ADVANCES IN AGROFORESTRY RESEARCH

Proceedings of a seminar held in
CATIE, Turrialba, Costa Rica from
September 1 to 11th, 1985, and sponsored by
Centro Agronómico Tropical de Investigación
y Enseñanza (CATIE) and Deutsche
Gessellschaft für Technische Zusammenarbeit (GTZ)

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CENTRO AGRONOMICO TROPICAL DE INVESTIGACION Y
ENSEÑANZA (CATIE)
DEUTSCHE GESELLSCHAFT FUR TECHNISCHE ZUSAMMENARBEIT
(GTZ) GmbH
1987

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1. INTRODUCTION TO THE SEMINAR

J. Heuveldop*

Sometimes one gets the impression that people talk about agroforestry as either:

- the solution of the problems in the tropics
- the new technology that was discovered by science and is now under development
- a complication of traditional land-use practices

Many foresters play and have played an important but also contradictory role in the use and promotion of agroforestry as one instrument for rural development. The contradictions between foresters and agriculturists are more than just a tradition: it is competition between two different ways of thinking, two philosophies. And as far as the combination between the two sciences and land-use forms are concerned, it sometimes seems almost impossible to achieve a consensus about problem identification, principle goals and management, or choice of techniques. Resources are limited. Land, especially arable land is not multiplicable. We are confronted with the dilemma that we depend on both forest and agricultural products, which are not increasing at the same rate as populations increase. This is not specific for the tropics. The same problem has occurred wherever demographic pressure was high and increasing. The problem is not new, it has always existed all over the world where man has settled and begun to cultivate the land. This problem consisted in the deterioration of soil fertility, scarcity of wood products and disbalance in ecological cycles, leading to general impoverishment. Higher inputs were required and whenever limits were reached the only remaining solution was to seek new areas.

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About 200 years ago the English economist Robert Malthus stated in his famous paper "On the principles of population" that man would soon suffer terribly from hunger and diseases as population growth is much more rapid than any growth in food production can be. As far as the industrialized countries are concerned, history has shown that he was mistaken. Malthus did not appreciate the potentials for technical development, and that higher living standards lead to reductions in the rate of population increase.

We now know, that total potential food production on earth is sufficient to support more than 6 billion people. But Malthus' thesis is still valid with respect to the situation in developing countries. Recently FAO presented a study on land, food and people, based on an analysis of 117 developing countries. This study shows, that 36 countries still would not be able to feed their populations, even if the total potential arable lands were cultivated and managed at least at a medium technical level. For some countries, as in Asia, this prognosis might not be alarming, as high levels of technology are already in use. But in Africa and many Latin American regions, present development seems to run into catastrophies. This is because of the lack of economic incentives but also because of the lack of knowledge. The priorities for these countries are obvious: there is an urgent need for site-adapted land-use techniques. And for this, problem oriented training, research and extension are basic requirements.

However, to expect immediate solutions would be unrealistic. But just because of this fact there is no time for waiting, and measures with long-term consequences have to be taken now.

Agroforestry is one of these measures and all the mentioned aspects fit into it. It is a technique for rural development in devasted, deforested areas as well as in areas still covered by tree vegetation where population densities are high and increasing. But what do we, as scientists, really know about potentials and contraints? Numbers of publications are already written about this and a lot of high-level workshops, symposia, seminars have tackled this same question. Not everything thus presented is unique! Of course, repetition is unavoidable. In fact, repetitions and a continuous and critical dialogue, not only on new but also on the old ideas, is one of the most important fundamentals for development.

For this meeting we have invited a number of colleagues whom all have years of practical experience. Several could not attend and the list of well known scientists in the field of agroforestry is of course much longer than the list of participants of this seminar, but we had to limit the invitations. However, we hope that the proceedings, which will be published in both English and Spanish, will reach all those who could not participate. And thus we hope that the "circle" of discussion will be open to all.

The structure of the seminar, as you hopefully have seen from the programme, shows that we aim at a global view of what is going on in agroforestry research. The emphasis of this meeting is set on the analysis of what is known and what we have done so far, to exchange experiences, and finally to summarize the results in a recommendation paper for the research centers and the organizations we are connected to.

The first set of presentations focuses on something we could call "the state of the art". Dr. v. Maydell starts this series with a presentation on "High lights in agroforestry research and practice".

As is well known, before development comes research, and the second group of presentations is concerned with functions and dynamics in order to understand the mechanisms and cycling patterns that govern agroforestry production systems.

Transfer of knowledge and technology is always a key point. This involves problem identification, problem orientated studies, farmers' perceptions and long-term effects of applied techniques. The next group of presentations will handle various questions related to this item.

Biologically orientated field work quite frequently misses out social aspects, economics and ergonomics. This easily leads to invalid concepts, policies and techniques, and finally in that our target group finds itself confronted with products that are hard to understand and to assimilate. We have to be more concerned about this and the final group of presentations will high-light some experiences and ideas for a better approach.

After this final set of presentations, participants will join one of 3 working groups to make a critical analysis of all papers. The lack of knowledge and the gaps detected are to be outlined briefly. More importantly the groups will elaborate recommendations that will guide us to a more problem orientated approach.

The three working groups will analyse the presentations on:

A soil and plant aspects of agroforestry systems;

B diagnosis and technologies for agroforestry;

C economics and ergonomics in agroforestry.

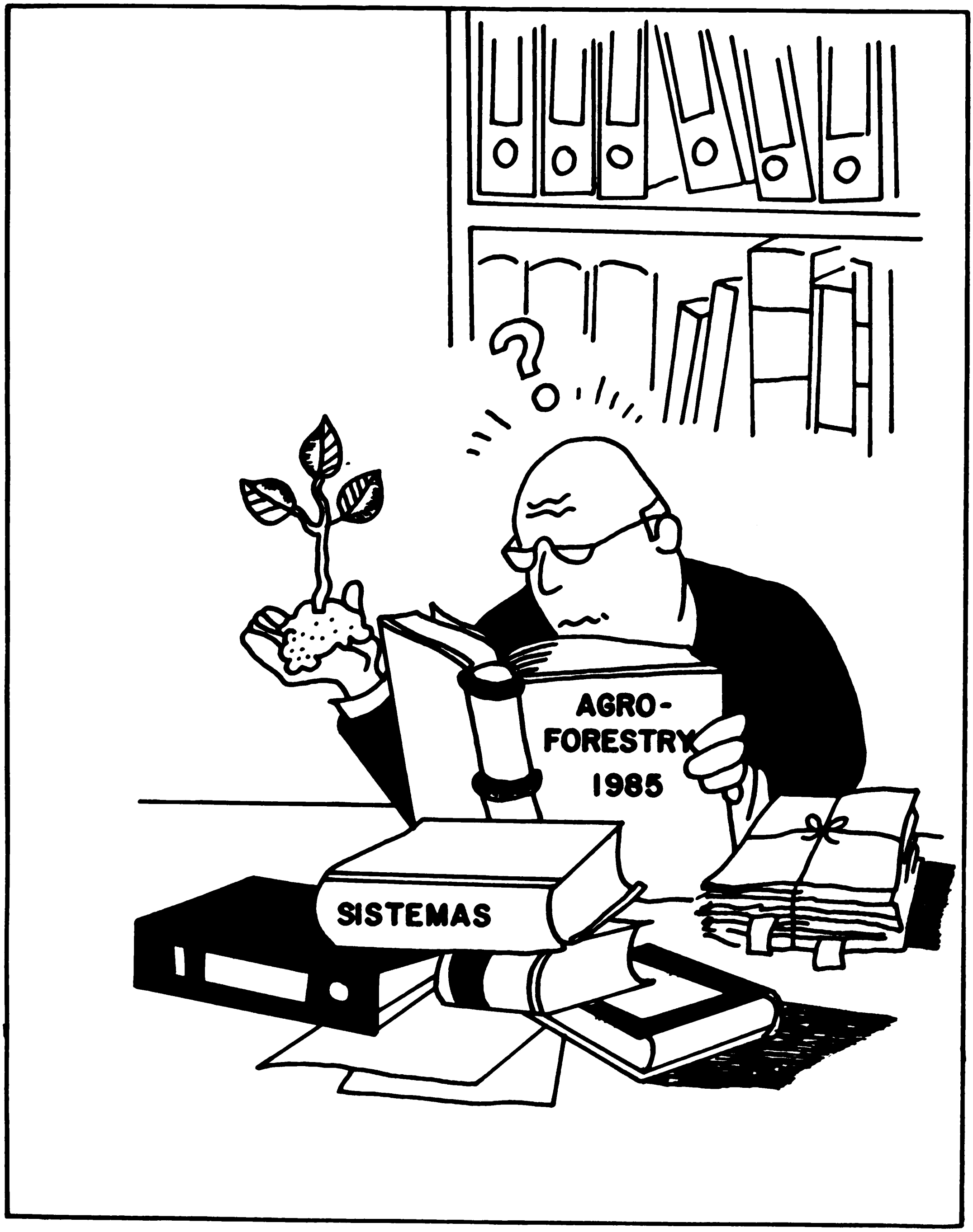
2. ACKNOWLEDGEMENTS

This seminar forms part of the terms of reference of the technical agreement between GTZ and CATIE. It is thanks to both institutions that we could hold this meeting and publish the proceedings. GTZ provided the necessary funds and CATIE all the infrastructure.

The editors thank all participants for their presentations as well as their critical and constructive observations. We also thank all colleagues at CATIE who helped in reviewing the texts.

The English version of the proceedings was the first to be edited. Editing of the Spanish translation was meticulously carried out by Carmen María Rojas. Special credit is also due to her for completing the tedious task of verifying and correcting the bibliographies of each paper. Many of the authors helped with translations of their papers; the rest were principally translated by Tirso Maldonado (English to Spanish) and Susan Shannon (Spanish to English).

Finally we give our warmest thanks to the "keystone" of the "CATIE-GTZ Agroforestry Cooperation project", Lilliam Ugalde de Brenes, who served as executive secretary for the meeting, and who did most of the typing for both versions of the proceedings. In this work she was assisted by Rita Aguilar, Ana Cristina Marschall, Yorlene Pérez, Miriam Romero, Ana María González and Gloria Rojas. Emilio Ortiz prepared the figures for the technical articles and A. Roesler the drawings dividing the different sections. Elizabeth Mora provided essential advise on the layout of the text and supervised the preparation of the final copy for the printers. Full credits for the various activities involved in the organization and publishing of this seminar, both in English and in Spanish, are given in the Appendix.



STATE OF ART IN AGROFORESTRY

HIGHLIGHTS IN AGROFORESTRY RESEARCH AND PRACTICE

H.J. von Maydell*

SUMMARY

During the past decade agroforestry has succeeded in becoming widely accepted in many rural development programmes of the tropical world. This was due to a straightforward problem orientation, an outstanding flexibility of strategies and practices, and a high adaptabilility to environmental and socio-economic conditions. The future challenge lies in finding answers to overcome the general crisis resulting from obvious limits to overall quantitative growth. This can be achieved through more intensive cultivation methods rather than expansion, through qualitative improvement, diversification and a holistic approach to developing land use systems.

INTRODUCCION

"Agroforestry is only a new word, not a new practice. Its novelty lies in the realization that so many land use systems and practices ... have a common denominator in approach, worth exploring and developing in a more systematic and scientific way" (3).

A multiple use of woody perennials as components of ecosystems and land use systems is perhaps as old as any human interference with the environment. Why, then, has "agroforestry" as a new term and "new concept" become so vigorously, if not explosively, established? What happened within the last two

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decades, or rather within the eight years since the Bene/IDRC-report (1) and ICRAF's foundation?

Isn't agroforestry a relapse into stone-age practices, based on unrealistic (by far too high) expectations, unproven assumptions, nostalgic/ideologic feelings and/or helplessness vis-a-vis increasing problems of future rural development?

Highlights - what does that mean and does it apply to agroforestry? I have more questionmarks to offer than exclamation marks. But our "western" society and civilization was built on the "philosophy of questionmarks", and we are all members and components of this "questionmark society" - even if we question its validity!

I believe in agroforestry, I am optimistic. This paper is not to add another list of definitions and of expectations. It is rather an attempt to briefly reflect upon some evolutionary trends arising from the past decade and the challenges - and hopefully highlights - that lie ahead.

LIMITS TO GROWTH

Fighting for survival and progress is one of the basic axioms of our development-oriented strategies. But fighting destroys or at least consumes resources, time and energy. Nature achieves an incomparably high degree of energetic efficiency by what may be called the "Jiu-Jitsu-Principle". This means simply to utilize already existent forces and energies and to divert these in a desired direction instead of combating them. Combining ones own forces with those of others is always more effective than subtracting them from each other.

This simple rule has more and more been neglected or even suppressed as people, disposing of powerful capital and technological means, felt strong enough to rule "their world". We are now in the process of discovering previously unexpected or underestimated limits to growth, limits of the ecosystems' carrying capacity, critical values, and alarming feedbacks between man and his environment.

According to "Global 2000", the "Club of Rome" and other sources, Homo sapiens is obviously facing basic problems of survival. He is reaching (or has even surpassed) limits of quantitative-expansive growth. Population growth, technical and economic growth, and even individual and social freedom growth have come to critical values which may - sooner or later - result in a collapse of the overall ecosystem. I may briefly mention that only within the past 100 years an hitherto unprecedented, incredible "mining" of the globe's fossil energy resources has inaugurated an explosive growth of resource conversion, growth of knowledge and "manpower", of communication, information, etc, and last but not least, population. Someone has calculated that - assuming an average weight of 60 kg per person, and assuming the present population growth rates continue - in about 1,500 years the world's population would have surpassed the globe's total present weight, in about 2,400 years the weight of our solar system, etc.

I am not going to predict a gloomy future. We should not forget that paradise has never existed on earth and that in fact most if not all cultural developments and achievements were reactions to crisis. Our crisis is that our quantitative growth will have to come to an end. That means the economizing of the use of resources and a revision of the philosophy of "eliminate the useless and/or competitor". We have to join our efforts in order to survive. Even if this will be a slow and stony evolutionary process, I would call this hope.

What does all this mean in simple words and facts for agroforestry? The general experience appears to be that the less resources that are available, the more we need to concentrate our efforts to make an optimal use of time, space and life (species diversity). This is a mandate for agroforestry, and if you agree, the highlight for agroforestry's future. Like all living organisms we will have to change from exponential quantitative to qualitative forms of growth. This is the natural process of maturing of individuals and societies which we will have to imitate, or in which we will have to join.

In land use this will imply intensification instead of expansion. There is anyway hardly any cultivatable land available for expansion. Forces should be concentrated on achieving higher "values" per biomass unit instead of higher mass production per area unit, etc. We know from homegarden systems in Java and other places that a family can live from even less than one hectare. In Central Europe about 4.5 people are fed from one hectare, whereas 150 years ago the figure was 0.8. For shifting cultivation and several recent settlement programmes more than 100 times that area merely support a marginal subsistence. And even this entails an increasing, sometimes irreversible destruction of soils, gene resources, etc., which threatens the future of millions. Sustainable land use on small areas will have to be developed, reducing risks, reducing external dependencies, improving the life quality and allowing for reasonable development aspirations to overcome "burning" problems. A challenge, indeed.

The foresters amongst us have learnt from harmful experience that we cannot protect our beloved forests against invading farmers, herdsmen and other "aggressive" land users. One of the reasons is that we are in a minority.

The main reason, however, appears to be that the foresters have not at all times, and at the right place, succeeded in proving that the benefits from their forests are irreplaceable and of immediate importance for those who live in or near the forests. Forestry is thus steadily forced back to ever more marginal sites, loosing its best sites and thus its potential, loosing its importance for human life. This is a well known vicious circle. One way out, maybe one of the best, is to join efforts with the former competitors in order to serve man. This trend has very impressively come out from the themes of the four last World Forestry Congresses. Stretching out one's hand was initiated, and is further supported by agroforestry, at all levels from the UN and research centres to the individual working in the field.

The benefits are obvious, and they are mutual. A new awareness for trees and shrubs and the role of forestry for both ecology and economy has been created amongst non-foresters, and a much better understanding has been reached amongst foresters for agriculture and livestock, and in fact, for the rural societies' needs and potentials. This appears to me to be one of the real highlights.

THE HOLISTIC APPROACH

From experience over the past decades of efforts to develop tropical rural areas, it is evident that one-sided, isolated action almost inevitably leads to a disturbed balance of the relevant systems. This may have quite different consequences, subject to varying degrees of persistence and/or resilience of the systems and their components. Hence a comprehensive appraisal of the structures/interrelations and dynamics of such rural systems, and a holistic approach to solving their ruling problems, has been accepted as a pre-condition for sustained development.

Agroforestry offers strategies and practices to meet these requirements, although not generally and as a rule, but subject to different specific ecological, economic and social prerequisites. The expectations have been, and still are, high with regard to three main tropical biomes:

- the humid closed forests ("rain forests"),
- the semiarid lands (open woodlands, savannas, etc.),
- the mountain ranges

Obviously, there are basic disparities between these biomes which require different strategies in land use. Moreover, all three - not only the tropical rain forests -are amazingly heterogeneous and site-specific. Thus, no standardized large scale programme has succeeded in overcoming prevailing constraints and halting further degradation. For many of the sites (not all of them) however, there is a common denominator: marginality (4).

Agroforestry has been able to prove that by its extreme flexibility, adaptability and concentration on small area units, it has a chance to improve land use, especially on those marginal lands. There are many, although certainly not too many, hard facts available from all tropical regions, and a variety of agroforestry land use systems. That is to say, we need not depend on pure assumptions and expectations but can offer results. Many of these results are highlights in practice, others may be disappointing.

The positive results have largely been achieved thanks to a holistic approach, not only to the systems' structures and functions but also to the societies' needs.

These can be roughly grouped into the following categories:

- food
- energy,
- renewable resources,
- environment,
- socio-economic and cultural development

Optimizing the contribution of a given rural system to meeting a spectrum of different demands hiding behind these five categories, has always been agroforestry's prime mandate. And this is obviously more and different from what has been aimed at in most previous forms of land use, which are designed to maximize rather than optimize outputs.

AGROFORESTRY'S CONTRIBUTION TO THE FAO-STRATEGY FOR ACTION

The Food and Agriculture Organization of the United Nations (FAO), in close cooperation with the World Bank, UNDP and other organizations, have developed proposals for "action programmes in tropical forestry". In view of the alarming degradation of the world's tropical forest resources and the threatening consequences for man and the biosphere, five action programmes of high priority have been discussed at the "Seventh Session of the Committee on Forest Development in the Tropics" in Rome, 10-12 June 1985 (2) and at the IX World Forestry Congress in Mexico, July 1985.

The whole strategy comprises:

Forestry in land use

- Harmonization of increasing food requirements with declining areas of productive lands and the implications of various farming systems such as shifting cultivation, nomadic pastoralism and permanent agriculture in forest land use.

- The strengthening linkages of forestry with agriculture and means of creating awareness among political leaders and decision-makers of the contribution of forestry to food security.

- Integration of forestry in land use planning and in rural development projects.

- Involvement of rural people in the conservation and rational utilization of forest lands for the production of food, wood and other forest products and the provision of services, including environmental protection.

Forest-based industrial development

- Establishment of priority actions within this priority area.

- The more effective participation of rural population in forest-based industrial development.

- Solution of possible conflicts between technical and economic, social and managerial issues for the establishment of appropriate industries catering for local markets and for exports.

Fuelwood and energy

- Fuelwood for energy is still considered a noncommercial source of energy: how can this perception on the part of government planning offices be changed in order to achieve a closer integration of wood energy within forestry and with the agricultural and overall energy sectors?

- Producers of fuelwood generally receive a low share of the price paid by consumers, hence they are not motivated to reinvest in production: how can the economics of fuelwood be organized to make growing of fuelwood more attractive? What other incentives are likely to encourage the participation of people in fuelwood production and distribution for domestic and commercial energy generation?

Conservation of tropical forest ecosystems

- Ways of coordinating activities in conservation, management and utilization through involvement of interested groups.

- Strategies for the conservation of genetic resources and ways of reinforcing networks of protected areas as an integral part of overall land use planning.

Institutions

- How the problems of inadequate trained manpower, lack of or out-dated policies and legislation, should be addressed.

- Strengthening and up-grading of public forestry administrations and their cooperation with other government agencies and the private sector.

- Ways and means of creating public awareness of the role of forestry in socio-economic development and of attracting financial and political support to forestry.

The above are but a few examples of the numerous issues that need to be addressed in planning an effective programme for the conservation and development of tropical forests.

It is obvious that agroforestry is not only expected to play an important role in the implementation of this action programme. In fact agroforestry can not only offer a remarkable potential for solving the prevailing problems but has already been contributing in a remarkable way. The future challenge for agroforestry will, however, be to intensify and concentrate efforts, to act as a catalyst when joining efforts worldwide, and at the same time not to loose its originality and identity. Another challenge that appears to arise from the FAO-Strategy is to involve agriculture and livestock management (including game, fish, insects, invertebrates). Agroforestry could play a catalytic role in this.

THE ROLE OF RESEARCH

A relatively small number of scientists, managers and experts have succeeded in directing rural development over the past centuries and decades. These people were generally not involved with the cultivation of their own lands but were rather "remote", with laboratories, trial plots, desk research, advisory or executive boards and administration. Millions of rural people, however, were recipients rather than contributors, somehow excluded from the (upper) decision levels in rural policy and technical and/or economic progress.

A common activity of agroforestry programmes is that the wisdom of traditional land use and even of the "rural poor" is systematically re-discovered. Whereas modern systems analysis,with their holistic and necessarily interdisciplinary approaches, demand high level team work of specialists, simultaneously the simple, unskilled farmer or herdsman quite often has less problems in implementing the systems in the field. He does not need a computer either! Since ages, he has applied the so-called "fundamental biocybernetic rules" like the aforementioned Jiu-Jitsu principle or that of multiple use, of recycling, of symbiosis. He will have used other names, but does that matter? He is using competition, complementarity and mutual dependence of plants and animals to optimize, in a sustainable way, (rather than to maximize) productivity, stability and diversity. And he just "lives" adoptability instead of trying to justify what he thinks to be appropriate. Adoptability, as an essential criterion for effective land use, has been rediscovered, analogous to what nutritionists mean if they say that the nutritional value of any food that is not eaten is zero, regardless of its chemical composition (5). The improving dialogue between scientist or planner and the practical "agroforester", the man or woman in the field, is another highlight, an encouraging trend.

What, specifically, has the researcher got to tell the man in the field? I think, it is a lot both in quantity and in quality, but it will have to be carefully screened. In some way he has to replace the "prophets" as well as the craftsmen of olden times. His means, however, of achieving and distributing knowledge are technically more efficient than previously. That is to say, he has got an enormous responsibility.

In fact, the main question he is expected to answer is "where do we go from here?" Thus he will have to identify problems and to find out ways of avoiding or overcoming them. He will have to discover potentials and opportunities and to find out how to make the best use of them. And, almost everywhere, he will be expected to build the bridges between the widening gaps of here and today to there and tomorrow, across quite inaccessible "environments". This is a pioneer, a spearhead role which depends on a steady feedback with those who follow.

The past decades have brought tremendous achievements in technology. I may just briefly refer to the results of the Institutes of the Consultative Group on International Agricultural Research (CGIAR) and the national and private research bodies. Tissue culture, gene technology, biochemistry, electronic data processing are only a few terms indicating developments similar to the previous discovery of how to make and maintain fire.

Does agroforestry participate in these revolutionary efforts or does it return to slightly modernized stone-age levels? Where are our future highlights in strategic research? Is it a highlight to become aware that we must not do all that we can? Is it a highlight to discover that our technical means are, by far, more advanced than our social and cultural structures? Do our researchers recognize limits to growth and does their spearhead information reach the man in the field?

I think, the ICRAF concept of diagnosis to agroforestry design is an important answer to some of these questions.

But let me insist: Does agroforestry establish a bridge between old, traditional land use practices and the off-take of modern technologies? How does agroforestry respond to the problem that we may move from former mono-species cultures to mono-cultivar cultures with all their problems? When considering specific plants or animals do we take the chance to enlarge rather than to narrow their range of uses,-their resistance,their site adaptability? There are more question marks than answers, if I am right.

THE OUTPUT

The crucial question from the farmer's point of view is: "Does it pay"? Similar questions will have to be answered for industrial land use enterprises, projects at all levels and governments. Can agroforestry as but one amongst many other options to land use successfully compete? This will have to be carefully investigated and proven, based on hard facts. There is, however, still a gap in appropriate monitoring and evaluation methods for agroforestry. Agroforestry's output is not limited to a specific crop, to cash income, etc. but to a much wider and more diversified contribution to human welfare.

A number of criteria can be applied to get answers:

- is agroforestry effective, i.e. are the methods and practices appropriate to meet rural development targets?

- is agroforestry efficient, i.e. can the input/output ratio be justified for a given project or farm?

- is a specific agroforestry project significant, i.e. does it have a lasting relevance and a multiplier-effect? Is it transferable?

Most important is the question, whether the so-called target group, the rural population, will be ready and capable of continuing with their own means and resources after an initial, outside-sponsored introduction of agroforestry systems to their land use.

If returning, after years of absence, to a formerly initiated agroforestry project we discover that the environment was ameliorated, people are better off and the farmers have improved our previous system, only then may we rightfully speak of a "highlight" in agroforestry. I am looking forward to hear about such highlights in the course of our meeting.

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SIGNIFICANCE OF SOCIAL ORGANIZATION AND CULTURAL ATTITUDES FOR AGROFORESTRY DEVELOPMENT

K. F. Wiersum*

SUMMARY

Several socio-cultural factors should be considered in agroforestry development. Many of these factors influence any land-use practice, but some are specifically related to the cultivation of trees. During recent years our understanding about the significance of several such factors has advanced significantly. These include lack of homogeneity in village structure, land and tree tenureship arrangements, division in sexual roles and local perceptions and attitudes to trees. These factors are often interrelated and there exists a consistency between the behavioural pattern of a society and its resource use practices. Based on such consistencies various types of lifestyles with specific strategies for resource use can be distinguished. Such lifestyles are not static, but dynamic. Consequently both traditional and adaptive strategies of resource use can be found. Often the strategies also involve the use and management of trees. Such indigenous practices of tree management can often form the basis for further agroforestry development.

INTRODUCTION

In one of the early definitions of agroforestry one of the specific characteristics of this form of land-use was indicated as "the application of management practices that are compatible with the cultural practices of the local population" (13). Later definitions have omitted such prescriptive characterization of agroforestry. However, this example shows how one major

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reason for the scientific development of the concept of agroforestry was closely linked with the desire to develop land-use systems which are well-adapted to the socio-cultural life of rural people, especially those living under marginal conditions.

It is obvious that such a claim for agroforestry development can only be substantiated if close attention is paid to socio-cultural factors influencing land-use and tree management. This paper will discuss several such core factors of human behaviour and way of life, and social organization. First some of the major socio-cultural variables influencing agroforestry development will be indicated. These variables are interrelated with other variables of human environment such as economic and bio-ecological conditions. Together they result in specific strategies to use and manage natural resources. Different broad categories of traditional lifestyles may be used to designate different levels of intensity of such resource use, including the control of forest and tree resources. These lifestyles, however, are not static and adaptive strategies may evolve to respond to changes in the human environment. In the second part of the paper the significance of these traditional and adaptive strategies of resource use for the development of agroforestry will be discussed.

SOCIO-CULTURAL FACTORS INFLUENCING TREE GROWING BY RURAL PEOPLE

Many socio-cultural variables may influence the adaptation and management of trees in farming systems. (4, 5, 15, 16) (Table 1). Naturally, most of these factors do not act in isolation, but they are interrelated with each other as well as with several economic factors. For instance, different demographic conditions will result in different cultural attitudes, while class relations and power structures within a village are often directly reflected in the degree of control over natural resources and other production factors. Other examples are the functional relations between family structure and labour relations. Furthermore, most of the socio-economic variables do not affect tree management only, but they influence the land-use practices in general. In this paper it is not intended to reiterate the significance of all these factors, as many are obvious and well-recognized. Rather the discussion will concentrate on several factors, with relevance for tree growing by rural people, about which our understanding has advanced significantly during recent years. Consequently the following discussion will highlight factors such as the lack of social homogeneity in villages, the many intricacies of land and tree tenureship, the division of sexual roles and local perceptions of trees.

Table 1. Major socio-cultural variables influencing agroforestry development

Demographic situation	population density and distribution population growth migration patterns
Village structure	ethnic groups class relations power structure local institutions
Family organization	kinship relations family structure household composition
Labour relations	household labour mutual labour relations rented labour
Tenureship arrangements	land tenure tree tenure grazing rights
Sexual roles	
Local knowledge and beliefs	education level religion attitudes to trees food preferences

Lack of homogeneity in village structures

In many tropical countries villages are made up of a mosaic of different population segments. Such stratification may apply both to the cultural background and socio-economic position of villagers. Although in some traditional societies, villages may be only populated by people from one tribe with similar cultural backgrounds and land-use practices, at present in many villages the cultural background of people is more heterogeneous due to the influx of migrants from other regions. The people of these different descent groups often apply different land-use practices and consequently various types of land-use systems may be found in one village. The differences between such systems may be drastic, e.g. in the case of pastoralist nomads migrating to areas with settled agriculture, or lowland farmers migrating to mountainous areas. But more often the differences will be more subtle. For instance, under the influence of both cultural and economic factors immigrants may not have the same rights to land as autochthonous people. Or conversely, immigrants may have access to labour sources or financial resources from their area of origin, while local people lack such resources.

An interesting example of how various factors may interact is provided in the South West Ivory Coast. Immigrant Baoulé farmers managed to secure large tracts of land in spite of the traditional control over land by the autochthonous people. Factors contributing to this change were the more intensive land-use systems of the Baoulé and their use of tree planting as a means of establishing rights to land. The autochthonous farmers practiced an extensive system of subsistence shifting cultivation with rice (Oryza sativa) as the main food crop. The Baoulé preferred yam (Dioscorea sp.) as a staple crop. The cultivation of this crop could more easily be combined with the growing of coffee (Coffea sp.) and cocoa (Theobroma cacao) than the cultivation of O. sativa. Furthermore, application of such intensive land-use practices was facilitated by the possibility to hire seasonal labourers from their native area (21, 22).

But even without ethnic differences many tropical villages are characterized by socio-economic stratification, e.g. in relation to access to production factors such as land or labour, or ownership of livestock. Such stratification often has implications for the development of appropriate agroforestry designs, as demonstrated by Veer (25) in the Machakos region in Kenya, and by Belsky (1) on the island of Leyte in the Philippines. Consequently, in most cases agroforestry programmes should not be based on the introduction of standard technology packages for whole villages, but rather they should offer different options in line with the needs and potentialities of individual farm units.

Land and tree tenure

For most trees it takes at least several years to produce valuable harvests. Because of this long production period secure tenure arrangements are essential for tree planters to be assured of benefitting from the harvests. In this regard much attention has been focussed on the role of land tenure in agroforestry (12, 14, 16). People who have insecure or short-term rights of access to land can obviously not be expected to make the long-term investments involved in tree planting. More recently it has been recognized that in many tropical countries rights over trees are often distinct from rights over land, and that the ownership of land does not necessarily coincide with ownership of trees (6, 16).

Tenureship arrangements are made up of various kinds of rights, of which the most important are the right to own and the right to use. In regard to ownership three situations are commonly found, i.e. communal ownership, ownership by (extended) families or private ownership. Owners of land may give the rights to use this land to other people. Such a situation cannot only be found on private lands which are rented out or given out under sharecropping arrangements, but also on collectively owned lands. For instance, communal lands may either be used collectively by all villagers, or by certain families and other selective groups, or even by individuals. Such user rights sometimes apply only to certain activities such as grazing or wood collection from the natural vegetation. In other cases these rights may extend to the right to cultivate the land, but different arrangements may still apply to the cultivation of annual as opposed to perennial crops.

A further complicating factor in tenureship is the fact that there may be a difference or even conflict between traditional and modern rights of land and tree use and usufruct, or a difference between the de jure and the de facto situation in control over resources. Tenureship relations are not static, but they are shifting over time, mostly in the direction of privatization. Especially in relation to agroforestry it is of importance, that planted trees are often owned by the planter, even if naturally regenerated trees are considered as a common resource. In many cases it is a sign of land ownership beginning, and indicates a start of privatization of land-use.

Because of the complex situation in regard to land and tree tenureship, these factors need very careful examination in any agroforestry development project. It is essential to identify who holds what rights in order to assure that the planter reaps the benefits of his investments and to avoid unintended destruction of existing rights for gathering or grazing, the exclusion of certain groups from project benefits because they have no rights to plant or own trees, or the capture of the project by people who use it only for the purpose of establishing rights to land (6).

Sexual roles

Forestry has traditionally been a profession dominated by men. On the farm level, however, the role of women in cultivating trees and/or harvesting tree products is often as important as those of the men. In agricultural production as well as in the use and management of trees, women and men usually have separate but complementary traditional responsibilities. For instance, women are usually involved with the collection of fuelwood and vegetables or fruits from the forest. In addition, they often have to take care of the trees around houses, which supply food for both human and animal needs. In contrast, men are often more involved with the use and management of trees for commercial purposes (7, 10). Because of these different responsibilities of men and women, their knowledge on trees may be different. Women are most knowledgeable about such aspects as burning characteristics and dietary value, while men may know more about the value of trees for construction purposes or the preparation of tools. For instance, in Sierra Leone women could list 31 products which were harvested or produced in nearby bushes and trees, while men listed only 8 (10).

The differentiation in sexual roles with women being primarily responsible for subsistence tree production and men for commercial tree production is especially prominent in Africa. An extreme case has been reported from the Kakamega district in Kenya, where all tree planting activities are dominated by men. These trees are used for construction purposes and are marketed outside the village. Women are not allowed to harvest planted trees for fuelwood, but have to rely on the dwindling wood resources of the bush vegetation. This male domination in tree planting is sustained by taboos, which state that if a woman plants a tree, she will become barren or that her husband will die (3). In other areas of Kenya, however, very successful tree planting programmes by women have been developed, not only for fuelwood production, but also for the production of commercial wood, poles, fruits and ornamentals as well as for conservation purposes (7, 24). This demonstrates again, how variable cultural traits of various tribes can be.

Not only are women mostly responsible for the use and management of subsistence tree crops, but also for the planting, management and harvesting of food crops. Under such conditions it is clear that women normally should be involved in agroforestry projects, especially those which aim at the intercropping of food crops with trees producing fuelwood and other subsistence needs. Sometimes women may know best which tree species are most suitable. In other cases agroforestry designs may need to be directed at making a compromise between the interests of men and women. Or special practices may be needed geared to specific women's interests, e.g. in the Kakamega case efforts were undertaken to introduce Sesbania sesban as a fuelwood crop for women, as this woody species is not considered a tree in the region.

In addition to these sexual divisions in interests for tree products, also the sexual division in labour should be considered when introducing new agroforestry schemes. As men and women are often involved in different aspects of agroforestry management, the labour needs and calendar should be assessed for each sex separately. In many cases working days of women are longer than those of men. Under such circumstances needs for women labour may be a limiting factor to agroforestry development. But on the other hand, well-designed agroforestry systems may lighten the time consuming task of women to collect fuelwood.

Women do not necessarily assume traditional roles in all households. In many regions women-headed households (without men) are already common in over one fourth of all households, e.g. as a result of men seeking employment in cities. However, many programmes to provide assistance to agricultural development, including agroforestry schemes, are still based on the assumption that men are heads of households and responsible for all production factors.

Consequently women often do not have access to credit schemes or are left out of land reform programmes. Adjustments in such policies may be necessary to assure that women can also profit from agroforestry development (7).

Local perceptions and attitudes to trees

As indicated by the example from Kakamega, rural societies often have certain cultural attitudes to trees, which can affect tree growing schemes. Such attitudes may take many forms with certain species having a positive significance for religious or harvest functions, while other trees may be subject to certain kinds of taboos. Trees may be seen as dwelling places for friendly ghosts or evil spirits, or as heavens for crop-attacking birds or life-threatening animals. Such beliefs may influence the behaviour of local people in regard to tree management in agroforestry systems.

Although such attitudes should certainly be considered seriously in developing agroforestry, they should not be viewed in isolation from other aspects of society. Some of these attitudes may have an empirical basis, while others may be superstitions which are dying out. Also the degree to which such ideas have actually influenced behaviour should be carefully assessed. For instance, the Sukuma people in Tanzania have been said to have an aversion to trees, which could be related to the pests (weaverbirds) nesting in trees around agricultural fields. But it has been disputed if such an aversion affected tree planting (23).

Local attitudes to trees are not restricted to religious values and local taboos, but relate to an even greater extent to the functions of trees. In several examples it has been found that supposedly local objections to tree growing were not caused by dislikes of trees in general, but rather to the fact that the trees offered in planting schemes did not fulfill the requirements of the villagers (10, 23). In several projects the planting of trees with one purpose only has been stimulated, but in most tropical societies trees have diverse functions (18) and people prefer multipurpose trees. For instance in Malawi a survey of people's attitudes showed, that they were more concerned with the shortage of construction poles than that of fuelwood. Consequently they did not want to plant trees producing fuelwood only. In other regions people have expressed greater priority for fodder and shade trees instead of fuelwood trees, or they preferred fruit trees (5).

Because of the values attached to trees, many rural people have long been actively involved in the conservation and cultivation of certain trees. Local people are often more familiar with raising trees than has been presupposed in the design of official tree growing schemes. For instance in a fuelwood development project in Kenya, which aimed at the increased cultivation of trees on farmlands, it was found that 78% of all households already planted or directly seeded trees. In 38% of all households small backyard nurseries were being managed. In one district an estimated 50 million seedlings were raised in these farmer nurseries, an amount which compares favourably to the number of seedlings produced in the combined national government nurseries (9). The management of such small-scale nurseries or the silvicultural treatment of planted trees often differ from the professional practices of foresters. For instance regular pruning, coppicing and pollarding are common practices for locally planted trees (5).

In the past such traditions of managing trees based on their multiple values for local farmers have gone unnoticed and they have too often been ignored in programmes to stimulate agroforestry. But experience has shown, that indigenous knowledge has to be integrated in rural development efforts (2). The development of agroforestry, wherever possible, should be based on the principle of utilizing the existing practices and in making incremental improvements in them (5, 20). Such an approach assures optimal incorporation of indigenous knowledge and attitudes in agroforestry development.

TRADITIONAL LIFESTYLES AND ADAPTATIVE STRATEGIES

In the above discussion about the significance of various socio-cultural variables for the development of agroforestry, several examples were given of the interrelations between these factors. In a specific society the various demographic, social, religious, productive and other factors are normally integrated within a lifestyle with specific cultural values. Based on these values, there is an internal consistency between the behavioural pattern of the society and their practices for the use and management of natural resources. Such traditional strategies for resource use will be different under various ecological and socio-economic conditions.

The various basic patterns of traditional lifestyles have often been characterized on the basis of the indigenous practices of resource use. A very basic division is that of hunting-gathering, shifting cultivation, permanent field cropping and pastoralism. This typology can be further refined on the basis of various socio-economic characteristics, e.g. by identification of differing levels of skills, the importance of the practices to the local economies, the length of the tradition of the practices, etc. A further important distinction is that between partial and integral systems, relating to the degree that various practices are supplementary to each other (19).

As indicated earlier, a valuable approach in developing agroforestry is to utilize knowledge and perceptions of the local population in regard to trees and forests. These will be different for societies with different lifestyles. Consequently the distinction in various patterns of resource use is of obvious relevance to agroforestry development. Such a typology of behavioural patterns does not only point out some broad differences and similarities about social, cultural, economic and ecological conditions, but also about the roles and values of forests and trees.

However, for developing agroforestry local societies should not only be interpreted in such static ways. Equally important as the identification of traditional lifestyles and strategies of resource use is an analysis of the dynamics of them. In most tropical regions traditional societies are confronted with a growing pressure on resources, because of population growth and migration, alterations in economic conditions, agricultural and technological changes, and rising aspirations and expectations. These increasing pressures have caused a heavy demand for both land and tree resources, which in many cases has resulted in overexploitation of trees not only in forests, but also of those on agricultural lands (5).

Under such conditions where traditional strategies for using trees are breaking down, obviously new strategies have to be developed. But it should not be assumed that such a job can only be achieved through outside interventions. Indigenous strategies of resource use are not static, but rather they adapt to the changing rural situation. Also tree use and management may be involved in such adaptive strategies; interesting examples have been documented for instance for shifting cultivators in the Philippines (17) or for the growing of palms in East Indonesia (8).

Adaptive strategies often start with individual people. For although the overall practices of resource use are normally standardized within a certain society, important individual variation can still occur depending on the experimental basis of individual skill and personal preference for certain crops (11). The final conclusion can be that for the development of new agroforestry techniques attention should not only be given to the presence of traditional strategies, but also to local adaptive strategies and to the integration of experimental skills of local people and professional scientists.

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CLASSIFICATION OF AGROFORESTRY SYSTEMS*

P. K. Nair**

SUMMARY

Classification of agroforestry (AF) systems is necessary in order to provide a framework for evaluating systems and developing action plans for their improvement. The AF Systems Inventory (AFSI) being undertaken by ICRAF provides the background information for an approach to classification.

The words "system", "sub-system" and "practice" are commonly used in AF literature. An AF system refers to a type of AF land-use that extends over a locality. Sub-system and practice are lower-order terms in the hierarchy with lesser magnitudes of role, content and complexity. In common parlance however these terms are used loosely and almost synonymously.

Several criteria can be used to classify and group AF systems (and practices). The most commonly used ones are the system's structure (composition and arrangement of components), its function, its socio-economic scale and level of management, and its ecological spread. Structurally, the system can be grouped as agrisilviculture (crops, including tree/shrub crops, and trees), silvopastoral (pasture/animals and trees), and agrosilvopastoral (crops and pasture/animals and trees). Other specialized AF systems such as

*Already published in Agroforestry Systems 3: 97-128. 1985. Abstract only included here.
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apiculture with trees, aquaculture in mangrove areas, multipurpose tree lots, and so on, can also be specified. Arrangement of components can be in time (temporal) or space (spatial) and several terms are used to denote the various arrangements. Functional basis refers to the main output and role of components, especially the woody ones. These can be productive functions (production to "basic needs" such as food, fodder, fuelwood, other products, etc.) and protective roles (soil conservation, soil fertility improvement, protection offered by windbreaks and shelterbelts, and so on). On an ecological basis, systems can be grouped for any defined agro-ecological zone such as lowland humid tropics, arid and semi-arid tropics, tropical highlands, and so on. The socio-economic scale of production and level of management of the system can be used as the criteria to designate systems as commercial, `intermediate', or subsistence. Each of these criteria has merits and applicability in specific situations, but they have limitations too so that no single classification scheme can be accepted as universally applicable. Classification will depend upon the purpose for which it is intended.

Nevertheless since there are only three basic sets of components that are managed by man in all AF systems, viz. woody perennials, herbaceous plants and animals, a logical first step is to classify AF systems based on their component composition, into agrisilvicultural, silvopastoral and agrosilvopastoral (or any other specialized) systems. Subsequently the systems can be grouped according to any of the purpose-oriented criteria. The resulting system name can thus have any one of the three basic categories as a prefix; for example agrisilvicultural system for soil conservation.

Some of the major AF systems and practices of the tropics are grouped according to such a framework. The scheme appears a logical, simple, pragmatic and purpose-oriented approach to the classification of AF systems.

ECONOMICS IN AGROFORESTRY

D. A. Hoekstra*

SUMMARY

A brief literature review of the methodological aspects of the economics of agroforestry is presented. It is stressed that there is in general a lack of economic data on most systems, and hence much more attention should be given to data collection. Attention is also paid to non-numeric methods of analysis, treatment of risk and valuation of typical agroforestry outputs, especially sustainability.

In the second part of the paper, the underlying economic principles of the most common agroforestry systems are looked into. Special consideration is given to the availability of resources as a determinant for the type of agroforestry system practiced.

INTRODUCTION

Before embarking on a review of the economics of agroforestry, it may be useful to dwell briefly on the economic concepts underlying agroforestry land-use systems. Several institutions/individuals have proposed definitions for agroforestry and although there is still no concensus amongst scientists, for the purposes of this review, I will use the definition proposed by Lundgren and Raintree (22).

"Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, palms, bamboos, etc) are deliberately used on the same land management unit as agricultural crops and/or animals, either in

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some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between different components".

Granting this definition, the basis for each successful agroforestry system is a positive ecological interaction, in time and/or space, between the tree and crop and/or livestock components. In economic terms this means that a given product mix of trees and crops and/or livestock can be produced on a smaller area under an agroforestry land-use system as compared to the same product mix being produced in a tree-based non-agroforestry land-use system in which there is no ecological interaction between the tree and crop and/or livestock component.

Such positive ecological interaction may by itself be the basis for a positive economic interaction between the system components, i.e., less land cost per unit of production. However, this need not be the case because labour and capital cost per unit of production could be higher. It seems obvious that should the latter cost exceed the savings in land cost, this "ecologically" acceptable agroforestry system would be "economically" unacceptable.

On the other hand, ecologically acceptable agroforestry systems may be further enhanced by positive economic interactions between the system components other than the already reduced land cost. In fact it is quite likely that labour and capital costs per unit of production under an agroforestry system will fall as well, since these costs are frequently linked to land acreage (15).

METHODOLOGICAL ASPECTS

The socio-economic analysis of agroforestry systems has received considerable attention lately (1, 9, 16, 23). The major reason for this attention is a need to lift agroforestry out of its present unquantified status.

Several authors have started to outline how such analysis should be conducted while some have tried/are trying to put it into practice. The Australian National University in collaboration with ICRAF also developed a micro-computer programme (MULBUD)for the analysis of agroforestry systems (8).

In attempting to do an economic analysis, one problem immediately surfaces, i.e., a lack of economic data on the various systems. This in turn raises two important issues:

1. how to collect/obtain data on agroforestry systems

2. how to conduct non-numeric methods of economic analysis

These two issues will be dealt with in some detail, and a review of the conventional numeric analysis of agroforestry systems will follow.

Data collection

In fact very little has been written on how to collect economic information from either existing or proposed agroforestry systems.

Reiche prepared a set of recording sheets for monitoring and analysing firewood projects based on generally accepted principles (27). IITA and ILCA have started recording data on the alley cropping system. Similar recording systems should be produced for other agroforestry systems, i.e., silvi-pastoral, agri-silvi, and agri-silvi-pastoral systems. Much of the input-output recording can be derived from a system like FARMAP (10). Difficulties do arise, however, with the measurement of physical output, i.e., standing volumes as well as harvested/collected quantities of fodder and fuelwood. The assistance of technical scientists is essential in this respect.

While recording systems may be a means of obtaining data from newly established agroforestry "projects", a questionnaire/survey approach may have to be adopted for the extraction of information on already existing agroforestry systems. Special attention also needs to be given, on how to obtain reliable input and output data on events which occurred long before or after the time of the interview.

The task ahead in this area seems one of consolidating/developing usable procedures/forms for monitoring and/or surveying agroforestry systems.

Non-numeric economic analysis

In the absence of numeric data, an alternative approach to the economic analysis of a proposed agroforestry system, is a non-numeric type of analysis.

The main purpose of such an analysis is to find out whether a proposed change in land-use has a reasonable chance of adoption by the land-users. Recently some authors have started tackling this problem.

Jones describes the evaluation process of an agroforestry technology in which, first and formost, the farmer's goal preference for family and farm development are ascertained (19). Such interviews are followed by a presentation of technological requirements for alternative technologies. A comparison of farmers' goals and technological requirements is then carried out in the final interview after a visit to a demonstration farm.

Bonnicksen developed a package called Initial Decision Analysis (IDA), which is a package of decision-making techniques that are organized so that a rational step-by-step procedure can be followed to use existing knowledge to develop resource management policies (3). This package may have a potential for rationalizing agroforestry policy issues at the national level.

Hoekstra developed a tree-location matrix in which tree productive and service functions are linked to potential planting sites (16).

To the present date limited experience has been gained with the application of these methods for agroforestry designs. It seems therefore that emphasis here should be on testing the methods under practical circumstances.

Numeric economic analysis

The numeric type of economic analysis of agroforestry land-use systems may be based on an optimization or non-optimization approach.

Because of the multi-period nature of agroforestry land-use systems, linear programming techniques have to be adjusted. Some attempts have been made to introduce multi-stage linear programming to analyse agroforestry systems (5, 32). However, the main drawbacks of this technique are the large amounts of data and computational power required. It is therefore not expected that it will become a very popular method and that most analysts will try the non-optimization budgeting approach, better known as cost-benefit analysis. While the principles of this analysis are well established, its applications for agroforestry systems require special attention to the valuation of agroforestry benefits, risks and time.

Valuation of agroforestry outputs

One of the most frequently quoted benefits of agroforestry systems is "sustainability". This "service" output may be obtained by individual trees (N fixation) but more often by tree arrangements (contour planting, shelterbelts, alley cropping). Much of the valuation of these outputs can be learnt from the mushrooming literature on resource and environmental economics (18). The most common method practiced is to measure differences in the output/income flows between the "with" and"without" situation (Fig. 1).

Although it is relatively easy to explain, the physical decline of the land and the subsequent change in its use and yields are difficult to accurately forecast. A second method to estimate the sustainability benefits is to determine the costs required to prevent the system's deterioration.

Besides the service-oriented output of an agroforestry system there are also direct material outputs, like woodfuel, tree fodder, small timber, fruits and mulch. The valuation of these benefits will not only differ between the private and public economies but also between subsistence and commercially oriented farmers. The opportunity cost principle will have to be applied if little or no trade is taking place in a product; market prices may be used if the item is commercially traded in an area. Special care should be exercised in determining the market prices of woodfuel, poles, and timber, since prices paid for these products often include harvesting and transport cost. Several authors have argued that the on-farm stumpage prices of these products are, in fact, rather low (2, 16). These low prices are understandable because until very recently most of these products had never entered the commercial market and/or were traded exclusively by Forestry Departments rather than farmers. However, for trees to become attractive to farmers, the development of a market infrastructure is a top priority.

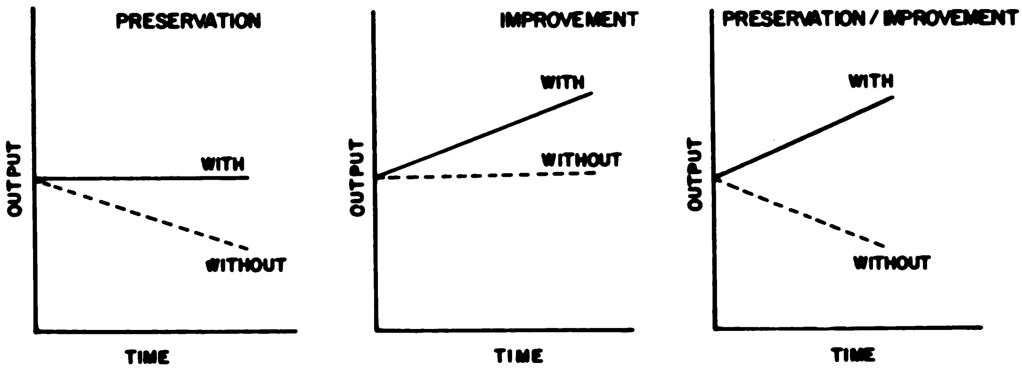

Fig. I Environmental output

Risk

Risk (or uncertainty) is another frequently encountered topic under agroforestry (1, 11, 17). A risk or an uncertainty or both may exist with regard to yields and prices of the components of an agroforestry system, resulting in a fluctuating income flow. The question is, will risks/uncertainties be lower in an agroforestry land-use system? To answer this question, it is necessary to understand the yield reactions of agroforestry components to different meteorological and entomological situations. If all components react more or less in the same way, the fluctuation in the system's income will not be confounded. However, more often than not, yields of the agricultural crops are not systematically related to the yields of the tree crop and, as a result, income fluctuations will be confounded. For example, trees will often be less susceptible to drought than animals. Information is also required on the causes of price fluctuations. Are the causes similar, thus resulting in similar income fluctuations, or do they differ, thereby reducing the system's income fluctuations? Again, the causes for price fluctuations of agricultural crops will be different from those affecting tree crop prices. As mentioned earlier, it should be noted that many agroforestry products have only recently entered the market-place and therefore markets for such products are much less organized than for agricultural crops, not only resulting in comparatively lower prices but also in more uncertain prices.

The above applies equally to an agroforestry production system as to a tree-based non-agroforestry production system, producing the same product mix. There may, however, be exceptions with regard to the yield fluctuations within agroforestry and non-agroforestry production systems if the tree/crop interface reacts differently to varying environmental situations. An example is susceptibility to diseases and pests. After a brief examination of the literature, Price draws the tentative conclusion that "there is some concensus between authors that diverse plant communities may be better adapted to avoid disease problems" (25). Although this is probably true in general, some agroforestry systems could certainly become exceptions (birds!).

Several methods have been suggested for incorporating risk and/or uncertainty in an analysis. Most authors agree, however, that one should not reflect such differences in the discount factor used (9, 11). A more appropriate method is to incorporate risks into the benefit stream of an agroforestry system by assigning probabilities to the likely income of the alternative land-use system.

<u>Time span</u>

A characteristic of the production, be it in an agroforestry or in a tree-based non-agroforestry system, is the fact that inputs are required now, while outputs usually occur some years later. Individuals, as well as society as a whole, experience this as a disadvantage for various reasons, especially if the same inputs could have been used for producing more immediate outputs. Expressing this disadvantage of delayed benefits is normally done through a procedure called discounting, which results in a lowering of values of expected future benefits.

While the theory and the arithmetical procedures are well known, and need no further elaboration for agroforestry system analysis, more attention (not only for agroforestry) needs to be paid to the selection of the discount rate especially under subsistence-oriented farming systems. For many farmers practicing subsistence, the choice is often to produce more or less food and energy now as opposed to having more or less food and energy in the future. Perception of the future, partly depending on the available resources, partly depending on the psychological make-up of farmers and partly on the effectiveness of the awareness campaign, will differ between farmers, and hence different discount rates may have to be chosen (17).

SOCIO-ECONOMIC INFORMATION ON AGROFORESTRY SYSTEMS

A few attempts have been made to pull together literature dealing with the economics of agroforestry and/or tree based non-agroforestry (notably 4, 6, 12). There are, furthermore, some bibliographies on specific topics, especially on woodfuel (7). ICRAF also initiated a world-wide inventory of agroforestry systems in which, amongst others, socio-economic information was requested. A preliminary evaluation of this inventory, as well as the bibliographic material, reveals that in fact very little 'hard' economic evidence of the viability of agroforestry systems is available. However, the actual presence of the systems proves that land-users do find them beneficial under their present conditions.

There is still a great need for economic data on the various systems to enable decision makers (including small farmers) to introduce/make alterations to agroforestry systems and for planners to determine the physical inputs and capital required.

Although many systems are location specific, there are of course some similarities which may be more generally applicable, especially in the use of inputs. It seems therefore, that some labour/material input standards could be developed for typical agroforestry activities, such as tree establishment, lopping of trees for fodder, mulch or woodfuel.

Based on the available information, the following conclusions may be drawn:

1. Most analyses are conducted on an "ex-ante" basis, leaving doubts about the reliability of the data
2. Subsistence-oriented agroforestry systems are the least quantified and analysed
3. Commercially oriented agroforestry systems, especially systems based on plantation crops, like coconuts and rubber, as well as some of the

"older" agroforestry systems, like taungya and shifting cultivation, have received more attention

The salient economic features of some of these better known systems are described below.

Taungya system

Most authors conclude that this system is advantageous to the forestry departments. Savings in establishment costs of up to 60% (31) and sometimes improved growth of trees because of better weeding practices, are considered to be the main contributions to the profitability. Although considerable acreages of forest have been established worldwide with the taungya method, it is also true that at the same time plantation forests were established directly. There may have been an unwillingness of forestry departments to venture into these schemes. However, in many instances the major reason for embarking on a plantation model is purely economic, i.e., labour is scarce to the extent that the renumeration from the taungya system is too low to attract many farmer participants. King found, in a worldwide study, that the system was not generally practiced if the "per capita" income was below 150 pounds (sterling) per annum (20). Several authors therefore speak of the traditional taungya as an exploitive system and, perhaps as a result of social pressures, the system has gradually been improved for the participating farmers not only by improving their welfare conditions (health, sanitation, schools), but also by giving them a larger share of the additional benefits.

Such increased attention to the farmers' interest does not necessarily have to go at the expense of the Forestry Department, although in practice it often will. In the past very little attention was paid to the agricultural component of the taungya system mainly because the system was geared to the interest of the Forestry Department. Therefore, it is quite possible in many instances to increase the overall returns to the system through increased agricultural production. Even if the Forestry Department's per unit area income lowers because less trees are grown, it is not necessarily uneconomic for the Department. To a large extent it will depend on the scarcity of potential forest land and the objectives of the Forestry Department. Besides environmental objectives the main production objective is to produce a certain amount of timber for domestic consumption and/or export as cheaply as possible. If potential forest land is scarce, this objective is likely to be achieved by maximizing timber returns per unit of land. However, if potential forest land is relatively abundant in relation to the timber production target, the use of more land, resulting in a more than proportional reduction in labour cost, could be beneficial to the Forestry Department (14).

Finally, in examining the farmers' share of the costs in the taungya system it is important to determine whether their "activities in the forest" are supplementary to other activities (farming, off-farm employment) outside the forest, or if they are in direct competition with other activities outside the forest. While the opportunity cost of the farmers' labour in the case of supplementarity is close to zero (maybe the prices of leisure), in the case of competition it will be the returns made from outside the forest.

Shifting cultivation

The economic essence of traditional shifting cultivation is the fact that labour is more scarce than land, and therefore shifting cultivators, knowingly or unknowingly maximized their returns to labour rather than land. It is for the same reason that the traditional system is only viable for as long as the land/man ratio remains more or less stable; if not, technological changes to the cropping system which result in higher yields per unit of land will have to be adopted (26).

In most literature on the subject, the decline in soil fertility and the increased weed growth as time goes by, are identified as the major reasons for abandoning the cultivation of agricultural crops in 2 to 3 years' time. Economically it means that the expected returns to labour from further cultivation are considered to be too low as compared to the alternative use of labour (opening up new land). For as long as land is available, the system works perfectly, economically as well as ecologically, because the fallow period will be adequate to restore soil fertility. Under increasing population pressure the system will gradually collapse since fallow periods will be shortened, thus, resulting in a gradually deteriorating soil fertility status.

Most authors in fact examine the modified shifting cultivation systems. Most prominent among them are the biologically and economically enhanced fallows planted with tree crops. As is to be expected, such improved systems offer higher returns per unit of land than the traditional systems, but the returns to labour are not necessarily higher.

Ultimately, with ever increasing population densities, the fallow period will completely give way to a system of permanent agricultural cultivation in which soil fertility is maintained through artificial fertilizers and/or through tree-based ecologically sustainable systems like alley cropping, home gardens and other tree-based systems.

Alley cropping

The alley cropping system is, in fact, a newly conceived system which is mainly found on research stations and on-farm research plots. Its main aim is to maintain/improve soil fertility and to reduce soil erosion. However, in the Philippines, where the system is being practiced by farmers, its main use seems to be production of fodder and/or fuelwood and the conservation of soil, rather than improving soil fertility.

Because of the experimental nature of the system, input-output data are still subject to discussion, and most analyses only cover the early stages of the system's lifespan. Most authors leave little doubt about the high labour requirements of the system in the early stages of development. There may, however, be considerable savings in labour if seeds or cuttings are used instead of seedlings. Obviously, the feasibility for such establishment methods are much better under humid and sub-humid conditions than under semi-arid conditions. Another saving in labour costs, on family operated farms, may be obtained by scheduling and phasing out activities to avoid high labour opportunity costs.

After establishment, the hedges need to be lopped regularly to provide the green manure/mulch and/or to reduce light competition for the crops in the alleys, especially under humid/sub-humid conditions.

The effect on yield will be negative in the first season(s) because of a reduced plant population. Once lopping has started, yields will increase, although this will differ between different ecological zones. Labour requirements for lopping are additional compared to the traditional cropping systems; labour savings may, however, be obtained in land preparation and weeding.

Although the system looks promising, there is as yet no convincing evidence that it is an economically viable system which can be widely recommended. There seems to be some indications, however, that the system may be more adaptable to low-input agriculture rather than to high-input agriculture (13, 30).

Home gardens

Home gardens have recently received considerable attention in the literature. Studies have shown that this is a fairly common form of land-use in the wet tropics (28). The compound area does have a few distinct advantages for production as compared to fields further away: availability of inputs; manure of livestock kept in pens; household residues; residual water; labour (walking to and from outer fields may account for up to 30% of the time farmers devote to agriculture); food, fruits and fuel for domestic consumption; fodder for stall-fed animals; shade.

Most authors also agree that the per unit area production value from home gardens ranks as number one amongst the different land-uses. Still the actual size of home gardens per farm seems to be less subject to variations than other land-uses. Hence, home gardens usually occupy a larger proportion of the farm on "small" farms than on "large" farms. In other words, if farmers obtained more land they would not significantly increase their home garden area but rather their other land-uses. Similarly if farmers see their acreage reduced, they do not significantly reduce their home garden area but rather their other land-uses.

This seems to suggest that home gardens have their area limitations. This may be in part explained by the fact that with an increase in the home garden area, some of the inherent advantages of the system (availability of inputs and outputs) will disappear. Furthermore, some of the outputs produced in the home gardens are mainly for home consumption and may therefore have little scope for expansion. Also, for biological reasons (for example rice), some products can only be produced in the home garden with difficulty, if at all.

Another "economic" explanation for the comparatively stable home garden area could be the use of labour. As mentioned earlier, home gardens tend to appear when land becomes scarce, because they give highest returns per unit of land. However, once the home gardens have absorbed a substantial portion of the farms' labour, the remaining land/remaining labour ratio may favour a less labour intensive form of land-use. However the literature does not always confirm this hypothesis. Of notable interest is the fact that some authors observed that the land-use within the home garden seemed to change depending on the availability of additional land and/or income opportunities, i.e. the more land the less labour intensive use in the home gardens (21, 24, 29).

Plantation crop agroforestry systems

Several commercial tree crops have been intercropped with agricultural crops and/or animals either to increase benefits or to reduce costs. The choice of intercrop will, in the first instance depend on biological factors, like demand and supply of water, light and nutrients during the life-cycle of an inter-crop combination, but also on economic factors, like marketability of produce and relative scarcity of land, labour and capital.

In areas where labour is relatively more scarce than land and capital is not a limiting factor it is common to opt for labour-extensive systems like livestock keeping or perennial intercrops. On the other hand, if land is relatively scarce, and capital is not abundantly available, there is a tendency to incorporate more annuals into the land-use system. Furthermore livestock activities may be favoured under some circumstances (labour shortage) to reduce the cost of weeding.

Based on these general economic principles it is not surprising to find the silvopastoral plantation systems in Europe, Australia, parts of the United States and some of the more developed and "underpopulated" countries like Malaysia, while the more labour -and less land- and capital-intensive systems are found in the less developed, "over-populated" countries, like India, Sri Lanka, Indonesia, etc.

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SILVICULTURAL CONCEPTS IN AGROFORESTRY

J. Heuveldop*

SUMMARY

As forests in the tropics are disappearing at an alarming rate, all feasible measures have to be taken to promote forestation as well as for management improvements. Agroforestry provides one possibility to introduce and/or maintain trees by including them in crop and pasture production systems. In order to facilitate selection and planting of appropriate tree species on agricultural lands, and to improve production and maintenance of existing agroforestry systems, various silvicultural techniques can be applied. Some concepts that agroforestry and forestry have in common are considered and examples are given of some successful combinations and management practices for traditional as well as for new agroforestry techniques.

INTRODUCTION

One of the main environmental problems we are faced with in the tropics is deforestation (24, 43). Improvements in forestation activities are urgently required and according to Spears (57) emphasis will have to be given to fast growing tree species to meet industrial demands as well as the demands of rural populations for fuel, fodder and building materials.

Much of this forestation will have to be realized by planting trees individually on agricultural lands. Thus agroforestry has an important role. Key questions are: "Where, what, how, when and by whom can improvements be

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achieved?". "How do silvicultural concepts apply to agroforestry production goals".

PROBLEM IDENTIFICATION AND GOALS

Due to different production goals, as well as the wide variation in site conditions, local needs and constraints, clearly defined strategies have to be developed according to each specific situation (58, 66).

As stated by numerous authors with wide experience in the tropics, much can be learned from indigenous farmers (e.g. 2, 10, 19, 50, 54). However, the need to sustain yields and economic productivity, as well as the consequences of population increases, mean that improvements in traditional practices are urgently needed.

Various rural development projects have succeeded in introducing new or better land use systems and techniques, but quite a number have also failed. Failures often result from an unsuitable diagnosis of constraints and needs, inappropriate project design and the non-incorporation of local authorities or target groups.

ICRAF has developed a methodology for rural agricultural development "Diagnosis and Design" (51) that has been tested in various regions. The principle aim is to identify both the scientist's and the farmer's research priorities and to elaborate development projects with improved agroforestry designs. It is a tool for researchers, planners and development field workers, and requires a specific although simple procedure, which means that training of a team is necessary in each zone. One of the several interesting and important aspects of this methodology is the design of a continuous follow-up process. Many well implemented projects have failed finally, just because of the lack of this long term perspective. Farmers are often left alone with maintenance, utilization and marketing problems, as far as new tree species and products go, once a project has finished.

Wiersum (69) states, that problems which frequently impede forestation efforts can be classified according to the major input categories, such as: land, labour, capital, knowledge and management. The identification of priority areas is the first step to be taken on a national level. This will strongly influence the final choice of agroforestry systems, techniques and species to be developed. Although it is obvious that the specific site conditions for each particular case have to be investigated and analysed, a more general approach has to be applied for this discussion of silvicultural concepts in agroforestry. For this reason, the following general land classification suggested by the World Bank (73), is used here as a guide line:

- Wood deficient marginal lands
- Wood deficient areas with good physical environment
- Overpopulated wood deficient areas
- Wood abundant poor areas
- Wood abundant rich areas
- Wood abundant areas with severe population pressure

V. Maydell (40) states that any combination of agriculture, animal husbandry and forestry activities have to solve 5 priority problems in rural development programmes:

1. Improve the food supply for humans
2. Guarantee the energy supply
3. Secure the supply of raw materials
4. Generate positive effects on the environment
5. Improve the socio-economic conditions

For a better understanding of the systematical framework of agroforestry Combe (18) presents a scheme showing 8 systems found under 3 types of combination, grouped according to their typical spatial distributions, subdivided amongst permanent and temporal durations and the major function of the tree component.

In summary, a discussion of silvicultural concepts in agroforestry has to take into account the characteristics of the area (e.g. World Bank scheme), the nature of priority problems (e.g. v. Maydell's breakdown) and hence the type of agroforestry system to be developed (e.g. Combe and Budowski's classification). The ICRAF D + D methodology covers these aspects.

GENERAL SILVICULTURAL ACTIVITIES

The first silvicultural activity in common for all forestation efforts is the identification of suitable plants. The selection of species to be introduced into traditional agroforestry lands should give priority to multipurpose trees. Emphasis should be given to fast growing timber, fodder and fuelwood species in areas where there are no trees. However, it has to be kept in mind that the landowners need to be involved from the very beginning, as the final selection must be theirs. Basic information on species characteristics is given in the following publications.

Huxley (29) gives a comprehensive presentation on trees and woody perennials to be considered for agroforestry systems, taking techniques, management and socio-economic aspects into account. Information on commercial tropical timber species has recently been published by Erfurth and Rusche (20) and Chudnoff (15). "A guide to species selection for tropical and Sub-tropical plantations" was prepared by Webb et al (67). The present edition comprises climatic, edaphic and silvicultural data for more than a hundred species, at least half of which are suitable for agroforestry combinations. The U.S. Academy of Sciences is continuously publishing booklets on different multi-purpose tree species and in 1984, together with CATIE, presented the Spanish version of "Firewood Crops" with descriptions on shrubs and trees for energy production and for other possible uses ("Especies para leña, arbustos y árboles para la producción de energía") [22]. Another important publication is "Multipurpose Tree Germplasm: Proceedings of a planning workshop to discuss international cooperation" (42).

Seed selection and seed handling is the next step to be considered. General aspects and specific rules for selection and treatment are given by the International Seed Testing Association (30), and a new text book dealing with tropical seeds was recently published by DANIDA, Denmark (71). In regard to seed sources, Buck (9) has indicated some 30 international suppliers.

Some general aspects of nursery techniques and plant production are given by Maghembe (38). Lemckert (37) presented a practical and detailed guide on the installations and management of forest nurseries in the tropics.

However, the obvious bottleneck for small farmers in rural areas is the availability of suitable plant material. This leads to the question of local production and distribution. Small nurseries have been established by a number of rural development projects and are managed in cooperation with local farmers or communities. The "Firewood Project" at CATIE, has a long and positive experience in Central America and Martínez (39) has just presented a paper on the situation in Guatemala as one specific example. The perception and interest of the local population, for the need to produce planting materials, is a basic requirement. Inputs may come from outside but have to provide adequate incentives for success without "spoiling" the farmers (62). Kotschi and Adelhelm (34) refer to a case study in Tanzania, where wood scarcity has lead to severe problems which were perceived by the farmers. They applied for help to establish their own tree nurseries with very good results. Another promising similar project is described by Behmel and Neumann in Rwanda (5). But there are also other examples from all over the tropics, where indigenous groups have become aware of the important role of trees and have practiced tree production and planting by themselves. A good example is the tree gardening practices in

Java, which have been described and analyzed by Wiersum (68) and others in several publications.

Many different successful site adapted practices can be found when considering species, species combinations and maintenance. But it also has to be mentioned that there is clear evidence that trees compete with other land use forms in terms of space, nutrient and water consumption. Also shading effects, that might lead to reductions in yield or exclude certain crop species, have to be taken into account. On the other hand, some crop and pasture management practices create competition with trees, or might impede regeneration. This brings up the question: "WHERE to plant trees?" In crop lands and along border lines, establishment and maintenance problems are normally less than those we are confronted with in pastures. Techniques to overcome these problems need to be well designed which means they have to be productive, sustainable and adaptable to specific environmental and socio-economic conditions.

The evaluation and economic analysis (global, and for each component of the system) of forest plantation projects are a basic requisite which is nearly always applied. The question: "Does it pay?" has to be applied to all silvicultural activities in agroforestry although these are far more complicated systems. Suitable techniques are still being tested and developed (see contributions by Hoesktra, Navarro and Reiche in this Proceedings) [28, 46, 52].

The final item under these general aspects of silvicultural concepts in agroforestry is timing or the question WHEN to carry out certain project activities, for example "Temporal analysis of agroforestry systems for rural development" (Kronick [35]). This model starts with a description of a project, and constraints to the sequence of activities are examined. Assumptions and values in regard to past, present and future conditions are analyzed so that changes caused by innovations may be anticipated.

