AGROFORESTRY IN THE HUMID TROPICS

its protective and ameliorative roles to enhance productivity and sustainability

Edited by
NAPOLEON T. VERGARA and NICOMEDES D. BRIONES

ENVIRONMENT AND POLICY INSTITUTE, EAST-WEST CENTER
Honolulu, Hawaii, USA
SOUTHEAST ASIAN REGIONAL CENTER FOR GRADUATE STUDY AND RESEARCH IN AGRICULTURE
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Editors:

MR. NAPOLEON T. VERGARA
Research Associate
Environment and Policy Institute
East-West Center
Honolulu, Hawaii, USA

and

Dr. NICOMEDES D. BRIONES
Professional Associate
Environment and Policy Institute
East-West Center
Honolulu, Hawaii, USA

FOR COPIES, WRITE TO: The Director
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PREFACE

This book arose from the "Regional Workshop on the Roles of Agroforestry in Site Protection and Amelioration" held in Los Baños, Laguna, Philippines, in September 1985 under the joint sponsorship of the East-West Environment and Policy Institute (EW-EAPI), the Forest Research Institute (FORI), the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA), and the University of the Philippines College of Forestry (UPCF). Its publication was undertaken after it had been ascertained that the materials presented at the workshop would be useful references for planners and practitioners of agroforestry in the Asia-Pacific region. The editing and printing were made possible through the joint efforts of SEARCA and EW-EAPI.

The 15 papers presented at the workshop and edited to form the body of this book were prepared by 25 authors from 8 countries who wrote about agroforestry cases from 5 different nations in East Asia, Southeast Asia, and South Asia. They brought in much-needed primary data relevant to the workshop's theme and derived from the author's own research or extension projects.

Due credit is accorded to the four above-mentioned sponsoring agencies for making the workshop possible; the various authors who presented the valuable papers; and the international donor organizations (UNEP Regional Office in Bangkok, IDRC of Canada, FAO/Bangladesh, and USAID/ASEAN Watershed Project) for funding the participation of some of the delegates. The special contributions of certain individuals are likewise duly acknowledged: Dr. Marcelino Dalmacio of FORI and Dr. Reynaldo de la Cruz of UPCF for chairing the sessions of the workshop groups; Dr. Mercedes Garcia of UPCF for making a special presentation on the state of the art in employing rhizobia and mycorrhizae for greater tree survival and growth; Ms. Helen Takeuchi of EW-EAPI for the careful editing of this lengthy manuscript; and to Dr. Cesar C. Jesena, Jr., Prof. Melanio Gapud and Mr. Rudy A. Fernandez, all of SEARCA, for attending to the tedious process of printing this book.

NAPOLEON T. VERGARA
NICOMEDES D. BRIONES
Editors

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I.
INTRODUCTION

Agroforestry as a land-use system has been increasingly regarded as an effective and low-cost means for minimizing the degradation processes associated with land cultivation (protective role), and for maintaining or even increasing the productive capacity of agroecosystems (ameliorative role). Since there is a wide array of agroforestry systems as influenced by variations in species composition, espacement, climatic and edaphic factors, and socioeconomic conditions, it follows that the above-mentioned roles of agroforestry may or may not be realized depending on whether or not the appropriate system is selected for the right biophysical and socioeconomic conditions.

As a background section, this introductory overview presented through two papers discusses in sufficient quantitative detail the biological and physical processes that enable agroforestry to achieve its two major roles. It is designed to make it much easier for users of this book to understand and appreciate the succeeding chapters.

PROTECTIVE AND AMELIORATIVE ROLES OF AGROFORESTRY: AN OVERVIEW

by

R.E. de la Cruz and N.T. Vergara[1]

ABSTRACT

A conceptual framework for the protective and ameliorative roles of agroforestry is presented with more emphasis on the quantitative data of the system. A few examples cited in this chapter point out that agroforestry is a viable tool for upland management although several flaws are expected. Agroforestry can increase and sustain crop productivity in the uplands and improve environmental conservation.

INTRODUCTION

Many countries in the tropics formerly had rich natural forests. In time, these forests were cut down to make way for agricultural farms, rangelands, or settlement areas. As the agricultural and open lands increased, the forested areas decreased correspondingly. The situation now in many countries is that the residual forests are mostly found in high mountains over rugged terrain and steep slopes. However, increasing demands for forest products still continue to reduce the natural forest areas. On another dimension, the subsistence farmers continue to exert pressure on the uplands. In many cases, lowland agricultural practices are duplicated in the uplands. The slash-and burn-agriculture is still one of the biggest problems in the uplands. All these practices result in soil fertility decline, high soil erosion, surface runoff, sediment yields, and, ultimately, crop failures.

[1]Research Fellow and Research Associate, respectively, Environment and Policy Institute, East-West Center, Honolulu, Hawaii.

The flat lowlands, especially those near the sea, are almost always devoted to the growing of agricultural crops. Monocultures of rice, corn, sugarcane, and other purely agronomic crops are found in this area. Because of intensive cropping practices, available irrigation facilities, and use of fertilizers and pesticides, crop failures seldom occur in these areas, although pest and disease may be a real problem.

Many of the natural forests, tree plantations, and horticultural crops are grown in the uplands. The deep-rooting characteristics, accumulation of litter, and large multistoried canopies of these trees help stabilize the soils in the uplands such that soil erosion, surface runoff, and sediment yields are minimized. These, plus the ability of trees to immobilize nutrients in their biomass for future recycling, help sustain the fertility of upland systems.

The practice of lowland agriculture in the uplands, particularly with slash-and-burn agriculture, has led to wide-scale degradation of the uplands. Cutting down of the forests, followed by burning of the biomass, may initially give high yields of agricultural crops because of the inherent favorable fertility of cleared and burned forest lands. This is one reason why slash-and-burn agriculture has attracted many of the lowlanders to the uplands. Continuous cropping of the area, however, leads to reduced yields, on account of decreases in soil fertility due to soil erosion and crop removal.

In time, the concept of combining pure agricultural and forestry practices evolved. The concept of agroforestry is therefore born as a system to combine the good attributed to agriculture (i.e., high productivities of food crops) and forestry (decreased soil erosion and maintenance of soil fertility). Agroforestry is the name given to land-use systems based on age-old practices of intentionally mixing or growing trees with crops/animals in the same area. It combines agriculture — both crop production and animal production — with forestry, in sustainable production systems, on the same piece of land either simultaneously or sequentially (Nair and Fernandes, 1984). Agroforestry is a collective name of land-use systems and practices where woody perennials (e.g., trees, shrubs, palms, bamboos) are deliberately planted on the same land management unit with agricultural crops and/or animals, either in some form of spatial arrangement or temporal sequence. The term *agroforestry* is fairly new although the practice evolved a long time ago. Agroforestry has been practiced by many upland farmers. It took time for scientists to give a name to this efficient and self-sustaining system.

Many papers on agroforestry speak of the protective and ameliorative roles of agroforestry. However, many of these papers talk about the *qualitative* beneficial aspects of the system. The *quantitative* aspects of agroforestry in site protection and amelioration are not well defined. The objective of this chapter is to discuss a conceptual framework by which the practice of agroforestry contributes to the protection and amelioration of fragile uplands. Quantitative aspects of the protective and ameliorative roles of agroforestry will be emphasized.

THE CONCEPTUAL FRAMEWORK

The protective and ameliorative roles of agroforestry systems and how these are brought about are illustrated in Figure 1. The natural resource bases with their components – water, land, forest, and human resources – are influenced by many environmental factors such as climatic, socioeconomic, political, cultural, and biophysical factors. Agroforestry systems were evolved to take advantage of these influencing factors in effectively managing the natural resource bases.

The immediate benefits or services that can be obtained from effective agroforestry systems are protection and amelioration of the site. Protection includes the reduction of soil erosion, landslides, surface runoff, nutrient loss, and evaporation. Amelioration refers to improvement of nutrient status, soil organic matter, soil pH, soil structure, pest and disease control, and decrease in temperature and solar radiation.

These immediate benefits derived from agroforestry may lead to long-term benefits such as increased crop productivity, sustained crop productivity, improved nutrition and health, improved socioeconomics, stabilized land-use policy, and improved environmental conservation. If effectively applied, agroforestry systems therefore can be an effective tool for rehabilitating and managing degraded uplands and promoting rural development.

THE NATURAL RESOURCE BASE

Water Resource

To a large extent, water is influenced by climatic factors – specifically the amount of rainfall and the occurrence of seasonal phenomena such as monsoons and typhoons. In the uplands, the type of

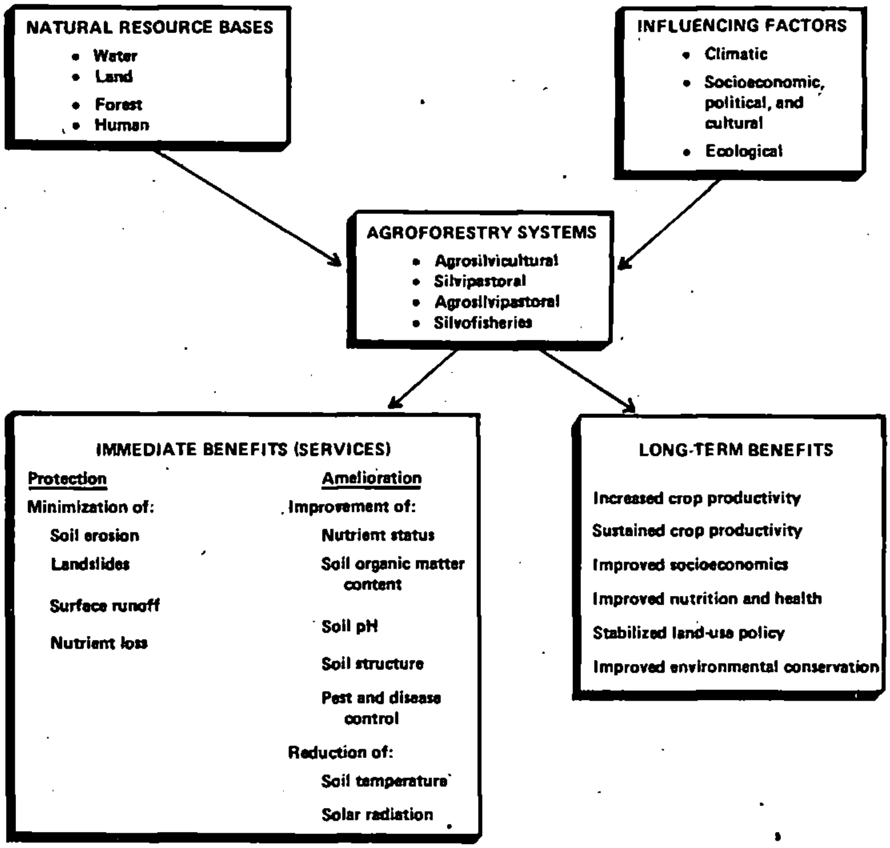

Figure 1. Conceptual framework for the protective and ameliorative roles of agroforestry.

vegetation, soil properties, management practices, and land-use policies play important roles in maintaining this important resource.

Land and Forest Resources

Most of the land subjected to slash-and-burn agriculture is forest land and is generally state or government owned. Population pressures and poverty are two reasons that drive lowlanders to the uplands. The land and forest resources need to be managed properly for the general good of the people. Mismanagement of these fragile resources not only affects erosion rates, surface runoff, landslides, and nutrient losses in the uplands, but also may cause destructive floods, siltation of rivers, dams, and agricultural fields in the lowlands during the rainy season, and possibly destruction of marine and coral ecosystems downstream. In essence, the removal of the forest resource in the uplands by a minority group of the population may create a chain of harmful consequences in the lowlands affecting a greater number of people.

Human Resources

Two groups of people occupy the uplands — the ethnic uplanders and the migrant settlers. The uplanders are those who have been living in the upland forests. They have evolved an effective system of agroforestry, combining crops that protect the soil from erosion and rapid surface runoff. Their practices help sustain the fertility of the soil and, for this reason, have created a stable system that allows them to maintain stable communities in the uplands spanning several generations. One distinct characteristic of the uplanders is that they have a system of organization either as a tribe, an ethnic group, or a community. Members of the group work in conjunction with others to attain long-term goals. The traditional practices of the uplanders therefore become models of our present-day knowledge of sustainable agroforestry.

The migrant settlers include all lowlanders who are forced to migrate to the uplands. These people occupy forest lands and clear the forest of vegetation to make way for annual agricultural crops. Many of them are poor and landless. The settlers differ from the uplanders in that the former are composed mostly of small, independent groups or families. They are not organized in a system comparable to their upland counterparts. This and their inexperience in managing the fragile uplands have contributed immensely to the degradation of the uplands.

The human resources in the uplands are important components of the natural resource base. Agroforestry systems should direct their attention especially to the settler components of the human resource in order to achieve sustainability.

FACTORS INFLUENCING AGROFORESTRY PRACTICES

Climatic Factors

Farming the uplands is a never-ending struggle between the farmer and the climatic factors. Crops are usually planted at a time when climatic conditions are favorable for plant growth. Rainfall, solar radiation, temperatures, and humidity are important factors that directly affect crops planted in an agroforestry system. These climatic factors, especially rainfall, also affect the rates of soil erosion, sediment yields, and surface runoff.

Socioeconomic Factors

Most of the upland farmers belong to the landless groups who occupy the lowest economic strata of society. Their illegal occupancy of public forest lands is a matter of survival for these people. Although some countries recognize the ancestral or communal nature of the native uplanders, the settlers are considered "squatters" in the public domain. By sheer number and type of activities, the settlers exert tremendous pressures and have the greatest adverse impacts on upland systems.

Political Factors

Inappropriate land-use policies, improper implementation of laws and regulations, and a lack of thorough understanding of upland ecosystems are important factors affecting upland development. Both the native uplanders and settlers sometimes serve as pawns of political leaders on one side and the agencies supposed to control illegal activities in the uplands on the other. In many cases, political interference in the implementation of laws and regulations in the management of uplands becomes a major hindrance to forest conservation.

Cultural Factors

The tribal or community nature of the native uplanders and their well-organized structure have evolved into a cultural system where preservation and conservation of the resource base is an accepted communal goal. On the other hand, the independent and unorganized nature of upland settlers brought diverse cultures and practices to the uplands, making it difficult to arrive at one course of action for this heterogeneous group.

Biophysical Factors

Site factors such as soil characteristics, slopes, and terrain, as well as plant communities, play important roles in agroforestry practices. It is generally agreed that tropical soils are much older and infertile than temperate soils. Much of the fertility of tropical soils are tied up with the biomass or organic matter of green plants. In slash-and-burn agriculture, removal of the tree biomass also decreases the fertility levels of the soil. The increased soil erosion rate due to removal of ground cover leads to faster degradation of upland soils.

THE AGROFORESTRY SYSTEMS

Agroforestry systems can be classified according to the combination of agricultural and forestry crops in a given area. Some major systems are agrosilviculture, silvipasture, silvofisheries, and agrosilvipasture.

Agrosilviculture involves the combination of agronomic crops such as rice, corn, vegetables with horticultural crops, and/or forest trees. The combination may be achieved in terms of spatial arrangement of the crop components, i.e., trees planted as field borders or farm boundaries, alternate rows of food and tree crops, alternate strips of food crops and trees (alley cropping or corridor cropping), and random mixture of food crops and trees (Vergara, 1982). Another way of achieving an agrosilvicultural system is by the sequencing of planting time and crops over time, which can be done by an alternate or cyclical system (swiddening or shifting cultivation), partial overlap (Taungya), and simultaneous cropping (integral system).

Silvipasture involves the combination of trees and livestock in a given area as contrasted to a wide expanse of grasslands for traditional livestock growing. The latter usually includes fire as a management tool for the production of grass fodder. This practice, however, contributes to upland degradation because of biomass removal by burning.

Silvofisheries involves the combination of forest crops and fishery practices. Not much is known about this combination, but it can be done in mangrove forests or in areas bisected by streams. The presence of trees helps to control soil erosion and sedimentation of streams and rivers.

Agrosilvipasture refers to the combination of agricultural, forestry, and livestock components in a given site.

IMMEDIATE BENEFITS (SERVICES) FROM AGROFORESTRY

The immediate benefits from a successful agroforestry combination can be divided into their protective and ameliorative roles.

Protective Roles

The protective roles of agroforestry include minimization of soil erosion, landslides, surface runoff, nutrient loss, and evaporation.

Minimization of Soil Erosion

It is generally agreed that the tree component of agroforestry helps minimize soil erosion. Orallo and Lopez (1981) observed that soil erosion rates were significantly affected by vegetative cover. *Pennisetum clandestimum* was more effective in controlling soil loss with an average of 2.64 cm, followed by *Miscanthus philippinensis* (3.11 cm), *Alnus maritima* (3.21 cm), *Tithonia diversifolia* (3.33 cm), *Pinus kesiya* (3.36 cm), and the control (bare) plots (3.51 cm). The largest soil erosion rate of 4.11 cm was observed in plots planted to *Thysanolaena maxima.*

Peh (1980), while studying sediment transport in two tropical forests in Malaysia, reported that erosion rates ranged from 0.196 to 0.662 $cc/m^3/yr$ in Bukid Lagong Forest Reserve, which has an annual rainfall of 2470 mm, and from 0.248 to 2.75 $cc/m^3/yr$ in Pasoh Forest Reserve, which has a lower rainfall than the former.

Studying suspended and dissolved sediment load of three small forested drainage basins in Peninsular Malaysia, Peh (1981) showed that tropical rainforest provides an efficient protective cover for the deeply weathered land surface of the humid tropics. Concentrations of suspended sediment (28-112 mg/liter) and dissolved sediment (19-72 mg/liter) were generally low. The total sediment load carried by the streams was 0.077-0.175 $m^3/ha/yr$, of which dissolved sediments accounted for 35-42 percent. Some 44-61 percent of the load was carried in November and December, coinciding with seasons of heavy rainfall.

Several factors may affect soil erosion. Within a given field of tea at a uniform slope of 10 percent, Othieno and Laycock (1977) observed that rainfall intensity, runoff, and percentage ground cover were the major factors affecting soil erosion. The factors accounted for as much as 86 percent of the variability in soil erosion. There was no erosion when the ground cover provided by the tea canopy exceeded 65 percent.

The type of vegetative cover an affect soil erosion. Serrano et al. (1976) observed that pure stands of *Albizia falcataria* gave better protective cover against soil erosion than that of *Antocephalus chinensis*. The unfavorable canopy structure of the latter resulted in considerable compaction and increased runoff. Ghosh and Rambabu (1977), Shukla and Gupta (1979), and Tejwani et al. (1975) reported on the erosion rates under different vegetative covers. Their resports are summarized in Table 1.

The construction of physical barriers to soil erosion in steep slopes drastically reduces soil erosion. Borthakur et al. (1978) reported that soil loss was high under shifting cultivation (40.9 tons/ha) but was drastically reduced to 5.8 tons/ha under one-third terracing or 4.0 tons/ha under complete terracing.

The practice of shifting cultivation contributes significantly to soil erosion losses. Singh and Singh (1980), studying erosion rates on 50-60 percent slopes in Meghalaya, northeastern India, found 147 tons of soil loss per hectare under the first year *jhum* (shifting cultivation), 170 tons/ha in the second year *jhum,* 30 tons/ha in an abandoned *jhum,* and only 9 tons/ha in a natural bamboo forest. Thay concluded that shifting cultivation caused erosion rates many times more than the acceptable limits and therefore should be abandoned in such sites.

Studying the erodibility (susceptibility to erosion) properties of soil under shifting cultivation against similar soils not under shifting cultivation, Jha and Rathore (1981) showed that erosion ratios of Orissa soils under shifting cultivation in India were 18.03 and 18.78 in the surface and 6.5 and 11.4 in the subsurface as compared with erosion ratios of soils not under shifting cultivation of 10.7 and 10.8 in the surface and 3.7 and 11.7 in subsurface soils. Erosion ratios were higher in the upper layer than in the lower layers. Soils under shifting cultivation had high erosion ratios while soils not under shifting cultivation were within the safety limits of erodibility.

Table 1. Effect of different plant species on soil loss.

