staple foods such as rice, potato, salt, and other goods not normally realized from the garden, were estimated to be an average minimum of Rupees 20 000 per year per household. A comparison of the data in Table 5 also indicates the financial effectiveness of maintaining homegardens as opposed to leasing or selling the land. Selling the garden becomes a reasonable yet not comparable alternative with increases in land area. Small farmers would be best served if they retained their homegardens. Leasing was not an economically viable option especially for the small, medium or large gardeners.

4. DISCUSSION AND CONCLUSIONS

All homegardens surveyed in this study generated profits at steady state, thus justifying the need to consider them by the policy makers as on par with other mainstream agricultural production systems. The positive financial value, regardless of the number of years in cultivation, implies the renewable nature of these gardens year after year. The profit generated per unit area was highest for the small gardens

(Table 2) and was lowest in the commercial gardens, perhaps implying that the small farmers are particularly adept at adaptive management techniques. Holding size being a constraint, farmers intensify cultivation on available land in order to attain desired goals and objectives. Commercial farmers, however, may devote some part of their holding for intangible benefits such as aesthetics and ornamentation. Future studies could assess whether this difference in profit generation equals the opportunity cost incurred by those commercial farmers who do not intensify production. Coconut, arecanut and bananas were the three most economically important crops (Fig. 1). It was noted, however, that although market needs were extremely important in determining garden use, small gardeners used more than half their annual produce for household uses, e.g., vegetables, fruits and firewood. Allocation of garden space also was need-based; i.e., if the farmers possessed liquid cash at their disposal with which to buy subsistence products, they increased the acreage under commercial crops such as areca and spice trees. On an average, more than 75% of the household needs of an average family were met by their homegardens irrespective of the garden size. The sensitivity analyses (Table 3) reaffirmed the hypothesis that these systems are economically stable, not dependent on any one crop or factor, and that the farmers followed an age-old adaptive approach to farming. Harvests were staggered so as to retain food crops such as cassava, for times of the year when staple food crops such as rice were not readily available. No one crop formed a focal point in the garden. For example, the areca crop had been sustaining high returns during the 1990s, but suffered a crash in market prices during the past few years (2001 and 2002); many farmers would have sustained heavy losses had their gardens consisted of sole stands of areca palms alone. With the existing complexity and diversity of these gardens (Appendix I), however, the lagging arecanut prices did not substantially affect the overall profit from the gardens. After considering two potential alternatives to homegardening (Table 5), it was estimated that retaining the land under homegarden cultivation was more profitable than leasing or selling the land even without factoring in intangible benefits such as aesthetics, nutritional security, and improved quality of food. Plantation farming was not considered as an alternative because many of the gardens surveyed were deemed too small to be fit for plantation agricultural systems.

The household labor associated with homegardening was an important component of the alternatives because it was assumed that if the land were no longer available to farmers, they would earn money by working as laborers in the nearby farms. This is another debatable point, however, because many of the farmers reported that they were not equipped to perform any skilled work, nor did they desire to perform farm labor outside their properties. Furthermore, many of the farmers were older, and cherished the relative freedom they enjoyed from working in their own fields, and in their ability to set their own timings.

It needs to be acknowledged that the methodology used for the study had some constraints. Homegardens are so diverse in species richness and composition (Appendix I) that data collection becomes arduous and error-prone. Data analysis becomes further complicated because many homegarden species are retained to fulfill certain specific needs and functions, and these needs vary from farmer to farmer and from region to region. Intangible benefits of homegardens, such as aesthetics and ornamentation, nutritional security, food quality, and empowerment of women also need to be considered in order to obtain a more accurate assessment of the economic values as articulated also by Torquebiau and Penot (2006). Furthermore, some of the data presented here, especially the monetary values, are time-sensitive. Although these constraints set some limits to applicability of the findings to other regions, we believe that the methodology can be adapted in any geographic area to estimate the economic value of these multipurpose production systems.

ENDNOTE

1. The data were gathered during the first author's field study, which involved interaction with farmers and discussion with various officials of the Kerala Agricultural University and local field extension personnel of the government agricultural and other departments. The authors thank the Kerala Agricultural University, Thrissur, India for extending support to this project.

REFERENCES

Alavalapati J.R.R., Shrestha R.K., Stainback G.A. and Matta J.R. 2004. Agroforestry development: An environmental economic perspective. Agroforest Syst 61/62: 299 – 310.

Christanty L. 1990. Homegardens in tropical Asia with special reference to Indonesia. In: Landauer K. and Brazil M. (eds), Tropical home gardens, pp 9 – 20. United Nations University Press, Tokyo.

Current D., Lutz E. and Scherr S. (eds). 1995. Costs, benefits, and farmer adoption of agroforestry. The World Bank environment paper 14: World Bank, Washington, DC.

Drescher A.W. 1996. Management strategies in African homegardens and the need for new extension approaches. In: Heidhues F. and Fadani A. (eds), Food security and innovations – Successes and lessons learned. pp 231 – 245. Peter Lang, Frankfurt.

Jose D. and Shanmugaratnam N. 1993. Traditional homegardens of Kerala: a sustainable human ecosystem. Agroforest Syst 24: 203 – 213.

Karyono 1990. Homegardens in Java: their structure and function. In: Landauer K. and Brazil M. (eds), Tropical home gardens, pp 138 – 146. United Nations University Press, Tokyo.

Mendez V.E., Lok R. and Somarriba E. 2001. Interdisciplinary analysis of homegardens in Nicaragua: micro-zonation, plant use and socioeconomic importance. Agroforest Syst 51: 85 – 96.

Mohan S. 2004. An Assessment of the ecological and socioeconomic benefits provided by the homegardens: A case study from Kerala, India. PhD Dissertation, University of Florida, Gainesville, FL.

Nair P.K.R. 2001. Do tropical homegardens elude science, or is it the other way around? Agroforest Syst 53: 239 – 245.

Scherr S.J. 1992. Financial and economic analyses of agroforestry systems: An overview of the case studies. In: Sullivan G.M., Huke S.M., and Fox J.M. (eds), Financial and economic analyses of agroforestry systems. Proceedings of a workshop held in Honolulu, Hawaii, USA. July 1991, pp 3 – 12. Nitrogen Fixing Tree Association, Paia, Hawaii.

Torquebiau E. 1992. Are tropical agroforestry homegardens sustainable? Agric Ecosys Environ 41: 189 – 207.

Torquebiau E. and Penot E. 2006. Ecology versus economics in tropical multistrata agroforests. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 269 – 282. Springer Science, Dordrecht.

APPENDIX I

Woody perennials encountered in the sampled homegardens of Thrissur district, Kerala, India[1].

Scientific name	*Local/common name*	*Family*	*Uses*[2]
Tree and shrub species of primary economic utility to farmers			
Ailanthus triphysa	matti	Simaroubaceae	b
Anacardium occidentale	cashew	Anacardiaceae	d,b,a
Areca catechu	arecanut	Palmaceae	a, f
Artocarpus heterophyllus	jackfruit	Moraceae	d, b
Artocarpus hirsutus	aini	Moraceae	b,c
Bridelia retusa	kaini	Euphorbiaceae	b
Bombax ceiba	poola	Bombacaceae	b,f
Borassus flabellifer	palmyra palm	Palmaceae	f,e
Calophyllum inophyllum	punna	Clusiaceae	b,c
Caryota urens	fish-tail palm	Palmaceae	f
Cocos nucifera	coconut	Palmaceae	a, c, f
Coffea arabica	coffee	Rubiaceae	d
Corypha umbraculifera	talipot palm	Palmaceae	f
Dalbergia latifolia	rosewood	Fabaceae	b
Delonix regia	poomaram	Caesalpiniaceae	b
Garcinia cambogia	kodampuli	Clusiaceae	d, c
Grewia tiliifolia	chadachi	Tiliaceae	b
Hevea brasiliensis	rubber	Euphorbiaceae	c, f
Mangifera indica	mango	Anacardiaceae	d, b
Manihot esculenta	cassava	Euphorbiaceae	e
Michelia champaca	kaatu chembakam	Magnoliaceae	b,c,g
Morus alba	mulberry	Moraceae	c,f
Myristica fragrans	nutmeg/mace	Myristicaceae	a
Palaquium ellipticum	pali	Sapotaceae	b,g
Piper longum	thippili	Piperaceae	g,b
Pterocarpus marsupium	venga	Fabaceae	b
Santalum album	sandalwood	Santalaceae	f
Saraca indica	asoka tree	Caesalpiniaceae	b,c
Swietenia macrophylla	mahogany	Meliaceae	b
Syzygium aromaticum	clove	Myrtaceae	a
Tamarindus indica	tamarind	Caesalpiniaceae	d
Tectona grandis	teak	Verbenaceae	b
Terminalia tormentosa	maruthy	Combretaceae	b
Xylia xylocarpa	irumullu	Mimosoideae	b,c

Appendix 1 (contd.)

Scientific name	*Local/common name*	*Family*	*Uses*[2]
Trees and shrubs species of secondary economic utility to farmers, used mainly in the household			
Annona squamosa	custard apple	Annonaceae	d,b,c
Artocarpus altilis	breadfruit	Moraceae	d
Averrhoa bilimbi	irimbampuli	Oxalidaceae	d,c
Azadirachta indica	neem	Meliaceae	g
Cananga odorata	ylang ylang	Annonaceae	f,g
Carica papaya	papaya	Caricaceae	d
Casuarina equisetifolia	kattaadi	Casuarinaceae	f,h
Cinnamomum camphora	camphor	Lauraceae	f,g
Cinnamomum zeylanicum	cinnamon	Lauraceae	e,c
Citrus limon	cherunarakam	Rutaceae	d,c
Emblica officinalis	Indian gooseberry	Euphorbiaceae	d,g
Flacourtia inermis	louvi-louvi	Flacourtiaceae	b,c,d
Manilkara zapota	sapota (sapodilla)	Sapotaceae	d,b,c
Murraya koenigii	curry leaf tree	Rutaceae	e,c
Pimenta dioica	allspice	Myrtaceae	e,g
Pouteria campechiana	eggfruit	Sapotaceae	d
Psidium guajava	guava	Myrtaceae	b,c,d
Punica granatum	pomegranate	Punicaceae	d
Syzygium jambolana	rose apple	Myrtaceae	d,b
Terminalia catappa	Indian almond	Combretaceae	e,c
Theobroma cacao	cacao	Sterculiaceae	f,a

[1]In addition, 17 herbaceous species were identified under two categories each (having primary or secondary economic utility to the farmers); for details see Mohan (2004).

[2]Uses: *a* = nuts, *b* = timber, *c* = fuelwood, *d* = fruits, *e* = leaves, bark and other parts of plant used as food, *f* = leaves bark and other parts of plant used for other purposes, *g* = ornamental or medicinal purpose, *h* = shade; Local names appearing in italics are vernacular names (Malayalam).

SECTION 4

FUTURE OF HOMEGARDENS

CHAPTER 17

THE ROLE OF HOMEGARDENS IN AGROFORESTRY DEVELOPMENT: LESSONS FROM TOMÉ-AÇU, A JAPANESE-BRAZILIAN SETTLEMENT IN THE AMAZON

M. YAMADA* AND H.M.L. OSAQUI

*Division of International Environmental and Agricultural Science, Graduate School of Agriculture, Tokyo University of Agriculture and Technology, 3-5-8 Saiwaichō, Fuchū-shi, Tōkyō 183-8509, Japan; *E-mail: <masaakiy@cc.tuat.ac.jp>*

Keywords: Adaptive research, Farm cooperatives, Farmer innovation, Fruit trees, Institutional support.

Abstract. Agroforestry systems developed by the Japanese immigrants and their descendants in the Eastern Amazon region have been the focus of attention as a model for sustainable rural development in the humid tropics. This paper looks at the role of homegardens in agroforestry development at the Tomé-Açu *Nikkei* settlement in Pará, Brazil during the past seven decades. Potential crop species – native as well as exotic – were gathered and nurtured by the farm families in these homegardens of size 1 to 3 ha. Although the Tomé-Açu Multipurpose Agricultural Cooperative (CAMTA) had experimental nurseries and the Japanese public agencies established local agricultural research stations for supporting emigrant farmers in the Amazon, the homegardens functioned as individual validation fields where the farmers 'experimented' with new crops. Homegardens were also used for improvement and propagation of nursery stock making them on-farm laboratories for adaptive research and extension. The immigrants with the traditional *tokunō* (master farmer) education of East Asia analyzed the local environment and 'experimented' with various plant associations and management techniques, which led to the evolution of the exceptionally successful and popular multistrata agroforestry systems in the Eastern Amazon region.

1. INTRODUCTION

Since the early 1980s, various authors of Amazonian studies have discussed agroforestry systems developed by the Japanese immigrants and their descendents

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 299–316.

(the *Nikkei* farmers) as an economically viable and ecologically sustainable rural development option for the region (Jordan, 1986; Gradwohl and Greenberg, 1988; Uhl and Subler, 1988; Uhl et al., 1989; 1990; Anderson, 1990; Barrow, 1990; Subler and Uhl, 1990; Serrão and Homma, 1993; Fearnside, 1995; Serrão, 1995; Homma, 1998). While there are more than thirty rural Japanese-Brazilian (*Nikkei*) communities in the Amazon, most authors have focused on the Tomé-Açu settlement, which was the center of commercial rice (*Oryza sativa*) and vegetable production in the Amazon, and the location where first commercial black pepper (*Piper nigrum*) production was started in the Americas. The Tomé-Açu settlement was founded in 1929 *ca.* 120 km south of Belém, the capital of Pará (2°31' S and 48°22' W). At the end of 2002, there were 214 *Nikkei* farms in Tomé-Açu, covering 77 500 ha, with 7200 ha of agroforestry fields[1]. By the end of 1996, the *Nikkei* farmers in Tomé-Açu planted 6500 ha of agroforestry fields, with three perennial vine species, four shade trees, 33 fruit trees, 68 multipurpose tall trees, and numerous vegetable-, herb-, grain-, tuber- and green manure plants, forming a spatial mosaic of different ages and species combinations (Yamada, 1999). The main farm fields (6100 ha) excluding the homegardens around the housing/barnyard areas were occupied by ~70 crop species (90% arboreal) and some leguminous shade trees ("eritrina" = *Erythrina* spp. and "palheteira" = *Clitoria racemosa*). Sixty percent of the area involved polycultures, with approximately 300 different crop combinations, while the remainder was temporary monocultures based on sequential intercropping or "successional" agroforestry (Subler, 1993; Tanaka, 1997). For example, rubber (*Hevea brasiliensis*) and cupuaçu (*Theobroma grandiflorum*) fields were planted with annual crops (grains and vegetables) and perennial vines, but seedlings of shade tolerant arboreal and herbal species were subsequently introduced.

2. HOMEGARDENS IN TOMÉ-AÇU AS LABORATORIES FOR SPECIES INTRODUCTION, SCREENING AND BREEDING

2.1. Data collection

The first author lived in Tomé-Açu from January 1995 to January 1997 conducting field work on farm histories and crop inventories. He visited all 214 *Nikkei* farms and interviewed farm owners on land use (intact and explored primary forests, secondary forest, fallow, pasture, and area under agroforestry) and crop species (year planted, number, area, and nature of cropping, i.e., with or without intercrops). For the inventory of homegardens, the authors first acquired reference information from the Tomé-Açu Multipurpose Agricultural Cooperative (CAMTA), which listed about 30 candidates that typified the history and dynamics of plant introduction, screening and dissemination in the *Nikkei* settlement. Among them, a dozen gardens were randomly chosen. With assistance from the owners of these gardens, details on each species (year, route of introduction, from where it came, etc.) were gathered. Additional information was gathered by revisiting the site occasionally from May 2002 to March 2005, and reviewing published and unpublished documents.

2.2. Extent and diversity of components

Homegardens are maintained in areas of 1 to 3 ha around the house of almost every *Nikkei* farmer. The gardens contain a mixture of fruit trees, vegetables, medicinal plants, ornamental plants, and tall trees for shade, timber, nuts, fruits, and resin. In many farms, the housing areas were distinctively noticeable from a distance by the presence of 35 to 40 m tall trees surrounding the house. Homegardens often had a plant nursery for the main fields and sometimes a henhouse, a pigsty, a tortoise pen, or a small pond for pisciculture. The nursery was often close to the farmhouse to facilitate irrigation and close monitoring. The locations of animal sheds and fish-ponds depended on the species, source of water, and security against possible attacks by predators and thieves (guard dogs were also used for protection especially at night). Each homegarden had a unique appearance due to its history, species diversity, and physical arrangements. The owner's family, labor families, and domestic animals living on-farm consumed the homegarden produce. The native and/or traditional homegarden fruits such as açai (*Euterpe oleracea*), mango (*Mangifera indica*), jackfruit (*Artocarpus heterophyllus*), and guava (*Psidium guajava*), were often harvested freely for on-farm consumption even without the permission of the owner. In farms where the young successors took over the management of main fields, the retired but still active parents took care of the homegardens, which not only increased the product shipment off-farm but also provided engagement and recreational avenues to the senior citizens. Homegarden surpluses were also given to the neighbors, friends and relatives, and sold in unprocessed or home-processed form at the local markets. Each farm also had modest facilities for cleaning and packaging vegetables, extracting and freezing fruit juice, making jam and bonbons from fruit pulp, and baking cookies with fruits and nuts. The homegarden facilities were also used for processing the off-season main field produce, especially when there was not enough to ship to the CAMTA's juice factory. Marketing the homegarden produce gave income to the garden's caretakers, mostly elders, housewives and children, and provided them with an opportunity for socialization at the marketplaces.

2.3. Source of homegarden components

Most species found in the homegardens had been acquired by the male farmers, casually or purposefully, during their travels. In addition, the CAMTA used to send exploratory missions for collection of seeds and vegetative materials, when the members became interested in certain species/cultivars available at farther locations, such as the Caribbean and tropical Asia. Such materials were initially brought to the cooperative's experimental nursery for multiplication and eventual distribution among the associated farmers. The local research stations established by the Japanese public agencies for emigrant support, such as the Amazon Tropical Agriculture Experiment Institute (INATAM; eventually incorporated by the Brazilian Agricultural Research Corporation for Eastern Amazon – EMBRAPA Amazônia Oriental) also introduced potential crop species for the agricultural cooperatives and interested individuals. In addition, some housewives made

Table 1. *Inventory of tree species and other useful plants found in two Tomé-Açu Japanese-Brazilian homegardens, with information on their origin, route of introduction, and date.*

a. ***Sakaguchi Farm*** *(Lot # Açaizal 185; given from father-in-law in 1959; homegarden 2 ha)*

Species (Latin name)	*English name*	*Local name*	*Year and route of introduction*		*Origin*
Albizia spp.			?	volunteer	
Annona muricata L.	soursop	graviola	1991	friend	Tomé-Açu
Araucaria angustifolia (Bertol.) Kuntze.	Paraná pine	pinheiro do Paraná	1988	market	Belém
Artocarpus incisa L.	breadfruit	fruta-pão	1992	friend	Tomé-Açu
Artocarpus odoratissima Blanco.	marang	marang	1987	friend	Mindanao, Philippines
Averrhoa bilimbi L.	bilimbi	bilimbi	?	?	
Averrhoa carambola L.	starfruit	carambola	1974	CAMTA survey	Kuala Lumpur, Malaysia
Azadirachta indica A. Juss.	neem	nim	1984	friend	Thailand
Bactris gasipaes H.B.K.	peach palm	pupunha	1970	IPEAN	Belém
Bertholletia excelsa H.B.K.	brazilnut	castanha do Pará	1932	JPCB	Tomé-Açu
Bischofia javanica Blume.	Javanese bishopwood		1995	visitor	Ogasawara, Japan
Camellia sinensis (L.) Kuntze. (5 vars.)	tea	chá	1981	excursion	Registro, São Paulo
Carapa guianensis Aubl.	andiroba	andiroba	1960	friend (from JPCB)	Tomé-Açu
Carica papaya L.	papaya	mamão	1979	CAMTA survey	Kao-hsiung, Taiwan
Casuarina equisetifolia L.	Australian pine	casuarina	1985	friend	Philippines

Cedrela odorata L.	cedro	cedro	1984	farm laborer	Bujarú, Pará
Ceiba pentandra L.	kapok	sumaúma	?	volunteer	
Cereus jamacaru D.C.	mandacaru	mandacaru	1976	INATAM excursion	Pernambuco
Cinnamomum zeylanicum Blume.	cinnamon	canela	1978	Takasago Farm	Daini Tomé-Açu
Citrus latifolia Tan.	Tahiti lime	limão Tahiti	?	?	
Citrus aurantium L.	bitter orange	laranja amarga	1977	INATAM	Daini Tomé-Açu
Citrus deliciosa Ten. (mexerica)	common mandarin	mexerica	?	?	
Citrus deliciosa Ten. (2 vars.)	common mandarin	mandarina comum	1980	Dienberger nursery	Limeira, São Paulo
Citrus junos Sieb. ex Tan.	yuzu		?	relative	Japan
Citrus noblis Makino	mandarin	mandarina	1977	friend	Acará, Pará
Citrus noblis Makino	mandarin	mandarina	1980	Dienberger nursery	Limeira, São Paulo
Citrus sinensis (L.) Osbeck.	orange	laranja	1980	Dienberger nursery	Limeira, São Paulo
Citrus unshiu Marc.	Satsuma mandarin	Satsuma unshiu	1986	friend	Tomé-Açu (from Japan)
Cocos nucifera L. (praia)	coconut	coqueiro	1962	relative	Tomé-Açu
Cocos nucifera L. (anão)	coconut	coqueiro	1970	friend	Tomé-Açu
Coumarouna odorata (Aubl.) Willd.	tonka bean	cumarú	1965	friend	Tomé-Açu (from Belém)
Crescentia cujete L.	calabash tree	cuieira	1970	excursion	Igarapé-Açu, Pará
Cryptomeria japonica D.Don.	Japanese cedar	cedro japonês	1980	Japanese consul	Belém (from Yaku, Japan)

Table 1 (cont.)

Species (Latin name)	*English name*	*Local name*	*Year and route of introduction*		*Origin*
Cryptomeria japonica D.Don. (obi)	Japanese cedar	cedro japonês	1981	friend	Tomé-Açu (from Japan)
Cycas revoluta Thunb.	sago palm	cica, palmeira-sagu	?	friend	Tomé-Açu
Dalbergia spruceana Benth.	Amazon rosewood	jacarandá do Pará	1974	JICA	Monte Alegre, Pará
Delonix regia (Bojer ex Hook.) Raf.	flamboyant tree	flamboyant	1966	friend	Belém (from São Paulo)
Durio zibethinus L.	durian	durião	1979	CAMTA survey	Johor Bharu, Malaysia
Endopleura uxi (Huber) Cuatrec.	uxi	uxi	1982	friend	Daini Tomé-Açu
Euphoria longan (Lour.) Steud.	longan	longan	1979	CAMTA survey	P'ing-tung, Taiwan
Ficus elastica Roxb. ex Hornem.	Indian rubber tree	figueira-da-borracha	1978	friend	Atibaia, São Paulo
Garcinia dulcis (Roxb.) Kurz.	rata	mangostão falso	1960	friend	Tomé-Açu (from São Paulo)
Garcinia mangostana L.	mangosteen	mangostão	1961	IPEAN	Belém
Gliricidia sepium (Jacq.) Steud.	mother of cacao	gliricidia	1985	friend	Philippines
Gmelina arborea Roxb.	gmelina	gmelina	1970	friend	Belém (from Jari, Pará)
Hevea brasiliensis (Willd.) Muell.-Arg.	rubber tree	seringueira	1959	Goodyear nursery	Igarapé-Açu, Pará
Illicium spp.			1973	CAMTA excursion	Uruçuca, Bahia
Inga edulis Mart. (long variety)	inga	inga	1984	excursion	Abaetetuba, Pará
Lansium domesticum Corr.	langsat	langsat	1979	CAMTA survey	Kuala Lumpur, Malaysia

Leucaena leucocephala (Lam.) de Wit.	leucaena	leucaena	1976	INATAM excursion	Juazeiro, Bahia
Licaria puchury-major (Mart.) Kosterm.	pichury bean	puxuri	1982	relative (from JPCB)	Tomé-Açu
Litchi chinensis Sonn.	lychee	lichia	1979	CAMTA survey	P'ing-tung, Taiwan
Macadamia ternifolia F. Muell.	macadamia nut	macadâmia	1978	Dienberger nursery	Limeira, São Paulo
Moringa oleifera Lam.	horseradish tree	moringa	1976	friend	Tomé-Açu
Murraya paniculata (L.) Jack.	orange jasmine	murta	1981	JICA survey	Dominican Republic
Myrciaria dubia (H.B.K.) Mc Vaugh.	camu camu	camu camu	1987	friend	Belém
Myrciaria cauliflora Berg.	jaboticaba	jaboticaba	1973	CAMTA excursion	Uruçuca, Bahia
Myristica fragans Houtt.	nutmeg	noz-moscada	1976	INATAM excursion	Uruçuca, Bahia
Nephelium lappaceum L.	rambutan	rambutan	1979	CAMTA survey	Johor Bharu, Malaysia
Ocotea cymbarum H.B.K.	Brazilian sassafras	louro-inhamuí	1988	Takasago Farm	Daini Tomé-Açu
Pachira aquatica Aubl.	Guiana chestnut	munguba	1974	JICA	Belém
Paulownia spp.			1993	friend	Belém (from Taiwan)
Persea americana Mill.	avocado	abacate	1977	friend	Tomé-Açu (from São Paulo)
Pimenta dioica (L.) Merr.	allspice	pimenta da Jamaica	1976	INATAM excursion	Uruçuca, Bahia
Platonia insignis Mart.	bacurí	bacurí	?	volunteer	
Pouteria caimito Radlk.	abiu	abiu	1976	friend	Belém
Pouteria campechiana Baehni.	eggfruit	canistel	1976	friend	Tomé-Açu
Prosopis juliflora (Sw.) DC.	mesquite	algaroba	1982	CAMTA excursion	Ceará

Table 1 (cont.)