In summary, species selection, production and distribution of germplasm, diagnosis and design, economic evaluation, and the timing of activities, are the silvicultural activities all agroforestry projects should have in common. For a further discussion of some specific aspects two groups of problem areas are choosen here: 1) wood deficient areas on marginal lands with or without high population densities; and 2) wood abundant areas on poor lands or land with high population densities. With respect to agroforestry and/or simplification, these problem areas could be regarded respectively as: 1) land used for agriculture where out of various reasons, trees are to be incorporated; and 2) lands with traditional tree-crop combinations where overall production is to be increased through improved management.

SILVICULTURE ON AGRICULTURAL LANDS

Tree planting on agricultural land

There are of course many examples to illustrate this situation. One is given by Evans and Rombold (23) who present an agroforestry alternative, which is becoming popular in Paraguay under the name "Paraíso - Wood lot - System" for use on degraded, acid, sandy soils of the sub-tropical Guayaybi area. This example is choosen because establishment and management are designed for two different combinations in certain sequences, comprising annuals, perennials, (firewood and fodder producing species, timber trees) and cattle.

Two variations are described. The first one combines the exotic timber tree species, paraíso (Melia azedarach var. Gigante) with yerba mate (Ilex paraguarensis) and bananas (Musa spp.). At year 1, M. azedarach is planted as a bare root stump at 4 x 3 m spacing together with 4 rows of groundnut (Arachis hypogaea), followed by beans (Phaseolus sp.) between the tree rows.

Pruning is required for the first 2 years and thinning at years 3 and 6 (removing 50% of standing trees each time), thus leaving about 200 trees for the final harvest in years 12-15. After the first thinning I. paraguarensis is planted in the M.azedarach rows at 3 m distances, cassava (Manihot esculenta) and Phaseolus being planted between rows. Between the second thinning and final harvest, Musa spp. are planted at 3 x 3 m spacing.

The second combination is M. azedarach with Leucaena leucocephala (K67, K28 and Cunningham) and (Enterolobium contortisiliquum) (local name Timbo). M. azedarach is spaced at 3 x 6 m with L. leucocephala and E. contortisiliquum between these rows and at 2 m distances within the rows. To year 3, Phaseolus, Z. mays and M. esculenta are cropped between the tree rows. After year 4, grass is planted and cattle are moved in (2 heads.ha^{-1}). After year 15, M. azedarach is harvested and the remaining primary tree species is now E. contortisiliquum. The authors present production data, weaknesses and constraints, and potentials for extrapolation of these systems.

General aspects, grouped according to the different purposes for the trees to be grown in agroforestry systems, are given by Cannell (13) who discusses establishment, management and the control of population densities and the mixture of species. Cannell suggests that trees that are to be included for multipurpose use (MPT), should be established in combination with herbaceous crops (e.g. Z. mays or Phaseolus sp.) and when shade increases because of canopy closure of the quick growing trees, Manihot esculenta or pastures could be established. Also yams (Dioscorea spp.) and Musa spp. are recommended. The trees should remain unshaded, i.e. form the top canopy. They should be spaced widely or be in small groups to allow individual management and utilization, as this is the main purpose with MPT - species.

In combination with annual crops, the perceived problems of associating trees are easily overcome by an adequate timing of activities. Tree establishment costs are reduced by the weeding and fertilization of the associated perennial and annual crops, since survival rates and initial development are normally favourable compared to those in pure tree plantations (28, 32).

Where timber trees are to be planted in pasture lands, problems occur due to trampling and browsing by the animals. Fencing off small forestation patches is a commonly recommended practice but this is mostly not feasible for small farmers who suffer from a lack of resources, especially land. In these cases, fodder tree plantations seem more adequate since the terrain which is not appropriate for grazing can be used without reducing the overall carrying capacity of the farm. Information on potential fodder tree species is given by Torres (60) Skermann (55) and von Maydell (41).

A different form of tree establishment on agricultural lands is alley cropping or avenue cropping (31). A number of experiments have been carried out at CATIE for the evaluation of different techniques and species combinations. IITA (36, 47, 48, 72) has presented various reports on establishment, production and management costs using species like Cajanus cajan, L. leucocephala and Gliricidia sepium. L. leucocephala and G. sepium seem to be the two species for which most data exists, but many aspects on spacing, lopping heights and sequences are still to be investigated. Torres (61) states that for L. leucocephala distances between rows of more than 2 m did not provide optimal tree production. On the other hand narrow spacing gives more shade to the crop and depresses crop production. Increased tree density within rows or double row plantations at suitable distances from the crop species (like 3 or 4 m), might compensate for this.

The specific advantages of this alley-cropping system are that lopping material is used for soil cover, and the mulch increases soil fertility. Wijewardene and Weerakoon (70) report that Z. mays grain yields were increased by about 40% when loppings from L. leucocephala hedgerows, planted 2 m apart, were regularly applied, but was 30% lower in cowpea (Vigna unquiculata) which is a legume. For the latter, additional N apparently had no effect, but shade had a negative influence. Oven-dry wood production from the same hedgerows amounts to 7 $t.ha^{-1}.a^{-1}$. Chadhokar (14) reports that 5 year old hedgerows with G. sepium spaced at 3 m between, and 0.43 m within rows, yielded 4 $t.ha^{-1}.a^{-1}$ (dry wood). The system is labour-intensive. On the other hand there are also savings as costs for weeding, fertilizer and firewood have to be taken into account.

Lands with traditional tree-crop combinations

The main concepts for improving common practices are better management techniques and the introduction of higher yielding multipurpose tree species. Basic information on existing systems are given in numerous publications and several attempts have been undertaken to stratify them. A classification guide is given by Combe and Budowski (17) and a world-wide inventory has recently been carried out by ICRAF (45), and through regional studies by FAO (49). Advantages and disadvantages of the various combination forms, with respect to biological and socio-economic aspects, are listed and qualified by Budowski (11).

Timber production in combination with crops is a traditional practice. It exists in various combination and management forms and could well be transferred to other regions, where these combinations are unknown. Cedrela spp., Swietenia spp. or Cordia spp. are well-documented examples of high yielding naturally regenerated trees used for this purpose (4, 56). Spacing after the last thinning is frequently 8 to 10 m leaving some 100-150 $trees.ha^{-1}$. After 25-40 years, saw log dimensions can be achieved which means felling and re-establishment. Felling damage and excessive sudden radiation increases to any understory crop are often mentioned as limiting factors. Astonishingly enough, felling damage to perennials, like coffee, (Coffea spp.) is relatively low. Some informal observations from the CATIE coffee farm have confirmed this and the damaging effects can be reduced by intensive pruning of the Coffea bushes after logging.

In spite of the success of many existing practices, the needs and potentials for technical and managerial developments are well documented. New or improved techniques could well be derived from many of these traditional practices.

As an example Wiersum (68), describes the tree gardening and Taungya techniques on Java, stating that improvements could be reached by a better choice of species and varieties, breeding programmes, improved propagation techniques, better regulated planting distances, removal of unproductive trees, better drainage and water management, improved pruning techniques and introduction of new plant protection measures. Further examples are given by Halliday and Nakao (26) who prepared a resource document on the management of shade trees, discussing (Coffea spp.) cacao (Theobroma cacao), and tea (Camelia sinensis) plantations that are managed at highly developed levels by the local farmers. Potential and successful leguminous tree species for shade are also described by Budowski et al. (12).

The substitution of traditional species by exotics is an approach with various obstacles. Nevertheless, if quick results can be achieved farmers are more easily convinced, as the introduction of Calliandra calothyrsus in Asia has shown. CATIE projects have achieved impressive experimental results in Costa Rica, with Mimosa scabrella in Coffea plantations and Acacia mangium on abandoned, pasture lands. Both examples immediately gained farmers interest.

Further investigations have to be carried out on spacing and diversity. In general terms it could be stated, that with the traditional systems the smaller the farm, the higher the number of species and the total number of trees per unit area. Optimal density, of course, is a question of what to optimize. A high number of tree species, densly spaced, increases the production diversity and minimizes economic risks. However, yields of each species are at a low level and labour input is high. The economic features are more closely related to changes in species combinations and distribution than to tree species density when the ground crop is of high economic value. Looking at the timber production and at establishment and maintenance costs, wider spaced stands have more advantages than closer spaced stands (8, 63). Ecologically highly diversified systems are not necessarily more stable than those with less species diversity. The same applies for wider versus denser spacing. At a wider spacing the trees still provide some shade that reduces evapotranspiration of the understory crop, but they compete less. There are other bio-physiological effects between different species and in many regions it has been found that farmers are quite familiar with this, applying suitable management techniques since generations (50).

Changing or intensification of tree management does not normally lead to immediate cash returns. However, considerable biomass production increases can be reached with appropriate pruning regimes e.g. Russo (53), Benavides (6), Kass (31), Glover and Beer (25) and others at CATIE. By changing the timing of pruning regimes of trees in fence lines, considerable increases can be reached in annual foraje production, and maybe in total annual biomass production (3).

Russo (53) found that the amount of pruned material from 8 year old Erythrina poeppigiana over C. arabica was about 6 times the amount of fallen leaves. This provides good soil protection and nutrient recycling with immediate results. Production goals and species characteristics will determine the specific management form in each case.

Fruit trees and palms are commonly used in agroforestry systems and there is abundant literature. FAO has published information on the biology, uses and management of various tropical fruit tree species (21). Clement (16) gives some examples of the management and production of peach palm or pejibaye (Bactris gasipaes). Coconut (Cocus nucifera) and oil-palm (Eleais guineensis) are species frequently combined with grazing cattle (44).

But it has to be pointed out that many of these systems are aimed at commercial agroforestry and not subsistence farmers. Throughout the tropics about 250 million people practice shifting cultivation which is an agroforestry practice. Forest lands are cut by different techniques, cultivated and then abandoned for a certain time. While indigenous groups, living around the exploitation areas (e.g. in the Amazon region), leave mature trees for regeneration purposes, recent occupants clearfell their plots before cultivation. Increasing problems are the spreading of such unsuitable practices and also the shortening of the rotation time. Shorter fallow periods mean lower subsequent crop yields. However, the Proceedings of the Ibadan Workshop on Agroforestry in the African Humid Tropics (1) includes reports on how local farmers in various West-African countries have learned to improve bush-fallow management. Fruit trees and firewood species are being planted (enrichment fallows) or, when natural regeneration and resprouting has occured, these species are left to grow when the area is cleared again for the next crop cultivation period.

Denevan et al. cited by Peck (50), report that selective cutting is extensively applied as a basic fallow management technique in the American tropics. These practices come close to underplanting or enrichment planting, which are well-known techniques for the management of secondary forests. The OTA report "Technologies to sustain tropical forest resources" (64) and the "Proceedings of the International Symposium on Strategies and Design for Afforestation, Reforestation and Tree Planting " (59) are basic source documents.

Bowers (7) presents a concept for the wet tropics under the title "Agricultural tree crops as a no-tillage system". He promotes palms and trees to substitute annual crops and quotes, that the most efficient and cheapest source of vegetable oil is E. guineensis, producing up to 6 $t.ha^{-1}.a^{-1}$ which is better than any annual oil seed crop. C. nucifera, bread-fruit (Artocarpus altilis), shea butter tree (Butyrospermum paradoxum) and Bactris gasipaes could be combined as overstory species. Plantain (Musa paradisiaca), T. cacao and Coffea spp. could form a mid-story and Z. mays, Phaseolus sp., Manihot esculenta), sweet potato (Ipomoea batatas) and cocoyam (Colocasia esculenta) could be included in small patches in the bottom layer.

This is a basic concept, with the objective to grow crops in the wet tropics that outyield and are cheaper to produce than the main food crops grown in industrialized countries, in order to generate cash alternatives to common production schemes. If such a programme includes tree species for fodder, firewood and timber production (which many secondary species produce) it could well constitute an agroforestry concept.

Natural regeneration of secondary species in cut and burned areas have for example been studied in the MAB 1 project at San Carlos de Río Negro, Venezuela, showing considerable potentials (27). Other more recent, but by now also traditional agroforestry practices, are the well known Taungya system from Asia and the East-African Shamba system (33). Both require departmental control, i.e. a functioning forest department with all legal and technical bases. As is indicated by their widespread application, these systems have been rather successful. King (32) gives a comprehensive description of the Taungya system and its many local forms. Wadsworth (65) presents examples of practices where Terminalia spp., Cordia spp., Tectona grandis and Swietenia spp. have provided excellent results as a forest technology for the management of secondary forests and forest plantations in order to improve the use of tropical lands previously converted to agriculture. The previously mentioned Workshop at Ibadan (1) lists a number of case studies on Taungya in West-Africa with examples on improvements, that are mainly reached by better control.

In many areas tree planting and management is part of the tradition of local farmers, indicating profound knowledge and strong instincts. Silvicultural concepts therefore should be developed in accordance with their perceptions. Peck (50) says: "In forestation projects, that rely on small farmers' participation, it may often be better to design the project around their perceived needs rather than to try to impose a forestry project as part of a regional development plan. The indigenous forestation strategies, developed over time by these farmers, were adjusted to meet specific needs. Consequently, development of forestation projects in the tropics should be elaborated from local strategies and reinforce local participation in order to develop appropriate technology in line with local social and economic conditions".

DISCUSSION

With few exceptions, (e.g. Taungya), the "forest" component in agroforestry systems occurs as individual scattered trees or as trees in more or less regular single lines. The standard principles of silviculture do therefore not automatically apply to such systems. Silviculture is directed to the management of forests which means to biological and economic units. The trees in agricultural lands produce primary products, or by-products, which are not necessarily timber. The purpose of including trees is also to sustain associated crop yields and thus measures are applied which are designed to maintain or, if possible, improve soil conservation and fertility. Thus silviculture and agroforestry have certain concepts in common. In regard to the selection and production of appropriate germplasm, biology, phenology and management of trees, much can be learned from silviculture, for application in new or traditional agroforestry systems. In many cases local populations have developed their own strategies mainly through the planting of easily collected seed materials of surrounding tree species, management of regrowth and of natural regeneration. More intensive evaluation and application of such existing strategies are urgently needed.

Much more investigation on site adaptability, management and the economy of multipurpose tree species is required as well as the study of the competition between the tree, crop and pasture species. More attention should be given to social, cultural and ergonomical aspects. Also ways and means of applying incentives and better technical support through regional extension groups, are needed in order to really achieve improvements in tree production at the small farm level.

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ERGONOMICS AND ITS POSSIBLE APPLICATIONS IN AGROFORESTRY

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SUMMARY

Ergonomics could be defined as "fitting the job to the worker". Both in agriculture and in forestry, examples are available of ergonomical studies and how they can lead to improvements: e.g. appropriate tools, tasks, products and forms of organization. With regards to agroforestry very little ergonomical research has been carried out up until now. This paper tries to indicate the possible application of ergonomical research to agroforestry.

INTRODUCTION

Although various articles on the applications of ergonomics in tropical agriculture and forestry have been published (e.g. 13), its application to the subject of agroforestry is still relatively unexplored. Mueller-Darss has pointed out that ergonomics can be very important in agroforestry because of its high labour and low capital input, and its restricting social and environmental work conditions especially when applied within the concept of rural development (15).

The object of this paper is to try to give an idea of where ergonomics can possibly be applied to agroforestry and in which way ergonomical research can be used systematically in the development of improved agroforestry systems.

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ERGONOMICS

Ergonomics can be defined in different ways: The most commonly used definition is "fitting the job to the worker", this being a reaction to the historical situation, where a human being had to fit to the work being done, for example the workspeed, the tools, work place and work organization. A more precise but more comprehensive definition of ergonomics could be the following one: Ergonomics tries to design an optimal socio-technical system (also called man-task system) so that a condition is created in which efficiency on the one hand and health, safety and comfort on the other hand are in balance. The starting point hereby is the worker with his/her capacities and restrictions.

The different components with their relations to the man-task system are the following (Fig. 1).

- the human being (P) who can function as an energy source (heavy physical work) or as a driver (animal traction) or as a supervisor (foreman of a gang of labourers, operator in the control room); a human being observes with his senses(S) and operates with his muscles (M).

- the technical implement (T) can be a simple handtool (e.g. a hoe), a mechanically driven handtool (power-chainsaw) or a complete mechanically driven machine such as a tractor. A technical implement has controls (C) of which a (hoe) handle is the most simple example and for which muscles will have to be used (compare Fig. 1:M C) and where the senses receive information from the information points (I) about the implement as a whole (observed principally by the eyes), or from the controls observed by the tactile senses, e.g. the fingers (Fig. 1. S I).

- the task which can be weeding, planting, pruning or felling trees, etc.

- the object, for which an end product will be made, such as the soil being tilled or the trees being made into firewood

- the physical-chemical environment (Eph) such as weather conditions and dust

- the social-organisational environment (Es) such as the availability of labour (human or animal), the market as well as the price of the products

More than one man-task system is responsible for fulfilling the aims of a production system (for example the growing of maize (Zea mays) with Leucaena leucocephala) which in its turn meets the needs of the larger human-ecosystem.

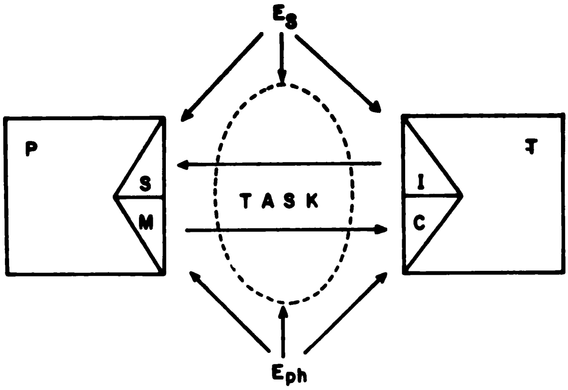

Fig. 1 Man-task system from the concept of ergonomics

AGROFORESTRY

Agroforestry is a collective term for systems of land use in which woody plants (trees and shrubs) are deliberately combined on the same land management unit with herbaceous crops and/or animals, either in some form of spatial arrangement or in sequence. For a land use system to fall within the concept of agroforestry, there should be both an ecological and economic interaction between the woody plants and other components of the system (14). A positive balance between woody plants, herbaceous crops and animals will permit the realization of the economical and ecological aims.

In this and other definitions the social objective together with the human component have not been explicitly named. Nevertheless one can state, (certainly in agroforestry for community development) that the human being is the spill in the agroforestry system, i.e. the centre point where all the threads come together. The positive economical and ecological interactions will have to finally result in the realisation of the social objective, which is the improvement of the social position of the human being (Fig. 2).

Now look back at the definition of ergonomics. In the original Taylor concept of work science, productivity was the main aim and the human factor was a constraint. Thanks to ergonomics, the human factor is now the focussing point in the modern enterprise and the social objective has been added to the productivity objective. Because of these specific characteristics ergonomics would appear to be preeminently suitable as an approach for the development of agroforestry systems.

THE MAN-TASK SYSTEM

The different components of the man-task system will be dealt with separately and the link to agroforestry systems will be suggested.

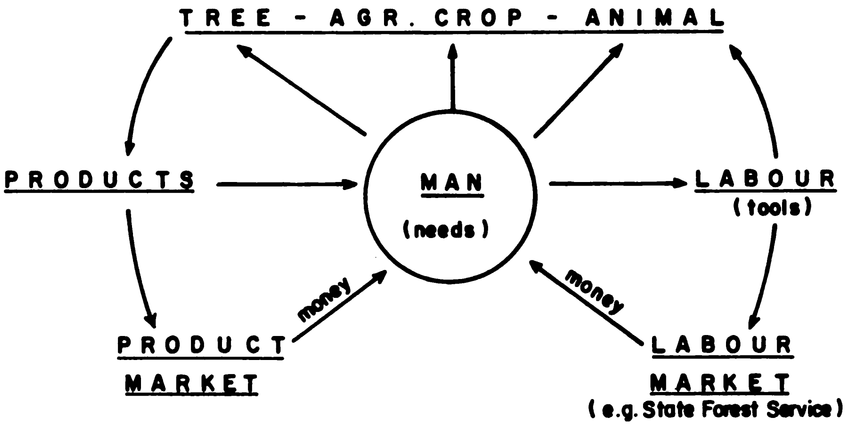

Fig. 2 Man as the central component in an agroforestry production system

The human being

The human being by using his physical and psychical capacities contributes essentially to different production and task systems in agroforestry. The physical factors which can be of influence on the working capacity of the human being can be the following: i) physical health; undermined by anaemia, infectious diseases such as malaria, bilharziasis, hookworm, etc.; ii) nutrition; bad nutrition can mean a shortage of energy, as well as of essential nutrients for good health; iii) body weight and fat free bodymass; iv) body measurements; v) sex; vi) age.

All these can be measured on individuals or on populations, but how these physical factors separately influence the working capacity is difficult to determine. The working capacity can only be measured as an overall external load in the form of aerobic capacity, i.e. the number of liters of oxygen a person can absorb during a few minutes by making a maximum effort.

Age and sex also will play an important role regarding the task allocation. Children and elderly people will preferably be doing tasks like tending and feeding the animals. A different set of tasks can be observed between men and women, based on physical factors such as body weight and muscle development, but also dependant on the cultural traditions. The aerobic capacity, in the same circumstances, is much lower in women than in men (10). This is possibly the reason why men are often responsible for the felling of large trees (in shifting cultivation systems) and women with the felling of smaller trees and cutting branches (when collecting firewood). This conclusion is of course not always valid, as can be seen in the transportation of firewood, which is very heavy physical work, and which is generally being done by women.

Nutrition is very important not only for one's health (sufficient proteins, vitamins, salts and minerals) but also for the energy consumption. In many developing countries insufficient nutrition is a restrictive factor to doing the daily amount of work. Men with a weight of 60 kg, by doing very active tasks, and agroforestry can be counted as one, need a daily energy consumption of 13.6 MJ (3240 kcal) (2). These amounts of energy are not available in a lot of cases. Edholm mentions a much lower energy intake for different groups in the tropics (13). I also found, in a group of regular workers in Surinam (S.Am.), a daily energy intake of 10.4 MJ whereas in a group of temporary labourers the average was 17.4 MJ (18).

Insufficient supplies of food are often found in the work intensive months before harvesting (hungry season). Because of this the effects on the productivity can be pronounced. This can be measured by weighing persons during the different seasons. Inadequate nutrition and consequently insufficient energy intake, can also be a result of the lack of firewood which is an increasing problem.

Body measurements (anthropometric characteristics) can be important in performing certain tasks. By using certain implements shortcomings can be overcome. The use of a ladder or a handle with the right length can overcome too much bending or stretching and facilitate heavy work.

Body length and bodyweight differ greatly between ethnic groups as well as within a group of workers. Sahbi mentions mean standing statures varying from an average of 1.59 m to 1.69 m for a group of male Vietnamese and Tunesian workers, respectively (17). As women are on an average 10 cm shorter than men this could have ergonomic consequences when they are using the same tools.

Technical implements

Tools or machines are used by men in performing practically every task. In agroforestry these can be a hoe, a bolo, a brushhook, an axe, a saw, a plow, a sledge, etc. From various experiences in agriculture and forestry we know that man does not always use the right tool or machine. The model is often not suitable and maintenance is insufficient. The materials used in the fabrication of the tools are often of poor quality. For the above mentioned implements we know, through literature, that some improvements have been made so as to lighten the work, to decrease the number of complaints and to increase productivity.

In India, Hanssen et al compared some local saws with new types and they also studied maintenance techniques (3). They found that the productivity was increased and work load was decreased when using a bowsaw in comparison with the locally used crosscut saw. The same result was found when comparing the locally used crosscut saws and one correctly maintained saw. Laarman et al mention better results when planting seedlings with an oval blade planting hoe as compared to the use of different shaped hoe's or the wooden dibble (9). In this case the local circumstances were of importance. The same authors found that productivity increased when the brushhook was used instead of the bolo when clearing saplings and brush. The same applies to the bowsaw as compared to the axe in the felling of trees (moreover when using the axe more wood is wasted).

The diameter and the hardness of the trees play an important role in choosing the right tools when felling. Roughly one can say that for diameters up to 5 cm. the bolo and the brushhook can be used, up to 10 cm the axe, up to 20 cm the one-man bowsaw and above 20 cm the two-man bowsaw.

A tool which seems ergonomically very attractive is the grasscutter used in Tanzania, East-Africa. It consists of an iron stick or knife of armlength which at the end has been bent in a right angle and then sharpened. In this way grass can be cut while standing quite straight instead of standing with a bent back when using the bolo for the same work, as I have observed in Surinam and Venezuela. Research in the use of this tool should be carried out.

In literature regarding agroforestry some authors do mention the complaints made by the farmers about certain tools, such as: trees too large to fell with a bolo, the grips of the bolo being unsuitable, causing blisters (11, 16). Unfortunately these cases are still exceptions and I hope that in the future more authors will pay attention to these aspects.

While searching for adapted tools one must not forget the safety aspects while working or during transportation (shielding sharp edges). Another safety aspect depends upon the maintenance. Well sharpened tools not only increase productivity but also the safety. To sharpen too much is also possible and not desirable. In this respect it is advisable to keep about one quarter of the blade of the bolo (close to the handle) unsharpened to diminish the risk of accidents (11). Very little is known about the number of accidents in agroforestry or their seriousness. Studies are urgently needed.

When introducing new or improved tools and expedients, it is very important that these can be locally produced. The main problem is that the right quality steel is often not available. Old car parts, e.g. springs, are then used. The characteristics of available steel can usually be improved by the local blacksmith. However, he must be skilled and must be able to control the temperatures of the processes very well.

When looking for the best adapted implements and when developing good and safe working techniques as well as maintenance techniques, ergonomics can play a very important role in agroforestry.

Tasks

To perform a specific task adequately, a number of conditions have to be met: i) knowledge and experience of the process; ii) correct expedients; iii) right working methods and organisation; iv) correct working posture, movements and forces; v) optimal energetic workload. In relation to the other tasks within the production or human-ecosystem a good division of labour over the year is essential.

A correct posture when working as well as moving about is a question of training (for example in lifting a heavy load) and also of the use of adapted expedients such as lengthening the handle of a hoe, as is seen in South-East Asia (4, 6, 7, 8).

The work load can be too heavy as an average during a working day or can have several peaks during the working day. Improvements may be found in a different choice of implements or work organisation. For example, the same work being done by two people with a two-man saw, the use of a sledge or cart, or in lowering the pace and adding more rests. Work physiological research has proved that short frequent rests are more effective than the same amount of rest taken during less resting periods.

Object and product

In trying to solve problems in ergonomics, which are caused by the object, it can be useful to look beyond the man-task system to the desired characteristics of the product within the production or even the human-ecosystem. It may well be that a certain task can be done more simply or left out altogether. Using the example of firewood, from an ergonomical point of view it is much more attractive to harvest stems from thin trees, or the branches from fullgrown trees, than the stems of the latter. These thinner sticks can be harvested with a bolo, do not have to be split, and are easier to transport over short distances. A limitation is that some trees do not produce sprouts after the stem or branches have been cut. Last but not least we must take into consideration the purposes for which the wood is going to be used. Are the ovens used suitable for different sizes of firewood?

The cutting of grass, when still green, is another example of solving a problem within the production system. A last example is the problem of tillage of the land at the end of the dry season. The animals are weakened and the soil has hardened. Improvements can be found within the task itself, in trying to find a better adapted plow, or within the production system by waiting until the soil is more workable when its moisture content has increased, or to introduce (woody) crops which supply fodder late in the dry season.

Physical-chemical environment

Factors such as (high) temperature, (high) humidity, wind, radiation, dust from harvesting and threshing as well as noise and vibrations from mechanized production systems, belong to the physical-chemical environment.

The above mentioned climatic factors influence the productivity. Above 25º ET (effective temperature), a decrease in the productivity is observed which increases logarithmically, and when the ET reaches 34º the productivity has reached 50% (1). From the organizational point of view something can be done about this, namely by shifting the working hours from the hottest hours of the day to the cooler hours of the morning. The wearing of appropriate clothes and broad rimmed hats also make working more bearable. An adequate intake of water will stimulate perspiration and will keep the moisture content of the body at a reasonable level. Protection from dust with locally available means is not so simple. The use of a wet cloth to protect the respiratory organs is not recommended from a hygienic point of view, neither is the use of special dust glasses to protect the eyes (expense and discomfort). The introduction of tree components to agricultural systems will allow the farmer to work in the shade, which improves the work environment.

Social-organisational environment

Various examples about an influence of the social-organizational aspects have been discussed already. They were mostly in regard to cases in which the production system or the human-ecosystem was of influence on the man-task system.

Examples of factors of influence are: available capital and labour; price of agricultural products; size of the family and the allocation of tasks; relationship with the neighbours; influence of culture and traditions; and infrastructure.

SYSTEM ERGONOMICS

The ergonomic approach depends strongly upon the development phase in which research is being carried out.

A distinction has to be made between:

a) the improvement of existing systems where only adaptations can be carried out; these applications are called curative ergonomics

b) the development of complete new systems; these applications are called preventive ergonomics

For the evaluation and improvement of already functioning systems, one can make use of existing ergonomic check lists to analyse the various components of the man-task systems, in order to work out the possible improvements starting with the most serious bottle-neck. A choice can be made between different types of check lists, from very general and therefore abstract ones to very specific ones designed for one type of machinery. For agroforestry purposes I would suggest the use of a series of three check lists (viz. one for tools, one for machines and implements, and one for fixed working positions) as are used during the training courses "Introduction to Ergonomics" organized by the Working Group PET (Promotion of Ergonomics in the Tropics) in Wageningen, The Netherlands (12).

The big advantage of starting to develop a new system is the fact that one can start from the beginning with new objectives and new constraints, without all the constraints inherited from an existing system.

The various steps which have to be taken in developing a new man-task system are the following: formulation of the objectives and constraints; distinction of the different main and sub-tasks; allocation of the tasks to the human being and the technical implements; listing of the specifications for the various components of the system (Fig. 1. P, T and E); the development of different alternative designs; the choice of a design; the introduction of the chosen design; evaluation and adjustment.

By going through the above listed steps a regular feedback takes place to the objectives, the constraints and the specifications. Meanwhile education and training also need attention.

In agroforestry, both check lists and the step by step system approach are already used. ICRAF has developed the diagnosis and design (D and D) methodology, through which the analysis and development of agroforestry systems is carried out in a comparable systematic way (5). Until now, within the

D and D methodology there is no room for ergonomic analyses and specification data. As far as I can see this is a question of priorities and the level of planning. However, the development of agroforestry systems, and ergonomical research, would both profit from procedures in which all data would be analysed and elaborated jointly.

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A CRITICAL ANALYSIS OF AN AGROFORESTRY PROJECT IN ACOSTA AND PURISCAL, COSTA RICA

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J. Heuveldop*

SUMMARY

The programme and implementation of an agroforestry research project, designed to provide the information base for a subsequent agroforestry development-extension project, are critically reviewed. A description is given of the basic studies carried out in the research zone of Acosta and Puriscal, Costa Rica, with emphasis on the need for socio-economic studies both before and during the research period. The most promising agroforestry techniques are: dry season forage production from living fence posts or cut-and-carry silvo-pastoril units; total confinement stall-feeding system for dairy goats fed partially with foliage from existing farm trees; management of the naturally regenerated timber tree Cedrela odorata in coffee (Coffea arabica) plantations; and the use of the tree Gliricidia sepium to provide a nitrogen rich mulch for beans (Phaseolus vulgaris)

INTRODUCTION

The purpose of this report is to describe how an agroforestry research project, designed to provide the information base for a subsequent agroforestry development project, was implemented. A critical analysis is made of the two main lines of work: A) basic studies of the area, B) development of new or improved agroforestry techniques. It is hoped that this analysis can be used as an example by other projects whose objectives include the development of agroforestry techniques for a specific area. This report only includes the

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conclusions of studies carried out in one of the areas where the CATIE*/GTZ** Agroforestry Project worked, and does not attempt to present all the data which was obtained. Such specific information has been and is being published in a series of articles and books which can be obtained from CATIE (see bibliography).

SELECTION AND DESCRIPTION OF THE RESEARCH AREA

The research area was selected in Costa Rica by a former GTZ supported CATIE project (Farming Systems in Central America) in accordance with national priorities. The selected area of Acosta and Puriscal, includes moist tropical forest to premontane rain forest life zones (16) with altitudes between 800 and 1200 meters above sea level. Due to differences in natural conditions, and consequently in land use, the study area was divided into two sub-areas: A) Acosta with smaller, highly diversified farms on steeper slopes, and B) Puriscal with somewhat bigger, less diversified farms and a smoother topography. There is little flat land in either area and slopes vary between 30 and 80% (22).

The ranges of annual total rainfall in Acosta and Puriscal are 1300-3400 mm and 1600-3500 mm, respectively, with annual averages about 2100 mm and 2500 mm, respectively. Both areas have a marked dry season between November (Acosta) or December (Puriscal) and May, with only 10% of the yearly rainfall during this period. Mean monthly temperatures vary between 19.6 in November-December and 22.3ºC in April.

The soils have been classified as Ustic Tropohumults on the smoother sites and as Ustic Humitropepts on the steeper slopes of Puriscal, and as Typic Tropohumults and Oxic Dystrandepts in the Acosta sub-area (1). Soils are clayey and characterized by relatively poor mineral contents. P and N contents are low and the soil pH ranges between 5 and 6. However, topography is a more serious limiting factor than soil fertility <u>per se</u>.

Both sub-areas have urban centres ("Santiago de Puriscal" and "San Ignacio de Acosta"). Population density is 100 and 77 inhabitants. km^{-2} in the sub-areas of Acosta and Puriscal respectively, and can be regarded as high in comparison to the average for Costa Rica which is 42 inhabitants.km^{-2}. A negative migration from both areas indicates that the region is not sufficiently attractive or does not support the current population (22).

Colonization in Puriscal began some 125 years ago, and about 25 years later in Acosta (8). Until 1935 the region was called the "breadbasket" of Costa

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Rica. At this time about 70% of the area was still covered by forest (21). Intensive industrial exploitation had not yet started because of low timber prices and very limited accessibility to the forested areas. The farmers penetrating the rough terrains of Acosta and Puriscal brought their knowledge and agricultural techniques from the flat Central Valley. Deforestation, repeated burning and the intensive annual cropping systems soon led to severe impoverishment of the soils, not so much because of an original low fertility but because of the high soil losses by erosion. Subsequently the area of extensive pasture lands increased.

BASIC STUDIES OF THE RESEARCH AREA

Information was collected on the physical environment, present land use, land use capacity, production and productivity patterns, socio-cultural aspects and on the basic needs as perceived by the local population. Superimposing the maps of present land use over land use capacity clearly shows discrepancies between the actual and recommendable land use, and hence priority areas for the project (20).

Several static surveys (i.e. 1 visit) were made on the existing ("traditional") agricultural practices and agroforestry systems, in order to classify them, and evaluate their particular potentials as well as constraints (350 farms). Three principal types of agroforestry combinations were identified (18):

i) Coffea arabica shade trees. C. arabica is the main cash crop in the area. The shade trees are poorly managed, sub-utilized and many could be replaced by more productive multiple-purpose tree species.

ii) Pasture-shade trees. The worst environmental degradation has occured in the extensively managed pastures (0.5 animal.ha^{-1}). Apart from browsing damage, trees are also affected by burning and harvesting for firewood.

iii)Live fence posts. This technique is associated with all kinds of land use. The posts are spaced at 2-4 m, principally as a support for barbed wire. The firewood and forage potential of these trees is underutilized, as is the fence line space where more multiple-purpose trees could be established.

A subsequent dynamic study (weekly visits for 1 year) was made on a sub-sample of 75 farms, which were selected according to farm size and structure, the farmers willingness to cooperate and year-round accessibility to the farm. This agro-economic survey of the former Farming Systems project gave results on agricultural practices, production and productivity, family structures, etc (23). Economic analyses, focused on the tree component (14), were never implemented because the Farming Systems project was unexpectedly terminated in 1982.

During the final stages of the project a socio-anthropological study is evaluating the farmers perceptions of problems and limitations as well as their acceptance of some new or improved agroforestry techniques. It is obvious that this kind of study should in principle preceed the development and testing of new methods. On the other hand this study includes concrete questions based on our own experiences and the results already obtained. As such, this socio-anthropological study can be regarded as an evaluation of the project activities in the zone and it has been provisionally concluded, for example, that timber production has been excessively emphasized (see section 4.3) since the farmers are more interested in fruit production (19).

RESEARCH ON NEW OR IMPROVED AGROFORESTRY TECHNIQUES

The following section describes four agro-forestry techniques which have been given research priority by the project. In order to explain why these particular techniques were chosen, and how feasible it is to continue them into an agricultural extension phase, each technique is described under the sub-titles: 1) Justification, 2) Results and 3) Potential.

Tree fodder production

Justification:

The limiting factor to pasture carrying capacity is the lack of forage in the dry season. Fodder trees are not a viable alternative to pasture grasses, when compared by total annual production. However, they do have the potential to produce high quality fodder (high protein content) in the dry season when pasture growth ceases and quality drops drastically. Some of the pasture shade species produce timber but most give firewood only, and fodder use is limited to browsing of the lower branches and fruit consumption (24). The production potential of fence lines is also subutilized (2). In both pastures and fence lines, fodder trees pruned at regular intervals could increase farm productivity (5, 6, 9). The establishment of additional trees might also reduce future erosion by:

i) taking the pressure off more sensitive areas assuming that the farmer does not just increase his herd;

ii) by providing living barriers to reduce run off (17).

Results:

Dry season forage production from existing Gliricidia sepium fence posts was studied at two sites in Acosta-Puriscal (5). In contrast to the traditional method of annual or biannual pruning in March, the trees were pruned in October or November and in March. The first pruning, at the end of the rainy season, stimulated the trees to produce succulent sprouts which were harvested at the end of the dry season. Although the treatments succeeded in halting dry season defoliation, forage production of both pruned and unpruned trees was much lower than expected, as fungal disease and root rot or nematode attacks were worse than in recent years*. Since, there are doubts about the ability of this species to resist frequent pruning (6), the technique needs more testing before it can be recommended.

The production of tree forage, from silvopastoril plots including "King-Grass" (Hybrid Pennisetum purpureum x P. typhoides), is being tested on seven farms. Large stakes of G. sepium, Erythrina poeppigiana, E. berteroana and Spondias purpurea, at 3 x 1 m. spacing, have been established in production units of 25 x 25 m. A problem for the extension of this technique in Acosta-Puriscal is the limited availability of suitable stakes, especially of E. poeppigiana. The farmers readily accepted the idea (dry season fodder reserve), even though they had to dedicate scarce land, and labour, to the project. The local extension service has also started to plant such units for demonstration purposes.

Multiple-purpose species trials were established at 6 different sites on degraded pasture lands. Species were selected for their potential to produce timber and fuelwood, as well as fodder. Initial results show that Acacia mangium, an emergency fodder source but principally a timber species, has exceptional drought resistance and the best growth rates of 1.3 - 1.9 m at age 20 months (13). On these poor soils survival and growth of forage trees such as G. sepium and Calliandra calothyrsus has not been good. Establishment costs are prolonged and high since the trees have to be fenced in to be protected from grazing animals for an excessive time (greater than 2 years).

Potential:

The dry season production of forage from fence lines, or from cut-and-carry silvo-pastoril units, is the most promising agroforestry technique for improving animal production and can now be promoted in certain cases (e.g. for goats in stalls). The inclusion of trees in grazed areas can not yet be recommended and the economics of planting trees for cattle fodder are unknown.

* Farmer's observations.

Goats in stalls fed with existing farm resources

Justification:

The five months dry season limits annual pasture carrying capacity and causes seasonal milk shortages. In more remote areas the availability of fresh milk is a year-round problem. Most small farmers have insufficient land to maintain dairy cattle, and those who do, pasture their animals on steep slopes (20) where poorly managed pastures provide inadequate soil cover, and hence permit excessive erosion. A productive dairy technique, using stall-fed goats which receive cut grass and arboreal fodder, can be maintained in humid tropical zones (7, 11). The forage production potential of fence-line and pasture shade trees (see 4.1), as well as from coffee (Coffea arabica) shade trees (12), lead to the idea of testing this intensive dairy goat technique in the area of Acosta-Puriscal. Goats, rather than cattle, were chosen to test the value of these potential fodder resources, because of their lower total intake, and acceptance of a broader range of fodder species (McDowell and Bove cited by Raun, (25)). Goats were already present in the zone but since there are problems to adequately regulate their browsing, and keep them free of parasites in such a humid area, we emphasized the necessity for continuously confining the animals to stalls which have a raised floor.

Results:

The technique of keeping goats in total confinement has been tested on 8 small farms. The raised stalls were designed to provide good aeration, a dry floor, and to permit excrement to fall through the slats, and hence reduce parasite problems. In order to reduce costs, most of the stall construction materials were obtained on the farms, e.g. main corner support poles of the rot resistant G. sepium, walls of bamboo or small roundwood. To avoid parasite reinfection the goats were never allowed to graze and were fed twice a day using a "cut-and-carry" management. Initially the existing farm resources (grasses, tree foliage, leaves and fruit of Musa spp., crop residues) were being used, but small forage production units (See 4.1) have also been established near to each stall. Potentially productive animals (over 150 kg milk in 150 days during their previous lactation), at the beginning of a new lactation, were loaned to the farmers by the Department of Animal Production, CATIE. The farmers had an option to buy "their" goats when the first phase of this study terminated.

Existing fodder resources were sufficient to maintain 1-2 goats. All farms had some Musa spp. and since there was an overall excess in the area, the fruits could be obtained free or at minimal cost from neighbours (C 20-30 = $0.5 per raceme, 1985). The Musa spp. provided the main energy source (fruits) and part of the goats fibre needs (leaves and stems). Grasses, from small paddocks or roadsides, were the other main fodder source. The animals protein requirements were partially met with leguminous tree foliage but initially it proved difficult to convince farmers that this was a valuable forage resource. Milk production levels fell, in some cases, below the optimal obtainable at CATIE when concentrates were included in the ration, but in 5 out of the 8 examples production was maintained at satisfactory levels and these farmers have voluntarily continued the intensive management. Although the technique is labour intensive, in most cases the farmer's family helped to manage the animal(s) (stall cleaning, milking, etc.). The results obtained so far show that the management of goats in stalls can be a productive small farm activity that should not conflict with existing labour commitments.

Potential:

There appears to be no general socio-economic nor biological limitations to the introduction of a "total confinement stall management" for dairy goats, and the units can be established and maintained using the existing resources of small farms (for example 2 ha). This technique is now being promoted by the extension service. However, future success will depend upon the availability of productive animals which have the capability of responding to "cut-and-carry" management. The problems of organizing the reproduction of the existing animals have yet to be addressed. Success of the extension phase will also depend on the selection of farmers who really want to keep goats rather than the selection of those with the most need.

Timber production from *Coffea*-shade tree associations

Justification:

The farmers have an urgent need for methods of producing timber on their small holdings, where the establishment of pure tree stands is seriously limited by land availability. In the area of Acosta-Puriscal, which is not an optimal *Coffea* zone (30), the government extension service recommends the use of some shade trees for *Coffea* (15). Most farmers continue to manage their *Coffea* under a diverse mixture of shade trees, including species which produce fruit and timber (12). However, in many plantations the distribution of the naturally regenerated trees is irregular, giving excessive shade in some sections. Moreover, tree management is inadequate, e.g. no selective thinning of timber trees, nor pruning. Given these antecedents, studies were initiated on how to improve shade tree management, rather than on the justification for using shade.

Results:

Based on the characterization of shade trees of Coffea (12), the timber species Cedrela odorata was identified as having the highest potential value for small farmers. Studies were initiated on how to reproduce and establish this species in Coffea plantations, as well as measurements of wood production. The final results of this work will not be available for several years, but provisionally it was concluded that stem diameter growth rates are 1.6 - 2.3 $cm.a^{-1}$ permitting a rotation of 25-30 yrs, (d.b.h. 45 cm) (26). However, it must be noted that the present natural occurence of this association is very irregular, suggesting that its promotion will be limited by very specific site requirements. Harvesting efficiency is often poor and the commercial volume conversion factor (vs total volume) could be increased (27).

The overall production can certainly be increased with a regular tree distribution, and by the early elimination of badly formed trees. Pruning, to reduce the consequences of shootborer (Hypsipyla grandella) attack, is another silvicultural method which should be promoted (29). Optimum densities of mature Cedrela odorata over Coffea are probably in the range 50-100 $trees.ha^{-1}$, assuming that the farmers continue to follow the traditional practice of maintaining an additional lower strata of other shade trees (4, 12). Uneven-age tree management is logical for fullfilling on-farm timber needs, whilst even-age tree management, arranged to coincide with Coffea bush renewal, is recommendable for commercial exploitations of the timber.

At present natural regeneration is used to replace harvested trees. To implement the above recommendations, artificial establishment is needed. However, in view of the questionable potential of Cedrela odorata on sites presently without natural regeneration (species-site requirements), and the uncertainty whether C. odorata is a good shade tree for Coffea, tree establishment methods were only tested on farms already using this shade species.

Seedlings were produced in small tree nurseries, managed by the farmer, but with regular supervision by project assistants. On 4 farms Cedrela odorata was amongst the species requested by the farmers, and they subsequently chose to plant these seedlings with Coffea. The dedication of the farmers to their nurseries was mostly excellent. However, this was to be expected since they were carefully selected from a group which requested assistance, and they made the choices of species. Labour limitations were not a problem as long as trees were out-planted early in the rainy season, to avoid clashing with the Coffea harvest. Weekly supervision visits proved necessary but caused high production costs. In addition to the establishment of Cedrela odorata with bagged seedlings or "stumps", tests were made on the rooting ability of 2 m stakes. The expected advantage is a reduction of the susceptible seedling stage when damage by H. grandella, cattle and herbicides is greatest (26). However, disadvantages could include butt rot, slower growth and poorer form when compared to natural regeneration. During 1984 only two out of 64 stakes (2 sites) rooted, but late planting in the rainy season, in a year when the dry season lasted 5 months, probably affected survival. In 1985, 5 plots or lines, of 30 stakes, were established early in the rainy season to see if the unquantified reports of farmers and investigators (Peck, R. B., personal communication; Ford, L.; personal communication; 10; 28) indicate an alternative method of establishing C. odorata in Coffea plantations or pastures.

Potential:

The production of Cedrela odorata in Coffea plantations, outside of the limited areas where it is presently known, is an attractive possibility. However, extensive long-term studies are needed on both Coffea production as well as silviculture, before this association can be widely promoted. The main limitation on decentralized tree nurseries is financial and not technical.

Tree foliage mulches for annual crops

Justification:

Virtually all Acosta-Puriscal farmers cultivate maize (Zea mays) and beans (Phaseolus vulgaris), principally for home consumption. The Z. mays fields, which are frequently located on steep hillsides, receive some inorganic fertilizer and are managed with clean cultivation techniques. Rapid erosion of the unprotected soil is common, and some farmers are obviously concerned about this problem since they have constructed narrow terraces in annual cropping areas. P. vulgaris may also be produced in clean weeded fields, but a more sustainable technique called "Frijol Tapado" has been maintained by the farmers, especially for the cropping of steep slopes. The technique involves broadcasting the seed into 1 or 2 year old secondary growth thickets. The vegetation is then immediately cut down forming a mulch. Unfortunately this method is not very productive, and some farmers now prefer clean cultivation with commercial fertilizer application. Apart from the erosion risk, this change implies an economic dependancy on an imported resource (22).

Results:

In an attempt to combine the traditional and modern cultivation techniques into a sustainable system, alley-cropping experiments were established with the leguminous tree species G. sepium. Contour line planting of the 2 m G. sepium stakes, with a close intra-line spacing and wide inter-line spacing, provides a source of N rich mulch that can partially replace the inorganic N-P-K fertilizers. In the Acosta- Puriscal trials, the application of a G. sepium mulch to P. vulgaris has consistently given favorable results, with yields at least as good as treatments including inorganic N fertilizer. However, the mulch has not yet consistently proven to be an effective alternative to inorganic N for the production of Z. mays (3). The unequal response is thought to be a consequence of the different timing of critical N demand by these two crops, and by delaying the mulch application the yield response of Z. mays could be increased. However, little is known about N release and decomposition rates of arboreal leguminous mulches, so the correct timing of mulch application will have to be determined by empirical methods. The long term effects of these mulches on soil fertility is another important aspect that needs to be studied, by continuing the existing experiments with alternating Z. mays - P. vulgaris cycles for several years. Although two trials are located on private farms, the experiments have been managed by the research team, and socio-economic limitations have yet to be studied.

In two of the trials, one "treatment" was provided by the farmers using their present clean cultivation methods. Although these cooperating farmers may have made special efforts due to their involvement in an experiment, the relatively good yields they obtained during the first cycle indicated that farmers are already benefitting from new technology (compared to the zero herbicide, zero fertilizer control). It is important to bear in mind that the farmer's adoption of any new recommendations, such as the use of a mulch, will depend upon demonstratable advantages over his present methods, and not over the zero treatment control so commonly used as a base line by scientists.

These trials were designed to show that leguminous mulches can replace N fertilizer. All plots received K and P inorganic fertilizer applications. However, commercially available fertilizers, which do not include N, are difficult to obtain in Costa Rica. Further trials are needed to show that mulch can provide all the nutrient needs of the crops; or the extension service will have to ensure that K and P fertilizer are available for use in combination with organic nitrogenous mulches.

Potential:

Leguminous tree mulches can replace inorganic fertilizers as a source of N for P. vulgaris. The use of organic mulches as the only source of all nutrients for annual crops in this area has yet to be proven, as has their value for the cultivation of Z. mays. Although there are no obvious socio-economic limitations to the method, which imitates the widely used "Frijol Tapado" technique, it is now necessary to establish pilot studies with the farmers managing the plots.

CONCLUSIONS

The basic aim of the project was to improve the agricultural productivity of small farms. The success of the new or improved techniques (as described above) should also be evaluated by contrasting erosion in areas under traditional versus new or improved management.

The experiences in this project have shown that rural development, through the improvement of traditional agroforestry land use systems, is possible. Careful selection of priority areas and trial farms, in cooperation with local authorities, is a basic requirement. The value of the results obtained, in terms of a cost-benefit balance, will mainly depend on the choice of the area, the quality and scope of the diagnosis applied, and the involvement of extension agencies and farmers. More emphasis has to be given to anthropological and socio-economic aspects, and an adequate timing of activities is essential for any success.

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CRITERIA FOR THE EVALUATION OF ORGANIC MATTER AND NUTRIENT CYCLING IN AGROFORESTRY SYSTEMS*

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L. Alpízar***

SUMMARY

A model is proposed for the description of the cycling of organic material and nutrients in agro-forestry systems. In order to apply this model, the reserves in the different compartments of the system (mineral soil, litter layer, crops and shade trees) are quantified, and measurements are made of the transformation processes (agricultural production, wood production, production and decomposition of organic residues, inputs and outputs in water). The results obtained for the agroforestry systems of coffee (Coffea arabica) with the shade trees "laurel" (Cordia alliodora) and with "poró gigante" (Erythrina poeppigiana), are presented.

MODELS OF AGROFORESTRY SYSTEMS

In the past few decades, special attention has been given to developing models to describe agricultural ecosystems and production systems. Modelling techniques for organic matter and nutrient cycles have also been applied to agroforestry production systems (10, 16, 18, 22). Specific studies exist that deal with the association of shade trees with coffee (1, 2, 3, 12, 13, 14, 15, 17, 19, 21, 24) as well as with cacao (1, 4, 11, 23). The criteria used to study these cycles, and the degree to which the results were utilized, vary amongst the authors.

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Models of organic matter and nutrient cycling are based on an evaluation of the reserves in each of the compartments within the established limits of the system, and the measurement of the interactions and transfers as well as the gains and losses (1, 2, 10, 12, 17) (Fig. 1).

In the studies conducted to date, arbitrary limits, generally associated with experimental plots, have been used. No information exists on the farm level. The differences in the definition of the components depend principally on the interests of the researcher. Generally, abiotic components like the mineral soil and the litter layer, and the biotic component, that is the species involved in the agroforestry systems, have been considered. Discrepancies exist in the differentiation of the plant compartments (e.g. leaves, branches, stems, roots, flowers, and fruits) and especially in the soil compartments (horizons, segments, and depths studied).

The accumulation of organic matter by photosynthesis, and of nutrients by absorption, is reflected in the biomass of agroforestry production systems (Fig. 1).

The interactions between the different components can be described by the dynamic transformation phenomena of the organíc matter in the system, through the deposition of residues (natural production and prunings) and its decomposition (mineralization and humus formation) in the litter layer (Fig. 1).

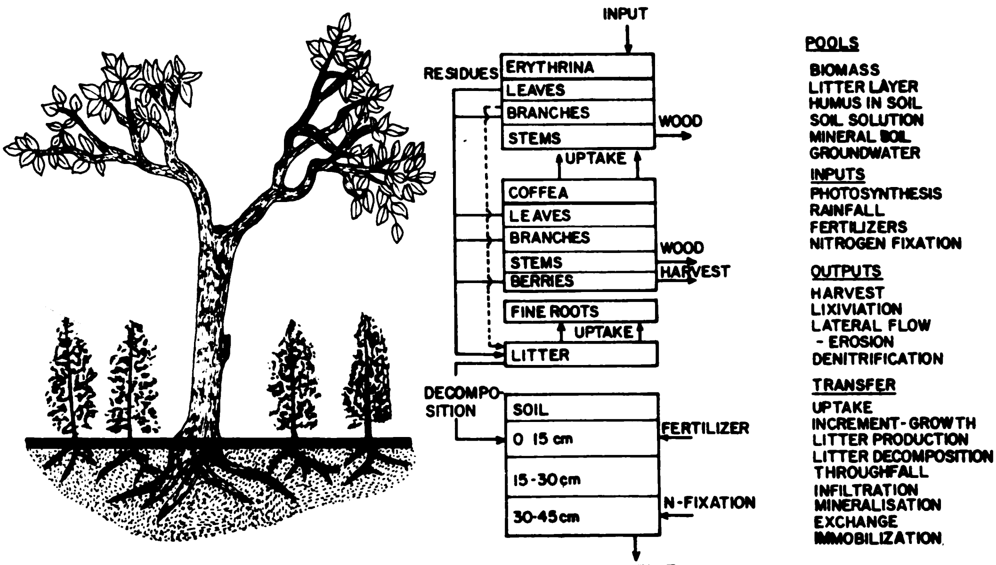

Fig. 1. Schematic representation of the agroforestry system Coffea arabica with Erythrina poeppigiana and of the organic matter and nutrient model

Other input sources that are considered are rain and the chemical elements that enter with it, fertilization with different nutrients,and N fixation. Outputs that are considered are the drainage of water that carries nutrients to the groundwater, lateral soil transport (erosion) and the harvests of fruits and wood from the system (Fig. 1).

In this paper the advantages and limitations encountered for the partial measurements and for the complete models will be presented and discussed using examples of agroforestry systems, especially the association of shade trees with coffee (Coffea arabica).

ORGANIC MATTER AND NUTRIENT POOLS

Quantifying organic matter and nutrients involves measuring the amounts in the biomass and litter, and determining the humus and nutrient content of the soil. Although information usually exists about the phytomass, very little data exists about the fauna, especially in the soil.

The organic matter pools of agroforestry systems that combine C. arabica (5,000 plants.ha^{-1}) with the shade trees "laurel" (Cordia alliodora, 185 trees.ha^{-1}) or "poró" (Erythrina poeppigiana, 555 trees.ha^{-1}), in the Central Experiment of CATIE (1, 2, 9) in Turrialba, Costa Rica (630 meters above sea level, 22.3º, 2648 mm, soil Typic Dystrandept) at an age of 4.5 years, can be summarized as follows (1, 2) (Fig. 2; t.ha^{-1}):

	Coffee with laurel		Coffee with poró	
	Coffea	Cordia	Coffea	Erythrina
Leaves	1.9	2.2	2.7	4.7
Branches	2.2	3.2	3.8	7.7
Stems	3.8	23.8	8.7	7.8
Fine roots	4.5		2.6	
Vegetation sub-total	41.6		38.1	
Litter	4.9		6.3	
Mineral soil (0-45 cm)	195.8		164.4	
TOTAL FOR SYSTEM	242.2		208.8	

The accumulated reserves in the vegetation are comparable (41.6 and 38.1 t.ha^{-1}) despite the unequal number of trees and their management. In the case of C. alliodora, the wood production (in 5 years: h = 11.9 m; d = 25.9 cm; timber volume = 54 m^3.ha^{-1}; dry biomass = 23.8 t.ha^{-1}) constitutes the largest part of the reserve (57%). E. poeppigiana has other purposes such as giving shade, N fixation, and litter production for mulch. The phytomass of Coffea is

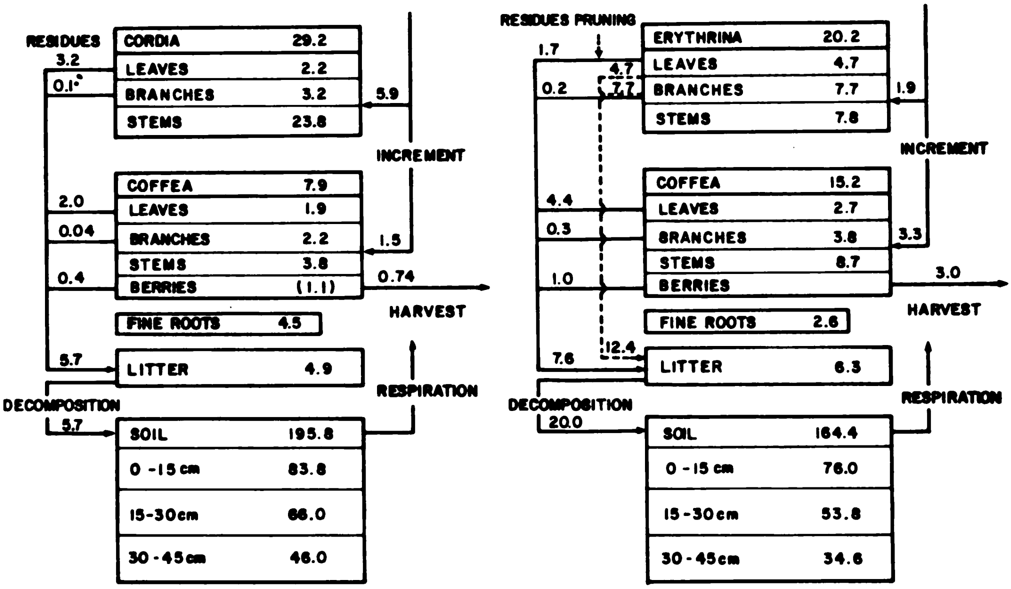

Fig. 2. Organic matter cycle in agroforestry systems of Coffea arabica under Erythrina poeppigiana and C. arabica under Cordia alliodora in Turrialba, Costa Rica

greater under E. poeppigiana shade (15.2 t.ha^{-1}) than under C. alliodora shade (7.9 t.ha^{-1}).

It is difficult to compare the biomass data from other Coffea agroforestry systems due to differences in ecological zones, soil, ages and densities of the Coffea bushes and the shade trees, and the management of the Coffea as well as the shade trees. Goldberg and Jiménez-Avila's (15) values of 16.7 t.ha^{-1} in 3,600 Coffea bushes and 27.9 t.ha^{-1} with 50 shade trees (Veracruz, Mexico) are close to the values found by Alpízar et al (1, 2). The values of Aranguren et al. (3) of 40.5 t.ha^{-1} in 5597 Coffea bushes (Caracas, Venezuela) are not consistent with the previously mentioned figures.

The values for the biomass, especially of the leaves and branches, depends on the phenology of the species involved as well as the climate.

The biomass data for E. poeppigiana (12.4 t.ha^{-1}) of Alpízar et al (1, 2) are based on the sum of two prunings per year. The leaf and branch biomass depends on the pruning interval and technique. Russo (21) found a dry leaf and branch biomass of E. poeppigiana of 11.8 t.ha^{-1} based on two prunings per year and 18.5 t.ha^{-1} based on one pruning per year. Glover and Beer (14) found a leaf and branch biomass of E. poeppigiana of 7.8 t.ha^{-1} from three prunings per year.

The nutrient accumulation in the agroforestry systems of the Central Experiment of CATIE, after 4.5 years, can be summarized as follows ($kg.ha^{-1}$) (1,2):

	Coffea with Cordia			Coffea with Erythrina		
	N	P	K	N	P	K
Coffea	99	10	31	182	16	124
Shade tree	187	23	198	341	30	214
Roots	58	4	28	43	3	18
Vegetation sub-total	345	38	257	566	49	356
Litter	110	7	14	133	10	17
Mineral soil (0-45 cm)	8,873	2,736	687	8,500	2,997	630
TOTAL FOR SYSTEM	9,328	2,782	958	9,199	3,056	1,003

Nutrient absorption by the vegetation has been quite different. The relation of Coffea with E. poeppigiana: Coffea with C. alliodora is:

N	P	K
1.64	1.27	1.39

These values permit a specific interpretation of the systems. The association with E. poeppigiana is characterized by a higher rate of nutrient absorption. Without doubt, the legume not only provides N, but also activates the absorption and recirculation of P and K through removal from the soil. The combination with C. alliodora shows less absorption and nutrient accumulation, especially in the stems and wood.

AGRICULTURAL PRODUCTION OF AGROFORESTRY SYSTEMS

The agricultural and/or wood production is one of the most important aspects in the interpretation of the advantages and disadvantages of agroforestry systems. The data from the harvest of Coffea associated with C. alliodora or E. poeppigiana (17), in the Central Experiment of CATIE, is summarized below ($kg.ha^{-1}.a^{-1}$):

	Coffea under Cordia	Coffea under Erythrina
1979/80	4,431	5,103
1980/81	3,816	11,873
1981/82	2,389	9,776
1982/83	16,736	11,338
1983/84	3,167	3,627
TOTAL GREEN WEIGHT (1979-84)	30,539	41,717
TOTAL DRY WEIGHT (1979-84)	9,043	12,897

The nutrient export can be quantified as follows ($kg.ha^{-1}.a^{-1}$).

	Coffea with Cordia			Coffea with Erythrina		
	%	1981/82	1979-84	%	1981/82	1979-84
N	1.50	11.1	135.6	1.65	49.9	218.8
P	0.15	1.1	13.6	0.15	4.5	19.4
K	1.63	12.0	147.4	1.45	43.8	187.0

In the five experimental harvests, the relation of nutrient absorption between Coffea with E. poeppigiana: Coffea with C. alliodora is:

N	P	K
1.61	1.43	1.27

Shade and its management play a decisive role in Coffea production. The intense shade of the C. alliodora lowered the harvest, but a thinning in 1981 induced a notable increase in the production. The data doesn't permit definitive comparisons since the plants are still young. Therefore, it will be necessary to wait until the crops have passed their peak production phase.

The harvests of processed coffee, registered for two years by Glover (13) in adult Coffea (twelve years) in La Suiza, Turrialba, are summarized as follows ($kg.ha^{-1}.a^{-1}$):

Coffea with Erythrina	1,916
Coffea with Erythrina and Cordia	1,887

The values in these experiments in the Turrialba area of Costa Rica therefore surpass the values found in other regions or countries (7).

The basic difference of agroforestry systems is observed when the trees not only produce shade for crops, but also produce wood (for construction, export, firewood) and/or fruits, or perform other functions (windbreaks, production of reproductive material).

TIMBER PRODUCTION

Heuveldop et al (17) published the following data about the growth rate of C. alliodora as Coffea shade:

	Diameter breast height (cm)	Total height (m)	Total volume ($m^3.ha^{-1}$)
5 years	25.9	11.9	54.1
7 years	30.3	14.7	90.0

The stumpage values are quite high in comparison with others found in the literature (6, 20). The annual increments are also high when compared to other data (5, 6, 20).

The economic implications of the agricultural and/or timber production can only be evaluated with long-term studies. An integral economic evaluation also implies measuring nutrient changes and balances in the plants and soil.

EXPORT INDEX OF THE SYSTEM

The harvests represent an export from the system. An adequate index for interpreting the productivity of systems is the percentage of the total biomass represented by the harvest. The following values for the agroforestry systems in the Central Experiment at CATIE were obtained during the fifth experimental year (17):

	Vegetation biomass ($t.ha^{-1}$)	Coffee harvest ($t.ha^{-1}$)	Export index (%)
Coffea with Cordia	41.6	0.74	1.78
Coffea with Erythrina	38.1	3.03	7.95

The export index of the nutrients is calculated in a corresponding way (%):

Coffea with Cordia			Coffea with Erythrina		
N	P	K	N	P	K
3.2	2.9	4.7	8.8	9.3	12.3

The quantities removed are therefore small. The dynamics of the systems are characterized more by the increase of biomass in the C. alliodora association and the transformation of the organic matter through the litter production, and the recycling of nutrients, in the E. poeppigiana association.

PRODUCTION AND DECOMPOSITION OF PLANT RESIDUES

The production and decomposition of plant residues represents the connection between the biotic (plant) and abiotic (litter layer and mineral soil) compartments of agroforestry production systems. The humification and mineralization processes produce humic substances and nutrients that are incorporated into the soil.

The results of the studies of the natural litterfall during 3 years (Nov. 1981-Oct. 1984) in the Central Experiment of CATIE are summarized below ($kg.ha^{-1}.a^{-1}$) (17):

	Coffea	Cordia	Coffea	Erythrina
Leaves	2,108	3,603	3,532	3,142
Branches	336	850	418	652
Fruits	523	-	1,103	
TOTAL	7,420		8,847	

The monthly litterfall pattern depends on the physiological and phenological characteristics of the species involved in the system, and the prevailing climatic conditions. The leaf fall of the Coffea plants occurs principally after flowering. The leaves of C. alliodora fall mainly in the dry season, between January and April, due to the deciduous characteristics of this species. The annual quantities have increased yearly as the tree crowns gradually grow.

The litter production of E. poeppigiana is notably affected by the pruning management. With the regrowth after the pruning, branches and leaves are formed that later contribute to the plant residue production.

The prunings in the agroforestry systems with legumes (Erythrina spp., Inga spp., Gliricidia spp., Albizzia spp.) regulate the shade, activate the Coffea flowering and maturation of the fruits, produce mulch, release N fixed in root nodules, and increase the humus reserves of the soil. During one year, the residue produced by the pruning of the E. poeppigiana in the Central Experiment of CATIE reached 12.4 $t.ha^{-1}$ (17).

The values of the annual organic matter (O.M.) ($t.ha^{-1}.a^{-1}$) and nutrient transfers ($kg.ha^{-1}.a^{-1}$), of the systems studied, can be summarized as follows:

	O.M.	N	P	K	Reference
Coffea - Erythrina	20.0	461	35	259	17
Coffea - Erythrina	17.8	377	31	279	14
Coffea - Erythrina	4.3	228	18	139	21
Coffea - Cordia	5.7	114	8	55	17
Coffea - Erythrina-Cordia	16.1	338	33	169	14
Coffea - leguminous trees	-	170	-	-	3
Coffea - Inga	7.5-8.5	-	-	-	15
Coffea - Inga-Citrus	9.2	-	-	-	15
Coffea - Inga	4.7-13.1	-	-	-	24

The decomposition curve and decomposition rate are of interest when evaluating the decomposition of the plant residues that are deposited on the soil. The decomposition curve of a mixture of Coffea leaves and C. alliodora or E. poeppigiana leaves is exponential (17); i.e. the process in its initial phase is more rapid. The leaf litter of shade trees (Erythrina and Inga) in a Coffea plantation decomposes by 50% in two months (3). An equilibrium has been found between the deposition and decomposition of plant residues, in the few studies that have been conducted to date.

ORGANIC MATTER RECYCLING INDICES

An adequate way to express organic matter recycling in agroforestry systems is the quotient between the plant residues produced and the aerial biomass, whether it be by species or by system. The results for the Central Experiment at CATIE are the following (1, 12):

	Recycling index %		
	Coffea	Shade tree	System
Coffea with Cordia	31	15	15
Coffea with Erythrina	37	71	56

The corresponding indices for the nutrients are the following (1, 12):

Coffea with Cordia			Coffea with Erythrina		
N	P	K	N	P	K
40	21	24	82	75	77

The high indices of Coffea with Erythrina indicate that only a small part of the organic matter remains stable in the system; the majority of the biomass and the nutrients are recycled.

NET PRIMARY PRODUCTION INDICES

The annual net primary production of the production systems can be calculated by adding:

- the increment of the timber reserves (stems and branches)
- the deposition rates of the plant residues (leaves, branches, stems, fruits, roots)
- the annual harvests

The following primary production values have been obtained in the fifth year of measurements in the Central Experiment at CATIE (1, 12) ($t.ha^{-1}.a^{-1}$):

Coffea	4.6	Cordia	8.2	Roots	4.5	TOTAL	17.3
Coffea	10.0	Erythrina	16.3	Roots	2.6	TOTAL	28.9

The values encountered are quite high, yet are representative of agroforestry systems (3, 5, 6, 18, 19, 20).

CHEMICAL CHANGES IN THE SOIL

As in all agricultural production systems, gradual changes in the physical and chemical characteristics of the soil are to be expected. There are chemical analyses for the soils of the Central Experiment of CATIE, made at the beginning of the experiment and after 4 years. The studies of the organic matter and chemical element balances have lead to the following results (1):

	Coffea with Cordia		Coffea with Erythrina	
	Mineral Soil	Litter Layer	Mineral Soil	Litter Layer
Organic matter ($t.ha^{-1}$)	- 6.6	+ 5.0	+ 29.8	+ 6.4
N ($kg.ha^{-1}$)	+ 808	+ 110	+ 1,135	+ 133
K ($kg.ha^{-1}$)	- 376	+ 15	- 211	+ 17

+ gains; - losses.

These changes are considered to be transitory and only over a long period can definitive statistically significant results be obtained. The balances are the overall result of all the processes that occur in the system. The pH values indicate soil acidification, and corresponding to the K losses, losses of Ca and Mg along with an increase in Al have been recorded (1). The process is detrimental and deserves detailed study.

DISCUSSION

The results obtained for the organic matter cycle in the agroforestry systems studied are presented in Fig. 2. In this new approach, all the static and dynamic details of the system are described in a spatial and temporal view. Each of the criteria proposed has a different ecological and economic scope:

- accumulation of organic matter and nutrient reserves;
- agricultural and timber production;
- production and decomposition of plant residues;
- export index;
- recycling index;
- net primary production index;
- soil chemical changes

Future studies should thus emphasize multidisciplinary approaches, based on complete models for each agroforestry system.

The experimental conditions -climate and soil- are quite favorable at the Central Experiment of CATIE. Therefore, studies should be initiated in zones with different ecological and soil conditions. Likewise on-farm observations under real socio-economic conditions should be started.

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AGROFORESTRY SYSTEM INTERACTIONS: MAN-TREE-CROP-ANIMAL*

R. Borel**

SUMMARY

Taking the Agroforestry Systems Programme (AFSP) at CATIE as a case study, an analysis is made of the advances obtained from research on the main interactions identified in agroforestry systems. The potential of provoking a significant impact in existing systems, through research on each of these interactions, is discussed. Amongst the systems considered as having priority in CATIE's mandate region, the following are included: live fence-posts and windbreaks; silvopastoral systems in their two forms of grazing in forests and trees in pastures; agroforestry systems with perennial crops (mainly Coffea and Theobroma cacao); alley-cropping; and enriched fallow systems. Biological aspects of agroforestry systems which merit greater attention are: agroforestry species management; nutrient cycling management in farming systems; development of stable silvopastoral systems; and the determination of the potential of agroforestry techniques for soil conservation and watershed management. The analysis of the principal interactions involving man make it clear that there is a need to considerably reinforce socio-anthropological studies for the design of improved alternatives.