Plant Species	Soil Loss	Reference
Strawberry with weed	4.49 tons/ha	)
Strawberry clean	23.70 "	)
Pineapple with weed	1.69 "	)
Pineapple clean	8.44 "	)Ghosh and Rambabu,
Pomegranate with weed	1.39 "	) 1977 (2-year average)
Pomegranate clean	20.38 "	)
Cymbopogon citratus	2.30 "	)
Cultivated fallow	18.46 "	)
Turmeric	2.17 tons/ha	)
Ginger	3.00 "	)
Colocasia	3.22 "	)
Pomegranate with weed	0.25 "	)Shukla and Gupta, 1979
Pomegranate clean	12.46 "	) (4-year average)
Cymbopogon citratus	0.11 "	)
Cowpea	17.52 "	)
Cultivated fallow (spaded)	1.72 "	)
Cynodon plectostachys	56 kg/ha	
Cenchrus ciliaries	137 "	On 5 percent slope
Panicum antidotale	67 "	
Pennisetum pletostachyum	67 "	
Urochloa stolonifera	78 "	
Eulalipsis binata	290 "	On 11 percent slope
Pueraria hirasata	180 "	Tejwani et al., 1975

Comparing soil losses from forest, tea plantations, and vegetable gardens, Tang et al. (1979) observed a ratio of 1:20:30 or the equivalent of 24.5:488:732 $m^3/km^2/yr$. This implies that larger soil losses occur under the shallow-rooted vegetable cover than in the deep-rooted forest cover.

A reduction in canopy cover plays an important role in soil erosion. Studying thinning intensities on Benguet pine plantations, Veracion (1983) reported sediment yields of 36.42 tons/ha in heavily thinned plots, 10.71 tons/ha in moderately thinned plots, 12.74 tons/ha in lightly thinned plots, and 10 tons/ha in unthinned plots.

Minimization of Landslides

No actual information is reported in the literature on the possible minimization of landslides by agroforestry systems. However, the deep-rooted characteristics of most trees in agroforestry farms, especially if they are planted along contours, may impart soil stabilizing properties. This is expected if the tree component of the system has already been established over a longer period of time.

The type of cropping system may affect soil erosion rates as measured by sediment yield. Cruz (1982) showed that cropping system B (nontraditional with buffer strips established along contours at 5 m intervals; buffer strips planted to leucaena, kakauate, black pepper, pepper, and ginger; and cropping system consisting of corn and peanut, followed by bush sitao) had a total sediment yield of 0.33 ton/ha and was found the most effective in minimizing sediment yield. Cropping system C (nontraditional system with buffer strips the same as B and cropping system consisting of mung bean, followed by soybeans and kadios), cropping system D (traditional system consisting of corn, gabi, banana, and citrus), and cropping system A (nontraditional system with buffer strips same as B and C, but the cropping system consisting of rice, followed by peanut and then garlic) produced sediment yields of 0.66, 0.88, and 1.12 tons/ha, respectively.

Minimization of Surface Runoff

The type of cropping system also affects surface runoff. Cruz (1982) reported that cropping system B gave a surface runoff value of 34.67 mm, which was the most efficient in minimizing surface runoff. Cropping systems C, D, and A yielded surface runoff values of 55.95 mm, 65.60 mm, and 79.03 mm, respectively.

Forest cover is no guarantee that surface runoff will not occur. Peh (1980), studying runoff in two tropical rainforest conditions in Malaysia, reported runoff values of 1.3 to 3.1 liters/cm/yr in Bukid Lagong Forest Reserve where annual rainfall averages 2470 mm and 0.53-10.6 liters/cm/yr in Pasoh Forest Reserve, which has a lower annual rainfall.

Pure stands of *Albizia falcataria* were found much better than that of *Antocephalus chinensis* in minimizing surface runoff (Serrano et al., 1976). The crown structure of the latter produced large throughfall drops resulting in considerable soil compaction and rain splash, thereby increasing surface runoff.

In Malaysia, Tang et al. (1979) reported that in steep slopes at the Cameron highlands, where the forest was converted to tea plantations and vegetable gardens, stream flows were reduced by 50 percent in small catchments (50 km^2) and 75 percent in larger catchments (500 km^2). Peak runoff per unit area from rubber and oil palm catchment was twice that of forested catchment.

Reducing the canopy cover of natural forest usually increases surface runoff. Veracion (1983) reported that surface runoff in heavily thinned Benguet pine stands reached 638.3 mm/ha, 433.00 mm/ha in moderately thinned plots, 317.1 mm/ha in lightly thinned plots, and 260.3 mm/ha in unthinned plots. Heavy thinning intensities contributed largely to surface runoff. This effect may be correlated with the decrease of rainfall interception when the canopy is opened. Veracion and Lopez (1976) reported that throughfall was highest in heavily thinned plots (90.64 percent of total rainfall), followed by that in intermediately thinned plots (87.97 percent), and unthinned plots (84.91 percent). The wider the opening of the crown canopy due to thinning, the more the throughfall was observed. The denser the crown, the more the water was intercepted. Rainfall interception was highest in unthinned plots (13.47 percent of total rainfall), followed by intermediately thinned plots (10.97 percent), lightly thinned plots (10.56 percent), and heavily thinned plots (7.99 percent).

Studies revealed that surface runoff in shifting cultivation areas may be significant. Borthakur et al. (1978) showed that surface runoff under shifting cultivation was about 11.40 mm. Partial terracing reduced surface runoff to 81.4 mm and complete terracing reduced runoff further to 32.8 mm. This study implies that the creation of physical barriers in the uplands by terrace construction considerably reduces surface runoff and soil loss. A strip of trees planted along contours may also serve the same purpose as terraces.

Minimization of Nutrient Loss

Since agroforestry practices minimize soil erosion, landslides, and surface runoff, it is reasonable to assume that it may also minimize nutrient loss from the system. Siebert and Belsky (1985) reported that soil erosion from hillside farms presents a serious environmental problem in the Karela Watershed in Leyte, Philippines. Soil loss averaged 3.4 cm during the first six months after initial clearing and cultivation, representing approximately 435 tons of soil loss per hectare in six months. Evidence of sheet erosion, rill erosion, and gully erosion occurred in the area. Soil fertility exhaustion was evident on hillside farms. Under forest fallow (15 years) conditions, organic matter content decreased from 6.9 percent after burning to 3.8 percent after two corn crops during a six-month period; calcium, from 18.2 to 15.3 me/100 g; magnesium, from 25.1 to 19.9 me/100 g; available phosphorus, from 48.7 to 0.2 ppm; and ph, from 6.8 to 6.3. Under grass fallow (two years) conditions, organic matter content decreased from 6.4 percent after burning to 4.2 percent after two corn crops; calcium, from 9.6 to 7.2 me/100 g; magnesium, from 15.4 to 11.5 me/100 g; available phosphorus, from 1.9 to 0.1 ppm; and pH, from 6.5 to 6.0.

Minimization of Evaporation

Although it is well known that trees cause moisture loss through evapotranspiration, not much is known about the role of agroforestry systems in reducing evaporation in a given site. It is possible that the reduction of direct exposure of the soil due to the canopy and reduction of air and soil temperatures under the canopy may help reduce evaporation rates. Also deserving of study is whether the moisture loss through evapotranspiration by trees could be counteracted by reduced evaporation of moisture from the soil surface through shading.

Ameliorative Roles

Improvement of Nutrient Status

In a commercial oil palm plantation intercropped with the legumes *Centrosema pubescens* and *Pueraria phaseoloides* in Malaysia, legumes contributed about 150 kg N/ha/yr through nitrogen fixation (Agamuthu and Broughton, 1985). During the early stages of oil palm growth, the legumes absorbed about 149 kg N/ha/yr from the soil. With a loss through litterfall of 123 kg N/ha/yr, legumes accumulated a net amount of 176 kg N/ha/yr in their foliage. In comparison to natural covers, leguminous covers reduce leaching losses by 63 kg N/ha/yr. During the initial growth phase, oil palms need only 175 kg N/ha/yr. Since legumes fix nitrogen and thoroughly scavenge the soil for minerals, they eventually provide more nitrogen to the oil palm than is needed for growth. This surplus nitrogen is accumulated in the legume foliage. When the rooting systems of the oil palms have grown under the inter-rows, competition for nutrients causes a gradual decline in the cover crop. Nutrients accumulated in the legumes are then slowly released, stimulating root growth and general development of the oil palm.

Cropping systems used in agroforestry may affect the chemical properties of the soil. Anderson (1962) showed that total phosphorus contents were highest under banana (5813 ppm) and Rhodes grass (5229 ppm) as compared to other crops such as coffee and corn. Broughton (1977) studied the effects of various covers on soil fertility under *Hevea brasiliensis* and their effects on tree growth in Malaysia. Four cover management systems were tested, namely: a mixture of creeping legume (*Calopogonium mucoroides, Centrosema pubescens,* and *Pueraria phaseoloides*), grasses (*Axonopus compressus* and *Paspalum conjugatum*), a pure crop of *Mikania cordata,* and a naturally regenerating or colonizing system prevailing in the area. Among the four systems, legumes initially had the fastest growth rate and generally contained more nutrients than the other covers tested. The greater nutrient return to the soil from growing a leguminous cover was reflected in higher levels of these nutrients in rubber leaves. This, plus improved soil physical properties, led to an increased growth rate of the rubber tree. Nitrogen fixation under legumes grown in association with rubber averaged 150 kg/ha over a five-year period, with maximum rates of nitrogen fixation being about 200 kg/ha/yr.

Tree legumes are now commonly used in agroforestry as a source of green manure for crop plants. Bhardwaj and Dev (1985) studied the production and decomposition of *Sesbania cannabina* in relation to its green manurial efficiency for irrigated rice in a wheat-rice cropping system in Kanpur, Una, and Palampur, India. Sesbania produced an average of 18, 28, and 37 tons/ha of green matter and 98, 147, and 165 kg N/ha, respectively, after 45, 55, and 65 days of growth, respectively. The grain yields of rice transplanted immediately after turning under the green manure, irrespective of their stage of growth, were equivalent to 100-120 kg/ha of chemical nitrogen.

Leucaena leucocephala is one tree legume commonly used in many agroforestry systems. Torres (1983) reported that *Leucaena* hedges intercropped with maize can play a double role as a source of soil nutrients (green manure) and as fuelwood. Nitrogen productivity of the hedgerows cut approximately every eight weeks at a height of 15.30 cm and planted at a distance between rows wider than 150 cm is 45 g/m/yr. In addition to the mulch nitrogen directly supplied by the hedges, *Leucaena* contributes to the soil nitrogen status through symbiotic fixation. It is estimated that the hedgerow mulch from *Leucaena* will be sufficient to meet the phosphorus demands of maize to provide a yield of 1770 kg/ha at 150 cm spacing or 878 kg/ha at 225 cm spacing.

The fallow system appears to impart a good effect on crops. Hamid et al. (1984) studied the performance of rice grown after upland crops and fallow in the Philippines. After fallow or harvest of four upland crops (soybeans, cowpeas, mung beans, and sorghum), rice was dry seeded, fertilized with 0, 40, 80, or 120 kg N/ha as ammonium sulfate, and grown until maturity. Growth and grain yield of rice were highest after fallow; intermediate after soybeans, cowpeas, and mung beans; and lowest after sorghum at most nitrogen levels. Upland crops appeared to affect rice by influencing the soil nitrogen status or carbon and nitrogen ratio. Upland crops might decrease rice performance as compared to fallow, but higher combined economic returns of upland crops and rice over fallow system is reported.

Juo and Lal (1977) studied the effects of fallow and continuous cultivation on the chemical and physical properties of an alfisol in western Nigeria. Properties of sandy surface soils over clayey subsoils under continuous cropping were compared with those under planted fallows and natural bush regrowth at an experimental farm in Ibadan, Nigeria, over a three-year period after clearing secondary forest in 1972. The fallow treatments included pigeon pea (*Cajanus cajan*), *Leucaena leucocephala, Panicum maximum,* and natural bush regrowth. The planted fallows were slashed annually (three times for grass). In continuous soybean and unmulched maize plots, soil organic matter and pH declined rapidly, whereas residue-mulched maize plots maintained a soil organic matter level comparable with the fallow treatments. In cropped plots, favorable physical characteristics in the surface soil were maintained when sufficient plant residue (16 tons/ha/yr) was returned, whereas the subsoil structure of the original forest soil deteriorated in all cropping treatments. Guinea grass fallows had a distinct advantage in recycling mineral nutrients and in maintaining soil physical properties and organic matter.

The tree component in agroforestry systems plays a key role in improving nutrient status in stemflow and throughfall. George (1979) studied the nutrient concentration from stemflow, throughfall, and rainwater from *Eucalyptus* stands in Dehra Dun, India. He observed that the highest concentrations of nutrients were in stemflow, followed by throughfall, then rainwater. These nutrients came from the leaves and/or stems of the *Eucalyptus* washed down by rainwater. Total annual nutrient returns from stemflow, throughfall, and rainwater were K 18.5, Ca 18.5, Mg 4.7, N 3.9, and P 0.4 kg/ha compared with returns of 15, 40.2, 5.0, 29.8, and 1.6 kg of the element from the litter per hectare, respectively.

The most important roles of trees in an agroforestry system are their ability to minimize soil erosion, to effectively extract nutrients from the soil, to accumulate such nutrients in their biomass, and to gradually release these nutrients through litter. Maghembe et al. (1983) determined the biomass of a six-year-old plantation of *Prosopis juliflora* partitioned into stem, large branches, small branches, and leaves. Macronutrient compositions in the different three components were determined, and total nutrient content per hectare was calculated. The study was done in Mombosa, Kenya, where the mean annual rainfall for the period 1975-81 was 1220 mm; with rainfall season from October to June, and a dry spell from January to February, mean minimum temperature ranging from 21 to 25°C and mean maximum temperature ranging from 27 to 36°C. Total stem volume at age six was 209 m^3/ha and large branch volume was 75 m^3/ha. Total above ground biomass was 216 tons/ha. Of this, 4.6 percent was accounted for by the foliage, 18 percent by small branches, 19 percent by large branches, and 58.4 percent by stem. Nutrient contents were highest in the leaves, decreasing in the order of leaves, small branches, large branches, and stems. However, leaves and small branches accounted for less than 29 percent of the biomass in small trees; they contained percentages of 60, 57, 63, 31, and 63 of the total N, P, K, Ca, and Mg, respectively. In average and large trees, the proportion of leaves and small branches was less than 20 percent but their proportions of total N, P, K, Ca, and Mg were 50, 46, 52, 24, and 58 percent, respectively. These imply that removal of stemwood alone would extract only negligible amounts from the total nutrient pool but will leave at the site 70, 67, 77, 50, and 73 percent of the total N, P, K, Ca, and Mg pool, respectively, or the equivalent of 1.7 tons N, 0.12 ton P, 1.2 tons K, 1.4 tons Ca, and 0.1 ton Mg.

Much has been said about the detrimental effects of slash-and-burn agriculture. A general effect of this practice is a decline of crop productivity attributed to nutrient depletion. Mishra and Ramakrishnan (1983) studied the effect of slash-and-burn agriculture (jhum) on soil fertility at high elevations of Meghalaya, northeastern India using 15-, 10-, and 5-year jhum cycles and a terrace system. Soil nitrogen concentration under a 5-year jhum cycle was significantly lower than under the 10- and 15-year cycles. The concentration of this nutrient declined sharply after the burn in the surface layers and was attributed to volatilization. The degree of volatilization is dependent on the intensity of the burn and, therefore, the nitrogen decline is lower in a 5-year cycle than in longer cycles with a greater fuel load. Nitrogen concentration in the soil improved at the end of one year under all cycles, but such an improvement was observed only under 10- and 15-year cycles.

Under terrace cultivation, nitrogen losses continued up to the end of two years. Available P was generally lower under a 5-year cycle than under 10- and 15-year cycles. Available P under the three jhum cycles declined significantly after the burn. Recovery occurred after 30 days under 10- and 15-year cycles and after 100 days for the 5-year cycle with subsequent decline during cropping. In the terrace system, the available P declined during cropping after an initial increase. The concentrations and total quantities of all cations on the surface soil layers under the three jhum cycles improved markedly after the burn owing to releases through ash, but subsequently declined sharply. The decline is partly due to absorption by the developing crop, but due more to losses through sediment and water. Large quantities of cations were released under 10- and 15-year jhum cycles owing to greater quantities of slash burned than that under a 5-year cycle. Starting from a lower level in a 0-year fallow, the recovery of C, N, and available P occurred in older fallows of 5 and 10 years, with a slight decline in a 15-year fallow. Longer fallows gave greater improvement in humus and nutrients in order to sustain slash-and-burn agriculture. A jhum cycle of 5 years is definitely short as far as nutrient recovery is concerned. Longer cycles of 10 years are preferred. A terrace system does not offer a better alternative to a short cycle because it cannot sustain continuous cropping without heavy fertilizer inputs.

Similarly, Salas et al. (1976) studied the bioelement loss in clearing and burning a tropical rainforest in Colombia. The approximate range of element losses attributable to clearing, burning, and cultivation for one year was found to be 60-140 kg K, 100-120 kg Ca, and 30-80 kg Mg. Such quantities could be restored by rainfall input after about 10-20 years of fallow. It was estimated that the 1300-1400 kg of N lost above and below ground is restored by nitrogen-fixation rates of 100-150 kg/ha/yr, rather than by rainfall input.

One way of monitoring chemical changes in the soil is to simulate burning practices at varying temperatures of burn and to note the resulting changes that occur. Andriesse and Koopmans (1984) did simulated burning studies in Sarawak, Malaysia, through temperature ranges of 20-350°C and observed changes in soil pH, electrical conductivity, carbon, nitrogen, carbon-nitrogen ratio, phosphorus, cation exchange capacity, exchangeable cations, copper, and zinc. They reported that available P increased slightly up to 150°C and then strongly up to 200°C. Cation exchange capacity (CEC) increased significantly until 150° but decreased dramatically until 250°C. The changes in CEC appeared to be linked with that of exchangeable Al, especially in the range of 150-350°C, showing a gradual increase up to 150°, followed by a strong decrease at 250°C. This probably indicates the temperature range at which most organic materials are disappearing and, consequently, also the CEC linked with it. Calcium and Mg appeared to decrease upon heating to 200°C and 250°C, but increased thereafter. Potassium appeared to have no significant decrease up to 200°C but a significant increase after 250°C. Sodium increased slightly with temperature increase. Exchangeable Fe increased significantly with heating up to 200°C but decreased significantly between 250°C and 350°C. Base saturation upon heating was proportional to pH, decreasing gradually with heating up to 150°C, increasing slightly between 150°C and 200°C, followed by a strong increase between 200 and 350°C. Heating showed no appreciable effect on extractable Cu and Zn.

A basic question in agroforestry work is what effect cropping combinations has on soil fertility. Ojeniyi and Agbede (1980) studied the effects of intercropping *Gmelina arborea* with food crops such as yam (*Discorea rotunda*), cassava (*Manihot utilissima*), and maize (*Zea mays*) in three ecological zones in southern Nigeria. Intercropping of *Gmelina* with food crops caused no significant change in soil fertility. However, slight reductions in organic carbon and increases in soil N and P as a result of agrisilviculture were observed. No definite change in pH was observed. In a follow-up study, Ojeniyi et al. (1980) showed that intercropping *Gmelina* with food crops increased soil N and P, but exchangeable bases, exchangeable acidity, and percentage carbon did not vary significantly.

Improvement of Soil Organic Matter

It is generally known that the fertility of a tropical soil is related to organic matter. The yield reduction in slash-and-burn agriculture may also be related to a reduction of organic matter content. The fallow system used by shifting cultivators has a sound ecological basis in that it builds up the organic matter (and nutrients) content of the soil. Mishra and Ramakrishnan (1983) reported that the concentration and total quantity of soil carbon was significantly higher under long jhum cycles of 10 and 15 years than under 5-year cycles. After the burn, carbon concentration, particularly in the 7-14 cm depth, and the total quantity in the surface layers declined significantly with time under all jhum cycles. The marked decrease in carbon content after burning under 10- and 15-year jhum cycles was attributed to higher intensity of the burn than that under a 5-year cycle.

Carbon content in the soil is very much related to nitrogen. In the study of Andriesse and Koopmans (1984), they reported that heating the soil up to 150°C results in a very slight increase in organic carbon and nitrogen; upon further heating, the percentage of carbon and nitrogen (C/N) decreases drastically to very low values as a result of the oxidation. The C/N ratios show that up to 150°C, little change in C/N ratio occurred, but upon further heating, a strong decrease in the C/N ratio occurred, suggesting large losses in carbon from the formation of volatile CO_2.