Species (Latin name)	English name	Local name	Year and route of introduction		Origin
Quassia amara L.	amargo	pau amargo	1976	friend	Tomé-Açu
Rollinia deliciosa Saff.	biriba	biriba	1995	volunteer	
Spondias tuberosa Arruda.	umbú	umbú	1976	INATAM excursion	Juazeiro, Bahia
Tamarindus indica L.	tamarind	tamarindo	1977	friend	Pakistan
Theobroma subincanum Mart.	cupuí	cupuí	1990	volunteer	
Veronica condensata Baker	boldo verde	boldo verde	1988	friend	Daini Tomé-Açu
Virola surinamensis (Rol.) Warb.	virola	ucuúba	1995	volunteer	
(herbs; a portion)					
Capsicum spp.			1988	friend	Chili
Curcuma zedoaria (Christm.) Roscoe.	zedoary	zedoária	1980	friend	Campinas, São Paulo
Elettaria cardamomum (L.) Maton.	cardamom	cardamom	1971	CAMTA	Tomé-Açu (fr. Guatemala)
Manihot aypi Spruce	sweet cassava	macaxeira	?	?	Rio de Janeiro
Pogostemon patchouli Pell.	patchouli	patchouli	1960s	Takasago Farm	Daini Tomé-Açu
Spilanthes acmella Murr.	jambu, toothache plant	jambu	1959	relative	Tomé-Açu
Vanilla planifolia Andr.	vanilla	baunilha	1960s	IPEAN	Belém
Vanilla planifolia Andr.	vanilla	baunilha	1969	JICA	Mexico
Vanilla planifolia Andr.	vanilla	baunilha	1970s	Takasago Co.	Madagascar
Zingiber officinale Roscoe.	ginger	gengibre	1971	CAMTA	Tomé-Açu (from Trinidad)
***b. Maki Farm** (Lot # Cuxiu 2-241; purchased in 1969; homegarden 1 ha)*					
Achras sapota L.	sapodilla	sapoti	?	CAMTA nursery	Tomé-Açu

Aleurites moluccana (L.) Willd.	candlenut	noz da India	1975	San Stepano Farm	Daini T-Açu (from Hawaii)
Aniba canelilla (Kunth.) Mez.	casca preciosa	casca preciosa	1980	farm laborer	
Aniba rosaeodora Ducke.	rose wood	pau-rosa	1976	INATAM	Daini T-Açu (fr. Manaus)
Annona muricata L.	soursop	graviola	1977	friend	Daini Tomé-Açu
Annona squamosa L.	sugar apple	fruta-do-conde	1990	market	Belém
Artocarpus heterophyllus Lam.	jackfruit	jaca	1960s	former lot owner	
Averrhoa bilimbi L.	bilimbi	bilimbi	1977	relative	Daini Tomé-Açu
Averrhoa carambola L.	starfruit	carambola	1960s	former lot owner	
Averrhoa carambola L.	starfruit	carambola	1990	friend	Tomé-Açu
Azadirachta indica A. Juss.	neem	nim	1987	COPAMASA	Tomé-Açu
Caryocar villosum (Aubl.) Pers.	piquiá	piquiá	1981	forest	Daini Tomé-Açu
Cedrela odorata L.	cedro	cedro	1976	forest	Daini Tomé-Açu
Citrus aurantifolia (Christm.) Swingle.	lime	limão Galego	1960s	former lot owner	
Citrus latifolia Tan.	Tahiti lime	limão Tahiti	1982	friend	Daini Tomé-Açu
Citrus deliciosa Ten. (murcote)	common mandarin	murcote	1970s	INATAM	Daini Tomé-Açu
Citrus deliciosa Ten. (tangerin)	common mandarin	tangerina	1980s	relative	Daini Tomé-Açu
Citrus grandis (L.) Osbeck	pomelo	toranja	1975	friend	Daini Tomé-Açu
Citrus sinensis (L.) Osbeck.	orange	laranja	?	volunteer	
Citrus spp. (limãozinho)			1960s	former lot owner	

Table 1 (cont.)

Species (Latin name)	English name	Local name	Year and route of introduction		Origin
Cordia goeldiana Huber.	freijó	freijó	1974	forest	Daini Tomé-Açu
Dalbergia nigra (Vell.Conc.) Benth.	Brazilian rosewood	jacarandá da Bahia	1976	JAMIC	Bahia
Dendrocalamus giganteus Wall. ex Munro.	giant bamboo	bambu-gigante	1976	friend	Tomé-Açu
Diospyros kaki Thunb.	Japanese persimmon	caqui	1976	friend	Tomé-Açu
Endopleura uxi (Huber) Cuatrec.	uxi	uxi	1981	forest	Daini Tomé-Açu
Eugenia cumini (L.) Druce.	Java plum, jambolan	jamborão	1992	elementary school	Daini Tomé-Açu
Eugenia stipitata McVaugh.	araçá-boi	araçá-boi	1989	friend	Daini T-Açu (fr. Manaus)
Fortunella japonica (Thunb.) Swingle.	round kumquat	kumquat	1970	friend	Tomé-Açu
Garcinia mangostana L.	mangostin	mangostão	1990	relative	Daini Tomé-Açu
Macadamia ternifolia F. Muell.	macadamia nut	macadâmia	1985	CAMTA nursery	Tomé-Açu
Malpighia glabra L.	acerola, Barbados cherry	acerola	1980s	friend (fr. INATAM)	Daini Tomé-Açu
Mammea americana L.	mammey apple	abrico do Pará	1980s	friend	Tomé-Açu
Mangifera indica L. (haden)	mango	manga	1978	friend	Tomé-Açu (from São Paulo)
Mangifera indica L. (haden)	mango	manga	1978	friend	Tomé-Açu (from Manaus)
Mimosa caesalpiniaefolia Benth.	sabiá	sabiá	1990	CAMTA survey	Ceará

Morus bombycis Koidz.	mulberry	amora	1978	?	Tomé-Açu
Myrciaria cauliflora Berg.	jaboticaba	jaboticaba	1976	friend	Tomé-Açu
Pachira aquatica Aubl.	Guiana chestnut	munguba	1970s	friend	Tomé-Açu
Persea americana Mill.	avocado	abacate	1974	INATAM	Daini Tomé-Açu
Pilocarpus microphyllus Stapf.	jaborandi	jaborandi	1980s	friend (fr. INATAM)	Daini Tomé-Açu
Platymiscium ulei Harms.	macacauba	macacauba	1976	Museu Goeldi	Belém
Prosopis juliflora (Sw.) DC.	mesquite	algaroba	1982	CAMTA survey	Ceará
Prunus mume Sieb. et Zucc.	Japanese apricot	umezeiro	1990	friend	Daini Tomé-Açu
Psidium guajava L.	guava	goiabeira	?	volunteer	
Rauwolfia serpentina Benth.	Indian snakeroot		1980s	friend (fr. INATAM)	Daini Tomé-Açu
Rheedia macrophylla Planch. et Triana.	biribá	biribá	1988	CAMTA nursery	Tomé-Açu
Schizolobium amazonicum Hub. ex Ducke.	paricá	paricá	1980	friend	Tomé-Açu
Simarouba amara Aubl.	marupá	marupá	1977	IBDF	Santa Isabel do Pará
Spondias tuberosa Arruda.	umbú	umbú	1976	INATAM excursion	Juazeiro, Bahia
Stenocalyx pitanga O. Berg.	pitanga	pitanga	1980	friend	Tomé-Açu
Swietenia macrophylla King.	mahogany	mogno	1976	INATAM	Daini Tomé-Açu
Theobroma speciosum Willd. ex Spreng.	cacaui	cacaui	1980s	volunteer	
Veronica condensata Baker	boldo verde	boldo verde	1992	CAMTA nursery	Tomé-Açu
herbs; a portion					
Cephaelis ipecacuanha (Brot.) A. Rich.	ipeca	ipecacuanha	1992	friend	Daini Tomé-Açu
Curcuma zedoaria (Christm.) Roscoe.	zedoary	zedoária	1990	friend	Tomé-Açu

Table 1 (cont.)

Species (Latin name)	English name	Local name	Year and route of introduction		Origin
Egletodendron pariri	pariri	pariri	?	farm laborer	
Hibiscus sabdariffa L.	red sorrel	hibiscus	?	relative	Daini Tomé-Açu
Kaempferia spp.			?	CAMTA nursery	Tomé-Açu
Luffa operculata (L.) Cogn.	luffa	luffa	?	?	
Spilanthes acmella Murr.	jambu, toothache plant	jambu	?	volunteer	

CAMTA = Tomé-Açu Multipurpose Agricultural Cooperative; COPAMASA = Pará Cassava Corporation; IBDF = Brazilian Forest Defense Institute (today's IBAMA); INATAM = Amazon Tropical Agriculture Experiment Institute (today's EMBRAPA Eastern Amazon Research Station in Tomé-Açu); IPEAN = Northern Agriculture and Stockbreeding Research Institute (today's EMBRAPA Eastern Amazon); JAMIC = Japan Migration and Colonization Corporation (today's JICA); JICA = Japan International Cooperation Agency; JPCB = Japanese Plantation Company of Brazil.

collections of local medicinal plants from the yards of neighboring Brazilians. Friends, relatives, neighbors, contract workers, and visitors also brought in plant species often as gifts, or in exchange. Table 1 lists the species present in two sample homegardens in Tomé-Açu, along with the year of introduction and from where they were obtained.

2.4. Innovative approach of farmer-explorers

The Tomé-Açu homegardens became well known in the region since the late 1970s, thanks mainly to the efforts of two leading farmers: Noboru Sakaguchi (1933 –) and Takurō Maki (1947 –). Some details on these two farms are furnished hereunder.

- Sakaguchi farm: Noboru Sakaguchi is a forest science graduate from the Tokyo University of Agriculture, who traveled extensively on CAMTA missions in search of alternatives to black pepper that had been seriously threatened by diseases. From such expeditions, he brought back several species to the CAMTA nursery and to his own homegarden. Moreover, after studying the species composition and structure of rural Brazilian homegardens and writing accounts on traditional farming systems in the Amazon, Sakaguchi reported to the CAMTA administrative board that native *Theobroma* species planted with native multipurpose tall trees for shading (such as rubber and *andiroba* = *Carapa guianensis*) would be most appropriate for sustainable production in the region. CAMTA thus introduced the Bahian hybrid cacao (*Theobroma cacao*) to Tomé-Açu in 1971.
- Maki farm: Takurō Maki was one of the pioneer farmers to plant *freijó* (*Cordia goeldiana*) and *macacauba* (*Platymiscium ulei*), two highly appreciated native timber trees, for shading cupuaçu and cacao. Maki loved to wander around the forests and collect seedlings of useful trees that he learned about from the rural Brazilians. Although he did not have frequent chances of travel as Sakaguchi did, he looked for interesting species in the homegardens of friends and relatives within the settlement. The species procured from distant sources by Sakaguchi and others thus spread among the farmers of Tomé-Açu. Maki also provided seeds and seedlings from his homegarden to other interested farmers. With support from a Japanese public agency for emigrant support, he even shipped *freijó* seeds to other *Nikkei* settlements in Amazon.

Although the homegarden caretakers (elders, housewives, and children) evaluated the local performance of new plants, final decision regarding large-scale planting in the main fields was taken primarily by the male heads of households after considering the available market information. Moreover, those pioneering family heads had often received *tokunō* (master farmer) education in Japan that emphasized diligent practices based on careful observation of nature and taking pride in the vocation of producing food. The following case studies of key agroforestry species introductions in Tomé-Açu further illustrate the innovative approach of these farmer-explorers.

- Saitō-Oshikiri farm [specialty crops: cacao, rubber, brazilnut (*Bertholletia excelsa*) and black pepper]: According to Aiko Oshikiri (1920 – 2000), who wrote about the period in the 1930s when Tomé-Açu was called the "green hell of poverty and fatal endemics," she and her mother took care of the homegarden plants collected by her father, Enji Saitō (1891 – 1958). While acting as the president of the vegetable producers' cooperative (the predecessor of CAMTA) for the daily survival of the impoverished Japanese immigrants in the interior settlements, Mr. Saitō searched for seedlings of 'permanent crop' species including brazilnut, cacao, rubber, urucu (*Bixa orellana*), guaraná (*Paullinia cupana*), and black pepper ('*Singapura*' or *Kuching* variety). He later became known as the founder of black pepper culture in the Amazon and the Americas (Oshikiri, 1985). It was his son-in-law Tanio Oshikiri (1911 – 1987), Aiko Oshikiri's husband and CAMTA president, who promoted rubber and brazilnut among the Tomé-Açu farmers during the mid-1960s as substitute crops for black pepper. Today more than forty 70-year-old brazilnut trees remain in the Saitō-Oshikiri farm, with the largest ones attaining 200 cm diameter at breast height and a height of about 35 m.

- Shimomaebara farm [specialty crop: passionfruit (*Passiflora edulis*)]: In the early 1970s, black pepper fields in Tomé-Açu were severely affected by fungal blight (*Fusarium solani* f. sp. *piperis*) causing great economic hardship to the *Nikkei* community, which had made this crop their principal source of income. Mitsuji Shimomaebara (1914 – 1994), an honors graduate from Matsuda Farmer School in Matsubase, Kumamoto, Japan, where he received the *tokunō* education, however, developed a simple system of passionfruit culture through which the economic hardships of the *Nikkei* community could be partially mitigated. In this method, passionfruit, a common local homegarden vine grown on trellises, vigorously climbed on the abandoned black pepper stakes, taking advantage of the residual soil fertility and spreading horizontally on a single wire extended over the stakes. The fruit bearing vines hung from the wire like a curtain and produced excellent results. With growing demand from juice factories, passionfruit became a key crop in the black pepper plantations, which began succumbing to *Fusarium* five to six years after planting. In 1974, Mr. Shimomaebara was awarded the Marshal Rondon medal for interior development by the Brazilian government, as his method of growing passion-fruit became popular nation-wide. In terms of importance to agroforestry, both black pepper and passionfruit provided temporary shade, wind protection, and residual soil fertility to the young trees planted between the rows of perennial vines. Consequently, native fruit trees previously screened in homegardens such as cacao and cupuaçu, and tall trees including rubber, brazilnut, *freijó,* and *andiroba* established very well in this system (Yamada, 1999).
- Kusano and Yokokura farms (specialty crops: *Theobroma* spp. under shade trees): After the introduction of Bahian-hybrid cacao in 1971, it became the most popular tree crop in the region in the 1970s and early 1980s. However, it was susceptible to witch's broom disease caused by the fungus *Crinipellis perniciosa* (Stahel) Singer. By the mid-1980s, Hisaharu Kusano (1927 – 2003), another honors graduate from Matsuda Farmer School, and his son Tsuneo Kusano (1948 –) developed disease resistant cacao cultivars. They along with

families toiled for more than a decade in their homegardens and the adjoining cacao orchards, conducting individual selection, grafting, and cross-pollination of the tiny cacao flowers[2]. The cacao scions screened were disseminated to interested farmers along with information on grafting techniques. Their methods were also applied to cupuaçu, which had been established as a major field crop by Nobuyoshi Yokokura (1914 – 1997), a farming *haiku* poet who had learned *tokunō* discipline in his youth at the Kitami Colonization Training Center, Hokkaido, Japan. In the early 1970s, Yokokura anticipated the potential fruit pulp market for this homegarden species, which has a growth habit similar to that of cacao. He planted the first cupuaçu field at Tomé-Açu with tree shading, and distributed seeds to his young followers. Due to misplaced worries of cupuaçu transmitting the witch's broom disease to cacao, local agricultural extension authorities warned Yokokura to cut down his cupuaçu trees or lose institutional financing. However, he never gave up his orchard. In the 1990s, when cacao and the vine crops faced low prices, Tomé-Açu farmers were sustained by their cupuaçu pulp sales. The native and shade-tolerant *Theobroma*-based systems thus expanded to 3400 ha or 56% of the main field agroforests in Tomé-Açu and opened up new opportunities for planting cacao with various useful tall tree species screened in the homegardens (Yamada, 1999). Again, farmers were initially warned by the extension agents to plant only leguminous shade trees (*eritrina* and *palheteira*) with cacao, but they pursued their own ideas and created productive multistrata/multispecies farms within three decades, which now serve as officially recommended models for family farms in the region.

The *Nikkei* farmers of Tomé-Açu are perpetual innovators. In addition to the significant cases of local and regional agroforestry development history listed above, we identified during the farm visits various on-going studies involving promising crop species, such as acerola (*Malpighia glabra*), açai, araça-pera (*Psidium acutangulum*), avocado (*Persea americana*), lime and oranges (*Citrus* spp.), *uxi* (*Endopleura uchi*), bacuri (*Platonia insignis*), spice trees, and other tall tree species for timber and non-timber purposes. While each farm became specialized in certain species or cropping systems, successful results were shared quickly within the community and beyond, partially because of the easy access for curious visitors to the homegarden area near the farmhouse. However, it was essentially the multipurpose agricultural cooperative (CAMTA) that prompted the development and dissemination processes. CAMTA's Technical Assistance and Extension Division (ATEA) had experienced agronomists, who regularly visited these farms. Besides, the cooperative received public supports from Japan, such as visiting experts of various specialties, training and excursion programs for farmers, introduction of new species and varieties, and financial support for the cooperative projects including construction of the experimental juice factory. Considering that institutional support is crucial in developing complex agroforestry systems (Follis and Nair, 1994), in Tomé-Açu the long-lasting and comprehensive collaboration between CAMTA, the cooperative representing immigrant farmers, and the Japanese public agencies for emigrant support led to the success of agroforestry development. In this scenario, the *Nikkei* homegardens functioned as an informal 'institutions' run by the networked farmers with *tokunō* orientation, complementing the roles of the cooperative and public institutions and making their initiatives more effective. Tomé-Açu farmers thus realized the intensive and economically viable production systems that converted much less forested area to farmlands compared to other prevailing types of land development models in the Eastern Amazon, and generated rural employment (Yamada, 1999; Nair, 2001; Yamada and Gholz, 2002).

2.5. Outreach and technology transfer

Since the mid-1990s CAMTA board members became active in transferring agroforestry techniques to non-*Nikkei* family farms in the neighborhood. Michinori Konagano (1958 –), who was in charge of the cooperative's extension division, told the authors that raising production on numerous small family farms would make the rural societies peace-loving and the society at large would also be free from criminal activities. During the weekends, Konagano would, therefore, visit his neighbors, distribute seedlings, and teach agricultural techniques. Konagano was later appointed the secretary of agriculture of the municipality of Tomé-Açu.

Since the early 2000s, the Tomé-Açu agroforestry model gained wider attention as a viable alternative to mass forest destruction in the Amazon and orders to CAMTA for its products increased from the US, Europe, and Japan. In 2004, the Japan International Cooperation Agency (JICA) launched a project in Tomé-Açu, in collaboration with the local municipal office, CAMTA, EMBRAPA Amazônia Oriental, and POEMA (Poverty and the Environment in Amazonia – a local NGO), to establish an agroforestry training center for the young owners of the small family farms. In 2005, SAMBAZON, a US-based customer of CAMTA facilitated organic certification of açai products, which in turn led to doubling the capacity of the cooperative's fruit juice factory to 2400 Mg month^{-1}. It encouraged CAMTA to disseminate agroforestry among small family farmers of the region, teach them how to organize marketing cooperatives, and buy products from these cooperatives for processing at the CAMTA juice factory.

3. CONCLUSIONS

The individual, collective, and public efforts at Tomé-Açu over the past 75 years have led to the development of successful multistrata agroforestry systems that have attracted worldwide attention. The homegarden as the locus of individual experimentation with a variety of crops and their mixtures has been at the center of this historical process. Through this developmental process, immigrant farmers overcame difficulties in the unfamiliar climate, and established commercial crops such as vegetables, black pepper, passionfruit, fruit trees, and other products. This case implies that stimulating and supporting farmer initiatives in agroforestry homegardens is an effective approach to the development of sustainable rural development projects – perhaps more effective than the 'conventional' strategy of providing farmers with supposedly proven agroforestry modules for their main farm fields.

ENDNOTES

1. Nagasaki Y. 2003. Tomé-Açu ni okeru Nikkei Nōka no Sakumotsu Uetsuke Jōkyō ni kansuru Tsuiseki Chōsa. ACTA, Tomé-Açu, Brazil,19p.
2. The elder Kusano recounted his *tokunō* philosophy to the authors that farm crops grow by listening to the owner's footsteps (i.e., the owner needs frequent visits and careful observation of his field) and that a farm is established only after the pioneer's wooden house has been returned to the soil (i.e., it takes long-term efforts to make good soil for sustainable production). Thus, even after the crash in international market of cacao, or the sudden drop in cacao bean prices in the international markets in the early 1980s, the Kusanos continued their on-farm research. However, the traditional *tokunō* farmers sometimes overemphasized diligence over rationality and preferred clean culture rather than green mulch or grass cover methods in the tropical climate.

REFERENCES

Anderson A.B. 1990. Deforestation in Amazonia: Dynamics, causes, and alternatives. In: Anderson A.B. (ed.), Alternatives to deforestation: Steps toward sustainable use of the Amazon rain forest, pp 3 – 23. Columbia University Press, New York.

Barrow C. 1990. Environmentally appropriate, sustainable small-farm strategies for Amazonia. In: Goodman D. and Hall A. (eds), The Future of Amazonia: Destruction or sustainable development? pp 360 – 382. Belhaven Press, London.

Fearnside P.M. 1995. Agroforestry in Brazil's Amazonian development policy: The role and limits of a potential use for degraded lands. In: Clüsener-Godt M. and Sachs I. (eds), Brazilian perspectives on sustainable development of the Amazon region, pp 125 – 148. UNESCO Man and the Biosphere Series 15, Parthenon Publishing Group, Carnforth.

Follis M. and Nair P.K.R. 1994. Policy and institutional support for agroforestry: An analysis of two Ecuadorian case studies. Agroforest Syst 27: 223 – 240.

Gradwohl J. and Greenberg R. 1988. Sustainable agriculture. In: Saving the tropical forests, pp 102 – 137. Earthscan Publications, London.

Homma A.K.O. (ed.). 1998. Amazônia – Meio Ambiente e Desenvolvimento Agrícola. EMBRAPA, Brasília, 386p.

Jordan C.F. (ed.). 1986. Permanent plots for agriculture and forestry. In: Amazonian rainforests: Ecosystem disturbance and recovery, pp 58–75. Springer-Verlag, New York.

Nair P.K.R. 2001. Do tropical homegardens elude science or, or is it the other way around? Agroforest Syst 53: 239 – 245.

Oshikiri A. 1985. Nyūshoku tōji no omoide. In: Henshū Iinkai (ed.), Tomé-Açu Kaitaku Gojusshūnenshi, pp 74 – 75. Midori no Daichi, Tomé-Açu Cultural Association, Tomé-Açu.

Serrão E.A.S. 1995. Possibilities for sustainable agriculture development in the Brazilian Amazon: An EMBRAPA proposal. In: Clüsener-Godt M. and Sachs I. (eds), Brazilian perspectives on sustainable development of the Amazon region, pp 259 – 285. UNESCO Man and the Biosphere Series 15, Parthenon Publishing Group, Carnforth.

Serrão E.A.S. and Homma A.K.O. 1993. Sustainable agriculture in the humid tropics: Brazil. In: Committee on Sustainable Agriculture and the Environment in the Humid Tropics, Board on Agriculture and Board on Science and Technology for International Development of the National Research Council (ed.), Sustainable agriculture and the environment in the humid tropics, pp 265 – 351. National Academy Press, Washington D.C.

Subler S. 1993. Mechanisms of nutrient retention and recycling in a chronosequence of Amazonian agroforestry systems: Comparisons with natural forest ecosystems. PhD Dissertation. The Pennsylvania State University, State College, 203p.

Subler S. and Uhl C. 1990. Japanese agroforestry in Amazonia: A case study in Tomé-Açu, Brazil. In: Anderson A.B. (ed.), Alternatives to deforestation: Steps toward sustainable use of the Amazon rain forest, pp 152 – 166. Columbia University Press, New York.

Tanaka N. 1997. Nettai nōgyō ni okeru takakuka no tenkai to agroforestry ni kansuru ichi kōsatsu: Amazon chiiki Tomé-Açu mura wo jirei to shite. Hokkaidō Daigaku Nōkei Ronsō 53: 151 – 163.

Uhl C. and Subler S. 1988. Asian farmers: Stewards of Amazonia. Garden 12: 16 – 20, 31.

Uhl C., Nepstad D., Buschbacher R., Clark K., Kauffman B. and Subler S. 1989. Disturbance and regeneration in Amazonia: Lessons for sustainable land use. The Ecologist 19: 235 – 240.