INTRODUCTION

The relatively recent arrival of agroforestry as a scientific topic, and the great variety of unknowns that need to be studied, makes it relatively difficult to put priorities on research activities and their connection with the elaboration

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* Translation from the Spanish by S. Shannon.

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of useable products for farmers. The problem consists then in discerning the truly critical fundamental questions, and in efficiently channeling the study of these into applied research projects.

This document will analyze the Agroforestry Systems Programme (AFSP) of CATIE as a case study, assuming nevertheless that the perceived problems are relevant to other similar or future programmes in Latin America.

The research objectives of the Agroforestry Programme have been defined as follows:

Finding the circumstances in which the use of agroforestry systems is an advantage.

Developing improved systems for specific areas of the mandate region of CATIE.

The principal steps of the AFSP methodology appear in Fig. 1. Existing agroforestry systems are used as the starting point for the development of new systems, in that the first steps deal with the characterization of traditional systems and practices. Using results from this previous phase, supportive research on specific aspects of species and association management are started. Design and evaluation of improved systems are based on the results of the previous phases, and are orientated towards the development of alternatives which can be used by extension services and as a basis for future development projects (28).

Priorities for important systems have been established (Table 1) on the basis of their importance in CATIE's mandate area, taking into account the level of existing knowledge within the AFSP, which gives certain systems a comparative advantage for solving some problems within the next 10 years.

Table 1. Priority agroforestry systems for the Agroforestry Systems Programme, CATIE

- Live fences, shelter belts
- Silvo-pastoral systems (trees in pastures; grazing in forests)
- Plantation crops with multiple-use trees
- Tree fallows
- Alley cropping

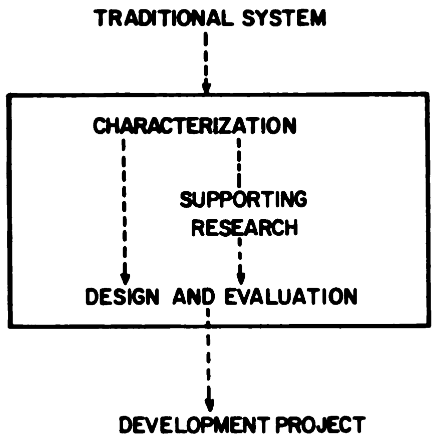

Fig. I. Methodology of agroforestry systems programme (PSAF), CATIE

Within these systems, the specific research necessities should be defined. Dividing the systems into the principal interactions which control them, can be a guideline for identifying these priorities. The task (which will be partly developed in this work) involves reducing the systems to their most significant interactions, or those showing greatest potential for effective intervention. Once selected they can provide an understanding of the system as a whole and can help solve some of the problems of that system. This procedure, which at first may appear simplistic, should be considered as one of the ways of giving priorities, or as a way of concentrating efforts on activities which should prove most beneficial, without ignoring other critical aspects of agroforestry systems whose practical importance may not be as obvious. It must be made clear that a definitive prioritization is made at different levels, starting from a political viewpoint, which may cause conflicts. It is important for researchers to learn to appreciate these different viewpoints and to include them in their definition of priorities. In other words, a biological problem does not by itself justify high priority unless complemented by socioeconomic problems that rank higher.

THE IMPORTANCE OF THE STUDY OF INTERACTIONS FOR RESEARCH ON AGROFORESTRY SYSTEMS

In the search for improved agroforestry systems, the goal is to satisfy the producers' basic needs (21). These needs may require the immediate production of goods and services or on a longer term, the adoption of sustainable production practices providing the same or greater satisfaction of the needs for an indefinite time in the same unit area of land. The hypothesis, for agroforestry systems research, is that the management, production and use of trees in the presence of other components of the system, satisfies some of these needs both in the short and long term. For this reason a high proportion of agroforestry research in the biological field concentrates on studying the following interactions:

Effects of animals and crops on trees

Effects of trees on animals and crops (including pasture)

The application and development of agroforestry systems is not only at the biological level but also involves the farmer and his surroundings in such a way that other higher ranking interactions should also be identified (19). In effect, agroforestry systems belong to a hierarchy of systems, each being a component of the next higher level (Fig. 2). Thus the farm system is part of the regional system, in which physico-biological, social, political and macroeconomic elements form a part. These constitute the surroundings of the farm systems. Within these farm systems, family components are recognized

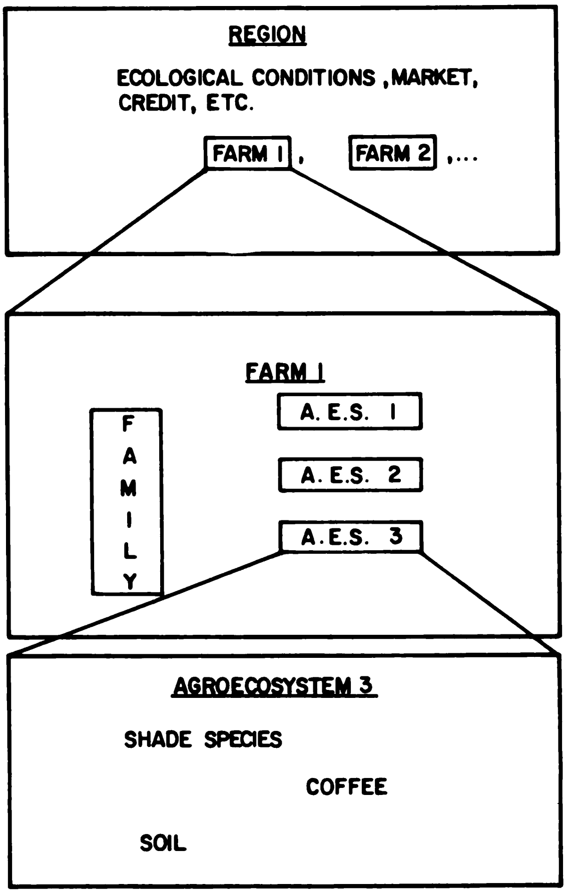

Fig. 2. Systems hierarchy (adapted from Hart)

and these are important in all aspects that depend upon labour use, motivation, preferences, problems, etc. Farm systems also include farming agroecosystems or speculations such as agroforestry combinations (*Coffea* spp. - *Erythrina poeppigiana*, grazing in forests, home gardens etc.) in which interventions could be attempted. In turn, within these agroecosystems, physico-biological components can be recognized including: trees, crops, animals, soils, pests, etc.

In order to apply the appropriate research methodology it is essential to identify at what level, or between which levels, are found the interactions under study, since the importance of interactions where man intervenes varies according to this criterion. Thus, two principal levels of study or intervention can be broadly differentiated (Table 2). The first, of a biological nature, is directed toward more simple interactions between system components, and the second which includes man, emphazises political, social and economic aspects with a view to application and development.

Table 2. Type of interactions according to the level of study

Level of study	Type of research	Type of interactions
Component. Agroecosystem.	Back-up research (Biological or ecological)	Effects of: trees on crops; crops on trees; trees on animals; animals on trees.
Agroecosystem. Region.	Application and development. Characterization, design, evaluation of systems according to farmer's needs.	Effects of: man on tree; tree on man; man on (crop + tree); (crop + tree) on man; man on (tree + animal); (tree + animal) on man.

ANALYSIS OF THE PRINCIPAL INTERACTIONS IN AGROFORESTRY SYSTEMS

The following analysis will attempt to divide agroforestry systems into their principal interactions (Table 2). For each interaction the following will be analysed: a) what does it involve; b) level of knowledge contributed by AFSP; c) achievements in the application of results either in extension programmes or prototype farms; d) potential for significant achievements in the future; and e) the priority that should be given.

Effects of trees on animals

These effects operate directly by way of animal nutrition (consumption of leaves or fruits), or through microclimatic changes, and indirectly by modifying the carrying capacity of the associated pasture.

<u>Foliage consumption</u>

Encouraging results have been obtained with the use of locally available tree foliage as a substitute for purchased concentrates (6). This has lead to technology trials on farms in Acosta-Puriscal, Costa Rica, where the use of forage cut from coffee shade trees and living fence posts has been evaluated as part of the feed for dairy goats (4). There is a great potential for the use of living fence posts in Central America, as a means of directly producing feed for ruminants, as well as concentrates, in spite of some problems with antiqualitative substances (10). Therefore, high priority will be given to expanding this work.

<u>Fruit consumption</u>

High seasonal consumption of <u>Psidium</u> <u>guajava</u> fruit by grazing cattle, probably as a pasture substitute, has been found (36). Although it is well known that cattle consume a variety of fruits in large areas of the dry tropics of Central America, it is not known whether these contributions from the trees have more than marginal importance. Models developed for <u>P</u>. <u>guajava</u> could possibly be adapted to these other species, but it seems that the potential for an appreciable improvement in the systems, by developing this interaction, is low.

<u>Microenvironment modification</u>

Although the practice of leaving some shade trees in dry tropical pastures is very widespread, and empirical information on the use of shade for cattle is common, experimental work has not been done. In high altitude zones, affected by strong seasonal winds, <u>Cupressus</u> <u>lusitanica</u> windbreaks are used (16), although whether their effect is directly on the animals or indirectly via the pasture, has not been explained. In practical terms there is little possibility for improving traditional practices through research. However, great potential exists for the transfer of these practices to other similar areas.

Changes in animal carrying capacity

Although there is a great deal of indirect experimental information (pasture productivity), no direct information exists (7, 30, 31, 37). Once again, the widespread use of windbreaks in high altitude zones, and their effect on pasture growth, suggest that this practice is well worthwhile. On the basis of existing experimental evidence, a great future potential can be seen for certain N-fixing species, which can increase productivity and sustainability of extensive grazing systems in the lowland tropics (11). Moreover, it is probable that the fine roots of regularly pruned trees, die back and decompose after pruning, thus allowing improved water infiltration and helping to reduce soil compaction in pastures (13). Further work on this topic has a high priority.

Effects of animals on trees

As in the previous case there are both direct effects, such as mechanical damage (including destruction of seedlings) and browsing, and indirect effects such as a change in the regenerative capacity of the trees (e.g. through seed dispersal in faeces), reduction of combustible material for forest fires, and soil compaction by animals which effects tree growth.

Mechanical damage

Grazing animals cause most damage to young trees (32) but no experimental work has been carried out in our region. According to the tree species, the naturally regenerated seedlings may or may not be eaten by the cattle who thus may impede or reduce stand renewal. For P. guajava, the relative effects of grazing and mechanical or chemical weeding, should be separated (38). In Alnus acuminata plantations the young plants are protected by special structures at high cost (12). To sustain future establishment of leguminous trees in pastures (even those started by means of large stakes), effective protection methods must be found for new plantations.

Browsing

This effect has been well studied in others parts of the world, but has received almost no attention in Central America. Experiments are being carried out to investigate the persistence of Erythrina spp. which are grazed by goats, but some methodological problems have still to be worked out. The importance of browsing management, and its advantages as a simple manner of utilizing the leguminous trees in pastures, justifies giving browsing studies a high priority.

Seed dispersal

Measurements taken from P. guajava stands show that cattle can play a preponderant role in seed dispersal, mainly by providing the appropriate conditions for germination (36). This work has not yet lead to practical applications, although simulation models which eventually should be applicable to other species, have been prepared. Hypothetically it may be proposed that cattle, given access to suitable seed, could be used as a reforestation agent in degraded areas.

Reduction of combustible material

In the natural pine stands of Central America, fires cause damage to young plants. The grazing of cattle in these plantations probably contributes to a reduction of combustible biomass and, therefore, reduces the intensity of the fires. The AFSP lacks quantitative data for this, despite the economic importance of these systems.

Soil compactation

On the most clayey soils of the humid zones of Central America, cattle cause considerable pasture degradation, and limit the growth of associated trees, because they compact the soil structure.

Effects of the trees on crops

These are brought about principally through microclimate modification, changes in the nutrient cycle, contribution of N through biological fixation, competition for water and nutrients, and changes in soil structure and susceptibility to erosion.

Microclimate modification

No CATIE research has been directed specifically to this subject, although many measurements have been taken from existing experiments or systems. Amount of radiation, temperature, relative humidity, and soil water potential are the variables which have received the most attention (7, 15, 31, 37). Among traditional practices, there are many systems which are justified by this type of effect: shade management for Coffea spp. and Theobroma cacao in order to control phenology and production (2, 8); use of A. acuminata as cloud condensers

(12), etc. Only a low potential exists for improving traditional practices, although there is some potential for transferring them to other similar areas.

Nutrient cycling

This type of measurement, which was started on farms, lead to fundamental experiments aimed at understanding certain agroforestry associations (2, 7, 15, 33). These trials demonstrated the importance of tree pruning as a means of speeding up nutrient cycling, which is reflected in a more efficient use of applied inputs (22). Despite their immense future importance, these findings have not yet been put into practice, even through pruning of leguminous trees in Coffea plantations is a common practice in vast areas of Central America. The potential for increasing the efficiency of the utilization of the recycled biomass is great for all types of associated crops (2), so that nutrient cycling research should receive the highest priority.

N fixation

It is clearly impossible, for logistical reasons, to determine the amount of N fixed by various species under different management. However, by calculating the N balance in experimental associations, it has been possible to estimate that E. poeppigiana fixes an appreciable amount of N (15). In another study, a selection has been made of several strains of ineffective, effective and persistent Rhizobium spp. for E. poeppigiana (17). These techniques can eventually be applied to other N fixing trees: Alnus spp., Inga spp., Gliricidia sepium, amongst many others already identified. In view of the significant contribution of the prunings of N fixing trees, to the nutrient balance in agroforestry systems, the techniques of managing N fixation should receive high priority.

Competition

Competition for water in the drier zones, and for nutrients in the more humid zones, may be an obstacle to the establishment of agroforestry associations. Measurements of these interactions have been made on farms and in experiments, and simulation excercises have been carried out to estimate these effects (2, 7, 30, 33). Effects on crops, during the early stages of tree establishment (e.g. Taungya system), have not been detected (9).

Soil conservation

Although a positive effect on soil conservation has been attributed to trees, the few existing experimental studies are not conclusive. Similarly, there are contradictions between the reports on the effects of trees in existing associations or plantations. Apparently the type of foliage and mulch cover are critical factors determining whether this advantage does or does not occur (18). Much of the work in watershed management is centred around these effects which need clarification, and therefore are receiving a high priority.

Effects of crops on trees

Both the type of crop and its management (cultivation practices) can affect tree growth and production. However, although it is certain that arboreal production is the least characterized direct output of traditional farm systems, in reality the importance of trees in agroforestry systems resides more in the effects they may have on the crops, than *vice versa*.

Type of associated crop

This effect has been evaluated for *Cordia alliodora* comparing *Coffea* spp., *Theobroma cacao*, pastures and sugar cane (*Saccharum* cvs.), showing differences between crops and sites (39). Potentially, these results can be applied in similar areas, although this has not yet been tried.

Cultivation practices

For plantation establishment (e.g. 'Taungya'), the benefits for the tree, of cultivation practices (e.g. weed control) carried out on the crop,are a critical factor. The method has been used in demonstration plots for the establishment of fuelwood plantations on small farms (26). These practices appear to have a high potential for extension and are being given some priority.

Effects of man on trees

Although it may seem to be somewhat artificial to talk about the effects of the farmer on the trees, there are two instances where the importance of the farmer is preponderant: a) in choosing the species which form the agroforestry association; and b) in their management. In both cases the aspirations and specific needs of the farmers are critical decision elements.

Species selection

In a very preliminary way, an attempt is being made to gather information on farmers' preferences for certain species, according to the use and management they are giving to the trees (1, 25, 26, 34). This information, once classified for the mandate region, will be a means of directing research to the most important species. At the same time, live collections and clonal gardens are being established for the most widely distributed species of the area. The aim is to subsequently make known material available for research, and further in the future to enable delivery of tested materials, to the extension services, for the principal needs of the farmers (34).

Species management

This is without doubt the most studied aspect of all the interactions in agroforestry systems (14). Significant advances have been made in pruning techniques (5, 33) propagation (1, 34) and planting densities (1, 31, 34). As a first practical application of these results, live fence-post management methods have been designed for Costa Rica and Nicaragua, to maximize forage production during the dry season (3). However, the quantity of work already carried out is deceptive. An understanding of the physiological mechanisms controlling the practices under study is still at an early stage. On the other hand it is surmised that the potential for improving traditional techniques, for a non-traditional product, justifies giving this work a high priority.

Effects of trees on man

The presence of the trees in agroforestry systems is felt mainly through two mechanisms: a) microclimate modification in the farm; and b) the contribution of diverse products for the family. Nevertheless, under certain circumstances they form obstacles which may cause substantial changes in the management of associated crops.

Changes in the microclimate

The characterization of home gardens has demonstrated the effect of trees on the comfort of the household (27). Application studies do not exist nor is there great potential for improving traditional systems in this respect.

Diversification of products

All surveys carried out, note diversification of products as one of the chief desirable characteristics of trees in agroforestry systems, and the importance to the farmers of this characteristic is clear (14, 23, 25, 27, 34). Another important consideration, is that diversification is a means of reducing risk. Thus, experimental work on tree management takes into consideration the optimization of multiple uses of the trees. At the level of application, valuable wood or fruit species are being promoted for the enrichment of coffee production systems (4). The potential for using similar methods to improve the living conditions of the poorest farmers is very great, and should be another priority.

Changes in crop management

The presence of trees in fields may force the farmer to substantially change his crop management since they form obstacles to the normal work of weeding, pest control, harvesting, etc. (without mentioning problems for mechanization), whilst actual tree management involves certain risks. The field of ergonomics in agroforestry systems is almost completely virgin and in the relatively long term may alleviate some of these negative effects.

Effects of man on agroforestry associations

In this context, the term agroforestry association is used for the sum of the simple interactions, discussed above. That is to say that these effects can be thought of as a triple interaction, as is shown in Table 2.

The choice of agroforestry agroecosystems, within the farm system, is perhaps the only noticeable effect of the farmer on the associations, except for all the management aspects already considered in the discussion of the simpler interactions.

Choice of association

This has been studied at two levels: a) system inventories including justifications and problems linked to each system or association (29); and b) determination of the farmers' motivations in choosing certain associations, as well as his preferences in response to given situations (25). Of course, this understanding is a cornerstone for the transference of successful systems to other similar areas and should be the first step in any agroforestry development project.

Effects of the association on man

These are demonstrated through: a) socio-economic benefits; and b) product diversification, that is, generally through the satisfaction or nonsatisfaction of the farmers' needs. These needs were the departure point for the research, and therefore studies of the effects of the association on man constitute the final trial for all the above methodology.

Socio-economic benefits

These are seen in a greater production of better quality, or with reduced costs. This last effect is common in "Taungya" systems (9), in plantations of Coffea spp. with shade trees, and in grazing systems in tree plantations where the presence of cattle reduces the need for chopping undergrowth (24). It is hoped that in the future there will also be cost reductions due to more efficient use of fertilizers, as can be forseen from experiences with alley cropping (22). The economic justification for the agroforestry alternatives under investigation, is all important to justify extension to large areas of the mandate region.

Product diversification

The need for this has been shown from many surveys (20, 23) and the first steps for on-farm evaluation of novel systems, for family diet improvement, have been made: e.g. introducing dairy goats in stalls, fed mainly with foliage from existing trees on the farm (4). Documents of a more general nature (35) indicate the immense existing potential to improve diets of the disadvantaged of tropical America, making this direction of research an obvious priority.

DISCUSSION

The problem is to ensure that both the establishment of research priorities according to the needs of the systems, and the use of this information in the design of new alternatives, are well related. This ensures the maximum advance in understanding and, at the same time, the maximum application to practical situations, the latter being a priority over the former.

The use of models is one of the potential tools which may help resolve the above problem. On one hand, constructing models helps to identify the most significant interactions which should be studied. On the other hand, once information has been obtained, simulation methods allow integration of this information into a coherent whole. It is obvious that modelling cannot replace on-farm technology evaluation whereby the producer assimilates new methods into his own model'. However, on-farm evaluation can only take place in a few isolated locations, so that appropriate models may in the future, allow extrapolation of results to other areas of the mandate region.

Separating agroforestry systems into their principal interactions proves to be very suitable for establishing 'biological' research priorities for the system. However, it may not, perhaps, be so useful for giving priorities to research involving man. This problem, in part arises from the difficulty in distinguishing interactions between man and tree, and those between man and the association. This obviously shows the need for greater work of a socio-anthropological nature. Also outstanding is the absence of consideration of interactions at higher levels than the farm system. For example, lack of a market for the new products, lack of credit to maintain the investments which a tree plantation represents, or insufficiency of technical assistance for the management of new technology. These may be among the chief deterrents to the adoption of new technologies.

The establishment of research priorities that results from this analysis (Table 3) tries to integrate the following elements: the importance of the systems in the region, the degree of advances achieved, the potential for achieving further advances through research, and the potential for intervention at the application level.

Table 3. Priority topics for Agroforestry Systems Programme, CATIE

Priority 1

- Cut fodder from trees.
- Direct tree browsing.
- Crop (pasture) production as result of nutrient cycling and N fixation by trees.
- Management of agroforestry species.
- Family diet diversification.
- Preferences and motivation for agroforestry species, and association selection.

Priority 2

- Soil conservation practices.
- Soil compaction and trampling effects on tree growth.
- Tree effects on stocking rate.
- Effects of crop management on tree growth.
- Competition for water between tree and crop.

Priority 3

- Fuel and natural regeneration reduction.
- Seed dissemination.
- Tree on crops (microclimate).
- Trees as shelter (animals-man).

The priorities which appear in Table 3 are related to the development of novel agroforestry systems. Relatively basic studies of the management of associations and agroforestry species, and more importantly, knowledge of the rural populations basic needs, motivations and preferences, are essential elements for the design of new alternatives. Amongst other priorities, although slightly less urgent, is the quantification of the potential of agroforestry systems to provide soil conservation. This plays an important role in watershed management, and the sustainability of each system.

It is hoped that this disjointed analysis of agroforestry systems may contribute to a better definition of the goals and priorities for research in the region.

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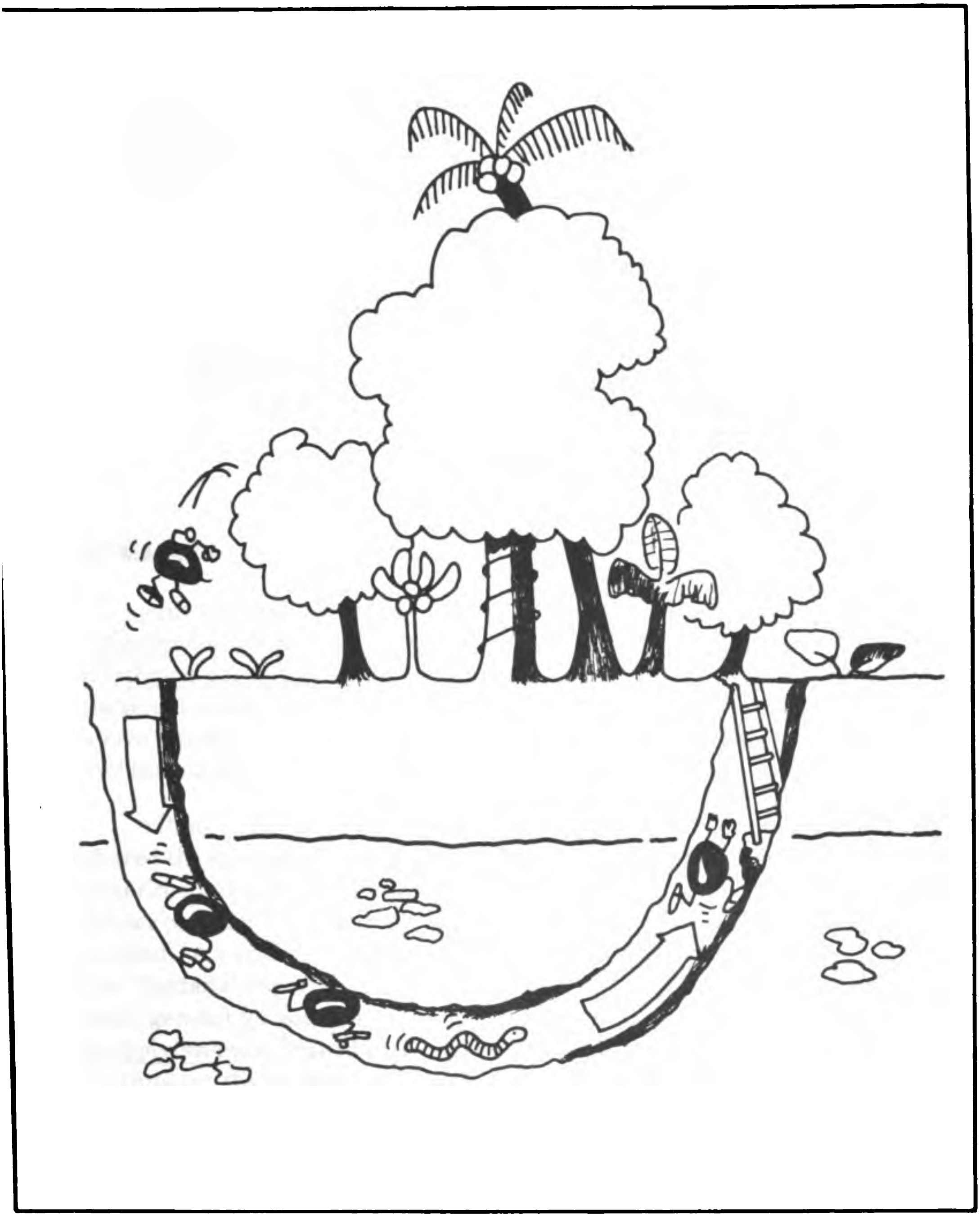

CASE STUDIES: SOIL AND PLANT ASPECTS OF AGROFORESTRY SYSTEMS

RESPONSE OF HYBRID Theobroma cacao TO TWO SHADE ASSOCIATIONS IN TURRIALBA, COSTA RICA*

G. A. Enríquez**

SUMMARY

In Central America, many systems for the cultivation of cacao (Theobroma cacao) exist, the most common involving associations with Erythrina poeppigiana and Cordia alliodora. There are few studies comparing these two associations, or other less important ones. This study compares the above named associations, in order to quantify their different yield responses and certain related ecological interactions.

Plots of 16 trees (4 x 4) planted at 6 x 6 m, were used. Neighbouring plots shared the same border trees. T. cacao was planted at 3 x 3 m, with 16 trees per experimental plot, using the interclonal cross 'Catongo x Pound-12'. A central border plot of 8 T. cacao trees (EET-400 x SCA-12 and UF-29 x IMC-67) was also studied. A partially randomized block design (four replicates) was used at the 'La Montaña' experimental site, Turrialba (600 meters above sea level). Plot management for both associations was as uniform as possible. From 1982, the E. poeppigiana was pruned twice a year. The first pruning (almost 100%) is in May or June, at the beginning of the rainy season, and the second (about 50%) in November, at the start of the second rainy period.

* Translation from Spanish by S. Shannon.

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Dry cocoa yields were always higher for the E. poeppigiana association, with a mean difference of 342 kg dry cacao.ha^{-1}, which is a 66% increase. Each tree under E. poeppigiana produced an average of 7 pods more than with C. alliodora shade, which is a 62% increase. The reason for the 4% difference between these two methods of comparison is that, although larger T. cacao pods have been produced with the C. alliodora association since 1981, taking means of pod sizes for all years the association with E. poeppigiana still shows a slight advantage (average 9% larger).

The mean number of suckers per T. cacao was 24% less in the E. poeppigiana association (17) than with C. alliodora (22). This characteristic is economically important since fewer work days are required to keep the plants free of suckers. Little difference in tree vigour was noticed by eye, although there was a slightly greater trunk development in the E. poeppigiana association (6.34 cm) than with C. alliodora (6.01 cm).

INTRODUCTION

Cacao (Theobroma cacao) cultivation has been traditionally carried out by farmers in very diverse ways under many ecological systems. The fastest, easiest and most economical system uses natural forest shade (7, 9, 11, 14, 16), selecting a few trees and eliminating the rest to later plant T. cacao. Yields have been low with this system, due in part to the difficulty of shade management, but plantations have remained productive for many years (often more than 100) (7, 9).

The use of improved materials and modern management techniques for T. cacao and shade trees (18), require systems quite different from traditional plantations (3, 4, 6, 8) with greater control of both the T. cacao and the shade, resulting in greater production. In some cases elimination of shade has been recommended (7), with good results for a limited number of years and high initial yields, which then fall rapidly due to plant deterioration, diseases and pests (13, 17). In reality, the farmer's economic situation demands maximum efficiency of land use (10, 15). One of the best ways of maximising or optimising land use is the association of different crops either simultaneously or sequentially (6, 7, 15). Although planting T. cacao without shade has also been recommended in certain countries, it has been a failure in other areas where factors such as climate, soil and on occasion variety have not been taken into consideration (1, 2, 11, 12, 13, 19).

There are hardly any descriptions of T. cacao/Cordia alliodora associations although the majority of T. cacao plantations in Costa Rica and northern Panama have C. alliodora as an important shade component (5, 10, 12, 14, 19). As in most T. cacao production areas, the majority (95%) of Costa Rican farms are small, with less than 20 ha (12). In spite of their size, these farms provide more than 50% of the total production.

The general objectives of the work presented here are as follows (only plant characteristics are dealt with in this report):

1. A comparison of the two T. cacao farming associations which include the shade trees most commonly used in the zone.

2. A detailed study of the environment in each of the two associations and its evolution and change over the duration of the experiment.

MATERIALS AND METHODS

The T. cacao plots studied in this presentation are part of a larger experiment described in greater detail in a CATIE guide to forestry plots (5) and in the Cacao Programme files of CATIE (6). The treatments compared are C. alliodora vs E. poeppigiana shade trees associated with 3 interclonal crosses of T. cacao: 1) Catongo x Pound-12; 2) EET-400 x SCA-12; and 3) UP-29 x IMC-67. T. cacao was planted at a distance of 3 x 3 m and the shade trees (E. poeppigiana and C. alliodora) at 6 x 6 m with 4 shade trees per experimental plot. A central line of shade trees was shared as a border (Fig. 1). The T. cacao experimental plots contained a total of 16 plants. The shade trees were planted in a partially randomized plot design, so that replicates 1 and 2 (likewise 3 and 4) of the respective associations are side by side (due to a lack of space). In the central area, there was a group of T. cacao originally planted as an inter-replicate border and as a source of pollen. These plants, which corresponded to the previously mentioned crosses "2" and "3", were also used for comparisons.

Plants were kept in the nursery for 5 months before transfer to the field and no selection was made at the time of planting. Ten months after planting, formation pruning of the T. cacao was started and continued for almost a year until the plants had a suitable shape. At planting, 100 g of 10-30-10 were placed in each planting hole, which is the equivalent of 111 $kg.ha^{-1}$ fertilizer as 11 kg $N.ha^{-1}$, 33 kg $P.ha^{-1}$ and 11 kg $K.ha^{-1}$. Every year, with the exception of 1981, each T. cacao was fertilized with 600 g of 18-10-6-5 divided into 4 applications. This represents 667 $kg.ha^{-1}.a^{-1}$ or the equivalent of 120 kg $N.ha^{-1}.a^{-1}$, 67 kg $P.ha^{-1}.a^{-1}$ and 40 kg $K.ha^{-1}.a^{-1}$ with an estimated 33 kg $S.ha^{-1}.a^{-1}$. At the start of the experiment, Glyphosato^{R} herbicide was applied to the whole area and the crop was subsequently kept weed free with 6 weedings the first year, 4 the second and 2 light weedings at the beginning of the third year.

At the time of planting the *T. cacao* (September 1977), maize (*Zea mays*) and pigeon pea (*Cajanus cajan*) were sown in association as provisional shade, and plantain (*Musa paradisiaca*) variety 'Pelipita' was established as temporary shade. Since there was no shade at the time of planting, the *T. cacao* was protected for 4 to 5 months by palm leaves folded over like a roof. The palm leaves dried and gradually allowed light to pass through until the wind or passing workers destroyed them. After 5 months, the palm leaves were removed. At the same time the *Z. mays* was harvested, but by this time the *C. cajan* had grown sufficiently to give the *T. cacao* adequate shade protection. After a year the *C. cajan* was harvested and the plants were removed since shade from *M. paradisiaca* and *C. alliodora* or *E. poeppigiana* gave sufficient protection to the *T. cacao*. During the second year the *M. paradisiaca* was gradually removed as the shade trees achieved sufficient growth. By the end of the second year all the *M. paradisiaca* had been removed, except for a few plants left to provide pseudo-stem material which was chopped and spread over the area to stimulate the breeding of pollinating insects.

Production data for individual *T. cacao* have been taken since 1979 up to the present, although data taking was suspended for 6 months during 1981 for reasons beyond the project's control. During this period, only the number of pods were counted, and this was used as a basis for estimating production. The first pods were harvested at the end of 1978, but since there were so few they were included in the 1979 harvest data.

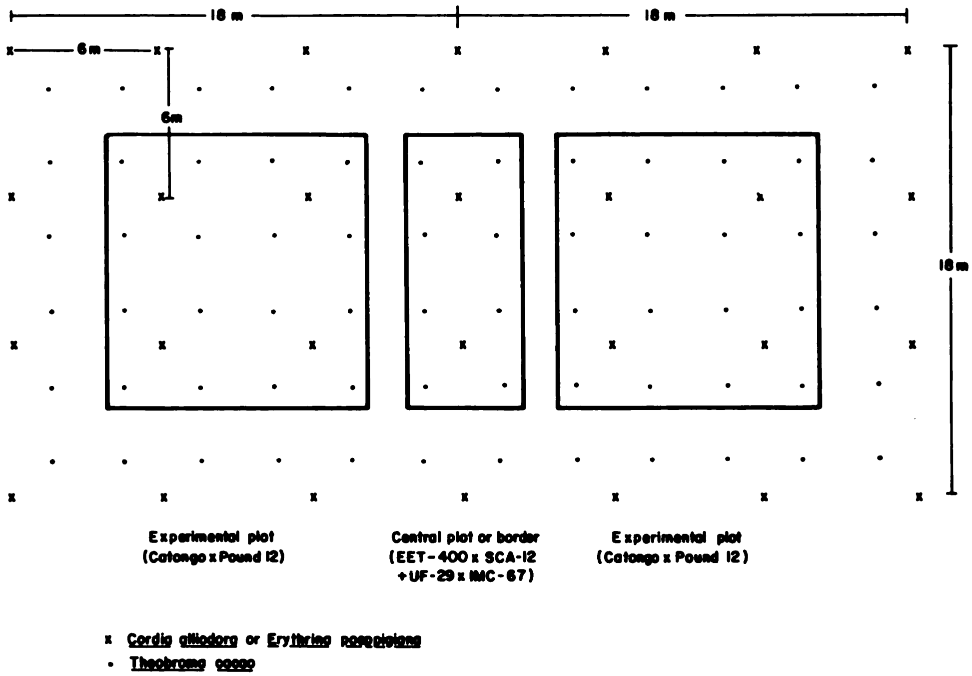

Fig. 1. Plot layout for *Theobroma cacao* with *Cordia alliodora* or *Erythrina poeppigiana* in the Central Experiment' for perennial plants. La Montaña, Turrialba, Costa Rica

RESULTS AND DISCUSSION

Yields from the experimental plots were early and high (Table 1) compared to unimproved T. cacao which begins to produce 4 or 5 years after planting (2, 7, 9, 17). During 1979, plants associated with C. alliodora showed an increased yield with a difference of 27 $kg.ha^{-1}$. During subsequent years production increases were constant for both treatments, but always a little higher in the T. cacao - E. poeppigiana association.

In the central plots, the interclonal crosses (UF-29 x IMC-67 + EET-400 x SCA-12) showed a markedly greater difference than those in the experimental plot (Catongo x Pound 12), with a much higher mean in the E. poeppigiana association, indicating that response to or benefit obtained from shading differs for each genetic material (interclonal cross). The difference between overall means for the two types of association gives a figure of 342 $kg.ha^{-1}.a^{-1}$, which is quite considerable for T. cacao production. If the experimental plots alone are examined, an increase of 24% is found, whereas the central plot containing the other two crosses shows an increase of 125%.

Table 1. Mean yield for Theobroma cacao (dry wt; $kg.ha^{-1}.a^{-1}$) Central Experiment, CATIE, Costa Rica

Association	Year	Experimental plot (Catongo x Pound 12)	Central Plot (UF-29 x IMC-67 + EET-400 x SCA-12)	$\bar{X}$
Theobroma cacao + Cordia alliodora	1979	97	12	
	1980	427	566	
	1981*	625	448	
	1982	648	370	
	1983	895	503	
	1984	909	687	
	$\bar{X}$	600	431	516
Theobroma cacao + Cordia alliodora	1979	70	30	
	1980	459	409	
	1981*	1,272	1,972	
	1982	729	968	
	1983	991	1,081	
	1984	945	1,359	
	$\bar{X}$	744	971	858

* Estimated values

During the first two years the number of pods per tree was slightly higher for T. cacao associated with C. alliodora, but at the beginning of 1981 there was a considerable increase in number of pods per tree, especially for T. cacao associated with E. poeppigiana (Table 2). As in the case of yield, the differences are more marked in the central plots than in the experimental plots, especially during 1984 and to a lesser extent in 1983.

During the first year, in the case of the experimental plot, the pod index (number of pods per kg of dry fermented cocoa) was lower (in other words better) for T. cacao associated with C. alliodora (Table 3). In the central plot, the figure was very high for T. cacao associated with C. alliodora, but was obtained from very few, badly formed pods and should not be considered typical (1). The indices for plots with E. poeppigiana were better during 1980 and 1981, but at the beginning of 1982 they increased greatly in both the experimental and central plots showing an advantage for the association with C. alliodora.

Comparing means for the central plots, leaving out the unreliable data for 1979, a slight advantage can be seen for the plot with C. alliodora. (22.7 vs 23.1 for the E. poeppigiana association). In the experimental plots, figures for the general means are also similar, but pods from the T. cacao - E. poeppigiana association were slightly larger than those from the T. cacao - C. alliodora association. This has economic advantages since the farmer has to deal with less pods per area, transport fewer pods and spend less time opening them.

Table 2. Mean number of pods per Theobroma cacao Central Experiment, CATIE, Costa Rica

Association	Year	Catongo x Pound-12	UF-29 x IMC-67 + EET-400 x SCA-12	$\bar{X}$
Theobroma cacao + Cordia alliodora	1979	1.7	0.4	
	1980	9.3	10.9	
	1981	14.2	10.5	
	1982	13.2	7.3	
	1983	20.2	10.1	
	1984	20.5	13.6	
	$\bar{X}$	13.2	8.8	11.0
Theobroma cacao + Erythrina poeppigiana	1979	1.3	0.4	
	1980	9.0	7.3	
	1981	21.3	32.4	
	1982	16.0	23.7	
	1983	22.8	23.9	
	1984	22.0	32.7	
	$\bar{X}$	15.4	20.1	17.7

Table 3. Pod index (number of pods.kg^{-1}.dry cocoa) Central experiment, CATIE, Costa Rica

Association	Year	Catongo x Pound-12	UF-29 x IMC-67 + EET-400 x SCA-12	$\bar{X}$
Theobroma cacao + Cordia alliodora	1979	19.7	35.3	
	1980	24.3	21.5	
	1981*	25.3	26.1	
	1982	22.6	21.8	
	1983	25.1	22.4	
	1984	25.1	21.9	
	$\bar{X}$	23.7	24.8 (22.7)**	24.2
Theobroma cacao + Erythrina poeppigiana	1979	20.6	14.0	
	1980	21.8	18.9	
	1981*	18.6	18.2	
	1982	24.4	27.2	
	1983	25.6	24.6	
	1984	25.9	26.7	
	$\bar{X}$	22.8	21.6 (23.1)**	22.2

* Estimated values.
** Means excluding 1979.

One of the less desirable characteristics of hybrid T. cacao, due to its precocity and vigour, is the development of suckers or vegetative buds from the main trunk. These lead to the formation of a series of strata. Modern T. cacao management recommends the maintenance of one stratum only, which implies the need to continuously remove the suckers (1, 2, 7, 16).

In this trial there was a marked advantage for the T. cacao - E. poeppigiana association, especially with the genetic material used in the experimental plot, where the mean number of suckers per T. cacao is fairly constant over the years, but differs by 39% from the mean for T. cacao in the C. alliodora association (Table 4). In the central plot, there was only a 17% advantage for E. poeppigiana shade. Within each association there are great differences between the hybrid crosses of the experimental and central plots, with increases of more than 100%. Comparing the means of the associations shows an advantage for E. poeppigiana shade, since the T. cacao - C. alliodora association has 20% more suckers.

Table 4. Mean number of suckers per *Theobroma cacao*. Central experiment, CATIE, Costa Rica

Association	Year	Catongo x Pound-12	UF-29 x IMC-67 + EET-400 x SCA-12	X̄
Theobroma cacao + *Cordia alliodora*	1979	4.2	20.1	
	1980	14.2	52.1	
	1981	16.9	32.1	
	1982	19.7	25.1	
	1983	13.1	18.1	
	1984	18.8	24.6	
	X̄	14.5	28.7	21.6
Theobroma cacao + *Erythrina poeppigiana*	1979	4.3	17.4	
	1980	10.4	38.4	
	1981	11.3	22.9	
	1982	13.5	17.9	
	1983	11.4	27.2	
	1984	11.7	22.9	
	X̄	10.4	24.5	17.4

In economic terms, a lower number of suckers is important since less manpower is needed to keep them controlled. It is also important from the point of view of energy expended by the tree as it tries to send out suckers to achieve a greater height for light competition. The different response may result from the shade management of the two associations. In the case of *C. alliodora*, the shade trees only received a general formation pruning which was applied to the whole experiment (including other treatments not mentioned here). The *C. alliodora* canopy is high and not very dense, resulting in plentiful diffusion of indirect light (18), especially when these deciduous trees lose their leaves. Since the *E. poeppigiana* shade trees are at 6 x 6m, they require more management. One light pruning per year was given during the first 4 years, until the trees acquired a strong and desirable shape. Starting in 1982, semestral pruning was applied, consisting in the elimination of 100% of the shade canopy at the start of the rainy season. This varied slightly from year to year but took place between April and June. In November, when there is another period of high rainfall, 50% of the shade canopy was again removed. The shade canopy was left untouched during the dry and less rainy periods in Turrialba (6, 18). This management may cause the *T. cacao* to produce less suckers when under *E. poeppigiana* than when under *C. alliodora*.

When the trees were classified for vigour in June 1985, using a 3 value scale, differences between association means were found to be very small (Table 5).

Table 5.a. Mean vigour per *Theobroma cacao** Central Experiment, CATIE Costa Rica

Association	Catongo x Pound-12 $\bar{X}$	min.	max.	UF-29 x IMC-67 + EET-400 x SCA-12 $\bar{X}$	min.	max.	$\bar{X}$
Theobroma cacao + *Cordia alliodora*	4.8	3.0	6.0	5.0	3.0	6.0	4.9
Theobroma cacao + *Erythrina poeppigiana*	4.9	3.3	5.7	5.0	3.7	6.0	4.9

* Scale: 3 = poor vigour 5 = medium vigour 7 = vigorous

Table 5.b. Frequency distribution of vigour classifications for *Theobroma cacao*, Central Experiment, CATIE, Costa Rica

Association	Frequency	Catongo x Pound-12	UF-29 x IMC-67 + EET-400 x SCA-12
Theobroma cacao + *Cordia alliodora*	1.0 - 3.0	1	1
	3.1 - 5.0	37	6
	5.1 - 7.0	26	9
Theobroma cacao + *Erythrina poeppigiana*	1.0 - 3.0	0	0
	3.7 - 5.0	39	7
	5.1 - 7.0	25	9

Table 6. Mean increase in trunk diameter of *Theobroma cacao* (cm)* Central experiment, CATIE, Costa Rica

Association	Month/yr.	Catongo x Pound-12	UF-29 x IMC-67 + EET-400 x SCA-12
Theobroma cacao + *Cordia alliodora*	4/80-10/80	0.7	0.8
	1/82-5/82	0.8	1.2
	1/84-6/85	1.7	1.8
	4/80-6/85	6.0	5.6
Theobroma cacao *Erythrina* + *poeppigiana*	4/80-10/80	0.9	0.8
	1/82-5/82	0.9	0.9
	1/84-6/85	2.1	1.8
	4/80-6/85	6.3	6.7

* Means taken 30 cm above ground level.

Generally speaking, T. cacao trunk diameter is positively associated with yield; in other words, the greater the diameter, the greater the yield. During 1980, in both plot associations, there was greater development in the E. poeppigiana system (Table 6). This was repeated in 1982 for the Catongo x Pound-12, but in other hybrid crosses greater development occured in the C. alliodora association. Comparing development from January 1984 to June 1985, all the hybrid crosses showed better development under E. poeppigiana. Comparing final trunk diameters, a small advantage can be seen for the E. poeppigiana association. The greater production of T. cacao in the E. poeppigiana association appears to be related to the growth of the T. cacao.

CONCLUSIONS

1. The T. cacao - E. poeppigiana association has advantages over the T. cacao - C. alliodora association, producing 342 $kg.ha^{-1}.a^{-1}$ more cocoa. This represents a 66% increase over T. cacao - C. alliodora.

2. Although the T. cacao - C. alliodora association produces less pods $tree^{-1}.a^{-1}$, it has produced larger sized fruits over the past few years, which provides an economic advantage by reducing harvest labour and the cost of transport and pod opening. However, for the overall average of all years of this study, the T. cacao - E. poeppigiana association still has a slight advantage in pod index.

3. The T. cacao in the E. poeppigiana association produces less suckers, representing a labour saving for crop management.

4. The economic advantages of the T. cacao - E. poeppigiana association could change with the harvest of the C. alliodora.

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ACKNOWLEDGMENT

The author wishes to thank Ing. Antonio Mora for assistance in data tabulation.

ASSOCIATIONS BETWEEN CACAO (Theobroma cacao) AND SHADE TREES IN SOUTHERN BAHIA, BRAZIL

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M. Santana*
A. Cadima Zevallos*

SUMMARY

A review is made of the information on Theobroma - shade tree combinations in the south of Bahía, Brazil. Following a description of the climatic and soil characteristics of the area, the principal shade tree species are presented. Data on biomass production and nutrient cycling for the association of T. cacao - Erythrina spp. are discussed. Practical inferences for the management of T. cacao plantations are deduced from the consideration of nutrient cycling models, and a newly recommended fertilization system is presented.

INTRODUCTION

Originating from the basins of the Amazon and Orinoco rivers, the cacao tree (Theobroma cacao) was introduced into the southern part of Bahia around 1850 (2) and found favourable edapho-climatic conditions as well as the absence of some natural enemies which occur in its original habitat, which facilitated the expansion of the crop. In the last decade this crop has spread to different areas of the Brazilian Amazon, but most of the plantations and production of seeds are found in the southern part of Bahia where more than 600,000 ha exist nowadays (37).

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As T. cacao is a component of an intermediary stratum of the forest in its original habitat, the "Cabruca" method, which consists of the partial cutting of trees or thinning of the native forest, was adopted as a traditional method for the establishment of new plantations. A variable number of trees are maintained as definite shade. This method permits irregular spacing between plants and very often more than one plant per hole is found due to the use of several seeds during the direct planting. For protection during the development phase the new T. cacao trees are generally associated with banana (Musa cvs.) or cassava (Manihot esculenta).

In accordance to what happened in the productive regions of Western Africa (Ghana and Nigeria), the T. cacao in southern Bahia have been predominantly established on soils of medium to high natural fertility indicating the greater demand of this crop in relation to other perennial crops of the tropics, such as the Africa oil palm (Elaeis guineensis) and the rubber tree (Hevea brasiliensis).

In the past 15 to 18 years new production systems have been developed to increase productivity. These systems include fertilization associated with the removal of excess shade, as well as the use of adapted germplasm for new T. cacao plantations. In these new plantations, spacings between T. cacao trees have been reduced, and leguminous trees of the Erythrina spp. genus are being used as a definite shade.

This paper presents some results of experiments made in Southern Bahia, which examined the advantages of the use of the T. cacao - shade tree associations, particularly with respect to nutrient conservation in the agroecosystem, and criteria for fertilizer recommendations.

ENVIRONMENTAL CONDITIONS

The T. cacao region, located in the southern part of Bahia, in the northeast part of Brazil, is situated between the coast line and Long. 41º 30'W and between 13º and 18º 30' Lat. S (Fig. 1).

Climate and vegetation

Similarly to most tropical regions, the temperature is relatively uniform during the year with an average of 24ºC (average 26ºC during the summer and never below 18ºC during the winter months) (36). The distribution of rains, which constitutes the main parameter used to differentiate tropical climates for agricultural purposes, permits the distinction of two sub-regions. One is near the coast with precipitations over 1000 mm well distributed during the year and defining an Udic hydric soil regime (28). The other sub-region which begins between 40 to 60 km from the coast, has a pronounced difference between humid and dry periods with annual precipitations below 750 mm. In these circumstances the Ustic type of soils prevail (28, 36).

Although 10 different types of vegetation have been described in this area, there is a predominance of the Higrofila perenifolia (rain forest) and Tropofila forest which shows a close correlation with the rainfall distribution as has been described for other tropical regions (28).

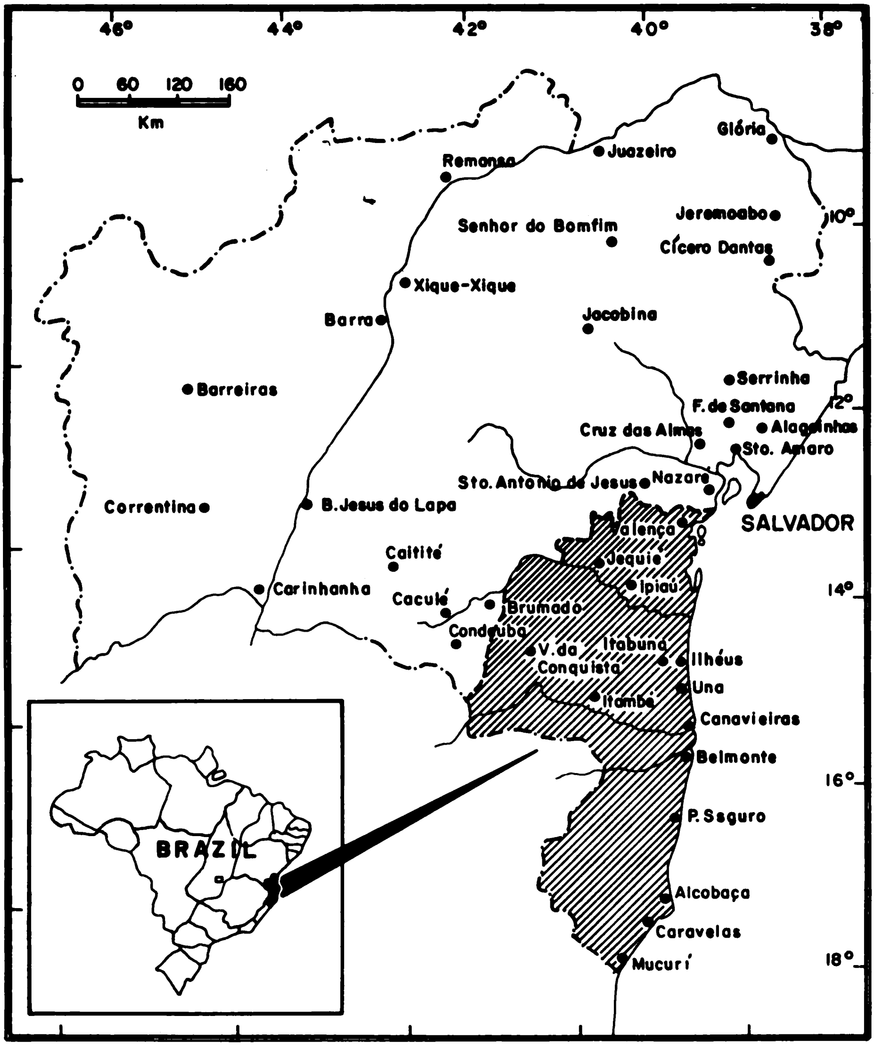

Fig. I. Location of the Cacao Region in Southern State of Bahia, Brazil

Soils and land use

There exists a great variability of soil types including nine of the orders considered in the classification system of the United States Department of Agriculture (35). Among these soils, units classified as Alfisols, Inceptisols and Ultisols (Table 1), with base saturation greater than 30%, have been traditionally used for T. cacao cultivation. Generally these soils are derived from intermediary and basic rocks and present medium to high fertility.

Table 1. Traditional soils used for Theobroma cacao in Southern Bahía, Brazil (35)

Order	Suborder	Group	Subgroup	Regional name
Alfisol	Udalf	Tropudalf	Typic Tropudalf	CEPEC modal
Alfisol	Udalf	Tropudalf	Typic Tropudalf	Itabuna modal
Alfisol	Udalf	Tropudalf	Lithic Tropudalf	CEPEC raso diaclasado
Alfisol	Udalf	Tropudalf	Lithic Tropudalf	CEPEC fase rochosa
Alfisol	Udalf	Tropudalf	Oxic Tropudalf	Vargito eutrófico
Alfisol	Ustalf	Haplustalf		Sao Paulinho
Alfisol	Ustalf	Paleustalf	Oxic Paleustalf	Sao Paulinho
Alfisol	Udult	Tropudult	Typic Tropudult	Vargito distrófico
Ultisol	Udult	Tropudult	Orthoxic Tropudult	Nazaré, Itabuna, Morro Redondo, Vargito distrófico
Inceptisol	Tropept	Dystropept	Oxic Dystropept	Rio Branco
Inceptisol	Tropept	Dystropept	Fluventic Dystropept	Aluvial argiloso

Soils of the Oxisol and Ultisol orders with base saturation below 30%, and low natural fertility, have special importance because they cover vast areas in southern Bahia and present a big potential for an increase of the agricultural production in this region.

Large areas (28.5%) of these soils are used as pastures for cattle on an extensive and semi-extensive scale, and a considerable part (55%) includes secondary and remnant primary forests where itinerant agriculture is used on a small scale to produce M. esculenta, corn (Zea mays) and beans (Phaseolus spp.) (24).

The factors which limit the fertility in Alfisols, Ultisols, and Oxisols are represented in the polygonal graphics of Figure 2. The "a" soil (**Typic Tropudalf**)

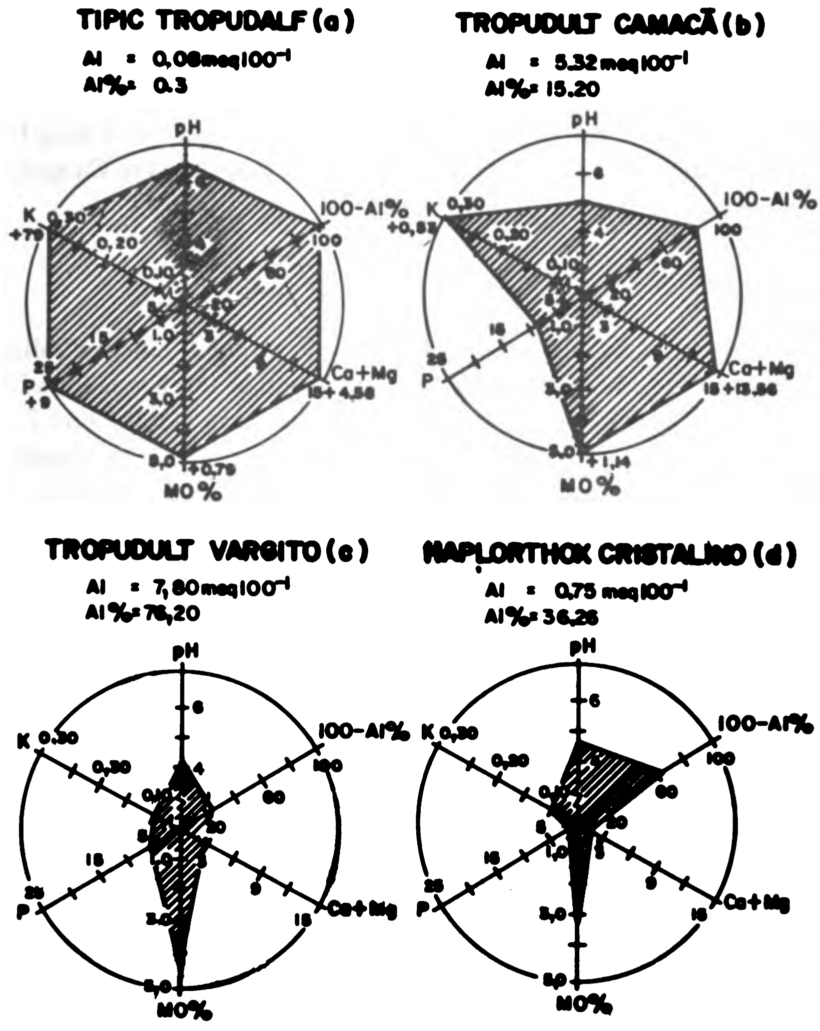

Fig. 2. Comparative fertility of soils of Southern Bahia, Brazil. a) and b) high fertility soils c) low fertility soil with high levels of exchangeable Al and d) low fertility soil presenting low contents of Al (9)

is of high fertility, and does not present chemical limitations. The "b" soil (Tropudult Camaca) is more acid, has low levels of P, and although the absolute levels of Al in the exchange complex are high, the percentage of saturation of that element is low because of the high exchangeable quantities of divalent bases. The "c" soil (Tropudult Vargito), which represents an acid soil poor in Ca and Mg and with high proportions of exchangeable Al, requires large quantities of dolomitic limestone, not only to attenuate the harmful acidity but also to elevate the levels of exchangeable bases. The "d" soil (Haplorthox cristalino) also represents an acid soil, with low buffering power and 1 to 2 meq.100 g^{-1} of Al. In this case the use of liming is more related to the supply of Ca and Mg than to acidity reduction.

T. cacao SHADING

In a survey of 61 plantations of T. cacao under "Cabruca", distributed among 30 southern Bahia municipalities, a relation of 1: 9.5 was found between shade trees and T. cacao, corresponding respectively to 76 ± 0.1 and 724 ± 0.3 trees. ha^{-1} (1). An excess of shade trees, and the necessity to gradually remove some of them, was suggested in order to provide better response to fertilizer additions (8). The shade tree species which occur more frequently in the T. cacao plantations are presented in Table 2 along with data on their heights and the diameter of their canopies (34).

Nevertheless, the need for and the influence of shading have been intensively studied since the pioneer experiments in Trinidad by McDonald (25) and Hardy (19), later repeated under artificial shade conditions by Murray (26, 27). Experiments have also been realized in Ghana, Nigeria (14, 40) and in Brazil (8) where greater productivity was obtained when fertilizers were applied in the absence of shade trees. Cunningham and Burridge also determined a faster growth with greater luminosity if fertilizers were applied, and problems, such as lack of water, air turbulence, weeds, pests and diseases were solved respectively by irrigation, wind breaks and use of pesticides (13).

These experimental results are related to a higher photosynthetic activity, intensification of the metabolic processes and greater consumption of nutrients under high light intensities (3) with a remarkable influence on flowering, flushing, number of leaves and fruits (5, 21).

Although greater flowering and higher productivity is obtained under higher light intensities, the shade trees offer other advantages such as protection of T. cacao from wind and direct insolation damage, as well as soil enrichment and conservation (18). The shade factor must be considered in each locality with respect to the climatic conditions and the soil physical properties as well as nutritional status (18).

Table 2. Canopy diameter and height of native trees of Southern Bahia, used as definitive shade for Theobroma cacao (34)

Common name	Scientific name	Total height (m)	Canopy diameter (m)
Imbiricu	Bombax macrophyllum K. Schum.	30.4	15.7
Pequi preto	Caryocar edule Casarreto C. Barnier	27.2	16.6
Sapucaia	Lecythis pisonis Cambess.	29.0	12.8
Arapacu	Sclerolobium chrysophyllum peopp. Gendl.	26.6	15.3
Massaranduba	Manilka elata	28.2	13.3
Juerana branca	Pithecolobium pedicellare	22.9	15.3
Bacumixa	Sideroxilon vastium Fr. Allem.	27.8	11.9
Faveira	Pterodon rubescens Benth.	20.6	12.9
Mucitaiba	Zollernia aff. mocytaiba Fr. Allem.	27.4	11.4
Bomba d'agua	Hydrogaster trinerve Khlim.	27.6	10.1
Ipé amarelo	Tabebuia serratifolia (Vahl.) Nichols.	23.3	11.3
Louro d'agua	Vochysia sp.	27.3	10.3
Massaranduba paraju	Manilkara coreaceae Miq.	22.7	12.1
Jatobá peloso	Hymenaea aurea Lee & Langenheim	28.7	12.8
Aracá vermelho	Psidium guineense Sw.	25.0	8.6
Oleo copaíba	Copaifera sp.	27.4	12.8
Bicuíba vermelha	Virola gardneri (A.DC.) Warb.	27.4	10.5
Bapeba preta	Chrysophyllum sp.	25.7	8.2
Aderno	Emmotum nitens (Benth.) Miers.	25.1	9.4
Cajazeira	Spondias lutea L.	18.8	11.4
Putumuju gigante	Centrolobium robustum (Vell.) Mart.	28.8	8.0
Arapati	Arapatiella psilophylla (Harms) Cowan	26.2	7.8

The T. cacao - Erythrina spp. associations

Cadima and Alvim observed, in a T. cacao germplasm plot grown on an hydromorphic soil of the Central Experimental Station of Urucuca, that the T. cacao plants located closer to the Erythrina shade trees produced more than those further away (12). To explain this behaviour these authors characterized the root distribution of the T. cacao, near to and far from these leguminous shade trees, establishing that in the former situation the tap-root goes as deep as 90 cm, whereas the tap-root of the more distant plants does not reach 60 cm (Figure 3). The number of roots of different diameters per sample square (30 x 30 cm) also established this difference, since there was a larger number of thin T. cacao roots (0-2 mm) in the 0-30 cm layer close to the Erythrina, than at more distant points. It was also verified that the soil was richer in nutrients, namely total N and exchangeable bases, near to the leguminous trees than at more distant poin

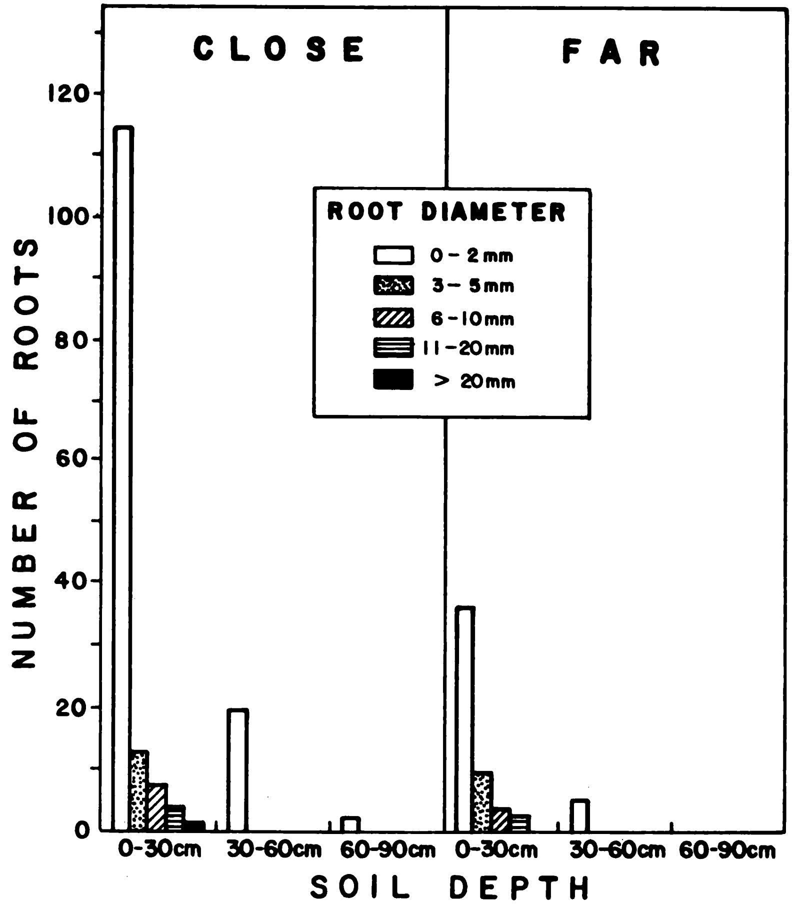

Fig. 3. Number of roots of different diameters found in 30x30cm sample squares close to and far from Erythrina trees in a Theobroma cacao plantation (12)

Santana and Cabala investigated the influence of Erythrina on the percentage of N in the soil, by taking samples at 3 to 9 m from the tree trunks (29). The total amount of N began to drop at a distance of 4.5 m. The Erythrina, apart from presenting a deeper root system than that of adult T. cacao, extends its superficial roots for more than 10 m. Therefore, with the spacings generally used in southern Bahia, a large proportion of the plantations are influenced by the canopy and the root systems of these shade trees.

The leaf fall which generally occurs from July until September, is associated with the sensitivity of Erythrina to photoperiod and thermoperiod which prevail during short days (4). In this period litterfall can be 2t (dry mass) ha^{-1} (29).

Recently, in a "Catongo" T. cacao plantation (Typic Tropudalf), shaded with Erythrina fusca, the litterfall and the rain water gathered under the trees were analysed for N, P, K and Mg, according to the methodology described by Santana & Cabala (30). During the first year (July 12, 1981 until July 12, 1982) there was a continuous fall of leaves and branches of both species with seasonal peaks in September, October and June for the leaves of the T. cacao. The largest litter contributions from the Erythrina occurred in July-September and January-March. The greatest leaf fall took place at the end of the dry period confirming the results obtained by Boyer (6). The input from the T. cacao flowers was more intense from December to May, whereas the input from the Erythrina flowers was limited to the period of August to September (31).

The chemical analysis of the residues showed that a large part of the N transferred to the system (143 kg), came from the T. cacao and Erythrina leaves, which represented respectively 49 and 33% of the 8146 $kg.ha^{-1}$ of the residues deposited during the experimental period. In Cameroun, it was estimated that 55 kgN ha^{-1} would be returned to the soil from the T. cacao leaves (6). Generally the Erythrina residues are richer in N than those of the T. cacao and this leguminous tree has a high production of nodules (29).

The rate of litter decomposition in T. cacao plantations varies according to the type of the residue, the species and the environmental conditions (30). Generally the residues of Erythrina decompose faster than those of T. cacao. However, most of the components of both species contained only half of their initial weight after 6-9 months (Figure 4). It is believed that in natural conditions, where the residues remain in a more direct contact with the decomposing agents and the soil organic fraction, that the process of decomposition must be faster.

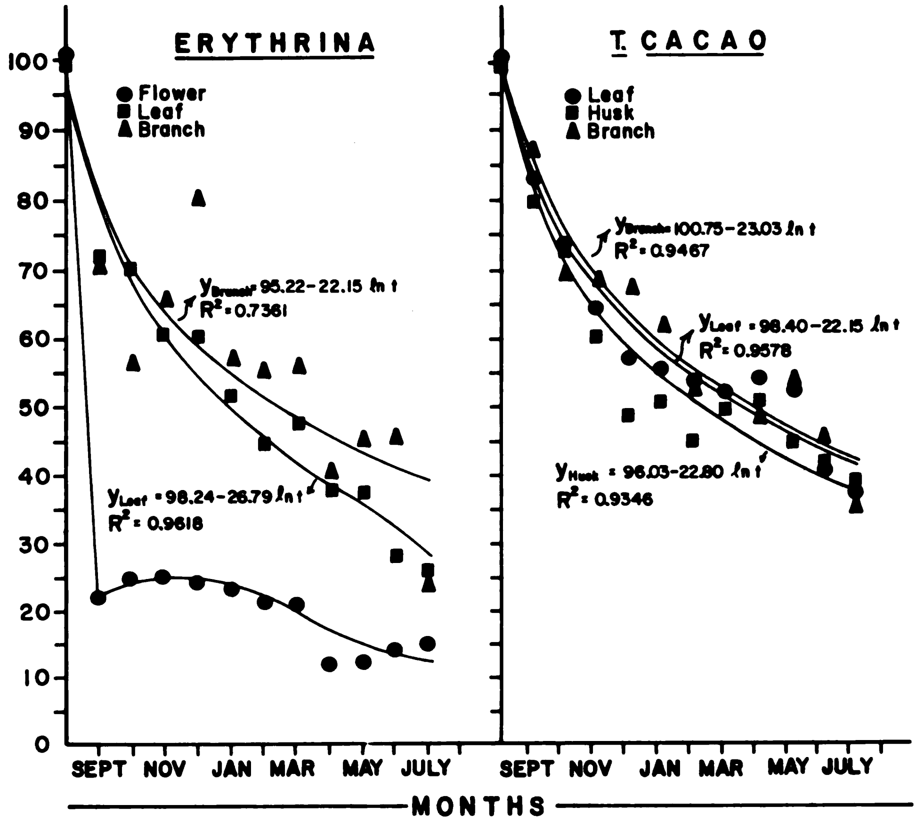

Fig. 4. Rate of decomposition and regressions for Erythrina and Theobroma cacao residues (30). t = time (months).

The nutrient content of the residues represents an important contribution to the T. cacao-Erythrina association especially in respect to N, Ca and Mg (Table 3) (31). The amount of K in T. cacao husks is high, showing the advantage of leaving them in the growing area. Important contributions of N, K, Ca and Mg were also observed in the rain water collected in the plantation, which results from the washing of the leaves. The quantities of nutrients removed from the system in the T. cacao seeds, and lost through leaching, are inferior to the inputs (litter and rain) and, depending on the mineralization rate, they could almost satisfy the total needs of the T. cacao plantation in the productive stage (31). The litterfall during the second and third year of investigation showed a decrease in relation to the first year due to the death of some T. cacao, resulting apparently from the rehabilitation of adjacent T. cacao areas and over-production caused by manual pollinization.

Table 3. Partial balance of nutrients in a 'Catongo' Theobroma cacao plantation shaded with Erythrina ($kg.ha^{-1}$) (31)

	INPUT				LOSSES	
	Litter residues* 1st. year	Litter residues* 2nd year	Husks**	Rain drip	Harvest**	Leaching
N	143.0	81.0	10 - 12	22.9	22	18.2***
P	13.0	13.9	5	2.8	5	0.5
K	34.4	17.4	40 - 42	21.4	10	2.2
Ca	180.7	142.5	1	17.9	1	53.6
Mg	63.2	42.3	3	11.7	3	37.6

* Corresponding to litterfall of 8,146 and 5,994 $kg.ha^{-1}$ in the first and second years respectively.
** Relative to 1,000 kg of dry matter.
*** As NO_3 and NH_4.