Studying the effects of various cropping systems in soil organic matter, Anderson (1962) showed that organic C was highest under grass (3.54 percent) intermediate under corn and bananas, and lowest under weeded coffee (2.76 percent). Continued clean weeding under coffee can bring about organic matter losses.

Maintenance of organic matter in a fallow system is attributable to the biomass produced by the trees. In agroforestry systems, it is possible that the tree component could provide the organic material in the form of litter or mulch. Juo and Lal (1977), in their study on the effect of fallow and continuous cultivation of the chemical and physical properties of an alfisol in Nigeria, showed that organic matter declined rapidly in continuous soybean and unmulched maize, whereas residue-mulched maize plots maintained a soil organic matter level comparable with the fallow treatments.

Improvement of Soil pH

Not much is known about the effect of agroforestry practices on soil pH per se. However, there are some data on the effect of slash-and-burn agriculture on soil reaction. In the study of Mishra and

Ramakrishnan (1983) where soil pH changes were followed in 15-, 10-, and 5-year jhum cycles, they reported that immediately after the burn, surface soil pH (0-7 cm) increased under all jhum cycles. The increase was more obvious in a 15-year cycle than in a 10- or 5-year cycle. The increase in pH was attributed to the release of basic elements from the ashes. During cultivation, the pH declined markedly starting from 30 days after the burn up to 365 days and 370 days after cropping under a 5-year jhum cycle.

In contrast, in the simulated burn studies of Andriesse and Koopmans (1984), they reported that heating the soil changes soil reaction considerably. Up to 150°C, a slight decrease in both pH in water and pH in KCl is discernible. Further heating to 250°C, however, results in an increase of almost 1 pH unit, the increase being greatest between 200 and 250°C.

There are only few reports on the effect of agroforestry systems on soil pH per se. It is difficult to reconcile the effect of agroforestry practice on soil pH at this stage. The soil itself is highly buffered and organic matter plays an important role in influencing soil buffering capacity. Removal of organic material by burning or soil erosion affects buffering properties and may cause a shift or change of the residual soil pH. Removal of water from the soil by evapotranspiration may decrease soil pH, but pH may increase after the soil water is recharged.

Improvement of Soil Structure

A granular or porous soil structure is preferred by plants for good growth. Such structure provides better aeration, root penetration, and water exchange. Soil organic matter is one of the factors affecting soil structure and which can account for the granular nature of the soil. The presence of trees and even grasses in agroforestry systems therefore improves the structure of the soil. The shade of trees from an agroforestry system also improves the soil microenvironment, which attracts beneficial organisms such as earthworms. Their burrowing activities also improve soil structure.

Improvement of Pest and Disease Control

Pests and diseases are usually high in monocultural field crops or plantation trees, because of the food available favoring the population buildup of a pest or a disease-causing organism. The presence of a diverse plant species or community, as in a tropical rainforest, generally reduces the incidence of major pest and disease outbreaks. The ecological principle behind this control is that the presence of other organisms serves as a check or control on pathogenic organisms. The presence of diverse plant species in an agroforestry system in contrast to that in pure forestry or agricultural system is beneficial from the viewpoint of pest and disease control. Crop diversity in agroforestry mimics the heterogeneous population of trees in the tropical rainforest to impart the "check and balance" against pest and disease. Wiersum (1983) studied the effects of tree fallow from *Albizia falcataria, Cassia siamea, Leucaena leucocephala, Samanea saman,* and *Tectona grandis* on the incidence of slime disease in intercropped tobacco. He observed a certain degree of correlation between tree species used as fallow and the incidence of the disease. Generally, the occurrence of slime disease decreased with longer fallow periods. Fallow species such as *Mimosa invisa* and *Imperata cylindrica* decreased the incidence of the disease. Some tree species such as *A. falcataria* also seemed to control slime disease.

Reduction of Soil Temperature and Solar Radiation

The vertical distribution of the canopy in a tropical rainforest is multistoried. This makes it efficient not only in reducing the velocity of raindrops passing through the canopy but also in reducing soil temperature and solar radiation reaching the forest floor. The agroforestry system, with its combination of trees and food crops, mimics the beneficial effect of the tropical rainforest. It is expected, therefore, that an efficient agroforestry system will reduce soil temperature as compared to a bare land system and also will reduce solar radiation passing through the canopy. Favorable soil temperature and solar radiation improve the soil microbial activities, decomposition, and nutrient cycling.

Ewel et al. (1982) measured and compared the vertical distribution of leaf areas by species and the transmission of photosynthetically active radiation in nine tropical ecosystems – six in Costa Rica and three in Mexico. Ecosystems included monocultures of corn and sweet potato; a year-old natural succession and vegetation designed to mimic succession; a 2.5-year old mixture of three arborescent perennials (cacao, plantain, *Cordia alliodora*); a 2.7-year old plantation of *Gmelina arborea*; coffee shaded by *Erythrina poeppigiana;* and an old, diverse wooded garden. Leaf area index ranged from 1.0 in young maize to 5.1 in natural succession and the *Gmelina* plantation. The vertical distribution of leaves was most uniform in diverse ecosystems, and most clumped in species-poor ecosystems. Light transmission was inversely proportional to leaf area, while two dense-canopied monocultures (sweet potato and *Gmelina*) were nearly as effective at light capture as were some of the more diverse ecosystems. Optical density of the canopy ranged from less than 0.5 (35 percent transmission) in the young maize to greater than 2.0 (1 percent transmission) in the natural succession.

LONG-TERM BENEFITS FROM AGROFORESTRY

The immediate benefits from agroforestry systems by virtue of their protective and ameliorative roles are envisioned to give further long-term benefits. For a subsistence farmer, agroforestry is designed to increase and sustain crop productivity in his land, and improve his socioeconomic standing and nutrition and health of his family. As a whole, however, agroforestry practices should lead to stabilized land-use policy for the uplands and subsequently to improved environmental conservation.

Increased Crop Productivity

Agroforestry practices include the planting of short-term cash crops (e.g., rice, corn, food legumes, vegetables, root crops) with long-term crops such as trees. The system ensures a steady income for subsistence farmers. They can harvest the short-term cash crops for their immediate needs while waiting for the long-term crops to mature.

Sustained Crop Productivity

The proper application of agroforestry practices may sustain the crop productivity of a given land. This attribute is due to the roles played by agroforestry in protecting and ameliorating a given site. In contrast, slash-and-burn agriculture, shifting cultivation, and monoculture (with forestry or agronomic crops) suffer in that crop productivity of the site decreases through time. In the study of Broughton (1977) where *Hevea brasiliensis* was intercropped with legumes, he observed that dry rubber yields in ex-leguminous plants extended for about 20 years and amounted to approximately 4 metric tons more than the yields achieved with any of the other cover systems studied.

Studying the energy flow in a traditional organic agroecosystem in China, Dazhong and Pimental (1984) reported that such agroecosystem was self-sustaining. In the crop system, the energy input/output ratio was 1:2. Fossil energy input into the total agroecosystem was less than 2 percent of the total. The rate of fossil energy input and crop energy output was 1:107. The sources of food and household energy for human society came from the crop, livestock, and forestry systems, with the crop system providing more than 80 percent of the energy.

How energy efficient is organic agriculture compared to inorganic agriculture that uses chemical fertilizers? Pimentel et al. (1983) assessed the energy efficiency, yield performance, and labor requirement for the production of corn, wheat, potatoes, and apples. Organic corn and wheat production was 29-70 percent more energy efficient than conventional production. However, conventional potato and apple production was 7-93 percent more energy efficient than organic production. It is important, therefore, to effectively screen the cropping components in an agroforestry system. Crops that require less care and maintenance should be preferred to those that are more energy demanding.

The practice of shifting cultivation in the uplands has persisted for several generations. It has always been observed that crop productivity declines through time in such a system. Uhl and Murphy (1981) analyzed the energy inputs and outputs between shifting cultivation and successful vegetation in southern Venezuela. They reported that yuca (*Manihot esculenta*) yielded 4.31 metric tons/ha wet weight in Year 1 but only 2.81 metric tons/ha in Year 2. The reduction was attributed to soil fertility decline. Shifting cultivation was more productive than an adjacent succession site (532 vs. 109 g/m^2 dry weight) during the first year. However, during the second year, the succession vegetation was more than twice as productive as the shifting cultivation (1446 vs. 529 g/m^2 dry weight).

Improved Socioeconomics

The increased crop productivity on a sustained basis in agroforestry practice is a boon to subsistence farmers. Many of these farmers are settlers from the lowlands who practice lowland agriculture in the uplands. Agroforestry for these people is an alternative to what many of them are practicing. Agroforestry can improve their socioeconomic standing, turning them into conservators of the fragile uplands, and therefore removing the stigma of squatters or shifting cultivators.

Improved Nutrition and Health

Thus, agroforestry farmers do not have to go far for most of their food requirements. Vegetables, cereals, fruits, and meat, plus the firewood they need for cooking, can all be grown *in situ.*

Stabilized Land-use Policy

Landownership is still a sensitive issue because many of the affected uplands belong to the state or government. The settlers migrate into the uplands and squat on public lands. Their harmful agricultural practices had been adequately documented and had been identified as one of the primary causes of upland degradation. Many countries are now recognizing this land tenure problem. In some countries such as the Philippines, long-term stewardship leases are given to upland farmers. The main purpose of such an arrangement is to give the upland farmers a legal ground in which they could grow and develop, but it also gives the government a way of monitoring and controlling the activities of such farmers. With the imposition of sustained agroforestry practices in such areas, the overall outcome is land-use policy designed to stop and stabilize the degradation of uplands.

Improved Environmental Conservation

The protective and ameliorative roles of agroforestry, while increasing and sustaining crop productivity, improving nutrition and health of the subsistence farmers, and improving their socioeconomic status, ultimately will lead to the more important goal of improving environmental conservation. Perhaps this is a tall order for agroforestry to attain, but alternatives to solve the present environmental crises are just unavailable.

CONCLUSION

A conceptual framework for the protective and ameliorative roles of agroforestry is presented with more emphasis on quantitative data of the system. It must be emphasized that although agroforestry has been practiced for several generations, the intricacies of the system are just beginning to unravel. However, the few examples cited in this chapter seem to point out that agroforestry is indeed a viable tool for proper management of the uplands. The concept presented may have several flaws. These are expected. But as more information is generated, many of these flaws will be corrected. The concept therefore is expected to be modified through time.

In conclusion, agroforestry plays the two important roles of protecting and ameliorating uplands. Agroforestry practices, therefore, augur well for the long-term goal of increased and sustained crop productivity in the uplands, stabilized land-use policy, and improved environmental conservation.

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THE PROTECTIVE ROLE OF TROPICAL FORESTS: A STATE-OF-KNOWLEDGE REVIEW*

by

D.S. Cassells[1], M. Bonell[2], L.S. Hamilton[3], D.A. Gilmour[4]

ABSTRACT

Perceptions of forest managers and development planners on the hydrological behavior of tropical forest lands are frequently based on the myths and misunderstandings that until recent decades characterized those of forest managers in the humid temperate latitudes. To contribute to the development of a more informed basis for forest development planning and policymaking, a review of the available results from sound scientific research on the hydrological behavior of tropical and temperate forest lands is presented. This review concludes that there is a radical need to rethink the watershed forest policies currently accepted by many tropical forest land managers and planners.

INTRODUCTION

In recent years, many articles and reports have established both the rapid rates of loss and of logging being experienced by the world's tropical forests and the importance and urgency of developing im-

[1]D.S. Cassells, Lecturer, Department of Ecosystem Management, University of New England, Armidale, NSW, Australia.

[2]M. Bonell, Senior Lecturer, Department of Geography, James Cook University of North Queensland, Townsville, Queensland, Australia.

[3]L.S. Hamilton, Research Associate, Environment and Policy Institute, East-West Center, Honolulu, Hawaii, USA.

[4]D.A. Gilmour, Principal Research Officer, Forest Research Centre, Queensland Department of Forestry, Gympie, Queensland, Australia.

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proved knowledge and management practices for tropical forest lands (FAO, 1976; Gomez-Pompa et al., 1972; Hamilton, 1976; Mathur, 1976; Myers, 1981; Qureshi, 1978; U.S. State Department, 1978; U.S. Interagency Task Force on Tropical Forests, 1980; World Bank, 1977). Like forest ecosystems everywhere, tropical forest ecosystems are composed of complex, cyclic relationships involving water, land atmosphere, vegetation, and fauna (Bormann and Likens, 1969; Fournier, 1978; Golley et al., 1978). When tropical forest lands are utilized for economic development, changes in these relationships occur that may generate favorable or adverse impacts on or beyond the actual development site (Carpenter, 1983).

Policy formation and decision making about tropical forest lands frequently involve a complex of development financing agencies and multinational corporations, as well as various levels of government in the controlling countries themselves (Carpenter, 1979). If favorable impacts of development are to be promoted while minimizing or preventing any adverse effects of the changes induced by the development process, decisions about forest land use must be based on accurate and complete ecological information about the forest lands in question (Carpenter, 1979). Information about the environmental impact of development activities on the water or hydrological cycle is commonly a paramount concern, because it is this cycle that integrates vegetation, soil, and water – the key components of many resource developments – over large geographic areas (Cassells et al., 1983).

Perceptions of the impacts of development activities on the hydrological behavior of tropical forest lands are frequently based on myths, misinterpretations, misinformation, and misunderstanding that until relatively recently characterized the perceptions that many forest managers held about the hydrological behavior of forests in the humid temperate latitudes (Hamilton, 1983, 1984). In this chapter, we hope to begin to counter these myths and misunderstandings and contribute to a more informed basis for forest development planning and policymaking by summarizing the available scientific information about the hydrological response of tropical forests to land-use change. We have written this chapter from the perspective of our collective backgrounds as active researchers involved with investigations of the hydrological dynamics of tropical forests and educators who have had recent experience in integrating and extending available hydrological research results for forest management and forest policy development.

THE WATERSHED FOREST AS AN ECOSYSTEM

A useful aid to understanding the role of tropical forests in watershed protection is an appreciation of the relevance of the ecosystem concept to natural resource management (Van Dyne, 1969). Adopting an ecosystem perspective provides a useful framework for discussing the structure of watershed forest systems. It also provides an appropriate framework for studying the impact of land-use change on the hydrological behavior of forest lands.

The Hydrological Cycle

An ecosystem is a natural area, such as a watershed, where plants and animals and their physical and chemical environment interact dynamically, influencing each other's properties and contributing to the maintenance and development of the system as a whole (Odum, 1963). Within any particular watershed forest ecosystem, water moves in a continuous cycle – from the atmosphere to the earth by precipitation and, ultimately, from the earth back to the atmosphere by evaporation and transpiration. This continuous process of water movement is called the *hydrological cycle* (Ward, 1975; Cassells et al., 1983). Its principal components and pathways are illustrated in Figure 1.

Within any watershed, the hydrological cycle can be considered to be the flux of water in its various states between water storage compartments such as the atmosphere, the vegetation, the soil, and the stream channel. The individual flow pathways between storage cimpartments – precipitation, interception, throughfall, infiltration, evapotranspiration, percolation, surface runoff, interflow, and streamflow – are called *hydrological processes* and have been described in some detail elsewhere (Ward, 1975; Lee, 1980; Cassells et al., 1983).

The streamflow response to a particular rainfall event is the end result of the processes listed above and is determined by a complex array of interacting factors (Ward, 1975; Lee, 1980; Cassells et al., 1983). Among the more important of these factors are:

- the amount, duration, and temporal changes in intensity of the particular rainfall event;
- the catchment's geomorphology;
- the condition of the vegetation and the soil surface; and
- the soil moisture status of the catchment immediately before the rainfall event.

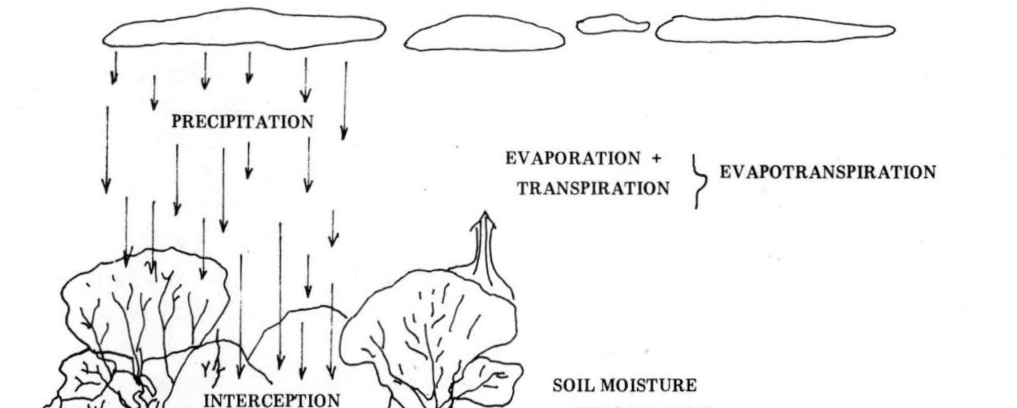


Figure 1. The hydrological cycle in a watershed forest ecosystem. (Adapted from Gilmour, 1975).

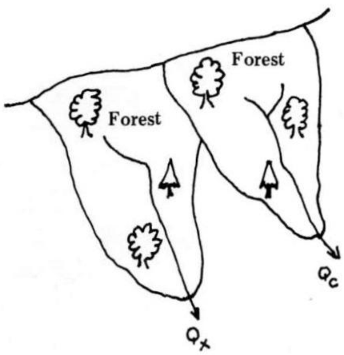
A Framework for Study

A major concern of the science of forest hydrology has been to quantify the impact of changes in forest land use, such as timber harvesting or clearing for pasture, on the quantity and quality of water yielded from forested catchments. However, with the complex array of factors influencing the streamflow response of a catchment to rainfall, this is not a single task.

Studies that monitor the streamflow from adjacent cleared and forested catchments have been undertaken in many regions since the early 1900s (Boughton, 1970). However, the results of these investigations have often proven to be inconclusive (Boughton, 1970). Simply monitoring adjacent catchments with different land treatments does not define whether any observed hydrological differences are in fact due to differences in land use or due to differences in other catchment characteristics such as geomorphology, soils, or even variations in the precipitation patterns over the two catchments (Lee, 1980). One of the more significant developments in forest hydrology has been that of the "paired" or "controlled" catchment experiment (Hewlett et al., 1969; Lee, 1980). The essential elements of this technique are illustrated in Figure 2. In essence, the technique involves establishing a statistical relationship between the hydrological output of two or more catchments during a calibration period before any treatments are applied to any of the catchments. This relationship, together with the output from the undisturbed control catchment, is then used to provide an objective basis for determining the magnitude of any hydrological changes in the treated catchments that result from the treatments that were applied. For example, in the hypothetical case in Figure 2, we can be confident that the streamflow of the treated catchment increased by an average of 170 mm per year during the measure period following the conversion of its forest cover to pasture.

The "control" catchment approach was first used in the Wagon Wheel Gap Study, which was initiated in 1911 in the mountains of Colorado in the United States (Bates and Henry, 1928). Since this pioneering work, it has become the most widely accepted method for evaluating the hydrological impact of land-use change in catchment areas (Hewlett et al., 1969; Boughton, 1970). However, in the past decade or so, much emphasis has also been placed on the investigation of hydrological processes within controlled catchment experiments (Hewlett et al., 1969; Gilmour et al., 1982). The results from

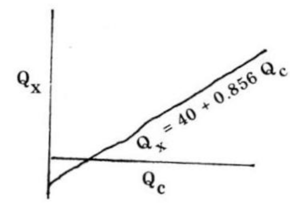
CALIBRATION PERIOD



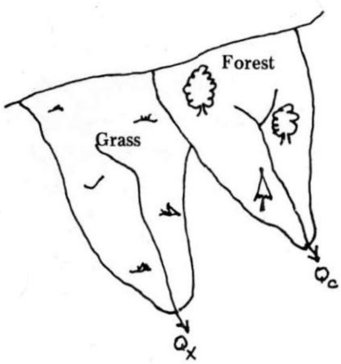
Stream flow in millimetres per year

Q_c	Q_x
625	495
400	300
725	580

To predict the stream flow (G,) that would occur in the treated catchment without the intervention of a treatment, a regression equation is established between the actual streamflow (G_c and G_x) during the calibration period.