Uhl C., Nepstad D., Buschbacher R., Clark K., Kauffman B. and Subler S. 1990. Studies of ecosystem response to natural and anthropogenic disturbances provide guidelines for designing sustainable land use systems in Amazonia. In: Anderson A.B. (ed.), Alternatives to deforestation: Steps toward sustainable use of the Amazon rain forest, pp 24 – 42. Columbia University Press, New York.

Yamada M. 1999. Japanese immigrant agroforestry in the Brazilian Amazon: A case study of sustainable rural development in the tropics. PhD Dissertation, University of Florida, Gainesville, 821p.

Yamada M. and Gholz H.L. 2002. An evaluation of agroforestry systems as a rural development option for the Brazilian Amazon. Agroforest Syst 55: 81–87.

CHAPTER 18

URBAN HOMEGARDENS AND ALLOTMENT GARDENS FOR SUSTAINABLE LIVELIHOODS: MANAGEMENT STRATEGIES AND INSTITUTIONAL ENVIRONMENTS

A.W. DRESCHER[1], R.J. HOLMER[2], AND D.L. IAQUINTA[3]

[1]Albert-Ludwigs-Universität, Freiburg, Germany; E-mail: <axel.drescher@sonne.uni-freiburg.de>. [2]Xavier University College of Agriculture, Cagayan de Oro, The Philippines. [3]Nebraska Wesleyan University, Lincoln, Nebraska, USA

Keywords: Food security, Households, Species diversity, Sustainable development, Urban agriculture, Urban planning.

Abstract. Diversity of food and income resources is one of the main buffers against vulnerability of the urban poor. Based on the authors' field experience in the Philippines, Latin America, and southern Africa, and involvement with various other project evaluations, this chapter discusses the major differences between individual homegardens and allotment gardens and their respective roles in urban livelihood support programs. Major differences between these two systems of gardening are in their respective decision-making processes and impacts—in terms of both quantitative and qualitative outcomes. Current land use planning, multistory housing, and land use competition from different sectors limit both open space and space for gardening in the urban centers, necessitating lobbying and public advocacy to support such garden systems. While homegardens need public advocacy and extension services, allotment gardens additionally require significant political intervention to secure land, organize access, and support development. Implicit in this is the need for identifying the institutional barriers as well as gathering support for gardening projects in urban and periurban environments, prior to promoting the urban-gardening programs.

1. INTRODUCTION

Urban agriculture is the general term used to refer to a wide variety of food production practices in and around cities. Together with periurban agriculture, it

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 317–338.

represents a continually growing activity and consequently an emerging research area. *Urban gardening* is perhaps the most significant component of urban agriculture from the perspective of individual practitioners. It includes three types of practices: homegardens, allotment gardens and community gardens. While there is no universal agreement on the precise meaning of these terms, we adopt the following definitions. *Homegardens* are maintained – typically, but not always, near the homes – by individuals or households who have some access to land (either customary or legal), which they have arranged for themselves. *Allotment gardens* are separate parcels of land allocated to individuals or households for personal use. While contiguous, each household works on the parcels independently and the land is made available through either government action or private enterprises. The individual households are organized into self-governing associations. *Community gardens* are maintained by a group of individuals or households who produce agricultural goods collectively on a piece of land primarily for self-consumption.

The extent and significance of urban gardening have been discussed elsewhere (Mougeot, 2005). Suffice to say that, it is widespread and that all three forms of gardening are growing throughout the world, particularly in response to income deprivation and the crises involving economic recession, natural disasters, and civil disorder (Jacobi et al., 2000). This is especially significant for the large segments of urban poor that continue to grow.

In an extensive treatment of urbanization, urban and periurban agriculture, and urban poverty, Drescher and Iaquinta (2003) addressed an array of issues relevant to this chapter. In particular, they identified the characteristics of urban and rural poor, the very different socioeconomic conditions of urban poor in the developed and developing economies (see also UNCHS, 2001), and the gender-related aspects of urban gardens in different social and cultural systems. Another important consideration is that people practice urban gardening – whether home or allotment – for more varied reasons in the developed countries than in developing countries, principally because of the size of the economically stable population. Food production and income generation are important in both places, but the objectives of middle-income urban gardeners in developed countries (who grow flowers, create leisure environments, build kids' playground, promote outdoor meeting places, etc.) are often different from those of their low-income counterparts.

This chapter discusses the importance of urban gardens, highlights the constraints faced by urban gardeners, and addresses possible resolution of such constraints. Central to this discussion is the extension of the homegarden model to allotment gardens and the elaboration of the institutional contexts within which household livelihood strategies operate.

2. DIVERSITY AND THE INVENTIVE SPIRIT OF URBAN GARDENING

A common problem for urban gardens is the increased demographic pressure on available land, which we call *spatial densification*. This is caused or exacerbated by planning regulations intended to avoid urban sprawl and the desire of homeowners and users to create more living space. Because spatial densification means adding more people to the same area, it involves increased housing construction, which competes directly with the land available for gardening. This is a major problem for the poor, urban squatters and for the residents in spontaneous, periurban land occupations. Despite this apparent space constraint, homegardens are common in many urban environments.

A probable solution to the constraints imposed by the overall urban situation is the development of alternative production systems adapted to lack of space, water, and other inputs. Soil-less cultures such as hydroponics, substrate cultures, and container gardens are just a few examples. Rooftop gardening is increasing in many densely populated cities. Even poultry farming and pig rearing take place on the rooftops or within houses, and are sometimes promoted by the local nongovernmental organizations (NGO) or international organizations such as the Food and Agriculture Organization (FAO, 1998; Drescher and Iaquinta, 2003). Since 1985, a cooperative of 100 poor women in Bogotá, Colombia, have used rooftops to grow hydroponic vegetables for city supermarkets. Unmarketable crops are either fed to livestock or used for home consumption.

In Lima, Peru during the past two decades, the Ministry of Agriculture, FAO and United Nations International Children's Emergency Fund (UNICEF) have promoted household and community kitchen gardens to avert widespread hunger. The Center for Education and Technology in Santiago, Chile, promotes 20 m^2 gardens, where plants are raised in containers stacked up in pyramids and walls are used for trailing vines (FAO, 1998). In Sri Lanka, "edible air-scapes" are promoted by the island nation's department of agriculture as a strategy for rebuilding in the aftermath of the tsunami. Walls, bottles, bags, and fences are used for raising plants as part of this (Ranasinghe, 2005). The Cuban example of "organoponics" (Cruz and Medina, 2003; Pinderhughes, 2004) is a well-established system incorporating both efficient water conservation and the use of compost and manure for fertilization in the urban context.

In other parts of Latin America also, a particular form of organized homegardens exists (the so-called *microgranjas*), which involves the production of vegetables, fruits, other products, and small animals (e.g., chickens, pigs, guinea pigs, or rabbits) (Arias, 2000). The distinguishing characteristic of the *microgranjas* is that with governmental support, the homegardeners have been organized into groups. It thus, provides a platform for exchange of information and knowledge, despite the spatial dispersion of cultivated plots. Thus, while there are several forms of urban gardening, they can broadly be classified as homegardens, allotment gardens, and community gardens.

3. URBAN HOMEGARDENS

An urban homegarden, a multispecies production system on the area of land around the house to meet different physical, social, and economic needs and functions, is traditionally an important land use activity for individual households. Although its functions are similar throughout the world, focusing principally on subsistence or income generation, their structure and size vary considerably. For instance, in Papua New Guinea, Vasey (1985) reported that house plots generally range between 300 to 400 m^2 but are often too small to meet the household demands. Consequently, many households establish second gardens away from the house. Christanty (1990) reported that the size of homegardens in Bangladesh ranged between 30 and 700 m^2, with an average of 200 m^2. Hoogerbrugge and Fresco (1993) also found wide variations in the size of homegardens even within a given country. For example, they reported size estimates ranging from 10 to 120 m^2 and 5000 to 20 000 m^2 in two separate studies in Zambia and ranges of 172 to 500 m^2 and 200 to 1700 m^2 in two Javanese studies. Drescher (1998) also observed large variations in this respect (17 to 865 m^2 in Lusaka, Zambia), but indicated that the majority of urban homegardens were less than 300 m^2 and that on average, women's gardens were more than double the size that of men's. Prosterman and Mitchell (2002) suggested that a great majority of homegarden plots in Java were less than 200 m^2. Christanty (1990) earlier showed that on the less densely populated Indonesian islands, homegarden plots averaged 2500 m^2, sometimes reaching a size of three hectares. In Lima, Peru, Hetterschijt (2004) also found that the size of urban organic homegardens varied between 25 and 900 m^2, with an average of 110 m^2 (n = 109). In several studies, however, the failure to designate the study areas as rural, urban, or periurban, and the lack of universally accepted definitions for these classifications complicate the matter. For example, in thickly populated regions such as Java (Indonesia) and Kerala (India), the distinction between rural and urban settings is rather blurred. Iaquinta and Drescher (2000) have shown that this is even more pronounced in periurban areas.

Nonetheless, four points emanate from the discussion above. First, the size of homegardens varies considerably across cultures and even within them. Second, the size of the majority of homegardens tends toward the low end of the range (positively skewed distribution pattern). Third, households sometimes make managerial decisions to locate some or all homegardens geographically distant from the house due to space or other constraints. Fourth, households make numerous management decisions, which, along with environmental constraints, determine both the physical structure and the outputs of the homegarden.

Urban homegardens integrate a variety of physical, social, and economic functions. Typical homegardens include (1) physical areas for living, storage, and waste disposal, (2) social areas for meetings, children's playgrounds, and display, and (3) economic areas for raising animals and for growing food, medicinal plants, and fruit trees. Overall, the homegarden is a place for people to live but also a place to produce a variety of foods and products for home consumption and income generation (Landon-Lane, 2004).

Homegardens also play an important role in the conservation of indigenous crops, thus enhancing biodiversity in rural, periurban and urban environments. Drescher (1998) and Boncodin et al. (2000) found a variety of indigenous vegetables in the homegardens and in the local markets of Lusaka, Zambia. In particular, *Amaranthus* sp. grows semi-cultivated in the gardens. Other examples include *Bidens pilosa*, *Brassica* sp., *Corchorus* sp., *Solanum macrocarpum*, *Hibiscus* sp., *Cleome* sp., *Ipomoea batatas* (sweet potato), and *Cucumeropsis edulis* (squash).

Indigenous tree species providing multiple products such as firewood, food, fruits, and medicines also abound in the homegardens, yet they are often overlooked when talking about urban homegardens. For example, the leaves of the horseradish tree (*Moringa oleifera*) grown in the homegardens are the most frequently consumed vegetable among the households of Cagayan de Oro City, the Philippines (Agbayani et al., 2001).

Urban homegardens compensate to a certain extent for the gardener's restricted access to natural resources. While gathering wild vegetables and roots is still prevalent in periurban and rural areas, such options are limited in the urban context. For example, only 39% of households included in a study in Lusaka gathered wild fruits and vegetables, compared to 76% in periurban and 86% in the rural areas. Thus, in the urban context, homegarden produce provides an economical and nutritious substitute for wild vegetables and roots (Drescher, 1998). As seen in Fig. 1, trees [e.g., peach (*Prunus persica*), papaya (*Carica papaya*), mango (*Mangifera indica*), and *Morus alba*] are an integral part of the urban homegardens in Lusaka.

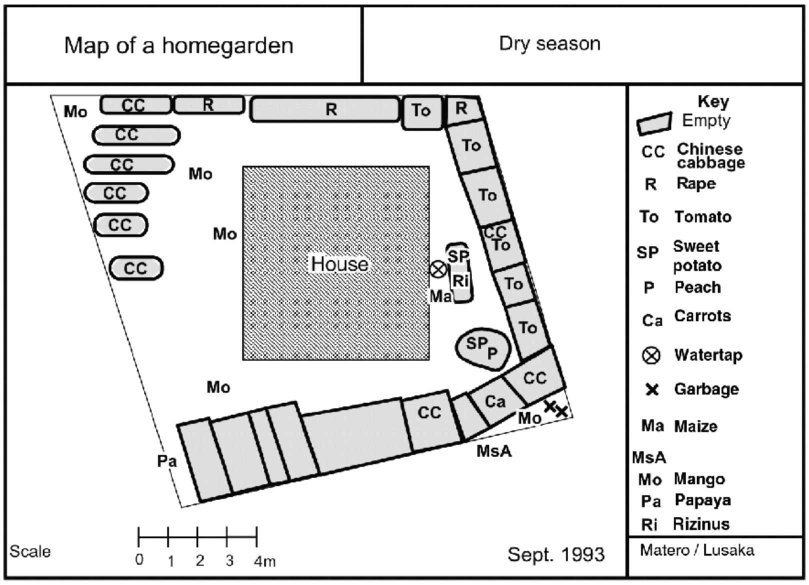

Figure 1. *Map of an urban homegarden in Lusaka (Zambia) (Source: Drescher, 1998).*

While homegardening provides subsistence and supplementary household food supply, Boncodin et al. (2000) showed that it concurrently makes a significant contribution to the amount of nutrients and variety in the household food intake. In a study of the rural homegardens in the Philippines, they identified 33 different food crops, including green, leafy, and yellow vegetables; starchy roots and tubers; and legumes, beans, nuts, and spices. Homegardens thus provide year-round food supplements to households not only in terms of quantity but also in terms of food diversity and variation, and play an important role in providing Vitamin A and Vitamin C as well as supplying one-third or more of calcium and iron needs (Kumar and Nair 2004). This is consistent with the findings of a study on urban homegardens in the Philippines[1].

3.1. Community and allotment gardens

Community gardens are defined as gardens where people share the basic resources of land, water, and sunlight (MacNair, 2002). Allotment gardens, a special type of community garden, were first developed in Germany. Introduced as *Schrebergärten* in the mid-1800s, they flourished over a century and a half (Kasch, 2001). Allotment gardens are characterized by a concentration in one place of several small land parcels (usually 200 to 400 m^2 each). Individual families are organized into an association, which assigns the land parcels. In allotment gardens, the parcels are cultivated individually, as compared to community gardens where the entire area is tended collectively by a group of people (Holmer et al., 2003). Community gardens are often organized around a particular institution such as school, workplace, faith organization, hospital, etc. They may also be organized around social characteristics such as ethnicity, age, or religious orientation.

In the Philippines, the production practices for vegetables in urban allotment gardens are similar to those in the rural areas; however, they differ particularly in the choice of cultivars and in the reduced application of agrochemicals due to the proximity to populated areas (Guanzon and Holmer, 2003). Although allotment gardeners are not excessively environment-oriented, nor are there many government restrictions on the use of agrochemicals, they are usually market-oriented. That is, about 70% of the produce is marketed directly within the garden itself—mostly to close neighbors; the consumers are generally well aware of the production practices and do not accept produce that has been heavily sprayed with chemicals. This situation differs greatly from the general system where vegetables are anonymously produced in far away locations and the customers mostly make assumptions regarding the production practices. This contrast is particularly true in the developing countries where government food safety controls are lax and quality labeling is either non-existent or unreliable.

A preliminary study[2] in Cagayan de Oro, the Philippines indicated that the local people perceive the multiple benefits of allotment gardens. While 25% of the vegetables produced were consumed by the family or shared among friends, 75% were sold to neighbors or walk-in clients who come directly to the garden and who appreciate the freshness of the produce, the convenience of proximity, and the relatively lower price than the public markets. The gardening activities, a secondary occupation for all association members, thus augmented their incomes by about 20%, while vegetable consumption also increased by about 75%. This is especially notable since the average vegetable consumption in Cagayan de Oro is only 36 kg per capita per year, about one-half of the minimum recommended intake suggested by FAO (Agbayani et al., 2001). In addition to these direct effects, the gardeners appreciate the strengthening of the community values brought about by allotment gardening.

The gardens are also essential for the successful implementation of the city's integrated solid waste management program. Segregated biodegradable wastes from neighboring households are delivered to the allotment gardens where they are converted into compost. The amount of residual waste delivered to the landfill site from these areas could theoretically be reduced by more than one-third, if all biodegradable wastes are channeled to a system of composting by allotment gardens in the city[3]. The city government of Cagayan de Oro is presently mainstreaming this concept into its overall city planning and development, using participatory GIS-based approaches to identify suitable areas for further expansion of allotment gardens (Emmanuel Abejuela, pers. comm., August 2005). The advantages of such an approach are manifold. For example, mineral fertilizer application can be drastically reduced by using enriched compost, thus reducing the danger of ground water pollution. The difference between urban and rural gardens is that the former uses biodegradable household wastes from many nearby households organized by the local government, and not only the bio-waste generated within the garden. Thus, urban gardens have a comparative advantage in their access to organic inputs generated by urban households, which is important in view of projected increase in demand for organically grown food.

3.2. Urban homegardens, allotment gardens, and community gardens: a comparison

The most important feature of allotment gardens is that they are institutionally administered and organized, and they serve as a community facility and a place of social interaction. In the German context, each gardener in an allotment garden needs to be a member of the respective *Kleingartenverein* (allotment garden association). In developing countries, however, gardeners are often not members of any associations, but are part of the community. The gardens are not necessarily near the homes, but rather located where sufficient space is available, and sometimes where favorable soil and water conditions exist. Obviously, transportation issues arise as the distance between homes and gardens increases. In other cases, the gardens are located in areas unsuitable for buildings or they are established as buffer zones along rail corridors and highways. They may even be located in protected areas necessary to balance the urban microclimate, as is the case in some German cities. Here allotment gardens are used on green belts to facilitate cold drainage, thus reducing urban heat island effects and the demand for air conditioning (Landeshauptstadt, 1998; Innenministerium, 2004).

In Lusaka, Zambia, community gardens can be found on the edges of densely populated compounds that do not allow people to grow food within the housing area. A similar situation existed formerly in Harare, the capital of Zimbabwe. In Port Elizabeth, South Africa, some allotment gardens are situated on common areas and on the grounds outside churches, schools and hospitals (Jarlöv, 2000). Unlike Germany where allotment gardens are located on public lands owned by the city or railway, all allotment gardens of Cagayan de Oro, the Philippines, were established on private lands, due to the lack of publicly owned open spaces (Holmer et al., 2003). In Cagayan de Oro, the chairpersons of the *barangay* (city district) simply asked the local private landowners if poor residents of the *barangay* could use their vacant land for food production. To preclude residential occupation, however, the gardeners are only permitted to construct a small shed for tools and other garden implements, and not allowed to establish residential structures. Conditions for land use are then formalized into a memorandum of agreement jointly signed by all stakeholders to legitimize access to the land for horticultural purposes (Vélez-Guerra, 2004).

Urban homegardens have several characteristics that are similar to those of non-urban homegardens: (1) their location adjacent to homes (2) close association with joint family activities and (3) wide diversity of crop and livestock species used to meet family needs (Landon-Lane, 2004). Thus, homegardening is not simply a spatial integration but is characterized by a social and socioeconomic integration of the families involved. Importantly, overemphasis on the first characteristic oversimplifies the realities faced by residents in places such as the seasonal tropics of Africa, where homegardens are not necessarily near the homes; rather, they are located near water sources due to long dry seasons (Fig. 2). This could be a major reason why these production systems have often been overlooked in the past (Drescher, 1998).

Figure 2. *Homegardens and adjacent community gardens in Southern Zimbabwe. Some gardens are near the houses (upper left) some others are distant to the houses near the water source.*

The choice homegardeners make in locating their plots represents a clear environmentally informed management decision, and not a decision to engage in something fundamentally different from homegardening, or one made by the local authorities. Such gardens are household-based small-production entities and it is best that our definition be concerned less with the location than the nature and aim of the activity.

The geographic separation of homegardens and dwellings is not unique to Africa. During the first half of the twentieth century in urban United States, immigrant groups such as Southern Italians practiced substantial levels of homegardening for both cultural and economic reasons similar to the poor around the world today. Evidence on the extent of such practices in the US is found in historical collections of folklore and ethnographic narratives. A particularly good example is from Pennsylvania[4], where the Southern Italians practiced urban gardening to produce subsistence items (direct consumables) and preserved food stock, highlighting the centrality of food to Italian culture, family, and gender roles.

More recent examples such as MacNair (2002) demonstrate that the same groups such as Italians continue to practice urban gardening often under conditions of land scarcity. In this example from Montreal, it resulted in policy interventions to regularize the practice under municipal authority. Often the gardens were at some distance away from the urban dwellings due to the nature of the land market. Multiple tenancy dwellings, however, made no provisions for land use by occupants. Available land was scattered and had to be purchased or leased. This meant that many households maintained multiple plots scattered around the neighborhood or further afield. As in the case of the African gardens in the semiarid tropics discussed above, we view these gardens as clear examples of homegardens because of their centrality to family activities and the absence of municipal facilitation. The difference in this case is that the management decisions on the part of the practitioners were conditioned primarily by land availability rather than the labor costs associated with transporting water. Nonetheless, the majority of homegardens are located adjacent to the houses.

4. ALLOTMENT GARDENS: A SPECIAL CASE OF HOMEGARDENS OR AN 'INDEPENDENT' SYSTEM?

4.1. Secured access to space: an important question

Stakeholders themselves differ in important ways, mostly in terms of economics and land tenure. Generally, homegardeners are not the "poorest" residents on the socioeconomic scale since they already have access to land. Their challenge is primarily political, mobilizing a fragmented group of individual households with shared but unrecognized common interests.

The establishment of allotment gardens also requires space within the city boundaries. This is important only partially to minimize transportation issues. Women with children need to be near the house because they are generally involved in multiple household tasks such as cooking, firewood collection, cleaning, and childcare. However, the reservation and allocation of land for allotment gardens is a major problem in most urban settings. City authorities rather tend to create public parks or golf courses, which they consider more in line with the urban disposition. Generally, gardening does not fit into the conceptualization of urbanization or the philosophy of urban planners, and this makes it difficult to convince urban authorities that agriculture in the city is not inherently a problem, but a solution to various other urban problems (Drescher, 2001).

Secured access to land is especially relevant when considering the role of trees in urban gardens of all kinds. To justify capital and labor inputs, the urban gardener must realize a return on investment. For some crops such as sweet potatoes grown along roadsides, this occurs in a single growing cycle. However, where soil building, tree planting, pond construction, or landscaping, for example, are involved, the time span of *guaranteed* access increases, and a number of years is required to recover labor and capital inputs. For allotment gardeners this means sufficiently long site-specific 'lease' arrangements for the allotment as a whole combined with binding association 'rules of access' for individual participants. For homegardeners this is an issue of legally formalized land tenure rights, meaning either a deed/title system or the legal enfranchisement of usufruct rights for individuals in communal ownership contexts or in long-term spontaneous land occupations.

4.2. Lobbying or political mobilization is particularly relevant to allotment gardens

Overcoming limited vision, economic constraints, and political resistance requires effective lobbying. Yet, allotment gardeners typically represent some of the most politically alienated and economically impoverished residents, requiring external expertise to facilitate participatory lobbying and support for allotment gardens. Often nongovernmental organizations (NGOs), educational institutions, or sympathetic municipal agencies play this role. However, effective lobbying also requires solutions tailored to local conditions. Urban and periurban environments represent a "lumpy continuum" of human settlement with important and varied institutional capacities (Iaquinta and Drescher, 2000; 2001; 2005). The respective roles of home and allotment gardens differ dramatically across this continuum, as do the lobbying strategies necessary, even within a single municipality.

4.3. Who makes the key management decisions that directly affect outputs?

Observations made in Zambia and Zimbabwe show that community gardens are often located in unsuitable locations, distant from water sources and/or with bad soil conditions. Further, as compared to homegardens, trees are generally lacking in the observed community gardens (Drescher, 1998). These facts suggest that some of the limitations experienced in community gardens are due more to poor administrative planning, constrained extension support and gaps in data collection related to the importance of trees than to problems inherent to community gardens *per se*. Bilateral and reciprocal transfer of knowledge between gardeners, extension officers, and local officials is required to properly understand the smallholders' land use system and management strategies (Drescher, 1996).

Development projects tend to over-regulate the maintenance and management of allotment gardens. Typically, "the authorities" select and provide the seeds and fertilizers and this minimizes growing traditional vegetables, mitigates the role of the garden as a site for household experimentation, and marginalizes the gardener as innovator. Further, attitudes of municipal authorities also reflect the general underestimation of the multifunctional role of trees in cities, including food security.

5. THE HOMEGARDEN MODEL

5.1. Relationship to household livelihood strategy

The homegarden model (Fig. 3) is based on the assumption that homegardening is a process that forms part of the household livelihood strategy. Household livelihood security is defined as "adequate and sustainable access to income and resources to meet basic needs, including adequate access to food, potable water, health facilities, educational opportunities, housing, time for community participation and social integration" (Frankenberger and McCaston, 1998). For the present discussion, our emphasis is on the access to food, directly, or by means of access to income and resources.

The model in Fig. 3 was originally designed for homegardens, but has been modified to incorporate allotment gardens. The major differences between the two systems of gardening are in the decision-making process and their differing impacts, in terms of both quantitative and qualitative results. Allocation of assets in the model follows the treatment of Swift (1989). Collective assets (e.g., tools, stores and buildings) are of particular importance for allotment gardens.