PRACTICAL INFERENCES

The development of organic material and nutrient cycling models for the interpretation of the functioning of an ecosystem, as an extension of forest ecosystem studies, is an aspect of growing interest for modern ecology (16). The organic and mineral reserves are located in the phytomass of the forest, sub-forest, epiphytes, litter and in the soil (16). The transference processes occur through rain and the production of residues which after decomposition release nutrients. In this scheme the participation of all living organisms and an appropriate management should be considered. In forest ecosystems developed on poor soils, as occurs in the Amazon Region, most of the mineral reserves are concentrated in the phytomass, in the litter and in the organic fraction of the soil (22). This type of vegetation has developed efficient mechanisms for nutrient utilization and conservation, to limit leaching through the soil profile.

The application of these models to T. cacao shade tree associations is still unclear on some aspects (17). Apart from the CATIE experiments in Turrialba, Costa Rica, studies have mainly been realized in existing T. cacao plantations. An understanding of the reserves and the transferences, beginning with the establishment phase, would be extremely useful for plantation management purposes as well as from the conservation point of view. Different technological options such as greater or lesser degrees of shading could be contrasted.

An estimate of the nutrient needs of T. cacao in different stages of development, based on the analyses of the different parts of the plant, was presented by Thong and Ng (Table 4) (38). P and Mg were absorbed in relatively small quantities whilst K needs were practically equivalent to those for N and Ca. These authors also verified, during the nursing period and the development stages, that the leaf is the most important component for nutrient storage. However, in the productive stage, leaves accumulate nearly the same quantity of nutrients as branches plus stem, with the exception of the K and Zn which predominate in the branches.

Table 4. Estimated quantities of nutrients ($kg.ha^{-1}$) absorbed by Theobroma cacao at different stages of development (38)

Stage of development	Plant age (months)	Average nutrient requirements						
		N	P	K	Ca	Mg	Mn	Zn
Nursery	5 - 12	2.4	0.6	2.4	2.3	1.1	0.04	0.01
Juvenile	28	136	14	151	113	47	3.9	0.5
Adult	50 - 87	438	48	633	373	129	6.1	1.5

It is still not known if these quantities of nutrients would be easily available in an agroecosystem of T. cacao, taking into consideration the efficiency of the root system of T. cacao and the competition which exists from the provisional shade species and the weeds. In this context, information must be obtained about the available reserves in the soil, and also about its capacity to supply nutrients to the plants during the establishment of the agroecosystem. In an experiment realized for this purpose, on three soils of southern Bahia, a clear difference was observed in the soil's capacity to release nutrients (Table 5). The **Tropudalf** soil presented a high capacity to release nutrients in comparison to the **Haplorthox** and the **Haplusthox** soils, in which P was the most deficient nutrient. This is consistent with earlier results obtained for all the southern regions of Bahia (7).

In the initial pre-production stage of T. cacao growth, split applications of the nutrients will surely contribute to a better development of the plantation

Table 5. Successive nutrient extractions ($kg.ha^{-1}$) by NH_4NO_3 of three soils of Southern Bahia (dilution 1:10 soil:water)

Extraction Nº	Soil	P (cm) 0-20	P (cm) 20-40	K 0-20	K 20-40	Ca 0-20	Ca 20-40	Mg 0-20	Mg 20-40
	CEPEC*	58	80	1,141	346	670	278	4,007	4,270
1	UNA**	21	20	71	60	16	4	82	50
	AGUA SUMIDA***	13	13	126	77	57	22	214	119
	CEPEC	31	54	482	40	73	40	1,900	930
2	UNA	6	4	11	8	2	0	15	7
	AGUA SUMIDA	3	3	23	21	7	3	38	34
	CEPEC	10	20	296	342	8	5	404	559
3	UNA	0	0	4	2	0	0	6	8
	AGUA SUMIDA	0	0	4	5	0	0	16	16
	CEPEC	0	0	192	251	0	0	291	374
4	UNA	0	0	0	0	0	0	3	2
	AGUA SUMIDA	0	0	0	0	0	0	6	6
	CEPEC	0	0	71	83	0	0	172	223
5	UNA	0	0	0	0	0	0	0	0
	AGUA SUMIDA	0	0	0	0	0	0	0	0
	CEPEC	0	0	29	30	0	0	87	121
6	UNA	0	0	0	0	0	0	0	0
	AGUA SUMIDA	0	0	0	0	0	0	0	0
	CEPEC	0	0	18	16	0	0	37	58
7	UNA	0	0	0	0	0	0	0	0
	AGUA SUMIDA	0	0	0	0	0	0	0	0
	CEPEC	0	0	10	7	0	0	13	24
8	UNA	0	0	0	0	0	0	0	0
	AGUA SUMIDA	0	0	0	0	0	0	0	0
	CEPEC	99	154	2,239	1,516	751	423	6,912	6,559
TOTAL	UNA	27	24	86	70	18	4	106	67
	AGUA SUMIDA	16	17	153	103	65	25	273	175

* Tropudalf ** Haplorthox *** Haplusthox

until the soil surface is completely covered. In the production stage, depending on the plantation management system, the production levels and the losses which occur from the agroecosystem, maintenance fertilization may be recommended. Santana and Cabala (31) compiled information from various authors on the nutrient content in the seeds and husks of the *T. cacao* fruits (Table 6) (32). Even allowing for the large variation of the data reported, this gives an idea of the amount of nutrients extracted along with the production of seeds. However, the husks do generally remain in the growing area.

Table 6. Nutrient contents (kg) of dry *Theobroma cacao* beans and husks (32)

	N	P_2O_5	K_2O	CaO	MgO	Reference
Dry Beans*	20.0	9.6	12.6	3.0	5.0	(15)
	24.0	12.0	19.0	-	-	(39)
	20.0	15.8	21.3	2.0	11.0	(23)
	20.4	8.3	12.6	1.5	4.5	(38)
	22.0	11.7	12.1	1.5	5.1	***
	20.0	5.0	53.0	-	-	(20)
Husks**	10.6	3.0	52.0	5.3	4.2	(38)
	12.0	2.5	46.6	7.4	5.9	***
	10.4	1.7	38.5	2.6	3.5	(23)

* 1,000 kg
** Cacao husks per 1,000 kg of dry beans
*** Santana and Cabala, unpublished data

This type of information, together with data on the reserves in agroecosystems shaded with leguminous trees of the *Erythrina* genus, has been taken into account in the presently recommended fertilization system (Table 7) (10).

Table 7. New fertilizer recommendations, and criteria to apply lime to *Theobroma cacao* plantations in Southern Bahía, Brazil (10)

a) LIMING

	Ca + Mg (meq.100 cm^{-3})	Al% (100 Al/Al+S)	Limestone requirement ($t.ha^{-1}$)
Oxisols	<3.0	-	3.0 - meq. (Ca+Mg)
Ultisols (Tropudult)	-	>30	[meq.Al(Al%-30)/Al%] x1.5

b) FERTILIZATION

	Available P	N		P_2O_5	K_2O		
Soil level	($ug.cm^{-3}$)	*	**		***	****	*****
Very low	0 - 4	00	30	90	00	30	60
Low	5 - 8	00	30	60	00	30	60
Medium	9 - 16	00	30	30	00	30	60
High	17 - 30	00	30	00	00	30	60
Very high	> 30	00	30	00	00	30	60

* Plantation with *Erythrina* shading (30 - 40 $trees.ha^{-1}$).
** Plantation with heterogeneous shading.
*** Traditional soils with high level of K.
**** Soils with medium level of K.
***** Soils poor in K.

It is also believed that the use of *T. cacao* cultivars which absorb nutrients (mainly P) more effeciently (11) will permit a better utilization of the nutrient reserves in the agroecosystem and an exploitation requiring minor inputs. In this respect, the investigations of mycorrhizae associations, the tolerance of *T. cacao* cultivars to adverse environments such as soil acidity (33) and water limitations, assume an important role.

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NUTRIENT CYCLING IN AGROFORESTRY SYSTEMS OF COFFEE (Coffea arabica) WITH SHADE TREES IN THE CENTRAL EXPERIMENT OF CATIE*

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SUMMARY

A description is given of the N, P and K cycles in shaded coffee (Coffea arabica) plantations of the Central Experiment of CATIE. The N cycle of the coffee-poró (Erythrina poeppigiana) association is characterized by a total absorbtion after 5 years of 912 kg $N.ha^{-1}$, which is much higher than that in the coffee-laurel (Cordia alliodora) association where the total absorbtion reached 605 kg $N.ha^{-1}$. The rate of N fixation was hence estimated as 60 kg $N.ha^{-1}.a^{-1}$. N fertilization of these agroforestry systems is subsequently discussed.

The accumulation of P was also greater below E. poeppigiana than below C. alliodora (16.1 and 12.4 kg $P.ha^{-1}.a^{-1}$, respectively). The interpretation of the P cycle is difficult due to the fixation of P in the soil. The losses of exchangeable K, Ca and Mg from the soil are notable. This is possibly due to acidification resulting from the mineralization of organic material.

INTRODUCTION

The nutrient cycles of agroforestry systems are complex since they not only present multiple interactions of soil processes but also spatial and temporal fluctuations of the crops involved (1, 5, 11). In order to develop adequate research methodologies, the implications of specific cases should be derived and generalized.

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28. Models of organic material and nutrient cycles are based on the determination of the accumulation in different compartments of the system, the measurement of the transfer processes between compartments, and the determination of the gains and losses of the system as a whole (1, 2, 5, 6, 7, 8). In the Central Experiment of CATIE in Turrialba, Costa Rica, these cycles are studied in associations of coffee (Coffea arabica) with laurel (Cordia alliodora) and poró (Erythrina poeppigiana) (1, 2, 6, 8). In this paper, some results on the N, P, and K cycles are presented.

NITROGEN CYCLING

Accumulation and exportation

The accumulation of N in the vegetation and litter during the first 4.5 years of the experiment, is summarized below (Fig. 1) (1, 2, 8).

	Coffea arabica- Cordia alliodora ($kg\ N.ha^{-1}$)	Coffea arabica- Erythrina poeppigiana ($kg\ N.ha^{-1}$)
Phytomass and litter	455	699
Harvest losses*	160	213
Total removal	615	912

* Coffee (1979-84) and tree thinning (1981)

The accumulation of N is therefore quite different. The relation of N in the phytomass Coffea arabica - E. poeppigiana with C. arabica - Cordia alliodora is 1.54. The accumulation of N in C. alliodora occured largely in the stems while in E. poeppigiana it accumulated principally in the leaves. The relation between the harvest of Coffea arabica - E. poeppigiana and C. arabica - Cordia alliodora is 1.33. The difference in the accumulation of N during the experimental period is 305 $kg\ N.ha^{-1}$ which is equal to an average of 60 $kg.ha^{-1}.a^{-1}$. This value shows the higher rate of nutrient cycling in the association with E. poeppigiana shade and can be considered as an estimate of the greater extraction and fixation of N by the legume.

N transfer in plant residues

The average rates of the natural deposition of plant residues in three years of study (Nov. 1981 to Oct. 1984), are 141 and 241 $kg\ N.ha^{-1}.a^{-1}$ for Coffea arabica - Cordia alliodora and Coffea arabica - E. poeppigiana, respectively, (Fig. 1) (1, 8). During the experiment the E. poeppigiana was pruned irregularly, at intervals of 6 to 12 months. In the fifth year of the experiment, the pruning provided 286 kg $N.ha^{-1}.a^{-1}$. This shows that the annual deposition in the E. poeppigiana association increases, reaching 526 kg $N.ha^{-1}. a^{-1}$ (Fig. 1). On the basis of rapid decomposition of the residues (8), the N mineralization rate is estimated to be comparable to the rate of N deposition in the residues. Therefore the deposition and decomposition of the plant residues notably influences the N cycle of the associations studied. An indefinite perpetual cycle, leading to the removal of N, is apparent when the annual export rates due to harvests and the annual recycling rates are compared. The amount of N fertilizer applied in the experiment (Fig. 1; 80 kg $N.ha^{-1}.a^{-1}$) is without doubt in excess, especially for the E. poeppigiana association.

Seasonal fluctuations in the forms of N

The soil of the experiment is from the normal "Instituto" series and is characterized by its high content of organic material and N (1, 2):

Depth (cm)	Humus (%)	N-total (%)	C/N
0-15	4.32	0.21	11.9
15-30	3.07	0.16	11.1
30-45	1.87	0.11	9.9

According to Martínez and Blasco's (9) analysis of the forms of N in soils of this series, 97.6% of the N is organic, of which the amino acids represent 25.1% and the amino sugars 4.2%. The values of soluble NH_4 N and NO_3 N (NaCl 1N) represent 2.4 and 0.4% of the total N respectively. Besides these N fractions, variable quantities of N appear in the soil solution due to the mineralization and exchange processes, N fixation in the soil, and rain inputs (1, 5). Water samples from depths of 0-15 cm and 15-30 cm, at distances of 0.5 and 1.0 m from the tree trunks, have been taken. The chemical analyses (N total, NO_3 N and NH_4 N) should show the seasonal variation of N in the soil. The available values have shown an increase of these fractions after the dry season (February to May) which coincide with the weeks following the pruning. Apparently the dilution effect by rain regulates the N content in the soil solution as Fassbender (4) found out in other soils of Costa Rica under different ecological conditions and different crops.

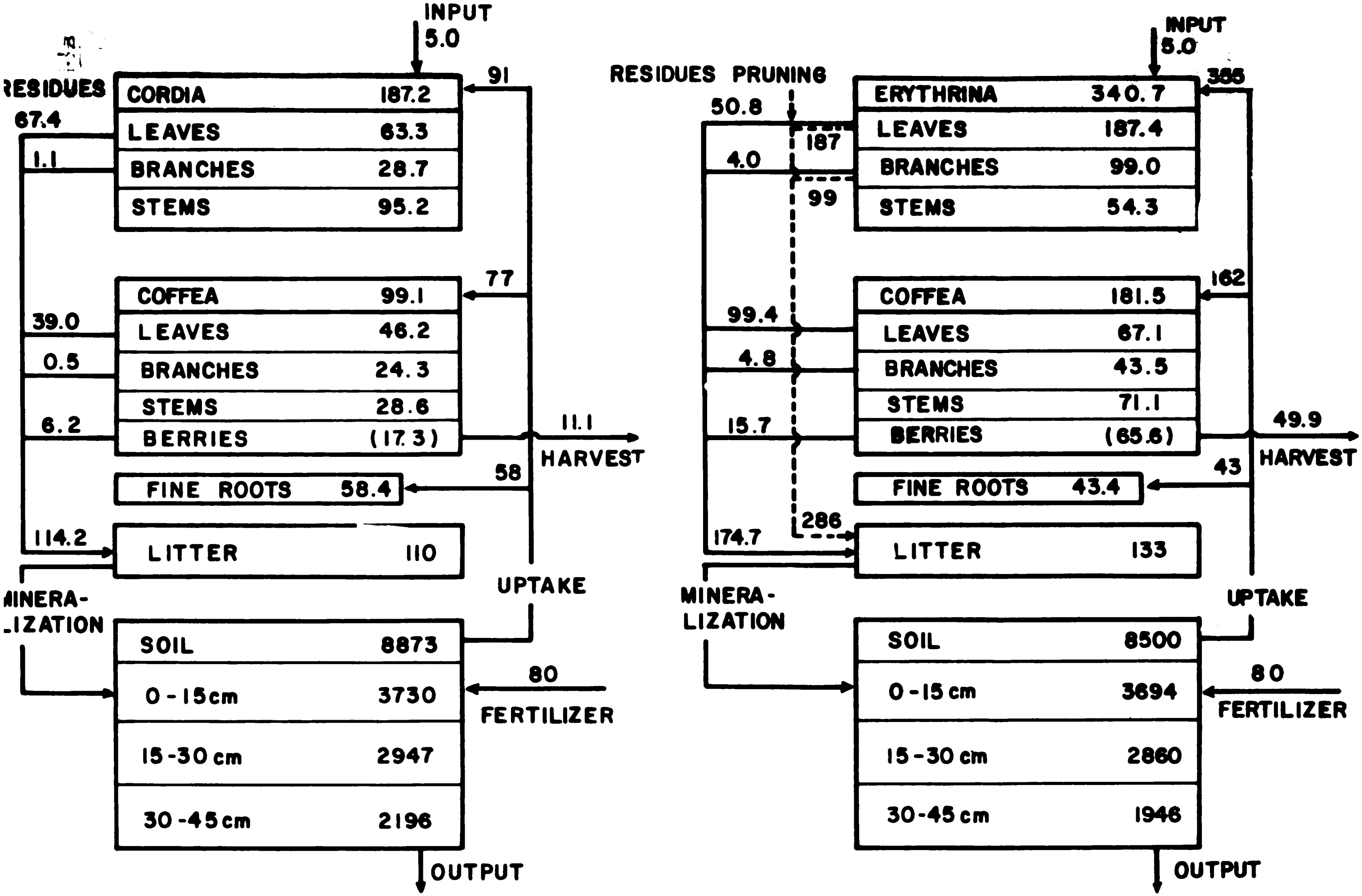


Fig. 1. Model of the nitrogen cycle. Reserves (kg.ha⁻¹). Transfers (kg.ha⁻¹. a⁻¹) in the fifth year

PHOSPHOROUS CYCLING

Accumulation and removal

The balance of P is summarized with the following values (Fig. 2) (1, 2, 8).

	Coffea arabica-Cordia alliodora (kg $P.ha^{-1}$)	Coffea arabica-Erythrina poeppigiana (kg $P.ha^{-1}$)
Phytomass and litter	45.6	59.2
Harvest losses	16.3	21.3
Total removal	61.9	80.5

The ratio for P, between the associations C. arabica - E. poeppigiana and C. arabica - Cordia alliodora, is thus 1.3. The weighted average P extraction from the soil, during the 5 experimental years, is 12.4 and 16.1 kg $P.ha^{-1}.a^{-1}$ for the associations Coffea arabica - Cordia alliodora and Coffea arabica - E. poeppigiana, respectively. The difference of 3.7 kg $P.ha^{-1}.a^{-1}$ could be due to the activity of mycorrhiza on the roots of the E. poeppigiana (10).

Forms of P and P fertilization

The production of plant residues, measured during 3 years, involves the transfer of 9.5 and 13.3 kg $P.ha^{-1}.a^{-1}$, in the associations C. arabica - Cordia alliodora and Coffea arabica - E. poeppigiana, respectively. (8). The data for 1981-82 is given in Fig. 2.

The deposition of P in the E. poeppigiana prunings reaches 24.2 kg $P.ha^{-1}$, assuming two prunings per year (Fig.2). The amount of P circulating with the litter surpasses, therefore, the amount taken out by the crop harvests. Nevertheless it is necessary to utilize the P reserves of the soil or apply P in a fertilizer (105 kg $P.ha^{-1}.a^{-1}$) to cover the increase in the phytomass. At a first glance this fertilization appears to be excessive but according to Fassbender (3), the availability of P in its different forms (P-org. 70; Fe-P 8.4; Al-P 4.2 and Ca-P 1.7% of the P-total) in the soil of the Instituto series is low. It is also necessary to consider the high P fixation (62.2% of the P offered) and the formation of insoluble phosphates (Al-P 67%, Fe-P 26%) (3). Therefore the utilization of P fertilizer is very limited.

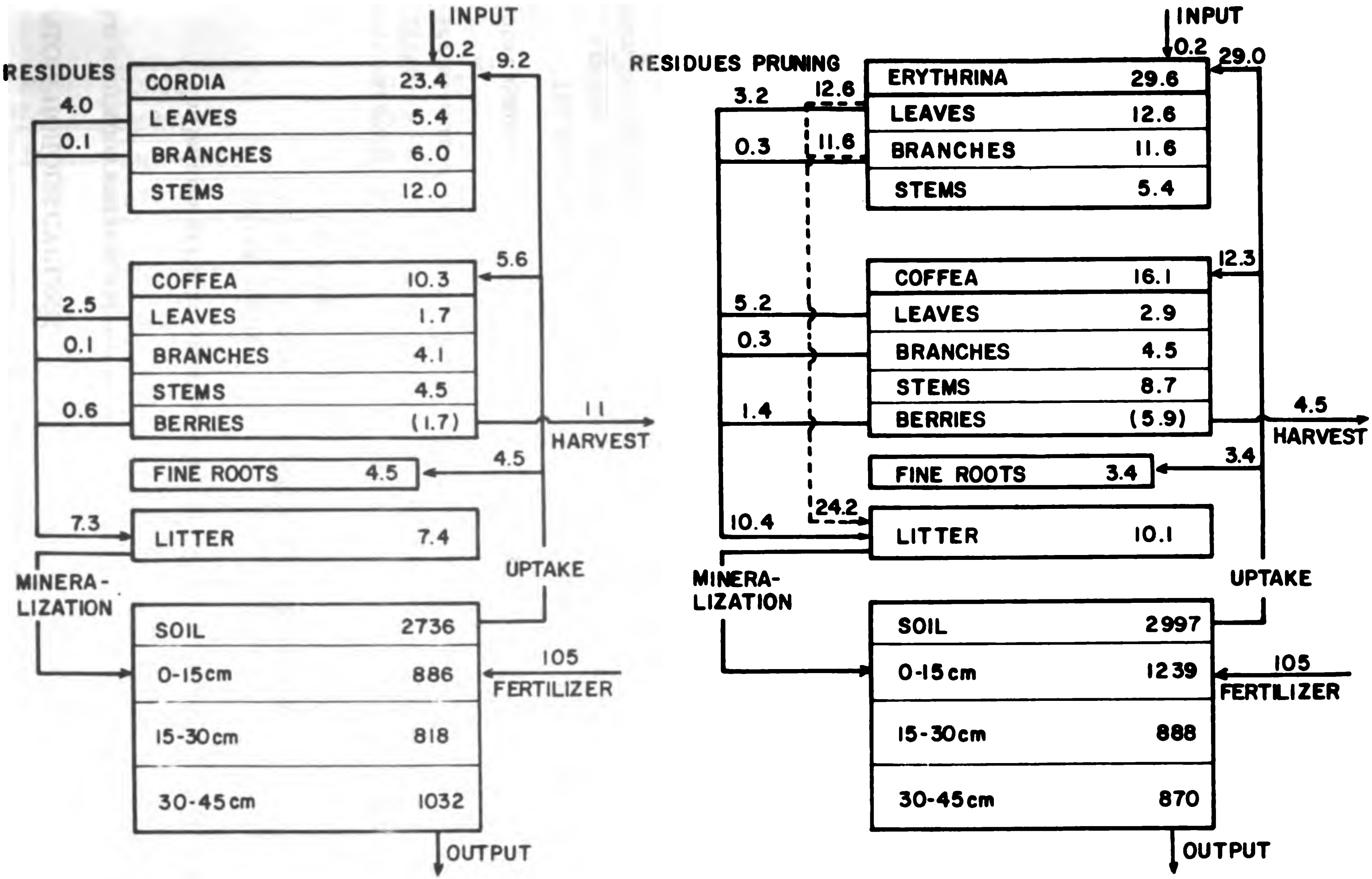


Fig. 2. Model of the phosphorous cycle. Reserves(kg.ha^{-1}). Transfers(kg.ha^{-1}.a^{-1}) in the fifth year

POTASSIUM CYCLING

Accumulation and removal

The K soil reserves (0-45 cm) at the beginning of the experiment (1977), and the accumulation of K in the vegetation and litter, as well as the export in crop harvests (coffee 1979-84 and one tree thinning), are shown below (Fig. 3) (1, 2, 8):

	Coffea arabica- Cordia alliodora (kg $K.ha^{-1}$)	Coffea arabica- Erythrina poeppigiana (kg $K.ha^{-1}$)
Soil reserves	687	630
Phytomass and litter	271	373
Harvest losses	174	187
Total removal	445	560

The depletion of the soil reserves is notable and represents 65 and 89% of these for the associations with Cordia alliodora and E. poeppigiana, respectively.

Effects of mineralization

The losses have been shown through soil analyses (Figs. 4 and 5) (1). A possible explanation for the K losses, as well as those of Ca and Mg, is the progressive acidification of the soils because of plant residue mineralization. This process liberates NH_4^+, which is subsequently nitrified to give finally NO_3^-, both ions appearing in the soil solution and participating in the interchange process. Likewise, residue mineralization produces SO_4^{--}, which is a strong acidifying factor. An increase in the amount of interchangeable H and Al results (Fig. 4). The notable K, Ca and Mg losses are a consequence of the interactions between all the elements. (Fig 5). Long term quantification, with permanent observation instalations (monitoring), is desirable.

It is also important to note that the roots reach depths greater than 45 cm where important amounts of K can be extracted. On the other hand, the fertilization (66 kg $K.ha^{-1}.a^{-1}$) is high, and may compensate K demands by the plants. Moreover, the plant residues play an active role in maintaining the K cycle. The average values of K found in the plant residues during three experimental years are 68.9 and 83.9 kg $K.ha^{-1}.a^{-1}$ for the associations with C. alliodora and E. poeppigiana, respectively. The E. poeppigiana pruning is an

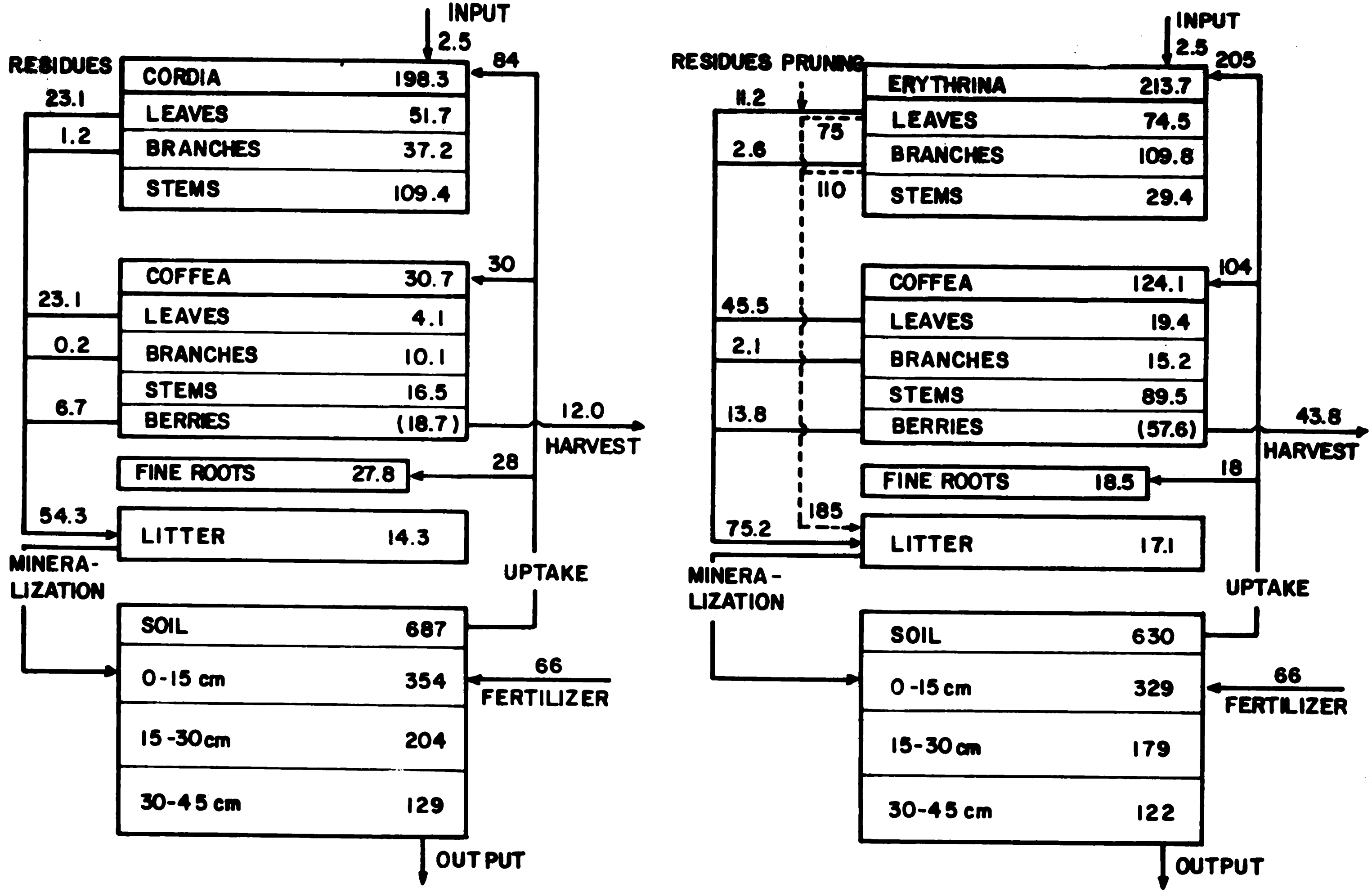


Fig. 3. Model of the potassium cycle. Reserves ($kg.ha^{-1}$). Transfers ($kg.ha^{-1}.a^{-1}$) in the fifth year

additional transfer of 184.5 kg $K.ha^{-1}.a^{-1}$. The recycling of K nevertheless originates in the soil (1, 2, 8).

The greatest limitation of the studies is the lack of information about the nutrient loss through leaching. Apparently K is a limiting element for the development and productivity of the agroforestry associations studied.

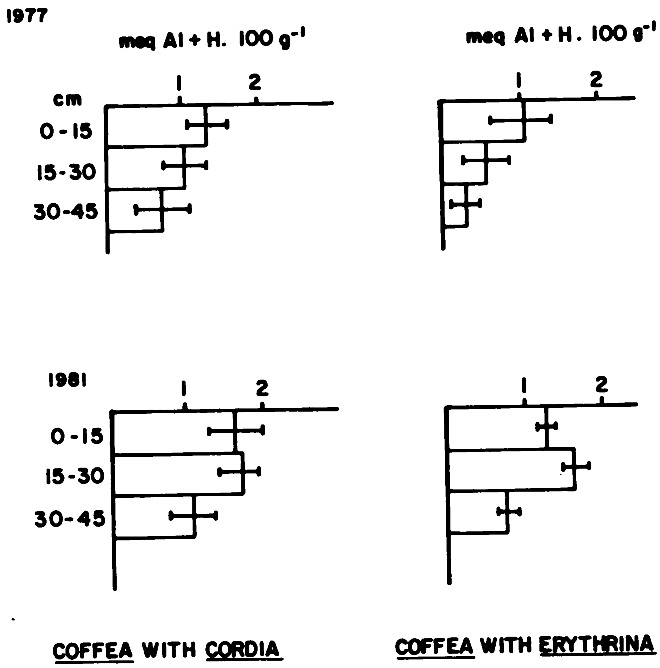
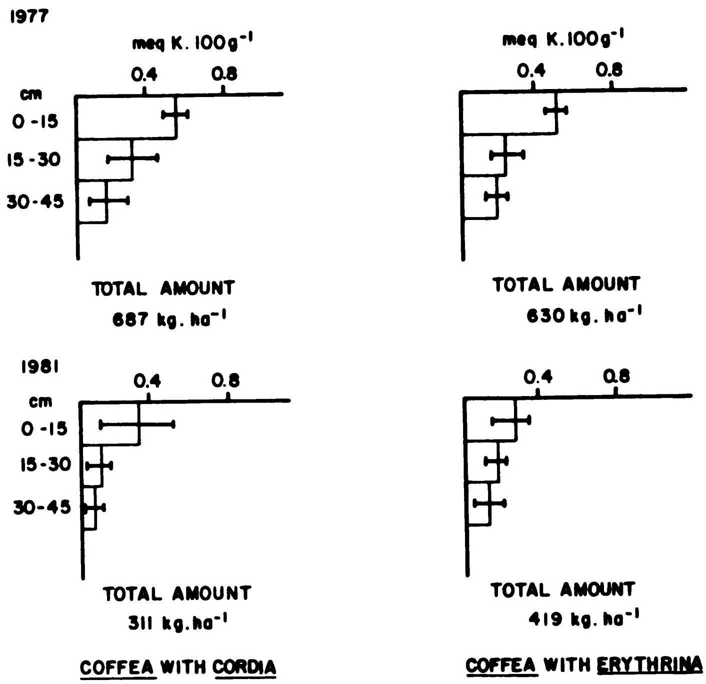


Fig. 4. Changes in the soil reaction (Exchangeable H and Al; meq.100g^{-1} soil)

DISCUSSION

The complexity of the studies needed for a complete and functional description of agroforestry associations can be derived from the models presented (Figs. 1, 2 and 3). The annual variations of the transfer processes (harvests, natural plant residue production, prunings) need to be measured on a long term. Other necessary studies should be considered such as the water balance, nutrient inputs in rain, loss of nutrients through leaching, direct determination of the N fixation rate, and long-term changes in the nutrient reserves in the soils. Monitoring installations would also be convenient.



-376	Δ K, kg.ha⁻¹	- 211
-625	Δ Ca, kg.ha⁻¹	-1125
- 46	Δ Mg, kg.ha⁻¹	- 216

Fig. 5. Changes in the exchangeable bases of the soil (K, Ca, Mg; meq.100g⁻¹ soil)

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EXPERIENCES WITH COFFEE-SHADE TREES IN COSTA RICA

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SUMMARY

Research on Coffea spp. (coffee)-shade systems in Costa Rica is reviewed under the themes of characterization, wood production, Coffea production and nutrient cycling. Traditional shade species, typical tree densities and the reasons for these choices are presented. Timber production values of up to 20 $m^3.ha^{-1}.a^{-1}$ are cited, and even with lower productivity the combined value of timber plus Coffea harvest will frequently exceed the value of Coffea harvests from monocultures. Fuelwood production volumes can be even higher especially when Coffea prunings are included. However, there is evidence for a reduction in Coffea yields due to tree-crop competition. The importance of shade tree litterfall for nutrient cycling and erosion control is discussed. Finally the need to extend the studies to associations other than those which include Cordia alliodora or Erythrina spp. is stressed.

INTRODUCTION

The advantages and disadvantages of growing Coffea spp. (coffee) under shade has been a controversial topic in Costa Rica (5, 26). After Budowski drew attention to the potentials of agroforestry (6) studies of traditional Coffea - shade associations were promoted (3). The main aim of these studies was to measure the productivity of all the component species, principally the commercial products: Coffea beans and sawtimber. Studies were also initiated on the interactions between the species, emphasizing their contributions to the

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nutrient cycles (11). This paper will give a brief review of the Costa Rican studies on Coffea - shade associations, i.e. characterization (species, densities, stand architecture); wood production (saw-timber, fuelwood); Coffea production; and nutrient cycling.

CHARACTERIZATION OF COFFEA-SHADE TREE ASSOCIATIONS

Many Coffea-shade associations have been identified, involving not only various shade species but also different Coffea varieties (8, 18). In the area of Acosta and Puriscal, 64 different shade species are used. The most common are: the fruit trees Mangifera indica, Persea americana and Citrus spp.; the legumes Diphysa robinioides and Inga spp.; and the timber species Cedrela odorata. It was suggested that the 100-300 trees.ha^{-1} form two principal shade strata (10). Two shade strata are also obvious in the association of Coffea arabica-Erythrina poeppigiana (200 trees.ha^{-1}; 3-5 m height) - Cordia alliodora (100-250 trees.ha^{-1}; 10-25 m height), which is common in the Turrialba area (3). The shade tree diversity is generally greater outside of the optimal Coffea zone. In the optimal Coffea zone intensive management has resulted in mono-specific shade or unshaded plantations. On small farms the choice of shade species, as well as their distribution and management, is also strongly influenced by socio-economic limitations such as total farm size and alternative resources available to the farmer (10). This critical factor has not been considered during the productivity studies described in the following sections.

WOOD PRODUCTION

Saw-timber production

Cedrela odorata and Cordia alliodora are the most valuable saw-timber species which are commonly included amongst other Coffea shade trees (8). Taking the average C. alliodora density over Coffea (220 trees.ha^{-1}), the total stem volume at the end of an optimal biological rotation of 34 years would be 690 m^3.ha^{-1}. The present commercial yield was estimated to be 64% of the total stem volume, corresponding to a form factor of 0.272. (25) However, data from Antioquía, Columbia (1200-1800 m.a.s.l.*) indicate optimal commercial yields of 130 m^3.ha^{-1} at age 30 when Cordia alliodora (170 trees.ha^{-1}) are associated with Coffea arabica (9). In Turrialba, Cordia alliodora growth rates in permanent sample plots were greatest when the trees were associated with Coffea, compared to associations with pasture or Saccharum officinarum (sugar cane) (25).

* Meters above sea level.

Previous case studies, which included Coffea yield measurements, showed that when Cordia alliodora was managed as an extra shade strata over the E. poeppigiana, the combined value of the timber and Coffea production exceeded the value of Coffea production from monocultures. (13, 15). Similar suggestions were made with respect to the association of Cedrela odorata (30-90 trees. ha^{-1}) with Coffea in the area of Puriscal (12, 22).

Fuelwood production*

Coffea bushes and their shade trees are both important sources of fuelwood in Costa Rica (19). On the CATIE farm, the former gives an average of 1100 $kg.ha^{-1}.a^{-1}$ (21). The quality and quantity of fuelwood from the shade trees depends upon species and management. For example, E. poeppigiana is usually heavily pruned twice a year but the pruning residues are only used as a soil mulch. In contrast 30 year old unpruned Gliricidia sepium, and 20 year old Inga densiflora which had not been pruned for 7 years, gave, respectively, 3400 and 2400 $kg.ha^{-1}.a^{-1}$ when the trees were harvested during the renovation of Coffea plantations (23, 24). The yield from 2 year old Mimosa scabrella (650 shade $trees.ha^{-1}$) was 9,250 $kg.ha^{-1}.a^{-1}$, which corresponds to 22.8 $m^3 ha^{-1}.a^{-1}$ (7).

COFFEA PRODUCTION

Comparisons of unshaded versus shaded Coffea production, in Costa Rica, have not been published. In adjacent Coffea arabica plantations shaded by E. poeppigiana, with and without Cordia alliodora, a weak inverse correlation was found between individual Coffea arabica bush yields (4 year average) and a competition index for each bush, calculated as $x_i.(D_i)^2$, where x_i is the C. arabica bush to tree (i) distance and D_i is the stem diameter of the tree (i)**. In this case the apparent yield depressing effect of E. poeppigiana on C. arabica is probably a consequence of the high fertility and good management at the study site. Shade management is more appropriate for sites of lower fertility where intensive management can not be guaranteed (1, 27).

A comparison of C. arabica yields under shade of unpruned Cordia alliodora (278 $trees.ha^{-1}$ latter thinned to 185 $trees.ha^{-1}$) vs shade of biannually pruned E. poeppigiana (555 $trees.ha^{-1}$) showed that the latter association gave

* Biomass values are for fuelwood only, oven-dry weights.
** Beer, J.W. Unpublished data.

37% more yield (cherries; green weights) over a five year period (30439 and 41718 $kg.ha^{-1}$, respectively) (16). This result provides part of an explanation of why Costa Rican farmers invariably include C. alliodora as a second strata over E. poeppigiana, rather than replace the latter by the former. However, it is not clear why, in other studies, the inclusion of this second shade tree has no effect on Coffea yields (13, 15), when the above result suggests a competitive effect.

NUTRIENT CYCLING* AND SOIL PROTECTION

One of the major benefits of Coffea shade trees is the litter they produce. For example, one study in Turrialba showed that the litter layer under: Coffea arabica; C. arabica - E. poeppigiana; and C. arabica - E. poeppigiana - Cordia alliodora, averaged 640, 5200 and 7100 $kg.ha^{-1}$, respectively (4). Erosion, but not run-off, measured over 6 months in the same plots, was much greater under a Coffea monoculture than under the shaded plantations (366, 59 and 104 $kg.ha^{-1}$. 6 $months^{-1}$, respectively). (4). However, many farmers mention that drip from tall trees can damage understory crops (e.g. the Coffea fungal disease Mycena citricolor [Ojo de Gallo]) and soils (1, 3). The choice of shade tree species and their management affects not only the total litterfall, but also the temporal fluctuations in litter inputs (14). Since E. poeppigiana litter can provide a nutrient input which exceeds the amounts applied in inorganic fertilizers (2), timely pruning in accordance with crop nutrient needs could feasibly increase productivity. However, any change in the timing of shade tree pruning would have to take into account Coffea phenology, and little is known about the release of nutrients from the litter of these species. In these relatively heavily fertilized plantations (up to 300 kg N; 30 kg P; 100 $kgK.ha^{-1}.a^{-1}$), nitrogen fixation is not the main benefit of including leguminous shade trees since this input probably does not exceed 60 kg $N.ha^{-1}.a^{-1}$ (2, 11).

CONCLUSIONS

The studies of the model agroforestry association Coffea arabica - E. poeppigiana - Cordia alliodora have provided detailed information on wood production and on nutrient cycling, but practical recommendations have still to be derived and tested. One of the main gaps in our information, especially when thinking of an extension programme, is how do the shade trees affect Coffea production. One trial to study the dependance of Coffea production on shade tree densities, using a mixture of E. poeppigiana (131-262 $trees.ha^{-1}$) and Cordia alliodora (114 - 348 $trees.ha^{-1}$), has been established at CATIE (Fig. 1). This

* See also Fassbender and Alpízar (9).

novel type of systematic spacing design, which allows the densities of the two shade trees to be varied independently (20), will be used to study the tree - crop and tree-tree interfaces (17). In addition to production, studies of the effect of shade on Coffea phenology will be emphasized.

More information is needed on the present and potentially useful range of this association in Costa Rica (probably only 600 - 800 m.a.s.l. on the Atlantic watershed), as well as other promising but less well known agro-forestry associations. The first priority should be the characterization of Central American Coffea - shade associations, and their correlation with specific ecological or socio-economical conditions. Subsequently production, competition and nutrient cycling studies will be needed; and then attention should be given to Coffea damage during tree harvesting, drip damage to the Coffea and soil, and N fixation by leguminous shade trees with and without inorganic N fertilizer. This obviously implies an enormous amount of work and hence a very strict selection of the most promising associations (i.e. those which could benefit the largest number of farmers) must follow the characterization phase and precede the other steps.

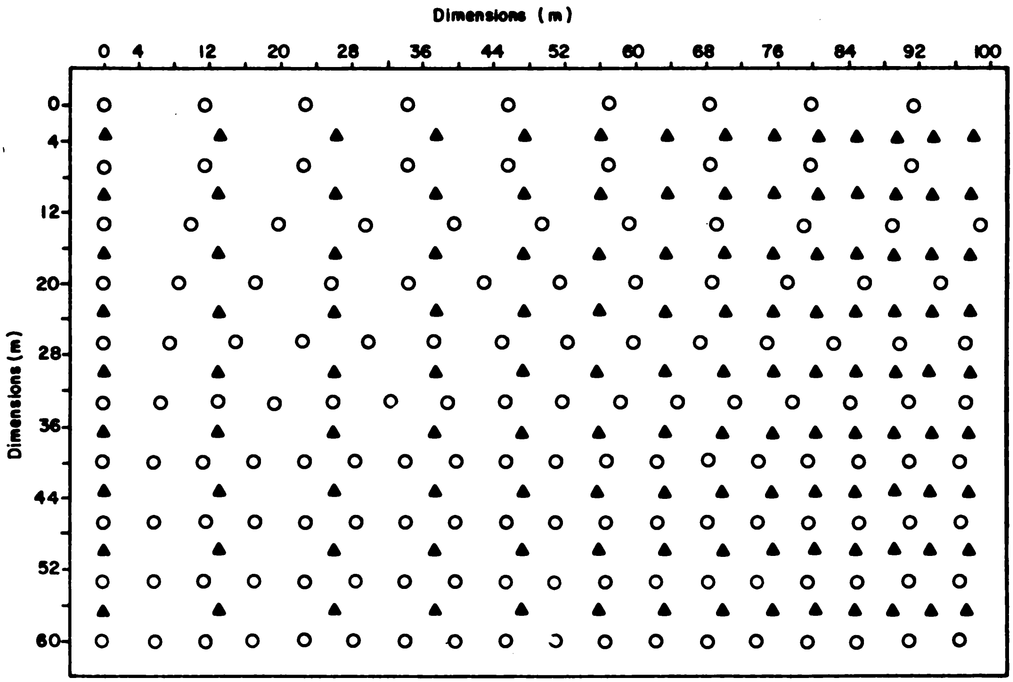

Fig. 1 Two-way systematic spacing design* for the coffee-shade trees Cordia alliodora ▲ and Erythrina poeppigiana ○

* Mead, R. and Stern, R.D. Designing experiments for intercropping research. Expl. Agric. 16: 329-342. 1980

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COFFEE AND CACAO PLANTATIONS UNDER SHADE TREES IN VENEZUELA

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G. Cuenca*

SUMMARY

The origin and development of the practice of planting trees, other than for shade purposes, in coffee (Coffea spp.) and cacao (Theobroma cacao) plantations is put into historical perspective. Based on the work carried out under mixed shade trees in experimental Coffea and T. cacao plantations in Northern Venezuela, the main features of organic matter N, P, K, Ca and Mg cycles are discussed using a nested set of nutrient cycling models. The work stresses the importance of transfers through litter and the role of root systems in coupling the shade and crop sub-systems. The amounts of mineral nutrients exported by harvest were found to be a small fraction of the annual circulation in the litterfall, suggesting that there is a subsidy to the crop system from the shade components.

INTRODUCTION

Both Coffea spp. and Theobroma cacao grow naturally as understory plants in forest ecosystems. With their expansion as cash crops during the last centuries, allowance for this habit has been made in the form of planted shade

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trees (6). In Venezuela, T. cacao has traditionally been grown by indigenous populations as a semi-domesticated crop. During colonial times T. cacao became one of the mainstays of the export economy. Cultivation expanded mostly into the humid, low, north-facing valleys of the coastal range where it was traditionally managed under a plantation system. A number of shade trees have been used: Inga spp., Erythrina spp., Cedrela spp., Castilloa elastica, etc. Together with these species it was not uncommon to have some fruit trees such as Artocarpus altilis (breadfruit), Musa spp. (bananas and plantains), Spondias sp. (jobo) etc.

In the 18th century Coffea was introduced into the New World, where it spread rapidly to occupy the first place as an export crop in many Central American and South American countries. Many of the practices and even some of the same shade tree species were adopted from the T. cacao plantation systems, although the range of species was limited by the higher elevations where Coffea is normally grown. Again a number of subsidiary trees accompanied the Coffea and the main shade trees. Besides Erythrina and Inga, Musa, Citrus and Annona spp. are commonly found.

These associations are not merely there by coincidence. In the first place, in order for a species to be useful as a shade tree it should meet certain criteria: to be fast growing and to be compatible with, rather than a competitor of, the crop. Apparently two fast growing legumes were readily available and soon became dominant as shade trees: Inga and Erythrina spp. Both have recently been reported as efficient N fixers (10, 12). Although they produce edible fruits or even edible flowers (Erythrina spp.), they are principally planted for shade providing fuelwood as a bonus.

Since plantation work was organized during colonial times using the abominable practice of slavery, the people tending the crops did not have their own fields to produce food. In order to complete rations provided by the owners, they cultivated some staples like Colocasia esculenta (taro) and Dioscorea spp. (yams) as side crops. Probably the practice of interspacing fruit trees in the T. cacao plantations had the same origin. Other forestry products were also obtained alongside T. cacao. Fine timber species like Cedrela and latex producing trees like Castilloa, are still commonly found in old T. cacao fields but little or no use of the latter is made at present. It seems reasonable to suppose that these combinations developed to meet various demands: cocoa beans for export, timber for construction, latex became important at certain times and could also be exported. For the labourers in the field, the plantation was also a source of fruits, starches and fuelwood.

Coffea and T. cacao plantations in Venezuela, have been traditionally managed at low-input levels. In the case of T. cacao, improved more productive but more demanding varieties have been planted but the present trend is to go back to the high quality "Criollo" varieties. Coffea continues to be grown under shade trees with only a few attempts to follow the trend towards unshaded plantations.

At the Center of Ecology and Environmental Sciences of IVIC near Caracas, a modest research programme was set up in 1978 in order to try to shed light on the factors controlling fertility and hence productivity in these T. cacao and Coffea plantations which are managed at very low input levels but still maintain their productivity for decades. The main approach has been to use ecosystem models as worked out for tropical forests. These models are centered around nutrient cycling patterns and try to interpret ecosystem functioning in terms of nutrient distribution and fluxes between ecosystem compartments.

Some published studies have made contributions to the understanding of these agroforestry systems (3, 4, 5, 11, 12, 13). However, several major questions still remain unanswered like: the role of shade trees in exploiting deeper soil levels and thus providing the crop with otherwise unavailable nutrients; phenological synchronism of crop and shade trees; root competition; and the influence of nitrogen fixers and mycorrhizal associations on crop productivity.

MATERIALS AND METHODS

The work on T. cacao agroforestry systems has been carried out in "Hacienda Monasterio" near Ocumare de La Costa, Aragua in Northern Venezuela at 12 m.a.s.l.*. Average annual precipitation and temperature are 750 mm and 25ºC, respectively. Only 3% of precipitation falls between January and March. Two main peaks of rainfall occur in July - September and October-November. In this experimental site we have chosen a 30 year old plantation which was last fertilized in 1972. In the plot, 720 trees of "Criollo Morado" T. cacao trees were counted in the area of 7,600 m^2. The main shade trees were Castilloa elastica, Erythrina poeppigiana and Artocarpus altilis with importance value indices of 204, 54 and 41 respectively. A few individuals of Spondias sp. and Inga sp. were also present (2). The soil has been described by Cañizales (7) as a Psamment of recent alluvial origin. The terrain is well drained and almost flat. An adjoining plot of "Criollo" T. cacao shaded exclusively by E. poeppigiana and managed under irrigation and fertilization, was also chosen for comparisons.

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* Meters above sea level.

The work on Coffea has been carried out in two different sites. The first is located at 1,380 m.a.s.l. in Miranda State. This plantation is predominantly shaded by E. poeppigiana and Inga sp. but Heliocarpus, Clethra, Ficus and Cedrela spp. were also present. A total of 596 mature Coffea plants were counted in 922 m^2 of hilly terrain. Coffea plants were of the "Caturra" and "Mundo Nuevo" varieties. The area received no fertilization since 1969. Annual mean temperature is 20ºC. Precipitation averages 1,200 mm with a marked dry period in the first quarter of the year. The soils are shallow Ultisols developed on deeply weathered mica-schists. The general slope in the experimental plot is 25%. A second experimental plot was chosen more recently in one of the areas where Coffea is beginning to be grown in open fields. This area is near Río Claro in Lara State at 1,200 m.a.s.l. The soils are richer, more clayey and calcareous in places. No shade trees are found in this experimental plot.

The research work has been designed around a nutrient cycling model as published by Aranguren et al. (3,4) and completed later for T. cacao by Accardi (1). The latter model considers 12 compartments separating shade-tree or crop biomass into: leaves and twigs; branches and boles; flowers and fruits; large and fine roots. The litter and three soil layers comprise the remaining compartments. Each biomass compartment was sampled by complete removal and determination of fresh and dry weights of a varying number of individuals according to species, and size for the trees. Crop and shade-tree litter was separated into: leaves; twigs; flowers and fruits; and the non-recognizable remainder classed as miscellaneous. Soil was separated by layers (0-20; 20-30; 30-60 cm). In all cases subsamples were taken for dry weight determination and analyses. The fluxes studied were: rain fall; throughfall; litterfall; litter decomposition rates; harvest export; return of harvest byproducts to the field; weeding; pruning; and fertilization when practiced. N fixation was studied by field evaluation of nodule presence and activity was determined by the acetylene reduction technique. The effect of mycorrhiza on litter decomposition was assessed in the Coffea plantation under shade trees (9). More detailed descriptions of specific methods have been published (1, 2, 3, 4, 8, 10).

RESULTS AND DISCUSSION

T. cacao (Fig. 1)

The average amount of litter on the T. cacao site was 2,460 $kg.ha^{-1}$. The rate of nutrient transfer to the soil by litterfall was 972 $kg.ha^{-1}$ a^{-1} of which approximately 80% comes from shade trees. This represents a total of 321 $kg.N.ha^{-1}.a^{-1}$. The net amount of nutrients exported by harvest of the T. cacao almonds is 102 $kg.ha^{-1}.a^{-1}$, only 1/9 of the total circulated in litterfall. The average decomposition rate of litterfall under T. cacao was found to be $k = 8.5$. Superficial roots of E. poeppigiana produce numerous Rhizobium nodules which

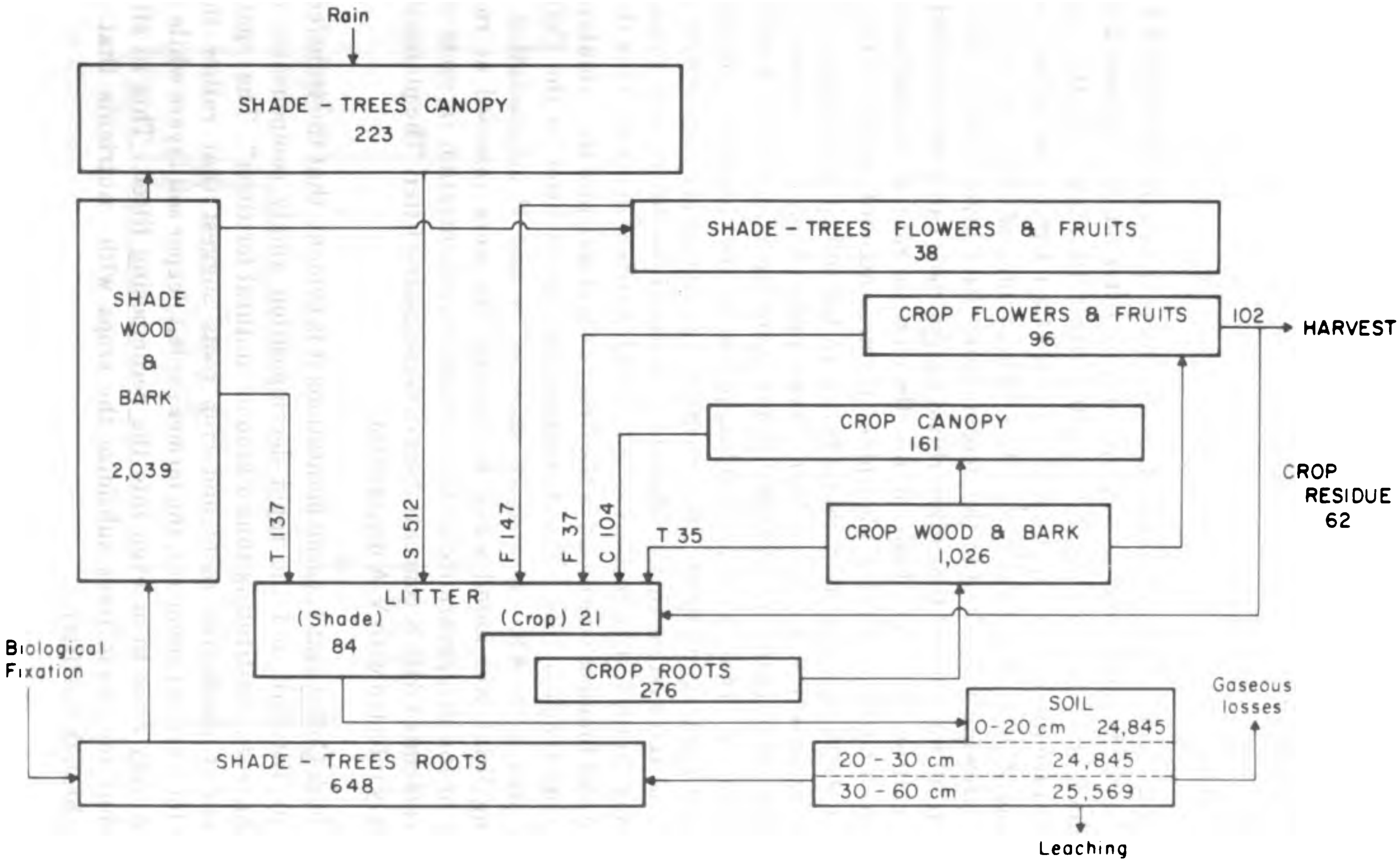

Fig. 1. Nutrient (N + P + K + Ca + Mg) cycles in a *T. cacao* agroecosystem under mixed shade trees. The blocks indicate compartments and their contents in $kg.ha^{-1}$. Arrows indicate transfers in $kg.ha^{-1}.\ a^{-1}$. Inputs to the litter compartment are: C=crop leaves; S=shade tree leaves; T=branches; F=flowers and fruits

are able to fix N actively, especially at the onset of the rainy period. The nodules reach a maximum biomass at the peak of the rainy season (148 $g.m^{-2}$) and practically disappear at the end of the dry season. This was considered by Escalante et al (10) as an important input of N to the soil since nodules contain on average over 4% N.

Coffea (Fig. 2)

Litterfall in the Coffea plantation under shade trees amounted to 11,159 $kg.ha^{-1}.a^{-1}$ and the quarterly average amount of litter on the soil was 2,314 $kg.ha^{-1}$. Shade tree litter represented over 50% of this litter layer. By this route the flux of nutrients reached a total (N+P+K+Ca+Mg) of 346 $kg.ha^{-1}.a^{-1}$ which included 172 $kg.N.ha^{-1}.a^{-1}$. The root system of the crop is quite superficial, growing very close to the decomposing litter layer or even into it. Cuenca et al (9) have found that mycorrhizal Coffea roots can grow attached to decomposing litter but have little or no effect on its rate of decomposition. Nutrients accumulated in the Coffea plant biomass account for 11% of total stores, litter 0.03% and the remaining 89% is in the soil compartments. The total nutrient (N+ P+ K+ Ca+ Mg) harvest export from the system is 57 $kg.ha^{-1}$ which represents only 1/7 of the amount annually circulated in litterfall and decomposition. The main leaf-shedding period for the shade trees precedes flowering and fruiting in Coffea. This synchrony is considered important for the functioning of the system in the absence of fertilization because it releases nutrients close to the Coffea roots at a time of high nutrient demand. One third of total fine root biomass was found in the first 10 cm of soil; and the cumulative total to 30 cm reached 73%. The decomposition rate of litter in the Coffea plantation was k = 4.8. A distinct phase of N and P accumulation in decomposing litter was found while K, Ca and Mg were released at rates equivalent to the disappearance of litter mass. K concentration in roots was positively correlated with K concentration in decomposing litter. The plantation was intensely infected with V-A mycorrhiza.

For both Coffea and T. cacao plantations it is evident that the transfer of nutrients by litterfall and the rapid decomposition amply compensates the export by harvest, constituting thus a kind of "natural fertilizer". The spatial distributions of shade-tree roots and crop roots suggest that rather than competing for nutrient resources, the former exploit deeper soil layers while the latter grow very close to or even into the decomposing litter. This in effect confirms that the shade trees subsidize the crops with nutrients that are circulated through the litter.

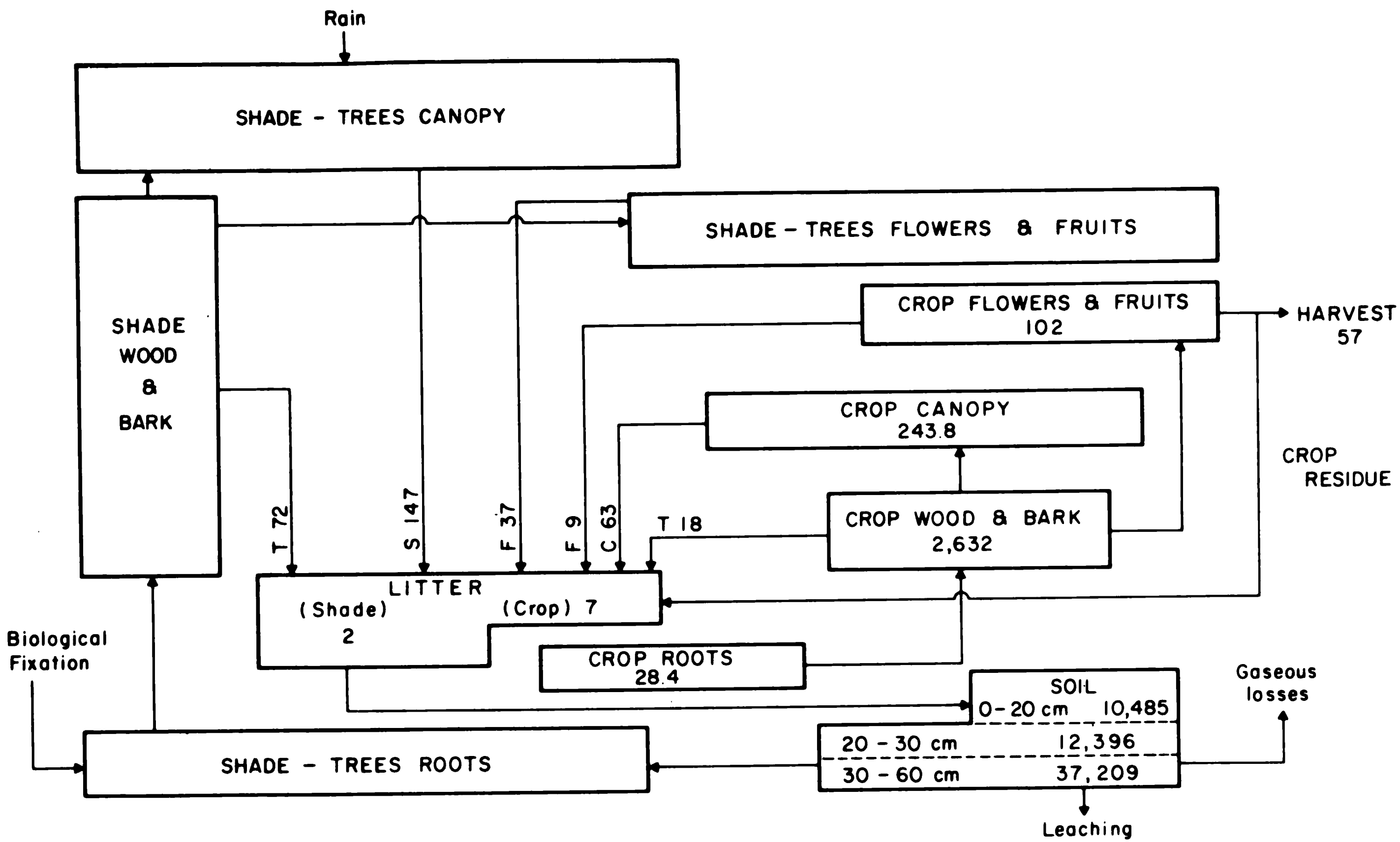

Fig. 2 Nutrient (N+P+K+Ca+Mg) cycles in a *Coffea* agroecosystem under mixed shade trees. The blocks indicate compartments and their contents in $kg.ha^{-1}$. Arrows indicate transfers in $kg.ha^{-1}.a^{-1}$. Inputs to the litter compartment are: C=crop leaves; S=shade tree leaves; T=branches; F=flowers and fruits

PRESENT AND FUTURE WORK

The presence of V-A mycorrhiza in Coffea plantations under shade is currently being studied. Also the effect of inoculation with Gigaspora margarita is part of a project to assess the nutritional effect of mycorrhiza in seedling growth and development. The nutrient cycling in a Coffea plantation under shade trees is presently being compared with the cycling in one of the unshaded plantations with particular emphasis being given to N cycling including the heavy fertilization.

Field and laboratory work continue to complete the biomass estimates of the mature shade tree stands in T. cacao plantations. Accardi (1) has found about four times more nutrients stored in the aerial parts of shade trees than in their root biomass. The vertical root distribution of four shade tree species, as compared to T. cacao plants, indicates that competition for the same soil volume does not seem to be important since the selected shade species have a deeper rooting habit in general. Nutrient flows in soil water are being completed in a recent phase of the T. cacao project. More detailed studies of precipitation input, throughfall, stemflow, drainage losses and N fixation are being advanced. A more detailed study of litter decomposition and the influence of superficial roots on the process, is being continued. The role of mycorrhiza and free living microorganisms in nutrient transfer to roots is also being studied.

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ACKNOWLEDGEMENTS

The authors wish to express their gratitude to the Ministry of Agriculture and the Faculty of Agronomy, "Universidad Central de Venezuela" for the use of the experimental area in "Hacienda Monasterio". To CONICIT for partially financing the thesis work of one of us (J.A.) in Coffea and T. cacao agroecosystems, and for financing at present the work on T. cacao and the theses work on Coffea of E.N. and M.T. The laboratory assistance of Ms. Laura Martin and Ms. Elisa Martínez and Mr. Saúl Flores is gratefully acknowledged. The authors also thank all the field workers in the experimental sites.

THE PEJIBAYE PALM (Bactris gasipaes H.B.K.) AS A POTENTIAL AGROFORESTRY SPECIES

C. Clement*

SUMMARY

The Pejibaye palm (Bactris gasipaes H.B.K.) was domesticated by the Amerindians as a part of their indigenous agroforestry systems. The multiple uses for its fruit make it an attractive food species and its potentially high production make it an attractive economic proposition. The growth habit of B. gasipaes is ideal for a canopy strata in some types of agroforestry schemes and, by controlling the number of stems to be maintained, may be modified to fit different species mixes. Several Brazilian policulture experiments are mentioned, although results are not yet available. The Costa Rican experience with B. gasipaes x coffee (Coffea spp.) policultures is examined, with special reference to Tucurrique, Cartago. It is concluded that the B. gasipaes has significant immediate potential for the small policulturalist and a greater potential if improved for agroforestry as well as monocultures.

INTRODUCTION

Johnson has pointed out that palms have a growth habit that makes them ideal for consideration as agroforestry components (6). Coconut (Cocos nucifera L.) has long been used in combination with pastures, cacao (Theobroma cacao L.) and other perennial and annual agricultural species, especially in South and Southeast Asia. The coconut, and other palms, have a relatively open crown structure, and a narrow, unbranched trunk. Many palms are easily propagated, self-pruning and have a widely appreciated economic yield that

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can be used fresh or processed on the farm, giving an attractive economic return to the farmer.

Pejibaye palm (Bactris gasipaes H.B.K.) is a native American species which has many of the same agroforestry qualities as the coconut and produces abundant, starchy or oily, egg-sized or larger fruit. This species was domesticated and improved by the Amerindians of the lowland humid tropics and widely distributed by them to many parts of tropical America. Throughout this region it was, and generally still is, a component of the native "agroforestry" systems. Major modern uses are restricted to its leaves, i.e. palmito, and to its fruit. Mora Urpí et al (7) and Clement & Mora Urpí (3) have extensively discussed potential uses of the fruit and how to breed for them. Due to reasonable protein levels, medium to high carotene levels, oil content and generally high starch (2) the B. gasipaes may be considered as a basic food crop. For agroforestry systems only the fruit is thought to be of interest and this may be used in four ways, depending upon fruit qualities: 1) fruit for direct human consumption, after cooking; 2) fruit for flour and meal production, for baking purposes; 3) fruit for oil production; and 4) fruit for animal ration. The present paper is to report on some of the experimentation that is underway with this species in Brazil and some practices currently in use in Costa Rica.

RESULTS

Brazilian Policulture Experiments

The Instituto Nacional de Pesquisas da Amazonia - INPA, in Manaus, Amazonas, Brazil has been studying B. gasipaes (locally known as Pupunha) since 1976. About half of the experimental area planted to this species is in policulture. The first experimental plantation was established in 1977. The experiment is to examine two systems of policulture using six fruit tree species.

The species used initially were: B. gasipaes, C. nucifera, Graviola or Soursop (Annona muricata L.), Biriba (Rollinia mucosa (jacq.) Bail), Cashew (Anacardium occidentale L.) and Guarana (Paullinia cupana H.B.K.). The P. cupana was substituted early because of an intense Anthracnose attack that inhibited establishment of the seedlings. Uvilla (Pourouma cecropiaefolia Mart.) was put in its place. The A. occidentale was substituted at a later date, also because of Anthracnose, which reduced early fruit and nut production to nearly zero by the firth year. Cupuassu (T. grandiflorum [Willd. ex Spreng.] Schum) took its place.

The two experimental designs are presented in Figure 1. The first is comprised of 16 trees per sub-plot in square spacing. B. gasipaes, A. occidentale and C. nucifera are at 7 x 7 m spacing. The other species are at 5 x 5 m spacings. The B. gasipaes with this spacing is being managed as a multi-stemmed species, with the principal stem and four laterals. Production started on the principal stem in the second year after field planting and has continued to increase at a steady rate. Production on the lateral stems started in 1983 and is increasing slowly. Johannessen has pointed out that full production on the lateral stems will only be attained when these are about the same height as the principal stem (5).

The second design is a complete mix of the species with *Paullinia cupana*, later substituted by the *Pourouma cecropiaefolia*, as a filler. The two palms are planted alternately in one row with the filler between them, all plants at 5 x 5 m. The other fruit species are planted in adjacent rows, alternating with each other and the filler in the row, and diagonal to the palms. In this design *B. gasipaes* is maintained as a single stemmed plant, since there is not sufficient space for more than one stem. This design was inspired by the idea that a complete mix would imitate the natural ecosystem more closely and thus reduce insect and disease attack.

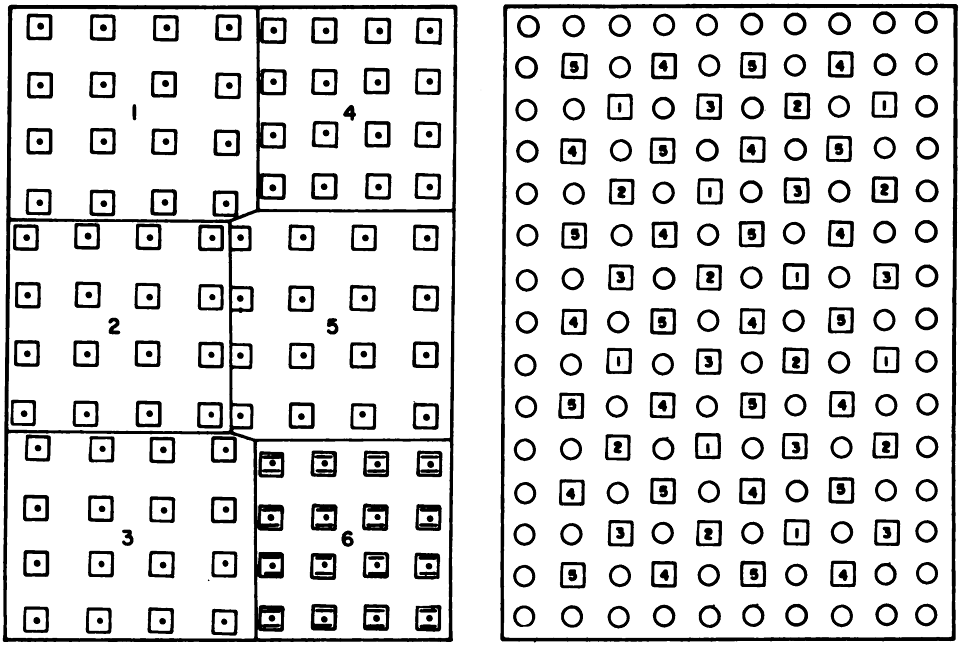

Fig. 1. The two experimental designs used in the INPA six species policulture experiment. Left side: 1 *Bactris gasipaes*; 2 *Pourouma cecropiaefolia*; 3 *Cocus nucifera*; 4 *Rollinia mucosa*; 5 *Theobroma grandiflorum*; 6 *Annona muricata*. Right side: 1 *R. mucosa*; 2 *T. grandiflorum*; 3 *A. muricata*; 4 *C. nucifera*; 5 *B. gasipaes*; o *P. cecropiaefolia*

Initial results suggest that the 16 plant sub-plots are more productive and are certainly easier to harvest and study. The B. gasipaes in this experiment will give detailed information on fruit production from multi-stemmed plants, which is currently available nowhere else.