TREATMENT PERIOD



To measure the change in stream flow due to the change in land use in the treated catchment, the actual stream (flow in that catchment after treatment (G,) is compared to the streamflow (G_x) that the regression equation established during the calibration period predicts would have occurred in that catchment without treatment.

Stream flow in millimetres per year

Q_c	Q_x^1	G_x	$Q_x^1 - Q_x$
500	600	390	210
400	475	300	175
600	600	475	125

Figure 2. A simplified example of a paired catchment experiment using regression analysis.
(Adapted from Hewlett and Nutter, 1969; 81).

these investigations provide information not only about *what* the effects are of land-use change, but also about *how* and *why* these results from specific catchment studies are to be realistically applied to other areas through generalized models of catchment response (Dunin, 1975).

THE HYDROLOGICAL EFFECTS OF CHANGING FOREST COVER

Land-use change in tropical forest lands range from harvesting minor forest products to conversion of forest lands to nonforest uses such as annual cropping, food tree plantations, or pasture and livestock production. Each land-use change results in modification of the forest structure with the degree of modification ranging from partial removal of the forest vegetation to complete removal accompanied in many instances by exposure of the mineral soil. We will use the general term *deforestation* to cover all of these activities except the low intensity harvesting of the so-called minor forest products. All of the other activities result in canopy opening and in understory and soil disturbance of various degrees. Light logging is only temporary deforestation, and in the humid tropics is usually immediately followed by vegetative regrowth. Clearing and conversion are of a more permanent nature. Most of the available literature on the *hydrological effects of deforestation* refers to the more *intense* forest modifications such as *commercial timber harvesting* or *conversion* of forest lands to nonforest uses. Then the hydrological impact of less intense uses can generally only be inferred from the results of these studies (Hamilton, 1983).

Figure 3 presents a framework for considering some of the *likely* effects of deforestation on the hydrological behavior of a catchment. In the context of land-use management, planning or evaluation, the variables of interest are the secondary effects summarized by the lower tiers of the diagram. The mechanisms or processes directly affected by removal of the forest vegetation are illustrated in the top tier, boxes A through E, while the linkages between these primary effects and the secondary outcomes of interest are illustrated by arrows and the intermediate boxes. The word *likely* is used because, as noted before, the hydrological response of a watershed is influenced by many factors of which the condition of the vegetation is but one, albeit an important one, over which man can exercise deliberate control.

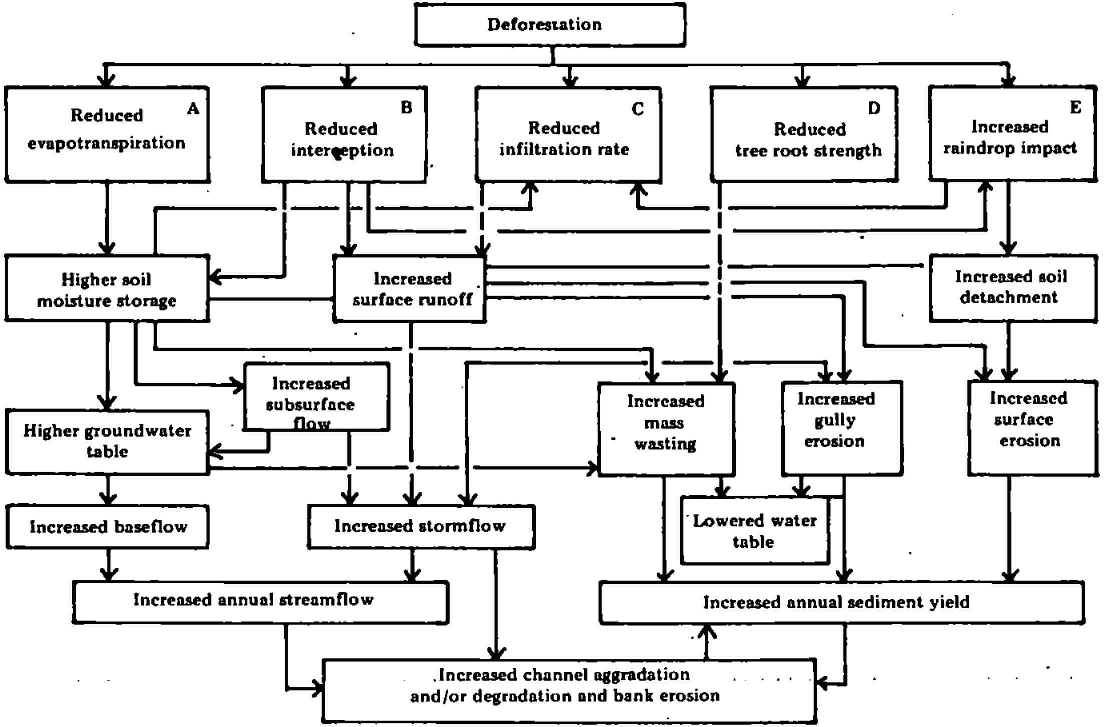


Figure 3. Some likely hydrological changes following deforestation. (Adapted from Cassells et al., 1983).

Effects on Total Rainfall

The influence of forests on total or gross rainfall is not referred to in Figure 3 because, due to the difficulty of measurement, little is known about it with any certainty. However, in major international reviews of forest influences in the late 1960s (Hewlett, 1967) and the early 1970s (Pereira, 1973), it was concluded that in the absence of convincing evidence to the contrary, we must assume that the mere presence of a forest cover does not in itself affect the gross precipitation over an area. Furthermore, in a recent review of forest influences on atmospheric water, Lee (1980:101) noted that the forests of the earth are restricted to areas of relatively high precipitation and concluded from a theoretical evaluation of the potential impact of forest influences on atmospheric water vapor dynamics and orographic processes that:

> The natural coincidence of forest cover and higher precipitation has undoubtedly caused, or at least reinforced, the popular notion that forests increase or "attract" rain and other precipitation forms. Acceptance of the forest as a causal factor leads naturally to the conclusion that forest cutting will reduce precipitation, or that afforestation will increase it; this conclusion played a major role in the development of forest policy in the United States and elsewhere and is still the basis of considerable concern among environmentalists. Objectively, however, the arguments in favor of a positive forest influence are severely weakened when the alleged mechanisms for the influence are critically examined.

There are, however, some notable exceptions to this generalization that the presence of a forest vegetation has no significant effect on the gross rainfall over an area (Hamilton, 1983). The most obvious of these exceptions are certain mountain environments where atmospheric moisture from wind-driven clouds may be "captured" by stem and canopy barriers and be added to effective precipitation through crown drip and stemflow. This may be a significant proportion of the total annual precipitation (Anderson et al., 1976). In these environments, complete deforestation will reduce effective precipitation, and in some tropical environments at least, this reduction can possibly be large enough to reduce the streamflow yield (Zadroga, 1981). The same capture process occurs in certain coastal areas where fogs are frequent. In dry tropical coastal areas this intercept precipitation is a major source of fresh water and is being collected and used for domestic purposes.

Effects on Annual Streamflow

In almost every case, *controlled* catchment experiments in both tropical and temperate environments have demonstrated *increases* in annual streamflow following partial or complete forest cutting. To date, only a few reports suggest the opposite result. These were spatial comparisons, not paired catchments with different treatments, and some had the complication of snowfall and snowmelt.

In a recent international review of some 78 controlled catchment experiments and 16 trend-line experiments covering a wide range of environments with mean annual precipitation inputs ranging from 265 mm to 3300 mm, Bosch and Hewlett (1982) reported that:

- none of the experiments resulted in reductions in water yield with reduction in forest cover, and
- none of the experiments resulted in increases in water yield with increases in forest cover.

The maximum change recorded in any experiment was a reduction in annual streamflow of some 660 mm at Coweeta in North Carolina (USA) when a 14 ha catchment with a mean annual precipitation input of 1895 mm was planted to pine (Swank and Douglass, 1974). Furthermore, none of the experiments evaluated in the review reported any change in annual streamflow when the change in forest cover affected less than 20 percent of the total catchment area (Bosch and Hewlett, 1982).

Unlike an earlier review of catchment experiments in forest hydrology (Hibbert, 1967), Bosch and Hewlett (1982) concluded that by 1980, sufficient data were available to estimate both the order and the approximate magnitude of the changes that could be expected following particular changes in forest cover, though they also noted that the variability of the data still precluded setting any meaningful error limits on these estimates. Bosch and Hewlett have suggested that:

- in pine and ecalypt type forests, a ± 10 percent change in forest cover causes approximately + 40 mm change in annual streamflow;
- in deciduous hardwood forests, a ± 10 percent change in forest cover causes approximately + 25 mm change in annual streamflow; and

in low brush forests, a ± 10 percent change in forest cover causes approximately + 10 mm change in annual streamflow.

The positive and negative signs associated with percent cover directly linked with the sign order for mm equivalent change in yield. For example, a 10 percent conversion of pine and eucalypt forests to another land use causes an increase of approximately + 40 mm in annual streamflow and vice versa. The increases following forest removal are of short duration, and disappear as the forest regrows. The decreases following forestation do not occur immediately but show up as the canopy closes.

In 10 of the 25 pine-eucalypt forest experiments, annual streamflow increases in the range of 450-700 mm occurred. Bosch and Hewlett's Figure 3 also strongly indicates that increases in annual streamflow are positively correlated with annual rainfall. In high rainfall (>2500 mm) regions, predictions of yield change using Bosch and Hewlett's pine-eucalypt relationship could be underestimates by as much as 50 percent.

The few tropical studies reported to date conform with the pattern described by Bosch and Hewlett (1982). Low and Goh (1972) and Toebes and Goh (1975) have reported increases of some 10 percent in annual streamflow following the process of clearing and burning lowland tropical rainforest in Malaysia for conversion to oil palm and rubber plantations. Edwards and Blackie (1981) have summarized the results of a series of controlled catchment experiments in East Africa in which replacement of rainforest by tea plantations resulted in a slight overall reduction in water use by the vegetation, while replacement of bamboo by pine plantations produced an initial increase in water yield that disappeared as the plantations matured. Edwards and Blackie have also reported that replacement of evergreen forest by smallholder cultivation on very steep slopes resulted in large increases in water yield.

Studies on the wet tropical coast of northeastern Australia, where the annual rainfall exceeds 4000 mm, closely conforms with the pattern reported by Bosch and Hewlett (1982), Gilmour (1977a), Gilmour et al. (1982), and Cassells et al. (1985). In these studies, the treated catchment undergoes a light salvage logging two years before 70 percent of the catchment is cleared for establishing tropical pastures. Based on Bosch and Hewlett's predictions, one would not have expected any real change in annual streamflow following the light logging operation, while an increase in annual streamflow yield of 280 mm would have been expected after clearing. In fact, no increases in annual streamflow were measured after logging. However, an increase in annual streamflow of 293 mm was measured in the two water years following clearing.

Some caution should be exercised in extrapolating these results to all tropical rainforest areas until the hydrological processes accounting for this change are further investigated. For example, Pearce and Rowe (1979) noted that much bigger increases in water yield (approximately 25 percent annual rainfall) were measured on clearing temperate evergreen forests in New Zealand and *in the* Oregon Coast Range of the United States (Harr, 1976). Based on these data, an increase in approximately 700 mm in water yield after logging and clearing 70 percent of the Babinda catchment would be expected. Assuming there is no groundwater leakage, the reduced measured yield may be a combination of several factors. These include:

- higher net radiation available for evaporation in temperate latitudes;
- persistent shower activity in the "dry" season for maintaining "wet" soils for long periods, encouraging high soil evaporation rates;
- continued water use of effluent groundwater seepage by the riparian rainforest within the buffer strips.

The 293 mm increase possibly coincides with periods when the surface soils dry out, especially in the last three months or so of the "dry" season between August and November. Under these circumstances, the soil water flux to the surface would dramatically decline.

Effects on Floods and Dry Season Flows

Changes in the timing of streamflow following changes in forest cover often have implications for land-use planning that are as important or even more important than changes in annual streamflow yield. Of particular concern is whether changes in streamflow yield are expressed as changes in stormflow during storm events or as changes in the baseflow that is maintained between storms and rainy seasons.

The available research evidence indicates that changes in streamflow following forest alterations in *low- to moderately*-responsive catchments (such as many in the eastern USA and western Europe) occur predominantly as baseflow or delayed flow (Anderson et al., 1976; Lee, 1980). However, changes to *quickflow* are common, particularly in highly-responsive temperate basins such as the experimental catchments in western New Zealand (Pearce et al., 1980). However, as Lee (1980) has noted, the influence of forests on the timing and distribution of streamflow is still widely misunderstood:

> The popular notion that forests tend to "retard and lower flood crests and prolong flow in low-water periods" . . . was still in vogue among foresters until the middle of the current century. It is true, to a degree, that forests "lower flood crests," but the statement requires careful interpretation; some of the largest floods on record have occurred in forested drainages . . . . The attractive notion that the existence of forest cover will "prolong increased flow in low-water periods is clearly false."

Thus, there is a need for *careful interpretation* of published research results with regard to forest influences on flooding in both temperate and tropical environments. For example, in the United States, controlled catchment experiments have usually, but not always, indicated increases in stormflow following forest clearing (Anderson et al., 1976). In a number of these studies, in deciduous forests, the increases were seasonal with the largest increases occurring during the season of active forest growth when the evapotranspiration demands of the forest were highest (Reinhart et al., 1963; Pierce et al., 1970; Hornbeck, 1973). In the temperate evergreen rainforests of western New Zealand, seasonal influences are also apparent, but the greatest yield increases occur in winter months because of the high importance of interception loss and the winter rainfall maximum (Pearce and Rowe, 1981).

These seasonal patterns occur because evapotranspiration from forested areas is usually higher than that from alternative types of catchment cover such as pasture. The season of greatest differences will depend on the relative importance of interception and transpiration and precipitation distribution at any specific locality. Net rainfall is less under forests (except cloud forests) than other types of vegetation, thus less soil water is available to percolate to groundwater and maintain baseflow (Douglass and Swank, 1975). Usually there is a greater potential detention storage under forest. Should flood rains occur, this extra detention storage delays stormflow initiation and reduces flood peaks. During the dormant winter season in much of the United States, and particularly with deciduous hardwood forests, evapotranspiration differences between forests and other catchment covers are smaller, and stormflows under different covers seem to be quite similar.

The *relative* increases in stormflow behavior following forest clearing have at times been quite dramatic with increases in small flood peaks as high as 250 percent being reported from individual storms at Hubbard Brook in New Hampshire, USA (Pierce et al., 1970). However, even in these studies, the *absolute* increases in stormflow volumes are less dramatic with the maximum increase in the stormflow from an individual storm being only 45 mm. The average total increase in stormflow volume on a water-year basis was 99 mm in this environment where the total annual quickflow yield from undisturbed catchments was 311 mm out of annual streamflow and precipitation regime of 670 mm and 1220 mm, respectively (Hornbeck, 1973). Similarly, Douglass (1983) has reported absolute annual quickflow increases ranging from 25 to 40 mm at Coweeta where the average annual precipitation regime ranges from 1768 mm at low elevations to 2300 mm at high elevations.

Clearing of temperate rainforests in highly responsive areas such as coastal Oregon and western New Zealand (Harr et al., 1975; Pearce et al., 1980) has also shown large increases (up to 300 percent) in stormflow volume from small rainstorms. In progressively larger rainstorms, the effect on stormflow volume decreased rapidly in both areas.

In the wet tropics of northeastern Australia, where 63 percent of the annual rainfall of 4000 mm occurs in four months, Gilmour et al. (1982) have reported that clearing lowland tropical rainforest in a controlled catchment experiment produced little or no impact on stormflow, with the increase in annual streamflow being largely expressed as baseflow. In this wet tropical environment, substantial surface runoff occurs under even undisturbed rainforest (Bonell and Gilmour, 1978). Process studies have subsequently demonstrated that this runoff response is produced by the low permeability of the catchment's deep subsoil (up to 6 m) in relation to the high rainfall intensities of the prevailing monsoonal storms (Bonell et al., 1981). In this environment, it is this lithologic feature, rather than the condition of the catchment's vegetation or soil surface, that is the fundamental influence on its stormflow response (Cassells et al., 1985).

Another reason for *careful interpretation* of forest influences on flooding is that controlled catchment experiments are of necessity undertaken in small headwater streams (Bosch and Hewlett, 1982), and there is no hard evidence of any direct cause-and-effect relationship between forest cutting in headwater streams and floods in the lower basin of major rivers (Hewlett, 1982).

Although at first this may appear surprising, it becomes less so when one considers the important factor of scale. While stormflow may well be increased close to the area cut, this effect appears to be reduced to insignificance as water is routed down to a major river basin. On this scale, other factors such as the nature and intensity of the precipitation, the direction the storm moves across the basin, and the size and geomorphology of the basin itself become of paramount importance (Hamilton, 1983). Moreover, although there may be some recognizable increase in flooding in the frequent "light" rainfall events, the vegetation has little influence on those events with a frequency of, say, once in 30 years or less.

Effects on Groundwater and Salinity

With the reduced evapotranspiration following reductions in forest cover, more soil water is available for percolation to groundwater (Holmes and Wronski, 1982). As a result, there is often a rise in the groundwater table following deforestation (Boughton, 1970; Lee, 1980). This runs contrary to most environmentalist expectations.

If the groundwater is saline or the soil profile contains salt, the rising groundwater tables associated with forest clearing may cause severe land management problems (Boughton, 1970). In these circumstances, the higher groundwater tables may increase the frequency of saline water reaching the soil surface. Subsequent evaporation from the soil surface allows salt to accumulate in the upper soil horizon in a process termed *dryland salinity* (Peck, 1978, 1980). Irrigation can cause similar salt accumulation problems termed *wetland salinity* (Peck, 1980), and in both cases the increased flux of water through the soil profile can mobilize salt for export from particular catchments in streamwater (Peck and Hurle, 1973; Peck, 1978). Wetland salinity problems affect approximately one-third of the world's irrigated lands (400,000 km^2), while dryland salinity problems affect a further 11,000 km^2 of arable land (Peck, 1980). Salinity problems occur in a number of tropical countries (Balek, 1983) though they are nowhere more prevalent than in Australia. In Australia, water quality problems associated with man-induced salinity affect many river systems, particularly in the southwest of the continent (Peck, 1980).

Conversely, planting trees has usually resulted in a drop in groundwater levels, and this may have adverse effects on springs and wells. It is possible that on previously abused, compacted sites with little infiltration forestation can improve watertable recharge, but no reliable data exist.

Effects on Erosion and Stream Sedimentation

Research in both temperate and tropical latitudes has demonstrated that reductions in forest cover associated with utilization of watershed forests can lead to increases in both soil erosion and stream sedimentation (Anderson et al., 1976; Hamilton, 1983). Equally, research in both tropical and nontropical environments has demonstrated that in many circumstances *appropriate management* of both forest and nonforest land can ensure that catchment areas do not suffer adverse erosional impacts from utilization of their resources (Anderson et al., 1976; Hamilton, 1983). In order to consider what appropriate management might apply in different circumstances, it is useful to consider the complex problem of erosion generation in forested landscapes (Dunne, 1984) under a series of process subheadings such as surface erosion, mass instability, and stream sedimentation (Douglas, 1977).

Effects on surface erosion. Wiersum (1984) has discussed the effects of forests on surface erosion and makes the important distinction between the effects of trees per se and the effects of forests as integrated ecosystems. Wiersum has noted that although rainfall interception by trees can reduce the total amount of water impacting on the soil surface, the concentration of intercepted rainfall into larger droplets means that the erosive power of rainfall may well be greater under forests than outside them, unless the soil surface of the forest ecosystem is protected by grass, litter, or herbage growing close to the ground. Thus, the relative paucity of leaf litter in many tropical rainforest environments suggests that natural erosion due to rainsplash and surface wash will be greater under these forests than under forests in humid temperate environments (Douglas, 1977).

The key role of soil surface cover in providing protection against surface erosion helps to provide a frame of reference for determining the *appropriateness* of particular land management practices in particular watershed environments (Wiersum, 1984). Forest and nonforest land management practices that can maintain effective surface cover will unlikely generate excessive levels of soil surface erosion. Thus, within the limits of available technology and the local economic biophysical environment, pasture, cropping, and agroforestry practices *can* be developed to maintain surface cover and ensure that surface erosion is not excessive. Equally, poorly managed forestry practices such as excessive burning, grazing, or extensive soil disturbance during logging operations can destroy the surface cover and, despite the residual presence of trees, produce high rates of surface erosion.