The model implies that the household decision to get involved in gardening depends on factors such as the existence of a supportive general environment, access to land and water resources, and the availability of specific inputs (seeds, knowledge, work and time). The model also identifies household vulnerability factors that either stimulate or inhibit household involvement in subsistence and market-oriented food production. The risk of livelihood failure determines the level of vulnerability of a household to income, food, health, and nutritional insecurity. Therefore, livelihoods are secure when households have secured ownership of—or access to—resources and income earning activities, including reserves and assets, to offset risks, ease shocks, and meet contingencies (Chambers, 1989).

The model in Fig. 3 implicitly depicts homegardening as embedded in the livelihood system, interacting with the socioeconomic and environmental conditions of the larger system. It helps to identify factors that promote or inhibit household gardening and assists in the development of scenarios for different contexts regarding climate, space, politics, institutional framework, culture, and economics.

Homegardens support important farm-development activities; some farm inputs come from homegarden activities such as plant propagation, raising and housing draught animals, and making and repairing tools. New crops and farming techniques are often first tried out in the homegarden, which is also an area for drying, processing, and storing farm products (Landon-Lane, 2004; Yamada and Osaqui, 2006). In small compound homegardens in Zambia, sweet potato seedlings are planted and later transferred into the fields during the rainy season. Sweet potato leaves are also used as a vegetable both in dry and rainy season. Nearly 40% of the compound residents of Lusaka are engaged in staple crop production during the rainy season, while about 25% are engaged in homegardening and community gardening (Drescher, 1998).

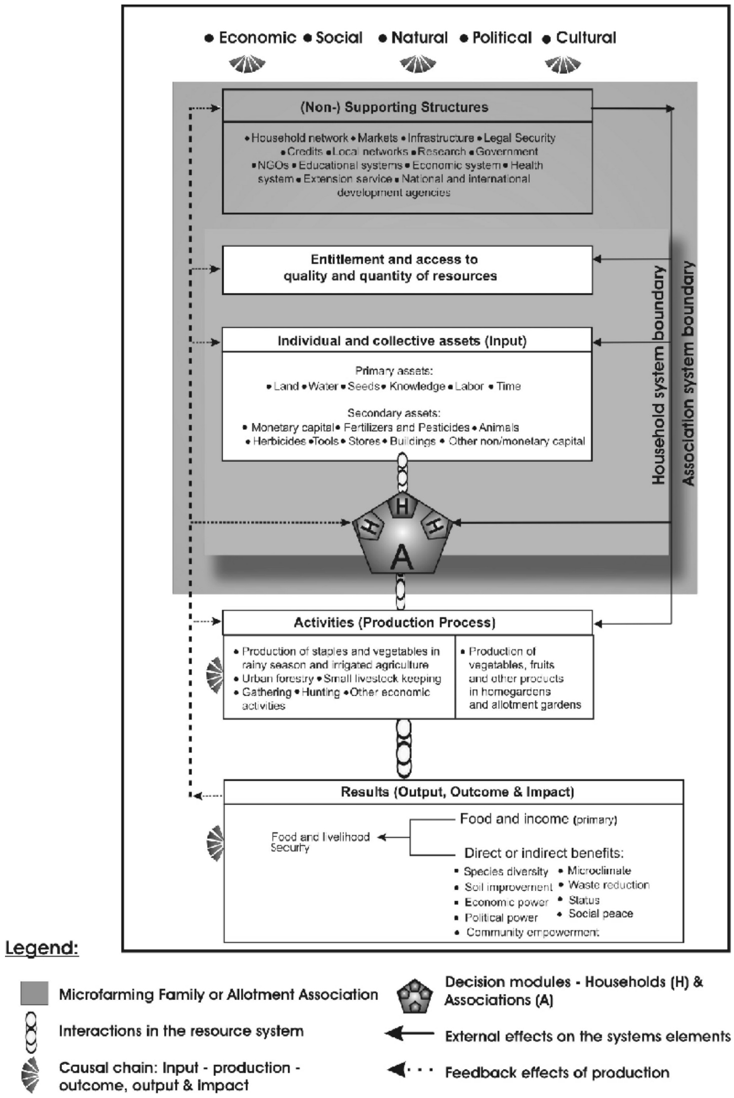

Figure 3. *The Homegarden Model (adapted from Drescher, 1998).*

5.2. Why so important in the urban context?

Urban environments differ considerably from rural environments. Urban poor dwellers are more likely to report food insecurity and heavy dependency on urban markets (Zalilah and Khor, 2004). At the same time, there are clear signs that poverty and malnutrition in cities are increasing, especially in slum areas and high-density compounds (FAO, 2001; Iaquinta and Drescher, 2002). Low purchasing power and declining access to food are major problems in many rapidly growing cities in the developing world (Drescher and Iaquinta, 2003).

Both home- and allotment gardening can partly compensate for the deficiencies of urban poor households and alleviate food insecurity. Thus, secured access to resources such as land, water, seeds, and tools is key to increasing food security in cities. Further, food production is only one dimension, *albeit* an important one, of the benefits to be derived from urban and periurban production. With proper assistance and management techniques, these environments are positively impacted through provision of shade, microclimate modification, waste recycling, soil stabilization, and soil building.

5.3. Applying the model to allotment gardens

If we apply the homegarden model (Fig. 3) to allotment gardens, it is evident, that the two systems are similar regarding access to resources, assets, activities, and outcomes. However, the arena of decision-making becomes more complex. Essentially, we need to "nest" the individual family as a decision-maker within the allotment association as the decision-broker. The decision module appears as a shaded pentagon in the center of the model and represents the decision-making process (e.g., what to grow, when to grow, where to grow, with whom and how to interact and cooperate, the balance between short and long-term investments, etc.). For homegardens, it is simply a single module (pentagon). For allotment gardens, however, it appears as a series of household pentagons nested within a larger "association" module. In practice, the entire decision-making process becomes more transparent and probably more standardized in the case of allotment gardens because individual family decisions are now directly guided and influenced by the association in a more public forum. Assets and activities can be better shared in allotment gardens and the transcendent outcomes are eventually more visible, mainly regarding community empowerment, social peace and status, and economic power. In this sense, we do not consider individual parcels in allotment gardens as independent farming systems in the way that homegardens are. However, an allotment garden association is an institution and it may conflict with preexisting institutions—particularly but not exclusively—those of a traditional form. That is why it is so important to understand the relationship between the type of urban or periurban environment and the respective institutions (Iaquinta and Drescher, 2000; 2001; 2005).

5.4. Contrasting roles of homegardens vs. allotment gardens within the general household gardening model

Allotment gardens, properly institutionalized and integrated into urban planning have their biggest influence on the level of the (non-) supporting structures and can regularize better entitlement and access to resources. Thus, allotment gardeners have an enhanced voice through the association, while homegardeners typically remain isolated, or “*just gardeners*!”

Because homegardening is seen primarily as a private activity, there is little public support for these gardens. Homegardening is only done when the specific circumstances permit it; for the most part space availability is the major determinant. Public support is more likely to occur in relation to allotment gardens, because of their greater visibility.

With respect to the environmental impact and output of both activities, the differences depend primarily on the management strategies employed. For both systems, space is restricted. Allotment gardens allow gardening for those who do not have access to land near their residences.

Thus, in terms of access, both homegardens and allotment gardens have a clear *political dimension*. On the one hand, The World Food Summit 2002 (FAO, 2002) reaffirmed the right of everyone to have access to safe, nutritious, and culturally relevant food. The ability to grow food is one important dimension of this access relevant to both types of gardens. On the other hand, community empowerment, which is especially relevant to allotment gardens, is inherently a process of advocacy and political negotiation among municipal authorities, local residents, and various interest groups.

6. HOW DO MANAGEMENT STRATEGIES FOR HOMEGARDENS AND ALLOTMENT GARDENS DIFFERENTIALLY IMPACT OUTPUTS?

6.1. The example of species diversity: observations from Africa

Species diversity or “garden biodiversity” provides an excellent example of the way management strategies and their outcomes differ between the two systems. Species diversity is determined by two factors: the number of species per garden and the abundance of each species within the community in a given area. Which species are planted and how much of each species gets planted represent fundamental management decisions.

Important inferences can be drawn from a study of rural homegardens and rural community gardens in southern Zimbabwe (Drescher et al., 1999), where, clear differences were found in the diversity of plant species in community and individual gardens. Individual gardens (average 8.6; range 5 to 12 species) showed a higher species diversity than community gardens. Community gardens averaged only four species (Drescher et al., 1999). In a related study, garden species-diversity was shown to be positively correlated with the prevalence of biological antagonists of crop pests (Drescher, 1998). Together, these results point to the benefits of promoting individual gardens and the need for extension strategies adapted specifically for community gardens.

Sweet potato, grown for both its nutritious leaves and starchy tubers, further illustrates the different approaches to management in the two types of gardens. Sweet potatoes were cultivated in all individual gardens but in only one community garden (Drescher et al., 1999). In homegardens, sweet potatoes serve as *early patch* leafy greens and are transplanted to fields later during the rainy season. This is a household decision that contributes to a more balanced diet, provides good early ground cover, and releases land for subsequent cultivation. Authorities decided, however, that the sweet potato would not be recommended for planting in community gardens, hence distributed no sweet potato seeds to gardeners. These two management systems could be brought into greater alignment with appropriate research and support. One opportunity for this is to transfer greater management authority to allotment associations, which typically function more interactively with households than do formal institutions and authorities.

6.2. Other outputs

In private homegardens, output in terms of yield can suffer due to the lack of labor and time. This can be more easily compensated for in allotment gardens, first by more cooperation between families and second by economies of scale relative to water supply and other capital investments and crop management techniques.

6.3. Marketing of surplus easier in allotment gardens?

Allotment gardens can produce marketable surplus produce too. Greater concentration of output creates economies of scale wherein both direct marketing and production are facilitated. In Cape Town, South Africa, for instance, the Siyazama community allotment garden produced both for the market as well as for home consumption of 15 dependent families. Public support for allotment gardens might help urban poor to get better access to markets[5,6].

The lack of public support for homegardens, however, reduces the number of such gardens in cities. Current land use planning, multistory housing and land use competition from different sectors often limit the open space and space for gardening. Nonetheless, in most cities, open space, unused sites, and idle land are still widely available. Fig. 4 shows the use of open spaces for gardening near Manila International Airport. Elsewhere in the Philippines, tax policy has been used to stimulate changes in land use. For example, in Cagayan de Oro, the municipal authorities taxed unused open lands motivating property owners to make the sites available to poor city dwellers for crop production.

In homegardens, important information flows through informal channels whereas the allotment gardens have enhanced information access through associations and extension support. This includes information on pest abatement strategies, management, and technologies. Effective systems combine the delivery and scientific advantages of extension with the firsthand user knowledge of gardeners in a reciprocal fashion.

Social interaction is higher in allotment gardens because of the joint activities of different families in close spatial proximity. Social interaction is even higher if there is a corporate identity like membership in an allotment garden association. Exchange of information, joint activities, and family-based participatory learning is more likely to happen in allotment gardens while homegardening is in most cases a purely family-based activity.

Figure 4. *Gardens near Manila International Airport with densely populated compound at the top.*

In contrast to homegardens, allotment gardens enable users to learn democratic rules more efficiently because they have to resolve many problems within the association. Usually, problems arise regarding the use of land, equitable distribution of land and water, and joint community work. Where democratic rules and civil society associations differ significantly from customary practices, participants need guidance and support in acquiring the necessary skills. New cultural forms and institutions may be strongly resisted since they can upset existing political and social arrangements. In such situations participatory process planning can be combined with knowledge of the institutional context to direct the structure and functioning of the association.

7. INSTITUTIONAL CONTEXT

In Table 1, we present the institutional context surrounding homegardens and allotment gardens. While it does not survey the complete range of possible relevant institutions, it gives a good idea of the complex ways that homegardens and allotment gardens are differentially affected. A more complete accounting of the context would classify institutions along at least two important dimensions: formal versus informal and traditional versus modern. Importantly, these two dimensions are neither collinear nor orthogonal. The utility of such a classification goes beyond the simple question of support or lack of support for one or the other type of gardening. The exercise points to the linkages between urban gardening and other social problems in the community, fostering the possibility for constituency building through integrated problem-solving. Nonetheless, even without such synergistic system gains, elaboration of the institutional context provides valuable insights into the gardening model presented and into the processes by which urban gardening – whether homegardening or allotment gardening – is facilitated or hindered.

8. RECOMMENDATIONS

- Allotment gardens need to be institutionalized. Ideally, they should be part of the concept of urbanization wherein land is specifically set aside for such activities in the planning process.
- Lobbying or public advocacy is required to support both garden systems. However, the nature of such lobbying efforts differs significantly between the two systems. Homegardens need public advocacy and extension services while allotment gardens additionally require political intervention to secure land, organize access, and support development.
- Allotment gardens should be developed as a package of services, including for example extension outreach, community and infrastructure building, delivery of health care, etc. Allotment gardens will be more protected and access to them will be better coordinated in such a configuration. For example, allotment gardens are well adapted to periurban environments when authorities are willing to regularize spontaneous occupations. Small- and medium-sized towns provide ideal conditions for such early intervention and land preservation when combined with proper waste management and extension services.
- Housing design and planning for backyards should facilitate homegardens.
- Provision of adequate water is a problem in many cities, and public water use often restricted. Solutions include urban rainwater harvesting and the use of grey water (i.e., non-septic household wastewater), but their effectiveness depends on developing cost-effective locally adapted designs/technologies. Other solutions such as modern irrigation techniques can be implemented rather cheaply in conjunction with the preceding but depend more on extension information services to be effective.
- The urban-periurban continuum is not uniform. Participatory process planning should be framed within the components of the periurban-urban typology and their corresponding institutions.

Table 1. *Institutional contexts of urban homegardens and allotment gardens.*

Institutional (non-) supporting structures[1]	*Type of urban gardens*			
	Homegardens		*Allotment gardens*	
	Characteristics	*Impact*	*Characteristics*	*Impact*
Allotment garden associations	Not applicable	Not applicable	Sometimes existent	Supporting
City councils	Mostly neglecting	Strongly inhibiting	Some recognition	Sometimes supporting
Town Planning	Generally not aware of the importance of homegardens	Strongly inhibiting	Generally not aware of the importance of urban food production	Strongly inhibiting
Educational system	Ignorant in many countries	Little support	Ignorant in many countries	Little support
Health Authorities	Generally not involved and not aware	Inhibiting but probably no effect	Generally not involved	Inhibiting

Water authorities	Prohibiting the use of public water for gardening without promoting alternatives (e.g. wells, rain water harvesting, grey water use)	Inhibiting	Prohibiting use of public water for gardening without promoting alternatives (e.g. wells, rain water harvesting, grey water use)	Inhibiting
Credits	Generally not available	Inhibiting	Generally not available	Inhibiting
Extension Services	Generally not available, rarely in the context of development projects	Inhibiting	Generally not available, sometimes in the context of development projects	Inhibiting
Markets	Mostly bartering with neighbors; production too small	Supporting social interaction	Access to markets difficult, direct marketing possible but not supported	Inhibiting
Markets and market information	Direct marketing, bartering, household networks	Sometimes supporting	Direct marketing, bartering, household networks	Sometimes supporting
	No market information system in place	Sometimes inhibiting	No market information system in place	Sometimes inhibiting

[1]By non-supporting structures we mean those institutions and bodies, which do not have policies on mechanisms to directly support gardens, and may even impede their development. Supporting structures in contrast clearly support the development of gardens.

- Extension strategies should be elaborated in close cooperation among all stakeholders, especially smallholders and extension officers.
- Strong advocacy for the multifunctional role of trees in both gardens and the broader urban context is required. Integration of this concept into extension programs aimed at both homegardens and allotment gardens is needed.

ENDNOTES

1. Velez C. 1997. Homegardening as a strategy for food and nutrition security: a case study of selected households in Lantapan, Bukidnon. MSc paper in Applied Nutrition, submitted to the Faculty of the Graduate School, University of the Philippines, Los Baños.
2. Urbina C.D., Miso A.U., Holmer R.J. 2005. Socio-economic impact of the allotment garden project in Cagayan de Oro. Paper presented at the 6th PUDSEA Network Conference. July 11-15, 2005, Cagayan de Oro, Philippines.
3. Segne J.B., Salcedo J.M. and Guiral H. 2004. Implementation of an integrated solid waste management system in two Sitios of Cagayan de Oro. Proceedings of the 16th NOMCARRD Regional symposium on research and development highlights, August 5-6, 2004, Central Mindanao University, Musuan, Bukidnon, Philippines (in print).
4. Saverino J.L. 1995. 'Domani Ci Zappa``: Italian immigration and ethnicity in Pennsylvania. In: Pennsylvania folk life. 45 (Autumn): pp. 2-22.
5. Abalimi, pers. comm., 2000; see also in Motion Magazine 2002, interviews related to the United Nations World Summit on Sustainable Development in Johannesburg, South Africa, August 26 - September 4, 2002.
6. Food and Agriculture Organization (FAO) 2001. Proceedings of the expert consultation on urban horticulture in Southern Africa. Stellenbosch, South Africa.

REFERENCES

Agbayani A.L.P., Holmer R.J., Potutan G.E. and Schnitzler W.H. 2001. Quality and quantity requirements for vegetables by private households, vendors and institutional users in a Philippine urban setting. Urban Agr Mag 5: 56 – 57, Leusden.

Arias G. 2000. Análisis de las políticas publicas en la agricultura urbana caso Texcoco, México. Dirección de Desarrollo Rural, Ayuntamiento de Texcoco, México, 20p. Programa de Gestão Urbana para a América Latina e o Caribe – PGU-ALC (CNUAH-HABITAT/PNUD) http://www.ipes.org/au /estudioc/texcoco.pdf (last accessed: January 2006).

Boncodin R., Prain G. and Campilan D. 2000. Dynamics in tropical homegardens. Urban Agr Mag 1: 19 – 20, Leusden.

Chambers R. 1989. Editorial: introduction: vulnerability, coping, and policy. IDS Bull 20(2): 1 – 7.

Christanty L. 1990. Home gardens in tropical Asia with special reference to Indonesia. In: Landauer K. and Brazil M. (eds), 1990. Tropical home gardens, pp. 9 – 20. United Nations University Press, Tokyo.

Cruz M.C. and Medina R.S. (eds). 2003. Agriculture in the city. IDRC, Ottawa, 244p.

Drescher A.W. 1996. Management strategies in African homegardens and the need for new extension approaches. In: Heidhues F. and Fadani A. (eds), Food security and innovations: Successes and lessons learned, pp 231 – 246. Peter Lang, Frankfurt.

Drescher A.W. 1998. Hausgärten in Afrikanischen Räumen – Bewirtschaftung nachhaltiger Produktionssysteme und Strategien der Ernährungssicherung in Sambia und Simbabwe. Sozioökonomische Prozesse in Asien und Afrika, 4. Centaurus, Pfaffenweiler, 290p.

Drescher A.W. 2001. The integration of urban agriculture into urban planning – An analysis of the current status and constraints. In: Annotated bibliography on urban agriculture, pp 343 – 357. ETC Urban Agriculture Programme and Swedish International development Agency (SIDA), Leusden. http://www.ruaf.org/bibliography/annotated/014.pdf (last accessed: January 2006).

Drescher A.W. and Iaquinta D.L. 2003. Urbanization – linking development across the changing landscape. Economic and social department publication (ESAC), FAO, Rome, 121p. http://www.fao.org/fcit/docs/sofa_01.pdf (02.pdf – 03.pdf) (last accessed: January 2006).

Drescher A.W., Hagmann J. and Chuma E. 1999. Home gardens - a neglected potential for food security and sustainable land management in the communal lands of Zimbabwe. In: Der Tropenlandwirt, 2/1999, pp 163–180. Kassel-Witzenhausen.

Food and Agriculture Organization (FAO) 1998. Food security and community nutrition, No. 22, Food and Agriculture Organization of the UN, Rome, 72p.

Food and Agriculture Organization (FAO) 2001. FAO warns of increasing malnutrition among urban poor. FAO Press release 01/36. 1p. http://www.fao.org/WAICENT/OIS/PRESS_NE/PRESSENG /2001/pren0136.htm (last accessed: January 2006).

Food and Agriculture Organization (FAO) 2002. Declaration of the World Food Summit: five years later. In: Report of the World Food Summit: five years later. FAO, Rome, http://www.fao.org/DOCREP/MEETING/005/Y7106E/Y7106E09.htm (last accessed: January 2006).

Frankenberger T.R. and McCaston M.K. 1998. The household livelihood security concept. In: FAO 1998. Food Nutr Agr 22: 30-35 http://www.fao.org/docrep/X0051T/X0051T00.htm (last accessed: January 2006).

Guanzon Y.B. and Holmer R.J. 2003. Basic cultural management practices for vegetable production in urban areas of the Philippines. Urban Agr Mag 10: 14 – 15, Leusden.

Hetterschijt T. 2004. Our daily realities: Urban organic homegardens in Lima, Peru. Urban Agr Mag (Gender and Urban Agriculture, May 2005) 12: 10-11, Leusden.

Holmer R.J., Clavejo M.T., Dongus S. and Drescher A.W. 2003. Allotment gardens for Philippine cities. Urban Agr Mag 11: 29 – 31, Leusden.

Hoogerbrugge I. and Fresco L.O. 1993. Homegarden systems: Agricultural characteristics and challenges. Gatekeeper, No. 39, International Institute for Environment and Development, London, 23p.

Iaquinta D.L. and Drescher A.W. 2000. Defining periurban: towards guidelines for understanding rural-urban linkages and their connection to institutional contexts, pp 8 – 27. Land Reform 2000/2, FAO, Rome.

Iaquinta D.L. and Drescher A.W. 2001. More than the spatial fringe: An application of the periurban typology to planning and management of natural resources in the periurban, DPU International Conference, "Rural-urban encounters: Managing the environment of the periurban interface", College of London, 9 – 10 November 2001. http://www.ucl.ac.uk/dpu/pui/events/EPM_conf_ abstracts.htm# DefiningthePeri-Urban (last accessed: January 2006).

Iaquinta D.L. and Drescher A.W. 2002. Food security in cities – A new challenge to development. In: Brebbia C.A., Matrin-Duque J.F., and Wadhwa L.C. (eds), The sustainable city II – Urban regeneration and sustainability. Advances in Architecture, pp 983 – 994. Wessex Institute of Technology, WIT Press, Wessex.

Iaquinta D.L. and Drescher A.W. 2005. Defining periurban: A framework for transportation planning in India, periurban workshop, Leeds (April 11 – 12, 2005). https://www.periurban.org/pub/home/events/0504_leeds/documents/PRESENTATION-DefiningPeriurban-Iaquinta.pdf (last accessed: January 2006).

Innenministerium B-W. 2004. Climate booklet for urban development references for zoning and planning. Amt für Umweltschutz, http://www.staedtebauliche-klimafibel.de/Climate_Booklet/index-2.htm (last accessed: January 2006).

Jacobi P., Drescher A.W. and Amend J. 2000. Urban agriculture: Justification and planning guidelines. GTZ, Eschborn, 70p, http://www.cityfarmer.org/uajustification.html (last accessed: January 2006).

Jarlöv L. 2000. Urban Agriculture in South Africa. In: Hoffmann H. and Mathey K. (eds), Urban agriculture and horticulture: the linkage with urban planning. International Symposium (July 2000), Berlin (on cd-rom). http://www.ruaf.org/conference/info_market/econf_papers/14jarlov.doc (last accessed: January 2006).

Kasch G. 2001. Deutsches Kleingärtnermuseum in Leipzig: Deutschlands Kleingärtner vom 19. zum 21. Jahrhundert. Band 4, Sächsische Landesstelle für Museumswesen, Chemnitz, 128p.

Kumar B.M. and Nair P.K.R. 2004. The enigma of tropical homegardens. Agroforest Syst 61/62: 135 – 152.

Landeshauptstadt D. 1998. Umweltbericht. Stadtklima von Dresden. Umweltamt, 39p. http://www. dresden.de/pdf /infoblaetter/umweltbericht_text.pdf (last accessed: January 2006).

Landon-Lane C. 2004. Livelihoods grow in gardens: Diversifying rural incomes through homegardens. FAO Diversification booklet 2. Agricultural Support Systems Division, FAO, Rome. 58p.

MacNair E. 2002. The garden city handbook: How to create and protect community gardens in Greater Victoria. Polis Project on Ecological Governance. University of Victoria, Victoria BC, 34p. http:// www.polisproject.org/polis2/PDFs/the%20garden%20city%20handbook.pdf (last accessed: January 2006).

Mougeot L.J.A. (ed.). 2005. AGROPOLIS: The social, political, and environmental dimensions of urban agriculture. CRDI, Earthscan. 308p.

Pinderhughes R. 2004. Alternative urban futures: Planning for sustainable development in cities throughout the world. Rowman & Littlefield Pub Inc. Lanham, MD, 271p.

Prosterman R. and Mitchell R. 2002. Concept for land reform on Java. Paper presented at the seminar: Rethinking land reform in Indonesia, Jakarta (8 May 2002). On file with the Rural Development Institute, Seattle. http://www.rdiland.org/PDF/RDI_LandReformOnJava.pdf (last accessed: February 2006).

Ranasinghe T.T. 2005. Family business gardens: Agricultural options in remodelling and modernising tsunami devastated townships in Sri Lanka. Cityfarmer, 9p. www.cityfarmer.org/subsouthasia.html (last accessed: 27 January 2006).

Swift J. 1989. Why are rural people vulnerable to famine? In: Chambers R. (ed.), IDS Bull 20(2): 8 – 15.