In 1979 a mixed plantation of B. gasipaes, Breadfruit (Artocarpus altilis L.) and Jackfruit (A. integrifolia L.) was installed. The idea of the plantation is explained by Arkcoll, who considers the possibility of producing all of a family's starch, as well as most protein, vitamins and minerals, from tree fruits and associated animals (1). Arkcoll calls this the food forest. The idea is very attractive as an alternative to cassava (Manihot esculenta L.), which is the major staple in the Amazon and requires shifting cultivation with all its attendent problems. Individual trees of A. altilis in Manaus have produced up to 500 $kg.a^{-1}$, while individual A. integrifolia trees have produced more than 1,000 $kg.a^{-1}$ (all yields in fresh weight).

The food forest experiment consists of monoculture and policulture plots to check on spacings for the species in the Manaus region and to determine whether it is better to go to small monoculture plots or bi- or triculture of these species. Both B. gasipaes and A. altilis started production in the second year after field planting. The first fruit of A. integrifolia was produced five years after field planting. Initial production of both B. gasipaes and A. altilis has been very promising in both monoculture and biculture. It seems that the A. integrifolia crowds the other two species at the spacings used in the triculture, so that production has been somewhat lower in that treatment.

An integral part of Arkcoll's thinking concerns the feeding of small animals with the fruit that is not consumed by humans. Pigs and chickens appreciate all three of these species. However, B. gasipaes needs to be cooked before direct use or else well rotted on the tree. Murillo et al have shown that this is due to a substance, probably an enzyme, that inhibits a proteolytic enzyme essential for normal protein utilization (8). This problem is not insurmountable, even on a small farm, and should not present problems for the acceptance of the system.

The Amazonas state unit of the national agricultural research system (UEPAE/EMBRAPA) planted a biculture experiment of B. gasipaes with Paullinia cupana in 1980. The B. gasipaes was planted at 10 x 15 m, with P. cupana planted at 5 x 5 m. B. gasipaes survival was nearly 100% but P. cupana did not survive well and was never replanted.

In 1982 the UEPAE installed several smaller experiments of B. gasipaes with semi-perennial species, partially to determine what species could be used to give initial early returns for the farmer while waiting for B. gasipaes to come into full production. Pineapple (Ananas comosus Mer.), Papaya (Carica papaya L.) and Passion fruit (Passiflora edulis L.) were used in these trials. Final results are not known by this author, but impressions gained from several visits suggest that all of these species can profitably be mixed with B. gasipaes in the early years to give a rapid, and significant return to the farmer.

The Center of Agricultural Research in the Humid Tropics - CPATU, also of EMBRAPA, has installed two experiments in the region of Belem, Para, BR, near the mouth of the Amazon river. These trials are to examine bicultures of Brazil nut (Bertholletia excelsa H.B.K.), Rubber (Hevea brasiliensis L.) and B. gasipaes with P. cupana , T. cacao and black pepper (Piper nigrum L.). The experiments were installed in 1980 and production of B. gasipaes, Paullinia cupana, T. cacao and Piper negrum is already significant.

The Cacao Research Center - CEPEC, of the Brazilian Cacao Commission - CEPLAC, has installed several trials of B. gasipaes with T. cacao. The trial that they installed in 1980 in Manaus has proved so successful that CEPLAC is considering the recommedation of B. gasipaes as productive shade for T. cacao in the Brasilian Amazon (P. T. Alvim)*.

The Costa Rican Experience

Although the Costa Rican research institutions, including CATIE, have not experimented as much with B. gasipaes policultures as have the Brazilians, it is in Costa Rica that B. gasipaes finds its greatest use as a practical example of agroforestry. Watson has pointed out that B. gasipaes policulture with coffee (Coffea arabica L.) is widespread in Costa Rica (9).

Granados, of the University of Costa Rica, has published a small study of B. gasipaes plantations in Tucurrique, Cartago, most of which are policultures with Coffea (4). Although he does not discuss the policulture aspects he does present an idea of what can be expected of B. gasipaes when grown as a multi-stemmed plant, at 8 x 8m or more, receiving only fertilizer that is applied to the Coffea (if it is applied at all). Granados reports an average yield for the region of 3.9 $t.ha^{-1}.a^{-1}$ which may be considered to be market quality fruit. The yields varied from a low of 0.4 $t.\ ha^{-1}.a^{-1}$ in a newly productive plantation, to 7.75 $t.ha^{-1}.a^{-1}$ in a well tended and fertilized plantation.

Granados also studied several small areas of some of these plantations to determine best yields obtained at different spacings. He reports the following maximum yields: 7 x 7m spacing = 9.5 $t.ha^{-1}.a^{-1}$; 8 x 8 m = 13.3 t; 9 x 9m = 7.5

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* Personal communication.

t; 10 x 10m = 10.9 t and 12 x 12m = 10.3 t. All of these plantations are with multi-stemmed plants, generally without specific control of the number of lateral shoots. In the author's experience in this area the number of stems per clump varies from 3 to 7. Unfortunately Granados did not take this variable into consideration when registering yield nor did he correlate this with plant age. However, many of these production figures are quite acceptable when considering that there was no specific fertilization of B. gasipaes and little other management of this species.

Mora Urpí* reports 32 $t.ha^{-1}$ a^{-1} in a well managed and well fertilized plot of B. gasipaes in Guápiles, Limon, about 70 km from Tucurrique. This may be near the maximum for unselected B. gasipaes germplasm and suggests that the yield figures for Tucurrique policultures are quite acceptable.

From the above discussion it is evident that the B. gasipaes can produce reasonably well when planted with Coffea. If special attention, in the form of adequate agricultural management practices, was given to B. gasipaes in these plantations it is quite probable that yields would be much higher and, as a consequence, so would the income of the farmers. However, there is currently a noteable lack of research into B. gasipaes as a policulture component in Costa Rica, in contrast to a strong programme of research into the monoculture of this species.

CONCLUSIONS

It is clear that B. gasipaes has considerable potential as an agricultural crop for the lowland humid tropics. Due to its growth habit it appears to be a species that would fit well into many agroforestry schemes and would produce valuable food resources for the farmer and his animals.

B. gasipaes in policulture is already common in Costa Rica and is expanding in many areas. Its use as a productive shade for T. cacao will probably be recommeded in the Brazilian Amazon. Economic returns from these systems appear to be advantageous to the farmer.

It may be concluded that B. gasipaes has a significant and immediate potential for use in agroforestry systems and that this potential can only increase with the improvement of the species.

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AGROFORESTRY SYSTEMS WITH Gliricidia sepium*

A. H. Moreno**

SUMMARY

Gliricidia sepium is a versatile species with respect to its functions and products, and with many suitable characteristics for its integration into mixed systems.

Specific observations made by the author, relating to the establishment, management and agricultural use of the species in the Dominican Republic are reported. These include aspects of forage conservation, as well as establishment in association with medicinal and aromatic plants in Costa Rica. In the latter case G. sepium acts as a protective crop and provides other secondary products for the farm.

INTRODUCTION

Gliricidia sepium is a leguminous tree of the Papilionaceae family. It reaches 15 m in height with a crown diameter of 8 to 10 m. The root is pivotal when grown from seed and adventitious when grown from cuttings. Because of its characteristics and qualities it is a good component for agroforestry systems of the humid and semi-arid tropics.

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* Translation from the Spanish by S. M. Shannon.

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MANAGEMENT AND PRODUCTS OF G. SEPIUM

Propagation

This can be done vegetatively or from seed, the two methods resulting in different anatomical and functional characteristics.

In San Cristóbal, Dominican Republic (50 m.a.s.l.; 2,000 mm ppt.*) plots for soil improvement and forage production were established by means of stem or thin branch cuttings (2 to 4 cm diameter and 50 cm long) planted in furrows. As soon as the sprouts had developed (20-40 cm) they were separated from the parent branch by cutting with a "machete". This system is useful and economical for large plantations, especially when little vegetative propagation material is available.

In Alajuela, Costa Rica (850 m.a.s.l.; 1,800 mm ppt.) a 1.0 ha G. sepium plantation was established by the author using stakes 1 m long and 3 to 10 cm diameter, with a spacing of 1 m between stakes and 3 m between rows. There was 70% survival at the end of the first year. Another plot of the same dimensions and spatial arrangement was established using seed from the same farm. There was 90% germination and 100% survival, of the seed which germinated, at the end of the first year.

Forage production

Forage was produced from the above mentioned Alajuela plots by means of selective rather than total pruning during the rainy season. In the case of plants grown from stakes, a "formation" cut was made after 15 months to promote branching and/or produce new shoots, and "production" cuttings were then continued every 45 days until the start of the dry season. With plants grown from seed several "formation" cuts were made and production started 15 months after establishment. A greater volume of forage was obtained from plants grown from stakes.

It is important to note the possible toxic and allelopathic effects which may result from an active complex of phenols, flavones and melilotic, hydrocyanic and protocathecic acids, produced by this species (14, 15). The toxic effect has been especially noted when G. sepium forage was used as a feed for non-ruminants (8).

* m.a.s.l. = meters above sea level; ppt = average annual rainfall.

Forage conservation

In the Dominican Republic a national forage conservation programme (13), with emphasis on leguminous trees, was carried out.

Foliage harvests from G. sepium fences were made by teams of 6 men. The foliage was transported to a cocoa production plant where it was sun-dried. At the same time, finely chopped leaves were dehydrated in a circular cocoa dryer using G. sepium as firewood. The dryer had a capacity of 1.2 $t.load^{-1}$ with each load needing 8 h for complete drying (2.4 $t.day^{-1}$ of fresh material gave a yield of 400 $kg.day^{-1}$ of dry material). 200 kg of fresh material was harvested per worker per 8 h working day, meaning that 12 working days were required to produce these 400 kg dry material. Transport and dryer operation costs, wages, cost of installations etc. have to be taken into account. The chopped and dried material was milled before being stored in sacks.

This operation did not prove to be economical for supplementing dairy cows when compared to commercial feed prices. As a secondary product of the harvest, 3 to 6 live posts per tree (3 m long) were obtained for replanting fences or occasional sale at a price of $0.10 per post.

On other farms of the Dominican Republic, foliage was harvested from fences and spread in the sun to dry beside the fence posts. Bales, covered with thin branches of G. sepium to prevent disintegration, were made and secured with strong wire. This material was supplied as a supplement to milking cows at a rate of 2 to 4 $kg.day^{-1}.animal^{-1}$.

Another operation, which has given favorable results and is worthy for further study, was making silage in polythene sacks compacted with a manual press. The material should be finely ground, fresh and without additives. Each sack had a fresh weight of 40 kg.

In an exploratory study an underground silo, in the form of a trench, was made with 30 t of forage which had alternative layers of ground G. sepium (20%) and forage grasses such as Brachiaria ruziziensis and Cynodon nlemfuensis. The resulting product appeared to have a very good quality and losses were only about 5%.

Charcoal production from living fence posts.

A complete inventory of living fenceposts on a 30 ha cattle farm (Hato Mayor, Dominican Republic; 200 m.a.s.l.; mean annual temperature 25º; ppt 2,500 mm), where 60 beef cattle are grazed, recorded 15,000 m of five year old G.

sepium fencelines. The mean distance between posts was 1 m, and they are continuously replaced.

An attempt was made to show: firstly that forage harvested in rotation from the fences saves buying feed concentrates for the calves, and cows in production; secondly that biannual charcoal production from pruned branches represents an important economic input to the farm (this practice was already carried out, albeit sporadically). These two year old branches can reach a diameter of 10 cm at the base, a length of between 3 and 6 m, and on average there are 6 branches per post. A pit kiln was used and for every 30 branches (5 living fence posts), one 15 kg sack of second grade charcoal was obtained. This was sold on the farm at US $ 4.00 sack^{-1}. Despite the inefficient charcoaling method, and the lack of planning of the cutting frequency, approximately 20 sacks, or $80.00, were obtained from every 100 m of fence line every two years. Moreover the cut branches of each tree produced 4.5 kg of dry leaf material which was given to the animals as a substitute for commercial feed concentrates.

In general, the quality of firewood from G. sepium depends on the age of the vegetative tissues. Branches more than two years old and trunks over 5 years old give higher quality (16, 18).

Timber production and use

The timber is hard and heavy, with well defined sapwood and heartwood. The heartwood varies in colour from yellow to dark brown with good marking. It has a moderately fine texture and an irregular interwoven grain. It has a density of 1,120 kg.m^{-3} (3).

Traditionally it is used as timber for rustic constructions such as support posts, house foundations, window and doorframes etc. Straight posts are used for telegraph poles. Other uses are as railway sleepers and new living fence-posts, and dead posts for corrals and fences (1, 6, 8).

The author sawed trunks of G. sepium which had been shade trees for Coffea sp. for over 30 years. These measured between 30 and 60 cm in diameter. After sawing, the timber was air-dried for 6 months and then tested for sawing, turning on a lathe and slicing properties. Various small articles were made, such as small coffee tables, carvings for wall hangings, lampbases, tripods, stools, parquet for floors and other craftwork. All these trials confirmed that the wood is easily worked and that it is very attractive. However, the wood should be dried with care to prevent the sapwood being stained with a bluish colour.

Use of flowers as a food

The flowers can be eaten by man, and are usually mixed with eggs (1).

Trials were carried out using flowers dried in the sun or in the oven and latter ground and mixed with: crude sugar cane juice; concentrated sugar cane juice; or soups as a thickener. The chemical composition of the flowers used in these trials (percentages based on dry weights) was (13):

Crude protein	Energetic equivalent	Crude fibre	Ash	K	Ca	P
19.5	4.0	22.6	7.2	2.78	0.25	0.29

The flowers contain 10% of the leaf Ca levels although P levels are similar. K and fibre content are relatively high.

G. SEPIUM IN AGROFORESTRY SYSTEMS

G. sepium can be found as the only tree species in forested areas such as natural forests, forage plots, soil recovery plantations, firewood production plots, or as a component of agroforestry systems where it functions as a protective or shade tree, living fencepost, windbreak, etc.

G. sepium may be associated with both annual and perennial crops. It is used as a shade tree in the cultivation of coffee (Coffea arabica) (1), tea (Camellia sinensis) (20), cocoa (Theobroma cacao) (11) and pasture (2). As a support crop examples have been reported with vanilla (Vanilla fragrans), black pepper (Piper nigrum) and yam (Dioscorea spp.) (1, 8, 11). As a protection or shade crop, examples exist in Costa Rica with maize (Zea mays), cassava (Manihot esculenta), beans (Phaseolus vulgaris) (7) and with aromatic as well as medicinal plants.

In the humid tropics, production of high quality protein containing forage is important for animal feed, and leguminous trees such as G. sepium can supply this need (15). The terminal portion of branches up to 1 m in length, irrespective of age, can be used as forage for ruminants (12, 13). The compound leaves are an ideal foodstuff for non-ruminants (birds, rabbits, pigs, etc.) (10).

Other aspects that are very important are the so-called "service functions" of the species, one conspicuous example being its use as living fenceposts. Every cattle farmer knows that one of the chief improvements to a farm, and also one of the most expensive, is the establishment of fences. This is even more the case in humid climates where dead posts need frequent replacement (9, 19). In certain climates G. sepium is the most appropriate living fencepost species. There are in addition other "service functions" such as:

a) Improving pasture quality below the crown and the deposition of nitrogen rich material (7, 15);

b) Providing shade for cattle. In hot climates this shade is translated into increased production (17);

c) The allelopathic effect on weeds (2, 5)

d) Products already mentioned such as posts, dry season forage, firewood, flowers, etc;

e) Recovery of patches or 'islands' of low fertility in pastures.

In Alajuela, Costa Rica the cultivation of aromatic and medicinal plants, combined with strips of G. sepium, was designed with the aim of continuous production of leaves, flowers, fruits, etc., without the use of chemical products.

Due to the occurrence in this zone of a 4 to 5 month dry season with high temperatures and strong winds, a system of perimeter and internal fences was designed using different species, especially G. sepium. The aim was protection against sun and wind, and at the same time to impede the advance of insects and other pests, as well as protection against external contaminants. The medicinal plant species provide part of the raw materials required by a small local processing and packing plant (BIOTROPICA S.A.). Within the system some 20 different species are grown including: Cymbopogon citratus, Phoeniculum vulgaris, Lippia alba, Ruta chalapensis, Ambrosia cumanensis, Lippia berlandierii, Buddleia americana, Justicia pectoralis, Ocimum basilicum, Hibiscus sabdariffa, Mentha citrata and Pimpinella anisum.

CONCLUSION

The positive results obtained from the practical experiments carried out with G. sepium in different areas of tropical America, and the widespread occurrence of this species on farms, merit greater attention by scientists. The results need to be evaluated in a scientific and systematic way in order to deduce adequate management recommendations that will permit an integrated sustainable use of the species and that will promote the exploration of new possibilities.

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ALLEY CROPPING OF ANNUAL FOOD CROPS WITH WOODY LEGUMES IN COSTA RICA

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SUMMARY

Research in alley cropping of annual food crops with woody legumes began on the CATIE station in 1982. Results of associating a food crop production system, consisting of maize (Zea mays L.), common bean (Phaseolus vulgaris L.) and cassava (Manihot esculenta Crantz), with the woody legumes Erythrina poeppigiana (Walpers) O.F. Cook, and Gliricidia sepium (Jacq.) Steud, for three years, are presented. Yields of Z. mays and P. vulgaris could be maintained at over 2600 $kg.ha^{-1}.a^{-1}$ and 800 kg $ha^{-1}.a^{-1}$ respectively by association with E. poeppigiana in an alley cropping system. Even higher yields of P. vulgaris, but not of Z. mays, could be obtained with G. sepium. M. esculenta yields could not be maintained over the three years either with the application of up to 40 $t.ha^{-1}.a^{-1}$ of manures and mulches, with the application of mineral fertilizers (N-P-K-Mg-S), or with alley cropping with G. sepium or E. poeppigiana. Differences in the growth habits and seasonal biomass production by the woody legume species are considered the causes of the differences observed. Work on farms in Puriscal and San Carlos, begun in 1983 and 1984, has not progressed sufficiently for final evaluation but establishment of G. sepium from seeds instead of the more costly stakes was successful on a farm in San Carlos.

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INTRODUCTION

Alley cropping of annual food crops with woody legumes has become an established part of research programmes at several international centers (2, 4, 9) as well as in U.S. university sponsored research in the humid tropics (10). The objective of this work is to find a stable alternative to shifting cultivation for food production in the humid tropics as well as to evaluate woody legumes as a N source for annual crops. Only IITA, where experimental work started in 1978, has published yield data for maize (Zea mays) over three years (4), while ILCA has some data for Gliricidia sepium (Jacq.) Steud production over time (9). In this paper, I present results for Z. mays, beans (Phaseolus vulgaris) and cassava (M. esculenta Cranz) for three years using Erythrina poeppigiana and G. sepium as woody legumes in intercropping systems.

LITERATURE REVIEW

Results for a total of five years alley cropping of Z. mays with Leucaena leucocephala have been published by IITA (5). Without additional N, Z. mays yields declined slightly from 2.09 $t.ha^{-1}$ in 1979 to 1.92 $t.ha^{-1}$ in 1983, while with the application of 80 $kg.ha^{-1}.a^{-1}$ of mineral N, yields declined from 3.54 $t.ha^{-1}$ in 1979 to 3.16 $t.ha^{-1}$ in 1983 (Psammentic Ustorthent in Ibadan, Nigeria). They also report maintaining Z. mays yields at 4 $t.ha^{-1}$ using only G. sepium prunings when Z. mays was planted only in alternate years. They recommend a Z. mays-cowpea (Vigna sinensis) rotation for association with the G. sepium or L. leucocephala and are presently testing rice (Oryza sativa) and root based cropping systems for association with the woody legumes.

L. leucocephala prunings in the IITA experiments showed a slight decline from 6.3 $t.ha^{-1}.a^{-1}$ in 1981 to 5.79 $t.ha^{-1}.a^{-1}$ in 1983 when five prunings per year were made. Data for seasonal variation in pruning weight was not published. N content of the prunings did not decline with time and increased significantly when N was applied to the Z. mays crop (4). Over a six months period at Ibadan, Nigeria, G. sepium trees planted at 7500 $trees.ha^{-1}$ produced 3.63 $t.ha^{-1}$ of prunings in four harvests starting one year after planting from seed. Yields were highest after the beginning of the second rainy season. Higher yields were obtained with higher planting densities up to 31,250 $trees.ha^{-1}$ (9).

A six year old stand of G. sepium produced about 16,000 $t.ha^{-1}$ of prunings (dry weight), in CATIE plots in Nicaragua (7). Russo showed that pruned biomass of E. poeppigiana declined from 18,474 to 11,939 $kg.ha^{-1}.a^{-1}$ if two as opposed to one prunings per year were made (8).

MATERIALS AND METHODS

On a 7500 m^2 area of soil classified as a Typic Humitropept, fine, halloystic, isothermic*, at the "La Montaña" experiment station of CATIE (602 m.a.s.l.**, 9º 53'N latitude, 83º 34'W longitude) a split-plot experiment was set up with three repetitions in May, 1982. There were seven treatments in main plots:

1. Control
2. Mulch of E. poeppigiana, 20,000 $kg.ha^{-1}$ of fresh matter) applied twice yearly. (115 kg $N.ha^{-1}$ $application^{-1}$).
3. Dairy manure (20,000 $kg.ha^{-1}$ of fresh matter) applied twice yearly (77 kg $N.ha^{-1}$ $application^{-1}$).
4. Intercrop with velvetbean (Mucuna pruriens), changed to mulch of Gmelina arborea after 1st. year.(20,000 $kg.ha^{-1}$ of fresh matter) applied twice yearly (95 kg $N.ha^{-1}$ $application^{-1}$).
5. Intercrop with V. sinensis.
6. Alley cropping with E. poeppigiana (6 x 3 m =555 $trees.ha^{-1}$) pruned twice yearly.
7. Alley cropping with G. sepium (6 m x 0.5 m), increased to 3 x 0.5 m in second year (6666 $plants.ha^{-1}$), pruned twice yearly.

Main plots measured 12 m x 18 m and were divided into subplots of 6 x 18 m. One of the subplots received 150 $kg.ha^{-1}.a^{-1}$ of N as NH_4NO_3. The whole experiment was fertilized with 88 $kg.ha^{-1}.a^{-1}$ of P_2O_5 as triple superphosphate, 130 $kg.ha^{-1}.a^{-1}$ of K_2O as KCl and 17 $kg.ha^{-1}.a^{-1}$ of MgO as $MgSO_4 7 H_2O$.

In all plots, Z. mays (Cv. Tuxpeño C-7) at 30,000 $plants.ha^{-1}$ and M. esculenta (Cv. Valencia) at 10,000 $plants.ha^{-1}$ were planted in May of each year.

Z. mays was harvested in September and P. vulgaris (Cv. Turrialba 4), were planted at 100,000 $plants.ha^{-1}$. P. vulgaris were harvested in February

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* J. Kimble, personal communication.

** Meters above sea level

and M. esculenta in April of each year. Rainfall averaged 2600 $mm.a^{-1}$ during the experiment with a short dry period being experienced between February and April. Surface soil (0-15 cm) averaged 25% sand, 34% silt, 41% clay, pH 4.6, 4.80% organic matter, 11.8 $ug.ml^{-1}$ Olsen P, 5.4 Cmol. L^{-1} Ca, 1.3 $Cmol.L^{-1}$ Mg, 0.9 $Cmol.L^{-1}$ K, and 0.5 $Cmol.L^{-1}$ Al at the beginning of the experiment. Organic amendments and prunings were applied in May and November of each year. The present paper presents data for crop yields and tree prunings for the first three years (9 harvests) of the experiment.

In 1983, efforts were begun to put experiments on farmer's fields in Costa Rica. An experiment with 8 treatments including mulch of G. sepium and grass, with and without mineral N, with and without herbicides, in addition to alley cropping with G. sepium, was planted in Puriscal in September 1983, using a Z. mays-P. vulgaris cropping sequence. The experiment occupied a site with approximately 25% slope. Two similar experiments were established in 1984 on two other farms in this area.

In 1984, in connection with the IFAD project two experiments were planted on Dystropepts in San Carlos, again using G. sepium as a woody legume.

Trees were planted at two spacings: 6 m and 9 m rows, in addition to a mulch and control treatment. Plots were split among three levels of mineral N: 0,100 and 200 $kg.ha^{-1}.a^{-1}$, using NH_4NO_3. A Z. mays-P. vulgaris cropping sequence was again used, applying 40% of the N to the P. vulgaris and 60% to the Z. mays. In early 1985, it was decided to increase density in the 9 meter spacing to 4.5 m (1111 $trees.ha^{-1}$ to 2222 $trees.ha^{-1}$). This was accomplished by direct seeding of G. sepium seeds between two rows of Z. mays as suggested by Sumberg (9).

RESULTS

Since there was little difference between yields in the CATIE control plots and the V. sinensis intercrop plots, (Table 1), the V. sinensis intercrop treatment was combined with the control for the no amendment contrast (Table 2).

In the control plots, Z. mays yields declined sharply in the third year of the experiment, while with a mulch of E. poeppigiana or in the alley cropping treatment with this species, Z. mays yields were higher than in the first year of the experiment, even without the addition of mineral N (Table 1). Other treatments did not bring a significant yield increase over the control in the third year of the experiment.

Table 1. Crop Yields in Alley Cropping Experiment, La Montaña, 1982-1985

	Mineral	*Zea mays*			*Phaseolus vulgaris*			*Manihot esculenta*		
	N	1º yr	2º yr	3ºyr	1ºyr	2ºyr	3º yr	1º yr	2º yr	3º yr
Control	0	2379	2268	1306	662	716	482	12912	7651	3430
	+	2649	2915	1780	868	1155	660	14173	8838	5514
Erythrina poeppigiana mulch	0	2613	3318	2782	1310	1295	1040	13397	6734	3851
	+	2855	2782	2608	1063	1553	1201	15191	9496	4635
Manure	0	2325	2504	2155	617	887	667	13346	11152	5998
	+	2389	2824	2280	911	904	1087	16818	10627	5955
Gmelina arborea mulch	0	193*	2454	2147	1230	823	707	8789	10626	5619
	+	268*	2796	2207	1484	1094	1154	7378	11528	5619
Vigna sinensis intercrop	0	1651	2085	1259	530	686	459	14105	7786	5934
	+	1871	2860	2164	680	972	595	15905	9049	5008
Erythrina poeppigiana Alley crop	0	1588	2088	2621	304	1330	881	12707	4778	3156
	+	1483	2524	2502	549	1628	1061	12502	6111	2667
Gliricidia sepium Alley Crop	0	1427	1681	1449	321	1095	1004	14820	3261	1073
	+	1745	1460	1385	429	1222	1172	16548	3367	652
L.S.D. for comparison different subplots in different main plots (P = 0.05)		640	792	974	321	241	245	4776	3665	2951

* Low yields due to *Mucuna pruriens* competition.

Table 2. Significant effects in the 2nd and 3rd Phaseolus vulgaris harvests

	2º year		3º year	
EFFECT OF AMENDMENTS	kg.ha^{-1}		kg.ha^{-1}	
WITHOUT ALLEYS	1009		810	
WITH ALLEYS	1319		1029	
MULCH WITHOUT ALLEYS	1093		894	
WITHOUT MULCH WITHOUT ALLEYS	885		550	
MULCH (Gmelina arborea AND Erythrina poeppigiana)	1192		1011	
MANURE	896		877	
MULCH OF Gmelina arborea	958		931	
MULCH OF Erythrina poeppigiana	1423		1145	
SIGNIFICANT INTERACTIONS* (kg.ha^{-1})				
	- N	+ N	- N	+ N
AMENDMENTS FROM LEGUMINOUS TREES**	1240	1468	992	1144
NON-LEGUMINOUS AMENDMENTS***	856	999	687	1121

* Only significant in year 3
** Includes alley cropping and Erythrina poeppigiana mulch treatment
*** Includes Gmelina arborea mulch and dairy manure

With P. vulgaris, a response to the E. poeppigiana mulch was already apparent in the first year of the experiment. In the second year, both alley cropping treatments as well as the mulch of E. poeppigiana resulted in a significant yield increase over the control. Unlike the Z. mays, there was a response to mineral N in the treatments receiving the organic amendments as well as in the control (Table 2). In the third year, the yields of all treatments declined. Although all the mulch and alley cropping treatments produced significantly more P. vulgaris than the control both in the presence and absence of mineral N (Table 1), in the third year there was no difference in yields between leguminous and non-leguminous mulches when mineral N was also applied (Table 2). P. vulgaris yields in the alley cropping treatments or the E. poeppigiana mulch treatments without mineral N were higher in the third year than they had been in the control plot with mineral N in the first year. A slight problem experienced in the third year was germination of P. vulgaris in pods extending into the mulch. However, this only affected 2% of the P. vulgaris (Table 3). Yield data in Table 1 is corrected for this factor.

Table 3. Percentage of Phaseolus vulgaris which germinated in the different mulches, 3rd harvest, 1985

Treatment	Control	Erythrina poeppigiana mulch	Manure	Gmelina arborea mulch	Vigna sinensis intercrop	Erythrina poeppigiana alleys	Gliricidia sepium alleys
Germination (%)	0.11	1.23	1.57	0.33	0.19	2.17	1.01

M. esculenta did not respond to any of the treatments and after the first year of the experiment, yields declined markedly. In the second year, yields were higher in the treatments receiving high levels of low N containing residues (G. arborea mulch and manure) but not significantly higher than the control. In the third year, yields of commercial roots were low in all treatments and increases brought about by the mulch treatments were smaller than in the second year and were statistically insignificant.

Dry matter production of trees in alley cropping treatments from the 18th to 36th month of the experiment are presented in Table 4. Application of N fertilizer to crops increased biomass production in G. sepium but reduced it in E. poeppigiana. Dry matter production of E. poeppigiana demonstrated less seasonality than G. sepium, but tended to be lower in the rainy period (May - November) while G. sepium showed the opposite pattern. This effect was significant in both species. The effect was more marked in the absence of mineral N in the case of E. poeppigiana; and for G. sepium planted in 1982 compared to those planted in 1983.

Similar patterns were shown in N content of the prunings (Table 5) although N analyses for the last pruning period have not yet been completed.

Results of the experiments in Puriscal are presently being analyzed but the data were not available at the time of writing. Results for the first P. vulgaris crop at one of the sites in San Carlos are presented in Figure 1. There was a response to up to 40 $kg.ha^{-1}$ N in the control plots. The linear component of the response was not significant in the treatments with G. sepium mulch or intercropping. Without N fertilization, yields of P. vulgaris increased from 700 to 900 $kg.ha^{-1}$ with G. sepium mulch, confirming the results obtained at the Turrialba location, which is some 450 m higher than the San Carlos site.

Table 4. Biomass production (dry matter) of Gliricidia sepium and Erythrina poeppigiana in association with annual crops ($kg.ha^{-1}.pruning^{-1}$)

Period	Erythrina poeppigiana	Gliricidia sepium: Trees planted May, 82	Gliricidia sepium: Trees planted May, 83	Mean
Without N Fertilization:				
12-18 months (Nov., 1983)	4370	5440	2530	3985
18-24 months (May, 1984)	4650	5136	2682	3909
24-30 months (Nov., 1984)	2025	7018	5890	6454
30-36 months (May, 1985)	4345	4240	4902	4571
With N Fertilization:				
12-18 months (Nov., 1983)	3317	12214	2254	7233
18-24 months (May, 1984)	2942	5204	4696	4950
24-30 months (Nov., 1984)	1283	11178	7446	9099
30-36 months (May, 1985)	2659	4034	4036	4796
Significant F Effect	Years Season Years x Seasons N x Seasons	Age x cutting dates Age x seasons		N seasons

Erythrina poeppigiana Interaction N x season		Gliricidia sepium Interaction Age x season	
Rainy Season no N	3197	Rainy season-old trees	8963
Rainy Season + N	2299	Rainy season - new trees	4530
Dry season no N	4522	Dry season-old trees	5033
Dry season + N	2801	Dry season-new trees	4079

The effort to establish G. sepium from seed in San Carlos appears to be successful. A mixture of Afalon, Prowl, and Gramoxone applied at planting permitted good germination of both Z. mays and G. sepium and controlled most broad-leaves and grasses during the first month following seeding.

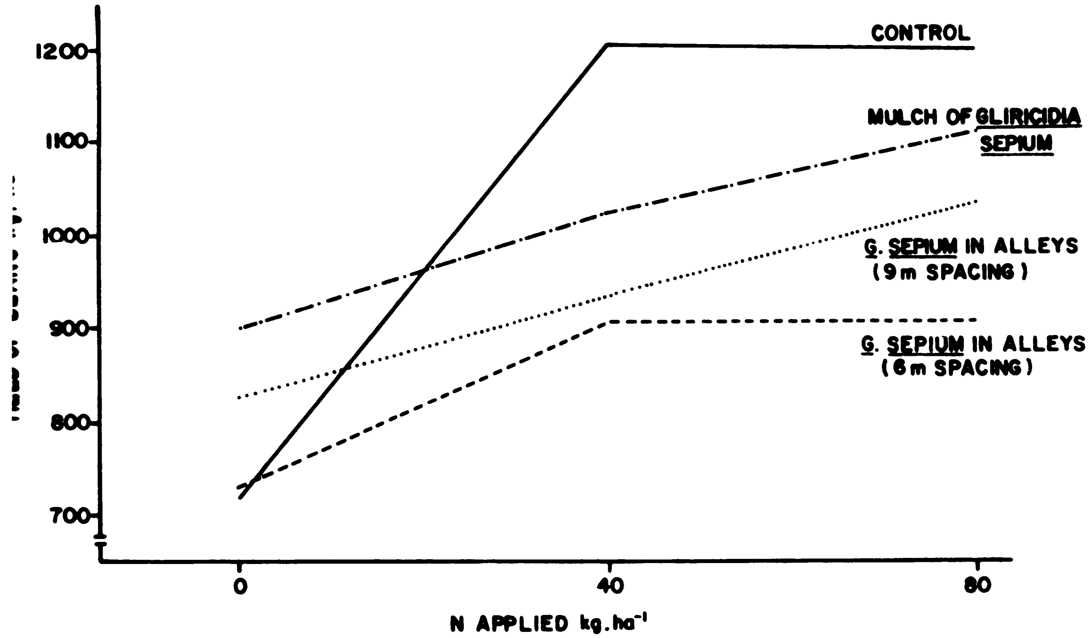

Fig. 1. Response of beans to nitrogen in Pital, San Carlos, 1984-85

Table 5. N content of *Erythrina poeppigiana* and *Gliricidia sepium* prunings over time ($kg.ha^{-1}$ $pruning^{-1}$)

Date of pruning	*E. poeppigiana*	*G. sepium* new tree	*G. sepium* old trees	*G. sepium* mean
Without Mineral N				
18 months (Nov., 1983)	148	87	147	118
24 months (May., 1984)	103	68	133	101
30 months (Nov., 1984)	51	125	170	147
With Mineral N				
18 months (Nov., 1983)	104	113	266	190
24 months (May, 1984)	67	107	121	114
30 months (Nov., 1984)	84	219	215	217
L.S.D. between pruning dates for same N level.	60			91

DISCUSSION

The data would appear to support the possibility that alley cropping with leguminous trees can maintain yields of annual food crops over several years without the addition of mineral N. Yields of Z mays are slightly higher than those obtained at IITA (4) but the Turrialba soil has higher organic matter and exchangeable Mg as well as more favorable physical properties (although pH is lower) than the Psammentic Ustorthent used for the IITA studies (4). Grain yield of P. vulgaris was also much higher than the yields reported from IITA (4).

The very positive response of P. vulgaris to alley cropping is probably partly due to N supplied by the prunings but conservation of moisture during the dry period may also be a factor. However, we were unable to detect higher moisture content in the alley cropped plots than in the control plots when samples were taken during the dry period. It is interesting that P. vulgaris showed a greater response to mineral N than the Z. mays in the alley cropping and leguminous mulch treatments. The P. vulgaris were nodulated but the inability of well-nodulated P. vulgaris to fix sufficient N is well-documented (1, 3). The better performance of Z. mays in the alley cropping systems with E. poeppigiana compared to the better performance of P. vulgaris in the alley crop system with G. sepium, may be ascribed to the differences in dry matter production by the respective woody legumes. The E. poeppigiana produced more dry matter and N during the dry season, leaving more available to the Z. mays in the wet season while the G. sepium produced more dry matter and N during the wet season, leaving more N for the P. vulgaris planted in November.

Dry matter and N production of both E. poeppigiana and G. sepium compare favorably with that reported for L. leucocephala in alley cropping systems in Nigeria (4). In the third year of the experiment, G. sepium began to produce more biomass and N than E. poeppigiana.

The difference in the response of the two woody legume species, to mineral N applied to the crops, may be explained by the planting patterns. The G. sepium, in 3 m rows, was much closer to the fertilizer applied to the crops. This explanation does not preclude the possibility of other species differences in regard to N fixation for which the present experiment does not present sufficient evidence.

The poor performance of M. esculenta in the alley cropping experiments may be attributed to either competition from the roots of the woody legumes, excessive shading of the M. esculenta by the trees, or compaction of the soil.

The response of the M. esculenta to high organic matter applications supports the latter hypothesis, especially as a decline in yields was also noted in the control treatment. However, both above and below ground competition was probably also a factor as the lowest yields were obtained in the alley cropping treatments in both the second and third years of the experiment.

Results in San Carlos are about what would be expected in the first year of the experiment with no prunings applied to the alley cropping plots. The response of P. vulgaris to the G. sepium mulch confirms the response to E. poeppigiana mulch observed in Turrialba in 1982.

CONCLUSIONS

1. Over three years it was possible to maintain yields of P. vulgaris and Z. mays at 800 kg $ha^{-1}.a^{-1}$ and 2600 kg $ha^{-1}.a^{-1}$ in an alley cropping system with E. poeppigiana.

2. P. vulgaris yields were slightly higher with G. sepium but Z. mays yields were much lower.

3. M. esculenta yields declined over the three years with alley cropping, addition of manures, or mineral fertilization, as well as in the control plots.

4. Biomass production of both tree species showed a seasonal pattern which seemed to be related to yields of the crops fertilized with prunings.

5. Production of both crops and tree biomass and N were comparable to results obtained in Nigeria with Z. mays, V. sinensis, and L. leucocephala.

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RESULTS FROM THE CATIE "CENTRAL EXPERIMENT": PASTURE AND SHADE TREE ASSOCIATIONS*

L. Alpízar**

SUMMARY

The "Central Experiment" was planted on CATIE land in 1977. During 1981-82 evaluations were made of both organic reserves and minerals (N, P, K, Ca and Mg), and also the harvest yields obtained from African Star Grass (Cynodon plectostachyus) without shade, in association with Cordia alliodora, or with Erythrina poeppigiana.

Results indicate that the highest nutrient reserves are found in the soil, with percentages varying between 76% and 99% of the total for the association, depending on the element. The highest pasture production was achieved with the E. poeppigiana association. Development of C. alliodora as a timber species was considered favorable.

INTRODUCTION

Cattle production in Central America has been one of the principal reasons for the clearing and subsequent deterioration of forest and agricultural soils (6, 8). Furthermore, many of these soils have a low capacity for cattle production, at around half a head per hectare (6). Research on silvopastoril systems offers a good alternative for increasing production from these soils.

The results presented here refer to organic and mineral reserves in both the vegetation and soil, and to pasture (Cynodon plectostachyus) and timber

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* Translation from the Spanish by S. Shannon

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production in the C. plectostachyus - Erythrina poeppigiana and C. plectostachyus - Cordia alliodora associations.

MATERIALS AND METHODS

Plots (18 x 18 m, four replicates) were established in August 1977. C. alliodora were planted at 2.6 x 2.6 m (1512 $trees.ha^{-1}$) and E. poeppigiana at 6 x 6 m (278 $trees.ha^{-1}$). The C. alliodora were thinned to 494 $trees.ha^{-1}$ in December 1980 and to 463 $trees.ha^{-1}$ in July 1982. The E. poeppigiana was pruned twice a year from 1978. With the exception of the primary branches all pruned material was left in the plots.

The pasture was cut manually and the cuttings were removed from the plots. Cutting frequencies varied from year to year.

At the time of planting the C. alliodora and E. poeppigiana pasture associations, they were fertilized with 3.1 $kg.ha^{-1}$ N, 9.3 $kg.ha^{-1}$ P_2O_5 and 3.1 $kg.ha^{-1}$ K_2O. Since 1978, plots which include trees have received 11 $kg.ha^{-1}$ N, 33 $kg.ha^{-1}$ P_2O_5 and 11 $kg.ha^{-1}$ K_2O. Pasture without trees has received double these amounts.

Stem biomass of C. alliodora and E. poeppigiana was calculated from volume and specific weight determinations made during 1982. Biomass of branches and leaves, from pruned material of E. poeppigiana, was estimated from data taken in the coffee (Coffea arabica) - E. poeppigiana association. Leaf and branch biomass of C. alliodora was determined from trees specially cut for this purpose. Biomass of fine roots (less than 20 mm diameter) was measured using a metal ring (27.4 cm diameter) that was hammered into the soil to a maximum depth of 45 cm, (15 cm intervals), using 16 replicates per treatment. Litter layer biomass was measured only once, using a 0.25 m^2 sampling square with 20 replicates per treatment.

The soil mineral content was measured in 1977 at depths of 0-15, 15-30 and 30-45 cm, with 2 replicates at each level in each treatment.

Samples of material collected for biomass determination were submitted for analysis of total N, P, K, Ca and Mg. Soil samples were analyzed for organic matter, total N, total P and exchangeable cations. Nutrient reserves per hectare were calculated using the soil apparent density. Further details of the experiment can be found in Alpízar (1), Enríquez (4) and Fassbender and Alpízar (5).

RESULTS AND DISCUSSION

With respect to reserves of organic material (Table 1), C. alliodora reached an aerial biomass of 45 $tm.ha^{-1}$, 70% of which was in the stems. The biomass of E. poeppigiana was estimated at 13 $tm.ha^{-1}$ and, unlike C. alliodora, the biomass of leaves and branches was almost equal to that of the stems. Fine root biomass was higher for C. alliodora, although the absolute values are considered low for pasture. Litter layer biomass is also greater for C. alliodora, undoubtedly influenced by the fact that many of the pruned branches of E. poeppigiana were removed from the plots. It should also be noted that the litter layer below E. poeppigiana will vary greatly in accordance with pruning dates. The organic material in the soil represents 83% of the total for the association with C. alliodora and 90% for the association with E. poeppigiana.

Table 1. Organic ($tm.ha^{-1}$) and inorganic ($kg.ha^{-1}$) reserves in the associations Cynodon plectostachyus-Cordia alliodora and Cynodon plectostachyus-Erythrina poeppigiana

Cordia alliodora	Leaves	Branches	Stems	Sub-totals	Litter layer	Roots	Soil (45 cm) 1977	for association
Dry matter	5.68	7.90	31.31	44.89	2.33	3.56	252	303
N	158.40	71.90	125.20	355.50	39.80	40.60	10711	11147
P	13.60	15.00	15.60	44.20	3.30	4.30	3136	3188
K	129.40	93.20	144.00	366.60	7.20	20.60	1312	1706
Ca	97.60	36.30	169.00	302.90	59.50	37.40	3702	4102
Mg	44.60	20.50	53.20	118.30	13.20	11.40	834	977
Erythrina poeppigiana								
Dry matter	2.35	3.87	6.75	12.97	1.86	0.97	247	263
N	83.60	47.90	41.80	173.30	41.50	13.10	10708	10936
P	6.10	5.80	4.70	16.60	2.80	1.10	2536	2557
K	34.20	53.3	38.50	126.00	6.50	11.50	1186	1330
Ca	35.80	37.90	52.00	125.70	30.10	10.50	3318	3484
Mg	11.30	13.50	12.10	36.90	3.90	2.40	758	801

With respect to mineral reserves contained in the vegetation, the trees retain the largest proportion of the nutrients with percentages varying between 78% and 92%. Due to its greater biomass, C. alliodora has higher nutrient reserves than E. poeppigiana. The same can be said of the respective litter layer and root reserves. Soil reserves of total N and P represent between 96% and 99% of the association totals, and exchangeable cations between 77% and 91%.

Greater pasture production occured under E. poeppigiana than under C. alliodora (Table 2). This difference may be due, amongst other factors, to: a) the high density of C. alliodora, both at establishment and after thinning, compared to the low density of E. poeppigiana, leading to greater competition for water, light and nutrients; b) the effects of pruning the E. poeppigiana, reducing shading as well as improving nutrient circulation within the system, especially of N. The possibility that pruning reduces root growth, hence benefiting the pasture by reducing competition for water and nutrients, should not be discounted (2).

Table 2. Pasture harvests (dry weights) from the associations- Cynodon plectostachyus, C. plectostachyus-Erythrina poeppigiana; C. plectostachyus-Cordia alliodora

Biomass ($tm.ha^{-1}$)	Cynodon plectostachyus	Cynodon plectostachyus Erythrina poeppigiana	Cynodon plectostachyus Cordia alliodora
1979	9.2	10.0	8.0
1980	28.7	27.9	18.5
1981	13.9	18.8	9.2
1982	15.9	16.2	11.1
Total 1979-82	67.7	72.9	46.8
1983	6.2	10.1	5.1

Pasture yields show a general tendancy to decrease over time. This trend may be explained in various ways. One consideration is that cut-and-carry pasture management removes considerable amounts of nutrients. Thus, the levels of fertilization used do not compensate for the export losses (Table 3), and a decrease in the availability of nutrients over the years would be expected, especially during 1983 when fertilization was discontinued (2).

Table 3. Nutrient extraction in grass harvests from the associations Cynodon plectostachyus, C. plectostachyus-Erythrina poeppigiana; C. plectostachyus-Cordia alliodora

	Cynodon plectostachyus		Cynodon plectostachyus Erythrina poeppigiana		Cynodon plectostachyus Cordia alliodora	
Nutrients ($kg.ha^{-1}$)	TF 1979-82	TEHG	TF 1979-82	TEHG	TF 1979-82	TEHG
N	139	643	69	1320	84	732
P	136	156	68	161	68	145
K	98	691	49	729	62	619
Ca	7	359	7	452	7	249
Mg	5	81	5	95	5	75

TF = Total fertilization
TEHG = Total extraction in harvested grass

It is interesting to note that forage N percentages, sufficient to meet the nutritional requirements of cattle, were only achieved under E. poeppigiana (1.81%) and C. alliodora (1.51%) and not in the pasture without trees (0.95%).

In November 1982 the C. alliodora had an average diameter at breast height (dbh) of 20.2 cm representing an increase of 2.9 $cm.a^{-1}$, and a total height of 10.4 m, representing an increase of 1.5 $m.a^{-1}$. Total timber production was 93.9 $m^3.ha^{-1}$, 71.2 m^3 of this in standing trees and the rest in the thinnings.

Although very young, the trees showed excellent growth and good form. The initial planting density followed by a thinning would have acted as positive factors. It is apparent that the pasture has not impeded an adequate growth of C. alliodora. The trees have benefitted from the natural soil fertility and the cut-and-carry pasture management, along with the provision of drainage canals, which means that soil structure deterioration by trampling and anaerobic conditions, which are harmful to this species (3, 7), do not occur.

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EXPERIENCES WITH FENCE LINE FODDER TREES IN COSTA RICA AND NICARAGUA

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SUMMARY

The management of traditional living fence post species is discussed with emphasis on their potential as a dry season fodder reserve. A list is given of the factors to consider when designing a study on the vegetative propagation of these species. Early survival of Gliricidia sepium and Spondias purpurea, in experimental plantations situated in the seasonally dry areas of Puriscal, Costa Rica and Jinotega, Nicaragua, is better than that of various Erythrina spp. However, assessments at 3-4 month intervals showed that survival should not be determined less than one year after planting. In an experimental planting of E. berteroana in the more humid area of Turrialba, Costa Rica, no mortality occured. Half of these one year old living fence posts were pruned in November and March, while the rest were only pruned in March. The non-traditional November pruning provoked shoot growth and halted deciduousness during the dry season, and provided 300% more forage in March.

INTRODUCTION

Lopping of trees to provide fodder is one of the most ancient agricultural practices with references dating back to the classical Greek and Roman literature (11). The indigenous people of Central America were establishing living hedges, by dense planting of large posts of arboreal species, before the Spanish arrived. With the advent of cattle ranching inter-post spacing was increased since the main purpose was now to provide a support for barbed wire

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(14). These living fence posts offer many other potential products and services (4). Many species have been identified (9,14) but with the exception of Gliricidia sepium (16) there has been little quantification of their management, existing products (e.g. firewood), or their potential products (e.g. fodder). This report concentrates on the management of some potential fodder trees which are commonly planted as living fence posts in Costa Rica and Nicaragua.

ESTABLISHMENT OF LIVING FENCE POSTS

Farmers have been experimenting with vegetative propagation techniques, of large posts, for several hundred years. The dissimilar management they have developed for different species (post diameters, ages, duration of storage in shade, etc.) is an indication of their empirical knowledge. For example, the conclusions of a survey of Costa Rican farmers, was that the majority plant G. sepium in March-April, to a depth of no more than 40 cm, immediately after cutting 4-8 cm diameter posts which are 2.5 m long (1).

In a study designed to test potential arboreal forages for goats (2), the initial survival of G. sepium and Spondias purpurea posts was much better than that of the two Erythrina spp. tested (Table 1). However, these trials clearly demonstrated the importance of the source of the posts, since the mortality of the local provenances of E. berteroana (Puriscal; old branches; planted 2 sites) was 85%, whilst mortality of the imported E. berteroana (provenance Turrialba; young branches; planted 4 sites) was only 3%.

Table 1. Initial mortality of four arboreal forage species vegetatively propagated with 2 m posts, Puriscal, Costa Rica*

	Erythrina poeppigiana	Erythrina berteroana	Gliricidia sepium	Spondias purpurea
Post diameter** (mm)	55	43	52	56
Mortality (%)***	47	30	3	0.5

* Average for 6 sites established 1985; random block design; 4 replications per site; 12 to 14 tree line plots; unpublished data J. Beer.

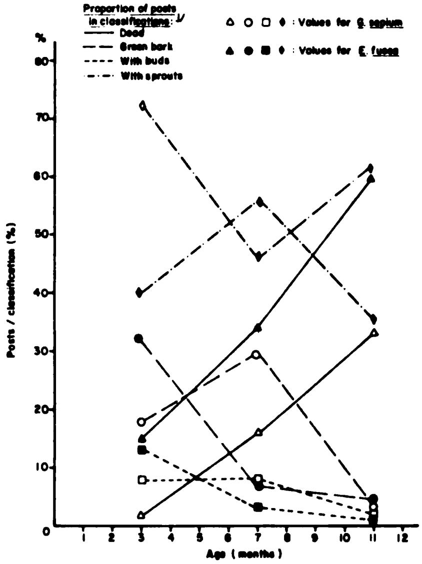
** Average of diameters 10 cm from base and 10 cm from top.

*** Based on replanting after 2.5 months (4 sites) and 1.5 months (2 sites).

Experiments designed to compare the rooting ability of different species are difficult to organize since the following factors should be equal for all species: provenance; age of parent tree; age of posts; origin of posts (basal or apical sections of branches or stems); diameter ranges; post height; cutting date; base and tip preparation (anguled cut, pointed, bark incisions, etc.); harvesting and handling methods (bruising during transport can be critical); duration of shade storage; planting depth. It is impossible to avoid some inter-species variation of these factors when using existing fence lines as a source of experimental material, since they are inevitably distributed over a wide area and have different management histories. In order to control these factors it would be preferable to initially establish all the experimental species in the same nursery, for the subsequent production of posts from the same site, with the same history etc. However, this still does not completely solve the problem since the nursery growth rates would be species dependant, and hence the size of posts harvested for an experimental planting would vary between species. Moreover the optimal post diameter for rooting is also species dependant. For example, in Costa Rica preferred post diameters are 8-15 cm for E. poeppigiana (13) and 4-8 cm for G. sepium (1).

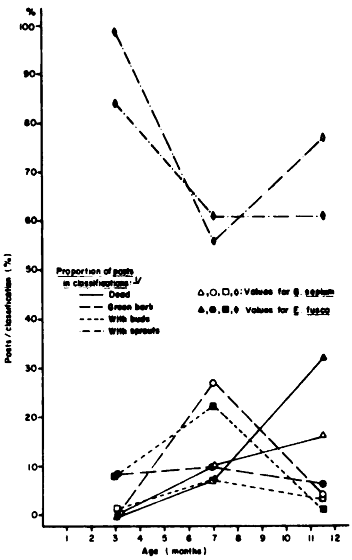
The data in Table 1 only shows an initial difference in survival (at ages 1.5 - 2.5 months) and can not be taken as conclusive evidence that the establishment of G. sepium and S. purpurea living fence posts is easier than that of the Erythrina spp. In 2 trials established on drier sites in Jinotega, Nicaragua (average precipitation approximately 1650 $mm.a^{-1}$) mortality was still occuring after 7 months (Figs.1 and 2). The posts were classified into one of 4 groups: dead; live bark; with new buds; with leaves on new sprouts. The dangers of an initial judgement on rooting success by counting the proportion of posts which had fully formed leaves on new sprouts is illustrated by Fig. 1.

The proportion of E. fusca in this class increased between the first (3 month) and second (7 month) measurements, but many subsequently dried up. In contrast many of the early sprouts (3 month) of G. sepium dried up, but other sprouts developed. After 7 months a judgement on rooting, based on the classification "with leaves on new sprouts", would have concluded that E. fusca was doing better. In fact at age 11 months a greater proportion of the G. sepium posts had branches, and there was less mortality of this species. These results show that living fence post survival should not be determined at less than one year after planting.



1/ A post included in any 1 of the 4 classifications ("dead, green bark, with buds, with sprouts") can not be included in any other

Fig. 1 Sprouting of *Gliricidia sepium* and *Erythrina fusca* fence posts at "La Yunay", Jinotega, Nicaragua



1/ A post included in any 1 of the 4 classifications ("dead, green bark, with buds, with sprouts") can not be included in any other

Fig. 2 Sprouting of *Gliricidia sepium* and *Erythrina fusca* fence posts at "Los Robles", Jinotega, Nicaragua

FREQUENCY AND TIMING OF LIVING FENCE POST PRUNING

The objectives of the traditional living fence post pruning methods are to reduce shading of adjacent crops, and to produce new posts for fence line replanting. It is unlikely that new research on pruning will result in dramatic improvements for these objectives. Nevertheless farmers have not traditionally managed these living fence posts for forage production and this new objective requires a non-traditional pruning frequency and timing, which is as yet little studied. Shorter intervals between pruning may reduce the total biomass produced per month but it increases the proportion of edible biomass (Table 2).

In the humid tropics trees are not a viable alternative to pastures for forage production when judged by total annual productivity and convenience. However, they can be a critically important forage source during dry seasons (8) when tropical pasture production and quality drops drastically.

Table 2. Productivity of live fence posts of Gliricidia sepium, Costa Rica

Post age (years)	Sprout age (months)	Average inter-post spacing (m)	Dry matter production* ($kg.km^{-1}.month^{-1}$) Forage	Woody material	Reference
0.5	6	2.0	50	30	1
3 - 3.5	3	1.2	90	50	7
3 - 3.5	5	1.2	50	50	7
5	3	1.5	150	60	3
5	6	1.5	220	390	3
5	6	2.0	360	330	1
5	8	1.5	60	380	3
5	9	1.5	125	470	3
5	12	1.5	50	600	3
5	24	1.5	40	620	3
?	24	1.7	30	525	10

* Sustainability of production unknown.

Since many of the potential forage trees are deciduous during part or all of the dry season, the realization of this potential depends upon the development of pruning methods that leave the trees with physiologically immature branches during the normal leaf shedding, flowering and fruiting periods (6,15). In Turrialba, pollarding (November) of one year old E. berteroana posts*, 2 months prior to the dry season, gave a 300% increase in dry season forage reserves (March) compared to posts which were not previously pruned (Table 3). The

* 100% survival was recorded in these plots

surprising result from this study was that there was no difference, between the two treatments, in the annual production of woody material. An explanation for this is that although growth of the plots cut in November was temporarily retarded, they continued to grow during the dry season when the previously unharvested fence posts ceased shoot growth and used up reserves to form flowers and fruits. Total annual biomass production from posts pruned twice (5000 $kg.km^{-1}.a^{-1}$) was considerably higher than that from posts pruned in March only (2900 $kg.km^{-1}.a^{-1}$). The difference is equal to the November and March forage production of the former group. Budowski et al. obtained much higher figures for 8 month old E. berteroana sprouts on 4 year old posts in a Turrialba fence line (19,200 $kg.km^{-1}.a^{-1}$) (5).

Table 3. Forage and biomass production from Erythrina berteroana living fence posts. Turrialba, Costa Rica*

		Pruned November 1984 and March 1985		Pruned March 1985 only	
		Dry biomass ($kg.stake^{-1}$)	Green biomass ($kg.km^{-1}$)	Dry biomass ($kg.stake^{-1}$)	Green biomass ($kg.km^{-1}$)
Forage	Nov.	0.185	1,480	--	--
	March	0.088	880	0.031	280
	TOTAL	0.273	2,360	0.031	280
Woody Material	Nov.	0.320	1,880	--	--
	March	0.078	780	0.449	2,640
	TOTAL	0.398	2,660	0.449	2,640
TOTAL BIOMASS		0.671	5,020	0.480	2,920

* Seven trees per line plot without borders; 15 plots per treatment; completely random design; all plots bordered by Gliricidia sepium; inter-post spacing 0.5 m.

The implication is that more frequent pruning gives greater biomass production; a conclusion that contradicts previous studies (3,12). However, these earlier studies were only concerned with pruning frequencies and the timing of the pruning operations did not take into account the phenology of the trees. On the other hand, it may be that the posts pruned twice are utilizing more of their original reserves and future productivity will be affected. This trial will be continued for several years to determine if E. berteroana can maintain forage productivity when pruned twice per year. Similar trials have also been established in the more seasonally dry areas of Puriscal, Costa Rica and Jinotega, Nicaragua, using both plantations and fence lines.

CONCLUSIONS

Studies of forage production from living fence posts must start with an analysis of the traditional knowledge on their establishment and management. The immediate potential of these species for the small farmers of Central America can be greatly increased by testing them in non-traditional associations such as cut-and-carry silvo-pastoril units; and by experimenting with more frequent pruning that is adapted to the phenology of these species, and hence provides a high quality forage reserve for the dry season.

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ACKNOWLEDGMENT

The Jinotega trials were established by Ing. E. Mendoza and J. Moreno (IRENA) and the Costa Rica trials by J. Alvarez, F. Mora, E. Martínez and F. Vargas. Support was provided by Ing. M. Reyes (IRENA), Ing. G. Durieaux, L. Chavarría and Dr. J. Heuveldop. None of these trials would exist without the advice and assistance of the cooperating farmers.

PRIORITIES FOR RESEARCH ON NITROGEN FIXATION IN AGROFORESTRY SYSTEMS

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SUMMARY

The key role of N in plant productivity is stressed as well as the possible role of N fixing trees (NFTS) in improving the nutritional status (and availability) of this nutrient in different ecosystems. Rather than make a review of the different agroforestry practices within which these plants are exploited, an inventory of research trends has been made, with the hope that at least some of them will be taken into account in future work with NFTS so that their contribution can be increased.

INTRODUCTION

In cultivated areas of the world, N is the second (after water), most limiting nutrient for plant growth and production (8). Soils are commonly amended with N fertilizer to improve plant productivity. This mostly effective and profitable approach is limited to a few crops in less developed countries. Moreover, the subsistence farmers rarely utilize this costly input. Thus the future seems gloomy in view of the mounting demands of a ever growing human population for grains, forage, timber, pulp and firewood. The outlook is even gloomier because of the increasing deterioration of tropical lands due to excessive deforestation, erosion and poor watershed management. N fixation technology can play a significant role helping to meet the above demands without a great need for external sources of N (23,36). An obvious attractive trait of N fixing trees (NFTS) is thus their ability to reduce the abundant, but

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inert, atmospheric nitrogen gas N_2 into ammonium (NH_4^+), a readily useable form. This occurs through symbiotic association of Rhizobium with legumes, especially of the sub-families Caesalpinoideae and Mimosoideae (4,15); or Franckia, especially with the tropical and sub-tropical genus Casuarina (50), and Alnus (1,43,49). This characteristic allows for a better tree growth under the common limiting N supply, encountered in most forest soils (19). The acretion of N would undoubtedly have an agroecological impact affecting the productivity of associated crops of non-nitrogen fixers (7,10,11,13). However, as Hines and Debell (9) state, "Far more people have philosophized about potential uses of nitrogen fixing species in forestry than have established well-designed research studies or attempted operational use of such plants. Most of the literature deals with opportunistic evaluation of natural occurrences (or unplanned comparisons of man-made situations) coupled with speculations regarding future potential for planned use of NFTS in management programs". It is necessary to pinpoint those aspects that urgently need investigation.

Therefore, in this paper I have avoided the description of the different managerial schemes in agroforestry practice. The reader is referred to other publications (4, 5, 7, 9, 15, 17, 35, 42) were this point is adequately covered.

RESEARCH PRIORITIES

Biological N fixation in trees

Better methodologies, to assess biological N fixation (BNF) in trees, are required. There is an urgent need to eliminate the current uncertainty about the N fixation estimates of active systems. This uncertainty stems from the difficulty of choosing and measuring parameters that can really give good estimates of the agronomical importance of N acretion due to fixation under field conditions. There are a myriad of problems that require accurate information. For example:

What is the overall contribution of BNF to the N economy of the trees?

What is the influence of farmers current practices (type and timing of pruning, propagation, fertilization, etc.) on BNF?

Is nodulation a limiting factor?

Do we need nodulated plants?

Is N the limiting factor?

Are there other nutritional constraints (P, Mo)?

Are there microbial constraints?

Can the trees grow and fix N under the conditions being considered?

What sort of variability exists between trees of related species or between "clones" of the same species?

What is the seasonal pattern?

How does the fixation change during the ontogeny of the trees?

What is the role of BNF in the establishment of the trees?

Some of the above questions can be approached using a very sensitive indirect technique (22, 40) which measures the activity of nitrogenase in the nodules. Basically nodules are incubated in a closed system (jars) with acetylene which is reduced by the nitrogenase enzyme to ethylene. The amount of ethylene produced, measured with a gas chromatograph, is an indication of potential fixation. However, care should be taken not to extrapolate to true N fixation rates (32, 52). The technique must be calibrated using $^{15}N_2$ (44, 51). It has the limitation of often being a destructive assay as well as a point measurement but it can be of great value in screening germplasm (plant, microbial). It has limited value as a means of quantifying longterm (seasonal) fixation. There are other more integrative approaches that can give better estimates of ecologically important amounts of fixed N. The "simpler" one is the N balance (26, 44). If the plants are fixing sizable amounts of N, especially when they are established on soils with a small N pool, the acretion should be measurable using standard N analysis (Kjeldahl). Indirect techniques such as the dilution of artificially enriched soil N with ^{15}N (51), used successfully with annual legumes, are yet to be widely used with tree legumes. There are problems that may preclude this, such as the cost and distribution of the labelled ^{15}N in the soil, since the soil volume being explored by the tree is far larger than that needed for annuals. This technique can be applied on a limited basis using large lysimeters. Another feasible, and hotly debated approach is the use of the dilution of the naturally enriched N as an indication of fixation. The more the plants reach the $^{15}N/^{14}N$ ratio encountered in the atmosphere the more N_2 is being fixed (44,51). For some (Fried, M*) this is a qualitative method, while for others (3, 11, Kohl, D.H*) there are some possibilities for quantitative work provided that:

A. Enrichment with ^{15}N in the soil is high.

B. There is little spatial variation (vertically and horizontally) in the soil.

C. No strong partitioning of $^{15}N/^{14}N$ occurs in the tissues of the plant.

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Unfortunately, there is no perfect technique to measure N fixation under field conditions. People must be extremely careful in being aware of the limitations of the techniques used as well as in the interpretation of the data being generated by such techniques.

A further set of questions arise when we consider the contribution of the NFTS to the overall nutrient economy of the system:

What is the fate of fixed N?

What are the major environmental or/and managerial determinants of mineralization?

How predictable is the impact of the legume biomass on the production of the associated crops?

What are the longterm effects on soil chemical and physical properties?

Is BNF per se having a positive impact or is it another factor?

There are simple experimental approaches to tackle these questions (10). The validity (and handicap) of simple experiments rests on their longterm evaluation. In many cases it would be desirable to use isotopic labeling of the legume biomass, such as the ones used with rice refuse (28,29), to further disect the processes in the soil.

Finally in order to utilize NFTS we must consider their management:

What sort of managerial practices can be adopted to increase the efficiency of the system?

Is it possible to reconcile maximum fixation with maximum utilizable (economic?) output?

How can competitive effects between NFTS and associated crops be controlled?

Is germplasm selection (plant, microbial) feasible for effectiveness and for tolerances to environmental stresses?

Are nutritional stresses manageable through fertilization?

Is microbial inoculation needed?

What to inoculate (seed, seedling or stake)?

What inoculation techniques should be used?

What are the short and long term effects of inoculation with Rhizobium, Franckia, mycorrhizae?
Is plant nodulation and/or mycorrhization limiting?

How can inoculation fit into the common farmers' practice?

What additional benefits can be expected from the manipulation of the Rhizobium?

There is ample room to improve the management of NFTS (21). Emphasis should be made on strain selection (2, 14, 20, 21, 37), inoculant technology (6, 12, 13, 41, 46), identification of soil nutritional stresses (16, 27, 34, 39, 45), studies on mycorrhizae (24, 33, 38), and on plant selection and breeding (13, 31).

One last point to bear in mind is that the scenario in which the NFTS are going to be introduced must be clearly defined to foresee management problems that require a certain research strategy, i.e. it is necessary to set priorities for research according to specific needs (site, climate, plant management, intensive vs non-intensive, etc.)

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POPULATION DYNAMICS OF GUAVA (Psidium guajava L.) IN PASTURES

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SUMMARY

A preliminary demographic model is presented for a population of guava (Psidium guajava L.) trees in a pasture. In this paper special attention is devoted to describing both the calculation of the parameters of the model and its manipulation. The transition probability matrix model developed predicts that the population size will gradually decline and that the form of the trunk diameter frequency distribution is changing from a normal to a positively skewed distribution.

INTRODUCTION

Psidium guajava L. (guava) trees are considered a noxious weed in many tropical pasture lands. Research has mostly been devoted to finding the most effective and cheap way of controlling the P. guajava (4, 5, 6, 7, 8). Little effort has been devoted to understanding the way P. guajava are dispersed and established in the pastures. It has been argued (10) that this kind of study would help in the design of sound management techniques. The management could be directed toward the complete eradication of the P. guajava or to the establishment and maintenance of an improved silvipastoral system which would minimize the adverse effects that P. guajava may have on pasture

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productivity or management costs, while increasing production of fruit (for both livestock consumption and/or marketing for industrial purposes) and firewood, as well as other services (e.g. shade). This paper focuses on the population dynamics of P. guajava in a private farm at 1200 m.a.s.l.* in Costa Rica. A preliminary demographic model is presented. A detailed description of the study site is presented elsewhere (10).

METHODS

Diameter frequency distribution

Trunk diameters (D), and the basal area of all branches at the first fork, of 832 standing P. guajava trees in a 22 ha section of the farm, were measured in 1984 and sorted into 4 cm diameter classes to obtain the size frequency distribution of the P. guajava population. Measurements were made with a linen tape at 10 cm above ground except for trees 1-4 cm in diameter which were measured with a caliper at the base of the trunk. Seedlings were counted once in 1984 in 800 randomly selected 0.5 mt quadrats. Seedlings were classified as being < 2 year old (< 0.5 cm basal diameter) or 2-5 years old (0.5 - 1.0 cm basal diameter). Seedling age-size estimates are based on non-rigorous observations made over more than three years at the study site.

Current annual increment in basal trunk diameter (CAI)

Early studies, showed that the sum of the basal area of all branches at the first fork (ABR) is the best predictor variable for standing volume and volume growth (9, 12). Measurements of the ABR of 80 P. guajava trees were made in 1982 and 1984. Changes in ABR were then used in a ABR-D regression model (calculated from the 832 P. guajava measured above) to estimate trunk diameter growth (12). CAI values for trees outside the data range were estimated by a regression model fitted to the CAI-D data. The diameter growth rate of seedlings with diameter < 0.5 cm was assumed to be such that any seedling in this class would move to the next class after two years (i.e. $CAI = 0.25\ cm.a^{-1}$). Diameter growth rate of seedlings 0.5 - 1.0 cm was estimated the same way assuming a "time of passage" of three years (i.e. $CAI = 0.5/3 = 0.17\ cm.a^{-1}$).

* Meters above sea level.

Tree and seedling mortality

Basal diameters of 101 dead P. guajava trees in 22 ha were measured in 1984. Trees in advanced decomposition were excluded. It is estimated that the data obtained refers to a period of accumulated tree mortality of six years. This estimate is based on non-rigorous observations of the decomposition of: 1) standing trees which died after initial measurements in 1979, 2) trees felled in 1980 for sprouting studies, and 3) trunk logs, 0.7 m in length, piled in 1982. The annual rate of individual tree mortality (M) was calculated as: $M = (Di)/(Ni*Dp)$; where Di = number of dead trees in diameter class "i"; Ni = number of standing living trees in class "i"; Dp = decomposition period, in years.

Mortality rates for trees with diameter 1-4 cm and 44-52 cm were assumed to be equal to the mortality rate in the upper and lower size classes respectively. Mortality for seedlings 0.5 - 1.0 cm was estimated as the ratio between the number of surviving saplings in the 1-4 cm class and the 0.5 - 1.0 cm class. Both figures were divided by the number of years of accumulated recruitment into both size classes. Mortality in the < 0.5 cm size class was estimated the same way taking the 0.5 - 1.0 cm size class as reference.

Seed production, seed dispersal and germination, and fecundity

Fruit production of 59 P. guajava trees with basal trunk diameters between 12 - 36 cm was measured in 1983 (10). Seed dispersal by cows was measured in 101 samples of fresh cow dung collected during the peak of the large fruiting season of 1983 (11). Studies on seed germination were conducted between 1982-1985 (13).