Mass wastage and slope stability. Slope instability or mass wastage occurs when masses of soil move downward, primarily under the influence of gravity (Douglas, 1977). Mass erosion may be rapid, as in the case of debris avalanches or landslides, or almost imperceptably slow as in soil creep (Douglas, 1977). Changes in vegetation can influence both shallow and deep rooted mass movements, but it is a particularly important influence on the occurrence of shallow slides (Cassells et al., 1983).

Mass erosion is controlled by the balance of shear stress and shear strength within the soil (Douglas, 1977). Where the shear strength of the soil is greater than the shear stress on the soil, the slope remains stable. Conversely, where the shear stress on the soil is greater than the shear strength within the soil, mass erosion occurs.

The ways in which a forest cover an influence slope stability have been outlined by O'Loughlin and Zeimer (1982) who note that forests can have both positive and negative influences on slope stability. The negative influences on slope stability result from the processes of:

- root wedging and wind throw, and
- surcharge due to the weight of the forest biomass itself.

The positive influences of forests on slope stability result from:

- the modification of soil moisture distribution and soil pore pressure caused by forest evapotranspiration, and
- mechanical reinforcement of the soil by tree roots giving greater shear strength.

O'Loughlin and Zeimer (1982) have noted that under different conditions of forest vegetation, climate and slope, the relative importance of these various influences may change, but that generally the net influence of a forest cover on slope stability is positive. O'Loughlin and Zeimer have also noted that the major forest factor enhancing slope stability is the mechanical reinforcement provided by the tree root system.

Endo (1980), O'Loughlin (1974), Swanston (1974), Waldron and Dakessian (1981), Wu et al. (1980), Gray and Megahan (1981), and O'Loughlin and Zeimer (1982) have all demonstrated that root systems contribute to soil strength by providing additional or artificial soil cohesion. O'Loughlin (1984) has reported that field tests have shown the additional cohesive force provided by tree roots ranges from 1.0 k Pa to 20 k Pa and that in many instances of soil saturation the additional cohesion provided by tree roots can account for a large proportion of the total shear strength of soils.

In terms of the influence of forests on mass wastage processes, the additional cohesive force provided by tree roots is of critical importance when shear strength and shear stress forces within a soil mass are finely balanced. In these circumstances disturbance to the forest will often induce considerable acceleration of mass wastage processes (Anderson et al., 1976). However, although scientific understanding of the mechanisms through which tree roots add to soil cohesion is not well developed (O'Loughlin, 1984), many predictive technologies of varying complexity and sophistication are available for application in forest management and land-use planning (Dunne, 1984).

The Importance of the Riparian Zone

The proportion of a catchment that contributes rapid runoff during storms to produce the stormflow response of a stream is termed a *source area* (Hewlett and Nutter, 1969). Source areas within particular undisturbed catchments will vary with differences in the soil water status immediately before the storm and differences in rainfall intensity and duration of storms (Hewlett, 1961; Hewlett and Hibbert, 1967; Hewlett and Nutter, 1969). In both tropical and temperate rainforests, extensive source areas can develop. In temperate forests stormflow is commonly generated by subsurface flow, even where source areas are extensive (Mosley, 1979; Pearce and McKerchar, 1979). In tropical catchments, prolonged and high-intensity rainfall events and limited soil permeabilities may be responsible for extensive source areas generating saturation overland flow (Bonell and Gilmour, 1978; Dunne, 1984; Cassells et al., 1985).

In both tropical and temperate forests, protection of the riparian zone that surrounds the stream channel is important if the transfer of upstream development impacts to downstream areas is to be minimized (Kunkle, 1974; Cornish, 1975; Cameron and Henderson, 1979; Cassells et al., 1985). With the exception of the more prolonged high-intensity rainfall events, the riparian zone is usually the most important sediment source area. Maintaining a riparian buffer zone will minimize the chance of generating sediment sources close to the stream channel and will act as a partial filter for any sediments, nutrients, and sediment-borne pollutants arising from activities on the upper catchment slopes. Maintaining a riparian buffer strip can also benefit aquatic organisms by reducing the fluctuations in stream temperature that may accompany forest disturbance.

Maintaining riparian buffer strips is equally important in tropical forest catchments when prolonged rainfall events extend runoff sources beyond the immediate riparian zone (Cassells et al., 1984, 1985). Riparian buffer strips help to preserve the forest root networks that ensure actual stream bank erosion is minimized. This is particularly important in the more hydrologically responsive tropical areas where frequent flashy stormflow events provide little opportunity for the revegetation of exposed soil areas along stream banks, and even a few of these areas can contribute large amounts of sediment to downstream areas (Gilmour, 1971, 1977). However, in all areas, riparian forests are often major water users during dry seasons (Anderson, et al., 1976). This implies that there may be a price to pay for water quality protection of riparian forests in terms of reduced dry season streamflow yield.

CONCLUSIONS

This review has presented a picture of forest influences that differs markedly from the perceptions that many foresters and land planners may hold about the protective role of tropical forests (Hamilton, 1983, 1984). Much confusion undoubtedly exists because many of the significant hydrological findings of recent decades have not been widely disseminated to the managers and planners who daily make important decisions about the future of tropical forest lands. Also, the science of hydrology is still young and much of the work has been undertaken in the temperate areas, particularly in catchments of the eastern United States, which have a low responsiveness to storms. This provides some problems for *accurate* extrapolation to tropical areas because of various differences, for example, in rainfall intensity-frequency-duration, in soil properties, and in vegetation characteristics between deciduous and evergreen forests and their effects on interception and transpiration. However, hydrological research in both temperate and tropical environments has now established the general direction of hydrological change induced by manipulation of forest vegetation.

A summary of this research follows:

- Reducing forest cover on a forested catchment increases the water yield from that catchment. Frequently the majority of this increase will occur as baseflow but changes in quickflow are common, particularly in highly responsive watersheds.
- Planting trees in nonforested catchments will tend to decrease the water yield, with the majority of the decrease in relative terms occurring in the baseflow component.
- Changing forest cover in headwater catchments will, at most, have only a minor impact on downstream flooding, particularly on large river basins.
- Reducing forest cover often leads to an increase in erosion and stream sedimentation. However, with appropriate management, catchment areas can be used to produce many forest and nonforest products, provided effective ground cover is maintained and land capability limits are not exceeded.
- In setting land capability limits, planners should be aware of the value of forests in minimizing mass stability problems on slopes where shear strength and shear stress forces are finely balanced.
- In catchments in both temperate and tropical environments, maintaining effective riparian buffer zones will minimize the transfer of upstream development impacts to downstream areas.

Recent advances in hydrological knowledge have not always been widely applied in forest management and forest policy development. Perhaps foresters have been guilty of acquiescing by silence to the use of some misinterpretations and misunderstandings, because the arguments or rhetoric being used were aimed at protecting forest resources or at establishing new forests – surely actions worthy of nations and statesmen. But, if we close the watershed forests to human use and reservoirs continue to silt up, and when we have totally reclothed the basin in planted forest and we still have floods, and if, on top of that, the streams still dry up or dry up even more . . . then there may be a well-deserved backlash and the credibility of foresters and other watershed professionals may be called into serious question. There are many eminently sound reasons for forest conservation and reforestation in the tropical developing countries. Let us not condone the use of unsupportable or questionable hydrologic and erosional relationships in this important policy scenario.

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II. Effects of Agroforestry on Soil and Water Conservation and on Productivity

Most of the areas now used, or earmarked for future use, for agroforestry systems in the tropics are on sloping lands. This is because excessive population growths have, in many cases, far outstripped the limited arable land resources of tropical countries, and the hilly lands now being placed under tillage require perennial plant components to minimize soil erosion and productivity loss.

Sloping lands are inherently fragile in the sense that when their surfaces are disturbed through intensive cultivation and the protective vegetative cover is removed in the process of site clearing and preparation or biomass harvest, torrential tropical rains and the resultant heavy runoff will leach out nutrients and carry away nutrient-rich surface soil particles, thereby impoverishing the site and rendering it unproductive in short order. The goal of farmers and planners alike is to seek appropriate land use systems to minimize this degradation process, maintain or improve nutrient levels, and sustain the production of desired goods and services.

An array of options for achieving soil and nutrient conservation to enhance productivity and sustainability is available ranging from mechanical means such as terracing, on the one hand, to vegetative means, such as establishing contour tree rows under agroforestry systems, on the other. What is needed is a series of trials and experiments to ascertain which of the options would be most effective under given agroecological conditions.

The papers in this section are derived from research projects or drawn from pilot demonstration plots of extension programs and present newly available information from the Asia-Pacific region that could augment and strengthen the data base of agroforestry literature in the tropics.

SOIL AND WATER CONSERVATION AND PRODUCTIVITY IN AN INTENSIVE AGROFORESTRY SYSTEM

by

Hoanh Hoang Nguyen[1]

ABSTRACT

Perennial crops [ipil-ipil (*Leucaena*) and papaya] and annual crops (pineapple, cassava, sweet potato, and peanuts) were intercropped in an experimental area with a clay loam soil and an average slope of 15 percent. The annual crops were planted on furrow contours for soil and water conservation. The soil analysis indicated that the nutrient content and bulk density of the soil were improved by the intercropping practice. Runoff and soil erosion were effectively controlled. Increased productivity levels of the crops were also observed. Papaya produced the highest net income while pineapple showed the lowest.

INTRODUCTION

Agroforestry is considered an important approach to satisfy the needs of upland farmers and forest occupants while helping check the rate of deforestation, conservation of soil and water, and improvement of productivity in a given forest area. The appropriate agroforestry technologies, particularly the method of farming, and the selection of forest tree species and agricultural crops in an intensive integrated cropping system are primary factors that must be considered to achieve these goals. Multipurpose, fast-growing tree species are usually chosen in different agroforestry schemes. The selection of agricultural crops is usually more complicated due to the crops' different requirements for water, nutrients and light; ability to resist pests and diseases; competition for nutrients; and market demand.

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[1]Consultant, Forest Research Institute, Los Baños, Laguna, Philippines.

This paper presents the findings from an agroforestry system using ipil-ipil (*Leucaena leucocephala* Lam de Wit) as the tree crop for the production of fuelwood, leaf meal, and living posts in combination with cash crops such as papaya, pineapple, peanut, cassava, and sweet potato. Soil and water conservation aspects as well as the crops' productivity have been emphasized.

Specifically, the objectives of this paper are (1) to determine the effects of crop combination and cropping pattern on the changes of some soil physical and chemical properties, (2) to determine the growth and yield of forest species and agricultural crops in this agroforestry system, and (3) to observe the effectiveness of crop arrangement and contour furrowing in the control of runoff and soil erosion.

MATERIALS AND METHODS

The study was conducted at Mudspring Experimental Forest of the Forest Research Institute, Los Baños, Laguna, Philippines, from April 1983 to October 1984. The 1440-m^2 area (30 m x 48 m) is of clay loam soil with color varying from brown to dark brown. The area was cleared of trees, shrubs, and weeds and then divided into four plots, with dimensions of 30 m x 12 m per plot. The field was prepared and subsequently planted first to ipil-ipil and papaya and then countour-furrowed for pineapple, sweet potato, and cassava. The planting distances were as follows: ipil-ipil, 2 m x 3 m; papaya, 2 m x 6 m; and annual crops, 0.5 m x 0.5 m (Figures 1a and 1b). Each ipil-ipil seedling was kept straight by supporting it with a 1.5 m stick. About eight months after transplanting when the ipil-ipil had reached a height of 4 m, each was top-cut and debranched. Ipil-ipil leaves were then harvested every two months thereafter for green manure.

After four months sweet potato was harvested ahd subsequently the plot was planted to peanuts. Cultivation (hilling-up) for weed control and maintenance of furrows to enhance crop growth and control of runoff and soil erosion were done whenever needed. One month after transplanting, commercial fertilizer (14-14-14) was applied at the rate of 20 g to each papaya seedling and 250 kg/ha was applied to subplots for annual crops. No herbicide or insecticide or water was applied throughout the duration of the study. Soil samples were obtained before and at the end of the study. Crops' growth and yield were closely monitored. Variance, regression, and correlation analyses were used in the statistical treatment of the collected data.

Fig. 1a Fig. 1b

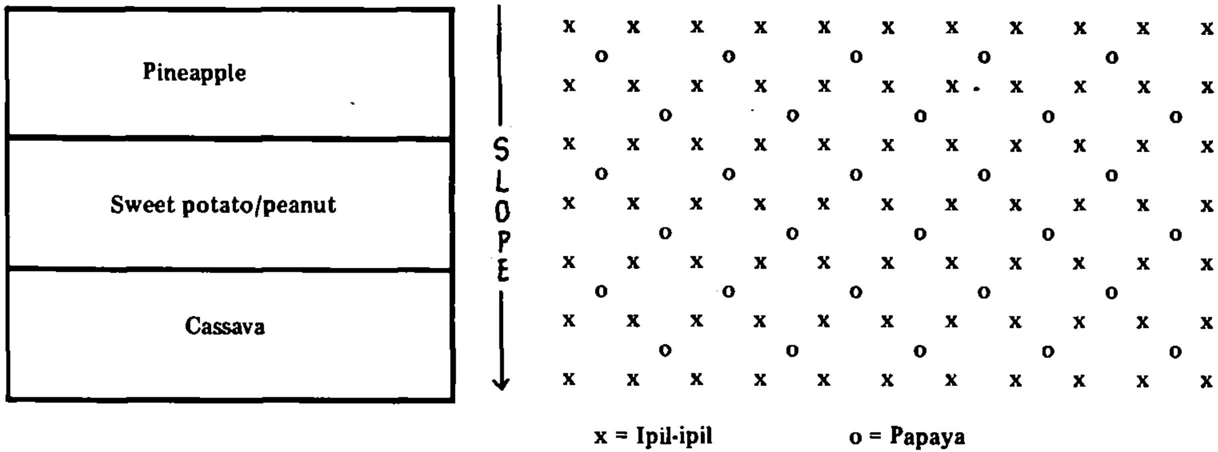

Figure 1. Experimental layouts for (a) annual crops and (b) perennial crops in agroforestry plots at Mudspring Experimental Forest of FORI, Los Baños, Laguna, Philippines.

RESULTS AND DISCUSSION

Soil Physical and Chemical Properties

Results of the analyses indicated some changes in soil properties during the observation period (Table 1). The average increase of 0.40 percent in organic carbon in the composite samples of the four subplots led to the increase in CEC (2.25 meq/100g) and a little reduction in soil pH (0.055). This may be due to the rapid development of the plant roots, especially that of sweet potato. The concentrations of nitrogen, phosphorus, and potassium increased by average values of 0.045 percent, 2.20 ppm, and 0.46 meq/100g, respectively, for all plots. These increases may be due primarily to commercial fertilization and the addition of green manure. The improvement of soil bulk density (0.29 g/cc) was probably caused by the cultivation (hilling-up) of the area as well as the development of roots and tubers and addition of organic matter.

The increase in macropores was the direct result of the development of abundant root systems of sweet potato near the soil surface and that of pineapple in the deeper soil layer. In additon, the development of cassava tuber and removal of tubers at harvest could contribute significantly to the reduction of soil bulk density and could be classified as good. Cracking of soil along the tubers, particularly in the case of cassava, during the tuber development phase was observed.

Generally, the cropping system under study improved the soil characteristics, except the soil pH. The rates of improvement varied with the locations of the plots. The greatest positive changes in the soil properties were always observed in the downslope plots. However, such changes from upslope to downslope did not seem to follow a linear pattern. Regression of changes in any soil parameter with locations was not significant in all cases.

Runoff and Soil Erosion Control

The impacts of raindrops on the furrows varied with the kinds of crops and their developmental stages. In the first two months after transplanting, more soils from the areas planted to pineapple and cassava were splashed down by raindrop impact than those from the areas planted to sweet potato where the energy of the raindrops was neutralized by the denser layer of potato leaves. Sweet potato proved to be the best vegetative cover in a short period after plant-

Table 1. Some soil chemical and physical properties in four agroforestry plots, FORI Mudspring Experimental Forest, Laguna, Philippines.

Soil Property		Plot Number				Mean
		1	2	3	4	
1. Soil pH	a*	6.20	6.20	6.10	5.90	6.100
	b*	6.18	6.20	6.00	5.80	6.045
	(b–a)	–0.02	–0.00	–0.10	–0.10	–0.055
2. Organic Carbon (%)	a	2.24	2.28	2.55	3.33	2.60
	b	2.57	2.58	3.33	3.51	3.00
	(b–a)	0.33	0.30	0.78	0.18	0.40
3. Nitrogen (%)	a	0.194	0.196	0.210	0.300	0.225
	b	0.210	0.209	0.310	0.350	0.270
	(b–a)	0.016	0.013	0.100	0.050	0.045
4. CEC (meq/100g)	a	14.40	14.67	21.20	24.31	18.65
	b	15.30	15.55	23.02	29.72	20.90
	(b–a)	0.90	0.88	1.82	5.41	2.25
5. Available P (ppm)	a	1.02	1.23	2.08	2.47	1.70
	b	4.14	4.35	3.27	3.85	3.90
	(b–a)	3.12	3.12	1.19	1.38	2.20
6. Exchangeable K (meq/100g)	a	1.66	1.75	2.64	2.88	2.23
	b	1.89	2.01	3.04	3.83	2.69
	(b–a)	0.23	0.26	0.40	0.95	0.46
7. Bulk density (g/cc)	a	1.39	1.35	1.24	1.23	1.30
	b	1.07	1.02	1.01	0.92	1.01
	(b–a)	–0.32	–0.33	–0.23	–0.31	–0.29

*Samples were taken at: a = establishment phase and b = after 1.5 years.

ing, while pineapple had a longer lasting effect on the soil for erosion control. After five months, when the crown of pineapples had fully developed, the same effect on checking of splash erosion was also observed. Cassava showed the same trend when its crowns were fully developed. However, the soil particles detached by splash erosion in every case were not transported far but were trapped between the furrows. Subsequent hilling-up for weed control and maintenance of furrows returned these soils to the hills.

Surface runoff and soil erosion were completely controlled due to the effects of contour furrow planting. Maximum surface roughness of the soil was always maintained during the observation period. When the soil was dry, or when rain was of low to moderate intensity, rainwater was trapped between furrows and infiltrated into the lower soil layer. When the soil was saturated at high rainfall intensity, the surplus water slowly flowed along the furrows to the waterways at both ends of the experimental areas. Thus, no rill erosion actually occurred in all plots.

Light Intensity in the Cropping System

Light intensity was monitored to determine the appropriate time to prune the ipil-ipil in order to avoid the shading effects over the ground crops, especially peanuts. The shading effect of ipil-ipil started at about five months after planting. Sunlight intensity was reduced to about 400-ft candles as compared to 4000 to 5000-ft candles in the open area. However, after the top and branches of ipil-ipil were removed on the eighth month, the values of sunlight intensity went up to more or less the same as those measured outside the plots. The papaya canopy also created some degree of shading, but its effect was limited to a small area following the sun's pathway. Cassava shading on ipil-ipil and papaya seedlings was also noticed during the vegetative stages of the seedlings; however, these crops overcame cassava shading in a short time. Pineapple seemed to be the best crop in terms of light competition. It did not create any shading problem to other interplanted crops nor was affected by shades of other taller crops.

Crops Growth Performance and Productivity of Crops

With a survival rate of 93 percent, most ipil-ipil seedlings reached a height of 4 m eight months after transplanting. The average base diameter was 2.70 cm. The height growth of papaya, only reaching 4 m after 15 months, was slower than that of ipil-ipil (Figure 2).