United Nations Centre for Human Settlements (UNCHS) 2001. The state of the world's cities report 2001.United Nations Centre for Human Settlements (UNCHS), Nairobi, 126p.

Vasey D.E. 1985. Household gardens and their niche in Port Moresby, Papua New Guinea. Food Nutr. Bull 7(3): 37 – 52.

Vélez-Guerra A. 2004. Multiple means of access to land for urban agriculture: A case study of farmers' groups in Bamako, Mali. Cities feeding people report series, December 2004, International Development Research Centre (IDRC), Ottawa, 88p.

Yamada M. and Osaqui H.M.L. 2006. The role of homegarden for agroforestry development: lessons from a Japanese-Brazilian settlement in the Amazon. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 299 – 316. Springer Science, Dordrecht.

Zalilah M.S. and Khor G.L. 2004. Indicators and nutritional outcomes of household food insecurity among a sample of rural Malaysian women. Pakistan J Nutr 3: 50 – 55.

CHAPTER 19

ARE TROPICAL HOMEGARDENS SUSTAINABLE? SOME EVIDENCE FROM CENTRAL SULAWESI, INDONESIA

K. KEHLENBECK AND B.L. MAASS*

*Institute for Crop and Animal Production in the Tropics, Georg-August-University Göttingen, Grisebachstr. 6, D-37077 Göttingen, Germany; *E-mail: <bmaass@gwdg.de>*

Keywords: Biodiversity, *In situ* conservation, Soil fertility, Sustainability indicators, Vegetation dynamics.

Abstract. Homegardens are regarded as sustainable agricultural production systems, although support for this statement by quantitative data has been rare. Out of the suggested indicators/descriptors for assessing sustainability, plant diversity has been frequently studied. However, species diversity is not static: it varies with time and according to ecological and socioeconomic factors and/or characteristics of the gardens and gardeners. In order to evaluate sustainability of the homegarden system, we assessed soil fertility parameters and changes in diversity of useful plants over time during 2001 – 2004 in 30 homegardens from three villages adjacent to the Lore Lindu National Park in Central Sulawesi, Indonesia. Soil carbon (C) and nitrogen (N) contents decreased over time. In large gardens with different production zones, soil of vegetable zones contained less C and N than that of cacao (*Theobroma cacao*) zones. Richness of useful plant species was high and increased over time, from 149 species in 2001 to 168 in 2003. Species composition of homegardens from one village, mainly inhabited by migrants, contrasted strongly with those from the other two, inhabited by native farmers. Diversity of useful plants was lower in the migrant village, where soil fertility was low, too. Plant diversity appeared to be influenced to varying extent by a combination of factors such as garden size/age, soil fertility, ethnicity and age of gardener, and market access. The surveyed homegardens did not seem to be managed appropriately to ensure sustainability in terms of soil fertility although they had a high diversity of useful plants.

1. INTRODUCTION

Tropical homegardens are generally regarded as sustainable production systems (Christanty, 1990; Landauer and Brazil, 1990; Soemarwoto and Conway, 1991;

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 339–354.

Torquebiau, 1992; Abdoellah et al., 2001; Kumar and Nair, 2004). However, quantitative support for this statement is mostly lacking, particularly because of the difficulties in measuring sustainability (Kumar and Nair, 2004). Therefore, researchers rely on indirect evidences using certain sustainability descriptors and/or indicators (Torquebiau, 1992; Huxley, 1999).

Among the available indicators, perhaps the criterion most used in homegarden research is biodiversity, particularly plant species diversity. The wide spectrum of useful plants creates a multilayered vegetation structure in homegardens, which is responsible for many benefits and advantages of the system. This diversity results in favorable microclimate, reduced risk of pests and diseases, efficient use of resources, year-round availability of products, and soil fertility maintenance. Thus, plant diversity is considered as contributing substantially to the sustainability of the system (Soemarwoto and Conway, 1991; Torquebiau, 1992).

Because of their diversity, homegardens are also regarded as an ideal production system for *in situ* conservation of plant genetic resources (Watson and Eyzaguirre, 2002), crucial for long-term sustainability. However, crop diversity is influenced by different factors such as size and age of homegardens or age of gardeners (Abdoellah et al., 2001; Gutiérrez et al., 2004). Besides, environmental and socioeconomic characteristics are known to influence homegarden diversity (Michon and Mary, 1994; Wezel and Bender, 2003; Gutiérrez et al., 2004). Nevertheless, the suitability of biodiversity as a sustainability indicator needs to be critically examined because there is no threshold value for an ideal number of species in a sustainable system. In addition, diversity seems to be highly variable over time, and the homegarden research so far has neglected to quantify such changes.

Another sustainability indicator generally accepted is soil fertility (Torquebiau, 1992; Huxley, 1999; Kumar and Nair, 2004). In homegardens, soil fertility is said to be maintained due to the closed nutrient cycling and low nutrient-export through harvested products (Gajaseni and Gajaseni, 1999; Kumar and Nair, 2004). Dense layers of litter and undergrowth are supposed to prevent or at least reduce soil erosion in homegardens (Karyono, 1990; Soemarwoto and Conway, 1991). Investigation of soil fertility parameters is common in homegarden research (Jensen, 1993; Gajaseni and Gajaseni, 1999), whereas soil erosion has rarely been assessed (Torquebiau, 1992). Usually, statements on sustainable soil fertility management in homegardens are supported only by a single 'snapshot' of the status quo without any further consideration on soil fertility variation over space and time. The role of different management practices leading to this variation in the long-term is not sufficiently investigated.

In association with the multidisciplinary German-Indonesian collaborative research program STORMA (Stability of Rainforest Margins in Indonesia, SFB 552), this study aimed at assessing the sustainability of selected homegardens on the island of Sulawesi with the help of selected sustainability indicators. A first assessment from a comprehensive dataset is presented here, focusing on aspects of:

- Stability/dynamics in diversity of useful plants over time
- Changes in soil fertility over time

- Specific influences of selected factors on diversity of useful plants

The ecological indicators 'diversity of useful plants' and 'soil fertility' were chosen because data from a previous study of the same homegardens were available (Kehlenbeck and Maass, 2004) and both indicators are essential for assured productivity of the system. Besides ecological indicators, social and economic indicators (e.g., labor requirement, cash input and biophysical output) as suggested by Torquebiau (1992) and Kumar and Nair (2004) have been assessed under the overall project, but those results will be presented elsewhere.

2. MATERIALS AND METHODS

2.1. Study area

The study was conducted from March to November 2001 and from June 2003 to June 2004 in the Napu Valley (1°23' to 37'S, 120°18' to 20'E), located on the eastern margins of the Lore Lindu National Park in Central Sulawesi (Indonesia), about 100 km south of the city of Palu. Elevation is around 1100 m above sea level; annual precipitation is about 2000 mm with a mean temperature of 21°C. Natural vegetation is classified as lower montane rainforest (Whitten et al., 1987); soils are mostly Cambisols (FAO; USDA: Tropepts, Inceptisols) and Fluvisols (Fluvents, Entisols).

The initially low human population density has been increasing in the region, especially since the 1980s, due to migration. Most inhabitants are farmers, and off-farm employment opportunities are scarce. Agricultural production is mainly based on paddy rice (*Oryza sativa*) production for subsistence, agroforestry with cacao (*Theobroma cacao*) and coffee (*Coffea* spp.) as cash crops, and rain-fed annual crops (Kehlenbeck and Maass, 2004). Large areas of the Napu Valley are under fallow or degraded grasslands.

Table 1. *Characteristics of three villages studied in the Napu Valley, Central Sulawesi, Indonesia.*

Parameters	*Wuasa*	*Rompo*	*Siliwanga*
Year of foundation	1892	1915	1992
Inhabitants (no.)	2600 (2003)	400 (2004)	600 (2004)
Ethnicity	mixed	>75% indigenous	>75% migrants
Distance to paved road	0 km	5 km	0 km
Market access	good	poor	medium

Source: Zeller et al. (2001) and Kehlenbeck (unpublished data).

For this research, three villages, which differed in their market access and origin of inhabitants, were chosen (Table 1). Wuasa is the administrative center of the Napu Valley with a junior and senior high school, a small hospital, many shops and offices as well as a market place. Rompo is a small village surrounded by forest, accessible by a dirt road. Siliwanga was founded only recently for settling migrant families, mostly from Bali, in the context of the transmigration program of the Indonesian government (Mayor of Siliwanga, pers. comm., 2001). For convenience, the three villages were labeled as ‘market village’ (Wuasa), ‘forest village’ (Rompo), and ‘migrant village’ (Siliwanga).

2.2. Data collection

Ten households with homegardens were randomly selected from each village. Information about local knowledge and management of the same homegardens was gathered in 2001 and 2003/2004, except for one garden in the migrant village that was abandoned in 2002. Gardeners were individually interviewed using an unstructured questionnaire with questions on age and functions of the homegarden, inputs and outputs, and the use of homegarden products, among others. Data concerning household characteristics, such as age, formal education, ethnic group, or occupation of the household members were also gathered through interviews, partly within larger surveys of the STORMA project.

Homegarden size was measured, excluding the area occupied by the house. Complete inventories were carried out in 2001 (July – October) and 2003 (July – August) to assess number of species and abundance of crops and ornamentals. In this study, the term ‘crops’ is applied to all useful plant species, including planted and spontaneously occurring except the ornamentals. Presence of weeds, defined as undesired plants from the gardener’s view, was documented but not quantified. Plants were recorded with local and/or scientific names. Crop species were classified into different use categories (Kehlenbeck and Maass, 2004).

In 2001, 20 soil samples per garden were randomly collected from 0 – 15 cm depth and mixed, except for four large gardens, where soil was sampled separately according to production zone (vegetables, coffee/cacao, or fruit trees). In 2003/2004, five soil samples per garden were randomly collected at 0 – 15 cm depth and mixed, if the garden was small (< 350 m^2) or planted uniformly. In large gardens with distinct production zones, five samples per zone were collected and mixed. Due to these different sampling strategies, soil fertility change over time was analyzed only in a subgroup of homegardens with comparable soil sampling in both years, i.e., gardens with one mixed vegetation zone only ($n = 10$) as well as large gardens ($n = 4$) already sampled by zones in 2001. Total C and N were quantified by C/N-Autoanalyser and pH with an electrode (soil: water ratio, 1:2.5). Bulk density was determined in 2003 only by assessing the dry weight of soil samples with known field volume.

2.3. Data analysis

Species density (no. of spp./100 m^2), Shannon index (H'), and Pielou evenness index ($E = H'/H_{max}$) were calculated for every garden (Magurran, 1988). To compare floristic similarity between the three villages, Sørensen’s coefficient was computed (Magurran, 1988). Data were analyzed using the statistical package SPSS 11.0.

Differences between means were determined by Mann-Whitney *U*-Test or Kruskal Wallis *H*-Test. Changes over time as well as spatial differences of soil fertility parameters between production zones within one garden were analyzed as 'paired samples' using the Wilcoxon-test. Influence of relevant factors on crop diversity was determined by correlation analysis (Spearman).

3. RESULTS

In 2003/2004, size of the homegardens ranged from 240 to 2400 m^2, and they had been established 4 to 41 years ago. Homegardens in the migrant village were significantly younger than those in the market village, and were managed by younger families (Table 2). In all three villages, homegarden size, farm size, and homegarden proportion in relation to the overall farm size were highly variable. Compared to 2001 (Kehlenbeck and Maass, 2004), farm size increased significantly only in the migrant village due to purchase or clearing of additional land. Therefore, the proportion of the homegarden in relation to overall farm size as well as its importance for staple food production recently decreased in the migrant village.

Table 2. *Characteristics of households and homegardens surveyed in three villages of the Napu Valley, Central Sulawesi, Indonesia, 2003.*

Parameters	*Market village (Wuasa)*		*Forest village (Rompo)*		*Migrant village (Siliwanga)*	
	Median	*Range*	*Median*	*Range*	*Median*	*Range*
Age of household head (years)	55^{a}	34 – 69	50^{ab}	25 – 89	35^{b}	30 – 50
Gardener's age (years)	48^{a}	32 – 67	40^{a}	20 – 60	34^{a}	28 – 50
Household members (no.)	8^{a}	3 – 14	5^{a}	1– 11	4^{a}	3 – 6
Farm size (ha)	2.6^{a}	0.9 – 11.1	5.9^{a}	1.7 – 11.5	3.1^{a}	1.5 – 5.5
Homegarden size (m^2)	720^{a}	236 – 1134	610^{a}	287 – 1450	820^{a}	471 – 2383
Homegarden size/ farm size (%)	2.2^{a}	0.5 – 10.0	1.2^{a}	0.5 – 4.3	2.3^{a}	1.2 – 11.9
Age of homegarden (years)	28^{a}	14 – 37	16^{ab}	4 – 41	10^{b}	6 – 11

Medians in a row followed by different superscripts are significantly different at $p \leq 0.05$.

3.1. Crop diversity and its changes

Crop species richness was high and increased markedly over time both per village and per garden (Fig. 1). In the three villages, a combined total of 149 and 168 crop species were identified in 2001 and 2003 respectively. Distribution of crops into different use categories was comparable in different sampling years (Kehlenbeck and Maass, 2004). Out of the 168 crop species grown in homegardens, about 35 were wild species (mainly used as fuelwood/timber or medicine) and about 44 were classified as underutilized species (mainly used as vegetable). In addition to the 168 crop species, 99 ornamental and 62 weed species were found in the homegardens surveyed in 2003.

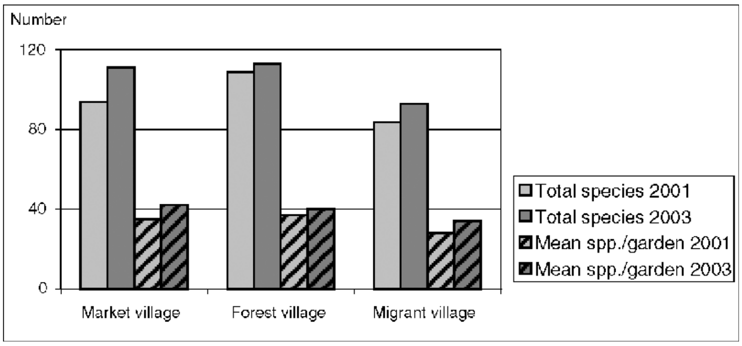

Figure 1. *Changes of total and mean crop species richness in homegardens per village, studied in the Napu Valley, Central Sulawesi, Indonesia, 2001 (n = 30) and 2003 (n = 29).*

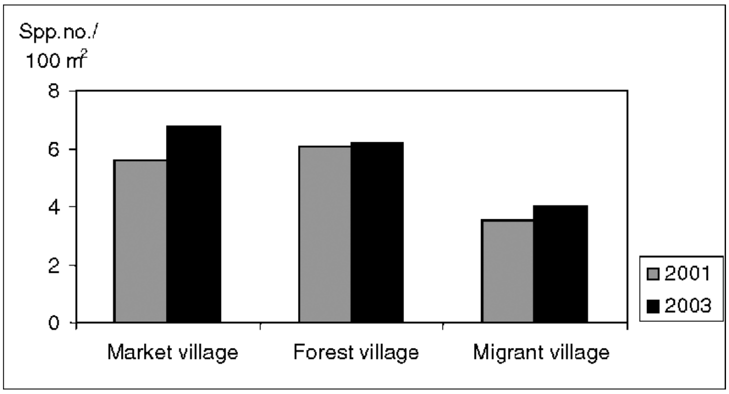

Figure 2. *Changes of mean species density in homegardens of three villages studied in the Napu Valley, Central Sulawesi, Indonesia, 2001 and 2003.*

Mean species density increased significantly over time, particularly in the market village (Fig. 2). However, in the migrant village, species density continued to be significantly lower than that in the forest village in 2001 or the market village in 2003. Changes in Shannon diversity and Pielou evenness indices were not so clear apart from the migrant village, where both indices were significantly higher in 2003 than in 2001 (Fig. 3). In the market village, Shannon and Pielou indices showed a slight tendency to decrease because in 2003 some gardeners started to grow spring onion (*Allium fistulosum*) for sale in relatively large plots, which dramatically reduced the indices. For example, in one homegarden an area of about 190 m^2 out of 865 m^2 was planted with a mixture of vegetables and spices in 2001, but only spring onion during 2003. This resulted in a decrease of Shannon index from 2.1 to 1.2 and Pielou index from 0.59 to 0.31. However, the total number of crop species increased in this particular garden from 35 to 47 during the same period.

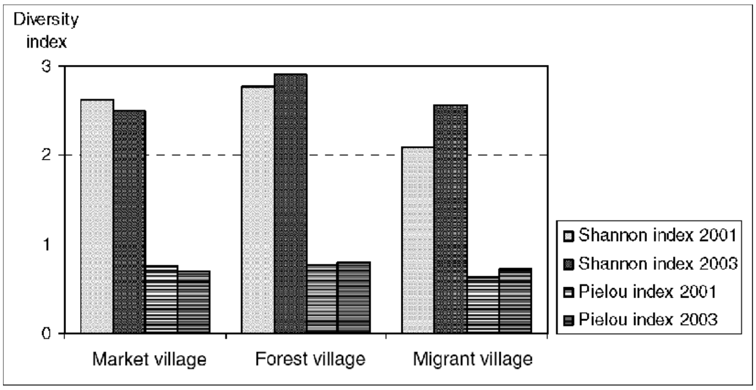

Figure 3. *Changes of mean Shannon diversity and mean Pielou evenness indices in homegardens of three villages studied in the Napu Valley, Central Sulawesi, Indonesia, 2001 and 2003.*

Crop species composition was clearly different among the three villages in both years. Sørensen's coefficients showed a higher similarity between the market and the forest villages (0.71) than between these two and the migrant village (market vs. migrant village: 0.63; forest vs. migrant village: 0.58). Compared to 2001 (Kehlenbeck and Maass, 2004), Sørensen's coefficient decreased slightly in all cases. The species common to all three villages remained rather stable over time, while obvious changes occurred in those crop species unique for one village and, hence, not found in the other two. Particularly in the market village, 22 unique crops were recorded in 2003 instead of 15 in 2001.

3.2. Soil properties

In large gardens with different production zones, soil fertility was obviously different among these zones. Across all 12 gardens where distinct vegetable and cacao zones existed, soil of the vegetable zone contained significantly less N and C than soil of the adjacent cacao zone (Table 3). Soil pH did not differ among vegetable and cacao production zones. Bulk density was significantly higher in vegetable zones than in adjacent cacao zones.

Because of these large differences in soil fertility between production zones within one single homegarden, it did not appear meaningful to compare mean values of the homegardens investigated in the three villages. Instead, soil fertility of cacao zones only was compared among the villages as this particular zone existed in most of the homegardens (n = 16), apart from the very small ones. In five homegardens, the cacao zone was even the only obvious production zone.

Table 3. *Properties of homegarden topsoil (0–15 cm) from different production zones in three villages of the Napu Valley, Central Sulawesi, Indonesia, 2003/2004.*

Soil attributes	*Vegetable zone*		*Cacao zone*	
	Mean	*Range*	*Mean*	*Range*
C_{total} (%)	1.64[b]	0.93 – 2.96	2.31[a]	1.40 – 3.42
N_{total} (%)	0.13[b]	0.06 – 0.21	0.18[a]	0.10 – 0.27
pH (H_2O)	5.87[a]	4.65 – 6.88	5.62[a]	5.24 – 5.83
Bulk density (g/cm^3)	1.17[a]	0.90 – 1.48	1.03[b]	0.77 – 1.17

Means in a row followed by different superscripts are significantly different at $p \leq 0.05$.

Table 4. *Properties of topsoil (0–15 cm) from cacao production zones of 21 homegardens in three villages of the Napu Valley, Central Sulawesi, Indonesia, 2003/2004.*

Soil attributes	*Market village (Wuasa; n = 8)*		*Forest village (Rompo; n = 7)*		*Migrant village (Siliwanga; n = 6)*	
	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*
C_{total} (%)	2.02[a]	1.43 – 2.95	2.31[a]	1.40 – 3.21	2.83[a]	2.32 – 3.42
N_{total} (%)	0.17[a]	0.12 – 0.21	0.19[a]	0.10 – 0.27	0.19[a]	0.15 – 0.24
pH (H_2O)	5.65[a]	5.24 – 5.84	5.48[a]	5.16 – 5.80	5.63[a]	5.21 – 5.85
Bulk density (g/cm^3)	1.10[ab]	0.92 – 1.24	0.98[b]	0.77 – 1.16	1.16[a]	1.08 – 1.24

Means in a row followed by different superscripts are significantly different at $p \leq 0.05$.

Table 5. *Changes of soil fertility parameters of topsoil (0–15 cm) from 14 homegardens in three villages of the Napu Valley, Central Sulawesi, Indonesia, 2001 and 2003.*

Soil attributes	*2001*		*2003*	
	Mean	*Range*	*Mean*	*Range*
C_{total} (%)	2.35[a]	1.20 – 3.58	2.12[b]	0.92 – 3.21
N_{total} (%)	0.19[a]	0.11 – 0.29	0.16[b]	0.07 – 0.27
pH (H_2O)	5.72[a]	4.70 – 6.50	5.75[a]	4.88 – 6.75

Means in a row followed by different superscripts are significantly different at $p \leq 0.05$.

Soil C and N contents of cacao production zones were highly variable in all villages, although these values were slightly lower in the market village (Table 4). Soil pH was relatively similar in all villages. Only soil bulk density was significantly higher in the migrant village and lower in the forest village. When comparing soil fertility over time, C and N contents decreased significantly from 2001 to 2003, whereas soil pH did not change (Table 5).

3.3. Influence of selected factors on crop diversity

To detect factors that possibly influence crop diversity, correlations between crop diversity parameters and several variables describing characteristics of homegardens (e.g., age, size, soil fertility parameters), the gardener (e.g., age, education), or socioeconomics (e.g., wealth status of household, size of paddy rice fields, market access) were analyzed (Table 6). Socioeconomic characteristics of the gardeners or households did not play an important role in determining crop diversity.

Table 6. *Spearman correlation coefficients between crop diversity parameters and different characteristics of homegardens, gardeners, and households in three villages of the Napu Valley, Central Sulawesi, Indonesia, 2001 and 2003.*

Parameters	*Species richness*		*Species density*		*Shannon index*		*Pielou index*	
	2001	*2003*	*2001*	*2003*	*2001*	*2003*	*2001*	*2003*
Garden age	0.45*	0.41*	ns	ns	ns	ns	ns	ns
Garden size	0.45*	0.52**	–0.83***	–0.81***	ns	ns	ns	ns
Soil pH value	ns	–0.40*	0.43*	0.40*	ns	ns	ns	ns
Soil N content	ns	ns	–0.50**	–0.38*	ns	ns	ns	ns
Soil C content	ns	ns	–0.58**	ns	–0.43*	ns	–0.42*	ns
Gardener's age	0.47**	0.49**	ns	ns	0.53**	ns	0.41*	ns
Gardener's education	ns	ns	ns	ns	ns	ns	ns	ns
HH members (no.)	ns	ns	ns	ns	ns	ns	ns	ns
Wealth status of HH	ns	ns	ns	ns	ns	ns	ns	ns
Size of HH's rice fields	ns	ns	ns	ns	ns	ns	ns	ns
Garden size/farm size	ns	ns	–0.68***	–0.43*	ns	ns	–0.47*	ns
Market access	ns	ns	ns	ns	ns	ns	ns	ns

*: $p \leq 0.05$; **: $p \leq 0.01$; ***: $p \leq 0.001$; ns = not significant; HH = household.

Crop diversity was mainly influenced by the gardener's age and by variables describing homegarden characteristics such as size, age, or soil fertility parameters. In large and old homegardens, higher crop species richness could be expected than in small and young homegardens. Furthermore, the older the gardener, the higher was the species richness, diversity, and evenness. However, the influence of all variables was rather weak, particularly of soil parameters. Within the tested socioeconomic variables, only the ratio of homegarden-size to farm-size showed a weak but significant negative influence on evenness index. Ethnicity of the gardener probably was linked with crop diversity because mean species richness and density were significantly higher in gardens of local families than that of the migrants. No differences in crop diversity were observed by grouping gardeners into male and female subgroups. However, direct influence of these two nominal variables on crop diversity could not be assessed by the correlation analysis.

4. DISCUSSION

4.1. Changes of crop diversity

In 2001 and 2003 total crop species richness as well as the mean per garden were rather high, but comparable to the data reported from other regions in Indonesia or even from the tropics as a whole (Kumar and Nair, 2004). Crop diversity in the homegardens surveyed was not only maintained, but even increased over time. Seasonal effects could not be made responsible for this because in both years species inventories were carried out in the same season. Partly, the increase in diversity can be explained by interventions of development projects. For instance, in all villages, seedlings of mandarin trees (*Citrus reticulata*) were provided to most gardeners in 2002/2003. Another project promoted the cultivation of medicinal plants in homegardens at the same time. As a result, the Mayor of the market village pushed gardeners to grow these recommended plants. This led to an increase of medicinal species from a total of 16 in 2001 to 21 in 2003 and a mean per garden from 3.4 to 5.4, respectively. However, in the other two villages the impact of these development projects on homegarden diversity seemed to be rather low. Additionally, research activities in 2001 (Kehlenbeck and Maass, 2004) have possibly stimulated interest of the gardeners in crop diversity. As a result, gardeners might have revived the networks of seed and plant exchange within their neighborhoods, and were more open for experimental cultivation of new crops.