Fecundity per reproductive tree in each size class was calculated as follows:

a) a permanent herd of 28 animal units (AU = 350 kg live weight) is grazed during 153 days out of a total 168 days when fruits are available. This gives 153*28 = 4284 AU-days. Cows eat c. 11 $kg.AU^{-1}.day^{-1}$ of fresh fruits with a mean seed content of 5960 $seeds.kg^{-1}$ fresh fruit (10). This gives a figure of 281,000,000 seeds dispersed per year in the study site.

b) **25% of the seeds germinate in the cow dung (13) and only 0.48% of the seedlings survive one year after dispersal*. Then the total number of surviving seedlings produced per year becomes: 281,000,000 * 0.25 * 0.0048 = 808,874.**

c) **The contribution from each size class was assumed to be proportional to the annual fruit production per tree in each size class. Fecundity values per tree were calculated by dividing the number of seedlings produced in each size class (808,874* % contribution per class) by the number of living trees. Fecundity values ranged between 413-7427 seedlings.tree^{-1}.a^{-1}; the larger values were obtained for trees with a basal diameter of 40-44 cm (Table 1).**

Table 1. Diameter size frequency distribution, diameter growth, mortality, and life table parameters of guava (Psidium guajava L.) trees in pastures, Turrialba, Costa Rica. Study area = 22 ha

Trunk diameter (cm)	Nºliving trees	Diameter growth (cm.a^{-1})	Annual survival (S)	(P_p)*	(P_r)**	b_{ij}	a_{ij}	Annual fruit production (kg.tree^{-1})	Fecundity (F)
< 0.50	99650	0.25	0.044	0.500	0.500	0.022	0.022	-	0
0.5 - < 1	6450	0.17	0.001	0.340	0.660	0.0009	0.0005	-	
1 - < 4	30	0.30	0.990	0.074	0.926	0.073	0.917	-	0
4 - < 8	48	0.30	0.990	0.074	0.926	0.073	0.917	10***	229
8 - <12	84	0.30	0.974	0.074	0.926	0.071	0.903	15***	343
12 - <16	138	0.22	0.983	0.054	0.946	0.053	0.930	20	457
16 - <20	146	0.97	0.974	0.241	0.759	0.235	0.739	32	731
20 - <24	127	0.80	0.978	0.200	0.801	0.195	0.783	41	937
24 - <28	104	0.71	0.979	0.177	0.823	0.173	0.806	84	1902
28 - <32	84	1.02	0.976	0.255	0.746	0.248	0.728	125	2857
32 - <36	40	0.37	0.983	0.091	0.909	0.090	0.899	31	709
36 - <40	21	0.30***	0.992	0.074	0.926	0.062	0.930	20	457
40 - <44	4	0.25***	0.958	0.063	0.931	0.056	0.898	15	343
44 - <48	4	0.25***	0.958	0.063	0.938	0.056	0.898	10***	229
48 - <52	2	0.25***	0.958	0.063	0.938	0.056	0.898	5***	115

* Proportion of trees "moving up".
** Proportion of trees "remaining".
*** Estimated by regression.

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* **Somarriba, E. Unpublished data.**

Transition probability matrix

A transition probability matrix model for individuals grouped in size classes (Fig. 1b) was used (3). An extensive discussion on the use of this model in the management of natural resources was presented by Usher (14), and its limitations have been discussed by Vandermeer (15). This model is adequate for populations with a simple uni-directional life cycle (1, 2) (Fig. 1a).

In Fig. 1a the circles represent the size (diameter) classes in which the population is arbitrarily divided. Trees in each size class grow at a rate such that some trees move up to the next size class or remain (e.g. trees near the lower limit) in the same class after a unit of time (e.g. one year). The proportions of "passing" and "remaining" trees are multiplied by the individual size-class probability of surviving from one year to the next, to obtain the probability that a given tree in a given size class will move up, and survive to the next size class (b_{ij}) or will remain and survive in the same size class after one year (a_i) (Table 1).

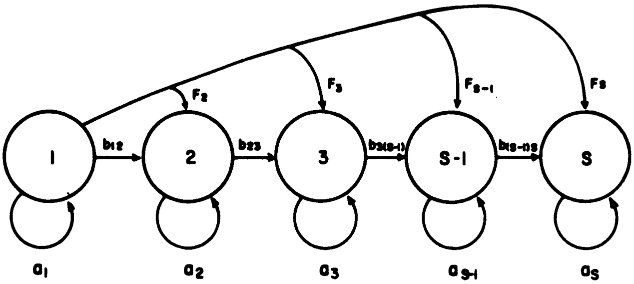

Fig. 1a. Hypothetic life cycle of *Psidium guajava* L. (After Caswell, 1, 2)

$$
\begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \\ \vdots \\ n_{s-1} \\ n_s \end{bmatrix}
=
\begin{bmatrix}
a_1 + f_1 & f_2 & f_3 & f_4 \cdots f_{s-1} & f_s \\
b_1 & a_2 & 0 & 0 \cdots 0 & 0 \\
0 & b_2 & a_3 & 0 \cdots & \vdots \\
\vdots & 0 & b_3 & a_4 \cdots & \vdots \\
\vdots & \vdots & 0 & b_4 \cdots 0 & 0 \\
\vdots & \vdots & \vdots & 0 \cdots & \vdots \\
\vdots & \vdots & \vdots & 0 \cdots a_{s-1} & \vdots \\
0 & 0 & 0 & 0 \cdots b_{s-1} & a_s
\end{bmatrix}
\times
\begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \\ \vdots \\ n_{s-1} \\ n_s \end{bmatrix}
$$

n_{t+1} M n_t

Fig. 1b. Transition probability matrix for population size projections (After Usher, 14). See text for details

Reproduction in each size class contributes new individuals to the first size class. Obviously the fecundity "F" values will be zeros for the non-reproductive size classes. The "F" values refer to fecundity values per reproductive individual in each size class. All these elements are arranged in a squared matrix (M), called the transition probability matrix, with all b_{ij} and a_i values in the main diagonal and subdiagonal respectively, and the "F" values in the first row.

The actual number of living trees per size class are represented by a s-dimensional vector (nt). This vector is multiplied by the transition probability matrix (M) giving as the product the vector n (t+1) which represents the size class distribution of the population after 1 year. Vector n(t+1) is also multiplied by "M" giving n (t+2), the size class distribution after two years. This process is repeated on the successive vectors n(t+3), n(t+4),.... n permitting the modelling of changes in the size and structure of the population over as many years as the worker chooses. Some asymptotic properties of the population under study (stable size and class frequency distribution, and the intrinsic rate of population growth) may be estimated by this model. Nevertheless this was not attempted with the preliminary data available. A computer program (in Fortran IV) which allows calculation of the size class frequency distribution is included in Appendix 1.

RESULTS

Size-class distribution, CAI, and mortality

Excluding the large number of seedlings (approximately 100,000) and saplings (approximately 6,000) found in the inventoried 22 ha, P. guajava show a normal size-class frequency distribution. Dead trees followed the same pattern. Diameter growth rates (CAI) ranged between 0.2 - 1 $cm.a^{-1}$ with the larger values in the middle-size classes (Table 1).

Seed production, dispersal, germination and fecundity

Fresh fruit production ranged between 20-125 $kg.tree^{-1}.a^{-1}$ with maximum fruit production in trees 28 - 32 cm in diameter (Table 1). With a mean seed content of 5,960 $seeds.kg^{-1}$ of fresh fruit (10), the seed production per tree ranges between 30,000 - 740,000 $seeds.tree^{-1}.a^{-1}$. Fruits are available to cows for 5-6 months a year.

Transition probability matrix, and future population size and structure

The transition probability matrix calculated from Table 1 predicts a steady decline in the population size of P. guajava from the actual value of 802 (only trees > 4 cm basal trunk diameter) to 183 P. guajava in 22 ha at year 100 (Fig. 2). The model predicts changes in the "shape" of the diameter class frequency distribution, from the actual "dome shaped" to a "U" shaped distribution between 40-60 years, and then to a slightly "rectangular" distribution at year 100 (Fig. 3). These changes are a consequence of both the larger CAI values in the middle-sized trees, and the higher mortality rates in the small size classes than in the large size classes.

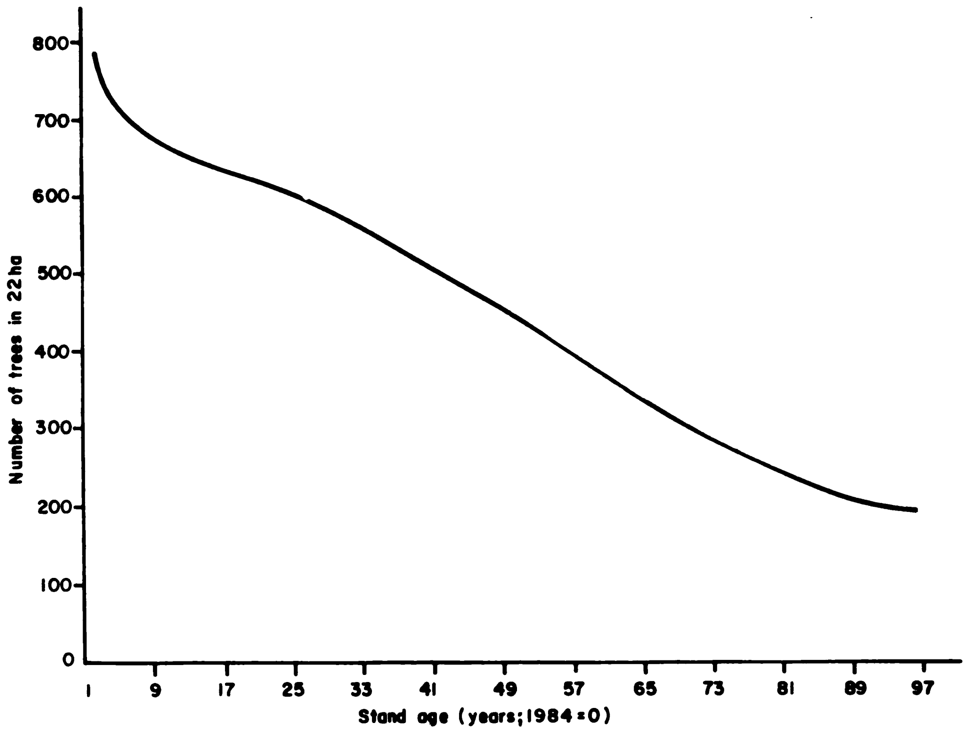

Fig. 2. Population size of guava (Psidium guajava L.) in pastures, Turrialba, Costa Rica. Study area = 22 ha. Only trees ≥ 4 cm in trunk diameter included.

DISCUSSION

P. guajava are susceptible to chemical control (6, 7, 8) and this could be the most important factor which determines the decreasing trend in the P.

guajava population size as predicted by the model. Weed control at the study site includes annual spraying with 2,4-D in the middle of the dry season, and manual control with a "machete" in the rainy season. It is very unlikely that this trend is merely an artefact of the model or of the way the model parameters were calculated, even though this would have to be carefully evaluated through sensitivity analyses. Special attention should be given to the evaluation of changes in seedling mortality.

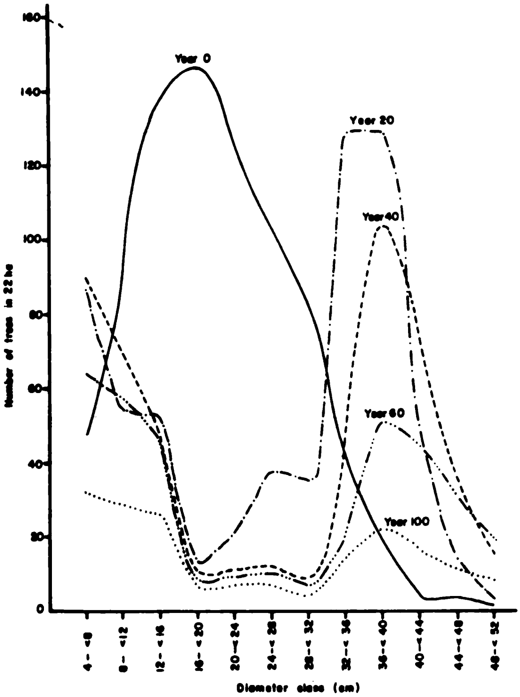

Fig. 3. Future diameter class frequency distribution as predicted by a population dynamics model developed for guava (Psidium guajava L.) trees in pastures, Turrialba, Costa Rica. Study area = 22 ha

The description and prediction of changes, in both population size and diameter size class frequency distribution of the P. guajava in this silvipastoral system, is a valuable tool for the evaluation of the management practices that could help to: 1) control the aggressiveness of the P. guajava in the pasture lands, and 2) find the best way of integrating P. guajava trees in pastures in order to optimize benefits (fruits, fuelwood, shade and other services, etc.) while minimizing disadvantages (weed control, excessive shading on the pasture, other management costs, etc.). In the former case, special attention should be given to the testing (with the model) of: 1) the effects that changes in herd management may have on both seed dispersal and tree fecundity, and 2) the use of P. guajava varieties with a low seed content and low seed germination and/or viability.

Modelling the population dynamics of the P. guajava allows for a quantitative evaluation of the advantages and disadvantages of having the trees in the pasture. At a given year, the vector of diameter size class frequency distribution of the population could be used to calculate: a) the total standing firewood biomass, b) the total fruit production, c) the total area under shade, and d) seed dispersal. An energy balance could then be calculated with the use of: 1) allometric relationships between trunk diameter (D) and firewood volume, D-fruit production, and D-crown diameter; 2) some cause-effect relationships between pasture productivity and floristic composition, with and without shade, and 3) calorific equivalents for each component. Sensitivity analyses should also be conducted.

CONCLUSIONS

A Lefkovitch matrix model of population dynamics of P. guajava predicts a steady decline in population size. Changes are also expected to take place in the diameter size class frequency distribution. Weed control with herbicides seems to be the most important factor determining the reduction in population size. Differential diameter growth rates in the size class range, together with differences in mortality rates between the small and the large trees, are responsible for the changes in the shape of the diameter size class frequency distribution.

Sensitivity analyses at both the biological and managerial levels should be carefully evaluated in order to assess the impacts that innovative technological recommendations may have on both the population dynamics of the P. guajava, and on the resulting balance between advantages and disadvantages associated with the presence of P. guajava trees in the pasture lands.

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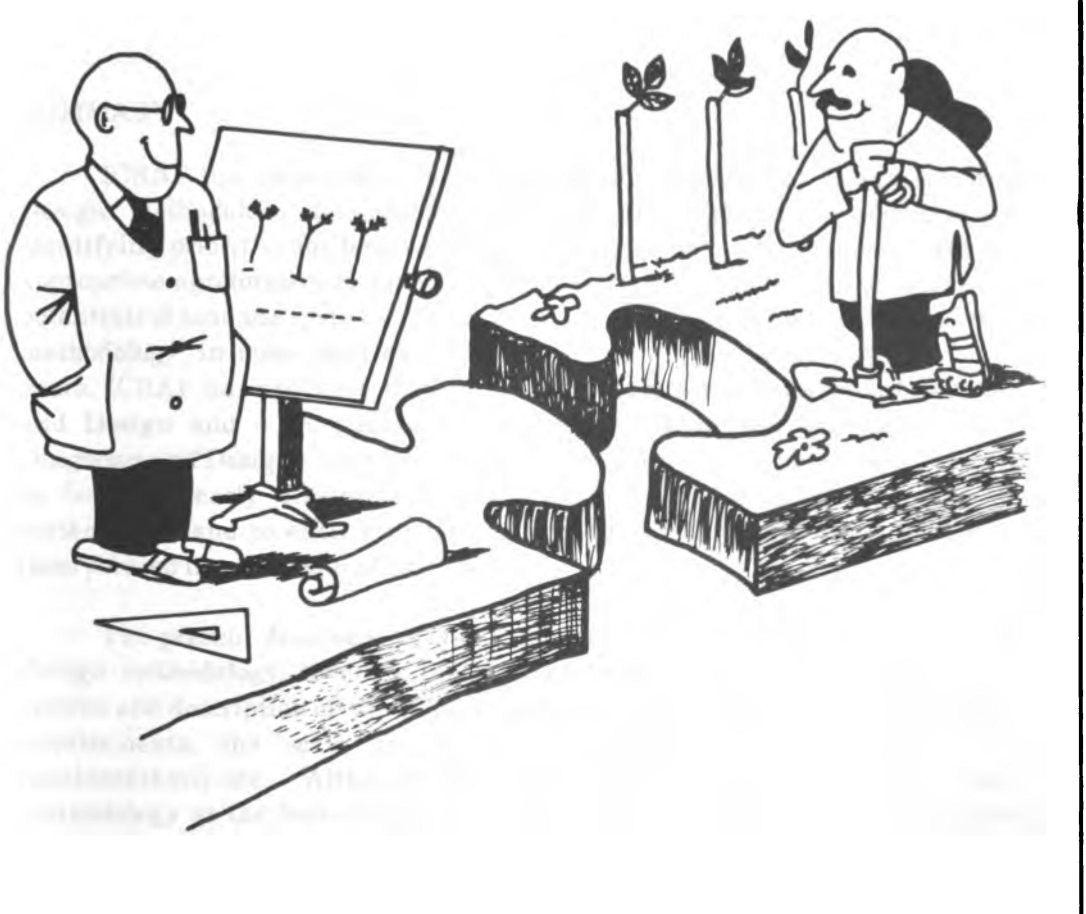
APPENDIX 1. Computer programme which calculates biennial (from year 2 to 100; year 0 = 1984) diameter frequency distribution of a population of guava (*Psidium guajava* L.) trees in pastures, Turrialba, Costa Rica. [Written by Javier Icaza, CATIE, Turrialba, Costa Rica. 1985].

```
DIMENSION X(15, 15), Z(15), Y(15), AUX(15, 50).
WRITE (6,2010)
Do 4  I = 1,15
READ (5,2000) Z(I)
2000              FORMAT (F5.0)
   4              CONTINUE
                  READ (5,2001) ((X(I, J), J=1, I=1,15)
2001              FORMAT (15F9.4)
                  DO 4000 L = 1,50
                  DO 4500 K = 1,2
                  DO 5000 I = 1,15
                  S = 0
                  DO 5500 J = 1,15
                  S = S+X(I,J)* Z(J)
5500              CONTINUE
                  Y(I) = S
5000              CONTINUE
                  DO 1600 J = 1,15
                  Z(J) = Y(J)
1600              AUX(J,L) = Y(J)
4500              CONTINUE
4000              CONTINUE
2010              FORMAT ('1',///,'DISTRIBUCION DIAMETRICA BIENAL',///)
                  WRITE (6,4600) ((AUX(J,L), L = 1,15), J = 1,15)
4600              FORMAT (/, 15F8.0,/)
                  WRITE (6,4600) ((AUX(J,L), L = 16,30), J = 1,15)
                  WRITE (6,4600) ((AUX(J,L), L = 31,45), J = 1,15)
                  WRITE (6,4600) ((AUX(J,L), L = 46,50), J = 1,15)
                  STOP
                  END
```



CASE STUDIES : DIAGNOSIS AND TECHNOLOGIES FOR AGROFORESTRY

THE ICRAF AGROFORESTRY FARMING SYSTEMS APPROACH*

International Council for Research in Agroforestry**

SUMMARY

ICRAF has undertaken to develop an interdisciplinary Diagnostic and Design methodology for agroforestry, to assist agroforestry workers in identifying priorities for technology-generating research, based on designs for appropriate agroforestry technologies derived from a diagnosis of the needs and potentials of land use systems. After initial development and testing of the D&D methodology, in more than twenty sites around the world, over the past two years, ICRAF has produced these draft **Guidelines for Agroforestry Diagnosis and Design** and a companion volume entitled **Resources for Agroforestry Diagnosis and Design**. They are being published in working paper form in order to facilitate early dissemination and wider field testing of the evolving methodology and to elicit comments and suggestions for improvements to be incorporated into subsequent editions.

The present document provides: an introduction to the Diagnostic and Design methodology; covering the logical framework of the methodology; an outline and description of the step-by-step procedures; a discussion of manpower requirements; the scale and timing of D&D activities; institutional considerations; etc. Although the emphasis is on the use of the D&D methodology at the formulation stage of agroforestry projects, the role of the continuing diagnosis and design process as part of the project's 'internal guidance system' is also discussed. For more detailed procedural guidelines

* Extracted from ICRAF Working Paper Nº 6, 1983, 25 p.

** Nairobi, Kenya.

and a variety of useful tools and materials, the reader is referred to the companion documents.

OBJECTIVES OF THE METHODOLOGY

The aim of ICRAF's Diagnostic and Design (D&D) methodology is to assist in the design of appropriate agroforestry systems, as a conceptual basis for the identification of research needs and the formulation of agroforestry research and development projects. The methodology is directed toward meeting the needs, solving the problems, or realizing the potentials of specific land use systems.The procedures described in these guidelines lead to the design of one or more agroforestry technologies which appear to have the potential to effect realistic improvements in the target land use system. The resulting 'design concepts' may then serve as the basis for planning a research programme to develop the identified agroforestry technologies through a combination of on-site and on-station research.

Although the logic of the D&D methodology is applicable to a wider range of technical options, and while non-agroforestry alternatives are given due consideration in the course of the D&D process, the methodology has been designed to focus on a systematic consideration of agroforestry related aspects of existing land use systems, i.e. not to miss, through lack of appropriate analytical techniques, any significant agroforestry potentials which may be inherent in the land use system.

A problem-oriented or diagnostic approach is adopted as a logical route to the goal of good agroforestry design and the basic methodological guidelines have been adapted to the need for an efficient 'rapid appraisal' approach (1) to project formulation.. The methodology incorporates elements of the Farming Systems Research (FSR) approach (2, 3, 7, 8) but goes beyond the content of existing FSR methodologies in order to address the broader range of production and conservation roles which can potentially be played by agroforestry. Although a major emphasis is placed on the household management unit as, in most cases, the basic decision-making unit vis-a-vis land use, the methodology employs a sliding scale of analysis ranging from intra-household processes to the local community, regional and national levels of socioeconomic and ecosystem organization.

While the focus of the present guidelines is on the use of the D&D methodology at the formulation stage of agroforestry projects, a continuing role for the basic D&D process is envisaged throughout the life of a project as part of its 'internal guidance system'.

AGROFORESTRY DEFINED

Agroforestry is a collective term for systems of land use in which woody plants (trees and shrubs) are deliberately combined on the same land management unit with herbaceous crops and/or animals, either in some form of spatial arrangement or in sequence. For a land use system to fall within the concept of agroforestry, there should be both ecological and economic interactions between the woody plants and other components of the system (5).

Agroforestry may involve the integration of trees into farming systems or crops and livestock into forests. In practice, a high proportion of agroforestry systems involve the growing of trees on what is primarily agricultural land. Crop or livestock production on land devoted primarily to forestry is less common but also within the scope of agroforestry. To avoid frequent qualifications, the terminology used here and in the companion document (4) is phrased primarily in terms of agroforestry applications in farming systems, but the methodology is also applicable to the design of appropriate agroforestry systems for forest reserves (see the companion document for specific guidelines on forestry applications). Similarly, the term "farmers" is employed, for brevity, to include all actual or potential categories of land managers, including pastoralists and foresters.

THE DIAGNOSTIC APPROACH

One of the major principles underlying the Diagnostic and Design methodology is derived from an analogy with medicine i.e. that diagnosis should precede treatment. In the first instance, this means simply that research oriented toward the development of new land management technologies should be relevant to the actual needs and potentials of land use systems. It is no use developing a technology which works beautifully on the research station if there are reasons why it cannot be taken up by a significant proportion of the intended users. Rather than leaving such aspects to chance, or to a later 'evaluation' stage in the project cycle, the diagnostic procedures are intended to insure that the research undertaken is oriented in the right direction from the start so that the technology to be developed will be relevant to the needs of the area.

The analogy with medicine entails the further implication that priority should be given to the development of problem solving agroforestry technologies. While it is true that agroforestry holds promise for achieving a wide range of land use potentials, it seems obvious that the priority claim on the use of scarce research and development resources lies in developing agroforestry's potential to provide urgently needed solutions to pressing problems of failing production systems and degradation of the resource base of future generations. As in medical practice, the principle of **triage** applies.

Furthermore, there is little use in conducting sophisticated research to realise some ideal conception of the biological potential of a land use system as long as the system in question is suffering from crippling problems which prevent it from achieving those potentials. By analogy, there is no use in trying to make an athelete out of someone suffering from a chronic debility. The debility must first be removed before the patient can go on to realize his atheletic potentials. The 'patient' in D&D perspective is the existing land use system and a diagnostic approach is a direct and logical route to the realization of system potentials through the identification and removal of system constraints.

While the medical analogy may help in defining standards for agroforestry practice, the situation in agroforestry departs from that of medicine in at least one very important aspect: in agroforestry the methods of 'treatment' have frequently not yet been developed or scientifically proven. In the present early stage of the scientific development of agroforestry there are few 'off the shelf' solutions. Hence, the need for research before widespread extension of agroforestry technology. Hence, also, the need for a reliable and efficient methodology for identifying priorities for cost-effective research based on sound agroforestry designs.

CRITERIA OF AGROFORESTRY DESIGN

There is no substitute for good design. The criteria of good agroforestry design are threefold: **productivity**, **sustainability** and **adoptability**. The improvement of productivity, or output from the land, is almost everywhere required, by governments as well as by farmers themselves and needs no further discussion here. The 'sustainability' criterion is an attempt to operationalize the conservation objectives of agroforestry in terms of the farmer's production objectives. In most cases it means that production aims should be achieved without degradation of the land resources. Where degradation has already occured, agroforestry technologies may seek to reverse the process and place the production system on a sustained-yield basis.

The 'adoptability' criterion means that the techniques and systems proposed for development should be capable of adoption by a significant percentage of the intended users. This implies, for example, that the technologies must not call upon resources which the farmers are not likely to possess (e.g. excessive capital, machinery or labour requirements) nor be incompatible with unchangeable features of the existing land use system, nor require forms of management the farmers are unable or unwilling to adopt (e.g. keeping livestock off pastures for prolonged periods). In recognizing adoptability as a design criterion on an equal footing with productivity and sustainability, the agroforestry designer accepts the challenge of addressing the social as well as the physical dimensions of land use systems. The D&D methodology is intended to provide assistance in carrying out this more demanding, and yet potentially far more successful, approach to design.

RAPID APPRAISAL AND MULTIDISCIPLINARITY

Although the D&D procedures are adaptable to a range of different needs and applications, the basic guidelines are designed to allow the use of rapid appraisal methods by a highly qualified multidisciplinary team. A rapid appraisal approach is adopted for practical reasons: the planning of research and development projects is usually subject to constraints on the cost and availability of skilled manpower which often severely limit the time available for survey and research planning activities. This is particularly true in the case of agroforestry, where the broad scope of the subject normally requires the participation of several disciplines in order to insure adequate diagnostic coverage and a broadly conceived approach to design.

MANPOWER REQUIREMENTS

Manpower requirements will vary with circumstances, but a minimal D&D team should normally include one or more representatives of each of the following disciplines: **agricultural science** (general agronomy, horticulture, and livestock sciences), **forestry** (in the broadest sense including, if relevant, individuals with a knowledge of horticultural and multipurpose trees), **social science** (sociology/anthropology, human geography and economics), and **natural sciences** concerned with land resource survey (ecology, soils science, climatology). Within these broadly defined disciplinary categories, generalists will normally be more useful as members of a D&D team than narrowly specialised individuals. It may often be possible to economize on the manpower requirements of a D&D team by recruiting individuals who combine within themselves a working knowledge of more than one discipline (e.g. climate and soils knowledge in a land evaluation expert, natural and social sciences in a geographer or a human ecologist). Arrangements can usually be made for consultation with specialists to supplement the knowledge of the generalists when the need arises.

Whenever a technology generating research project is to be formulated on the basis of the D&D survey results, every effort should be made to involve the eventual technology developers directly in the process as members of the D&D

field team in order to maximize the understanding and use of the results by the most directly relevant recipients.

THE INSTITUTIONAL SETTING

The intended users of the D&D methodology include: research scientists at national and international research institutes, land use planners and resource managers, development project implementation staff, rural development fieldworkers and non-government organizations, university researchers, and representatives of donor agencies involved in formulating projects to support agroforestry research and development activities at any of these levels. The methodology can be flexibly adapted to meet the needs and resources of these varied institutional settings.

Given the need for research in the present state of agroforestry, primary emphasis is placed on the use of the methodology in formulating research projects to develop and test needed agroforestry technology, but there is nothing to preclude the use of D&D procedures to arrive at agroforestry designs for more direct development-oriented applications, particularly if the development project incorporates a research component to support the testing and refinement of the proposed agroforestry systems.

Many client institutions wishing to make use of the D&D methodology will not possess a standing D&D survey team of the desired multidisciplinary composition. This is particularly true in the case of agroforestry, since agricultural and forestry staffs are often housed in separate institutions. Again, this need not prevent the use of the methodology since good D&D results have been obtained with ad hoc inter-institutional teams assembled for the purpose on a temporary basis. More permanent arrangements for inter-institutional cooperation may be necessary, however, to carry out a multidisciplinary research and development project in agroforestry.

The desirability of a multidisciplinary team approach, likewise, does not preclude the use of D&D procedures by clients lacking the resources to field such a team. Experience has shown that there is considerable scope for success in even single-person D&D applications, providing that the individual is adequately conversant with the relevant disciplinary perspectives and that there is opportunity for consultation with appropriate disciplinary experts in the course of the exercise. Simply attempting to follow the logic of the D&D procedure can be expected to produce some improvement in the planning of agroforestry efforts in almost any institutional setting, regardless of personnel or resource endowment.

DURATION AND TIMING OF D&D ACTIVITIES

There are two basic possibilities with respect to the duration and timing of D&D activities at the project formulation stage:

1. Rapid appraisal plus follow-up, or
2. Straightforward extended application

In a typical 'type 1' application of D&D procedures by a multidisciplinary team, it normally takes about two weeks to carry out the diagnostic survey, analyze the results and develop appropriate design concepts for agroforestry interventions to improve the existing land use system. This period of concentrated diagnostic and design effort is normally preceeded by a month or two of preparatory data gathering by a small prediagnostic working group and is followed by up to several months of less intense pre-project follow-up work, again by a smaller working group, to round out and refine the initial D&D results arrived at by the full multidisciplinary team and develop a detailed project implementation plan. This type of D&D application is designed to economize on the use of time and manpower resources and make the best use of limited time available for high level multidisciplinary collaboration.

The timing of 'type 1' applications also accords well with the normal phasing of activities in the formulation of donor-sponsored projects. The rapid appraisal D&D process corresponds to a substantial 'project identification' or a preliminary 'project formulation' type of exercise which defines the overall thrust and the framework of the project. This, then, serves as the basis for a request for proposals to formulate, in the pre-project follow-up phase of the D&D process, a detailed project implementation plan. If adopted by donor agency project identification teams, the D&D process in its rapid appraisal form could provide an efficient and reliable means of putting well conceived agroforestry projects out to bid. At present we can only speculate on the effect this would have on the cost-effectiveness of donor sponsored agroforestry projects, but one has reason to believe that it would be beneficial.

Although the developers of these guidelines have taken pains to insure that the suggested D&D procedures are compatible with a rapid appraisal approach (see detailed guidelines and suggested procedures in **Resources for Agroforestry Diagnosis and Design** [4], there is nothing to prevent the application of the D&D logic in lengthier 'type 2' exercises in cases where time and personnel resources are not constraining. In that case, rather than a 'type 1' D&D application which reaches the required depth through a two-stage process which postpones some of the more detailed and time consuming work until the follow-up stage, the 'type 2' application would proceed straightforwardly through the logical sequence, taking everything as it comes up in whatever detail is deemed necessary.

Thus, in 'type 2' applications it might take 6 months to a year to work through the D&D procedures, rather than 2 weeks for an initial 'type 1' application. It goes without saying that there are a whole range of intermediate possibilities as well. One variation worth mentioning is that of allowing a substantial pause in 'type 1' application between the diagnostic and design phases in order to allow the D&D team to fully digest the design implications of the diagnosis and to informally explore notional design alternatives.

It should be pointed out, however, that even when time is 'unlimited', there may be distinct benefits to an initial rapid appraisal application. Anyone who has ever managed a multidisciplinary research team knows how difficult it can be to reach an interdisciplinary consensus. Experience with the rapid appraisal form of the D&D methodology would suggest that the pressure of having to arrive at a definite consensus within a circumscribed time period can result in a higher degree of interdisciplinary synthesis than would otherwise be possible under less pressured conditions. Such a consensus, achieved at an early stage of the project cycle and regarded as 'provisional' and subject to revision as the project progresses, can have a beneficial impact on the quality of interdisciplinary collaboration throughout the life of the project. Even in the rare case where an excellent base of interdisciplinary collaboration has already been established in an existing multidisciplinary team, it may still be of value to first conduct a 'type 1' exercise to obtain an overview of the essential aspects of agroforestry diagnosis and design before getting down to the more detailed work of diagnostic elaboration and design refinement.

THE SCALE OF D&D APPLICATIONS

It is often said that agroforestry technologies are 'location specific', but it is more correct to say that agroforestry technologies are 'system specific', if by 'system' we mean a combination of biophysical and socioeconomic factors associated with a given land management unit which make it suitable for some specific and limited set of land management technologies and not some other. It follows, then, that any process of diagnosis and design undertaken for the purpose of developing appropriate technologies must, of necessity, be a system-specific exercise for the simple reason that technologies appropriate to one system of land use may not be appropriate to another.

There is considerable latitude possible, however, in the definition of 'the system' for D&D purposes. In the companion volume to these guidelines (4) specific suggestions are made as to the application of the basic D&D logic to a sliding scale of analyses involving a nested hierarchy of systems ranging from national and regional levels, to local watersheds and communities, to household and intra-household levels of organization.

For most purposes, however, the focal system, which is defined as the basic departure point or 'touchstone' for all other scales of D&D analysis, will be the household, family farm, or other similar land management unit, since this is where most land management decisions are made. If other, larger or smaller, decision-making units are present in the area and relevant to the D&D exercise (e.g. forest management units), then they too must be analysed to expose their own agroforestry-related objectives, constraints and potentials. All other relevant processes which are not under the jurisdiction of decision-making systems are treated as part of the environment of such systems.

In saying that applications of the D&D methodology must be system-specific it does not mean that the methodology is only applicable to very small areas or that the D&D team cannot deal with more than one land use system in a given exercise, and it certainly does not mean that a separate D&D analysis must be conducted for each and every farm. What it does mean is that the design of specific agroforestry technologies must be linked to the diagnosed needs and potentials of specific land use systems, at whatever scale they may exist. One of the first tasks in the D&D procedure is to define the relevant systems for D&D purposes.

It is assumed that agroforestry research and development efforts will not be undertaken for truly minor and insignificant land use systems within a country and it is expected that users of the D&D methodology will exercise judgement in the definition and selection of land use systems for D&D treatment. It is further assumed that the sites selected for D&D exercises, and within the sites the management units selected for D&D survey, will be broadly representative of major land use systems within the country which are important enough to justify the expenditure of scarce research and development resources. (See Resources for Agroforestry Diagnosis and Design (4) for detailed guidelines and suggested criteria for the definition and selection of land use systems for D&D purposes).

On completion of the D&D-based agroforestry research and development project it is very likely that the technologies developed for the selected land use system(s) can be treated as 'prototype' technologies which can be adapted to the needs of similar systems outside the original project area. Thus, even within the system-specific context of the D&D methodology, a certain amount of generalization will be possible with respect to the resulting technological products.

ON THE OPTIMUM LEVEL OF DOCUMENTATION

Regardless of the type of application, the purpose of the D&D methodology is not to generate a massive volume of documentation for its own sake. Documentation of the results of each step in the D&D process should be regarded, not as an end in itself, but as a means of 1) aiding the D&D team toward greater clarity and specificity in the consensus developed, and 2) communication of the consensus to others. Minimally, the team should strive for a level of documentation which adequately communicates the design result (in sufficient detail to avoid misinterpretation of precisely what technology is envisaged) as well as the diagnostic rationale for it. In regard to the maximal limit, the users of the D&D methodology should avoid producing such a volume of documentation that no one would be tempted to read it. As an aid to documentation the companion volume to these guide lines (4) contains a set of Worksheets for use at each step in the D&D procedures. These might form the basis for something like an 'optimal' level of documentation, but they would have to be tied together by a prose account to produce a readable case study report.

In an effort to assist in the documentation and dissemination of D&D results, ICRAF has inaugurated a series on Case Studies in Agroforestry Diagnosis and Design, where suitable case studies might be published. Also, to foster the use of case study material to aid in the development of agroforestry, similar to the use of case studies in the development of medical science, ICRAF is establishing a computer-based D&D data bank at its headquarters in Nairobi. A recording form for coding of case study information is being developed for users of the methodology who may wish to contribute to the global data bank, without necessarily having to produce a full case study report. All users of the D&D methodology are urged to contribute to this global documentation effort in one form or the other. Due acknowledgement will be given to the contributors of such information in any publication making specific use of it.

D&D AS PART OF THE 'INTERNAL GUIDANCE SYSTEM' OF AN R&D PROJECT

These guidelines concentrate on procedures for Diagnosis and Design at the formulation stage of agroforestry research and development (R&D) projects, but the need for the basic process of diagnosis and design does not vanish once the project is under way. Even with adequate pre-project D&D preparation it is unlikely that the project implementation staff will have the same view of technological prospects for the project area at the end of the project as at the beginning. There is usually a learning process which causes project staff to modify their view of technical options as the project progresses. Unfortunately many projects are 'writ in stone' from the beginning and there is little opportunity to benefit from this learning process.

The suggestion that the D&D process should be continued throughout the life of the project is intended as a corrective to this situation by formally acknowledging the importance of the mid-project learning process and giving it a central place in project design. Figure 1 presents a schematic representation of the key features of the D&D paradigm, showing the feedback linkages which enable it to fulfill its potential role as part of the project's internal guidance system.

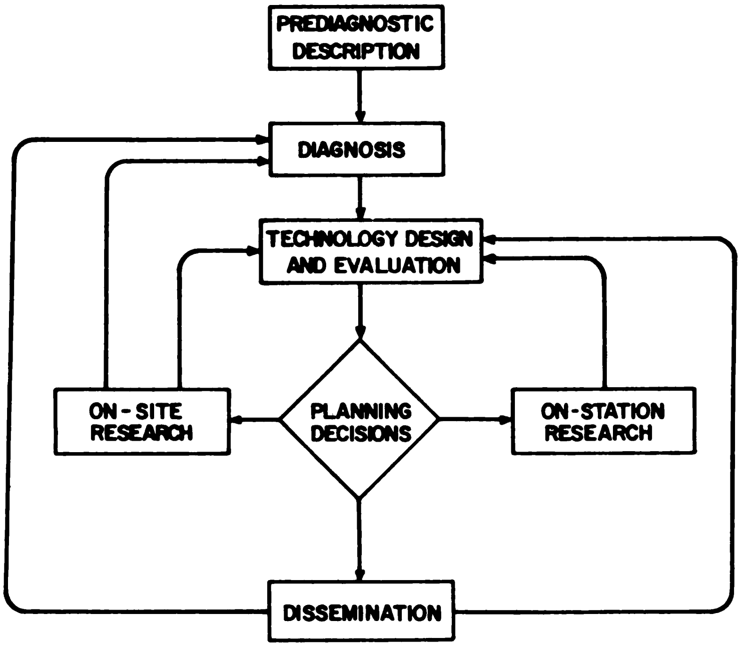


FIGURE 1 COMPONENTS OF PROJECT DESIGN INCORPORATING THE D&D PROCESS PART OF THE PROJECT'S INTERNAL GUIDANCE SYSTEM. NOTE FEEDBACK LOOPS

Both on-station research, involving controlled experimental investigation of fundamental aspects of the proposed technologies, as well as on-site research, involving in situ trials of candidate 'technology packages' on representative land management units in the project area, are necessary components of a coherent and effective R&D programme to develop appropriate agroforestry technologies. The initial guidance for the type of research which is needed for both of these research components is given by the initial D&D exercise. As the project progresses, however, new information will be generated, both from a deepening of the diagnosis resulting from longer exposure to the client land use system at the research site as well as from an improved understanding of the technical option from on-site and on-station research. This information provides feedback which may suggest refinements in the diagnosis and modifications in the design. The diagnosed situation itself will change, moreover, as a result of the introduced technology, thus requiring a fresh diagnosis of the new condition of the system. Feedback of these various types of information will allow the project implementation team to 'track' the changing situation and 'home in' on an increasingly optimal design for improved system performance.

If we may be allowed a martial analogy, an R&D project without a mechanism for continuing diagnosis and redesign is like a missile without an internal guidance system. Without it the ability of the project to reach its target will be dependent on the accuracy of the initial 'sitings'. With it the project can redirect its efforts in accordance with continuously improved information on what is needed and how to achieve it.

In its fully developed form D&D is an iterative process which is repeated throughout the project cycle for different purposes at different stages (see Figure 2). In the initial 'pre-project' or 'project formulation' stage the D&D process is used to arrive at prototype designs to initiate the R&D project and set it moving along generally appropriate lines. At the 'mid-project' or 'project implementation' stage, the D&D process is repeated more-or-less continuously to deepen the diagnosis and refine the prototype designs in order to develop specifically appropriate designs for the given land use system. In the course of time the project will arrive at the point where the technology developed is considered ready for dissemination throughout a wider recommendation domain. At this 'pre-extension' stage a modified D&D process incorporating an expanded land evaluation exercise comes into play to assess the extrapolability of the developed technology and define the recommendation domain. The dissemination to new sites at the 'extension stage' will, in turn, generate new feedback information which can be used, through a scaled-down D&D process, to adapt the technology to a wider range of site-specific conditions (see Raintree (6) for an elaboration of this scheme).

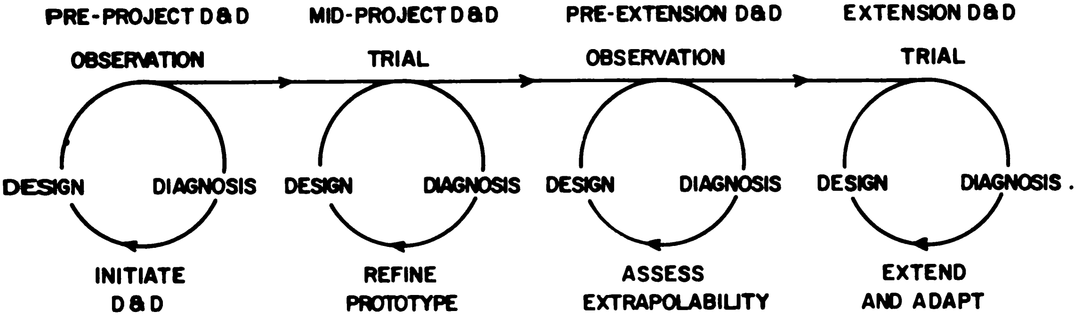


FIGURE 2 THE ITERATIVE D&D PROCESS IN THE LIFE CYCLE OF A TECHNOLOGY GENERATION AND DISSEMINATION PROJECT

Thus, in its fully developed form, the D&D methodology is a process approach to project implementation which, it should be noted, cannot be simply equated with 'Monitoring and Evaluation' as this is normally understood. In Monitoring and Evaluation various components of the project are monitored and the degree to which the project is meeting its objectives is evaluated. There is no explicit mechanism within the 'passive-critical' role conception of Monitoring and Evaluation to actively follow through with project modifications, let alone redesign project technology. What makes D&D different is its explicit focus on the technology generation process and its incorporation of active feedback mechanisms for institutionalizing the project learning process at the level of the implementing personnel. D&D does not replace Monitoring and Evaluation in the overall administration of the project, but it does provide an additional means by which project personnel may improve on their ability to generate appropriate technologies.

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FARMERS' ATTITUDES TOWARDS TREES

A. Marmillod*

SUMMARY

A survey was made of the farmer's perception of an agroforestry development project, and the problems the project sought to alleviate, in the mountainous areas of Acosta and Puriscal, Costa Rica. In sub-areas which were more developed, and which had higher population density, the following changes were noted: less diversity in land-use; lower incidence of trees with crops and pastures; greater preoccupation about future fuelwood supplies. Although many farmers approve of laws controlling tree felling, there was a mixed reaction due to the bureaucratic problems which affect the granting of permits.

Most of the trees are naturally regenerated, particularly those used for coffee shade and fuelwood, as well as most timber trees. The main motivation for planting trees is for fruit production, followed by timber production. There was no evidence that the farmers believed in a link between deforestation and the small landslides which are common in both areas.

It was concluded that the farmers will be receptive to tree planting programmes provided that their interests are met. In these areas the priorities for an agroforestry programme (tree component) should be: 1) fruit trees; 2) fuelwood trees; 3) fast growing trees that produce poles; 4) timber trees for saw logs. Emphasis should be given to the possibilities of establishing these trees in underutilized fence lines.

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INTRODUCTION

One of the goals of the CATIE*/GTZ** Agroforestry Project is to develop new, or improve existing, agroforestry systems in order to combat ecological and socio-economic constraints with which the farmers are confronted. However, response to an innovation depends very much on the way a person perceives the phenomenon for which the innovation has been developed and what his attitudes are towards it. For instance, a scientist's perception of an environmental event will not necessarily concur with that of a non-scientist; and if the scientist does not have the same cultural background as the non-scientist, discrepancies might be even bigger (9, 11). For a project working in rural development this means that attitudes of the target group towards the problems as defined by the project's technical staff, should be known in order to propose viable solutions.

In 1984 a study was made of the Acosta-Puriscal farmers' perceptions of the problems which had been identified by the CATIE-GTZ agroforestry project staff. The study was expected to show how far the project's activities (2) were meeting the needs and wishes of the farmers and, if necessary, to lead to modifications of those activities. The present paper refers only to one of the numerous problems identified: that is the gradual disappearance of trees from the area.

STUDY AREA

The study was carried out around two communities (Tabarcia and Guaitil) in the area of Acosta, whose characteristics have been previously described (2, 10). Between the northwestern and northern part (NW, N),which includes Tabarcia, and the much bigger remaining area (NE, SE, S, SW), which includes Guaitil, some important differences exist.

Topography: The whole area is very mountainous, but slopes are less steep in the NW and N (7).

Demography: Population density is approximately fifty percent higher in the NW and N, that is 73 vs 47 inhabitants km^{-2} (4).

Colonization: The NW and N were already populated in precolombian times (5) whereas the remaining area was colonized only 100 years ago (3).

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Urban influence: People living in the NW and N go to Santiago de Puriscal, the capital of the political entity ("cantón") Puriscal, in order to satisfy infrastructural needs such as secondary schools, extension office of the Ministry of Agriculture and Livestock, medical assistance, etc. People living in the remaining part of Acosta have access to San Ignacio de Acosta, capital of the "cantón" Acosta, which satisfies to a lesser degree the most important infrastructural needs and is also much smaller than Santiago de Puriscal.

METHODS

The main tool to determine perceptions and attitudes was a survey in the districts of Tabarcia and Guaitil, which are taken to represent the NW and N subregion, and the remaining area, respectively. There is evidence from other surveys in Costa Rica that responses may be unreliable in questionnaires completed by interviewers who are not previously known to the farmers. Therefore, in Acosta it was felt that more accurate results would be obtained if the surveys intensively sampled smaller areas, rather than randomly sampled larger areas.

In the study districts of Tabarcia and Guaitil, farmers were selected from the PIPA list; i.e. those farmers already selected by the Ministry of Agriculture for a "Project for Increasing Agricultural Production". Although this may imply a bias when the whole population is considered, it ensured that the survey results would be representative of the present agricultural development target group. 51 farmers were interviewed in Guaitil and 41 farmers in Tabarcia, which amounts to about 15% of the total number of farms in each district (8).

Data collection methods included direct observation, unstructured and structured interviews. For this study such procedures as sentence completion or other psychological tests (6) were thought to be too abstract for practical farmers. Instead, concrete questions were asked about each of the major problems identified by the project staff. Questions examined farmers' perceptions of environmental or socioeconomic problems like erosion, deforestation, lack of agricultural credits etc. Formulation of the questions was as neutral as possible. For example, in the section on trees, the term "deforestation" was never used. It is already value-loaded due to its use in mass-media and educational campaigns, and invited distorted answers.

In order to understand the farmers' perceptions of, and attitudes towards trees, the following aspects were examined:

1. Is the farmer accustomed to having trees on his land?

2. For what purposes does he have the trees?

3. Does he think of trees as a never-ending resource?

4. Does he see negative consequences caused by the lack or disappearance of trees?

Results for the two subregions were compared by the calculation of percentages to examine whether there existed inter-regional differences concerning perceptions and attitudes, and these differences are discussed with respect to the geophysical, historical and ecological differences between the two sub-regions.

RESULTS

General information

Farms are smaller in the district of Tabarcia (Table 1).

Table 1. Farm size distribution for groups studied in Guaitil and Tabarcia, Costa Rica (farms per size class; %)

Size classes (mz) (ha)	>0 - 5.9 >0 - 4.1	6 - 11.9 4.2 - 8.3	>11.9 > 8.3
Guaitil	57	14	29
Tabarcia	76	10	14

Coffee (Coffea spp.) is cultivated on all but one farm in both districts and corn (Zea mays) as well as beans (Phaseolus vulgaris) are also very important crops though the latter is more common in Guaitil (Table 2). The greater diversity of landuse in Guaitil is evident from the higher proportion of farms which have fruit trees, pastures, "charral"* and forest.

* Term used in Costa Rica for vegetation that regenerates naturally on an abandoned agricultural land.

Table 2. Land-use in the districts of Guaitil and Tabarcia, Costa Rica. (Occurrence on farms; %)

Land-use	Coffea	Zea mays	Phaseolus vulgaris	Oryza sativa	Saccharum cvs
Guaitil	98	73	73	14	43
Tabarcia	98	73	43	10	51

Land-use	Fruit trees	Tree plantations	Pastures	Charral	Forest
Guaitil	26	2	55	37	24
Tabarcia	15	2	46	17	17

Presence of trees

Trees are most commonly combined with Coffea and pasture (Table 3). They are also frequently present in home-gardens (84 and 58% of the farms in Guaitil and Tabarcia, respectively) and are used for live fence posts (61 and 76% of farms in Guaitil and Tabarcia, respectively). A surprisingly high percentage of Guaitil farms have trees combined with sugar-cane (Saccharum cvs) and the absence of trees in annual crop areas is noteable.

Table 3. Incorporation of trees in different land-use practices (proportion of farms with trees combined with the respective land-use; %)

Land-use	Coffea	Saccharum cvs.	Phaseolus vulgaris	Zea mays	Pasture
Guaitil	94	55	6	0	93
Tabarcia	85	10	0	7	79

Only one farmer in Tabarcia has no trees (Table 4). There appears to be a slight tendency for Guaitil farmers to diversify more their tree resources, since only there do some farmers have trees included in more than five land-use practices. However, the percentages in between these two extremes are very similar for both areas.

Table 4. Number of land-use practices which include trees (proportion of farms; %)

Nº of practices	0	1	2	3	4	5	6	7
Guaitil	0	2	12	29	20	16	18	4
Tabarcia	2	7	22	29	22	17	0	0

Products obtained from existing trees

The principal purposes for which trees are used have the following order of descending importance: fruit, fuelwood, stakes, timber and shade (Table 5). Most farmers in Guaitil use timber for construction on their own farm and only a few sell it. However, the opposite occurs in Tabarcia.

Table 5. Purposes for which trees are used (proportion of farmers*; %)

Purposes	Fruit	Fuel-wood	Timber sale	Timber own use	Shade	Stakes	Other
Guaitil	92	78	8	55	55	51	6
Tabarcia	95	77	20	37	23	67	6

* The one farmer who has no trees is excluded from this table.

Reasons for planting trees

Almost all farmers in the two districts plant fruit trees, although the proportion is slightly higher in Guaitil (Table 6).

The proportion of farmers who plant timber trees is noteable, but none of the farmers interviewed in Tabarcia ever plant shade-trees, whereas some farmers do so in Guaitil. Also, there are clearly more farmers planting trees for fuelwood in Guaitil than in Tabarcia.

Table 6. Reasons for planting trees (proportion of farmers; %)

Reasons	Fruit	Fuelwood	Shade	Timber	Live fences
Guaitil	96	22	12	29	55
Tabarcia	85	5	0	35	60

The importance of trees in terms of diversity of reasons for planting them is higher in Guaitil. Some of the Tabarcia farmers (13%) never plant trees. In Guaitil as in Tabarcia, two different reasons are usually given for the planting of trees.

More farmers in Tabarcia than in Guaitil think that the fuelwood supply will become critical in the future. The proportions of farmers with an attitude which was interpreted as non-conservationist ("not problematical because of abundance of wood") are almost equal for the two districts (Table 7), but was overall the smallest group.

Table 7. Opinions on future fuelwood supply (proportion of farmers*; %)

Opinions	Problematical	Not problematical**	Not problematical***
Guaitil	42	44	13
Tabarcia	54	29	16

* Only those using fuelwood and claiming their own farm as the main source.

** Because of conservation of wood resources.

*** Because of abundance of wood.

In both districts, most of the farmers who think that the fuelwood supply will be precarious in the future, offer conservational measures such as "tree planting" and "careful treatment of resources" as a solution (Table 8). Only one farmer considers the situation serious enough that he is prepared to steal it!

Table 8. Possible solutions for fuelwood shortage (Number of farmers)*

Solutions	Plant trees	Careful treatment of resources	Buy fuel-wood	Steal fuel-wood	Use elec-tricity
Guaitil	7	6	1	0	2
Tabarcia	13	1	1	1	1

* Only those farmers who think that the fuelwood supply will be problematic in the future (see Table 7).

Disappearance of trees

Almost all farmers interviewed in Guaitil and a majority in Tabarcia claim to approve of the law which obliges farmers to obtain a permit before cutting a tree (Table 9). More farmers in Tabarcia than in Guaitil state their restricted approval or disapproval. The usual explanation was that obtaining a permit is a complicated bureaucratic procedure.

Table 9. Opinions on "permit" for cutting trees (proportion of farmers; %)

Opinion	Approval*	Approval**	Restricted approval	Disapproval	No opinion
Guaitil	53	37	4	6	0
Tabarcia	35	23	28	13	2

* Because of protection of water resources.
** Because of protection of wood resources.

DISCUSSION

Farmers are obviously accustomed to having trees on their land. This is more noteable in Guaitil where very steep slopes and difficult access to some areas reduce the probability of cutting trees. It is also possible that farmers there are not as pressured to cultivate every piece of land in an optimal way. As a consequence we even find trees in many sugar-cane (Saccharum cvs.) fields.

The higher percentage of Guaitil farmers having "charral" could be related to the more frequent occurence of "covered bean" cultivation (Table 2) (2), which involves a fallow period. The percentage of farmers cultivating P. vulgaris does not correspond to that of farmers owning land with "charral" because many farmers use clean cultivation techniques.

The more frequent association of trees with Coffea in Guaitil (Table 3) could be related to a lesser influence of the Government extension agency, which has been recommending a reduction in the use of shade, sometimes interpreted by both extensionists and farmers as a recommendation to eliminate shade (which it is not). The small numbers of farmers accustomed to plant shade trees is related to this advice (Table 6) but is mostly a consequence of the practice of using natural regeneration for shade rather than deliberately establishing shade trees.

The main uses of trees in both areas, are for fruit, fuelwood, stake and timber production. Only the last use has a definitely destructive character, whereas fuelwood and stakes can be repeatedly harvested without eliminating the trees. Stakes are needed both for dead and live fences and to establish Coffea shade trees.

This study did not measure the quantity of fuelwood coming from trees. However, a parallel study in the same region found that fully grown trees constitute the most important fuelwood resource. Only small percentages of the fuelwood used came from Coffea-prunings (11% and 35% for Guaitil and Tabarcia, respectively) and even smaller percentages from live fences (1).

Considering the deforested state of the area (7), surprisingly high percentages of farmers in both regions have timber trees on their farm and use or intend to use them. Most farmers in Guaitil use timber for construction on their own farm and only a few sell it. However, the opposite occurs in Tabarcia, probably because a small saw-mill exists only there and also because the valuable cabinet timber species Cedrela odorata is especially common in this district.

The main product obtained from the trees is fruit and farmers are very interested in planting fruit trees, which promise a relatively quick and regular return. Especially for Guaitil farmers fruit trees constitute a non-labour intensive cash-crop. Although the use of trees for fuelwood is very high, very few farmers in either area plant trees for this purpose. Timber tree planters constitute only half of the timber tree cutters. So, even taking into consideration natural regeneration, which provides some trees without man's intervention, and the existing positive planting mentality, the number of trees on these farms is likely to continue to decrease. It appears that trees are not specifically planted for stake production. However, obviously live stakes are produced from live fences. For dead stakes "guachipelín" (Diphysa robinioides) is often used,since its wood is known to be rot resistent. However, it rarely appears in live fences in these districts. Farmers do not regard D. robinioides as a timber tree and consequently it is not included in the percentage of timber tree planters. One explanation for its frecuency and the extent of its use could be abundant natural regeneration (3).

A "planting" or conservationist attitude is also reflected by many farmers' appraisal of future fuelwood supply (Table 7). The percentage of those who are already doing something to prevent fuelwood shortages, either by planting or treating the resources carefully, is higher in Guaitil. It would appear as if on the whole, Guaitil farmers are slightly more concerned about the tree resource than Tabarcia farmers. Many of the farmers interviewed are aware of the potential importance of trees for water conservation. It is the opinion of the author, however, that theoretical knowledge will probably never outweigh immediate material considerations as regards the use of timber trees. Who will blame a farmer, who wants to build a house for his son, for using trees from his own farm (even if cutting them down will have a negative environmental effect), rather than buying the wood at a considerable expense? Moreover, the negative effects of tree cutting are not yet severe enough to scare the farmers. It is noteable, that there was no evidence from the interviews that the farmers were aware of a link between landslides and deforestation.

On the other hand, the Ministry of Agriculture and Livestock has not done its best to facilitate acceptance of the tree cutting permit. More than one farmer has had to undertake several trips to the office where the permit is issued. This means loss of time and money, sometimes without even reaching the objective at all. The less enthusiastic approval of the permit by Tabarcia farmers is probably related to the occurrence of the commercial species Cedrela odorata in pastures and Coffea-plantations on many farms in that sub-area. These trees cannot be harvested without a permit. On the other hand, the use of forests, which rarely includes commercial tree harvesting, is less influenced by the regulations. This probably explains the absence of any relationship between ownership of forest and the farmer's attitude to the permit. Neither were there any relationships between the farmer's attitudes and other individual variables such as educational level of the farmer, size of the farm, years of managing the farm and contact to extension programmes. It should be emphasized that such a lack of relationships is not considered as unusual (9). However, it is possible that multivariate analysis of the data will reveal correlations between attitudes and groups of these variables. Such an analysis is in preparation.

CONCLUSIONS

The situation can be considered as promising for any project that wants to strengthen the tree component on the farms, provided that the farmers' needs and wishes are met.

The importance given by farmers to fruit trees has special relevance for the CATIE-GTZ project, which has tended to emphasize timber species, although some fruit trees have been introduced through the small farm nursery programme. Advantage should be taken of this very clear interest expressed by the farmers, although attention should be given to aspects like commercialization before wide-spread changes are promoted.

Apart from fruit, fuelwood seems to be the most important tree product. Since quite a lot of farmers do think that the future fuelwood supply will be problematical, and also quite a lot actively work with live fences, another possibility to strengthen the tree component and reduce the pressure on existing trees would be to intensify the use of live fence posts. But as a first step it must be clarified why farmers presently obtain so little fuelwood from live fences. Perhaps the trees used for this purpose at the moment are not producing fuelwood with optimal characteristics, and other species, or alternative management techniques of the existing trees, should be tested.

Since "timber for own use" and "stakes" are also clearly important tree products, the CATIE-GTZ project should give emphasis to fast growing species that provide products like small round wood, and not so much to species like C. odorata whose principle value is as a saw timber.

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FACTORS AFFECTING THE ADOPTION OF AGROFORESTRY INNOVATIONS BY TRADITIONAL FARMERS

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SUMMARY

There are two distinct kinds of factors affecting a farmers's willingness to adopt or reject a given technological innovation:

a) objective, situational or "economic" factors, and
b) subjective, cultural or "cybernetic" factors

The latter category includes culturally patterned perceptions, values and ways of thought, and the analyst will have to pay special attention to this in order to find clues to understand the farmers' behaviour, that is often unexplainable by situational factors.

The major components of the process of decision making by the farmers to adopt (or reject) given technologies are:

1. Characteristics of the potential adopter,
2. Characteristics of the candidate technology,
3. The nature of the communication process.

The special attributes of the potential adopter that merit attention here include: the behaviour of man as a biological organism in a given environment;

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as a rational individual ("economic man", who frequently is a woman); as a member of the society; and as a member of his particular culture.

Characteristics of the candidate technology that are of significance here are: its observability; trialability; technical complexity (or simplicity); cultural compatibility; and its relative advantage over other known technologies.

After getting the right technology, the communication and information processing should be shaped in such a way that farmers have a full participation and involvement in demonstrations and trials. The assimilation - accommodation strategy should follow the path of least resistance when introducing new information into a traditional cultural system. Once the candidate technology has been subjected to a fair and reasonable trial as above, the technologist may leave the scene, leaving it to the farmer to decide for himself whether or not to adopt the innovation.

INTRODUCTION

For the sake of discussion, let us assume that, as researchers and/or extension workers, we are in possession of a stock of agroforestry technologies that we think are, in themselves, "pretty good things". In principle, we believe, if farmers adopted our technologies, the productivity and sustainability of their farming systems would be improved and the general welfare would be raised. We are encouraged in this view by the fact that many of the technologies in our current bag of tricks were themselves taken from or inspired by indigenous practices in traditional farming systems in some part of the world.

That being the case we are somewhat perplexed when farmers are less than sanguine about the adoption of agroforestry technologies. How do we account for this?

Let it be said straightaway that, no matter how much we like our technologies, it is gratuitous to assume that they have a simple, objective and universal reality, independent of the context in which they are to be applied. Technological relativity is such that it is impossible to evaluate the appropriateness of a technology without knowledge of its intended context. Let us also agree from the outset that it is no longer acceptable to employ such vague notions as "the backwardness of the farmers" to explain their lack of interest in our technologies. We don't speak of soils or plants in such simplistic terms, so why should we assume that the complexities of farmer decision making can be dealt with in much simpler terms than those with which we analyze the other components of land-use systems?

In order to understand why a farmer might decide to adopt or reject a given technological innovation it is necessary to deal with farmer decision making on its own terms, in other words to try to achieve an "inside view" of the technology, as seen from the farmers' standpoint. In doing this we need to overcome our own "technological ethnocentrism". The technology might look good to us, given our backgrounds and ways of looking at things, but how in fact does it look to the farmer? Perhaps the statement made by a farmer to a researcher in Sierra Leone may help put the issue in perspective (7 cited in 1).

> "Who does not want to improve his lot? We like the present farming method--make no mistake about that--but if there are new techniques which are better, I would like to try them. However, for me to accept a new technique, it must not only produce more food; it must be cheap enough for me to cope with, and it must above all, be beautiful in the ways of our society".

This statement clearly exemplifies some of the key points of the discussion which follows: "who does not want to improve his lot"? (rational man); "we like the present farming method" (attachment to traditional ways); "but if there are new techniques which are better..." (willingness to innovate). The farmer then goes on to state the criteria which a candidate technology would have to meet in order to be seriously considered for adoption by him. The first two criteria are quite intelligible to us, but what does the farmer mean by "beautiful in the ways of our society?" (Actually the last part of the statement is a reference to the ceremonial activities of the dry season, which would be disrupted if multicropping, the technology under discussion, were adopted).

What the farmer's statement illustrates, and what my own experience leads me to believe is generally the case, is that in trying to understand the farmer's decisions we are always dealing with two distinct kinds of factors:

1) objective, situational or "economic" factors and what we might call, for lack of a better term,

2) subjective, cultural or "cybernetic" factors.

Under the first category we include those factors which anyone can see who takes the time to look at the farmers' situation. Once these "situational" factors are seen and understood the farmers' behaviour often becomes intelligible as, more-or-less, "what any rational person would do under the circumstances". The second set is defined by a kind of residual category of factors associated with decisions, whose rationale remains obscure to us even after the situational factors have been taken into account. It includes those factors which can be seen only when a particular point of view or attitude is adopted, i.e. those culturally patterned perceptions, values, ways of thought, and other aspects of information processing which inform us of "what these particular people are likely to do under the circumstances as they see them". I am alluding here to what is commonly referred to by anthropologists as the "etic" and "emic" points of view.

As a general rule of thumb it is recommended to first examine the situational factors. If situational constraints and opportunities (ecological, economic and social) do not explain a farmer's decisions, then it will pay the analyst to look deeper into cultural factors for clues to the farmer's behaviour.

COMPONENTS OF THE ADOPTION DECISION PROCESS

In order to better understand what is important about the distinction just introduced, it may be useful to first examine the processes by which decisions about adoption are made. The subject has been treated extensively in the literature on the adoption and diffusion of innovations, for example Rogers and Shoemaker (14). For present purposes it is sufficient to distinguish three essential components of the adoption decision process:

1) characteristics of the potential adopter,
2) characteristics of the candidate technology,
3) the nature of the communication process by which information about the technology is transmitted, along with aspects of internal information processing leading up to the adoption decision.

We will briefly examine each of these in turn, to see what constraints and opportunities might arise at each point.

Characteristics of the potential adopter

In dealing with an individual decision-maker we are always dealing with a complex personality composed of several different layers of identity, each of which exerts a characteristic influence on his/her decision making processes. A farmer is:

1) A biological organism in an environment, subject to a whole set of ecological influences which determine his primary survival feedback; of particular importance are the long-term effects of Man, as an ecological dominant, on the biological carrying capacity of his environment and the land-use changes which human modification of the environment force him to adopt. Man and environment are intimately linked through the process of "coevolution".

2) A rational individual whose innate shrewdness and self-interest lend some common sense predictability to his behaviour. This is "Economic Man" or "the rational producer" so basic to economists' models of human behaviour. Social scientific evidence provides overwhelming support for the conclusion that much of the traditional farmer's behaviour is predictable by this model, once the relevant situational factors are known. Of late, it has been brought to everyone's attention that in many cases "Economic Man" is a Woman and that this has important implications for the kinds of decisions she, given different situational constraints from men, is likely to make about agroforestry (3, 4).

Another important dimension of individual difference is whether the farmer has a predominantly commercial or subsistence-oriented production strategy. Both may be considered eminently rational in context: commercial orientations make sense when there is a viable cash enterprise, when the market supply of food and other basic needs is reliable, and when favourable price relations exist between what is sold off the farm and what must be purchased in; subsistence orientations are rational whenever any of these conditions is not met. In practice we often find a mixed strategy, balancing potential gain against potential risk.

Individuals also differ with respect to the ease with which they take to change. Rogers and Shoemaker (14) distinguish five categories of adopters (the figures in parentheses are roughly indicative of their relative proportion in human populations): innovators (2.5%), early adopters (13.5%), early majority (34%), late majority (34%), laggards (16%).

3) A member of society subject to all the constraints and conventions that govern behaviour between individuals in a social group and make an orderly social life possible. Many of these conventions are concerned with the regulation of competition between individuals in order to achieve the level of cooperative behaviour which is, despite repeated setbacks, still highly characteristic of human social life. The kinds of decisions an individual will or can make are to a very large extent determined by who he or she is in the eyes of society, i.e. the individual's status and role identities, group membership, etc. One very influential set of land-use constraints and conventions is that whole body of statutory and customary law concerned with land and tree tenure (2, 12). A person may decide to forego an otherwise attractive agroforestry innovation for the sole reason that he or she does not have sufficient security of tenure to justify the investment.

4) A member of a culture bearing population. Closely related, but conceptually distinct from the farmer's identity as a member of society is his/her role as a culture bearer. Simply put, culture is the informational basis of human

life, both individual and social. Human instincts are notoriously underdeveloped as a detailed blueprint or programme for human behaviour. Without the knowledge, values, attitudes and conventions supplied by our "cultural software", we simply would not know what to do most of the time. Culture encodes a vast body of survival knowledge and experience which otherwise would not be available to the individual. Culture makes social life cumulative, without culture human life would remain quite primitive. Culture has to a large extent surplanted biology as Man's adaptive dimension. Culture is not something to be lightly changed or dismissed. On the other hand, cultural conservatism--a necessary thing in itself if accumulated knowledge and experience are to be preserved--can constitute a significant, although usually temporary, barrier to innovation.

All viable cultures (by definition) maintain both a capacity to innovate and a means to preserve the cultural heritage and resist excessively rapid cultural change, thus achieving some kind of continuity-in-change or "ultrastability". In the end, if we are optimistic, we may expect economic realism to prevail over cultural conservatism, but we must never think that the resulting change is easy to accomplish. Of course, some cultures actively foster continuous change by nurturing the formation of personalities well adapted to life in the fast lane. It remains to be seen whether this will prove to be adaptive in the long run.

Characteristics of the candidate technology

Roger's and Shoemaker (14), identify 5 adoption-facilitating attributes of technological innovations (not necessarily in order of importance):

1) Observability. How visible is the innovation? Do farmers have a chance to observe it? Are the advantages of the innovation apparent?

2) Trialability. How easy is it for the farmers to gain direct experience with the candidate technology on a trial basis? Very often mere observation is not enough. Most farmers must try it for themselves before they fully comprehend the operational aspects of a new technology. Only then can they make a well informed decision about adoption. Those tree based systems which have a long establishment period may suffer from lack of trialability.

3) Low technical complexity. No matter how efficient a technology may be in energetic or "economic" terms, if it is informationally complex and difficult for the farmer to master, it's adoption may be retarded by low "cybernetic efficiency". Even if an agroforestry system is capable, for example, of achieving substantial savings in human physical effort, it may require too much mental effort (management attention) to be easily adopted by farmers as long as the old

familiar ways are still capable of providing reasonable results. Relatively simple or self-managing agroforestry systems will usually stand a better chance of success than complicated or management-intensive ones. Given the inherent temptation toward complexity in agroforestry designs, simplicity, effectiveness and economy of effort-in short elegance-may well become an important design criterion in agroforestry.

4) Cultural compatability. Other things being equal, technologies which are non-disruptive of social conventions and consistent with the general style of established land-use traditions stand a better chance of adoption, obviously, than those which depart from these conditions. Technologies which build upon established practice and incorporate deliberate elements of cultural familiarity are simply more likely to succeed. This is another aspect of "cybernetic efficiency". Technologies which are otherwise highly appropriate to local conditions may require too much learning, too much rethinking, too much cognitive or social restructuring to be easily adopted unless under pressure. If trees are foreign to the local land-use tradition, agroforestry may be at a disadvantage.