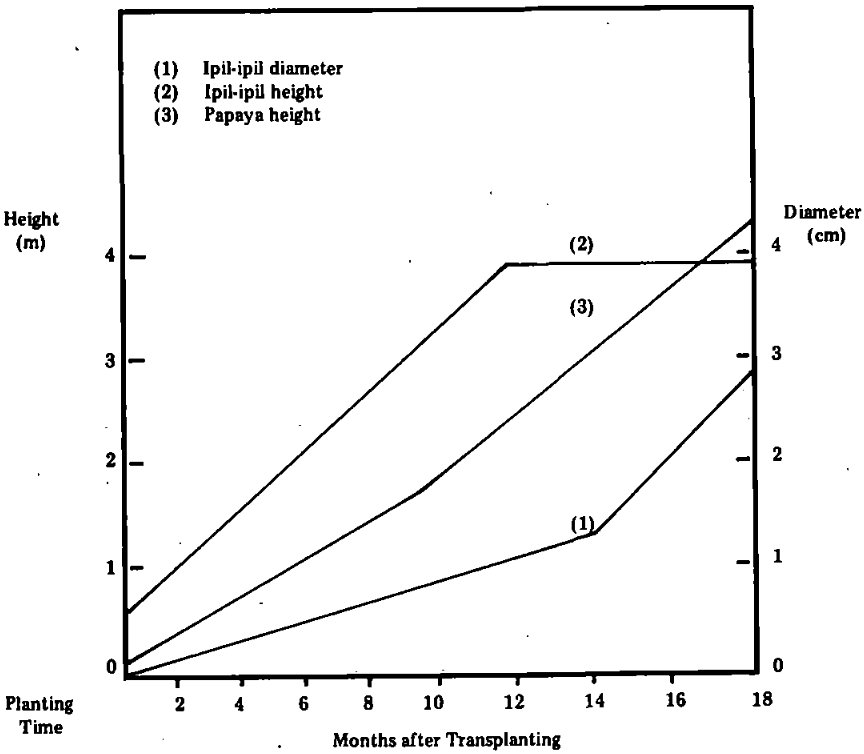

Figure 2. Growth performances of ipil-ipil and papaya.

Total green leaf weight of ipil-ipil was 2904.84 kg for the whole area or about 20 tons/ha. The leaf weight as well as wood volume of ipil-ipil increased from plot 1 to plot 4 (Table 2). Wood volume increased linearly from upslope to downslope as revealed by linear regression analysis ($R^2 = 0.9741^*$, $P < 0.05$). This may be the result of a better nutrient status and lower soil bulk density downslope, as shown previously in Table 1.

The changes in wood volume can be expressed mathematically as:

$$Y = 6.7 + 1.62\,(X)$$

where:

Y = volume in m^3
X = 1, 2, 3, 4, for plots 1 to 4, respectively.

The yields of papaya, pineapple, sweet potato, cassava, and peanut are shown in Table 3. Yields of these crops also increased in the same manner as that of ipil-ipil; their average yields for each plot were 291 and 109 fruits, and 30.3, 117.8 and 12.1 kilograms, respectively. The linear regression analysis indicated that the pineapple yield increased at the same trend as that of the wood volume of ipil-ipil.

In order to compare the productivity of the three crops, their market value equivalents were computed and then converted into the percentage contribution of the individual crop to the total output. The statistical analysis for the Arcsin transformed data indicated no significant differences among contributions of peanut, cassava, and sweet potato. The highest significant contribution to the total gross income was from papaya while the lowest was from pineapple, as indicated in Figure 3.

Cash crops in this system were harvested either once (cassava, sweet potato, and peanut) or several times (pineapple and papaya). Papaya fruits could be picked every five to ten days for more than 1.5 years; their fruit yield thereafter is reduced both in number and size.

The projected total crop yields based on the experimental plots' results are shown in Table 4. The inclusion of ipil-ipil (leaves and wood) in the estimation after 1.5 years was aimed to give an overview of the whole range of agroforestry products. Ipil-ipil was purposely used in this system as a living post for supporting another

Table 2. Ipil-ipil leaf weight and wood volume in agroforestry plots.

Item	Plot Number 1	2	3	4	Total	Mean
1. Leaf weight (kg)	349.92	397.08	838.72	1,318.92	2,904.64	726.16
2. Wood volume (m^3)	8.40	9.60	12.00	13.20	43.00	10.75
Leaf weight $R^2 = 0.9133^{ns}$; Volume $R^2 = 0.9741^*$						

ns: Not significant.
*: Significant at 5% level.

Table 3. Yields of papaya, pineapple, sweet potato, cassava, and peanut in agroforestry plots.

Crop	Plot Number				Total	Mean
	1	2	3	4		
1. Papaya[a]	176.0	289.0	324.0	375.0	1,164.0	291.0
2. Pineapple[a]	80.0	90.0	123.0	146.0	439.0	109.8
3. Sweet potato[b]	23.2	25.1	29.1	43.6	121.0	30.3
4. Cassava[b]	104.0	104.0	115.0	148.0	471.8	117.8
5. Peanuts[c]	11.1	11.3	13.0	13.0	48.4	12.1

Papaya $R^2 = 0.934^{ns}$; Pineapple $R^2 = 0.9651^*$; Sweet potato $R^2 = 0.8310^{ns}$; Cassava $R^2 = 0.7860^{ns}$; Peanut $R^2 = 0.840^{ns}$.

where R^2 are the correlation coefficients
ns : not significant
* : significant at 5% level.

a Number of fruits.
b Tuber weight (kg).
c Weight (kg) of nut.

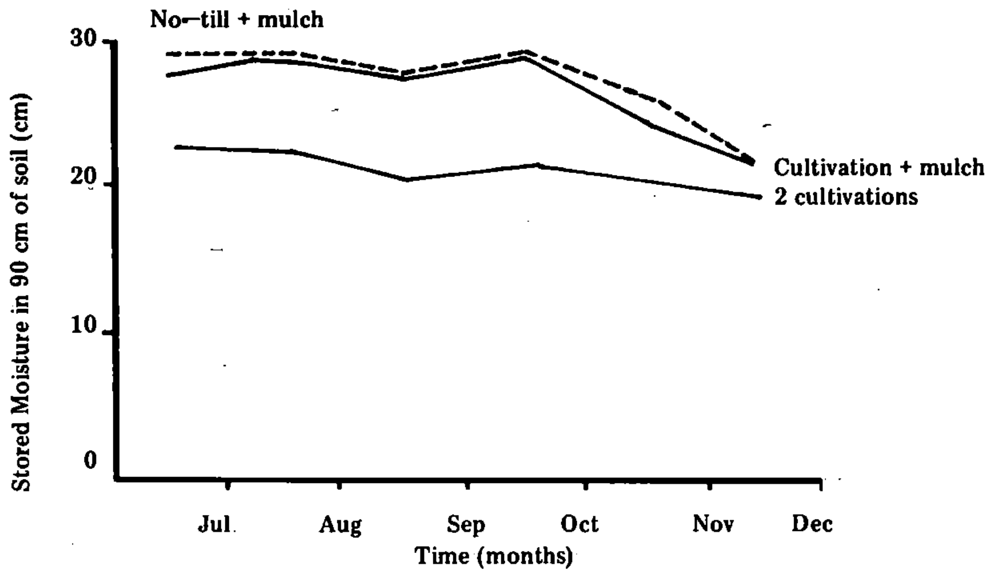

Figure 3. Stored moisture (volumetric) in 0-90 cm soil profile for rice crop at Hang Chat in 1982 (Buddee, 1985).

Table 4. Projected crop yields for 1 ha of agroforestry farm after 1.5 years, Mudspring Experimental Forest, Laguna, Philippines.

Crop	Projected Yield	Yield Unit
Ipil-ipil:		
Leaf	20,172	Kilogram (kg)
Wood	300	Cubic meter (m^3)
Papaya	8,083	Fruit
Sweet potato	2,520	Kilogram (kg)
Pineapple	9,145	Fruit
Cassava	9,812	Kilogram (kg)
Peanut	1,008	Kilogram (kg)

crop (e.g., black pepper) which will be introduced in a latter phase of the study – a source of leaf and fuelwood or construction material after five years. From these yield projections, the profitability of the agroforestry system can be easily figured out once the unit prices of the crops and the total input costs are known.

CONCLUSION AND RECOMMENDATIONS

Various crops that have different durations of cropping seasons – e.g., short term (sweet potato, peanuts); medium term (pineapple, cassava); and long term (papaya, ipil-ipil) – produced a continuous income and partial vegetative cover for the surface area of the land. Vegetative cover, when combined with contour furrows, proved its effectiveness in controlling soil erosion and surface runoff. The fast development of annual agricultural crops, especially sweet potato, also showed their capability in the control of splash erosion. However, the height of furrows need always be maintained in order to cut down the length of the slope and to minimize runoff. Hilling-up was not only for weed control but also for satisfying this requirement. Soil properties were improved in this system, especially the nutrient status and the soil bulk density.

The productivity of this intensive agroforestry would certainly encourage researchers, farmers, other private sectors to adopt agroforestry technology for their lands. However, further studies should be made of crop combinations and soil erosion control with application of combined engineering and vegetative treatments (e.g., buffering contour, terracing and crops). Market supply and demand, as well as market values of crops, should not be overlooked in the selection of an agroforestry system.

Composting should be carried out from the wasted organic residues and returned to the soil to supply plant nutrients and improve some soil properties such as infiltration capacity, available water-holding capacity, bulk density, and cation exchange capacity, while replacing partially or totally, commercial fertilizers in the future.

Forest crops should not be considered as the only means of soil erosion control because they could not develop their vegetative cover in a short time, unless they were planted closely on the contour strips. Serious soil erosion may occur during the first year of operation.

Finally, forest trees that are straight with few branches, deep root systems, high market value whether they are nitrogen fixing or nonnitrogen fixing species, fast-growing or slow-growing should be given more attention.

EFFECTS OF HIGHLAND AGROFORESTRY ON SOIL CONSERVATION AND PRODUCTIVITY IN NORTHERN THAILAND

by

Samyos Kijkar[1]

ABSTRACT

This study investigated the appropriate cash crops, conservation measures, and optimum period of cropping suitable for highland sites. Shade-tolerant root crops such as taro, sweet potato, and ginger seem ideal for agroforestry systems because they grow competitively with forest trees and produce satisfactory yields within the first three years of tree plantation establishment. Contour ridging is the most appropriate conservation measure when compared to trash bunding and contour cropping.

INTRODUCTION

To establish low-cost teak plantations, the Burmese "taungya" system of agroforestry was introduced in Thailand as early as the 1920s. However, this system was gradually adopted by the country's highlanders only during the past decade. As tribal farmers changed their traditional shifting cultivation to more sedentary practice, they cleared forest lands that are now used for cash crop production continuously for three to five years in addition to the fruit trees planted in these lands.

The rapid population increase and the migration of many tribal people from neighboring countries during and after the Indo-China war, coupled with the lack of suitable lands for agriculture, are causing exploitation of forest areas. Although forest lands can be

[1]Forester, Watershed Management Division, Royal Forest Department, Ministry of Agriculture and Cooperatives, Thailand.

used to produce food crops and forest trees simultaneously, the practice of shifting cultivation is still a problem to watershed managers in the country. This study was carried out to investigate solutions to soil erosion problems by means of agroforestry practices. Specifically, the objectives are to investigate the appropriate (1) conservation measures suitable for highland agroforestry, (2) cash crop species for introduction to the system, and (3) period of intercropping under the taungya plantation.

STUDY METHODS

Time and Location

The study began in June 1981 and ended in November 1983 (Mae Sa Watershed Project, 1981-83).

The Mae Sa Project's forest plantation of *Docynia indica* (Deone) was selected and used for this experiment. The plots are located at approximately 1,000 m above mean sea level with an average slope of 35 percent.

The soil is moderately fertile, reddish brown lateritic or palaeustult. The 30-cm topsoil is clay loam, dark colored with good to very good drainage. Subsoil is sticky loamy clay to clay, very dark red with very poor drainage.

Design and Installation

The forest trees were planted in early June 1981 at a spacing of 4 x 4 m. In the early wet season of the same year, the site was slashed and staked at the contour lines 10 m apart along the inclined distance for the treated plots. The total area was divided into 11 plots for 5 cash crop species, namely, upland rice, maize, taro, sweet potato, and ginger. Each species was planted in two plots: one plot (treated) involved a simple conservation measure (contour trash bunds and contour ridges), and the other plot (untreated) was planted to cash crop in a traditional manner. One plot was left without interplanting (i.e., as a conventional forest plantation to serve as the control plot). Weeding twice a year was done for the control, which is the normal practice for a forest plantation.

All the treated plots were staked at the contour lines. Trash bunds were formed along the contour with the use of pulled-out weeds. Upland rice was planted between the trash bunds by contour row planting. Rice seeds were dibbled in single rows parallel to the bunds in the treated plot, and hole dibbling at 20 x 20 cm in the untreated plot. Maize was dibbled in contour lines in both treated and untreated plots at 50 cm apart within rows, and 75 cm between rows. The root crops were planted at the contour ridges of the treated plots. The ridges were 50 cm wide and 30 cm high, with 30 cm wide contour furrows in between. Roots crops were planted in two rows on each ridge.

All plots were fertilized chemically (15:15:15) at a rate of 62.5 kg/ha and regularly weeded. To obtain the soil loss data, a staking method was designed. The wooden pegs, with a nail pounded on each stake to mark the original soil surface level, were staked in every plot. The depth of the eroded soil was determined by measuring the distance from the nails to the new ground surface level. In the 1982 cropping seasons, sample plots to study soil loss were installed. A trench 30 cm wide and 50 cm deep was dug at the foot of each plot, lined with a punched plastic sheet so that the runoff water could penetrate through the sheet and the sediment could be collected on top.

Conservation Measures

To protect the land from severe erosion and to maintain soil fertility, the following simple conservation measures were applied on the treated plots:

1. Contour trash bunding — After contour staking, weeds and undergrowths were collected and deposited along the contour lines to form mounds of plant residues partly covered with soil. This contour bund was used to check surface runoff and to filter sediment.

   Along the upper sides of the trash bunds, permanent legumes such as *Leucaena* or pigeon pea were sown in rows. These legumes formed a vegetative barrier that controlled erosion and served as boundaries of plots.

2. Contour ridging — Contour beds were formed along the trash bunds at 50 cm wide and 30 cm high and interrupted with 30 cm furrow in between. The ridges acted as contour bunds and the furrows collected the runoff, resulting in less erosion.

RESULTS AND DISCUSSION

Crop Yields

Yearly yields of cash crops in trial plots are shown in Table 1. Crops yields rapidly decreased when forest trees were at the earlier stages of development. The closeness of tree crown canopies affected the growth of the crops and thus decreased the yields. Competition for nutrients, soil moisture, and sunlight for photosynthesis became intense as the plants matured. In three years, yields of rice and maize decreased by half when compared with the first yield data. Decrease of root crop yields was slower than that of grain crops. There was nearly no difference among the crop yields from the treated (with conservation measures) and untreated plots in the first year, except sweet potato and ginger, but yields were significantly different in the second and third years.

Crop yields in the first year were not different significantly from normal farming but became highly significant in later years due to plant shading and more competition. Two years after forest plantation establishment appears to be the appropriate period for simultaneous cropping under the agroforestry system. The shade-tolerant root crops can be prolonged until the third year, after which simultaneous cropping is not economically feasible.

Tree Growths

Tree diameter. Diameter at stump height was measured at the end of harvest periods (see Table 2). The average tree diameter from plots planted to upland rice, taro, sweet potato, and ginger was significantly different from that of the trees of the control plot. Only maize showed no effects on the tree diameters when compared with the conventional forest plantation. There was a slight difference between the tree growth from the treated and untreated plots of the same cash crop species. This could be the effect of contour ridging (within the root crop plots) and the contour (row) planting of upland rice. These structures retard runoff, retain more water in the soil, and at the same time keep and retain more fertilizer applied within the plots. More soil moisture and fertilizer result in better growth of the forest trees.

Tree height. Total heights of *Docynia indica* Deone were measured every year after harvesting the cash crops. First and second

Table 1. **Crop yields from trial plots, with and without conservation measures, by year (tons/ha).**

Year	Maize		Upland Rice		Taro		Sweet Potato		Ginger	
	A[1]	B[2]	A	B	A	B	A	B	A	B
1981	1.830	1.796	1.220	1.185	2.250	2.160	3.440	3.265	3.885	3.555
1982	1.424	1.086	0.885	0.765	1.850	1.660	2.895	2.655	3.245	2.825
1983	0.850	0.625	0.545	0.335	1.220	0.975	1.530	1.225	2.110	1.675
Mean	1.368	1.169	0.883	0.762	1.773	1.598	2.622	2.382	3.080	2.685
Normal[3] Farming	2.0 – 2.5		1.5 – 1.75		5.0 – 7.0		5.0 – 8.0		7.0 – 10.0	

[1]With simple conservation measures.

[2]Without any conservation measures.

[3]Results of a conservation farming at Pong Khrai Demonstration Area (Source: Sheng, 1978).

Table 2. Mean tree growth and soil loss from plots under agroforestry and control plots.

Item	Year	Control	Maize		Upland Rice		Taro		Sweet Potato		Ginger	
			A[1]	B[2]	A	B	A	B	A	B	A	B
Mean tree diameter at stump height (cm)	1981	1.45	1.50	1.60	2.60	2.20	2.50	2.20	2.80	2.20	2.95	2.05
	1982	3.85	4.40	3.90	5.65	4.60	5.95	4.80	6.10	5.50	6.50	5.20
	1983	8.20	8.80	8.20	10.15	9.90	12.35	10.80	12.55	11.10	14.20	12.10
Mean tree height (m)	1981	0.82	1.15	1.32	1.50	1.15	1.55	1.20	1.40	1.20	1.65	1.10
	1982	3.75	4.85	4.50	4.90	4.40	5.10	4.65	4.95	4.50	5.75	4.85
	1983	6.80	7.35	6.80	7.15	6.75	7.70	7.10	7.75	6.95	8.15	7.20
Soil losses (tons/ha)	1981	Not available										
	1982	0.43	3.85	4.50	3.75	4.40	1.50	2.95	1.55	2.65	1.25	2.65
	1983	0.41	2.50	2.95	2.40	3.85	1.05	1.80	1.10	1.95	0.95	1.45
Rainfall (mm)	1981		1,516.8									
	1982		1,286.8									
	1983		1,082.0									

[1]With simple conservation measures.

[2]Without any conservation measures.

year results showed that average tree heights from the trial plots were significantly different from the control plot. After three years, however, average tree heights from the untreated agroforestry plots of ginger and taro were slightly different from the control; but no difference occurred in other crops when compared with the control. Average total tree heights from the treated agroforestry plots, on the other hand, were greater than the control. This reveals the effects of the agroforestry system on the productivity of the land. After three years, average tree heights tend to be the same as that of normal forest plantation.

Soil Losses

Because soil loss data for the first year were not collected, only 1982 and 1983 data were used for the analysis. The control plot showed less soil losses due to the dense forest cover and the abundant undergrowth. Soil losses from the control plot were, however, nearly double that from the natural hill-evergreen forest, which amounted to only 0.24 ton/ha (Chunkao, 1983). This is because the sparse crown canopies of young trees did not prevent splash erosion and ashes from forest fires in the dry period were washed down and deposited in the trenches.

The exposed soil of the agroforestry plots splashed and washed down easily. Soil losses from these plots were significantly different from those of the control. There were also differences between the treated and untreated plots of every cash crop species. This reveals the role of simple conservation measures on soil losses in the agroforestry system. Among these, trash bunding within the maize and upland rice plots protects the land less than contour ridging of root crop plots. Soil losses from trash bunding were greater than those from contour ridging. By year, less soil losses were obtained in 1983. This could be the effect of closing tree canopies that protected the land against direct splashing by intercepting rainfall, which lessened runoff and soil losses. Soil losses from the agroforestry plots resulted mainly from the early storms before the exposed soil was covered with crops after which, soil losses decreased.

Contour ridging appears to be the most appropriate conservation measure for the highland agroforestry system when compared to trash bunding or contour cropping. Soil losses from agroforestry plots both with and without conservation measures averaged one-half to one-fifth of the bench terraced farming, or 1/4 to 1/50 of the normal swiddening (Table 3). Agroforestry practices protect land

Table 3. Soil loss from agroforestry and normal tree plantation plots (tons/ha).

Year	Check	Maize		Upland Rice		Taro		Sweet Potato		Ginger	
		A[1]	B[2]	A	B	A	B	A	B	A	B
1982	0.43	3.85	4.50	3.75	4.40	1.50	2.95	1.55	2.65	1.25	2.65
1983	0.41	2.50	2.95	2.40	3.85	1.05	1.80	1.10	1.95	0.95	1.45
Average	0.42	3.175	3.725	3.075	4.125	1.275	2.375	1.325	2.30	1.10	2.05

[1]With simple conservation measures.

[2]Without any conservation measures.

from erosion more effectively than normal swiddening. Agroforestry with simple conservation measures reduces soil loss significantly different from nonconservation practices.