At the same time, gardeners stopped to grow some crop species (a mean of six species per garden). According to the gardeners, many of these species died during an unusual dry period in 2002. Another reason for decrease of diversity in homegardens could be that production became more market-oriented, as described by Soemarwoto and Conway (1991). However, in this study, the market-oriented production of spring onions in the market village resulted only in a slight decrease of Shannon and evenness indices but not richness or density of crop species. Besides, in 2004 it was observed that the gardeners already stopped growing spring onions for sale due to a decline in prices and problems with diseases.

It can, therefore, be concluded that crop diversity in homegardens is very dynamic and every species inventory reflects only the diversity at the very instant of assessment. Thus, the temporal dynamics observed in this study might not reflect long-term trends. Nevertheless, the suitability of homegardens for *in situ* conservation of plant genetic resources needs to be critically revised based on these results. For this purpose, specific target groups of crops or even key species instead of the overall diversity should be emphasized (e.g., Watson and Eyzaguirre, 2002). Furthermore, it is crucial to make gardeners active stakeholders of such conservation efforts by sharing both responsibility and benefits. Finally, crop diversity should not be used as the only sustainability indicator of this system because of its changes with time.

4.2. Soil fertility

According to Landon (1991), soil of vegetable and cacao zones surveyed had low to very low mean C and N contents, whereas mean pH values were classified as medium. Therefore, the current situation with limited N available in the soil most likely restricts the level of production, particularly for N-demanding vegetables. Considering the significant decrease in soil C and N contents over time, crop production may become more constrained in the near future, particularly in the market and forest villages, where C and N contents were already very low in many garden soils. Insufficient soil fertility management by the gardeners caused this alarming situation. For example, only about 30% of the gardeners used farmyard manure as a fertilizer, although it was available to all of them. Many gardeners removed weeds including their roots for burning or depositing in garbage pits instead of using them for compost preparation. Use of compost or mulch was virtually unknown, and industrial N fertilizer was available to only 15% of the gardeners, an overall situation that has not changed since 2001 (Kehlenbeck and Maass, 2004). Deterioration was accelerated also by the habit of gardeners to remove the litter layer by daily sweeping and regular burning. Typical reasons given by the gardeners for this practice were keeping away snakes and insects from the house. Sweeping and total weeding was carried out in all front gardens, in most vegetable and ornamental zones and in some cacao or fruit tree zones, which led to severe soil erosion (Fig. 4).

In general, soil fertility is said to be maintained in homegardens in the long-term (Gajaseni and Gajaseni, 1999; Kumar and Nair, 2004). Only few reports (Soemarwoto, 1987; Soemarwoto and Conway, 1991; Hvoslef, 1994; Benjamin et al., 2001) stated problems of soil deterioration and erosion due to insufficient management practices similar to those identified here. Soil management in the present study, however, needs also to be seen in the context of changing traditional land use in the Napu Valley. The dominant shifting cultivation was replaced by permanent agriculture only about 10 to 30 years ago (Burkhard, 2002). Therefore, indigenous as well as newly arrived migrant farmers may not be familiar with appropriate sustainable land management practices. Negative environmental consequences have similarly been documented for other cases of resettlement, e.g., in Ethiopia (Wood, 1993) and Tanzania (Charnley, 1997).

Spread of household waste materials in homegardens might cause a new problem affecting long-term soil fertility and, consequently, system productivity. This has never been mentioned in the homegarden literature. Due to lack of opportunities for waste disposal, many gardeners in the research area spread all garbage on the soil of the backyard, including non-biodegradable items such as glass and plastic bottles, tins, plastic bags, and old batteries. Mixed with organic wastes from the kitchen, this garbage formed the 'litter' layer in many backyard gardens. This practice will probably cause soil contamination; the spread of biodegradable waste on soil will, however, contribute to better nutrient cycling and reduced soil erosion.

Figure 4. *Example of soil erosion in the front yard of a homegarden in the forest village Rompo, Napu Valley, Central Sulawesi, Indonesia, 2004. The broken line indicates soil surface during planting of the ornamentals along the fence; the dotted line shows the present surface.*

To achieve sustainable soil fertility management in the study region, the existing extension service should not exclusively focus on paddy rice production but also on agroforestry systems (including homegardens) with their great significance for cash income generation (Maertens et al., 2002). Advantages of using compost, mulch, and farmyard manure should be explained. Growing N_2-fixing cover crops ought to be promoted, not only in the homegardens, but also in other cropping systems. Besides, villagers should be enlightened about disadvantages and risks of soil and water contamination in order to preserve the resources on which they rely.

4.3. Factors influencing crop diversity

Within the major factors influencing crop diversity, garden size is one of the frequently analyzed. Among others, Abdoellah et al. (2001) and Gutiérrez et al. (2004) reported a positive relationship between garden size and crop species richness. Results from the present study (Table 6) showed a slightly positive, but non-linear relationship. In very large gardens, crop species richness tended to reach a plateau. On the other hand, the larger the garden the lower was crop species density because of more uniform planting patterns in very large gardens. A positive influence of garden age on species richness was also stated by Gutiérrez et al. (2004). In this study, however, garden age had a highly significant positive correlation with gardener's age because, generally, young families establish a new homegarden, starting with a rather small set of crop species.

Besides age and size of homegarden, soil fertility is another factor describing garden features, but its influence on crop diversity has not yet been studied in detail. Hodel et al. (1999) assumed an influence of soil factors on diversity without quantifying this. In forest gardens, Kaya et al. (2002) reported lower species diversity on marginal soils compared to soils that are more fertile. Many crop species, particularly vegetables and spices, do not give adequate yield under unfavorable soil conditions. Therefore, gardeners stop cultivating these species while switching to a reduced set of crops that can cope with low soil fertility. In the migrant village Siliwanga with its rather poor soil conditions, for example, acid-tolerant species such as tea (*Camellia sinensis*), cassava (*Manihot esculenta*) and cashew (*Anacardium occidentale*) were found in many homegardens, whereas vegetable cultivation was rare (Kehlenbeck and Maass, 2004). However, influence of soil fertility parameters on crop diversity in this study must be seen in the context of the significant correlations between garden size and soil pH (negative) as well as between garden size and soil C and N contents (positive) that probably biased the results of analysis (see Table 6).

Gardener's age can influence crop diversity positively, possibly because, over the years, gardeners try to cultivate new crops while they continue to plant well-tried species (Gutiérrez et al., 2004). Besides, older gardeners often have more time for homegardening and are supported by their grown-up children. A higher time-allocation to homegardening leads to a higher diversity of useful plants (Hodel et al., 1999; Gutiérrez et al., 2004). In the present study, however, the positive relationship between gardener's age and plant diversity was rather weak.

Within gardener's characteristics, ethnicity also may be a factor explaining variation in crop diversity (Soemarwoto and Conway, 1991; Hodel et al., 1999). Contrary to the findings of Soemarwoto and Conway (1991), crop diversity in the present study was lower in homegardens of migrants as compared to locals. Admittedly, migrant gardeners brought various useful species from their home regions. Due to the unfavorable soil and climate conditions of the lands assigned to them, a large part of these plants did not establish. Another reason for the low crop diversity in the migrant village might be the socioeconomic status of the gardeners. After arrival, young migrant families focused strongly on paddy rice production, with a resulting shortage of labor for homegarden management. Furthermore, field crop failures and poor access to suitable agricultural land might have led to cultivation of additional staple crops in the migrants' homegardens. The result of correlation analysis that a high portion of homegarden size to overall farm size was related with a low Pielou evenness index (Table 6) support this statement. A reduction in diversity of homegardens is known to be caused by a high proportion of staple food crops (Soemarwoto and Conway, 1991) as well as by labor shortage (Hodel et al., 1999; Gutiérrez et al., 2004).

Among socioeconomic factors, the negative influence of market proximity and commercially oriented production on crop diversity has frequently been recorded (Christanty, 1990; Soemarwoto and Conway, 1991; Michon and Mary, 1994; Abdoellah et al., 2001; Gutiérrez et al., 2004). In the study area, however, this effect was only slightly recognized (Kehlenbeck and Maass, 2004). Nevertheless, there seemed to be a high risk of decreasing crop diversity with an associated loss of plant genetic resources, if production of cash crops such as spring onions were to be successful. In summary, our results suggest that diversity is not only influenced by clearly identifiable single factors but rather by a complex interaction among several factors studied and probably others. This interaction is not yet understood, and additional intrinsic characteristics of gardeners, such as individual preferences and practices might play an overriding role. Obviously, further research is needed for a better understanding of these interrelationships and the processes leading to them. This would help assessing the sustainability of the system as well as its suitability for *in situ* conservation of plant genetic resources.

5. CONCLUSIONS

Although the homegardens surveyed maintained high crop diversity over time, their management at present in the study region was not conducive to sustainability in terms of soil fertility management. The set of the two common sustainability indicators chosen was found to be adequate only for a temporary assessment of homegardens. Nevertheless, an estimation of soil erosion as an additional indicator of sustainability should be considered, particularly where soil fertility monitoring is not practicable over time. Homegardens can play an important role in *in situ* conservation of plant genetic resources as long as gardeners participate in the whole process.

ACKNOWLEDGEMENTS

Many thanks to all the people in Wuasa, Rompo and Siliwanga, especially to the 30 respondent families, for their cooperation and ready help during the field survey. The support provided by members and staff of STORMA (SFB 552) in Bogor, Palu and Göttingen is also gratefully acknowledged, particularly the subproject 'Economic Analysis of Land Use Systems of Rural Households' (A4) for making available their survey data set and subproject 'Central Laboratory Unit' (Z3) for carrying out soil analyses. The German Academic Exchange Service (DAAD) and German Science Foundation (DFG) provided financial support.

REFERENCES

Abdoellah O.S., Takeuchi K., Parikesit, Gunawan B. and Hadikusumah H.Y. 2001. Structure and function of homegarden: a revisited. Proc. Seminar 'Toward harmonisation between development and environmental conservation in biological production' (21-23 February 2001), pp 167 – 185. University of Tokyo, Tokyo.

Benjamin T.J., Montañez P.I., Jiménez J.J.M. and Gillespie A.R. 2001. Carbon, water and nutrient flux in Maya homegardens in the Yucatán peninsula of México. Agroforest Syst 53: 103 – 111.

Burkhard G. 2002. Natural resource management in Central Sulawesi: Past experience and future prospects. STORMA Discussion Paper Series No. 8 (online). Universities of Goettingen and Kassel, Germany, Institut Pertanian Bogor and Universitas Tadulako, Indonesia. http://www.storma.de /DPS/pdf/SDP8.pdf (last accessed: July 29, 2004).

Charnley S. 1997. Environmentally displaced peoples and the cascade effect: Lessons from Tanzania. Hum Ecol 25: 593 – 618.

Christanty L. 1990. Home gardens in tropical Asia, with special reference to Indonesia. In: Landauer K. and Brazil M. (eds), Tropical home gardens, pp 9 – 20. The United Nations University, Tokyo.

Gajaseni J. and Gajaseni N. 1999. Ecological rationalities of the traditional homegarden system in the Chao Phraya Basin, Thailand. Agroforest Syst 46: 3 – 23.

Gutiérrez M., Quiróz C., Pérez D., Rodríguez D., Pérez T., Marques A. and Pacheco W. 2004. Conservación in situ de diversas especies vegetales en '*conucos*' (home gardens) en los estados Carabobo y Trujillo de Venezuela. Plant Gen Resour Newsl 137: 1 – 8.

Hodel U., Gessler M., Cai H.H., Thoan V.V., Ha N.V., Thu N.X. and Ba T. 1999. *In situ* Conservation of plant genetic resources in home gardens of Southern Vietnam. International Plant Genetic Resources Institute, Rome, 106p.

Hvoslef H. 1994. Homegardens of Javanese transmigrants in Seberida subdistrict: Description, agroecological constraints and evaluation of potential solutions to declining productivity. In: Sandbukt O. and Wiriadinata H. (eds), Rain forest and resource management. Proceedings NORINDRA seminar, pp 127 – 136. Indonesian Institute of Sciences (LIPI), Jakarta.

Huxley P.A. 1999. Tropical agroforestry. Blackwell Science, Oxford, 371p.

Jensen M. 1993. Soil conditions, vegetation structure and biomass of a Javanese homegarden. Agroforest Syst 24: 171 – 186.

Karyono 1990. Home gardens in Java. Their structure and function. In: Landauer K. and Brazil M. (eds), Tropical home gardens, pp 138 – 146. The United Nations University, Tokyo.

Kaya M., Kammesheidt L. and Weidelt H.-J. 2002. The forest garden system of Saparua island, Central Maluku, Indonesia, and its role in maintaining tree species diversity. Agroforest Syst 54: 225 – 234.

Kehlenbeck K. and Maass B.L. 2004. Crop diversity and classification of homegardens in Central Sulawesi, Indonesia. Agroforest Syst 63: 53 – 62.

Kumar B.M. and Nair P.K.R. 2004. The enigma of tropical homegardens. Agroforest Syst 61: 135 – 152.

Landauer K. and Brazil M. (eds). 1990. Tropical home gardens. The United Nations University, Tokyo, 257p.

Landon J.R. (ed.). 1991. Booker tropical soil manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman Scientific & Technical, Essex, 474p.

Maertens M., Zeller M. and Birner R. 2002. Explaining agricultural land use in villages surrounding the Lore Lindu National Park in Central Sulawesi, Indonesia. STORMA Discussion Paper Series No. 4 (online). Universities of Goettingen/Kassel, Germany; Institut Pertanian Bogor/Universitas Tadulako, Indonesia. http://www.storma.de/DPS/index. htm (last accessed: July 27, 2004).

Magurran A.E. 1988. Ecological diversity and its measurement. Croom Helm, London, 179p.

Michon G. and Mary F. 1994. Conversion of traditional village gardens and new economic strategies of rural households in the area of Bogor, Indonesia. Agroforest Syst 25: 31 – 58.

Soemarwoto O. 1987. Homegardens: A traditional agroforestry system with a promising future. In: Steppler H.A. and Nair P.K.R. (eds), Agroforestry: A decade of development. pp 157 – 170. ICRAF, Nairobi.

Soemarwoto O. and Conway G.R. 1991. The Javanese homegarden. J Farm Syst Res-Ext 2: 95 – 118.

Torquebiau E. 1992. Are tropical agroforestry home gardens sustainable? Agric Ecosyst Environ 41: 189 – 207.

Watson J.W. and Eyzaguirre P.B. (eds). 2002. Home gardens and *in situ* conservation of plant genetic resources in farming systems. Proceedings of the second international home gardens workshop (17 – 19 July 2001), Witzenhausen, Germany. International Plant Genetic Resources Institute, Rome, 184p.

Wezel A. and Bender S. 2003. Plant species diversity of homegardens of Cuba and its significance for household food supply. Agroforest Syst 57: 39 – 49.

Whitten A.J., Mustafa M. and Henderson G.S. 1987. The Ecology of Sulawesi. Gadjah Mada University Press, Yogyakarta, 777p.

Wood A.P. 1993. Natural resource conflicts in south-west Ethiopia: State, communities, and the role of the National Resource Strategy in the search for sustainable development. Nord J Afr Stud 2: 83 – 99.

Zeller M., Schwarze S. and van Rheenen T. 2001. Statistical sampling frame and methods used for the selection of villages and households in the scope of the research program on stability of rainforest margins in Indonesia (STORMA). STORMA Discussion Paper Series No. 1 (online). Universities of Goettingen and Kassel, Germany, Institut Pertanian Bogor and Universitas Tadulako, Indonesia. http://www.storma.de/DPS/pdf/SDP1.pdf (last accessed: January 20, 2003).

CHAPTER 20

WHITHER HOMEGARDENS?

P.K.R. NAIR

School of Forest Resources and Conservation, University of Florida, Gainesville, Florida 32611, USA; E-mail: <pknair@ufl.edu>

Keywords: Commercialization, Species diversity, Sustainability, Urban homegardens.

Abstract. Although homegardens provide sustenance to millions of households in the tropics, their underlying scientific foundations have not been fully explored, and therefore they are not a part of development agendas. While their integrated and complex nature are a challenge to scientific investigations that are often compartmentalized, these very same attributes form the bases of the ecological, economic, and social sustainability of homegardens. In the wake of recent trend towards commercialization and consequent conversion of homegardens to produce market-oriented crops, concerns have been raised about the future of traditional homegardens. Lack of rigorous scientific evidence makes it difficult to make predictions. Nevertheless, experiences about the role and value of homegardens from around the world suggest that homegardens are not on the path to extinction. They will continue to be an essential part of the way of life, but their nature and functions will change in tune with the rapid changes happening all over. The concept of homegardens will increasingly be adopted in urban and periurban areas, not only in the tropics, but also in industrialized societies, reflecting the society's increasing appreciation of traditional values and ecosystem functions.

1. INTRODUCTION

> *"… that whoever could make two ears of corn, or two blades of grass, to grow on a spot of ground where one grew before, would deserve better of mankind and do more essential service to his country …"*
>
> Jonathan Swift

The above quote that I included at the beginning of my first book nearly three decades ago (Nair, 1979) is as apt now as it was then. The subject matter of that book "*Intensive Multiple Cropping with Coconuts in India*," written before the

B.M. Kumar and P.K.R. Nair (eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, 355–370.

advent – or just at the beginning – of "modern" agroforestry, is not very different from the subject matter of this book, i.e., homegardens: multiple cropping with coconuts (*Cocos nucifera*) and other tree crops, now commonly referred to as multistrata agroforestry, is a distinguishing feature of (most) tropical homegardens. What Jonathan Swift envisioned in *making two ears of corn, or two blades of grass, to grow on a spot of ground where one grew before* is exactly what homegardeners have been practicing, especially in the warmer biomes, for centuries, i.e., growing an array of herbaceous species, shrubs, vines, and trees, all in intimate association on the same piece of land around their homes. Yet, these magnificent farming practices and intriguing plant associations are seldom recognized as worthy of consideration in development paradigms and ecological studies, nor are their practitioners treated as "*… better of mankind doing more essential service to their countries …*"

In spite of this apparent neglect of homegardens and homegardeners, the reasons for which have been discussed in several previous writings (Nair, 2001; Kumar and Nair, 2004), the appeal, relevance, and lessons to be learned from this time-tested practice are so overwhelming and fascinating that time and again it attracts the attention of some researchers. For example, publications on homegardens can be found in almost all volumes of *Agroforestry Systems*. While some of them are at best scientific descriptions of a set pattern (characteristics of systems at specific locations), some deal with examining homegardens in the context of current trends and issues in land use systems, such as environmental integrity, carbon sequestration, biodiversity conservation, economic valuation of intangible benefits, and social equity, to name a few. Only very few of these are scientific analyses, however. Nevertheless, all such publications – old and new – on homegardens have had only "good things" to say about the practice: irrespective of its focus – be it C sequestration, biodiversity, soil fertility, or whatever – the study will have the inevitable conclusion that homegardens are "great" on that score.

Other than these occasional researcher-motivated efforts – and, of course, the incessant individual efforts of the homegardeners – there has been no organized institutional initiative to promote homegardens either locally anywhere or internationally. That is hard to understand: if homegardens have all these desirable characteristics, why have they not earned a rightful place as a development vehicle? If homegardens are the "epitome of sustainability" (Torquebiau, 1992), how is it that they "defy" scientific explanation, or is it that homegardens are just a "backyard" activity with little prospects as a development tool and therefore not worthy of any serious scientific investigation? No answer has yet been found to the question that was posed five years ago: "Do homegardens defy science or is it the other way around?" (Nair, 2001). In the meanwhile, commercialization seems to make its way to homegardens that have traditionally been known as anything but commercial. Two chapters in this book report the recent tendency for growing crops in homegardens mainly for commercial use, in Java, Indonesia (Abdoellah et al., 2006) and Kerala, India (Peyre et al., 2006), the two best-known bastions of traditional homegardens. Is this an indication of the heralding of a new genre of homegardens and possibly the demise of the traditional ones? Is such an "evolution" of homegardens good or bad? In other words, what does the future hold for homegardens?

In order to address the above key question, we need to discuss why homegardens (especially their species diversity) have traditionally been important to the households and what the relevance is of the much-acclaimed sustainability attributes of homegardens to the current context and future prospects.

2. SPECIES DIVERSITY IN HOMEGARDENS AND HOUSEHOLD FOOD SECURITY

The most distinguishing and possibly important characteristic of all homegardens is their species diversity: the intimate admixture of plants of all types – herbs, shrubs, vines, trees, other perennials, and so on – on the same small parcel of land (Fig. 1). From the homegardener's point of view, the primary objective of growing all these plants together is to produce food, often as a supplementary source. In order to appreciate the role of these plants grown in apparent disarray, we have to first of all recognize the fact that 'he', the traditional homegarden practitioner, is a 'she':

Figure 1. *A "typical" rural homegarden in Kerala, India, showing a large number of economic species in intimate association around the home (Photo: B. Mohan Kumar).*

women have primary responsibilities, or are as involved as men, for homegarden maintenance. This is common wherever homegardening is practiced. Considering that it is primarily the woman's responsibility in many societies to feed the families, it is perhaps a combination of both inspiration and desperation that prompt them to grow food around their homesteads: inspiration from experience and innovative instinct, and desperation from the lack of other avenues for finding food for the family. Species diversity in these systems may be a consequence of the interplay of these forces of inspiration and desperation. Mixing annual food crops with frequently harvestable tree crops that provide food and sometimes cash income to the family represents a confluence of human ingenuity with ecological ambience, such that the opportunity offered by year-round growing seasons and the amenability of the various species to grow in mixed stands makes it a "win – win" situation. Tracing the historical development of homegardens, Wiersum (2006) observes that in the most widely studied homegarden systems in South- and Southeast Asia, homegardens are used to produce products with high nutritional va1ue (proteins, vitamins, minera1s), medicina1 plants and spices, firewood, and sometimes a1so forage crops and construction wood, and homegardening is always combined with field-crop cultivation often in the form of wetland rice (*Oryza sativa*) in South- and Southeast Asia. These regions with good farming conditions and high population densities contributed to optimal development of the complementary system of staple food cultivation in open fields and supplementary diversified homegarden production for the family's self-sufficiency and trade.

Whatever be the reason for species diversity, and irrespective of whether it will continue to be a conspicuous feature of future homegardens in the wake of the push to commercialization, researchers seem to be quite obsessed (perhaps more than the practitioners) with species diversity of homegardens. Cataloging of species lists is such a common feature of most homegarden literature to the extent that many authors believe that a paper on any aspect of homegarden is incomplete without a species list (Nair and Kumar, 2006). An interesting point that comes out of such species lists is that, irrespective of the geographical focus of the study, the species that dominate such lists are the same from similar ecological regions. This is evident from the species listed in four chapters of this book, summarized in Table 1, from homegardens in Kerala, India (Mohan et al., 2006); Peruvian Amazon (Wezel and Ohl, 2006); and two locations in the Pacific islands (Lamanda et al., 2006; and Thaman et al., 2006). The situation may not be different if the study is extended to all the 135 case studies included in Fig.1 of Nair and Kumar (2006), with the exception that in some locations, the locally important species that are not common outside their limited geographical areas of distribution will be common in homegardens as well. Examples of this category include the peach palm (*Bactris gasipaes*) and various other palm species in Central and South America, fruit trees such as durian (*Durio zibethynus*) in Southeast Asia and breadfruit (*Artocarpus altilis*) in the Pacific islands, and various fruit trees in West Africa (*Cola* spp., *Dacroydes edulis*, *Pterocarpus* spp., *Treculia africana*: Okafor and Fernandes, 1987). Similarly, in the tropical highlands, the dominant species in homegardens will be different from those in tropical lowlands (e.g., Fernandes et al., 1984; and Soini, 2005; for the *Chagga* homegardens of Tanzania and Tesfaye Abebe et al., 2006, for the homegardens of Ethiopian highlands).

The bottom line is, dominant food crops, both herbaceous and woody, that are locally adapted have been the dominant species of homegardens in different ecological regions. The easy access to these crops in the backyard and the opportunity offered by many of them for staggered harvesting as needed (e.g., tuber crops, vegetables, plantain) make them quite attractive to the women who take it on themselves as their obligation and responsibility to find food for the family. Nutritional security (rather than food security) of the homegarden is another important benefit of homegardens. It is well known that several of the tree fruits in the gardens (Table 1) are nutritionally richer than the common, carbohydrate-rich grain crops, and are indeed the main sources of vitamins and minerals to the family (Niñez, 1984; Okafor and Fernandes, 1987; Kumar and Nair, 2004; Nair, 2006). The cash-income opportunity offered by saleable products (especially tree products) from the homegardens make it an attractive proposition for men too. Social and cultural value of the species in the homegardens is yet another important factor to be considered (discussed later). Species diversity of homegardens is thus quite an appealing feature to the homegardeners for a variety of reasons, and has been a major driving force in the maintenance of the gardens over centuries.