5) Relative advantage. Usually thought of by outsiders in economic terms, what this criterion really refers to is the farmer's total evaluation of the candidate technology vis-a-vis other alternatives, including the traditional technology. As we have seen, both "economic" and "cybernetic" factors may enter into the weighing process. First judgements are not necessarily best judgements. Usually, a thorough demonstration and trial will be necessary before farmers in an area will be able to get beyond their initial reactions and bring their best, fully informed judgement to bear on the adoption decision. Perhaps the innovators and early adopters in the area can assist as co-developers, early demonstrators and trial adopters of the technology, but primary feedback on its wider adoptability must come from representatives of the majority of potential users. Are they or are they not adopting it? Adoption need not be an all-or-nothing phenomenon; modifications of the prototype technology, which originate from the farmers, are likely to enhance its adoptability.

Farmers' time is valuable. Indeed, time is running out for a solution to the critical environmental and production problems of some areas. As researchers and extensionists, it is encumbent upon us to focus in as quickly as possible on what is really needed and limit our research and extension efforts to those technologies which are most likely to be effective and adoptable. Given the relatively long gestation periods for agroforestry systems on the ground, we really cannot afford to take a "hit or miss" approach. ICRAF's "Diagnosis and Design" (D & D) methodology offers one way of arriving at appropriate agroforestry designs for a given locality (5, 6, 11).

Although much research needs to be done to validate the soundness of existing agroforestry practices and to develop improved components and management systems, the contents of agroforestry's eventual bag of tricks are beginning to be discernable. Figure 1 presents an intuitive synthesis of my own expectations regarding the conditions under which some of the most promising agroforestry systems will find their greatest relative advantage. Different agroforestry options and development pathways (arrows) open up from different stages in the evolutionary sequence from forest fallow shifting cultivation to multicropping. The R index shown on the left gives a rough indication of the land-use intensities corresponding to the population densities shown on the right. R = (C/C+F) x 100 where: C = cropping period, F = fallow period. The R index is also equivalent to the percentage of land in cultivation, as read from aerial photos. Boserup's treatment as a "frequency of cropping" index allows the interpretation to be extended to multicropping. For R > 100, R corresponds to the number of crops taken per year x 100.

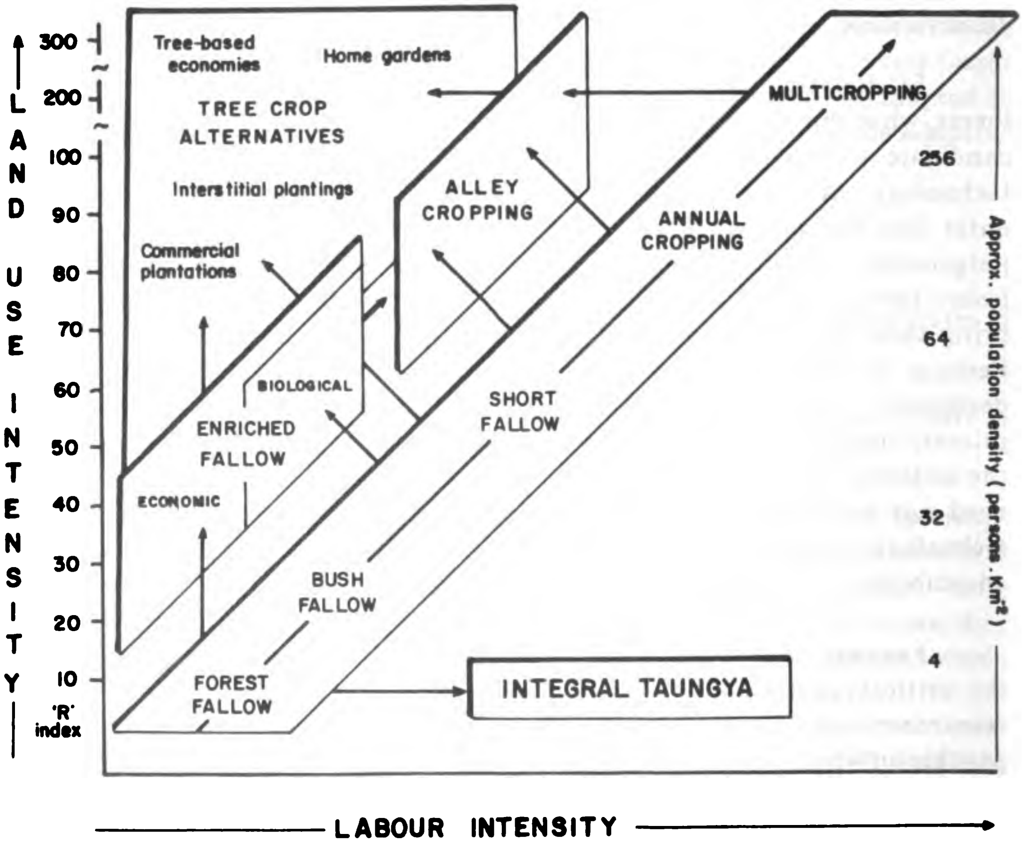

Fig. I. Agroforestry pathways for intensification of land-use in major tropical farming systems

Aspects of communication and information processing

This abbreviated treatment of the subject would be seriously incomplete without some discussion of communicational and information processing aspects of the adoption-decision process. The following five points are certain rules of thumb which I have found to be useful in dealing with critical aspects of communication and information processing in traditional communities (cf. Raintree (9) for a more complete discussion of these aspects).

1) First get the technology right; then, recognizing that there may be cultural barriers of a superficial or temporary nature which impede the adoption of what would in time be regarded as a genuinely appropriate technology, see what can be done to catalyze information processing, and work through the resistance to a deeper resolution of the issue. There is a good chance that this advice will be misunderstood. I am not advocating a forceful approach to extension which assumes that the extensionist knows best for the farmer. But it is naive and, in fact, unfair to the farmer to assume that his first impression of a new technology will be his last, or that his initial reaction will represent his best, most informed and balanced judgement. In order to give the farmer a fair chance to become informed about the technology, it may be necessary to help him overcome certain virtually "automatic resistances" originating in the conservative rather than the innovative side of his culture, and then win through to a balanced judgment.

2) Never underestimate the value of demonstration and trial. If a picture is worth a thousand words, a demonstration is worth a million and a trial by the farmer himself ten million! The opportunity to experience the actual operational characteristics of an agroforestry innovation is what farmers need, more than anything else, to arrive at an informed decision on the adoption question.

3) Develop the technology with the full participation of the farmers. This is a logical extension of the foregoing rule. All demonstrations, in principle, should be conceived of as trials, since all technologies should remain open to corrective feedback and improvement by the intended users. The extensionist, should never think that he has the final answer, nor should he underestimate the value of farmer originated improvements. In the first place, some minor modification that the researcher/extensionist would never think of, might be all that is needed to make a technology click. The very fact of farmer participation in the design of an agroforestry system may go a long way toward reducing its "foreigness". On-site research along these lines may amount to a head start on the extension process, made all the smoother by farmer participation from the very beginning.

4) Make use of the assimilation-accomodation strategy to follow the path of least resistance when introducing new information into a traditional cultural system. Jean Piaget's model of the two stage "assimilation-accommodation" process, first discovered through research on human cognitive development is quite widely applicable, I would argue, as a description of the way all learning systems take in information. First, the individual or social group assimilates the new information to itself by relating it to pre-existant cognitive constructs or culturally patterned ideas. At this stage the internal image of the external object or idea may be highly distorted, but at least it has been incorporated. Once the idea has taken root inside the system, it then undergoes gradual accommodation toward a more accurate representation of the external reality. In other words, when trying to introduce a new technological idea it is counter-productive to insist on a fully detailed and accurate understanding of the thing right from the start. Let people first relate to it in their own terms, and then later, if necessary, refine the image they have of it until it reflects the reality one is trying to convey. In the process of communicating about the technology a new and better reality might be created.

5) Once the candidate technology has been subjected to a fair and reasonable trial, get out of the way and let the local people themselves decide whether or not to adopt it, for to them alone belongs the sovereign right of decision making in all matters of livelihood and survival.

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DEVELOPMENT AND APPLICATION OF AGROFORESTRY PRACTICES IN TROPICAL ASIA

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SUMMARY

The origin of both traditional indigenous agroforestry practices and of scientifically developed agroforestry techniques can be found in tropical Asia. Many different agroforestry systems prevail in the region, a lot of which evolved from the adaptive strategies, of local farmers, to the changing socio-economic situation. Often such strategies were based on partial incorporation, into their farming systems, of certain cultivation practices developed in scientifically managed tree crop plantations. Research on the potential of agroforestry in tropical Asia has increased considerably during recent years. Most research consists of descriptive and analytical studies of existing systems, while experimental studies on innovative techniques are still scarce. The latter research is more often directed at commercial practices than at subsistence techniques. During the last years an increased application of agroforestry techniques also can be observed. But this development is not primarily based on the transfer of scientifically developed innovative agroforestry techniques, but rather on farmers' responses to increased demands for tree products and to government programmes which stimulate tree growing by providing better access to critical production factors such as land, credit or market outlets.

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INTRODUCTION

It has been hypothesized that gardening is the oldest form of agriculture and its origin has been associated with communities living in the moist tropical regions of South-East Asia (31). Such gardening probably started as a spontaneous growth of plants from leftovers brought to the camps of collectors, and the gradual development of deliberate planting at these sites to facilitate future collections. As such planting took place in a forest environment these practices can be designated as agroforestry.

Not only does tropical Asia provide the oldest example of indigenous agroforestry practices, but also the origin of professional agroforestry practices can be traced to this region. As is well-known, over one century ago foresters in Burma developed the taungya system. The development of this system was based on the example provided by the indigenous shifting cultivation techniques. As such it is the first example of the professional application of principles underlying indigenous agroforestry practices. The taungya system proved successful and spread to many other countries in the region (13) as well as outside the region.

Another example of the development of professional tree cropping systems in tropical Asia is provided by the cultivation of commercial tree crops such as coffee (Coffea spp.), tea (Camellia sinensis), rubber (Hevea brasiliensis) and oilpalm (Elaeis guineensis). Although the development of these exotic tree crop plantations took place under a colonial system of dual economies, in which only selective efforts were undertaken to involve local farmers in the production of tree crops for the export market, the development of the colonial tree cropping still had a profound impact on traditional farming systems. Many of the exotic tree species were gradually incorporated in indigenous cultivation systems. Mostly such adaptations occurred spontaneously, sometimes even in spite of the government's pessimism about the ability of local farmers to cultivate these tree crops. For instance, in Indonesia colonial government officials were of the opinion that Hevea rubber could only be properly cultivated in estates managed by professionals; they even advised local smallholder farmers against this crop. Nonetheless, shifting cultivators quickly and easily incorporated rubber trees into their swiddening systems, stimulated by high market prices and the encouragement and seed supply from Chinese traders. Some of the cultivation techniques of the swidden cultivators were even found to be superior to the management practices in the rubber estates (27).

The farmer's adaptation of exotic trees, originally introduced for estate purposes, not only involved commercial crops but also certain kinds of multipurpose trees. A common practice for the cultivation of certain cash-crops was the use of auxiliary trees providing shade, mulching material and other services. Several such trees (e.g. Albizzia falcataria, Erythrina spp., Gliricidia sepium, Leucaena leucocephala) are at present important constituents of indigenous agroforestry systems.

From this short historical review, it is evident that agroforestry practices have long played an important role in land husbandry in tropical Asia. Many systems gradually evolved as a result of the interplay between traditional and newly developed scientific methods for land management. As a consequence, at present a large variety of agroforestry systems can be found in tropical Asia (Table 1). Many of these systems have been neglected for a long time in scientific studies on land-use practices in the region. During the last decade, with the advent of international recognition about the potential for the use and development of agroforestry in tropical Asia, increased attention is being given to research and the promotion of agroforestry. This is reflected in a host of national meetings and reports, e.g. in India (14, 33), Indonesia (30, 42), Pakistan (2), the Philippines (12, 26, 32) and Thailand (15, 19). Regional reviews have also been provided (e.g. 1, 16, 37).

This growing interest in agroforestry is also reflected in an increasing number of research projects on agroforestry, and of projects to stimulate agroforestry practices in the field. This paper is concerned with the present situation in regard to technology development and the application of new agroforestry practices in tropical Asia.

TECHNOLOGY DEVELOPMENT

Research on agroforestry can broadly be divided into three categories:

a. Descriptive studies which inventory the existing systems and describe their general features;

b. Analytical studies which investigate the structure and function of specific systems in more detail;

c. Experimental studies which test new agroforestry designs

In general it seems that in tropical Asia many agroforestry studies belong to the first category. Indeed, such studies are still urgently needed because there is a dearth of information on existing systems. Recently several very interesting examples of indigenous agroforestry practices have been published, e.g. the presence of Dipterocarp agroforest in Sumatra (39) and rattan fallows in Borneo (41). New data are also becoming available through the ICRAF agroforestry systems inventory (4, 21). Such scientific discoveries makes one wonder how many tropical Asian systems remain to be described.

Of the many systems already described (Table 1), only a few have been subject to more detailed analytical studies. Many of these have concentrated on shifting cultivation and since the pioneering works of Freeman (6), Conklin (11) and Spencer (35) many studies have been made on ecological and anthropological features of shifting cultivation in different Asian countries (1, 19, 20, 25). More recently a lot of attention has also been focussed on home-gardens and related multistoryed systems (5, 23, 34, 43). Most of these studies analysed the structure and function of indigenous agroforestry systems, but in some studies attention has also been given to the dynamic nature of the systems and their historical development in relation to socio-economic change (10, 22, 25).

Although the results of such analytical studies cannot be translated automatically into the design of new agroforestry techniques, these studies are still essential to provide a firm scientific base from which to start designing new technologies. The applicability of such innovative techniques will have to be proven in further experimental studies. In several cases the translation of the analytical understanding of traditional systems, into improved agroforestry designs, may not take too much time. Indeed, it has been proposed that for the time being most progress in agroforestry can be expected from small incremental improvements of existing practices. By basing innovations on existing indigenous systems not only will they be compatible with known practices, but also their advantages and effects will be easily observed and understood by local farmers (28). The dynamic nature of several indigenous agroforestry systems in tropical Asia indicate that in the past local farmers have been very successful in developing such adaptive designs. Far less examples are available of the translation of the results of analytical studies into scientifically developed innovative designs, although undoubtedly important advances have been made by scientists in regard to the development of new technologies.

The most important scientific contribution to agroforestry development in Asia, based on experimental research, probably concerns the development of efficient cultivation techniques for commercial tree-crops and timber plantations. Originally this research was mainly oriented to the development of improved production of single commodities. For instance the early taungya practices were mainly directed at decreasing establishment costs for forest managers. Similarly, the use of shade trees in cash-crop plantations aimed at increasing yields of C. sinensis, Coffea or cocoa (Theobroma cacao). An interesting example is also the development of planted fallows for more efficient tobacco (Nicotiana tabacum) cultivation in Sumatra(44). In much of this early

Table 1. Agroforestry systems in tropical Asia (modified after Tejwani, 37).

Agrisilvicultural systems natural forest trees		Occurrence and examples
Systems dominated by natural forest trees	Shifting cultivation	Prevalent in whole region with tropical rain forest, mixed deciduous forest or montane coniferous forest
Systems dominated by planted (timber) trees	Shifting cultivation with planted fallow	Rattan fallows in Borneo, Prosopis fallows on saline soils in arid South Asia.
	Taungya	Used in India, Indonesia, Malaysia, Philippines, Sri Lanka, Thailand for establishment of plantations of Tectona grandis, Pinus spp., Gmelina, etc.
	Intercropping in forest plantations	e.g. cultivation of medicinal crops in forest plantations in India, Indonesia.
System dominated by fruit trees or cash crops	Multistoryed cropping	Prevalent in humid regions: forest gardens, mixed gardens, homegardens with mixtures of timber trees, fruit trees, cash crops, vegetables and/or root crops. In more open systems also staple crops such as Oryza sativa, Manihot esculenta.
	Interplanting under commercial crops	Widespread in smallholder estates in humid regions especially under Cocus nucifera, sometimes also on estates
	Shade trees over commercial crops	Common in whole region for cultivation of Camelia sinensis, Coffea spp., Theobroma cacao. Main tree genus: Grevillea, Erythrina, Gliricidia, Leucaena.
Systems with scattered trees or trees in rows	Trees amongst crops	Widely used whole region in the form of scattered fruit and shade trees in agricultural fields with staple crops. Other examples: Robinia, Populus, Salix and Grewia on bunds in agricultural fields in Himalayas. Sesbania, Gliricidia or Combretum on bunds in rice fields in Southeast Asia, Prosopis in millet and Sorghum bicolor fields in India and Pakistan.
	Alley cropping	Locally well-established in Philippines (Cebu) and Indonesia (Timor)

Table 1. Agroforestry systems in tropical Asia (modified after Tejwani, 37). (continuation)

	Live fences	Prevalent in whole region, no details available.
	Shelterbelts and windbreaks	Mainly in arid zones, e.g. *Populus* and *Eucalyptus* along irrigation canals and fields in Pakistan
Silvipastoral systems		
Systems dominated by natural forest trees	Forest grazing	Prevalent in more arid regions
Systems dominated by planted (timber) trees	Pasture in forest plantation	Cattle grazing in *Tectona grandis* and *Pinus* forests, common in whole region; cattle grazed under *Leucaena* in Philippines; widely used in semi-arid regions
	Fodder plantations	Zero grazing systems under plantations, and fodder tree plantations, being developed
Systems dominated by fruit trees or cash crops	Pasture under commercial crops	Cattle under *Cocus nucifera* common in humid region, also animal raising under *Hevea* rubber
Systems with scattered trees	Trees in pastures	Commercial, shade or fruit trees commonly used, e.g. *Prosopis* and *Ziziphus* in arid zones India and Pakistan; *Samanea*, *Bauhinia* and *Leucaena* in Philippines
Agrosilvipastoral systems		
Systems dominated by fruit trees or cash crops	Livestock in multistoryed cropping systems	Usual in homegardens e.g. poultry, goats, pigs, sometimes also fishponds.
	Livestock in intercropped commercial plantations	e.g. in Philippines *Cocus nucifera*, arable crops and cattle or poultry
Other systems		
Trees and fish	Fishbreeding in mangroves	Present in Indonesia, Philippines
	Trees on bunds of fishponds	Common in Indonesia and Philippines e.g. *Nypa*, *Sesbania*
Trees and insects	Sericulture	Present in several countries
	Beekeeping	Common in whole region
	Shellac production	e.g. India, Indonesia

work attention was not only given to improving yields, but also to the effect of auxiliary trees on the incidence and control of pests and diseases.

Much of this research had already started many decades ago at a time when commercial plantations were managed under conditions of relatively low inputs. With the advent of high-input management practices, such as the increased use of fertilizers and pesticides, several of these techniques lost prominence. However, they are gaining attention again with the growth of interest in the development of agroforestry and smallholder plantations. At present new research efforts are directed at the further refinement of the taungya system (4, 17, 43) and of techniques for intercropping, pasture management or shade management in tree-crop plantations (21, 24, 38, 45). More than in the past attention is now given to optimize total production of several products instead of maximum production of a single commodity. Increased attention is also being given to an equitable distribution of benefits, e.g. taungya practices are changed to guarantee more profits for the farmers. The rapid take off of such experiments are to a large extent based on the facts that: in Asia well-established research institutes exist for the most important tree crops; the commercial significance of these crops; and the relatively simple structure of their management systems.

In contrast to the experimental studies on commercial agroforestry systems, much less experimental work has been done to improve subsistence agroforestry practices. For instance, hardly any studies have been made on improved designs for primarily subsistence based multistoryed systems or improved fallow management in shifting cultivation systems, despite the prominence of these systems in many Asian countries. More attention has been given to the development of experimental techniques for cultivating sloping areas through the combination of terracing, tree growing and alley cropping. Special attention has been given to the use of legumes in such systems as a means to improve the soil and stabilize terraces (40). In arid Asian zones important work has also been carried out to develop silvopastoral systems (7, 36) and shelterbelt systems around crop fields.

APPLICATION OF NEW AGROFORESTRY PRACTICES

Even if the design of scientifically developed innovative techniques for agroforestry is still in its infancy in tropical Asia, as is the case in much of the rest of the tropical world, this does not mean that during recent years no efforts were undertaken to implement new agroforestry programmes in the field. The most important lesson learned during this period is probably that the main present limitation to the application of agroforestry practices is not the lack of experimentally proven scientific designs for innovative agroforestry techniques, but rather a series of socio-economic constraints to tree growing by local farmers. During the last decade many constraints have been identified, often as a result of the analytical studies on the presence and dynamics of traditional agroforestry systems. Consequently a whole series of new approaches to stimulate tree growing by rural people have been developed. These are not primarily based on the introduction of new cultivation systems, but rather on providing farmers with access to the necessary inputs, to cultivate trees. Tree-crop cultivation has been stimulated in schemes for smallholder cultivation in addition to estate cultivation. Moreover, in the field of forestry many kinds of social forestry schemes have been developed. Under such programmes farmers have been provided with several basic inputs which are necessary for tree growing, such as legal access to land, credit, subsidized seedlings, assured market outlets for tree products and technical assistance (8, 9, 18). In several Asian countries such as India, Indonesia, Malaysia, the Philippines and Thailand, much progress has been made in the development of different schemes to stimulate tree growing by rural people. In some cases such programmes have explicitly aimed at the application of agroforestry techniques. Sometimes this has even resulted in a confusion about the nature of agroforestry and social forestry (1, 12, 16, 29). But even in programmes directed at the stimulation of tree growing, it has become clear that farmers are rarely motivated to grow trees for one purpose only. Rather they expect multiple benefits from trees and their farming systems (8, 9). Consequently in most social forestry and smallholder tree-cropping schemes farmers adopt agroforestry techniques. Often these are based on an incorporation of valuable trees into their traditional agricultural cropping systems.

The final conclusions that can be made is that the increased application of agroforestry practices in tropical Asia is not primarily based on the transfer of innovative agroforestry practices developed through experimental studies by scientists, but rather on adaptive strategies of farmers to increased needs for tree products and stimulative government programmes for tree growing. These latter programmes have been developed as a result of a continuous stream of information about the potential for tree growing by rural people, which resulted from descriptive and analytical studies of indigenous agroforestry systems.

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AGROFORESTRY IN AFRICA: POTENTIALS AND CONSTRAINTS TO TECHNICAL AND SOCIO-ECONOMIC DEVELOPMENT

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SUMMARY

Generalizing potentials and constraints to technical and socio-economic development of agroforestry in Africa is very unsatisfactory, even if a rough breakdown into the main agro-ecological zones is made. Heterogeneity and often outstanding diversity is a characteristic of land use.

Previous attempts to solve Africa's growing problems of food, energy and renewable raw material supplies, environmental degradation, and socio-economic stress situations have largely failed. Vast parts of the continent are facing unprecedented disaster if immediate action is not taken to intensify, diversify and improve rural subsistence production in a sustainable way. This can be achieved through integrating, in various forms, forestry, agriculture and pastoral land use.

The main constraints, however, are neither technical nor financial. Social structures and traditional practices, no longer practicable under prevailing and future conditions, will have to be changed drastically. Social and political conflicts will also have to be overcome, and more efficient practical work implemented on the farm and community level.

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INTRODUCTION

Africa -at a first glance- appears to be rather homogeneous. It is not. Like a tropical rainforest, which appears to the layman looking from outside as an extremely uniform "green block" without existing disparities, Africa is considered by some people to be a sparsely structured "black block". For those who know better, both the rainforest and Africa turn out to be extremely heterogenous, exciting, problematic, challenging and often more impressive than productive.

Thus, for any further evaluation of Africa's agroforestry potentials and constraints we will have to subdivide the continent into "handy" subregions. All systematic attempts to do this will, however, very soon encounter problems of definition, overlapping, and an overwhelming variety. Africa can not be simply cut into pieces like a cake.

One can name North, Tropical and South Africa; East and West Africa; black and non-black Africa; arid, etc. to perhumid Africa; former French, British, etc. Africa; Islamic and non-Islamic;and many more "Africas" to be distinguished. Last but not least, there are 54 countries (seven of them are islands), which comprise thousands of different ethnic groups and well over a thousand different spoken languages.

We are all aware of the continuously frustrating news from Africa. There, only there, do we have considerable homogeneity within the continent! African economies are for the most part small in economic terms with low average incomes and small populations. Only Nigeria has a GNP greater than that of Hong Kong.

They are narrowly specialized economies, most of them agricultural, dependent on the export of two or three primary commodities. Only 20 percent of the population is urban, and modern wage employment absorbs generally less than 10 percent of the labour force.

More seriously, many African countries are threatened by proceeding desertification or degradation of their natural resources, there is an -at least medium or longterm- deficiency in energy resources, water, minerals, and cultivatable land. Hunger and drought are almost permanently recorded, diseases and pests (like Trypanosomiasis) control vast regions. Worst of all, however, are racial discrimination (which in fact is not limited to South Africa), social disparity and even genocide, resulting in millions of refugees and incredible hardship.

Slow overall economic growth, sluggish agricultural performance coupled with rapid rates of population increase, and balance of payments and fiscal crises -these are the dramatic indicators of economic trouble. In agriculture, export crop production has been stagnating over the past two decades. Food production per person declined - in some countries drastically - in the last decade. Imports of food grains soared - by 9 percent per year since the early 1960s - reinforcing food dependency.

This alarming information, taken from the World Bank report "Accelerated Development in Sub-Saharan Africa ", (8), could be continued and elaborated. They are, however, only a very abstract and modest picture of what "the man up-country" has got to bear as his individual burden.

Can agroforestry help to overcome constraints, to solve problems, to improve life and to build a better future?

THE POTENTIALS

In order to find at least a few common denominators, we will have to limit our discussion to the three main biomes: savanna - rainforest - desert. This is, although very arbitrary and unsatisfying, the only choice I can offer for a brief review.

The savannas

Africa is the continent of savannas. However broad or narrow we may define savannas, they are tropical grasslands with a varying share of woody perennials. Their total area, including South Africa and parts of North Africa is difficult to estimate but appears - as a phytogeographic zone - to extend over 1,400 million hectares (almost half of the continent's surface).

The savanna climate is semiarid to subhumid with a pronounced seasonality and uncertainty of rainfall and in most parts at least temporal water deficiencies. As a standard pattern we may encounter grassland with more or less evenly distributed trees and shrubs, large mammals (livestock or game), typically in multitude,and mobile (e.g. nomadic or transhumant) men.

There is no time to elaborate on the savanna systems' structures and dynamics, but turning to their potential for agroforestry development we may note the following features:

- All components of agroforestry systems are represented in the ecosystems: annual (seasonal) plants, woody perennials, animals and man. The systems functioning depends immediately on their site-specific equilibrium. Agroforestry is thus obviously the most appropriate form of land use. There is a focus on forage trees/shrubs.

- The ecosystems and the socio-economic systems have a relatively low persistence but a high resilience, i.e. they are very flexible with regard to external interference.

- There is a vast land resource available (the average population density hardly exceeds 8 people.km^{-2}; although there are areas with a high population concentration, e.g. the Mossi plateau).

Thus, the savanna regions of Africa, although quite different in structure (e.g. West African Guinea-savannas to the Sahel, North African steppes, East African Miombo and highland savannas, South Africa) have a need for various categories of agroforestry:

- silvo-pastoral,
- agri-silvicultural
- agro-silvo-pastoral

Whereas silvo-pastoral systems in the semiarid and agri-silvicultural systems in the subhumid parts are rather well established, the transition zone appears as the most dynamic and problematic one. Agro-silvo-pastoral is easier to spell than to implement under the prevailing constraints which will be mentioned further below.

The rainforest

This is a very unprecise term, summarizing many different types of closed moist tropical forests in Africa. They cover about 200 million hectares, i.e. 7% of the continent's surface. Another 400 million hectares would belong to the phytogeographic zone but have been converted to agricultural land, wasteland, settlements, etc. Rainforests are concentrated in a region stretching from Liberia to the north of Angola, forming a belt of about 100 - 300 km width from the Atlantic coastline into the continent, and in the Congo river basin (which comprises the bulk of these forests).

Trees or rather closed forests are the dominant components of that biome as long as it is not disturbed. Grass and herbs are secondary, invadors of clearfelled sites, or occur with specific edaphic conditions. Large mammals are scarce, livestock, especially cattle, are practically excluded due to the Tsetse fly, spreading Trypanosomiasis. The climate is humid to perhumid with only short seasonal intervals. Population densities are low with the exception of coastal ranges and a few urban centres.

The potentials of the rainforest zone of Africa are to be seen in:

- typical forest ecosystems which allow for certain annual crops (preferably tubers) to be combined with timber-yielding trees.
- the necessity to maintain the forest structures (ecological as well as economical) and to replace hitherto destructive shifting cultivation practices by sustainable land uses, preferably multistory cropping and alley cropping, with high quality yields (5).
- the availability of many useful plant species, local as well as introduced, including tree crops like coffee (Coffea sp.), cocoa (Theobroma cacao), oilpalm (Elaeis guineensis), etc.;
- a high persistence to external interference, but a relatively low resilience.

The rainforest zone thus lends itself predominantly for agri-silvicultural types of land use, combining timber trees as well as fruit trees/shrubs, with specific starch yielding tuber crops and a few cereals such as rice (Oryza sativa) and maize (Zea mays).Home gardens, as yet under-developed, appear to have a potential for local subsistence as well as for cash crops (including exports). Local food demand is increasing, and a further intensification of the production is as necessary as a wider diversification to meet basic nutritional demands of the region (4).

The deserts

More than one third of the African continent is covered by deserts (Sahara, Kalahari, Namib, East-African deserts). These can be characterized by their permanent water deficiency (as the ruling feature), low population densities (below 2 people.km^{-2}), few plant and animal species that can survive, and marginal biomass production. Thus the majority of desert sites are virtually excluded from agroforestry. If there is any land use this is generally restricted to nomadic pastoralism.

There are however exceptions. As everywhere under extremely harsh environmental conditions plants, animals and people tend to concentrate on small favourable sites. These are, in the deserts, generally called "oases".

Oases represent almost ideal models of highly intensified agroforestry systems. Due to the availability of water for irrigation, cultivatable soils, manpower and markets, multistory and rather diversified crop systems have been developed. One prototype is characterized by the cultivation of date palm (Phoenix dactylifera) sometimes combined with fruit or multipurpose trees, cereal and/or vegetable gardening, and livestock, in an almost perfect symbiosis and based on almost complete recycling. Thus the agroforestry potential of pry

African deserts lies in their oases, or more precisely, in a network of functioning oases.

THE CONSTRAINTS

If there are potentials, and there are many outstanding examples of agroforestry in all three main biomes of Africa, why has agroforestry not (yet?) gained more importance? Where are the problems, the constraints to be overcome, the gaps to be closed?

This is not easy to answer if one tries to generalize. The biological potential is there although variable, the technologies are available, capital can be provided if programmes and projects are really promising. It is man who creates the decisive constraints.

"Starve the city dwellers and they riot; starve the peasants and they die. If you were a politician, which would you chose?" This is a quotation from a relief worker in the Sahel, taken from page 5 of Timberlake's book (6).

Moreover, the development of an individual and of a society does not entirely, not even mainly, follow logical rules. There is much more involved. This turns out to be especially true for Africa.

The savannas

We could start with a long list of constraints for agroforestry land use in the savannas of Africa. These will, of course, differ from region to region, and from locality to locality.

Life in the savanna regions has been based on age-old well balanced socio-economic and cultural interrelationships and mutual dependencies of various human groups. This "network" or rather very sensitive equilibrium is increasingly disturbed by both internal and external development.

Internal factors include growth problems, mainly the number of people and their individual demands. Internal factors also involve social changes (e.g. the degree of mutual dependencies, labour availability).

External factors include inputs like: deep-wells mining fossil water resources; human and veterinary medicine; transport (roads, trucks); foreign markets absorbing mineral, agricultural and human resources; political borders; and social/racial tensions within the newly established independent countries.

A closely related constraint appears to be the traditionally approved mobility, most evident in nomadic or transhumant systems. Wherever problems arose, people and livestock used to roam and to occupy, seasonally or sporadically, more favourable lands. Such "niches" for environmental, economical or political refugees are hardly available any more. People have, however, not yet endeavoured to persist. Thus, the way out is at least temporarily sought by resorting to the "green pastures" of foreign aid (which includes also aid from better-off parts of the same country) instead of drastically changing traditional land use patterns.

Another constraint of the savannas, but closely linked with the former, is that of land tenure. Generalizing one may say that there is very rarely private land property, that the majority of land is allocated/concessioned to temporal (usually rather short term) individual tenants, by traditional institutions (e.g. elders, chiefs) or government agencies. This is a practice which severely impedes investment and thus long term sustainable cultivation, going as far as to prohibit the planting and/or utilization of trees, because this would establish property rights.

Last but not least, in some African countries, the "primitive" nomads and herdsmen are severely discriminated against out of cultural/racial and/or political reasons. The main catastrophies of the past two decades, therefore, happened in the savanna regions (Sahel, Ethiopia, Sudan to quote just a few). People living under almost permanent and constantly increasing stress, do not behave and react "normally". Desertification, explosive population growth, wars, incredible individual hardships are commonplace. There is not much time left for experiments and discussion as generally performed in relief programmes. There is "fire" in the African savannas. Planting trees is not enough to combat these "fires"; to combat desertification.

The rainforest

Climatically, the tropical rainforest zone of Africa is certainly better off than at least the majority of dry savanna lands. But nevertheless, the overall human-ecological carrying capacity is limited as in all other tropical rainforest systems. The zone must, therefore, not be regarded as a hitherto underexploited vast land reserve for future large-scale transmigration programmes.

One constraint has already been mentioned: the Tsetse-fly. At least cattle are excluded from medium-term extension programmes. Small ruminants, however, as components of agro-silvo-pastoral systems are promising.

Another constraint is the dwindeling forest resource. About two thirds of Africa's previous closed forests have been destroyed within the past two decades (e.g. Ivory Coast: from 11.4 million ha in 1960 only 3.5 million ha were left in 1985). Moreover, the value and productive potential of many forests has been reduced through former shifting cultivation and selective and/or destructive timber harvesting practices. The present annual rate of destruction is about 1.3 million ha, the main part of which is due to forest invasion by rural people who practice shifting cultivation or sedentary farming (2).

Thus, a great number of formerly privileged sites have already been degraded and are now marginal from various aspects. Agroforestry is now expected to restore these sites, but this is obviously more complicated and expensive than timely prevention of further degradation.

As a rule, many people of the region exibit an outstanding skill to exploit the formerly rich resource rather than to cultivate, i.e. invest. Moreover, cultivation tended to be oriented towards cash crops for export markets (coffee, cocoa, palm oil, etc.), neglecting local demands and an adequate diversity. Where agricultural development was promoted with priority, as in the Ivory Coast, the consequence was a remarkable dependency on overseas' markets. One may say that the agricultural development, at least in the coastal parts of the rainforest zone, was "facing the ocean and turning its back towards the interior". Agroforestry, however, is not primarily suited to meet export market demands.

The deserts

It is unnecessary to mention that deserts offer more constraints than potentials for agroforestry. This also holds true for the aforementioned oases. Due to similar external and internal developments as in the savanna zone, an alarming degradation of oases systems can be observed.

Among the main bottlenecks are an increasing resource depletion (water, soil, nutrients) and deficiency of manpower. Oases systems are extremely labour-intensive. More attractive jobs and overall "environmental" conditions have caused emigration of the young and active people, and competition from goods and services produced outside are drastically reducing the markets for oases' products. There is, so far, no substitute for the former traditional balance of mutual complementarity, not even through mining or tourism. Oases-agroforestry is thus threatened by incompatibility and finally extinction.

THE OUTLOOK

In discussing future prospects of agroforestry in Africa we should not be pessimistic, but we will have to be realistic. Once more, Africa is not a homogeneous "black block" but a continent with enormous variety, overwhelming problems but also exciting challenges.

If we agree that cultural development is largely induced through crises of the relevant human societies, Africa is the continent to concentrate efforts.

If we take up the challenge, on what assumptions may we build our engagement? The present population of Africa is about 500 million. Within one generation there will be more than 1,000 million Africans. It is inconceivable that mankind will experience the starvation of more than 500 million people within about 30 years. Thus action will have to take place. The international organizations like FAO, World Bank, etc. are concentrating on Africa. The European Community, within the Lome III treaty, has already allocated substantial funds for rural development in Africa and is in the process of increasing its input. Other donors have joined or are likely to join. The CGIAR institutes and many national research centres are developing strategies and techniques for a breakthrough in agricultural production (IITA, ILCA, ICRISAT, etc.). Last but not least, the individual farmer will give priority to his family's subsistence and thus concentrate on food production for local supply (3).

Agricultural policies of the governments are likely to finally accept the indispensable needs to meet demands and to provide for the legal, administrative, financial, etc. preconditions which have been seriously neglected so far. (1). The way in which land is held, inherited, acquired or disposed of, as well as the conditions enabling the farmer to transfer his land from agriculture to forestry or vice versa, or to make combinations of both, are a main concern of rural development, predominantly of agroforestry. Unless new, effective strategies are developed at the national level, many if not most efforts will be likely to fail.

The land resources of Africa are still considerable. Through intensification of cultural practices the outputs in many regions could be increased substantially if only well-known technologies were applied. Even better results would be feasible if modern methods of biotechnology and genetic engineering come to a breakthrough (7). But: "If the hungry could eat words, Africa would recover". This is a BBC-television commentary, 1985.

Practical work at the farm level and at the community level will have to be implemented, based on self-reliance but supported by external resources.

Agroforestry will have to play its role within this battle for the survival of mankind:

- by providing for subsistence,
- by recultivating degraded lands,
- by diversifying and qualitatively improving biomass production,
- by reducing risks and external dependencies,
- by establishing the principle of sustainable land use,

"Africa's hope lies in the well-being of its farmers. Its farmers would perhaps be better off if world commodity prices were higher, if oil were much cheaper, if interest rates were lower, if there were a New International Economic Order (assuming it were fairer than the present one). But in the meantime, perhaps the best the farmers themselves can hope for is to be a little less vulnerable to drought, to be able to produce a little more food, to be a little healthier. And their best hope for this lies in the spread across the continent of farmer-based rural development efforts, locally led, sustainable, spreadable" (6).

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AGROFORESTRY EXPERIENCES IN SOUTHERN SUDAN WITH SPECIAL REFERENCE TO SMALL FARMERS

R. Wolf*

SUMMARY

Farming systems in the project area are, in a broad sense, a combination of hunting, gathering, subsistence agriculture, and cash cropping. Cash cropping is gradually being incorporated into this system to meet the increasing needs and desires for cash expenditures.

Trees are mainly regarded as a cash crop and therefore the small farmers were quite interested in planting them. In the first year of the programme tree seedlings were distributed free of charge, and in the second year the farmers were successfully trained to establish their own nurseries in order to become independent of the project supply.

BACKGROUND

The Sudanese German Forestry Project (SGFP)

The SGFP started in 1974. The project headquarters, Kagelu, is located in Southern Sudan, Equatoria Region, about 50 km north of the border to Zaire and 70 km west of the border to Uganda. The project was originally designed to promote afforestation activities and better wood utilization (2).

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* Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)

History of Kagelu

The Kagelu research farm was one of two experimental centres in the Equatoria Region. It was set up by the Belgians around 1900 to experiment with trees for timber production and with field crops. Cassava (Manihot esculenta), sweet potatoes (Ipomoea batatas) and dura (Sorghum bicolor) were widely grown for food, while other crops like cocoa (Theobroma cacao), sugar cane (Saccharum cvs.), coconut (Cocus nucifera), coffee (Coffea spp.), camphor, tobacco (Nicotiana tabacum), soya bean (Glycine max) and upland rice (Oryza sativa) were introduced. Ceara rubber (Manihot glaziovii) was planted but was not used on a big scale. Teak (Tectona grandis) was introduced in 1919.

Later, around 1930, the British made a nursery of forest and fruit trees and extended the plantations of Citrus spp., T. grandis, Eucalyptus spp., Cedrela spp. and oil palm (Elaeis guineensis). Crops like banana (Musa spp.), pineapple (Ananas comosus), pawpaw (Carica papaya), mango (Mangifera indica) and guava (Psidium guajava) were also planted (9).

NATURAL CONDITIONS OF THE REGION

The western part of Equatoria Region lies between latitudes 3º 30'N and 5º N and between longitudes 30º E and 32º E and encloses about 16,000 km^2. Exact figures of the population are not available. In 1981, the area had an estimated population of 150,000 but a big influx of refugees, mainly from Uganda, doubled the population within a short period. The location of settlements is largely determined by availability of water and by proximity of roads. The position of the region on the borders with Zaire and Uganda created a cosmopolitan population who are relatively commercially oriented and receptive to new ideas.

The climate is wet monsoon. The rainy season lasts from April to November with small rainfall peaks in May and August. The mean annual rainfall ranges from 1200 to 1800 mm. The lower rainfall areas often coincide with land of shallow, sandy and gravelly soils with low water holding capacities.

Concerning geology, gneisses are predominant. The main soil types are lateritic soils with loamy topsoil. Land is susceptible to soil erosion due to intense rainstorms particularly at the beginning and the end of the rainy season.

The predominant vegetation type is woodland savanna, which was in former times mainly woodland. This change was caused by the influence of man, especially by the annual burning of vast areas for hunting and farming purposes. The remaining gallery forest along rivers are increasingly destroyed by the population, for dry season farming areas.

FARMING SYSTEMS IN EASTERN EQUATORIA

Enterprise pattern

Food crops grown for sale are becoming increasingly important but meeting subsistence needs is still given priority. Sheep, goats and chickens are widely kept but they are allowed to roam freely and are not properly integrated into the farming systems. Sorghum bicolor and Manihot esculenta are the staple food crops. Other crops that are widely grown are maize (Zea mays), I. batatas, sesame (Sesamum indicum), groundnuts (Arachis hypogaea) and O. sativa, as well as fruits like Musa spp., Citrus spp., Carica papaya and Mangifera indica. Coffea as a cash crop is undergoing a remarkable expansion among smallholders as is N. tabacum (7).

Enterprise calendar

The farming systems in this area are, in a broad sense, a combination of hunting, gathering, subsistence agriculture, and cash cropping. Practices such as intercropping and staggered planting emphasize the importance of risk minimization and ensure, combined with hunting and gathering, a continual supply of food for the family throughout the year. Cash cropping is gradually being incorporated into this system to meet the increasing needs and desires for cash expenditures (7).

Land and its constraints

Land in Equatoria Region generally belongs to the Government. Authority over it is exercised by chiefs from whom permission to settle or cultivate must be obtained, but no rent is charged for its use. In areas with an influx of refugees, farmers are beginning to feel the effects of population pressure on land. Average farm size in terms of land under cultivation is about 1.5 ha (7). Farm size appears to be determined largely by family size and by the decision to cultivate cash crops.

Labour and its constraints

Labour is probably the most limiting production factor at the present time. The main reason is poor labour productivity due to low levels of technology, inadequate diet at the busiest time of the year and debilitating diseases. (6).

Capital and its constraints

Capital remains a minor production factor in the farming systems. Most of the capital assets have been produced by family labour. Equipment is generally limited to simple cultivation tools. Livestock are playing an important role as a form of saving and investment capital.

Infrastructure

Most of the roads within the region are in poor condition. Transport is unreliable and expensive. Because of the poor marketing system, prices in towns are considerably higher than in rural areas.

THE FORESTRY COMPONENT-EXPERIENCES IN AGROFORESTRY WITH SMALL FARMERS

A forestry component has many effects on the farming methods of the smallholder. It will influence soil (3) and crops located between the trees. It will influence labour input (8) and the economic situation, and it will influence the land use system and even the ecological situation of the whole area (5). The use of agroforestry methods in plantations, in the form of the classical "Taungya-system" (4), was already well known in the project area and widely practiced within forest reserves. The whole system was highly mechanized and the tree component had absolute priority (1). The situation with small farmers is completely different. The crop component has priority and the work is done manually with simple tools. Nevertheless, the farmers showed great interest in an agroforestry programme. For the success of the programme it was important to hold close contact to the chiefs and to inform them about the intentions and aims of the agroforestry programme, but fortunately it was the tribal chiefs who participated strongly in the programme and promoted the idea of agroforestry.

In the first year (1983), plant material (mainly T. grandis) was distributed free of charge. In 1984 we organized farmers to establish their own tree nurseries in order to learn the know-how of seed treatment etc., and to enable a "self-help-effect" within a short period. Again we concentrated on T. grandis since the techniques are well known and because T. grandis seedlings (stumps) are easy to handle.

The main reason that small farmers would integrate a tree-component into their farming systems was that they were able to sell poles for a good price on the market. The first poles, e.g. with T. grandis, are harvestable after about five years.

In regions with low infrastructure and where hunting, gathering and subsistence farming are still prevailing, the interest in agroforestry (for planting trees) was low. In cooperation with UNHCR (United Nations High Commission for Refugees) the project initiated activities. This proved to be difficult since planting trees leads to ownership of the site. Refugees however are not allowed to own land. The refugees themselves are not very interested in planting trees since they don't know how long they will stay in Sudan and whether they will be able to enjoy the benefits of their work. At the same time it was the refugees, who were responsible for large scale deforestation in order to have farm areas for building purposes and for firewood. Unfortunately, civil war started again between Southern and Northern Sudan and the project had to close down most of its activities in mid 1984.

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CHARACTERISTICS OF FARMS PRODUCING BASIC GRAINS IN FOUR AREAS OF CENTRAL AMERICA*

L. A. Navarro**

SUMMARY

A survey of 38, 46, 41 and 41 farms producing basic grains, in the areas of Guápiles and San Isidro in Costa Rica, Matagalpa in Nicaragua and Yojoa in Honduras, was made during 1977. Its purpose was to study the structure and management of the farms in relation to the producers' motivations, resources and knowledge.

Food grain producers also included livestock and perennial crops, as well as forestry, as part of their production strategies. Their farms provided most of the food, employment and income for the families of seven or more members.

On average, farms ranged from 4.3 ha in Yojoa to 23.3 ha in Guapiles. Family labour was not enough and extra-farm labour was hired in all cases. Capital was restricted and usually in the form of livestock. Farms were highly diversified. Most land was allocated to livestock and food grain production. Most available credit and technical assistance favoured the production of food grains. This production also accounted for most of the labour used and income generated on the farm, except in San Isidro. Perennial crops, however, were the most efficient in terms of income per hectare.

Even though most farmers recognize the importance of food grain production, their general attitude tended to favour the production of livestock and perennial crops. Their emphasis on food grain production seemed tied to 1) subsistance and security needs, 2) lack of appropriate resources for the more

* Translated from the Spanish by M. Major.

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attractive production activities and 3) the bias that results from the little support received from society for food grain production.

INTRODUCTION

The reconnaisance of an area and of the production systems that constitute its agriculture is now a generalized component of research for technology development of production systems throughout Central America.

One of the first reconnaissances, conducted by CATIE in 1977, included a structured survey of 38, 46, 41 and 41 farmers of Guapiles and San Isidro in Costa Rica, Matagalpa in Nicaragua, and Yojoa in Honduras, respectively. Its purpose was to study the structure and productive management of the farms and their relation to the motivations, resources, and knowledge available to the farmers. The findings would serve as a base to orientate and evaluate the results of a project on research and technology development for farms producing basic grains in these areas. The sites visited were selected from the most important grain producing areas and farms in each country. The reconnaissance was part of a regional research project on cultivation systems for small farmers that was coordinated by CATIE and various national institutions, and financed by AID/ROCAP.*

The following analysis and presentation of the results demonstrates the mixed character of the farms and consequently, the importance of the combination of enterprises for the production strategy, generation of income and employment of small farmers.

AREAS AND SAMPLING METHODS

The principal characteristics of the areas are given in Table 1. The farm sampling method was partly directed and based on the knowledge of agricultural researchers and extensionists of each country. Preference was given to farms that were known to produce food crops.

To minimize costs uniform samples of 30 - 40 observations were made in each area. This number does not represent a specific percentage of the sampled population, but are "large samples" appropriate for routine statistical analyses (1).

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* Regional Office for Central American Programmes of AID.

Table 1. Location and some characteristics of the areas covered by the agricultural systems reconnaissance

Country and Area Characteristics	Costa Rica Guápiles	Costa Rica San Isidro	Nicaragua Matagalpa	Honduras Yojoa
Location	10º20'N 83º40'W	09º22'N 83º42'W	12º53'N 84º54'W	15º06'N 87º56'W
Altitude(m.a.s.l.)*	50	700	700	80
Influence	Atlantic	Pacific	Pacific	Atlantic
Life Zones**	T-wf P-mf	T-mf P-wf	P-mf	ST-mf
Temperature(ºC)	25 - 27	22 - 25	21 - 24	24
Annual rainfall(mm)	3000-5000	3000-4000	1200-1500	1500
Rainfall "peaks"				
. Principal	December	October	July	June
. Secondary	July	June	October	September
Dry periods				
. Principal	March	February	March	March
. Secondary	September	July	August	August
Predominant soils	Latosols Ultisols Oxisols Histosols	Ultisols	Alfisols	"Urupas"***

* Meters above sea level.
** According to Holdridge: T-wf = Tropical wet forest; P-mf = Premontane moist forest; T-mf = Tropical moist forest; P-wf = Premontane wet forest; ST-mf = Sub-tropical moist forest (4).
*** Series of volcanic soils with a high content of P and adequate levels of the majority of the nutrients except S.

MOTIVATIONS, RESOURCES AND TECHNICAL KNOWLEDGE

The motivations, resources, and technical knowledge of the farmers determine what they produce, how much they produce, and how they do it. The motivations are principally determined by the needs and aspirations of the farmers and their families. Their manifestations, nevertheless, are molded by the quantity and quality of the resources, knowledge, and technical capacity, available to the farmers. This availability is influenced by the orientation, support, and reinforcement that the farmers receive from society.

As an indication of needs, the average family size was seven members in Yojoa and eight or more in the other areas. At least 50% of the families had one or more of their children in school; nevertheless, between 80 and 92% of the farms visited had at least three children under the age of 15.

Without doubt, the farms were the main source of food, employment and income for the families. All the edible grains and fruits consumed by the family, as well as almost all the meat (pork and poultry) was produced on the farms. In the different areas, at least 40% of the farmers used two to four children for farm work. No more than 20% claimed to have children working off the farm. The reconnaissance also showed that 85% of the average income of the farm and the area came directly from the farms.

Table 2 summarizes the data about the available resources on the farms. Capital, as a resource, could not be well quantified; nevertheless, the information about the type and number of animals can be used for comparisons as can the hired labor index (2). In summary, Table 2 shows that the level of resources is greater in the two areas of Costa Rica.

As for the knowledge and technical capacity, the data shows that the average age of the farmers is quite uniform (43-45 years old) in the different areas. The ranges of the modal age, nevertheless, fluctuate from 30 to 40 years old in San Isidro and from 50 to 60 years old in Matagalpa. The proportion of farmers with some education varied from 37% with an average of 2.7 years in Matagalpa, to 55% with an average of 2.6 years in Yojoa, and 74 and 83% with averages of 3.2 and 3.4 years in Guapiles and San Isidro, respectively.

Table 2. Average farm resources

	Costa Rica		Nicaragua	Honduras
	Guápiles	San Isidro	Matagalpa	Yojoa
Land under management (ha)	23.3	13.5	4.4	4.3
Labour				
. Family (man-year)	1.0	0.9	1.0	0.8
. Hired (man-year)	1.5	1.9	0.4	1.1
Animals (number)				
. Cattle	16.2	7.8	12.4	5.3
. Pigs	1.2	1.0	1.2	1.0
. Horses	1.5	0.8	0.3	0.4
.Poultry	31.7	19.9	10.0	13.3

The reinforcement and orientation of the productive activities, that the farmers receive from society, depends on the contact they have with that society and of the existence of support efforts. The data from the survey show that on the average between 73 to 96% of the farmers per area visit the closest important population centre from four to seven times per year and from 18 to 80% visit a major city at least once a year. In all areas at least 12% of the farmers read some newspaper, although it may be occasional, and at least 90% listen to the radio frequently.

At the time the survey was conducted, the farmers showed little sign of inter-farm organization, although cooperatives, associations, and farmer committees did exist. The cooperatives included up to 17.4 and 30.0% of the farmers and the associations up to 23.9 and 35.0%, in San Isidro and Yojoa, respectively. Committees were most important in Guápiles (15.8%) and Matagalpa (24.4%). Since the survey was completed this situation has changed, particularly in Matagalpa, where almost all of the farmers now belong to some organization.

At least half of the farmers of each area claimed that they used some type of credit and in Costa Rica the proportion was greater than three quarters. The use of technical assistance was mentioned by 47% in Matagalpa and 46% in Yojoa, but only 14 and 22% in San Isidro and Guápiles respectively. In each area a public agricultural marketing institution maintained the prices of the basic grains and purchased a large part, but not all, of the farmers' produce. These institutions were the National Production Board (CNP) in Costa Rica, the National Provisions Enterprise (ENABAS) in Nicaragua, and the Honduran Institute for Agricultural Marketing (IHMA) in Honduras.

PRODUCTIVE STRUCTURE OF THE FARM

The productive structure of the income and of the expenditures for the farms of each area is presented in Table 3. Annual crops and cattle raising are the most common agricultural activities in the area. Cattle raising uses more area and is more extensive in Costa Rica, particularly in San Isidro. Annual crops generate the greatest proportion of the income, except in San Isidro where it is surpassed by permanent crops, particularly coffee (Coffea arabica). Likewise, annual crops require the greatest proportion of production costs and labour. With the exception of Guápiles, more than 50% of all costs correspond to basic family expenses which reflects the farmers' degree of self-sufficiency in all areas. The importance of annual crops in these farms was expected given the type of sampling.

Table 3. Productive structure: income and expenses of the farms*

Structural components	Costa Rica Guápiles	Costa Rica San Isidro	Nicaragua Matagalpa	Honduras Yojoa
ANNUAL CROPS				
- Surface area (ha)	6.8 (31)	2.6 (19)	2.4 (48)	2.2 (50)
- Income (US $)	2831 (79)	681 (22)	538 (45)	639 (55)
- Expenses (US $)	601 (23)	158 (7)	98 (10)	52 (6)
PERMANENT CROPS				
- Surface area (ha)	0.9 (4)	2.0 (15)	0.6 (13)	0.5 (10)
- Income (US $)	104 (3)	2006 (64)	371 (31)	164 (14)
- Expenses (US $)	38 (2)	258 (10)	16 (2)	6 (1)
CATTLE RAISING				
- Surface area (ha)	7.2 (33)	6.9 (51)	1.5 (30)	1.7 (38)
- Income (US $)	463 (13)	254 (8)	92 (8)	200 (17)
- Expenses in:				
pastures (US $)	136 (5)	48 (2)	11 (1)	10 (1)
livestock management (US $)	83 (3)	65 (3)	23 (2)	38 (4)
FORESTRY (not agricultural)				
- Surface area (ha)	7.0 (32)	2.0 (15)	0.4 (8)	0.1 (1)
- Income (US $)	112 (3)	181 (6)	13 (1)	37 (3)
- Expenses (US $)	--	5 (0.2)	--	--
OTHER				
- Constructions (ha)	0.009 (0.4)	0.07 (0.5)	0.06 (1.2)	0.04 (0.8)
- Extra farm income (US $)	68 (2)	40 (1)	169 (14)	114 (10)
- Expenses:				
labour (US $)	680 (26)	266 (11)	37 (4)	109 (12)
family (US$)	1040 (39)	1418 (60)	738 (79)	660 (73)
miscellaneous (US $)	68 (2)	164 (7)	10 (1)	33 (4)
TOTAL				
- Surface area (ha)	21.9	13.6	4.96	4.54
- Income (US $)	3579	3156	1183	1154
- Expenses (US $)	2645	2382	933	886

* Values in parenthesis are % of respective totals.

The diversity that the areas and grain-producing farms present is notable in spite of their biased selection. The results show a strong interaction between the different enterprises, particularly annual crops and cattle raising. In terms of efficiency, measured by the generation of income per hectare, permanent crops always surpass cattle raising and, with the exception of Guápiles, annual crops.

Other characteristics that permit a comparison of the relative importance of the various activities of the farms are presented in Table 4. The index of credit and technical assistance use, clearly indicates the interests of the farmers who look for this support, and of the institutions that provide it. Thus, annual crops are the most favoured. As was already suggested, annual crops are also the main employment source within the farms. Furthermore, the farmers of all areas, except Guápiles, recognize that annual crops constitute the most important activity for generating income, followed by permanent crops and cattle raising. Nevertheless, the general attitude of the farmers appears less positive towards annual crops than towards other activities. Cattle raising and permanent crops appear more attractive to them.

Table 4. Other important indices for the different productive activities of the farm

Index*	Costa Rica Guápiles	Costa Rica San Isidro	Nicaragua Matagalpa	Honduras Yojoa
Use of credit and tecnical assistence (I.1)				
- Annual crops	0.68	0.46	1.46	0.54
- Permanent crops	0.10	0.30	0.00	0.02
- Cattle raising	0.29	0.33	0.05	0.10
- Forestry**	0.00	0.00	0.00	0.00
Use of labour (I.2)				
- Annual crops	81.3	39.4	64.1	76.0
- Permanent crops	3.7	45.7	11.0	9.2
- Cattle raising	12.2	10.0	1.9	4.9
- Forestry**	0.8	0.1	0.1	0.1
- Extra farm work	2.0	4.0	22.9	9.8
Man days/year	3583	2316	1803	2239
Farmer's statement (I.3)				
- Annual crops	4.50	3.61	4.44	3.98
- Permanent crops	1.13	4.22	2.42	0.93
- Cattle raising	2.82	2.02	0.80	1.15
- Forestry**	0.00	0.00	0.00	0.00
- Extra farm work	0.58	0.39	1.90	0.63
Farmer's attitude (I.4)				
- Annual crops	- 1.59	-0.63	-1.59	-0.49
- Permanent crops	0.05	1.00	1.44	0.46
- Cattle raising	2.00	0.50	0.93	0.43
- Forestry**	0.00	0.00	0.00	0.00

* See following for explanation of indices I.1; I.2; I.3; I.4.
** The low values for forestry are probably due to the bias of the survey toward other agricultural activities.

I.1. Indicator of the importance determined by the sum of the proportion of farmers that use credit and the proportion of those that receive technical assistance for each activity in each area.

I.2. The percentage of the available man-days per year utilized in each activity.

I.3. Indicator of the importance attributed by the farmers to each activity according to their appraisal of its potential to generate income. It is based on the following formula:

$$I.3 = \sum_{i=1}^{5} X_i \, (6 - i)$$

where: X_i = proportion of the farmers that place the activity under evaluation in the place of importance (i).

i = 1,2, ... 5, where 1 is of highest importance and 5 is of least importance.

I.4. An "attitude index" (3) toward each activity. To calculate it the questionnaire included 10 questions that denote positive attitude (for example,activity that you like most) and 10 questions that denote a negative attitude (for example, activity that you consider least profitable). The following formula was used:

$$I.4_j = \sum_{i=1}^{10} \frac{X_{ij} - Y_{ij}}{Z}$$

where: $I.4_j$ = attitude index for activity (j)

X_{ij} = number of farmers that identify the activity "j" when they are asked the question of positive attitude "i".

Y_{ij} = number of farmers that identify the activity"j" when they are asked the question of negative attitude "i".

Z = total number of farmers interviewed

The previous comments support the observation that farmers with few resources continue to produce annual crops principally: 1) for subsistence needs and security; 2) due to the lack of more and better resources which stops them dedicating themselves to more attractive activities and 3) because the little orientation and reinforcement that they receive from society directs them to annual crops. It is one of the few activities in which they can compete thanks to their low production costs and labour-intensive technology.

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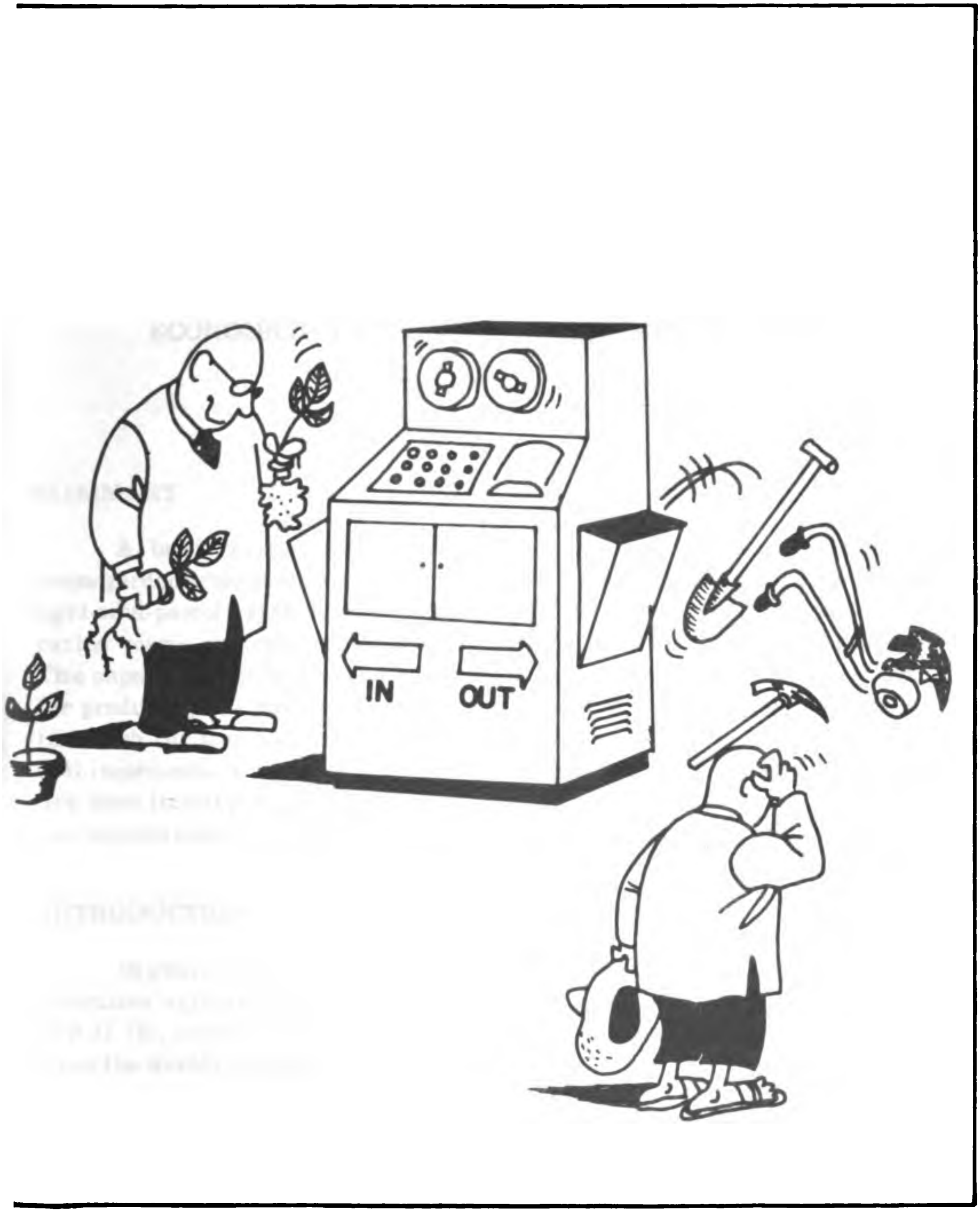

CASE STUDIES : ECONOMICS AND ERGONOMICS IN AGROFORESTRY

ECONOMICS OF AGROFORESTRY SYSTEMS IN AFRICA

D. A. Hoekstra*

SUMMARY

A brief review is made of the economics of the taungya and the homegarden/treegarden systems in the tropical forest zone of Africa, and of the agri-silvi-pastoril system in the arid/semi-arid zone. The review is based on the rather scarce economic data published on these systems over the past decade. The paper also briefly looks at the potential economics of relatively new systems for producing tree products such as woodfuel and fodder, and considers systems in which the tree has mainly a service role such as fencing/demarcation and soil-improvement. It is argued that in large parts of Africa, labour and capital are more limiting production factors than land and therefore labour and capital saving techniques should receive a high priority in agroforestry design.

INTRODUCTION

In general, the African continent is characterized by a dominance of land-extensive agricultural systems (15). This is substantiated by statistics from F.A.O. (5), clearly showing that per capita land area in Africa is much higher than the world's average (Table 1).

* International Council for Research in Agroforestry, Nairobi, Kenya.

Table 1. Comparative land/man ratio for Africa (ha, 1982)

	World	Africa
Total land area/capita	2.85	5.94
Total land area/economic active person in agriculture	15.74	25.23
Agricultural land*/capita	1.01	1.94
Agricultural land*/economic active person in agriculture	5.58	8.23

* arable land+ permanent crops + permanent pastures

Although there are exceptions, notably in some humid/sub-humid areas, it may be assumed that in relative terms, labour and capital within Africa are scarcer production resources than land. Therefore, for agroforestry to be a superior land-use system within land-extensive farming systems, relative savings in labour and capital cost per unit of production will have a bigger impact than the savings in land cost.

The scope for agroforestry and/or tree-based non-agroforestry land-use systems within Africa, is potentially good because there is/will be a great demand for woodfuel, small timber and tree fodder.

Based on a preliminary analysis of the information collected from ICRAF's Agroforestry Systems Inventory Project, the following systems appear to be the most prominent (Table 2).

Table 2. Common agroforestry systems in Africa

Tropical forest zone (highlands, lowlands)
- Taungya
- Home garden/tree garden
Arid/Semi-arid zone
- agro-silvi-pastoral system

AGROFORESTRY SYSTEMS IN THE TROPICAL FOREST ZONE (HUMID/SUB-HUMID)

Within this relatively wet zone (45% of Africa's land area) (3), population densities are expected to be higher than the average African densities. Therefore, in those tropical forest zones where settlement has taken place, land is likely to become a relatively scarcer production factor and therefore creates a conducive resource environment for agroforestry.

Taungya system in Nigeria and Tanzania

The taungya system as practiced by the Forestry Department in Nigeria has been the subject of a few economic reviews (1, 2, 14).

A distinction has been made between the traditional taungya, in which the farmer receives the food crop income, and the departmental taungya in which the Forestry Department is the recipient of the food crops while the farmer is an employee of the Department.

Ball compared both systems with a direct plantation model (1) and concludes:

> Supervisory costs of the Forestry Department for tree establishment are lowest under the plantation model, followed by traditional taungya and highest under departmental taungya.
>
> The direct costs to the Forestry Department in the first two years are lowest for traditional taungya (Naira (N) 215.ha^{-1}) followed by pure plantation (N 525.ha^{-1}) and highest for departmental taungya (N 1,007.ha^{-1}). The differences are caused by an absence of clearing and burning costs (estimated at 100 man days.ha^{-1}) in the traditional taungya system; an absence of crop cultivation costs in both the traditional taungya and the plantation model; and differences in supervisory costs.
>
> The increased cost for the departmental taungya are offset by the agricultural revenues during the first two years (N 890.ha^{-1}) making this system the most attractive to the Forestry Department for establishing trees (not yet considering possible differences in timber yields).
>
> From the farmer's viewpoint the traditional taungya systems gave the highest net benefits (N 1,492.ha^{-1}) while the labour income from

departmental taungya and plantation work was, respectively, N 850.ha^{-1} and N 445.ha^{-1} over a two year period.

An observation worth making is the fact that most participating farmers have other lands outside the forest where they grow the financially more attractive perennial crops. Also, those farmers who had little or no other land resources (aliens in the area) appeared to make the best use of the land.

An economic study of taungya in Tanzania (8) also concludes that a taungya system is a more profitable form of land-use than a pure plantation model, mainly because of cost savings for tree planting estimated at Shs. 800 (80 man days).ha^{-1}. However, the system seems to be endangered because the expansion of the plantations in some areas ended. As a result farmers refused to move on to other areas when the canopy closed in the plots they were cultivating.

Home gardens/compound farming

The home gardens or compound farms are usually found in the humid areas of the tropical forest zones. The continuous cover of the trees and shrubs minimizes the adverse impact of high intensity rains in terms of structural deterioration, excessive runoff and erosion*.

Some of the home garden systems have been described recently, notably the Chagga system on Mt. Kilimanjaro (3) and the Ibo system in south-eastern Nigeria (13). Some salient economic data, in respect of the latter system, are presented below:

> Three villages with increasing population densities were incorporated in this land-use study. In the village with the lowest population density (200 persons.km^{-2}), compound farming was not practiced. Land was apparently not the scarcest production factor.
>
> The compound gardens in the more densely populated villages had an upper story of oilpalm (Elaeis guineensis), coconut (Cocus nucifera) and various fruit trees and an understory of cocoyam (Colocasia esculenta), yam (Dioscorea spp.), cassava (Manihot esculenta), maize (Zea mays) and vegetables.

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* Fernández, Personal Communication.

The cropping intensity of annuals and perennials was highest in the most densely populated village (750-1,000 persons.km^{-2}); however per unit area production in the compound is lower as compared to the less populated village (350-500 persons.km^{-2}).

The gross revenue per unit area of the compound was 4 to 10 times higher than that from the outer fields.

The labour inputs in the compound are not much higher than in the outer fields.

The return to labour from the compound was 5 to 8 times higher than the same return from the outer fields.

The labour input per unit of compound and outer field area increased with population density; however returns per unit of labour decreased (diminishing returns to scale).

IITA*, in collaboration with the Imo State College of Agriculture and the Forestry Commission of Anambra State in Nigeria, have recently embarked on a project aimed at making socio-economic studies of the home compounds.

AGROFORESTRY SYSTEMS IN THE ARID/SEMI-ARID ZONE

About 55% of Africa's land area is classified as arid/semi-arid (4). Water has been the main bottleneck to agricultural production, while manpower is also relatively scarce. As a result much of this zone is maintained as grazing land/woodlands. Where grazing and cropping takes place, certain trees and shrubs have been deliberately retained and managed while others have been removed. Such removal is partly based on reducing competition for the grasses and crops, partly on a policy of maintaining useful trees only, thus improving the ecological interaction between the system's components. Favourable economic interactions between system components may furthermore be obtained through labour and capital saving, e.g. combining herding and fuelwood collection.

Agri-silvi-pastoral systems

Very little quantitative information is available on these systems. This is due to a variety of reasons:

* International Institute of Tropical Agriculture.

Much of the area belongs to subsistence-oriented societies.

Many of the tree products derived are difficult to measure (fuelwood, fodder).

Because of the low and unreliable rainfall, the system's yearly inputs and outputs fluctuate widely.

Two of the better documented systems are the ones based on the Acacia albida and on Butyrospermum paradoxum/Parkia spp. ILCA* made an economic evaluation of an A. albida plantation from which the following data are derived (9):

Millet yields around the A. albida trees may be increased 2 to 2.5 times (at a low yield level), i.e., 500-800 $kg.ha^{-1}$ to 1,000-1,500 $kg.ha^{-1}$. This fertilizer effect of the trees does not begin to show before the trees reach 10 to 15 years and probably takes about 10 years thereafter to reach its full extent.

Pod production averages 200 to 600 $kg.ha^{-1}.a^{-1}$, after about 15 years, at a final density of 10 to 50 $trees.ha^{-1}$. In 1980 these pods were sold at US $\$0.21.kg^{-1}$ in Senegal.