CONCLUSIONS AND RECOMMENDATIONS

Grain crops (maize and upland rice) and root crops (taro, sweet potato, and ginger) were planted under forest trees with some conservation measures – trash bunding for the grain crops and contour ridging for the root crops. Three-year data on tree diameters and total tree heights and two-year data on soil losses were used for analysis, arriving at the following conclusions:

1. The grain crop yields are promising only within the first two years. Appropriate period for simultaneous cropping under the agroforestry system should not exceed two years.

2. The root crops, which are normally the more shade-tolerant species, gave satisfactory yields within the first three years after forest plantation establishment. The period of simultaneous cropping with root crops should be limited to only three years.

3. Appropriate conservation measures for highland agroforestry, without any additional inputs, should be contour ridging. This measure favorably affects tree growths, soil protection, and crop yields.

4. Soil-depleting crop species such as maize should not be introduced into agroforestry plantation. These species appear to compete seriously with forest trees for plant nutrients and soil moisture and contribute nothing to tree growth. However, intercropping with such crops may protect the plantation from forest fires.

5. Shade-tolerant root crops appear suitable for agroforestry systems, because they grow competitively with forest trees and produce satisfactory yields within the first three years of forest plantation.

6. For long lasting simultaneous land use for wood and food production, other permanent tree crops such as coffee, tea, and fruit trees may be introduced.

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FARMING IN A MOUNTAIN FOREST WATERSHED IN TAIWAN: ITS IMPACTS ON EROSION, RESERVOIR SEDIMENTATION, AND POLLUTION

by

Pao-chang Kuo[1]

ABSTRACT

Mountain watersheds are not recommended for intensive farming because of erosion problems associated with the accompanying crops' cultural practices. Vegetable and fruit farming in the De-chi watershed has caused accelerated sheet erosion and consequently shortened the reservoir's service life and polluted its water. Fruit tree farming, however, caused less erosion than vegetable farming.

INTRODUCTION

Two-thirds of Taiwan's total land area are mountainous where important watersheds are located. More than thirty dams have been constructed in these areas to supply water for irrigation, hydropower, industrial, and municipal uses. Development of mountain areas is now the major target of the government.

The De-chi Reservoir Watershed is a typical example of a mountain area where the development of land and water resources is being undertaken. Its climate is suitable for growing temperate fruits and highland vegetables for summer consumption, which greatly contribute to the local economy. The watershed is a major part of a hydroelectric program being developed by the Taiwan Power Company. The control of reservoir sedimentation is then a key concern of watershed management. This paper presents the experience of mountain farming in this watershed with its impacts on erosion and sedimentation and the ensuing pollution problems of the reservoir.

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[1]Professor of Silviculture, Department of Forestry, National Taiwan University, Taipei, Taiwan, Republic of China.

THE DE-CHI RESERVOIR WATERSHED

The watershed, with an area of 532 km^2, is located in the northern center of Taiwan near the upstream of the Tachia-chi River basin. The Tachia-chi River is 140 km long with a total drainage area of 1235 km^2. Ninety percent of the region is mountainous. Forest covers 93 percent of De-chi watershed. The forest type varies with elevation: hardwoods grow on elevations of less than 1500 m and conifers are on higher levels. Ninety-five percent of the forest is maintained for conservation purposes. Logging is prohibited. Reforestation and fire prevention are part of a forest management program.

The average slope of the watershed is 60 percent. The annual mean temperature is 15°C with a miminum of −10°C. Annual precipitation is 2434 mm, and the number of rainy days is approximately 140 per year. Soil layer is shallow. Agricultural lands are at elevations 1000-2500 m and are regionalized by elevation.

1. The low elevation region (1000-2000 m) includes reservation lands, such as the Wu-ling Farm that produces peaches, pears, and some vegetables.
2. The high elevation region (2000-2500 m) includes the Lishan area and the Fu-show Shan Farm that produce apples, highland vegetables, and tea.

The publicly-owned Taiwan Power Company operates a US$15 billion multipurpose project in Tachia-chi basin. De-chi has the largest dam in the basin that is capable of storing 175 million m^3 of water. The project supplies water for irrigating 8000 ha of farms and 880 ha of industrial lands. It also supplies water for 2 million people; serves as a recreation site for 200,000 people yearly, and controls floods.

Illegal cultivation of forest areas is a problem. Squatters in these areas grow highly profitable fruit trees. The watershed's residential community at Lishan is a fruit- and vegetable-growing center and a stopover for many tourists. A cross-island highway passes through the watershed. Due to road construction and illegal cultivation of forest areas, accelerated erosion has increased the sedimentation rate of the reservoir. A sizable portion of the national forest has been illegally occupied and cultivated since the completion of the highway. For socioeconomic reasons, the government legalized the growing of fruit trees on cleared forest lands with slopes less than 55 percent. Cultivated lands with slopes greater than 55 percent are returned to the Forestry Bureau for reforestation.

In 1983, the area of forest land leased for fruitfarming was 724 ha (about 16 percent of the total agricultural land area of 4,483 ha). Sixty-nine percent of this area is used for growing fruit trees; 1 percent (48 ha) for vegetable production; 2 percent (68 ha) for mixed fruit-vegetable farming; and 12 ha for tea plantation.

Intercropping vegetables between rows of young fruit trees is often practiced to obtain quick returns while waiting for the trees to produce. The important vegetable crops intercropped with apple or pear are cabbage, Chinese cabbage, spinach, kidney bean, radish, and potato. Vegetables are generally grown on relatively flat or gently sloping lands near the streams, but some farms are located on elevations as high as 2500 m. Growing season is from June to November. Vegetable production is more expensive than fruit farming due to higher labor inputs, but the returns are two to three times greater.

In recent years, the depressed market prices of pears and apples caused many less efficient fruit growers to switch to vegetable production for higher profits. Fruit farming is mainly located along the highway and banks of the Tachia-chi River, which conveniently favor farm management and product transport. Fruit trees normally start to bear fruits five to six years after planting and are most productive when they are 10-15 years old.

Intercropping vegetables with fruit trees has disadvantages. Vegetable crops normally require periodic applications of pesticide. Such operation often wets the apple foliage and makes the application of apple-compatible pesticides to apple trees very difficult. Apples then become susceptible to disease infection, which significantly decreases the apple yield.

MOUNTAIN FARMING AND SOIL LOSS

Mountain watershed forests in Taiwan have been frequently reclassified legally or illegally for agricultural uses because of population demands. This is the case of the De-chi watershed where land pressure is great. Some farms practice some conservation measures to control soil erosion. By 1983, more than 30 percent of fruit tree farms constructed terraces or rock walls for erosion control.

Seventy percent of the farms employed grass cover. However, a number of farms have not employed any soil conservation measures. About US$5,000/ha is needed to ensure a good soil conservation work, which is beyond the means of many farmers.

Cover grass such as rye grass (*Lolium peronne*), white clover (*Trifolium repens*), and kikuyu grass (*Pennisetum clandestinus*) have been extensively planted on the orchards. Generally, no weeding is needed in grass-covered orchards. However, occasional mowing is done to reduce grass competition with fruit trees. Orchards with grass covers showed good results on erosion control. Because grass cover and ditch construction are not applicable on vegetable farms, erosion is serious in these areas.

The removal of topsoil by sheet erosion is the most serious problem related to mountain farming. In the De-chi watershed, most fruit trees and vegetables are grown on areas along the highway and around the reservoir. Great amounts of eroded soil have been washed into the reservoir. Erosion from vegetables fields is greater than from fruit farms. Vegetable cropping during summer brings more erosion problems because it coincides with the heavy rainfall and typhoon period.

Data compiled in the De-chi watershed in 1984 indicated that annual soil loss is 6.89 mm. The average soil loss in Taiwan is 5-10 mm annually; the heaviest is 25 mm from a badly denuded watershed. Comparing these figures, soil erosion in this watershed does not seem very serious.

In 1983, the estimated annual sediment in the De-chi Reservoir was 1242 million m^3. Sedimentation analysis showed a 68 percent suspension load and a 32 percent bedload, indicating that sediments are mostly small particles coming from sheet erosion caused mainly by the cultivation of steep mountain lands.

MOUNTAIN FARMING AND WATER POLLUTION

One of the major functions of the De-chi Reservoir is to supply water for municipal, industrial and agricultural purposes in the lowlands of the Tai chia-chi basin. Thus, safeguarding the water quality is essential to protect water users. Water quality is generally determined by natural factors (geology, soil and climate characteristics) and man-made factors (accelerated soil erosion and application of pesticide on farms).

Farming is a major cause of water pollution in the watershed. Surface runoff degrades water quality. In addition, farmers use more than 20 different types of pesticides to control plant diseases and insects. Fungicides (98 percent) are applied more often than insecticides (2 percent). From March to June, farmers spray their crops about 12-18 times at a rate of 30 kg of chemicals per hectare. About 100 tons of pesticides (mostly heterocyclic nitrogen compounds and dithiocarbamate) are being used annually for various horticultural practices in the entire watershed. This amount is 10 percent of the total pesticides used in Taiwan. The application of herbicides is prohibited to protect water quality.

A recent study by Ding and Chen (1981b) indicates that the results of chemical analyses of the water samples collected from the De-chi Reservoir and the Shih-kang Reservoir (a downstream water-storing dam) showed the presence of primary hydrocompounds of chlorobenzilate and kelthane. The study pointed that there is a limited water pollution by pesticide application because fruit farms are scattered over a wide area and are in small patches. Trees growing on buffer zones could absorb some pollutants and prevent them from moving into the streams and reservoir (Ding and Chen, 1979, 1981a).

Sound soil conservation practice could also reduce the surface runoff carrying pollutants down into the streams. Chung and Yen (1985) made a thorough investigation of the physical, chemical, and biological properties of water samples collected from various locations over the watershed. The study concluded that water quality had not been seriously degraded by indiscriminate cultivation and other land uses and that the water quality was still quite acceptable. On the other hand, water samples collected from streams near residential communities and inlets of the reservoir showed relatively higher levels of turbidity, dissolved oxygen, biological oxygen demand, total coliform bacteria, and fecal coliform bacteria. This means that the water is unpotable due to the improper disposal of sewage and excreta from the communities near the reservoir.

Vegetable cultivation usually requires more insecticides than fruit tree farming. Vegetable farms would therefore be more responsible for the degradation of water quality than fruit farms.

CONCLUSIONS

Fruit tree and vegetable farming on the De-chi watershed has accelerated sheet erosion and degraded the reservoir's water quality. Mountain watersheds are not recommended for farming because of erosion problems associated with agricultural activities. Dils (1978) suggested that production maximization on mountainous land is not feasible from the agronomic and conservation standpoints. Hence, the practice of mountain farming in the De-chi watershed should be reassessed.

Immediate and long-term solutions to mountain farming problems in the De-chi Reservoir water shed are available. Conservation measures for fruit tree farms on gentle slopes should be strengthened. Since tree farms cause less erosion than vegetable farms, vegetable farming in the watershed should not be allowed (Williams, 1979). Farming on lands having slopes greater than 55 percent should also be prohibited and, instead, should be reforested. Pesticide application should be carefully regulated. To ensure a sound water resources management program, any decision on watershed land use should be made carefully based on the findings of economic and ecological evaluations.

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SOIL NUTRIENT CHANGES UNDER VARIOUS UPLAND CROPPING SYSTEMS IN NEGROS ORIENTAL PROVINCE, PHILIPPINES

by

Rowe V. Cadelina[1]

ABSTRACT

Nutrient levels of soil samples from selected upland farms under various cropping systems and lengths of cultivation were analyzed. Farms with trees have higher levels of available macronutrients such as nitrogen, potassium, and calcium but with lower levels of phosphorus than farms without trees. Available amounts of micronutrients such as boron, molybdenum, and manganese are higher on farms with trees. Multicropping and monorotational cropping with trees have consistently produced higher nutrient levels than cropping without trees in all lengths of cultivation periods.

INTRODUCTION

Farmers recognize that methods of farm cultivation and the kinds of crops grown affect soil fertility levels. This is an argument for using appropriate farming techniques and against the application of commercial chemical fertilizers and pesticides.

This paper analyzes the soil nutrient variations under various cropping practices with length of cultivation period and tree component of the farm as independent variables. It shows also the protective and ameliorative functions of agroforestry for sustainable soil condition.

[1]Director, University Research Center, Silliman University, Dumaguete City, Negros Oriental, Philippines.

METHODS

Soil samples were taken from 32 farm plots surveyed in 1983. Four soil sample trials were taken from each plot. The farms were then categorized based on four cropping systems: multicropping (with and without trees) and monorotational cropping (with and without trees). The farms using multicropping system with tree crops are characterized by the presence of few tree stands randomly spread all over the plot. If 20 percent or more of the total farm area is covered with tree canopy, it is categorized as multicropping with trees; otherwise, it is classified as a farm with multicropping system without trees. The trees include jackfruit, avocado, coffee, cacao, coconut, *Leucaena*, and others that are close to the edge of the forest. The diversified crops include root crops, vegetables, and cereals.

The monorotational cropping system characterizes the farms that are planted to a single crop at any one time. It is monocropping characterized by crop rotation. As in the multicropping system, the total area of the tree canopy is also measured to indicate the extent of the planted trees on the farm: If less than 20 percent of the farm area is covered by tree crowns, it is considered as farm without trees and vice versa.

The farmers were also asked to estimate the length of time the farm had continuously been cultivated. The estimation started from the time the area was cleared from a primary forest to the time when the soil sample was taken. Other information gathered in the survey includes household labor, area of farm, and slopes of the plots.

A year after the first soil sampling, ten subsample plots from the original were resampled to determine changes in the nutritional values of the soil. The data basically showed no change, indicating that perhaps a one-year period is not long enough to bring about changes in the soil nutritive characteristics.

The Study Area

Lake Balinsasayao is located in the central mountain ranges of Negros island, about 25 km northwest of Dumaguete City (Figure 1). Sixty percent of the entire forest cover of the area has been cleared mainly for crop cultivation. The remaining forest cover is dominated by hardwood trees (e.g., *Myrtaceae, Agathis*) and Dipterocarps (Bascug, 1983).

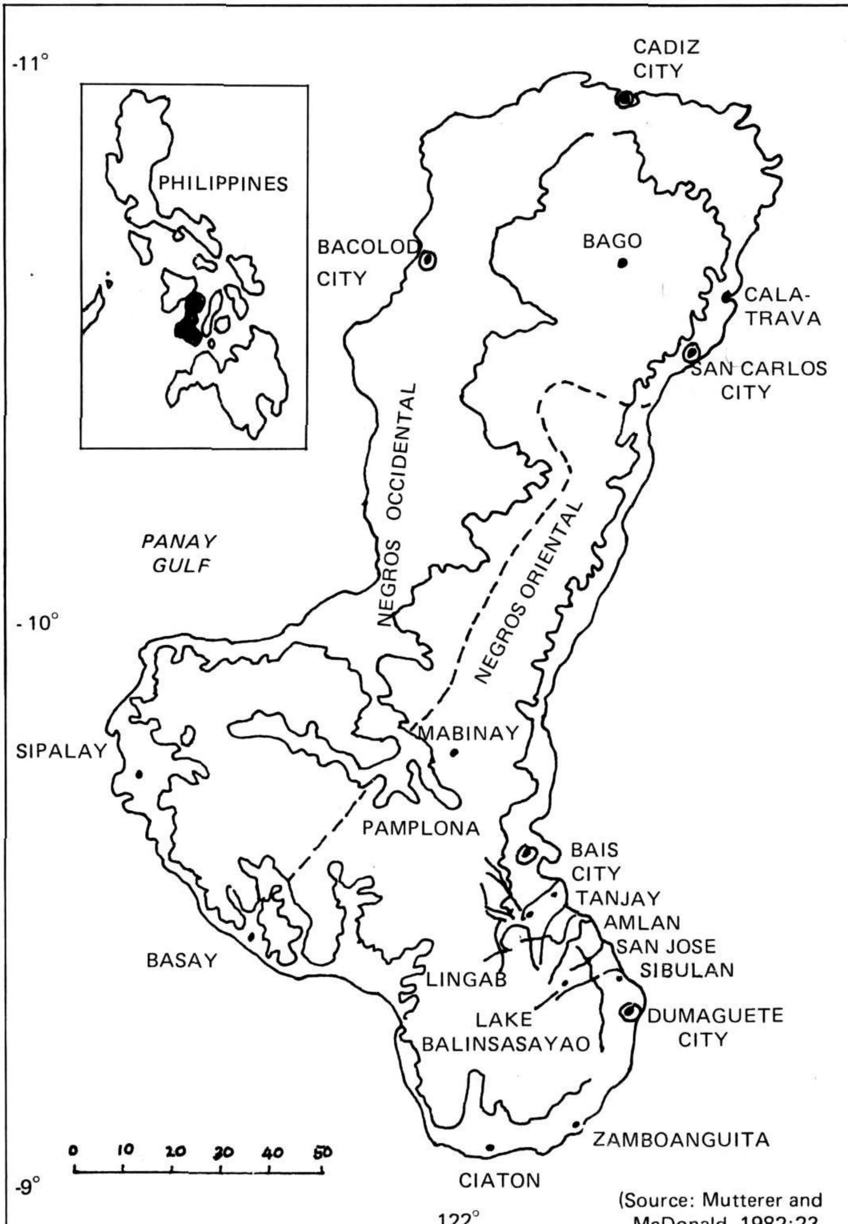


Figure 1. Location map, Lake Balinsasayao, Negros Oriental, Philippines.

Most farms lie on slopes ranging from 10 to 60 degrees. The soils are histosols which range from loamy to clayey. The area is dry from March to June and wet during the rest of the year.

RESULTS AND DISCUSSION

Table 1 shows the distribution of the sample plots according to the length of cultivation and by the cropping system employed on the farm. Table 2 indicates the sample farm households' available labor and plot areas that range from .6 to 1.5 ha with slopes from 18 to 30 degrees. The soil nutrient analysis is centered on the soil pH and the macro- and micronutrient levels.

Soil pH

The pH values of the soils of farms around Lake Balinsasayao were determined to range from 5 to 5.5 (Figure 2). The longer the farm has been cultivated, the more acidic the soil becomes. Of the seven sample farms that had been cultivated for 20 years or more, most of the farm categories yielded a pH of less than 5. This suggests an accumulated acidity of soil as cropping activities continue. On the whole, farms using either multicropping or monorotational (both with trees) yielded a pH value greater than 5 while farms with no trees had less than 5 pH. Farms under monorotational cultivation for the past 20 years showed similar pH values for both with and without trees.

Macronutrient Levels

The levels of four macronutrients (nitrogen, potassium, phosphorus, and calcium) in the soil samples were analyzed. Calcium is usually considered a secondary nutrient, but in some other literature, it is grouped together with the macronutrients.

Nitrogen. Most of the soil's nitrogen are from plants' organic matter. Plant tissues absorb nitrogen (in the form of nitrates), and it is recycled to the ground when these tissues are decomposed. Figure 3 suggests that farms planted to trees maintain a relatively higher level of available nitrogen in the soils than farms without trees. Although it is difficult to test whether the difference is significant due to limited sample cases of farms, the data suggest the ameliorative functions of trees in providing nitrogen in the soil.

Table 1. Number of plots by length of cultivation and cropping system.