Table 1. *Commonly reported plants in homegardens of humid tropical lowlands.*

Category	*Species in homegardens*
Root and tuber crops	*Colocasia esculenta* (taro), *Dioscorea alata* (greater yam), *Dioscorea esculenta* (sweet yam), *Ipomoea batatas* (sweet potato), *Manihot esculenta* (cassava), *Xanthosoma* spp. (tannia or cocoyam)
Other food crops	*Ananas comosus* (pineapple), *Arachis hypogaea* (peanuts), *Cajanus cajan* (pigeon pea), *Passiflora edulis* (passion fruit), *Phaseolus, Psophocarpus* and *Vigna* spp. (beans and other legumes), *Saccharum officinarum* (sugarcane), *Zea mays* (corn = maize), and various vegetables
Fruit and nut yielding perennials	*Anacardium occidentale* (cahew nut), *Annona* spp. (soursop and sweetsop), *Averrhoa carambola* (carambola), *Artocarpus heterophyllus* (jackfruit), *A. altilis* (breadfruit), *Carica papaya* (papaya), *Citrus* spp. (lemon, lime, orange, tangerin), *Cocos nucifera* (coconut), *Ficus* spp. (edible figs), *Mangifera indica* (mango), *Musa* spp. (bananas and plantains), *Persea americana* (avocado), *Psidium guajava* (guava), *Spondias dulcis* (vi apple, hogplum), *Syzygium malaccense* (Malay apple), *Tamarindus indica* (tamarind)
Spices, Social beverages, and stimulants	*Areca catechu* (betel nut), *Cinnamomum zeylanicum* (cinnamon), *Curcuma longa* (turmeric), *Cymbopogon citratus* (lemon grass), *Piper betle* (betel vine), *Piper methysticum* (kava), *Zingiber officinale* (ginger).

3. SUSTAINABILITY AND HOMEGARDENS

Sustainability is perhaps the most widely discussed, yet least well-defined, term across disciplines in contemporary agricultural and land use literature. Even before publication of the much-acclaimed and so-called Brundlandt Commission report (WCED, 1987), sustainability has been a cornerstone of many traditional land use systems and it used to figure prominently in the early debates on agroforestry (Bene et al., 1977). Without going into any discussion on this much-discussed issue, suffice it to say that sustainability is about meeting today's needs without compromising the ability of future generations to satisfy their needs; it is not a new concept, simply the retrieval of ancient wisdom dictating that "you don't eat your seed corn"; and it strives to achieve a balance between ecological preservation, economic vitality, and social justice.

Much of the discussion on ecological sustainability of homegardens is linked to their species diversity. While dealing with species of various forms, life cycle, and nature of products, the number or frequency of occurrence of a species in the homegarden is not a sufficient indicator of the importance or dominance of the species. Ecological parameters and indices that are commonly used to express population complexity and diversity such as Sorenson's index of similarity, Shannon-Weiner and Margalef Indices of species diversity, and Importance Value Index, have lately been reported in homegarden studies (Kumar and Nair, 2004 – for literature until then; Mohan et al., 2006; Abdoellah et al., 2006; Kehlenbeck and Maass, 2006). Some authors have also used statistical procedures such as cluster analysis and correspondence analysis to group descriptive characteristics of homegardens, and to find out factors that may play a significant role in explaining patterns of floristic composition of the complex system; one such study is reported by Tesfaye Abebe et al. (2006) in this volume.

The rationale is to use these indices as a basis for comparing homegardens with nearby natural vegetation – usually forests – on the assumption that in terms of species abundance and diversity, homegardens are in between natural systems and managed systems. Homegardens are perhaps the most diverse agroforestry practice, and among all agroforestry practices, they are at one end of the spectrum, two-species (a tree and a crop) associations such as alleycropping being at the other end (Nair, 1993; Rao et al., 1988). Species abundance and diversity of homegardens should not, however, be equated with ecological succession that is characteristic of natural systems and the benefits of which are exploited in some traditional low-input agricultural systems such as shifting cultivation. The fact that natural systems are more diverse than agricultural systems has been known for long, one of the most widely cited articles on the subject being that of Odum (1969). In the very few examples of low-input agriculture that take advantage of the process of succession, the species are all carefully selected, but are not random successional species that seed-in naturally. In homegardens too, the species are selected carefully, and are therefore similar to such systems. Homegardens start off from one particular stage of the natural successional process, but keep natural succession from carrying the community to a so-called "climax" community. On the other hand, agroforestry practices such as alleycropping that are at the "other end" of the species-diversity spectrum have little similarity with the natural systems and do not fit into the realm of successional processes. Thus, in terms of complexity and species diversity, homegardens represent a unique set of ecological sustainability characteristics of natural systems as well as production benefits of agricultural systems. Another aspect of ecological sustainability in homegardens is the benefit of nutrient cycling experienced in multistrata systems, which is again a consequence of the species diversity (Nair et al., 1999).

It needs to be pointed out in this context that the premise that diversity provides stability to ecosystems, which is the basis of the concept of ecological sustainability of homegardens, is being debated by ecologists: the so-called "diversity – stability debate" (e.g., McCann, 2000). Although the consensus of this debate as of now is that diversity can be expected, on average, to give rise to ecosystem stability, diversity is not the driver of this relationship; rather, ecosystem stability depends on the ability of communities to contain species, or functional groups, that are capable of differential responses. At present, in ecological studies, the role of keystone species is receiving increasing attention; this concept has hardly been used in homegarden studies yet, but seems to offer scope for further studying the diversity – stability issue in homegardens (see Tesfaye Abebe, 2006). If simplified communities are more vulnerable to invasion by other communities/species, then the trend towards commercialization of homegardens (discussed later) should result in higher frequency of invader species as well as pests and diseases in homegardens. The profit-oriented commercial homegarden enterprises will then resort to keeping such invading species under check through use of chemicals, which will inevitably disrupt the harmonious biodiversity and species associations (including micro-organisms and species other than plants) that have been so characteristic of traditional homegardens.

Economic and social sustainability attributes of homegardens are even less well studied than ecological-sustainability attributes. A common problem seen mentioned in most attempts to study economic benefits of homegardens is, again, lack of widely accepted procedures to measure economic benefits of intangible benefits and services. Alavalapati and Mercer (2004) described some procedures for economic valuation of agroforestry systems. Most attempts at economic valuation have two common features: first, they acknowledge the importance and need for "proper" evaluation of the intangible benefits of homegardens, such as aesthetics and ornamentation, nutritional security, food quality, and empowerment of women; then they highlight the difficulties involved in collecting realistic data and therefore caution about the error-prone nature of such analyses. The two chapters on economic analysis presented in this volume are no exception to this general trend: Torquebiau and Penot (2006) articulate the importance of including valuation of such benefits in homegarden evaluation, but stop short of suggesting any new procedures; and, Mohan et al. (2006), following a study applying conventional and some "non-conventional" economic procedures in some Kerala homegardens, confirm that the results are along expected lines and caution that their study procedure will need considerable "fine-tuning" to adapt to local conditions before it is applied elsewhere. Thus, economic sustainability of homegardens remains another attribute, the importance of which can only be felt qualitatively and intuitively, but is difficult to quantify.

The same can be said about social sustainability. All social studies on homegardens exclaim the social attributes of homegardens, ranging from their role in ensuring gender equality and nutritional security to societal harmony and cultural heritage. Several chapters in this book touch upon these issues. Howard (2006) presents a well researched account of the major role of women in homegardens in Latin America: the presence of a garden rich in a variety of plants epitomizes the woman's exertions on behalf of kin and her proficiency as primary provider of food, health, and overall well-being of the family, and demonstrates her freedom from dependence on products from neighbors and commercial vendors. Abdoellah et al. (2006) describe how the tendency towards conversion of homegardens to produce commercially valuable crops for market in Indonesia has disrupted the community's equality, sharing, and harmonious living (*rukun*) that used to be built around traditional homegardens, and decreased the number of common grounds (*buruan*) in front of homes that serve as playground for children, and as a place for socializing with neighbors and for children to learn cultural and social values from their elders. The strength of these threads that are woven together in the fabric of social sustainability of homegardens cannot be expressed in quantitative terms.

4. HOMEGARDENS AND SOME CURRENT LAND USE ISSUES

4.1. Biodiversity

Biodiversity (short form for biological diversity) is often used as a synonym for species diversity. The importance of maintaining biodiversity in sustaining food production and protecting human and ecosystem health is now universally recognized, and land use systems that promote biodiversity are considered to be quite desirable from that perspective. A classification based on the production systems and species diversity ranked homegardens top with its highest biological diversity among all manmade agroecosystems (Swift and Anderson, 1993). Species richness and extent of biodiversity in homegardens depend, however, on ecological and socioeconomic factors and household preferences. Gajaseni and Gajaseni (1999) have reported, for example, the existence of non-commercial indigenous varieties of durian (*Durio* sp.) and rare varieties of mango (*Mangifera indica*) in homegardens of Thailand. Large numbers of cultivars of banana (*Musa paradisiaca*), coconut, and breadfruit have been reported in the homegardens of Micronesia (Falanruw, 1990; Thaman et al., 2006). Indeed, as already mentioned, most publications on homegardens from around the world (see Fig. 1: Nair and Kumar, 2006) report the large numbers of species present. The role of homegardens as repositories of plant biodiversity is thus indisputable. In a recent study from seven New- and Old-World tropical forest dynamic plots, Wills and 33 collaborators from 21 institutions around the world reported that an erosion of an ecological community's species diversity (that tends to happen as a result of stochastic extinction, competitive exclusion, and unstable host-enemy dynamics) can be prevented over the short-term through preferential introduction of rare species (Wills et al., 2006). They found that when species were rare in a local area, they had a higher survival rate than when they were common, resulting in enrichment for rare species and increasing diversity with age and size class in these complex ecosystems. Thus, it can be surmised that the preferential introduction of rare species such as medicinal plants (Rao and Rajeswara Rao, 2006) and fruit trees that homegardeners have been practicing for centuries around the world contributes to species biodiversity even if economic and social gains are the primary motivations for such introductions.

4.2 Genetic-diversity conservation and species domestication

In addition to the wide array of plants grown in homegardens for a variety of reasons, homegardens have high potential for *in situ* conservation of genetic resources (Watson and Eyzaguirre, 2002; McNeely, 2004; Schroth et al., 2004). An important issue, the significance of which is seldom recognized in the extant species-listing-dominated literature on homegardens, is the continuous interaction of homegardeners with these large groups of plants and the resultant contribution to species domestication. Simons and Leakey (2004) describe the deliberate selection and management of trees (*domestication*) by humans that has been going on for millennia in agroforestry systems. For example, Leakey et al. (2004) present evidence that subsistence farmers have domesticated locally popular indigenous fruits (*Dacroydes edulis* and *Irvingia gabonensis*) in Cameroon and Nigeria. It is reasonable to assume that much of this *in situ* domestication has taken place in homegardens. It is also likely that similar patterns of domestication have happened for other plant species in homegardens around the world, especially in those with long history as in South- and Southeast Asia (Wiersum, 2004).

4.3. Carbon sequestration

Most discussions on carbon sequestration potential of homegardens – and, indeed agroforestry systems in general – are based more on hypothetical considerations than empirical results. The argument is that these systems have high carbon storage (*sequestration*) potential in their multiple plant species, especially in woody perennial species, and soil; they help in *conservation* of C stocks in existing forests by alleviating the pressure on natural forests (Schroth et al., 2004); and, to some extent, in C *substitution* by reducing fossil-fuel burning through promotion of wood fuel production. Most reports indicate that the addition of a large proportion of the relatively high quantity of plant materials produced in a system will increase C stock in soils (Lal, 2004); therefore it is reasonable to surmise that homegardens will help substantially in C sequestration. All reports on C sequestration potential of homegardens (e.g., Montagnini and Nair, 2004; Kumar, 2006), however, are related to aboveground biomass. In the case of soils, C stored in surface soils has received some mention. But C exists in soils in labile (mobile) or recalcitrant (stable) form; the latter is more important for C sequestration; and, no study has been reported on this “real” form of C sequestration within soil profiles in homegardens. Most C sequestration reports also have disclaimers and caveats that lack of reliable inventories/estimates and uncertainties in the methods of estimation present serious difficulties. Thus, as in the case of other intangible and difficult-to-measure benefits and services, C sequestration benefit of homegardens remains one of the "potential benefits" that has not been even quantified, let alone exploited.

5. NEW DIMENSIONS OF HOMEGARDENS

5.1. Commercialization of homegardens

Consequent to liberalizations in many formerly tightly controlled economies, agricultural enterprises, just as other production enterprises, are becoming increasingly subject to market pressures. A direct consequence of this is development and adoption of new strategies to promote commercialization of even traditional operations such as homegardens. Abdoellah et al. (2006) describe a case study of such a transformation in a West Java village in Indonesia, where some villagers, attracted by economic possibilities, have transformed their homegardens in such a way that they have become dominated by few plant species or are approaching even monocultures; the dominant species are cash crops such as vegetables that are in high demand in nearby urban markets. Similar examples are also prevalent in the Pacific islands as described by Thaman et al. (2006), where promotion of a wide range of export cash crops in rural areas has led to the clearing of diverse agroforests. Increasing trend towards commercialization has also been reported from Kerala homegardens (Kumar and Nair, 2004).

This so-called commercialization is, however, not new to homegardens. It has been in existence to varying degrees in most well-known homegardens (of South and Southeast Asia). Perennial species that produce commercial products such as spices, fruits and nuts, medicinal plants, and even timber have been a component in many of these systems. As Kumar and Nair (2004) have pointed out, although interest in homegardens has been primarily focused on producing subsistence items, its role in generating additional cash income has been quite substantial in many places. Considerable variations from place to place have also been reported in the proportion of homegarden products that are used for household consumption as opposed to sale, and the contribution of the net income derived from sale of products to the total household income. Conversion of homegardens to intensive production units of market-oriented systems as described by Abdoellah et al. (2006) is not a totally new phenomenon; similar trends have occurred in several rapidly urbanizing and periurban centers. A case in point is the conversion of the traditional *shamba* gardens of Kenya's highlands to produce vegetables for sale in Nairobi, the capital city, and for export to Europe (author's personal experience).

5.2. Urban homegardens

Another relatively new trend related to commercialization of homegardens is the extension of the homegarden practice from its conventional rural settings to urban environments. Two chapters in this book (Drescher et al., 2006; and Thaman et al., 2006) describe such developments; while the former includes examples from several places around the world representing both developing and developed countries, the latter deals primarily with such developments in the Hawaiian Islands, USA. These urban homegardens are often the "modern" cousins of their traditional relatives in the sense that while they maintain the species diversity that is characteristic of the traditional homegardens, their aesthetic and recreational value is as important as – if not more than – their nutritional role. As Fig. 2, a photograph of an urban homegarden in Kona, Hawaii, USA, shows, the gardens with manicured lawns and hedges, well tended fruit trees, and attractive ornamentals surrounding a "modern" home look more like tourist resorts, in sharp contrast to the "natural" look of the subsistence-oriented homegardens and the type of "traditional" homes they surround (Fig. 1).

Figure 2. *An urban homegarden with fruit trees such as avocado (*Persea americana*), litchi (*Litchi chinensis*), mango (*Mangifera indica*), papapya (*Carica papaya*, and various ornamentals, in Kona, Hawaii, USA (Photo: Craig Elevitch).*

This trend towards urban homegardening may be seen in the context of other similar activities such as urban forestry and organic agriculture that have gained considerable prominence in urban and periurban areas during the recent past. These activities constitute a substantial portion of the green space and are considered to be the lungs of the cities. For example, the role of urban vegetation in mitigating atmospheric greenhouse gas concentrations and improving air quality in Santiago, Chile (a city of more than 4 million inhabitants), was illustrated in a recent study

(F. Escobedo, personal communication; January 2006). Gaston et al. (2005) reported that the 'domestic gardens' with mean area of only 151 m^2 per garden covered approximately 33 km^2 or 23% of the predominantly urban area of the city of Sheffield, U.K., and provided tremendous opportunities for maintenance of biodiversity and provision of ecosystem services in urban areas. Furthermore, there is a revival of appreciation of recreational and social values of ornamental and other types of homestead gardening in the industrialized world such as the United States (Westmacott, 1992) and Europe (Vogl and Vogl-Lukasser, 2003). An increasing number of gardeners are now finding pleasure in growing plants for various uses and deriving satisfaction from agrarian life-style, self-reliance, and private ownership – a clear expression of the appreciation of the aesthetic, cultural, and landscape values of such integrated systems, and perhaps the bygone days.

6. FUTURE OF HOMEGARDENS

Prompted by the lack of appreciation of the value of homegardens in development paradigms and the trends towards commercialization of homegardens and urban homegardens, the question has been posed "are homegardens becoming extinct?" (Kumar and Nair, 2004). Wiersum (2006) argues that this illustrates that "the notion of socioeconomic sustainability of homegardens should be interpreted as referring not only to their ability to contribute towards the livelihood needs of traditional rural dwellers, but also to their ability to adjust to the process of rural change."

Obviously, no one can accurately predict the future of an activity such as homegardening that is deeply rooted in ecological, socioeconomic, and cultural milieu of the land and its people. Some of the well-known predictions such as the 200-year-old Malthusian theory are even better known today for their failures to hold up in a changing world. As the old adage goes, change is the only constant thing. Homegardens are no exception; they will certainly be affected by the changes happening in the local ecology, economics, and culture. The rate and extent of the impact of such changes will depend on a myriad of factors. Economic and cultural forces often pull the society and people's attitudes in opposite directions. If some farmers in periurban centers are attracted by the forces of economics to convert their homegardens or sections of them to growing crops that can fetch money in the market, there will be an equally strong (if not stronger) section of farmers who are not attracted by the lure of money to abandon their age-old traditions. When, rather than if, some genetically modified crops find their way to homegardens, that may not necessarily mean a proliferation of transgenic homegardens – at least in the near future. In fact, homegardens are "testing grounds" of many innovations of the gardeners, and today's gardens of long standing are a result of such continuous innovation and improvement. The migration of the youth to urban and even overseas centers in search of jobs and cash income, a common feature in many homegarden-dominated societies, naturally raises concerns about the future of homegardens, particularly the scope for bringing any technological innovations to the practice of homegardening. What is seldom recognized, however, is the reverse migration of older workforce who, after long stays in industrialized urban centers get disenchanted and seek to return to their roots in increasing numbers and take up hobby farming and homegardening for the pure pleasure of doing something they have grown up with and to which they possess a cultural bondage; this reverse migration seldom gets the media attention of out-migration of youth.

What conclusion can, then, be drawn on the future of homegardens? Will they survive or will they become extinct? It is anybody's guess. I, for one, have relentlessly argued for quantitative and measurable evidence in support of a conclusion. But I don't have much evidence of that nature to draw upon in this case. So, I would rather make no prediction. Nevertheless, my intuition is that homegardens will not become extinct. Because of the difficulties in quantitative valuation of the sustainability attributes of homegardens, it is unlikely that homegardens will become a part of the development bandwagon; therefore it is unlikely that there will be any "big push" towards research on homegardens. But that will not lead to the demise of homegardens. I have only my personal experiences of interactions with homegardeners around the world to support this intuitive prediction: the innovative spirit of the Japanese settler farmer in Tomé-Açu (Brazil), the sentimental attachment to ancestral land and way of life of the homegardeners in Kerala (India), the tenacity of the farmers who maintain economically attractive Kandyan homegardens (Sri Lanka), the community's commitment to traditional life style of the homegardeners in Nakhon Sawan (Thailand), the intuitive skills of the industrious and tradition-bound homegardeners of Java even after they were transmigrated under government pressure to unfamiliar and distant lands in Kalimantan (both in Indonesia), the friendliness and confidence of the ecotourism-oriented homegardeners of the Blue Mountain region (Jamaica), the hope and aspirations built around homegardens of the hapless rural folks in Koutiala (Mali) and Cap Haitien (Haiti), the satisfaction of the gardeners in being able to produce a variety of food and other essential needs in their homegardens in mountainous landlocked terrains in Mount Hagen (Papua New Guinea) and water-locked Gizo (Solomon Islands), the pride and self-confidence effused by the female gardeners in the *shambas* of the Kikuyuland (Kenya) and the *chagga* in Arusha region (Tanzania), the ingenuity of the farmers who have successfully introduced rearing in captivity through stall-feeding of the African grasscutter (*Thryonomys swinderianus*, a herbivorous rodent that is harvested for delicious and pricy bush meat) in Kumasi (Ghana), … – the list can be long – all point to continuation of the homegardens, of sorts, in perpetuity. So, my submission is, homegardens will undergo changes; but they will not become extinct; they will continue to exist with their mysterious, enigmatic charm to provide sustenance, satisfaction, income, and aesthetic appeal to many, and fascination to scientists who care to look at them.

ACKNOWLEDGMENTS

I thank Drs. Michael Bannister, Vimala Nair, and Freerk Wiersum for comments and suggestions on the manuscript.

REFERENCES

Abdoellah O.S., Hadikusumah H.Y., Takeuchi K., Okubo S. and Parikesit. 2006. Commercialization of homegardens in an Indonesian village: vegetation composition and functional changes. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 233 – 250. Springer Science, Dordrecht.

Alavalapati J.R.R. and Mercer D.E. (eds). 2004. Valuing agroforestry systems: Methods and applications (Advances in Agroforestry # 2). Kluwer, Dordrecht, 314p.

Bene J.G., Beall H.W. and Côte A. 1977. Trees, food and people. International Development Research Centre, Ottawa, Canada. 52p.

Drescher A.W., Holmer R.J. and Iaquinta D.L. 2006. Urban homegardens and allotment gardens for sustainable livelihoods: Management strategies and institutional environments. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 317 – 338. Springer Science, Dordrecht.

Falanruw M.V.C. 1990. The food production system of the Yap Island. In: Landauer K. and Brazil B. (eds), Tropical home gardens, pp 94–104. United Nations University Press, Tokyo.

Fernandes E.C.M., O'Kting'ati A. and Maghembe J. 1984. *Chagga* homegardens: a multistory agroforestry cropping system on Mt. Kilimanjaro, northern Tanzania. Agroforest Syst 2: 73 – 86.

Gajaseni J. and Gajaseni N. 1999. Ecological rationalities of the traditional homegarden system in the Chao Phraya Basin, Thailand. Agroforest Syst 46: 3 – 23.

Gaston K.J., Warren P.H., Thompson K and Smith R.M. 2005. Urban domestic gardens (IV): the extent of the resource and its associated features. Biodivers Conserv 14: 3327 – 3349.

Howard P.L. 2006. Gender and social dynamics in swidden and homegardens in Latin America. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 159 – 182. Springer Science, Dordrecht.

Kehlenbeck K. and Maass B.L. 2006. Are tropical homegardens sustainable? Some evidence from Central Sulawesi, Indonesia. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 339 – 354. Springer Science, Dordrecht.

Kumar B.M. 2006. Carbon sequestration potential of tropical homegardens. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 185 – 204. Springer Science, Dordrecht.

Kumar B.M. and Nair P.K.R. 2004. The enigma of tropical homegardens. Agroforest Syst 61: 135 – 152.

Lal R. 2004. Soil carbon sequestration impacts on global change and food security. Science 304: 1623-1627.

Lamanda N., Malézieux E. and Martin P. 2006. Structure and dynamics of coconut-based agroforestry systems in Melanesia: a case study from Vanuatu archipelago. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 105 – 121. Springer Science, Dordrecht.

Leakey R.R.B., Tchoundjeu Z., Smith R.I., Munro R.C., Fondoun J-M., Kengue J., Anegbeh P.O., Atangana A.R., Waruhiu A.N., Asaah E., Usoro C. and Ukafor V. 2004. Evidence that subsistence farmers have domesticated indigenous fruits (*Dacryodes edulis* and *Irvingia gabonensis*) in Cameroon and Nigeria. Agroforest Syst 60: 101 – 111.

McCann K.S. 2000. The diversity – stability debate. Nature 405: 228 – 233.

McNeely J.A. 2004. Nature vs. nurture: Managing relationships between forests, agroforestry and wild biodiversity. Agroforest Syst 61: 155 – 165.

Mohan S., Alavalapati J.R.R. and Nair P.K.R. 2006. Financial analysis of homegardens: A case study from Kerala State, India. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 283 – 296. Springer Science, Dordrecht.

Mohan S., Nair P.K.R. and Long A.J. 2006. An assessment of homegarden diversity: A case study from Kerala State, India. J Sust Agric (in press).

Montagnini F. and Nair P.K.R. 2004. Carbon sequestration: An under-exploited environmental benefit of agroforestry systems. Agroforest Syst 61: 281 – 298.

Nair P.K.R. 1979. Intensive multiple cropping with coconuts in India: Principles, programmes and prospects. Verlag Paul Parey, Berlin, 149p.

Nair P.K.R. 1993. An Introduction to Agroforestry. Kluwer, Dordrecht, 499p.

Nair P.K.R. 2001. Do tropical homegardens elude science, or is it the other way around? Agroforest Syst 53: 239 – 245.

Nair P.K.R. 2006. Agroforestry for sustainability of lower-input land use systems. J Sust. Crop Production (in press).

Nair P.K.R. and Kumar B.M. 2006. Introduction. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 1 – 10. Springer Science, Dordrecht.

Nair P.K.R., Buresh R.J., Mugendi D.N. and Latt C.R. 1999. Nutrient cycling in tropical agroforestry systems: Myths and science. In: Buck L.E., Lassoie J.P., and Fernandes E.C.M. (eds), Agroforestry in sustainable agricultural system, pp 1 – 31. CRC Press, Boca Raton, FL.