Wood production from the trees is very low, consisting mainly of the sale of eliminated trees after 20 years.

Planting costs at an initial density of 100 $trees.ha^{-1}$ were estimated at US $\$55.ha^{-1}$ and an additional production cost for the next 14 years was estimated at US $\$3.ha^{-1}.a^{-1}$. Enclosure costs were estimated at US $\$450.ha^{-1}$ (barbed wire) and US $\$150.ha^{-1}$ (hedges).

POTENTIAL/NEW SYSTEMS

Tree output-oriented systems

Within the last decade several agencies have engaged in tree planting activities. Emphasis in most of these activities has been on the supply of fuelwood, small timber and fodder as well as on the conservation of the environment. Although they were thought to be profitable, many projects, especially in the arid and semi-arid regions, did not live up to the high expectations. Such disappointments were partly caused by design deficiencies,

* International Livestock Centre for Africa.

under-estimating local conditions (human as well as environmental), and a lack of knowledge on appropriate technologies for the areas.

Fuelwood

For the Sudanian and Sahelian zone Gorge estimated direct establishment costs at US$1,000.ha^{-1} for state-managed tree plantations (6). Rural tree plantations are cheaper but production is estimated to be 50% lower owing to lack of soil preparation and regular tending. The average production.ha^{-1}.a^{-1} from different land uses, according to a 1982 FAO report (12) on these zones, is presented in Table 3.

Table 3. Average annual increment of fuelwood ($m^3.ha^{-1}.a^{-1}$)

	Sahelian	Sudanian
Dense forests	0.80	1.50
Woodland & woodland savannas	0.50	1.20
Tree savannas	0.20	0.80
Shrub savannas	0.05	0.02
Weighted average production	0.09	0.92
Bush fallows	0.05	0.30
Agri-silvi-pastoral associations	0.02	0.02
Rural tree plantations	1.00	1.50
State-managed tree plantations	2.00	10.00

While physical production is rather low, fuelwood prices are also low because most wood being sold in these zones was derived from bush fallows or "stolen" from the unprotected forest.

To make these projects more successful the following points should be considered:

More attention should be paid to an analysis of the physical and human environment.

Critical review of the existing technologies.

Improvement of the tax/price policies for fuelwood.

Fodder

Most of the economic analyses of tree fodder in Africa have been summarised in ILCA publications, (9, 10). While both publications contain a wealth of quantative information, their main drawback is the fact that they deal mostly with fodder grown in plantations, excluding fodder grown on/around farmers fields.

Establishment costs of fodder plots (under arid and semi-arid conditions) are estimated to be between US$200-500. ha^{-1}, excluding the cost of enclosures, which could double the establishment cost. The value of browse is seen mainly in terms of its role as a supplementary source of fodder during the dry season. Some productive figures are presented in Table 4.

Tree service-oriented systems

There is considerable scope for tree service functions within Africa, notably for preventing wind and soil erosion, preventing declining soil fertility and demarcation/protection of different lands. If possible, such tree service functions should be combined with tree production functions to improve the economics of the interventions.

One system which has received considerable attention recently is alley cropping, especially for the humid/sub-humid areas. Trials at IITA have shown very promising agronomic results (11).

Table 4. Production from browse plantations at maturity ($kg^{-1}.ha^{-1}.a^{-1}$)

Species	Location	Browse			Wood	Age at maturity (years)
		D.M.*	F.U.	D.P.		
Atriplex	Tunisia	5,000	2,000	600	5,000	7
Acacia cynophylla	"	6,000	2,000	400	6,000	7
A. senegal	Senegal	2,500	1,000	200	4,000	5
A. albida	Sudan	1,000	700	140	-	25
Prosopis	Cape Verde	1,000	350	35	1,500	6
Leucaena	Malawi	2,500	-	-	-	2

* D.M. = Dry Matter; F.U.= Forage units; D.P. = Digestable protein

A proper economic analysis of the system is required however. Both IITA and ILCA have put this on their list of priorities. It is expected that further on-farm research will be required to reduce labour inputs especially during critical labour periods.

A few attempts have also been made to examine the possibilities for introducing the alley cropping system into the semi-arid areas. Although an ex-ante economic analysis of the system (7), looks promising, a substantial amount of research is required to validate the various hypotheses.

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ECONOMICS OF AGROFORESTRY SYSTEMS IN ASIA

D.A. Hoekstra*

SUMMARY

Agroforestry systems are quite commonly found in Asia. The economics of both the traditional and adopted/new systems are briefly reviewed in this paper. While there are often insufficient data on the traditional systems, there is little doubt about their socio-economic viability in the past. The available information on some of the adopted/new systems, especially woodlots, improved taungya and silvi-pastoral systems, usually shows a good economic return. However, further socio-economic study will be required to determine their viability for different farmers.

INTRODUCTION

Land pressure in the Asian continent is amongst the highest in the world and per capita land area is much below the world's average (3) (Table 1). Since agroforestry (AF) in comparison with non-agroforestry tree-based land-use systems is a more economical form of land-use, the Asian environment is quite conducive to AF systems. According to ICRAF's AF system's inventory, the following major systems are commonly found in the Asian continent (Table 2).

* International Council for Research in Agroforestry, Nairobi, Kenya

Table 1. Comparative land/man ratios for Asia (in ha. 1982)

	World	Asia
Total land area/capita	2.85	1.0
Total land area/economic active person in agriculture	15.74	4.34
Agricultural land*/capita	1.01	0.41
Agricultural land*/economic active person in agriculture	5.58	1.79

* arable land + permanent crops + permanent pastures.

Table 2. Common agroforestry systems in Asia

Tropical forest zone (highland, lowlands)

- Taungya
- Home gardens
- Tree farming/woodlots
- Plantation crop based AF systems

Semi-arid/sub-humid

- Silvipastoral system
- Tree farming/woodlots

TROPICAL FOREST ZONE

This ecological zone covers most of South-East Asia. Where development has taken place, population densities are usually high. However, there are still large areas of relatively undeveloped forest areas where population densities are low.

Taungya system

Although the taungya system was practiced in Europe, the system arose independently in Burma (8). It is therefore not surprising to find it was/is practiced in the Asian continent, notably Indonesia, Malaysia, Philippines and Thailand. However, the system has evolved considerably and a larger share of the "additional" benefits is now obtained by the farmer participants. One such development is the Thai forest villages which were initiated in 1967. Under this system, villages with services are created for the farmer participants at the expense of the Forestry Department. Incentives/bonuses are given for tree planting activities, while the farmers also derive an income from the crops they grow as well as from daily labour activities for the Forestry Department. A comparison between establishing forest plantations without and with forest village schemes (1) gave the following results:

i) 10-year cost to forestry department US \$930 and 960.ha^{-1} for without and with respectively (based on teak [Tectona grandis]).

ii) Returns to family labour US \$771.a^{-1}, of which 34% was derived from agricultural crops, 15% from rewards and bonuses, 51% from daily wage labour in the forest plantations.

Unfortunately no data are provided on opportunity returns for such family labour and hence it is difficult to judge whether or not the aforementioned returns (and benefits) are sufficient to attract farmers.

Home gardens

Home gardens in Asia are mainly found in the humid zones. There is a considerable amount of socio-economic literature on the Javanese home gardens, some of which is summarised below:

i) The use of the home garden is very much related to the overall economic position of the household (5)

ii) The smaller the farm the more intensive the use of the home garden

iii) Stoler found that cassava (Manihot esculenta) production increased in the home garden when farm size (and home garden size) decreased (10). The same study furthermore found that labour input per hectare was 3 times as high in small gardens of 0.1 ha as in large gardens of 0.3 ha (4,700 and 1,600 person hours.ha^{-1}, respectively).

iv) Penny & Singarimbun found that the labour intensive coconut-sugar (Cocus nucifera-Saccharum cvs.) enterprise was practiced by the smaller farmers (with smaller home gardens) while the less labour intensive C. nucifera production was practiced by the larger farmers with larger home gardens (9).

v) The overall returns from home gardens are much higher than from any other land use. Penny & Singarimbun quote a value of output from irrigated rice (Oryza sativa) fields of Rp. 144,000 .ha^{-1}, whereas the value added from just one home garden enterprise (C. nucifera - Saccharum cvs.) is Rp. 162,000 .ha^{-1} (9). Stoler estimated that the production from home gardens in the study area was between Rp. 112,000 and 367,400.ha^{-1} (10).

vi) The returns to labour decrease when labour input per unit area of home garden increased.

Tree farming/woodlots

Perhaps the most frequently quoted tree farming/woodlot systems are the ones in the Philippines and Korea. Several authors have written on these projects and given detailed, mostly ex-ante, economic analyses, which on the whole conclude that wood production for commercial purposes is a sound investment for small farmers.

A recent mid-term evaluation concludes that profitability may vary considerably depending on the perspective of the study (public or private), cultural practices, yields, wage rates and shadow prices of labour (6). It is concluded that participants following typical tree farming practices, are able to earn an acceptable return in all cases except in scenarios where wages are "high" and yields are only medium (Internal rate of return (I.R.R.) between 20-30% for successful tree farmers and between 14 and 22% for average farmers). When labour is shadow priced (public viewpoint), returns to society are slightly higher (I.R.R. 18-26%). However, in the high wages and medium yield scenario returns to society are uneconomical. The author also points out that these returns are in fact not incremental, because contrary to the original set up, many tree farms were established on agricultural land.

Plantation crop based system

In Asia, C. nucifera and rubber (Hevea brasiliensis) are more often than not intercropped with crops or animals. The understory selected depends on land/man ratios and capital availability. In Malaysia where the land/man ratio is relatively high and capital not all that scarce, livestock (including chickens) are often considered as an intercrop. A review of animal production in H. brasiliensis plantations was made by Wan Mohamed (11).

This study concludes:

i) Broiler production in H. brasiliensis plantations can give an additional net family income of M$ 370 to M$ 1,650 over a 2-3 month period.

ii) 3-4 sheep.ha^{-1} may be kept for long term integration of animals and H. brasiliensis trees.

iii) To obtain economics of scale in sheep production, plantation size should not be below 40 ha.

iv) Some indirect benefits are obtained from savings in weeding costs and fertilizer costs

Studies on more labour intensive understory systems with C. nucifera as an upperstory have been conducted for Sri Lanka (7).

It was found that:

i) Early yielding intercrops such as betel (Areca catechu), ginger (Zingiber officinale) and turmeric (Curcuma domestica), which require higher labour inputs, are more suitable for farmers who operate small and medium size farms.

ii) Crops such as pepper (Piper nigrum) and coffee (Coffea spp.), which take some time to mature, are more suitable for the larger farmers.

SEMI-ARID/SUB-HUMID ZONE

The bulk of the semi-arid/sub-humid ecological zone in the Asian continent is found in India.

Silvi-pastoral system

On much of the Indian sub-continent, trees have been deliberately retained on the private and communal lands. Not only do they provide fodder and fuelwood, but they also help to sustain the production systems.

A comprehensive study on systems based on Prosopis cineraria was published by CAZRI in 1980 (2):

i) Tree density in the grazing land varies from about 5 to 50 trees.ha^{-1} although there are locations with up to 250 trees.ha^{-1}

ii) Firewood lopping starts between 8 to 10 years and average 2 to 3 $kg.tree^{-1}.a^{-1}$ (dry weights). By the 15th year it ranges from 35 to 40 $kg.tree^{-1}$ while yields are between 40-70 $kg.tree^{-1}$ from the 20th to 30th year.

iii) Pod production averages 5 $kg.tree^{-1}.a^{-1}$ (air dried) for 30-50 year old trees, and 2-3 $kg.tree^{-1}.a^{-1}$ for 10-30 year old trees.

Tree farming/woodlots

Growing trees for commercial purposes (sometimes under irrigation) has become increasingly popular. A recent publication by Gupta looks specifically at the use of marginal lands for tree-crop production (4). The main conclusion from this study is that the annual return per hectare from crop enterprises derived from marginal land is much lower than from tree enterprises (RS 40 to RS 300 as compared to RS 360 to RS 3,270). Although these figures may require some further studies, the fact is that many farmers have taken up tree crop production at the expense of food crop production.

POTENTIAL/NEW SYSTEMS

Tree planting within agroforestry systems or tree-based non-agroforestry land-use systems is already a common practice in Asia. Most of the systems described may therefore be considered as future systems as well.

Another system which may have some potential for Asia is the alley cropping system, since rainfall intensities are high, much of the land sloping and land-use is quite intensive.

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ADVANCES IN ECONOMIC STUDIES OF AGROFORESTRY PLANTATIONS IN CENTRAL AMERICA*

C. Reiche**

SUMMARY

In the Central American Isthmus, firewood represents more than 50% of the energy used. The "Firewood Project" of CATIE has promoted the establishment of agroforestry demonstration units which are regularly assessed and given a silvicultural follow-up, and in some cases are economically evaluated. The intention is to increase production levels and the net incomes of the producers. The implementation of simple and practical methods, for registering costs and incomes, has shown that for agroforestry programmes in Costa Rica it is cheaper to produce seedlings in temporary nurseries than in permanent nurseries ($40 and $47 per 1000 trees, respectively).

The plantation establishment costs vary from country to country and with respect to: slope, stoniness, number of trees, presence of secondary vegetation, fence costs, and the use of other materials. In a case study of the agroforestry system Eucalyptus saligna and Zea mays, the internal rate of return was 20.15%. In a case study of Gliricidia sepium living fence posts it was 6.19%. The preliminary financial indicators show that the production of firewood from agroforestry systems is a viable alternative which can generate financial returns.

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* Translated from the Spanish by R. Moore.

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INTRODUCTION

In Central America, firewood provides more than 50% of the energy consumed within the region. 72% of the total population, whom are distributed in rural areas and in the low income sectors of the urban areas, depend upon firewood as a domestic fuel source (10). The high dependence of the population upon this energy resource, as well as directed and spontaneous colonization, affects not only the forest cover but also has ecological, social and economic impacts caused by the uncontrolled exploitation.

Since 1980, CATIE, through its "Fuelwood and Alternative Energy Sources Project", and the national forestry institutions in Central America, have established a forestry research programme with fast growing species for the production of firewood. At the same time socioeconomic studies have also been carried out to orientate the project and to understand why and how firewood is used, where the demand is concentrated and at what cost one can produce trees on a small scale (6).

The target group of the research carried out, is the small farmer in Central America. Within the demonstration units for firewood production there are agroforestry systems (temporary association of trees with crops; living fence posts; windbreaks; line planting of trees; shade trees over crops; strip planting of trees; silvo-pastoral) which are evaluated with respect to species, sites, climate, growth, yield and management (2). For some of these systems information about costs and incomes have been compiled for financial and economic evaluation.

In this document only certain aspects of the cost of firewood production from agroforestry systems will be presented, with a preliminary analysis of some of the fuelwood demonstration units.

ECONOMIC IMPORTANCE OF THE AGROFORESTRY SYSTEMS IN CENTRAL AMERICA

In Central America there are a wide range of associations of crops, trees and animals which correspond not only to the particular ecological conditions of each site but also to the diverse objectives, restrictions on, and felt needs of, the farmers (8, 9). They, in their desire for an efficient utilization of their resources or production factors, have developed technological patterns for making an intensive use of the land and to satisfy at the same time their needs for food, firewood, lumber, shade for crops, protection, raw materials and to obtain an income or other products.

A challenge for agroforestry research is to design and produce alternatives that not only diversify and raise levels of production but also raise incomes and the social well-being of the families by means of an efficient use of the production resources. This challenge implies a participatory effort of various disciplines in the design and development of agroforestry systems, but in accordance with the scarce resources, limitations and objectives of the producers.

In general the present efforts in agroforestry research have been oriented towards the identification, characterization and biological evaluation of the existing systems. Based upon the results obtained, efforts are made to design more efficient systems that contribute not only by reducing the gap between traditional technology and modern technology, but also with a sustained production over time.

The present advances permit the researchers to understand the indicators and biological benefits of the technological alternatives, but it is still necessary to show the economic feasibility. That is, one needs to understand or to know if a rational or an effective use of the resources is being carried out and what is the risk for the farmers of introducing adjustments or adopting new systems. But the most important is to show with numbers, the benefits and net incomes which will be derived from the diverse agroforestry options which are proposed.

A limiting factor, for economic analyses of the agroforestry alternatives, is the lack of information about production costs in nurseries, costs of establishing plots, maintainance and management costs, exploitation costs and marketing prices. Moreover, the tree component has been emphasized at the expense of other aspects of these systems such as the animal and crop components. As a response to this limitation for the socio-economic research of the "Fuelwood Project", efforts have been made to systematically collect information about costs. These experiences have permitted the design and promotion of simple practical methodologies for the systematic recording of nursery costs as well as establishment and harvesting costs of plantations for the production of firewood (9). Some of the preliminary results are presented in this document.

NURSERY COSTS

The production of vigorous healthy plants at low cost, is a key element for developing improved agroforestry systems, as well as for other reforestation activities. In Central America the production of plants for research activities and for establishing demonstration plots, have been carried out in permanent and in temporary nurseries. The latter constitute models and practical examples for groups or organizations of farmers who wish to produce plants with local resources and labour, and in this way avoid the cost of transportation and possible transport damage to the plants.

In order to orientate data collection of nursery costs, a preliminary methodology (3) has been developed together with field staff and nursery managers in charge of plant production in the nurseries of Costa Rica. The methodology for recording systematically the costs and activities in a nursery, was developed and tested in 7 small nurseries in Costa Rica. In other Central American countries, general data was obtained on the production costs in temporary and permanent nurseries (1, 4), but utilizing other formulae. In Table 1 a summary is presented of the costs of producing 1000 plants.

Table 1. Average costs for the production of 1000 firewood species seedlings in Central American nurseries (local currency and dollar equivalents)

Country	Year	Official exchange $ 1.00	Production method	Temporary nursery		Permanent nursery	
				Local currency	$	Local currency	$
Costa Rica	1984	C 45.0	bags	--	--	C2,523	56
		C 45.0	beds	C1,820	40	C2,133	47
Honduras	1984	L 2.0	bags	L 250	125	L 329	165
		L 2.0	beds	L 180	90	--	--
Panamá	1983	B 1.0	bags	--	--	B 82	82
Guatemala	1982	Q 1.0	bags	--	--	Q 50	50
Nicaragua	1983	Cs 28.0	bags	--	--	C 380	14
		Cs 28.0	beds	--	--	C 400	14
El Salvador	1983	C 2.5	bags	--	--	C1,100	440

The data shows that the production costs, with both systems of production, are less in temporary nurseries than in permanent nurseries. In addition, it was found that the cost of producing plants in bags is higher than producing them in beds. At the country level there is a large difference between all of the costs. Nevertheless, this does not mean that production is more efficient in one country than in another.

In general terms the differences in the costs are a function not only of the greater or lesser labour requirements per system or type of nursery, but also of inputs, fixed costs, physical characteristics of the land, climatic factors, infrastructure and duration of the working day in each country (5).

Although the experiences in taking cost data with the proposed methodology were positive, adjustments will be made to simplify the control and the data taking for some activities.

The production of seedlings in temporary nurseries is important for agroforestry programmes not just because costs are lower but also as a means of facilitating the adoption of these systems.

ESTABLISHMENT COSTS FOR SMALL PLANTATIONS FOR FUELWOOD AND OTHER PRODUCTS

From an economic point of view an agroforestry plantation is conceived as a business or economic means designed to efficiently utilize scarce resources, and traditional or modern technology, for the production of various products which provide the greatest net income.

Labour needs and establishment costs per ha are greater for the tree plantation systems which include crops. (Table 2). This is due to the greater number of activities during the establishment of crops as well as the trees, and because of the subsequent cultivation needs such as weed control. Nevertheless, these costs are partially compensated by the income which comes from the annual crops.

Table 2. Examples of establishment costs for small forestry plantations (in local currency with dollar equivalent, all values per ha)

Country	Species	Year	Number of trees	Man-days Number	Man-days cost	Material costs	Total costs	$ equivalent
Costa Rica	E. saligna + Z. mays	1982	2,500	124	C8,624	C17,829	C26,452	(588)
Guatemala	C. velutina+ Z. mays	1981	2,500	118	Q 354	Q 18	Q 372	(372)
Honduras	L. leucocephala	1984	2,500	*23	L 117	L 729	L 846	(423)
Nicaragua	E. camaldulensis	1981	2,500	*68	C2,532	C 1,121	C 3,653	(130)
Panamá	E. camaldulensis	1982	1,666	*62	$ 310	$ 259	$ 569	(569)

* Site prepared with machinery.

In general terms it was observed that the variability of establishment costs on the farmer's lands was due to the factors: slope, stoniness, presence of secondary vegetation, fence costs, and the use of other materials.

The systematic collection of costs and incomes does not constitute an end in itself, but it is one of the fundamental needs for carrying out a financial and economic analysis of the alternatives under study.

In order to prepare the following financial analyses, the costs and incomes at present market prices have been considered, and financial indicators such as the internal rate of return (IRR), the net present value (NPV) and the benefit-cost relation (B/C) have been calculated. These indicators, together with a sensitivity analysis, will enable decisions to be made concerning the selection of the agroforestry alternatives which provide the maximum profit or net income for the producers.

Association of Eucalyptus saligna with Zea mays to provide fuelwood for one "trapiche" in San Ramón, Costa Rica

The "trapiches" are small rural processing plants which utilize fuelwood and sugar cane residues for concentrating sugar cane juice in order to produce "dulce", an unrefined sugar. The production volume in the "trapiche" which was studied, is about 156,000 $kg.a^{-1}$. This results from the processing of 17 mt of sugar cane (Saccharum officinarum) per day. Every week about 5.8 m^3 of fuelwood (stacked) are used (302 m^3 stacked $fuelwood.a^{-1}$). The fuelwood is extracted from secondary forests of the farm where the "trapiche" is located. However, there will be future supply problems unless fuelwood plantations are established (11).

As a response to this need, in 1982 the owner established a small agroforestry plantation (0.55 ha). Initially he planted corn (Zea mays) at a spacing of 2.00 by 0.84 m (3 seeds per planting hole = 17,857 $plants.ha^{-1}$). After the germination of the Z. mays he planted E. saligna at a spacing of 2.00 by 2.00 m (2,500 $trees.ha^{-1}$) and he fertilized each tree with 40 g 10-30-10 (N-P-K). After the harvesting of the Z. mays he planted 2 rows of tiquisque (Xanthosoma spp.) between the tree rows. However, this crop failed because of the shade produced by the E. saligna.

The establishment and maintenance cost data were systematically collected from the beginning of the plantation, and the evaluation of growth and exploitation was carried out after 30 months. The oven dry firewood yield was 41.3 $mt.ha^{-1}$ (16.5 $mt.ha^{-1}.a^{-1}$). The total oven dry biomass yield was 53.9 $mt.ha^{-1}$ (27.7 mt $ha^{-1}.a^{-1}$). In terms of stacked green firewood, the yield was 160 $m^3.ha^{-1}$, equivalent to 64 $m^3.ha^{-1}.a^{-1}$ (11). However, the "trapiche" needs 302 $m^3.a^{-1}$. In other words this means that there is a need to manage a total area of

5 ha under forest production, assuming the same annual yield with 3 year rotations under an adequate coppice management. The yield of the Z. mays in the 1st. year was 500 kg.ha^{-1}.

Based upon these costs and the yields, a financial analysis was carried out considering only the first cycle. A discount rate of 10% and present price of ¢ 250.m^{3} of stacked firewood were used.

The association not only has a high technical feasibility, but also from a financial point of view it is a desirable alternative, since for each colon invested there is a profit of 0.11 (Table 3). In addition, the IRR was higher than the current bank interest rates in Costa Rica. An advantage of this kind of agroforestry system is the production of food and income from the annual crops, the latter helping to reduce forestry plantation costs. When the annual crop is not present (sensitivity analysis), financial indicators show clear reductions. In the above case only small differences were observed because only one annual crop harvest was possible. Nevertheless, with more appropriate inter-tree spacing, it would be possible to obtain more than one harvest from the annual crops during each forestry rotation.

Table 3. Financial indicators for the agroforestry association of Eucalyptus saligna-Zea mays, San Ramón, Costa Rica (3 year rotations; costs in colones.ha^{-1})

Indicators	With Zea mays (Discount rate 10%)	Without Zea mays (Discount rate 10%)
Present net value (C.ha^{-1})	3,830	3,211
Benefit/cost ratio (C.ha^{-1})	1.11	1.10
Internal rate of return (%)	20.15	18.50

Live fences of Gliricidia sepium (Jacq.) Steud in the North-east of Honduras

The information for this analysis was taken from a document about the management and production from living fences, presented by Otárola and Martínez (7). It should be noted that many of the costs and yields (in time) are hypothetical, but are based upon field experiences.

As an agroforestry system, living fences constitute an alternative for small producers with land constraints for the establishment of pure plantations, and for medium and large producers who have more land, but who concentrate on other agricultural or animal production activities.

The research was carried out in the San Antonio farm in the Department of El Progreso, Honduras. A financial analysis was carried out using yield information, establishment costs, maintenance and harvesting costs. The information (Table 4) shows high establishment costs, principally the investment in wire and other materials. The financial analysis of the inputs and outputs, over a period of 9 years, shows a present negative net value of L 445.km^{-1}. This is due to high fence maintenance and coppice sprout management costs. However, in the case of a fence with dead posts, the farmer must pay out L 3,293.km^{-1} establishment costs without ever receiving any secondary benefits or income from the fence. Moreover, since the fence with dead posts will only last 5 years, this establishment cost is cyclical. Thus, in the case of live fence posts the farmer reduces his costs to one seventh of the total costs for the maintenance of fences with dead posts.

Table 4. Financial indicators for a live fence of Gliricidia sepium, and for a fence with dead posts in San Antonio, Honduras (Costs in Lempiras.km^{-1})

INDICATORS	LIVE FENCE (Discount rate) 10%	FENCE WITH DEAD POSTS (Untreated posts lasting 5 years)
Establishment cost (L.km^{-1})	2,861	3,293
Present net value (L.km^{-1})	-445	--
Benefit/cost ratio (L.km^{-1})	0.90	--
Internal rate of return (%)	6.19	--

Conclusions

In the analysis of the two cases presented above there are indications that the agroforestry systems are alternatives which from the financial point of view do pay; that is they do generate net return to the investment or they contribute by reducing costs.

Apart from the financial values analized, it must be taken into account that within agroforestry systems indirect benefits also occur, which have not been evaluated in the present analysis. In future studies we intend to evaluate not only financially but also from the economic point of view and with respect to the possible environmental impacts.

It is recommended that cost data collection be initiated from the very beginning of the establishment of an association, and to continue monitoring maintenance, management and harvesting costs.

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ERGONOMIC AND BIOLOGICAL ASPECTS OF HUMAN WORK IN AGROFORESTRY PRODUCTION SYSTEMS

H. Mueller-Darss*

SUMMARY

The production of an enterprise depends largely on the potential and functioning of work systems. In work intensive production systems, outputs are highly dependent on the physical work capacity of man, a parameter subject to considerable constraints in rural regions of the tropics, i.e. climate, tools, work technique and type of work procedures. Their analysis and design requires consideration of human conditions and demands, and will permit sustainable, calculable production.

THE PROBLEM

Human work is the pivotal point of efficiency and production at all levels of an enterprise. By means of intellectual and physical forces man sets productive processes into motion and controls their courses and results. While in economics, means of work and machines on one side, and the materials to be processed on the other side, are subject to a very differentiated evaluation, an equally intensive analysis is not made of man and his situation as a labourer. For machines for example, data are available which, in the sense of an input-output system, show and compare efficiency and costs. In addition such data permit an adaptation to the required task (e.g. development of a special gearbox for a tractor) or adaptation of the work objects to the machine (e.g. large fields for heavy machines) and thus effectively contribute towards an improvement of productivity.

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How does this compare to the assessment of man? He is generally referred to as "manpower" combined with the concept of an average work capacity, e.g. "man-day", where manpower is seen in a time-related context. This is a purely statistical concept which does not leave room for the large number of factors affecting the worker and the result of his work. Opposed to this common dimensional concept of man in economics (and management) is the analytical and conceptual aspect of a so-called "work-system" in ergonomics (Fig. 1) (2).

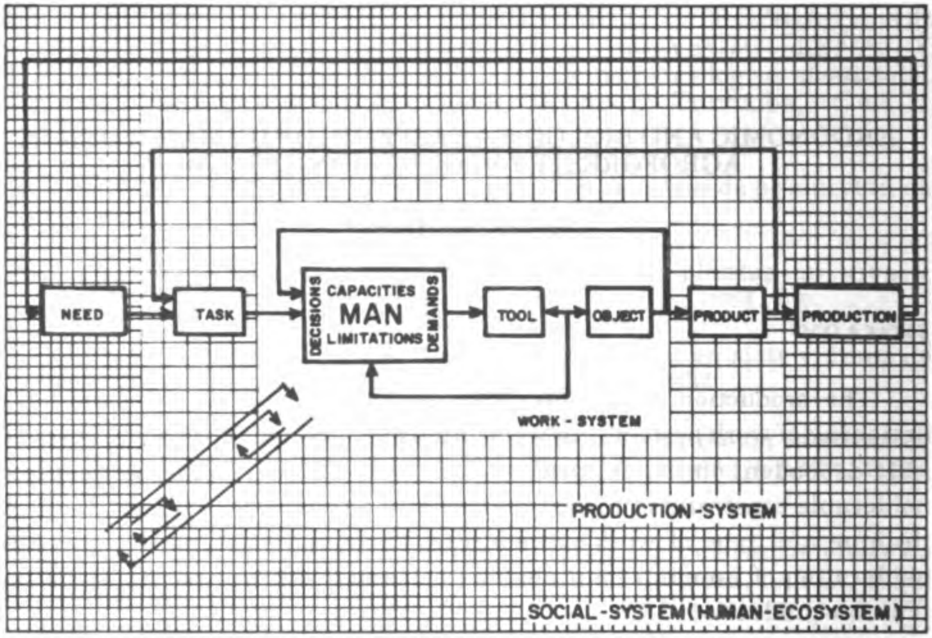

Fig. 1. Relationship of work-system and production-system. The central point is the work system, surrounded by the production system. Both of them are embedded in the social system or the human ecosystem, which formulates the basic decisions

THE SIGNIFICANCE OF MANPOWER IN RURAL PRODUCTION SYSTEMS

In the course of industrialization the potential of the means of work (tools and machines) has been continuously increased while for man the physical load of work (but only this part) has been decreasing. But what about the situation with production in the rural sector, in particular agroforestry systems, in Third World countries? It is well known that the degree of mechanization in the rural sector is very low. In comparison to mechanized systems this implies increased physical stress and strain on the working individual and a higher dependence of production on the human factor. This fact stresses the significance of the worker in these areas and justifies more detailed investigations of the potentials and limits of the physical work capacity. This could as well contribute to increase the efficiency of enterprises with salaried workers. However, neglected improvements could also be made up by hiring more workers. Nevertheless, this does not apply to smallholder agroforestry systems. They depend highly if not exclusively on the physical work capacity of the owner and of the members of his family. It seems therefore indispensable, for the planning and improvement of small agroforestry holdings, to analyze:

- which basic conditions exist for work (physical capacity) among agroforestry farmers;

- which environmental conditions affect work (e.g. climate, nutrition);

- how high is the sustainable human system input under these circumstances

Such analytical studies are the first steps to be taken before a methodological concept of different systems and work processes is designed. Evidently, the physical aspect of human work is of primary importance. But it must also be pointed out that within the work system man must also be seen under psychic, social and cultural aspects, a demonstration of the holistic approach taken by ergonomics in the analysis of man and his work environment.

To my knowledge no ergonomical analyses or concepts have so far been developed for agroforestry systems. The investigation of a group (85 persons) of rural workers (campesinos) from the Orinoco lowlands of Venezuela may help to outline the priorities to be set. Not only the methodological approach but also the implementation of the study are in a certain sense exemplary and are basically applicable anywhere.

ANALYSIS OF THE PRECONDITIONS AND CONDITIONS OF WORK

Human work must be dimensioned in a way, i.e. the output must be limited such that it can be safely and unconditionally sustained over the whole working life without any health risks. To make it clear we are speaking of safeguarding the sustained functioning of work systems. This dimensioning is achieved through the determination of the load and stress limits of work.

Preconditions of human work

The preconditions are determined by the individual or group averages, respectively, of the volume of physical capacity, generally derived via the maximum oxygen uptake. For the above mentioned group of Venezuelan farmers the average amounted to 3.5 $l.min^{-1}$ of which one third may be utilized for work, corresponding to an energetic metabolism of 19 kJ = 4.6 $kcal.min^{-1}$

Conditions of human work

The conditions with limiting effects on the possibilities of work are numerous. In Venezuela, the strongest constraining factors were nutrition and climate.

Nutrition

According to FAO statistics (1) the daily food requirement amounts to 11,100 $kJ.day^{-1}$ of which 6,390 kJ are consumed for the basic metabolism and 1,500 kJ for ancillary activities outside work. The remaining balance of 3,210 kJ available for 5.5 hours of work (actually determined active time) corresponds to a work metabolism of 10 $kJ.min^{-1}$. To put nutrition as a limiting factor into the proper perspective it must be mentioned that forest workers in Sweden or the Federal Republic of Germany dispose of a total daily (energetic volume) nutritional energy of up to 20,000 kJ.

Climate

The effects of climate on man, particularly under tropical conditions, have been extensively investigated. As far as outdoor jobs are concerned the term "weather conditions" may be more appropriate.

The effects of the environmental situation on the work capacity concern essentially the functions of the circulatory system, which under heat is predominantly occupied by maintaining the thermic balance of the body. Consequently, the amount of energy available for work may be substantially controlled by physiological constraints.

Many studies have been dedicated to the investigation of physiologically relevant climatic factors in Venezuela. Statistical tests revealed that radiation energy is the most significant environmental factor influencing heartrate, while in general the so-called corrected effective temperature (temperature + relative humidity + air movement + radiation energy*) is considered the adequate parameter for the assessment of the physiological situation of outdoor work.

* Radiation energy values are given in relation to the human body. The value 1,000 means that 1,000 $kJ.hour^{-1}$ are absorbed by 1 m^2 of body surface. The value zero indicates that the body is at radiation equilibrium with its environment.

The results of the investigations on the effect of climate on the human circulatory system and the related constraints have been interpreted as metabolic constraints because of the correlation between circulatory activity and oxygen consumption. During the average work day the Venezuelan campesino can metabolize 12 $kJ.min^{-1}$ (Fig. 2) or perform work corresponding to this energy, (approximately equal parts of the investigations were carried out during the dry and rainy seasons). The relations are shown in Fig. 3 and the graph permits, according to the respective weather conditions and intensity of radiation, to determine the estimated work load (and the related food demand). The critical parameter is the increase of the heart rate as an indicator that fatigue free, sustainable work is no longer possible.

Values of radiation energy for the area of investigation (200 m above sea level) are given in Fig. 4. They are typical of this latitude and altitude and show that the rather short-term physiological studies have produced acceptable results with only small deviations.

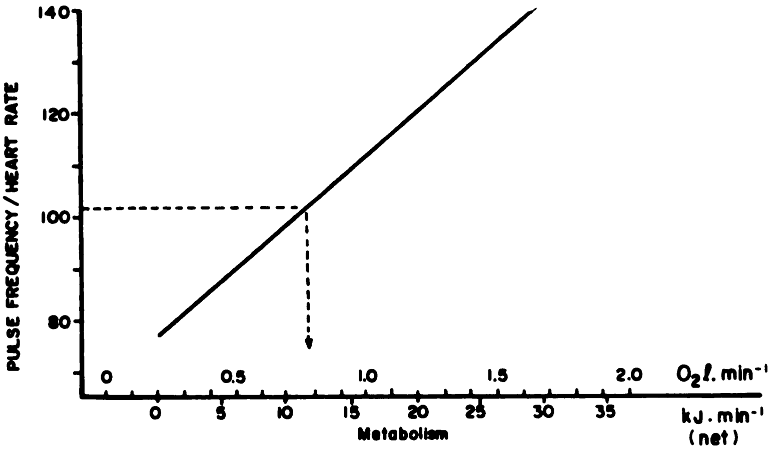

Fig. 2. Relationship between heart rate and energetic metabolism, and demonstration of possible climate-related permanent circulatory load and circulatory metabolism

Potential sustainable effort (system input)

Summarizing the results, the following energetic input parameters can be derived for the work-system:

- constitution-related input = 19 $kJ.min^{-1}$
- nutrition-related input = 10 $kJ.min^{-1}$
- climate-related input = 12 $kJ.min^{-1}$

This clearly indicates that the most severe constraint is caused by the nutritional situation. Its improvement largely controls possible productivity increases of the work-systems. However, an increase to the European

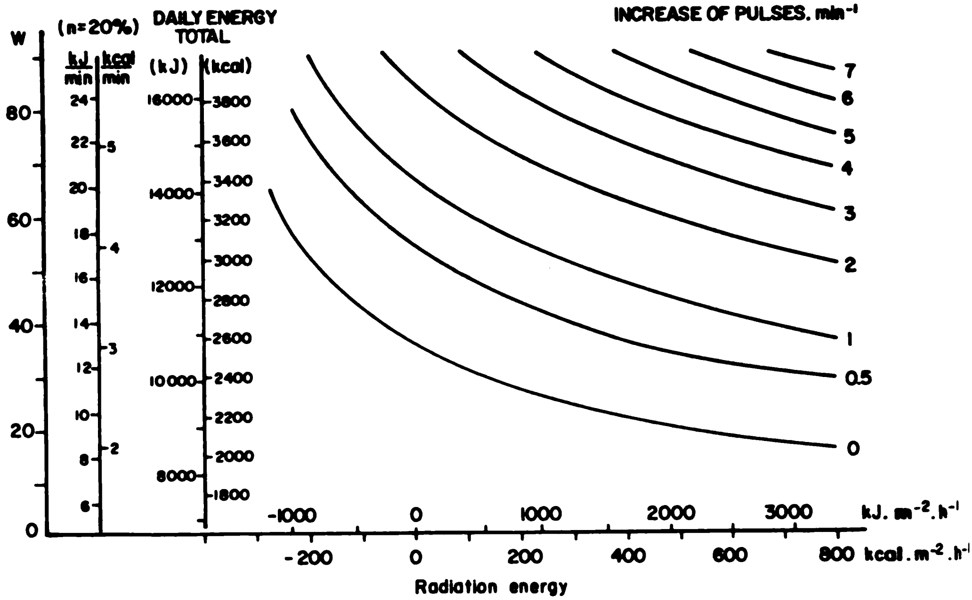

Fig. 3. Relationship between productivity and energy requirements on one side, and radiation stress on the other, with respect to circulatory response (fatigue at the beginning of the increase of the heart rate)

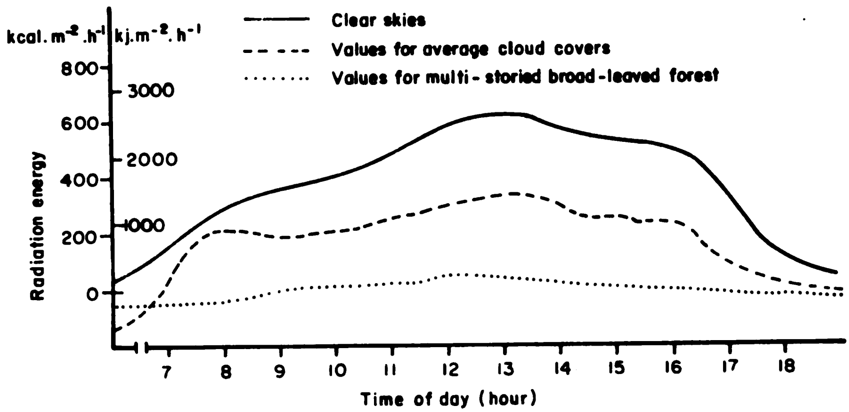

Fig. 4. Diurnal changes of radiation energy at 200 meters above sea level

nutritional level of 10,000 $kJ.day^{-1}$ available for work does not imply a corresponding productivity increase since a markedly earlier capacity limit is reached because of climatic conditions taking effect.

APPLICATION TO RURAL WORK

Ergonomics may be interpreted as a science or a technology. The investigation of the human situation in the production process and the related physiological, psychological and sociological aspects are subjects of scientific research. The actual improvement of working conditions, however, is a subject of work design - a technological aspect. Two basic concepts must be distinguished:

- analysis of the present state;
- design of optimum target states for
    - work procedures
    - work processes
    - global processes within the enterprise

Analysis of the present state (status quo)

The actual state of an enterprise or work system can be ergonomically analysed by investigating all work or work processes with regard to the human effort on one side and the respective outputs on the other. In the Venezuela study it was found, when cutting fodder grass with a machete, that the output was 65 $m^2.h^{-1}$, while 88 $m^2.h^{-1}$ could be cut using a scythe. Both outputs are under the nutrition-related energetic constraint of a maximum load of 10 $kJ.min^{-1}$.

This is one way of determining the potential total output, permitting decisions, e.g. on modifications of the production process.

Design of the target-state

The objective of work-design is to define and achieve the optimum state of a work system out of the total of all possible states. Usually, different alternatives of work techniques and processes are analyzed with respect to the best input-output ratio. It is not uncommon that insignificant modifications can produce considerable effects: in Venezuela the grass cutters would stop about every hour to sharpen their knives on stones at the resting place. Then they were given small grinding stones with the instruction to sharpen the machetes approximately every three minutes. These short and frequent improvements of the tool produced a decrease of 40% of the human effort per m^2 of cut area, meaning a saving in production inputs.

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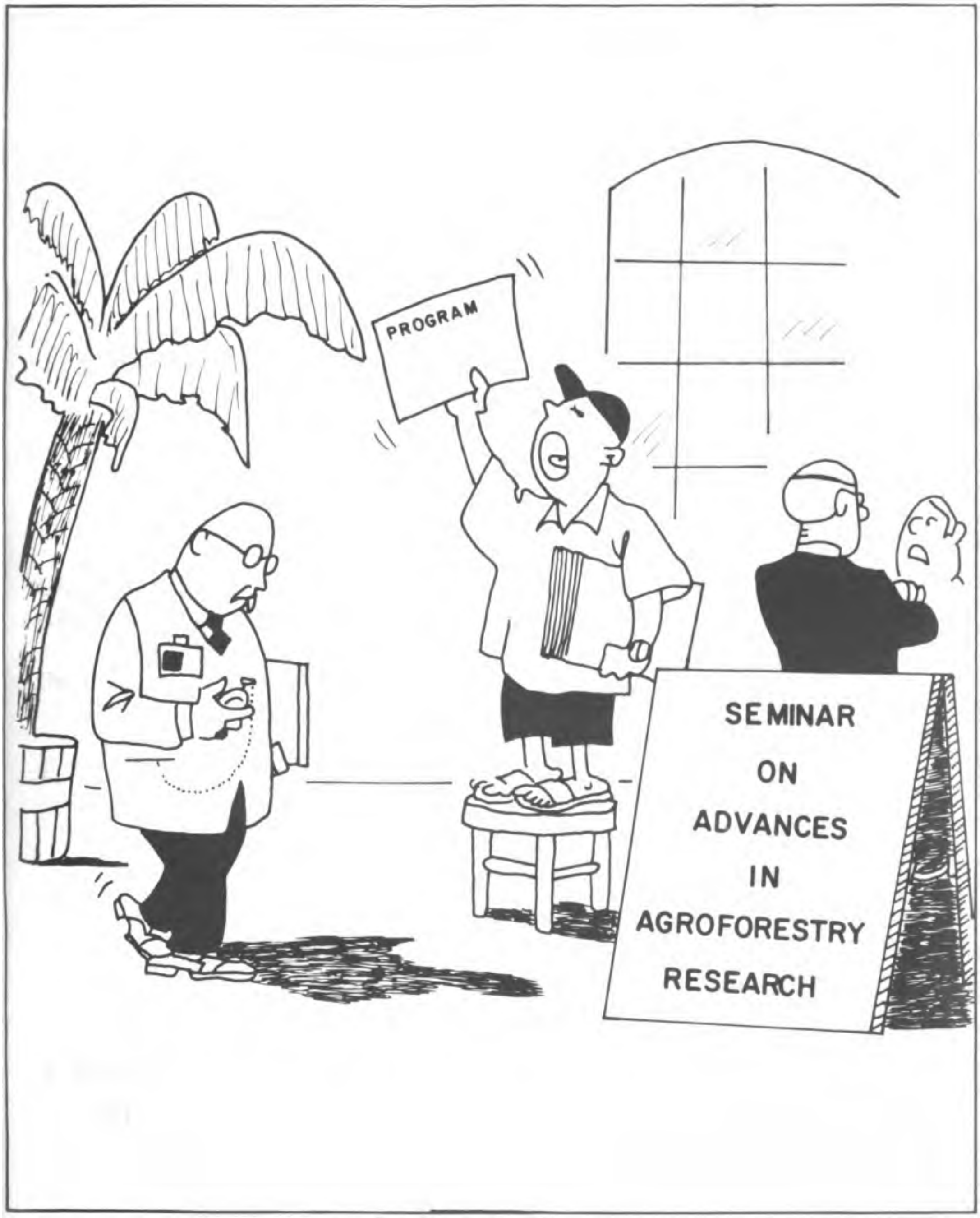

REPORTS OF WORKING GROUPS
PARTICIPANTS
PROGRAMME

7. REPORTS OF WORKING GROUPS: EVALUATION AND SPECIFIC RECOMMENDATIONS

7.1. Working Group A: Soil and Plant Aspects of Agroforestry Systems

Chairman: P. K. Nair
Relators (spanish): E. Somarriba
(english): C. Clement
Participants: R. Russo; G. Sánchez; H.W. Fassbender; J. Beer

1. Introduction

The information contained in the papers presented, and the discussions that followed, were analyzed and grouped under the following headings:

- systems;
- components;
- soil factors & nutrient relations;
- management and ecological considerations.

2. Evaluation

2.1. The systems that are fairly well studied and documented, generally with respect to their productivity and occasionally with respect to their nutrient relations, include:

- shifting cultivation;
- taungya;
- Coffea/Theobroma cacao under shade;
- silvopastoral;
- alley cropping

2.2. Most of these studies involved qualitative description with little, or partial quantitative data. This is particularly so in the case of traditional systems, such as "shifting cultivation" and "taungya". In the case of relatively well documented recent studies, such as "Coffea/T. cacao under shade" and "alley cropping", the available quantitative information pertains mostly to the understory species, with little on the overstory species. Among the nutrients, N has received the most, if not all, of the attention.

2.3. The available quantitative information relates to the following specific aspects of the above-mentioned systems.

2.3.1. Nutrient depletion under the cut-and-carry silvopastoral systems.

2.3.2. Nutrient dynamics and cycling (mostly in "Coffea/T. cacao - shade" and "alley cropping" systems) including:
- estimates of N - fixation;
- litter fall;
- biomass and nutrient reserves;
- nutrient storage in, and losses from the system;
- fertilizer-shade interactions.

2.3.3. Soil changes after shifting cultivation and taungya.

2.3.4. Some observations on pest and pathogen relations in mixed systems.

2.3.5. Crop and grass productivity from alley-cropping and silvo-pastoral systems.

2.3.6. Timber production from Coffea/T. cacao shade trees.

2.4. The components on which studies have been undertaken in Central America, include overstory species, such as Gliricidia, Leucaena, Erythrina, Cordia and Inga. Similar species have also been studied in other ecological and geographical regions. Various understory species have been studied with most emphasis on Zea mays, Phaseolus vulgaris, T. cacao and Coffea spp.

2.5. A number of advantages and potentials of several agroforestry systems, including some of the traditional ones, were highlighted. These include:

- soil improvement;
- soil conservation;
- microclimate amelioration;
- pest and pathogen relationships.

However, there is very little research data on these aspects.

2.6. Moisture relations in the Coffea/T. cacao under shade systems, are also being studied in several countries.

2.7. Silvicultural aspects that are commonly studied are:

- planting patterns and spacing;
- harvesting regimes and production patterns;
- phenology;
- nutrient relations including fertilization.

3. Identification of gaps

3.1. Systems

Analysis of agroforestry systems needs to be increased. Some areas of importance are:

- performance of different agroforestry systems and practices under various ecological and economic conditions (input levels);

- nutrient cycling and relations of individual components vis-a-vis the whole system;

- function of different systems for specific outputs, such as production (food, fodder, fuel) and/or protection (soil conservation, shelterbelt, etc.).

3.2. Components

The seminar has shown that the number of components that have been studied is quite limited. Therefore studies must be intensified and extended. On each proposed component such studies should include the following:

3.2.1. Rooting pattern and distribution, with respect to competition for nutrients and water.

3.2.2. Quantity and rate of turn-over of roots, especially fine roots.

3.2.3. Effect of silviculture and soil management on roots.

3.2.4. Root association with soil microorganisms, including mycorrhizae, Rhizobia and others.

3.2.5. Growth and behaviour under different environments and systems, with respect to the production of wood, fruit, fodder, mulch, etc.

3.2.6. Immobilization of nutrients in the above-ground biomass, and the rate and extent of mineralization, release and uptake of nutrients from litter.

3.2.7. Identification of toxic constituents and by-products in useable biomass, for example:

- alkaloids in Erythrina
- polyphenols in Gliricidia
- cectin in Bactris
- mimosine in Leucaena.

3.2.8. General chemical, organic and mineral composition of plant products.

3.2.9. Pest and pathogen relations.

3.2.10. Competition for, and sharing of, growth factors, such as light, nutrients and water.

3.2.11. Nutrient/shade interactions, especially in perennial crop systems.

3.3. Soils

Lack of information on all aspects of soil and nutrient related phenomena is evident. Studies should be directed at:

- N-fixation;
- acidification;
- depletion of cations;
- nutrient cycling and release, especially of P, K, Ca, Mg and micronutrients;
- soil erosion and conservation in agroforestry systems;
- soil moisture and other physical characteristics;
- soil survey and land evaluation directed at agroforestry.

3.4. Management

The management of systems and components must take into account the differential management of these according to seasonal, climatic and ecological conditions.

4. Recommendations

Research and development efforts should be intensified to tackle the gaps that have been identified. Items that require immediate attention include.

4.1. More long-term quantitative information is needed on agroforestry systems and practices from diverse ecological conditions.

4.2. The value of empirical observations on systems that have stood the test of time should be fully appreciated despite the lack of quantitative data on them.

4.3. Identification and characterization of additional over- and under-story components, for use in different agroforestry systems, should be accelerated. Special attention should be given to fruit trees.

4.4. Germplasm of under-exploited and other potential components of agroforestry systems must be collected, evaluated and distributed according to international norms.

4.5. Plant management, including that of the root systems, should be intensified, especially of the overstory components.

4.6. Detailed chemical analysis of edible products, (especially for potentially toxic elements), and other plant parts, should become a standard practice.

4.7. Full description of soil physical, chemical, microbiological and morphological characteristics must be undertaken in all agroforestry studies and published with them.

4.8. Study of all nutrients (P, K, Ca, Mg and micro-) is as important as that of N and should receive adequate attention.

4.9. Standardization and field evaluation of laboratory studies of N-fixation, and other microorganism symbioses, should receive close attention.

4.10. Advances made in biotechnology should be evaluated and their potential exploited in agroforestry.

4.11. Criteria for evaluating the sustainability of agroforestry systems in various situations must be developed.

4.12. Appropriate experimental methods and designs must be developed and made use of in agroforestry systems, giving emphasis both to the components and to the system as a whole.

7.2. Working Group B: Diagnosis and Technologies for Agroforestry

Chairman: H. J. von Maydell
Relators (english): K. F. Wiersum
(spanish): R. Borel
Participants: P. Anspach; G. Charpentier; L. Espinoza; R. Euler; O. Klein; A. Marmillod; W. Sequeira

1. Introduction

1.1. The working group took as a starting point for their deliberations the activities and results of the CATIE agroforestry programme in general and that of the CATIE/GTZ project on "Agroforestry Systems in Central America" in particular. The objectives of this research are:

- to identify and analyze existing agroforestry practices of the Central American region and to evaluate their potential for rural development;
- to develop appropriate systems and practices of integrated land-use for smallholders;
- to contribute to agroforestry research, education and extension.

1.2. The working group acknowledged the very significant progress made and the valuable results obtained. As a product of the data collected, much knowledge has been gained about the potential for agroforestry. Furthermore gaps in our understanding about the significance of agroforestry could be identified as a consequence of the studies. The following evaluation of results and experiences, and identification of newly recognized gaps in knowledge, is based on this progress through past research. It should by no means be interpreted as a criticism of the ongoing work but rather as a contribution to its further development.

1.3. The discussion of the working group concentrated on three subjects:

- strategies for agroforestry research;
- identification of possible new subject matter for agroforestry research;
- application of research findings through extension programmes.

2. Strategies for agroforestry research

2.1. In CATIE's strategy for agroforestry research, basically three steps can be distinguished:

- description and characterization of existing practices;
- supporting research on the functioning of certain systems;
- design and evaluation of new systems and management practices.

2.2. For research purposes four levels of integration are recognized: region, farm, practice, component. Ideally a sequence of research activities should take place starting with descriptive studies at a regional and farm level, as well as at the level of specific practices. Supporting research of an analytical nature should then concentrate at the level of practices and components. Based on the results of both kinds of studies, experimental studies on the design and evaluation of new or improved activities should take place at the level of practices and farms.

2.3. To obtain results which are of practical value to farmers, research should take place directly on farms whenever possible. In addition, supporting research of a fundamental nature may have to be carried out under controlled conditions on experimental fields, so as to gain a deeper understanding about the functioning of the system and to evaluate its potential for application outside the original area of investigation. CATIE's work provides a good model for such a combined approach of applied research at the farm level and fundamental research on experimental fields.

2.4. CATIE's research strategy is to use existing agroforestry practices as a starting point, and a main objective is to adapt such systems and improve their management. Because agroforestry is a new scientific endeavour, although it has been practiced for a long time by farmers, this is a very relevant approach. However, up till the present, most emphasis has been laid on studies from the point of view of natural sciences, while less attention has been given to the inclusion of social science aspects. Consequently, some of the opportunities offered by on-farm research have not been fully utilized. For instance, at the phase of description and characterization of existing systems, more attention could be given to the question <u>why</u> a farmer uses certain practices instead of only on <u>what</u> he does.

2.5. More attention could also be given to an analysis of the needs for trees, including possible new roles for trees. ICRAF's diagnosis and design methodology offers a model of such an approach. In such an analysis both basic needs and development aspirations of farmers, and environmental needs, should distinguish social objectives and environmental objectives for agroforestry development. Depending on the priority given to each of these objectives, it may be necessary to decide if research projects should primarily concentrate on certain target groups of the rural population or on certain ecological units (e.g. degraded pasture lands).

2.6. Even in the case that agroforestry development efforts are directed at certain specific target groups, it may be necessary to test new techniques with above-average farmers because this is operationally the most efficient and because of the opportunity to utilize such key-farmers as demonstrators of innovative technologies. However, the disadvantage of such an approach may be that it increases social differences or that the technologies are not appropriate to smaller farmers with less access to certain resources.

2.7. The diagnosis of the scope for agroforestry development should not only be based on an analysis of needed and available inputs, but should also give attention to possible constraints of distribution of outputs. Marketing studies should already be considered at an early stage of developing commercial agroforestry systems, as well as acceptability and processing studies, when promoting agroforestry systems with underutilized tree resources.

3. Possibilities for new research subjects

3.1. Agroforestry has been promoted as a holistic approach to sustained land-use. Consequently research institutes should formulate a medium or long-term inter-disciplinary strategy for agroforestry research, to which specific projects should make an appropriate contribution.

3.2. As indicated already, under such a systematic approach CATIE may find it necessary to give more attention to social studies in agroforestry as a follow-up of the present emphasis of the biological sciences approach. Such social studies should not be limited to socio-economic studies (however important), but attention should also be given to socio-cultural factors such as local attitudes, perceptions and preferences for trees and land-use systems, and adoptability of innovations.

3.3. Another important study area concerns possible conflicting priorities of local farmers and government institutions, e.g. if farmers' priorities are directed at short-term income generation and not at environmental control.

3.4. In regard to research in the field of the natural sciences, future CAT^r activities may need to include aspects such as:

- studies on methods to decrease risks from pests, diseases and weather conditions in addition to the studies on optimizing yields;

- inclusion of a larger variety of physical land conditions such as sloping lands or semi-arid regions where erosion and moisture availability are the respective limiting factors;

- more attention to annual crops and results with different crop/grass varieties/species grown in combination with trees.

4. Application of research findings through extension programmes

4.1. Agroforestry research can contribute to agroforestry extension programmes by developing appropriate extension strategies, and by developing new technologies for incorporation in extension programmes. The CATIE agroforestry research programme aims at a balanced approach between technology development and on-farm evaluation. But more resources could be made available to communicate the findings to extension workers and to increase the practical relevance of research findings for extension programmes.

4.2. Due to its holistic approach, agroforestry can contribute to rural development by optimizing land-use instead of maximizing yields of individual crops. For the implementation of such an approach, it is necessary to harmonize the activities of different (governmental) services involved with rural development. The transfer of research findings in agroforestry should therefore not be channeled to only one rural development institution, but to all relevant institutions in the field of land-use planning and development.

4.3. In addition to the stimulation of holistic approaches to land-use, agroforestry extension should also be directed at providing specific technical information. For efficient transfer of such information from researcher to extensionist, it is desirable that the specific objectives for research and extension are closely related during the phases of problem identification and testing of results. With the present state of scientific knowledge, extension workers will benefit most from information on possibilities for adaptive management practices for specific components of existing systems (e.g. effect of pruning/pollarding regimes; introduction of more suitable species/varieties). But gradually new technologies should also be made available to them, which supplement the information on how to manage specific components.

4.4. To stimulate a rapid application of research findings, an efficient form of communication between researchers and extension workers should be established. In this respect more attention should be given to establish links between research institutes, such as CATIE, and national agricultural services, extension agencies and large scale development projects. The very good cooperation between CATIE and MAG/CAR could serve as a model for such cooperation. Information should not only be distributed through scientific reports, but also through publications with practical information (e.g. lists of potential species with purposes and establishment procedures; papers giving advantages and disadvantages of specific agroforestry practices). Such information might well be presented in the form, elaborated during the symposium, for shade trees over Coffea or trees in pastures. The recently initiated CATIE project, for the preparation of a teaching manual for agroforestry, could play a significant role in such a transfer of information.

5. Specific recommendations

5.1. CATIE's agroforestry research should be continued because of its proven ability to contribute to the development of sustained land-use and environmental management, its regional significance as a centre for agroforestry research, and its important contribution to education.

5.2. In CATIE's agroforestry research, more attention should be given to social science aspects, not only during the phase of description and characterization of existing systems, but also during the phase of designing and testing new methods.

5.3. CATIE should organize a joint workshop of researchers and extension specialists to discuss improved ways to apply research findings through extension programmes.

5.4. Communication between agroforestry researchers and extensionists could be improved through the regular publication of a newsletter providing information on new publications, planned meetings, etc. ICRAF's newsletter forms a good starting point for such an information bulletin, but should be further developed to include information on activities of other institutions rather than ICRAF only, e.g. by appointing (regional) correspondents.

5.5. The results of CATIE's excellent research should be made more widely available by publishing these results in widely- distributed international journals in addition to the institute's own series of reports. In addition, special informative leaflets and brochures should be directed specifically at extension workers.

7.3. Working Group C: Economics and Ergonomics in Agroforestry

Chairman: D. A. Hoekstra
Relators (**english**): F. J. Staudt
(**spanish**): C. Reiche
Participants: R. De Camino; R. Jiménez

1. Evaluation of gaps

1.1. There is a lack of socio-economic research (including ergonomical research) within the existing agroforestry research and development programmes.

1.2. There is a lack of socio-economic information on agroforestry systems, and in the dispersion of the information.

2. General recommendations

2.1. Existing information should be pooled through:

- inventory of monitoring systems of existing agroforestry projects;

- inventory of available literature.

2.2. For future agroforestry projects, an information network could be considered.

2.3. Dissemination of information should go through the above mentioned network, journals and newsletters.

3. Recommendations regarding the gaps

3.1. Socio-economic research should be incorporated in proposed agroforestry projects by:

- adding a socio-economic expert, or
- training of the biological experts in socio-economical methods.

3.2. The tasks of such a socio-economic expert should include the following:

3.2.1. To identify the priorities for agroforestry research and design with emphasis on:

- existing whole farming systems, (clear definition of system and the interrelations between its components;

- speedyness;
- multidisciplinary approach;
- problems and potentials (less emphasis on descriptive information at this stage).

3.2.2. Guidance of the project implementation through monotoring.

3.2.2.1. Monitoring system:

- Regarding recording systems, there is a need for standardization (the use of biological experimental plots for obtaining economic data is not recommendable unless they were also designed for that purpose since in many cases they are too small and non-representative of the management intensity; on farm monotoring is more appropriate).

3.2.2.2. For an early assessment of a technology, the following methods should be considered:

- cross-sectional approach should get more attention;
- the study of relating practices;
- and the development of standards for labour output with attention to the working method, tools, work organization and human work load.

3.2.2.3. Physical measurement of output:

- special attention should be given to the measurements of specific agroforestry outputs such as fuelwood, fodder, sustainability, etc., by providing guidelines for physical measurements, e.g. fuelwood (volume, quality); fodder (weight, nutritional content).

3.2.2.4. Valuation of outputs

Pricing of products by a marker price or an opportunity cost.

Special points to be considered:

- future price of fuelwood and other products;
- seasonal fluctuations;
- future shortage;
- valuation of standing value;
- fodder pricing in dry season.

3.2.3. Data analysis.

The purpose is to check whether or not the interventions meet the project objectives. One could distinguish the following methods.

3.2.3.1.Ergonomic analysis (labour and nutritional profile; efficiency of different methods and tools).

3.2.3.2.Risk analysis:

- special studies regarding relationship between climatical data, diseases, pests, (fires) etc. and yields
- factors determining price fluctuations.

3.2.3.3.Cost - benefit analyses:

- with and without approach
- MULBUD computer package.

8. ORGANIZATION

8.1. Seminar Committee

Coordinators : Jochen Heuveldop, Coordinator, CATIE-GTZ Agroforestry Cooperation Project

Hans W. Fassbender, Technical Forest Faculty, Göttingen, Federal Republic of Germany, Consultant to the CATIE-GTZ AF Project

John Beer, Agroforestry researcher, CATIE-GTZ AF Project

Assistant Coordinator: Dr. Leonardo Espinoza, Consultant to the CATIE-GTZ AF project

Secretaries : Lilliam Ugalde de Brenes

Yorlene Pérez Mata

Miriam Romero

Translations
(English to Spanish): Tirso Maldonado, Gloria de Rojas, H. W. Fassbender

(Spanish to English): Susan Shannon, Michael Major

Editors

(Technical) : J. Beer

(English) : J. Beer

(Spanish) : Carmen Rojas

(Bibliographies): C. Rojas

Logistics

Field visits : J. Beer

Weekend programme

Publication English

Conference room : H. W. Fassbender

Audio-visual equipment

Organization of manuscripts

Translations

Support staff

Finances : J. Heuveldop and L. Espinoza

Arrival-departure

Accommodation

Reception

Farewell dinner

Programme and invitations

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(Session of Inauguration September 1, 1985)

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TARTE, Rodrigo
Director del CATIE
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8.3. Programme

SUNDAY, September 1, 1985

Arrival and accommodation

MONDAY, September 2

8:00 - 10:00	Inscription
10:00 - 10:30	Coffee
10:30 - 12:00	INAUGURATION Welcome addresses by R. Tarté, CATIE Director H. Nestroy, Ambassador of the Federal Republic of Germany G. Budowski, Head Natural Renewable Resources Department J. Heuveldop, Coordinator Agroforestry Project GTZ Seminar organization: H.W. Fassbender, J. Heuveldop, J. Beer
12:00 - 13:30	Lunch
13:30 - 17:00	Visit to CATIE installations and experimental fields
18:00 - 20:00	Cocktail at the International Club of CATIE

TUESDAY, September 3 CONFERENCES:

STATE OF ART IN AGROFORESTRY

Chairman: K.F. Wiersum

8:00 - 9:00	G. Budowski: Agroforestry today and tomorrow, synthesis of the IUFRO-Meeting CATIE, June 1985
9:00 - 10:00	H.J. von Maydell: Highlights in agroforestry research and practice
10:00 - 10:30	Coffee

Chairman: H.J. von Maydell

10:30 - 11:30	K.F. Wiersum: Significance of social organization and cultural attitudes for agroforestry development.
11:30 - 12:30	D.A. Hoekstra: Economics in agroforestry
12:30 - 14:00	Lunch

Chairman: D.A. Hoekstra

14:00 - 15:00 J. Heuveldop: Silvicultural concepts in agroforestry
15:00 - 16:00 F.J. Staudt: Ergonomics and its possible applications in agroforestry
16:00 - 16:30 Coffee

Chairman: H.W. Fassbender

16:30 - 17:30 J. Beer/J. Heuveldop: A critical analysis of an agroforestry project in Acosta and Puriscal, Costa Rica.

WEDNESDAY, September 4

Chairman: G. Budowski

8:00 - 9:00 H.W. Fassbender: Criteria for the evaluation of organic matter and nutrient cycling in agroforestry systems
9:00 - 10:00 R. Borel: Agroforestry system interactions: man-tree-crop-animal
10:00 - 10:30 Coffee
10:30 - 12:00 P.K. Nair: Classification of agroforestry systems
12:00 - 14:00 Lunch

CASE STUDIES: CYCLES OF ORGANIC MATTER, NUTRIENTS, WATER AND ENERGY IN AGROFORESTRY SYSTEMS

Chairman: E. Somarriba

14:00 - 14:45 G.A. Enríquez: Response of hybrid Theobroma cacao to two shade associations in Turrialba, Costa Rica
14:45 - 15:30 P. Cabala: Associations between cacao (Theobroma cacao) and shade trees in Southern Bahia, Brazil
15:30 - 16:00 Coffee
16:00 - 16:45 H.W. Fassbender: Nutrient cycling in agroforestry systems of coffee (Coffea arabica) with shade trees in the Central Experiment of CATIE
16:45 - 17:30 J. Beer: Experiences with coffee under shade in Costa Rica
17:30 - 18:15 R. Herrera: Coffee and cacao plantations under shade trees in Venezuela

THURSDAY, September 5

Chairman: G. Sánchez

8:15 - 9:00	J.B. Raintree (Presented by P.K. Nair): Factors affecting the adoption of agroforestry innovations by traditional farmers
9:00 - 9:45	E. Somarriba: Population dynamics of guava (Psidium guajava L.) in pastures
9:45 - 10:30	C. Clement: The Pejibaye palm (Bactris gasipaes H.B.K.) as a potential agroforestry species
10:30 - 11:00	Coffee
11:00 - 11:45	D. Kass: Alley cropping of annual food crops with woody legumes in Costa Rica
11:45 - 12:30	L. Alpízar: Results from the CATIE "Central Experiment": pastures and shade tree associations

Chairman: R. Borel

14:00 - 14:45	J. Beer: Experiences with fence line fodder trees in Costa Rica and Nicaragua
14:45 - 15:30	C. Ramírez: Nitrogen fixation in agroforestry systems
15:30 - 16:00	Coffee
16:00 - 16:45	G. Sánchez: Development of vegetative propagation techniques with Erythrina spp., a multiple purpose tree in agroforestry systems
16:45 - 17:30	K.F. Wiersum: Development and application of agroforestry practices in tropical Asia

FRIDAY, September 6

CASE STUDIES: DIAGNOSIS AND TECHNOLOGIES FOR AGROFORESTRY

Chairman: R. Russo

8:00 - 8:45	P.K. Nair/D.A. Hoekstra: The ICRAF agroforestry farming systems approach
8:45 - 9:30	A. Marmillod: Farmers' attitudes towards trees
9:30 - 10:00	Coffee
10:00 - 10:45	H.J. von Maydell: Agroforestry in Agrica: potentials and constraints to technical and socio-economic development
10:45 - 11:30	L.A. Navarro: Characteristics of farms producing basic grains in four areas of Central America
11:30 - 12:15	A.H. Moreno: Agroforestry systems with Gliricidia sepium
12:15 - 14:00	Lunch

CASE STUDIES: ECONOMICS AND ERGONOMICS IN AGROFORESTRY

14:00 - 14:45	R. Wolf: Agroforestry experiences in southern Sudan with special reference to small farmers
14:45 - 15:30	D.A. Hoekstra: Economics of agroforestry systems in Africa
15:30 - 16:00	Coffee
16:00 - 16:45	C. Reiche: Advances in economic studies of agroforestry plantations in Central America
16:45 - 17:30	D.A. Hoekstra: Economics of agroforestry systems in Asia
17:30 - 18:15	H. Müller-Darss: Ergonomic and biological aspects of human work in agroforestry production systems

SATURDAY, September 7

Free day, optional trip to San José, other tours arranged at request

SUNDAY, September 8

7:30 - 9:00	San José-Acosta
9:00 - 9:45	Experimental farm of the extension agency (MAG), Acosta Alley cropping maize and beans with _Gliricidia sepium_ (F. Araya)
9:45 - 10:30	Acosta-Tabarcia
10:30 - 12:00	Farm of Edgar Mata, Tabarcia: Stabled goats; cut-and-carry silvo-pastoril units; _Cedrela odorata_ over coffee: forage production from living fence posts (J. Beer)
12:00 - 12:30	Tabarcia-restaurant Tulim, Puriscal
12:30 - 13:30	Lunch
13:30 - 13:45	Puriscal-San Juan
13:45 - 14:30	Tree species trials in degraded pastures (R. Jiménez)
14:30 - 17:30	Puriscal-Turrialba

MONDAY, September 9

WORKING GROUPS

8:00 - 8:30	Plenary session (J. Heuveldop)
8:30 - 18:00	Separate sessions of groups A, B, and C (Coffee 9:30 - 10:00, Lunch 12:30 - 14:00, Coffee 15:30 - 16:00)

A. CYCLES OF ORGANIC MATTER, NUTRIENTS, WATER AND ENERGY IN AGROFORESTRY SYSTEMS

Chairman: P.K. Nair
Relators: C. Clement (english), E. Somarriba (spanish)
Aula : Reventazón

B. DIAGNOSIS AND TECHNOLOGIES FOR AGROFORESTRY

Chairman: H.J. von Maydell
Relators: K.F. Wiersum (english), R. Borel (spanish)
Aula : CEE-building, seminar room

C. ECONOMICS AND ERGONOMICS IN AGROFORESTRY

Chairman: D.A. Hoekstra
Relators: F.J. Staudt (english), C. Reiche (spanish)
Aula : CEE-building, television room

TUESDAY, September 10

8:00 - 10:00	Plenary session. Presentation of working group A
10:00 - 10:30	Coffee
10:30 - 12:30	Plenary session. Presentation of working group B
12:30 - 14:00	Lunch
14:00 - 16:00	Plenary session. Presentation of working group C
16:00 - 16:30	Coffee
16:30 - 17:30	Closing session
19:00	Dinner at the International Club at CATIE

WEDNESDAY, September 11

Departures
Excursion to other areas of CATIE activities (optional)