Niñez V.K. 1984. Household gardens: theoretical considerations on an old survival strategy. Potatoes in Food Systems Research Series Report No. 1, International Potato Center, Lima, Peru, 41p.

Odum E.P. 1969. The strategy of ecosystem development. Science 164: 262 – 270.

Okafor J.C. and Fernandes E.C.M. 1987. The compound farms of Nigeria: A predominant agroforestry homegarden system with crops and small livestock. Agroforest Syst 5: 153 – 168.

Peyre A., Guidal A., Wiersum K.F. and Bongers F. 2006. Homegarden dynamics in Kerala, India. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 87 – 103. Springer Science, Dordrecht.

Rao M.R. and Rajeswara Rao B.R. 2006. Medicinal plants in tropical homegardens. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 205 – 232. Springer Science, Dordrecht.

Rao M.R., Nair P.K.R. and Ong C.K. 1988. Biophysical interactions in tropical agroforestry systems. Agroforest Syst 38: 3 – 50.

Schroth G., da Fonseca A.B., Harvey C.A., Gascon C., Vasconcelos H.L. and Izac N. (eds). 2004. Agroforestry and biodiversity conservation in tropical landscapes. Island Press, Washington, DC. 523p.

Simons A.J. and Leakey R.R.B. 2004. Tree domestication in tropical agroforestry. Agroforest Syst 61: 167 – 181.

Soini E. 2005. Changing livelihoods on the slopes of Mt. Kilimanjaro, Tanzania: Challenges and opportunities in the *Chagga* homegarden system. Agroforest Syst 64: 157 – 167.

Swift M.J. and Anderson J.M. 1993. Biodiversity and ecosystem function in agricultural systems. In: Schulze E.D. and Mooney H.A. (eds), Biodiversity and ecosystem function, pp 15 – 42. Springer, Berlin.

Tesfaye Abebe, Wiersum K.F., Bongers F. and Sterck F. 2006. Diversity and dynamics in homegardens of southern Ethiopia. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 123 – 142. Springer Science, Dordrecht.

Thaman R.R., Elevitch C.R. and Kennedy J. 2006. Urban and homegarden agroforestry in the Pacific islands: current status and future prospects. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 25 – 41. Springer Science, Dordrecht.

Torquebiau E. 1992. Are tropical agroforestry homegardens sustainable? Agric Ecosyst Environ 41: 189 – 207.

Torquebiau E. and Penot E. 2006. Ecology versus economics in tropical multistrata agroforests. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 269 – 282. Springer Science, Dordrecht.

Vogl C.R. and Vogl-Lukasser B. 2003. Tradition, dynamics and sustainability of plant species composition and management in homegardens on organic and non-organic small scale farms in Alpine Eastern Tyrol, Austria. Biol Agric Hortic 21: 349 – 366.

Watson J.W. and Eyzaguirre P.B. (eds). 2002. Home gardens and *in situ* conservation of plant genetic resources in farming systems. Proceedings of the Second International Home Gardens Workshop (17–19 July 2001), Witzenhausen, Germany. International Plant Genetic Resources Institute (IPGRI), Rome, Italy, 184p.

World Commission on Environment and Development (WCED) 1987. Our common future. Oxford University Press, Oxford, 370p.

Wills C, Harms K.E., Condit R., King D., Thompson J., He J., Muller-Landau H.C., Ashton P., Losos E., Comita L., Hubbell S., LaFrankie J., Bunyavejchewin S., Dattaraja H.S., Davies S., Esufali S., Foster R., Gunatilleke N., Gunatilleke S., Hall P., Itoh A., John R., Kiratiprayoon S., de Lao S.L., Massa M., Nath C., Noor M.N.S., Kassim A.R., Sukumar R., Suresh H.S., Sun I-F., Tan S., Yamakura T. and Zimmerman, J. 2006. Nonrandom processes maintain diversity in tropical forests. Science 311: 527 – 531.

Westmacott R.N. 1992. African-American gardens and yards in the rural south. University of Tennessee Press, Knoxville, TN, 198p.

Wezel A. and Ohl J. 2006. Homegarden plant diversity in relation to remoteness from urban centers: a case study from the Peruvian Amazon region. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 143 – 158. Springer Science, Dordrecht.

Wiersum K.F. 2004. Forest gardens as an ‘intermediate’ land use system in the nature – culture continuum: characteristics and future potential. Agroforest Syst 61: 123 – 134.

Wiersum K.F. 2006. Diversity and change in homegarden cultivation in Indonesia. In: Kumar B.M. and Nair P.K.R. (eds), Tropical homegardens: A time-tested example of sustainable agroforestry, pp 13 – 24. Springer Science, Dordrecht.

SUBJECT INDEX

Adaptability 66, 67, 87, 123, 179, 275
Adaptive management 137, 185, 283, 293
Adaptive research 299
Aesthetic garden18
African-American yards and gardens 6, 7
Agricultural landscape 65, 203, 235, 271
Agrobiodiversity (*see also* biodiversity) 46, 55, 103, 117, 170, 173, 174, 179, 200, 269, 280
Agrodeforestation 25, 26, 34, 36, 39, 41, 118
Allotment gardens 9, 229, 317–319, 321–323, 325–327, 329–337, 368
Amazon 10, 23, 43–60, 62, 64, 73, 83, 84, 134, 139, 143, 144, 149, 154–158, 160, 161, 163, 165–167, 169, 170, 173, 175, 179, 180–182, 189, 201, 204, 206, 212, 213, 224, 225, 230, 231, 267, 299–301, 304, 309–312, 314–316, 338, 358, 370
Amazonia 23, 43–60, 62, 83, 144, 156–158, 160, 163, 165–167, 169, 175, 179–181, 189, 201, 204, 230, 231, 267, 299, 301, 314–316
Amerindians 75, 84, 160, 165, 175
Andes 145, 167, 170, 171, 173–175, 181
Animal husbandry 34, 247, 249
Aromatherapy 221, 223, 228
Aromatic plants 205, 208, 213, 226, 226–231

Benefit-cost analysis 283
Biodiversity (*see also* Agrobiodiversity, Crop diversity and Species diversity) 8, 27, 39, 41, 61–64, 69, 73, 74, 77, 80, 82, 83, 87, 88, 101, 134, 137, 139, 158, 181, 193, 199, 201, 203, 231, 270–274, 279, 280, 284, 320, 330, 339, 340, 356, 361–363, 366, 368, 369
Biodiversity conservation (*see also* Convention on Biological Diversity*)* 8, 77, 137, 199, 270–274, 279, 280, 356, 369
Biofactory 228
Biopesticides 214
Biopiracy 227
Budget garden 20

Caboclo 43, 44, 46–48, 50–52, 54, 55, 58, 167, 182
Canopy area 258
Canopy conductance 258, 263, 264
Canopy layers 251, 252, 260, 261
Carbon sequestration 9, 61, 80–83, 117, 119, 185–187, 189, 191, 193, 195, 197, 198, 200–203, 272, 274, 278, 281, 282, 356, 363, 368, 369
Carbon stocks 185, 188, 189, 191, 201, 203
Cash crops 9, 22, 38, 39, 90, 97, 100, 102, 123, 124, 127, 128, 131, 132, 134–138, 159, 162, 170–173, 214, 233, 235, 236, 244–247, 341, 352, 364
Catalonia 3, 4, 6, 8, 211, 212, 224, 228
Cattle grazing 106, 111, 112, 117
Chagga 2, 3, 9, 134, 135, 138, 139, 140, 207, 213, 229, 358, 367–369
Children 54, 57, 117, 162, 178, 181, 227, 244, 248, 301, 311, 319, 320, 325, 351, 362
Classification, homegarden 23, 89, 90, 92, 99, 108, 109, 112, 113, 127, 229, 253, 320, 333, 353, 362
Clean Development Mechanisms 198–200, 272, 279

Cluster analysis 69, 87, 89, 90, 92, 360
Commercial crops 18, 19, 47, 48, 50, 55, 98, 123, 124, 133, 233, 235, 240, 284, 293, 314
Commercialization 7, 8, 15, 21, 22, 37, 40, 60, 88, 101, 123, 124, 132, 133, 135, 137, 138, 159, 165, 173, 179, 214, 233–235, 237, 239, 241, 243–249, 355, 356, 358, 361, 364, 366, 368
Commoditization 179
Commodity production 94, 171, 172, 186
Community gardens 318, 319, 322, 322–324, 326, 330, 331, 338
Composition, homegarden 8, 9, 13, 15, 17–22, 35, 40, 51, 53, 58, 61, 66, 68, 69, 74, 81, 87, 88, 90, 100–102, 123–132, 135–139, 147, 148, 158–160, 165, 168–170, 173, 176, 180, 186, 194, 197–199, 201, 213, 224, 230, 231, 233, 235, 240, 245, 248–250, 253, 293, 311, 339, 345, 360, 368, 370
Contract farming 226, 228
Convention on Biological Diversity 187
Correspondence analysis 69, 129, 130, 360
Cosmology 54, 161, 166, 167, 170, 181
Crop diversity (*see also* Species diversity and Biodiversity) 18, 19, 23, 45, 124, 132, 136, 162, 176, 229, 340, 343, 347–349, 351–353
Cropping system dynamics 105

Diversity index (*see also* Shannon index, Shannon-Weaver index, and Margalef index) 94, 236–238, 245, 246, 345
Division of labor 159–162, 165–168, 171, 172, 177
Domestic animals (*see also* Livestock) 1, 2, 20, 32, 48, 61, 76, 77, 81, 206, 301
Domestication 43–46, 54, 56, 57, 59, 60, 73, 80, 82, 363, 369
Dynamics, homegarden 9, 13, 15, 20–23, 40, 82, 87–89, 91, 93, 95, 97, 99, 101–103, 105–110, 112, 115, 118, 123, 124, 126, 132, 135, 137, 139, 158–161, 163, 165, 167, 169, 171, 173, 175, 177, 179–181, 197, 201, 229, 235, 265, 275, 280, 300, 315, 336, 339, 340, 348, 362, 368, 369, 370

Ecological instability 247
Ecological succession 360
Ecological sustainability 78, 87, 88, 101, 102, 135–137, 271, 274, 280, 360, 361
Economic alternatives 284, 285, 291
Economic resilience 274, 284, 285, 290
Economic utility 283, 285, 287, 295, 296
Economic valuation (*see also* Financial worth) 356, 361
Ecosystem services 194, 198, 272, 203, 366
Ecotourism 225, 228, 367
Environmental economics 278, 279
Environmental services (*see also* Ecosystem services) 62, 81, 198, 269, 273, 278, 279, 281
Ethnobiodiversity 39
Ethnobotany 84, 180–182
Ethnohistory 23, 43, 44, 46, 83
Extension 10, 17, 21, 40, 43, 44, 56, 57, 106, 108, 110, 111, 118, 119, 173, 185, 273, 294, 299, 313, 314, 317, 318, 326, 330, 331, 333, 335, 336, 350, 364
External inputs 87, 88, 91, 95, 98, 100, 101, 135–137, 237, 243, 244, 247, 248

Externalities 198, 269, 270, 272, 273, 276, 278–280
Extractivism 278

Fallow 17, 26, 33, 46, 54, 55, 58, 65, 84, 105, 106, 109, 111, 112, 115, 117, 144, 145, 156, 162, 165, 188, 201, 207, 225, 300, 341
Farm size 123, 132, 133, 137, 343, 347, 348, 353
Farmer innovation 299
Farmer-explorers 311
Farmers' practices 106, 112
Farming systems 2, 9, 13, 15, 17, 19, 21, 23, 103, 106, 124, 139, 158, 230, 269, 273, 280, 311, 329, 354, 370
Financial worth (*see also* Economic valuation) 285, 287, 288, 290
Floodplains 51, 143, 144, 156, 158, 225
Floristic composition 69, 81, 180, 245, 249, 250, 360
Food security 3, 25, 26, 39–41, 55, 61, 62, 74, 75, 77, 81, 117, 119, 139, 173, 202, 203, 266, 294, 317, 326, 329, 336, 337, 357, 359, 368
Forest fallow 188, 225, 300
Forest garden 2, 17, 23, 24, 62, 139, 140, 182, 226, 231, 252, 270, 281, 282, 351, 353, 370
Forest rent 273, 279, 280
Fragmentation of holdings 133, 186, 275
Fruit trees 2, 3, 6, 7, 17, 26, 31, 35, 43–47, 49, 51, 53–56, 61, 62, 65, 66, 68, 72, 74, 75, 80, 94, 95, 98, 110–113, 115, 143, 144, 148, 149, 155, 172, 205, 224, 273, 299, 300, 301, 312, 314, 320, 342, 358, 363, 365
Functional characteristics 91, 94, 99
Functional differentiation 89
Functions 6, 16, 18, 21, 23, 52, 69, 91, 98, 117, 126, 129, 135, 136, 158–160, 165, 168, 174, 176, 234, 235, 240, 247, 248, 270–273, 293, 319, 320, 342, 355

Gender relations 159, 160, 181
Genesis, homegardens 2
Global distribution, homegardens 2–5
Globalization 26, 227, 275,

Handicraft plants 27, 30
Health care 144, 177, 333
Herbal medicine 206, 226, 227
Hillside gardening 38
Historic development, homegardening 15, 17
Historical accounts, homegardening 45
Homegarden management 53, 101, 178, 351
Homegarden model 318, 327–329
Homegarden, types 2, 15–18, 20, 89, 91, 92–100, 129–132, 237, 239, 240, 245, 246, 330, 336
Homegardens, extent 3, 4, 38, 186, 207, 301, 325

Importance value index 360
In situ conservation 69, 103, 205, 339, 340, 348, 352–354, 363, 370
Incident radiation 61, 68, 80, 81, 251, 252, 257, 260, 261, 263–265
Indigenous knowledge 8, 41, 43, 48, 62, 177, 180, 205, 225–227
Indigenous people 46, 80, 143
Institutional support 299, 313, 315
Intangible benefits (*see also* non-market benefits) 8, 283, 284, 286, 287, 293, 356, 361
Integrated farming system 9, 16, 123, 124, 129
Intellectual property rights 227
Intensification 2, 19, 20, 25, 101, 106, 118, 195, 199, 201
Intercropping 108, 118, 203, 229, 300
Internalization of externalities 269, 280

Japanese-Brazilian 10, 60, 84, 300, 302, 338
Javanese 2, 15–18, 21, 35, 30, 41, 140, 158, 187, 188, 201, 250, 271, 275, 281, 302, 320, 353, 354

Kandyan gardens 22, 266
Keystone species 123, 136–139, 195, 361
Kitchen garden 18, 38, 40, 176, 319
Knowledge transmission 177, 178
Knowledge erosion 178
Kyoto protocol 196, 198, 199, 272

Land tenure 51, 53, 169, 170, 181, 272, 274, 285, 325, 326
Leaf area index 258
Livelihood security 138, 198, 199, 327, 337
Livelihood strategies 15, 16, 24, 318
Livestock (*see also* Domestic animals) 4, 17, 26, 38, 53, 55, 62, 65, 76, 125, 128–133, 135–137, 139, 144, 161, 165, 200, 205, 207, 213, 225, 230, 236, 237, 243, 244, 270, 283, 286, 319, 324, 369
Living edible pens 34

Malnutrition 15, 41, 61, 66, 74, 77, 328, 337
Management intensity 17, 91, 95, 100
Management practices 26, 56, 78–81, 87, 90, 91, 95, 96, 100, 101, 137, 180, 193, 199, 226, 249, 337, 340, 349
Management strategies 9, 61, 229, 282, 283, 294, 317, 326, 330, 336, 368
Margalef index 360
Market access 19, 339, 341, 347
Market garden 18, 20
Market pressure 154, 233, 234, 364
Market value 130, 275, 278, 284, 285
Marketing 16, 19, 40, 56, 108, 118, 136, 172, 173, 226, 274, 275, 301, 314, 331, 335
Market-oriented systems 364
Matsiguenka 143, 145, 147–158
Maya 61, 62, 64, 65, 68, 70, 72–74, 76, 78, 80–84, 138, 157, 160, 162, 163, 165, 169, 170, 172, 173, 175, 176, 178–182, 199, 200, 207, 226, 229–231, 250, 265, 266, 353
Medicinal plants 8, 16, 27, 28, 35, 36, 46, 49, 68, 69, 91, 98, 142, 148, 153, 155, 171, 175, 177, 205–207, 211, 213–215, 224–231, 271, 285–287, 301, 311, 320, 348, 363, 364, 369
Melanesian agriculture 105, 118
Mesoamerica 2, 6, 44, 61–78, 80–83, 135, 139, 160, 162, 163, 165, 169, 170, 172, 182, 186, 202
Mestizo 48, 158, 160, 170, 179
Micro-economic approach 278
Microgranjas 319
Mixed gardens 17, 18, 235
Modeling 252, 266, 269, 270, 276–278, 280
Modernization 22, 66, 87, 101
Monocultures 187, 235, 245, 273, 300, 364
Multispecies systems 87
Multistrata systems 1, 2, 68, 82, 88, 105, 111, 116, 117, 138, 157, 185, 187, 192–194, 196, 199, 206, 225, 226, 229, 240, 245, 250, 269–271, 273, 275, 277, 279, 281, 294, 299, 313, 314, 356, 361, 370

Net primary productivity 185
Nitrogen fixation 78, 82, 185, 196, 294, 350
Non-food plants 27, 29, 30
Non-market benefits (*see also* Intangible benefits) 284
Non-monetary benefits (*see also* Intangible benefits) 283, 291
Nutrient cycling 55, 62, 67, 78, 80, 81, 124, 135, 202, 269, 272, 274, 280, 281, 340, 350, 361, 369

Nutrient outputs 194
Nutritional security 7, 14, 117, 274, 284, 287, 293, 294, 359, 361, 362
Nutritional value 16, 61, 117, 247, 271
Nutrition-related non-communicable diseases 26, 39

Olympe 276, 280–282
Opportunity costs 285, 288
Organoponics 319
Ornamentals 2, 18–20, 31, 36, 49, 71, 90, 98, 99, 101, 124, 133, 134, 162, 171, 211, 224, 342, 350, 365

Patrimonial analysis 277
Patrimonial strategies 271, 277, 280
Pekarangan 2, 3, 16, 17, 22, 186, 249, 271
Penman-Monteith equation 258, 263
Periurban typology 337
Physical environment 133, 234
Phytochemicals 205, 228
Phytoremediation 198, 274
Pielou evenness index 342, 344, 345, 352
Plant diversity *(see also* Crop diversity, Biodiversity, and Diversity index) 17, 30, 62, 70, 72, 143, 144, 158, 175, 181, 193, 197, 202, 203, 232, 233, 236, 237, 248, 339, 340, 351, 370
Plant genetic resources 55, 103, 340, 348, 352–354, 370
Policies 101, 199, 226, 249, 272, 275, 335
Population density 14, 27, 65, 66, 68, 108, 127, 132, 133, 247, 275, 341
Poverty 25, 36, 39, 61, 65, 66, 74, 75, 77, 80, 176, 198, 203, 312, 314, 318, 328
Profit 227, 283, 285, 287–293, 361

Radiation interception 251
Rainforest 59, 64, 83, 143–145, 149, 156–158, 201, 315, 340, 341, 354
Regression 132, 133, 193, 258, 262, 287, 290
Residue management 61, 78, 81
Resource utilization efficiency 196
Ribereño 43, 44, 46, 47, 50–52, 54, 55, 58
Rights 32, 51, 168–171, 181, 227, 272, 274, 326
Rights to plants 170, 181
Risk buffering 269, 271, 274, 276, 278, 279
Roadside gardening 69, 76, 326
Rooftop gardening 319
Rural development 22, 56, 61, 77, 90, 102, 234, 299, 300, 314, 316, 338
Rural transformations 13, 15, 20, 21

Sap flow gauges 251, 255, 265
Sap flow rate 251, 256–259, 262
Sapwood cross-sectional area 260
Sensitivity analysis 283, 289, 290
Shannon index 91, 93, 94, 342, 344, 345, 347, 348
Shannon-Weaver index /Shannon-Wiener index 105, 109, 110, 111, 114, 116, 236–239, 360,
Shifting cultivation 1, 2, 14, 16, 17, 20, 21, 106, 143, 144, 158, 162, 225, 228, 349, 360
Slash and burn 75, 143–145, 188, 225
Social and economic functions 235, 320
Social capital 249
Social dynamics 82, 88, 124, 159, 229, 368
Social networks 175, 178, 179, 248
Social status 159, 161, 174, 176, 179, 272, 278
Social sustainability 13, 22, 88, 101, 102, 274, 355, 361, 362
Social-ecological perspective 277, 281

Socioeconomic change 13, 14, 87–89, 101, 123
Socioeconomic sustainability 14, 15, 87, 89, 135, 136, 366
Soil biota 194, 195, 198
Soil carbon sequestration 82, 197, 202, 368
Soil erosion 78, 203, 274, 340, 349, 350, 352
Soil fertility 19, 37, 56, 117, 118, 135, 207, 270, 312, 339–343, 345–347, 349–352, 356
Soil organic matter 81, 185, 195, 197, 274
Sørensen's Index 147, 148, 342, 345
Spatial densification 318
Species abundance 130, 174, 195, 197, 330, 342, 360
Species composition (*see also* Species diversity) 9, 17, 53, 58, 61, 66, 68, 87, 100, 123, 128–130, 135, 147, 148, 158, 186, 199, 213, 224, 230, 240, 248, 311, 339, 349, 370
Species density 87, 90, 92, 342, 344, 347, 351
Species diversity (*see also* Species composition) 7, 57, 61, 69, 72, 73, 84, 98, 101, 109, 111–113, 116, 123, 128, 130, 131, 133–137, 143, 154, 156–158, 160, 162, 176, 185, 201, 203, 213, 225, 231, 245, 250, 281, 282, 301, 317, 330, 339, 340, 351, 353–355, 357–362, 365
Species introduction 49–51, 53, 56, 91, 98–100, 214, 230, 233, 235, 300, 302, 304, 306, 308, 310–313, 363
Species richness 91, 109, 130, 132, 133, 134, 137, 143, 154, 156, 157, 186, 293, 343, 344, 347, 348, 351, 362
Staple crops 32, 38, 80, 165, 352
Streuobst 6, 9
Structural complexity 8, 61, 67
Structure of homegardens *(see also* Vegetation structure*)* 13, 18, 22, 66, 69, 89, 116, 173, 234, 237
Structure, horizontal 61, 66–68, 69, 80, 109, 111–113, 234,
Structure, vertical 61, 66–68, 80, 89, 105, 109, 111, 113, 116, 171, 196,, 234, 241, 245, 252, 253, 259, 274
Subsistence crops 17, 57, 171, 271
Subsistence garden 6, 18, 20
Sundanese 16–18, 247
Survival garden 20
Sustainability indicators 339, 340, 352
Sustainable production 72, 234, 311, 315, 339
Swidden agriculture 51, 143
Swidden fallow/gardens 46, 58, 65, 84, 144, 145, 160, 165–167, 174, 176

Talun-kebun 2, 16, 17, 22, 249
Temporal dynamics 108, 110, 112, 115, 348
Thermal dissipation probes 251, 255, 256
Tokunō 299, 311–315
Totonac 70, 76, 79, 82, 171, 180, 181
Traditional agroforestry 9, 13, 22, 23, 25, 74, 83, 102, 103, 125, 139, 231, 249, 250, 354
Traditional homegardens 22, 52, 78–80, 82, 87, 88, 100, 101, 103, 173, 174, 180, 230, 234, 247–249, 294, 355, 356, 361, 362, 365
Traditional medicine 205, 206, 225, 227
Traditional vegetables 73, 247, 326
Transmigrants 18, 353
Transmigration 20, 342
Transpiration 251–267
Tree management 45, 69, 72, 73, 80, 87, 89–91, 95–102, 137, 161, 170, 176, 193, 195, 226, 228, 274, 330, 331

Tree root systems 190, 193, 196, 197, 201–203, 251, 252, 262, 264, 366
Tree tenure 170, 181, 280

Urban homegardens 7, 8, 19, 229, 317, 319–321, 323–325, 327, 329, 331–338, 355, 364–366, 368
Urban poor 317, 318, 328, 329, 331, 337
Urbanization 18, 25, 26, 179, 186, 235, 318, 325, 333, 337

Value addition 205, 225, 227, 228
Vegetation dynamics 339
Vegetation structure *(see also* Structure of homegardens*)* 17, 90, 91, 98, 99, 105, 106, 108–110, 112, 116, 124, 127, 137, 158, 201, 240, 241, 248, 252, 340, 353

Whole-farm analysis 276
Women 27, 74, 77, 159–182, 214, 216, 227, 230, 274, 294, 319, 320, 325, 338, 357, 359, 361, 362
World Trade Organization 227

Zonation 83, 103, 139, 158, 182, 230, 250, 281, 294

Advances In Agroforestry

1. P.K.R. Nair, M.R. Rao and L.E. Buck (eds.): *New Vistas in Agroforestry*: A Compendium for the 1st World Congress of Agroforestry, 2004. ISBN 1-4020-2501-7
2. Janaki R.R. Alavalapati and D. Evan Mercer (eds.): *Valuing Agroforestry Systems*: Methods and Applications, 2004. ISBN 1-4020-2412-6
3. B.M. Kumar and P.K.R. Nair (eds.): *Tropical Homegardens*: A Time-Tested Example of Sustainable Agroforestry, 2006. ISBN 1-4020-4947-1