Cropping System	Length of Cultivation (years)			Total Number of Plots
	<10	10-19	20>	
Multicropping (without trees)	2	2	2	6
Multicropping (20% or more of plot planted to trees)	7	5	3	15
Monorotational cropping (without trees)	1	1	1	3
Monorotational cropping (20% or more of plot planted to trees)	3	2	1	6
Total	13	10	7	30

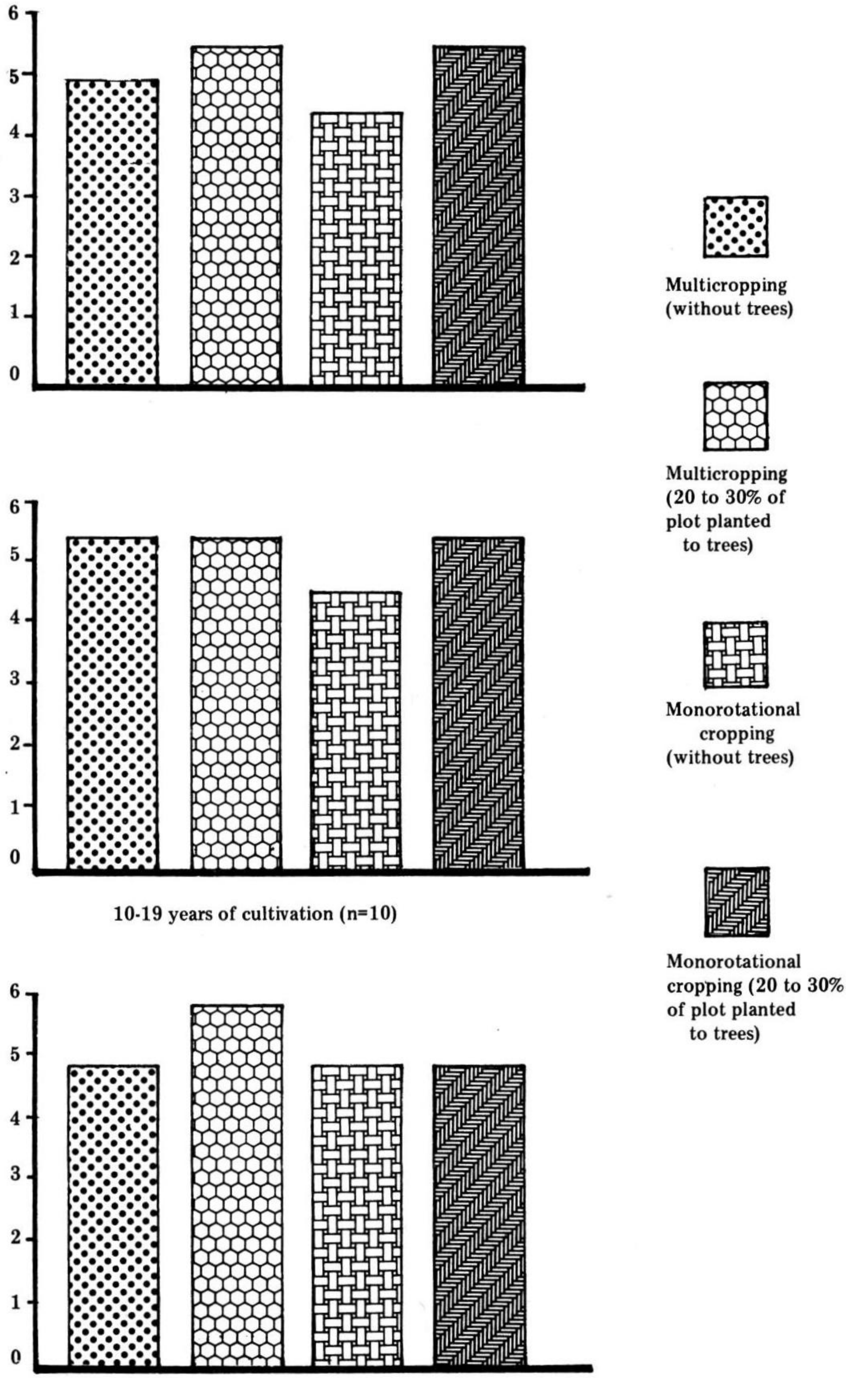
Phosphorus. Figure 4 shows that farms with trees consistently generated lower amount of phosphorus than farms without trees. Such situations may be explained by the peculiar characteristics of the phosphorus in the soils. Unlike some other soil nutrients, phosphorus in soil solution easily reacts with other compounds converting it into a less soluble phosphorus compound. Hence, when the soil samples were taken, these compounds may still have been in the form of less soluble phosphorus compounds. Further investigation is needed to fully explain this phenomenon.

Potassium. Figure 5 shows that sample farms with trees, regardless of the cropping system, produce the highest amounts of available potassium in the soil. Since potassium is very sensitive to leaching, the presence of trees and its root systems may reduce the process and the constant absorption of the readily available potassium by the plants constantly reversed the reactions so that the exchangeable potassium goes into the soil solution again. By having a good amount of standing trees, there will be a constant fixation and release of potassium into the soil (Follett et al., 1981).

Calcium. A large part of the calcium content in plants is located in the leaves. This suggests that plants whose leaves are not transported away from the site but are allowed to mineralize on the site will most likely pump calcium back into the soil. Under the monorotational cropping system, farms with trees yield higher amounts

Table 2. Social and biophysical conditions of sample farms by cropping systems, Lake Balinsasayao, Negros Oriental, Philippines.

Cropping Systems (1)	Average Number of Labor Force in Household of Farmers (2)	Average area of Farm Plot (ha) (3)	Average Slope of Plot (%) (4)	Number of Sample Plot (5)	Number of Soil Sample Trials Per Plot (6)	Total No. of Soil Sample Trials for Sample Plots (Col. 5 x Col 6) (7)
Multicropping (Without trees)	1.5	.60	22.5	6	4	24
Multicropping (20% or more of the plots is planted to trees)	3.9	1.60	25.0	15	4	60
Monorotational cropping (Without trees)	2.7	.60	17.7	3	4	12
Monorotational cropping (20% or more of the plot is planted to trees)	7.8	1.40	30.0	6	4	24
All Farms	4.0	1.05	23.8	30	4	120



20+ years of cultivation (n=7)

Figure 2. Alkalinity (pH) level of soils under various cropping systems and extent of tree cover.

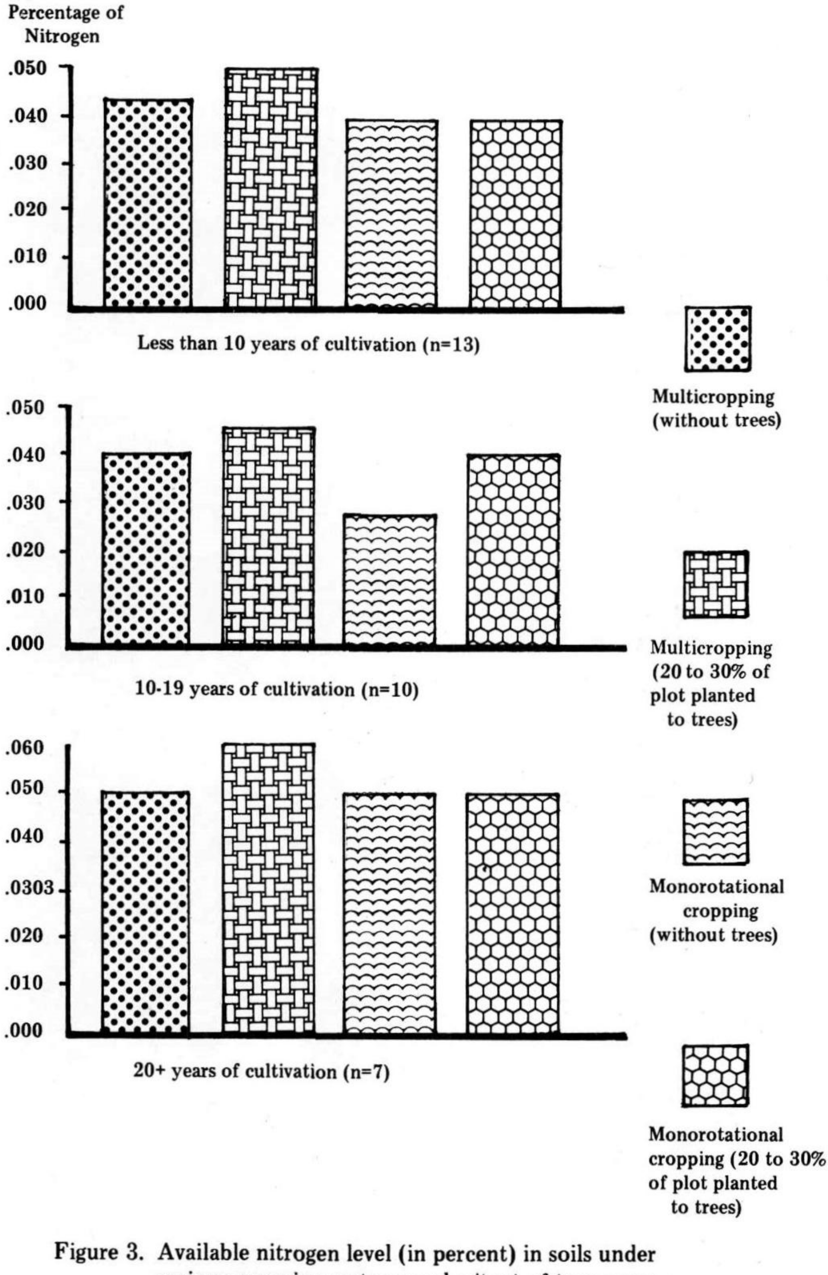


Figure 3. Available nitrogen level (in percent) in soils under various cropping systems and extent of tree cover.

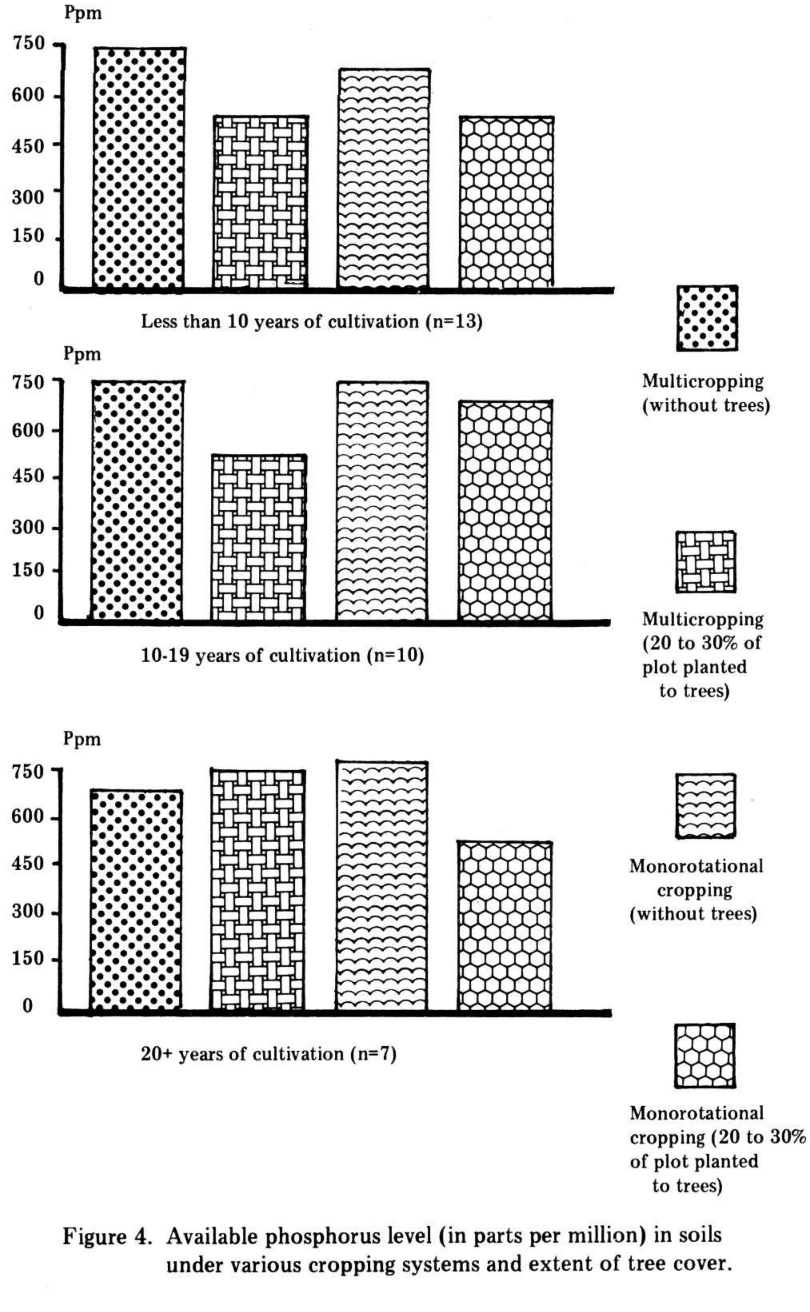


Figure 4. Available phosphorus level (in parts per million) in soils under various cropping systems and extent of tree cover.

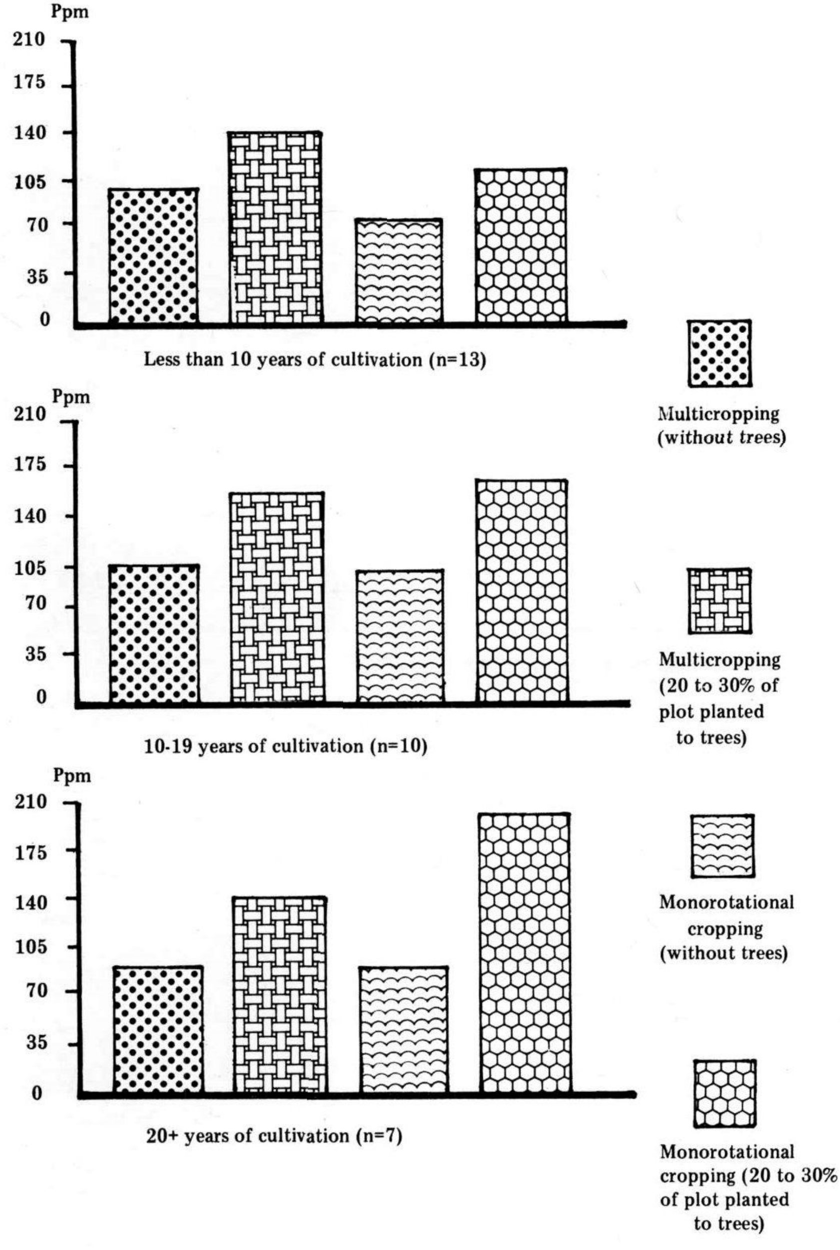


Figure 5. Available potassium level (in parts per million) in soils under various cropping systems and extent of tree cover.

of available calcium in the soil than those without trees. The same trend was observed on farms under the multicropping system (Figure 6).

Micronutrient Levels

Micronutrients generally depend on the nature of the parent material of the soil. Micronutrients tend to be a major limiting factor to plant growth when the following conditions on the farms are taking place: (1) highly leached acid sandy soils, (2) muck soils, (3) soils with very high pH, and (4) soils that have been very intensively cropped and heavily fertilized with macronutrients only (Brady, 1974). Because most of these conditions do not yet exist on the farms around the Lake Balinsasayao area, a fair amount of micronutrients analyzed in the soil samples are boron, molybdenum, and manganese.

Boron. Figure 7 shows that under three different lengths of cultivation period, the farms employing monorotational cropping (with trees) showed higher levels of available boron than the farms without trees. On the other hand, farms using multicropping systems and planted to trees yielded lower boron content than the ones without trees. However, this is only true for farms cultivated for less than 20 years. Multicropping farms cultivated for 20 years or more yielded higher boron supply. This internal inconsistency of data requires more investigation.

Molybdenum. Figure 8 consistently shows that farms planted to trees using either multicropping or monorotational cropping under three different lengths of cultivation produced higher molybdenum supply in the soil. This suggests that litter from tree crops and plants keep soil highly organic, reducing its acidity and consequently keeping molybdenum supply adequate for plants.

Manganese. Figure 9 shows that all the farms having trees under both cropping systems have soils containing higher manganese levels than those without trees.

CONCLUSION

The analysis shows that the behavior of soil nutrients represents high levels of specificity due to the more intricate interaction going on between various exogenous and endogenous factors impinging on the soils of the farms. While the limited sample size involved in the

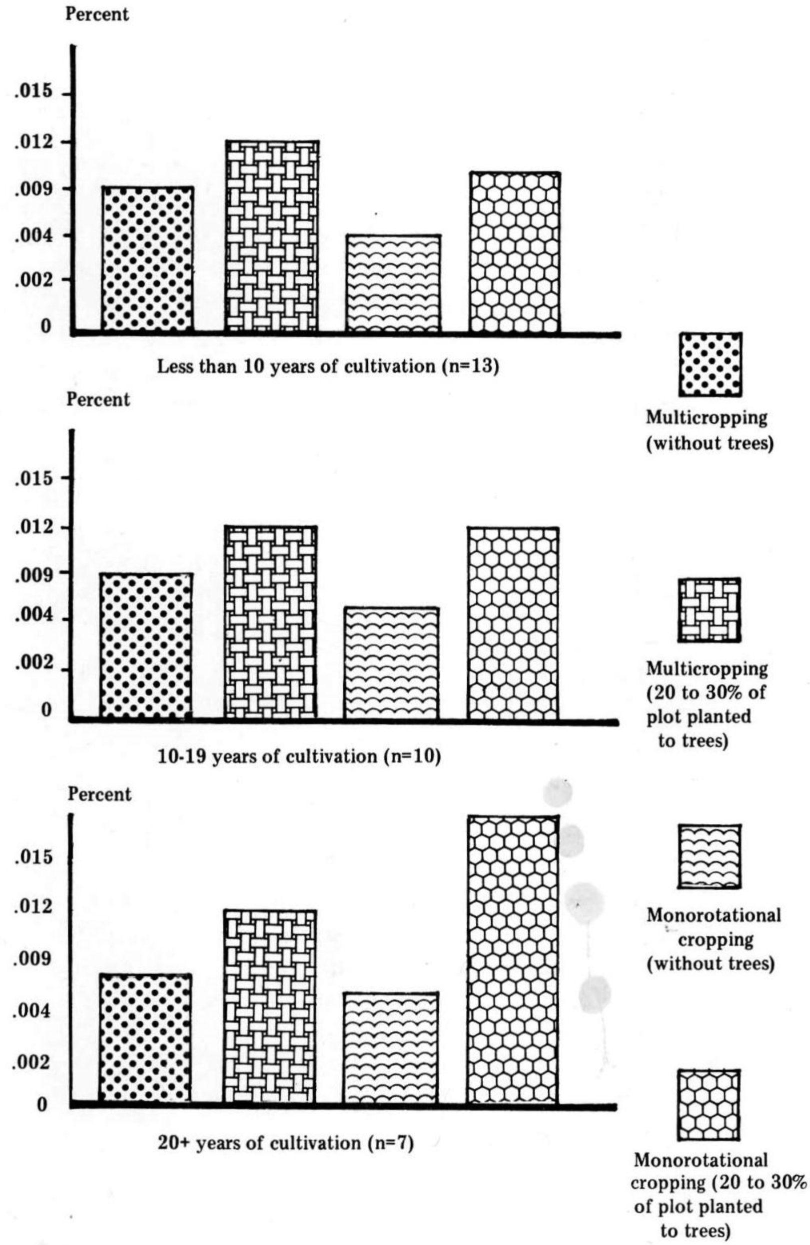


Figure 6. Available calcium level (in percent) in soils under various cropping systems and extent of tree cover.

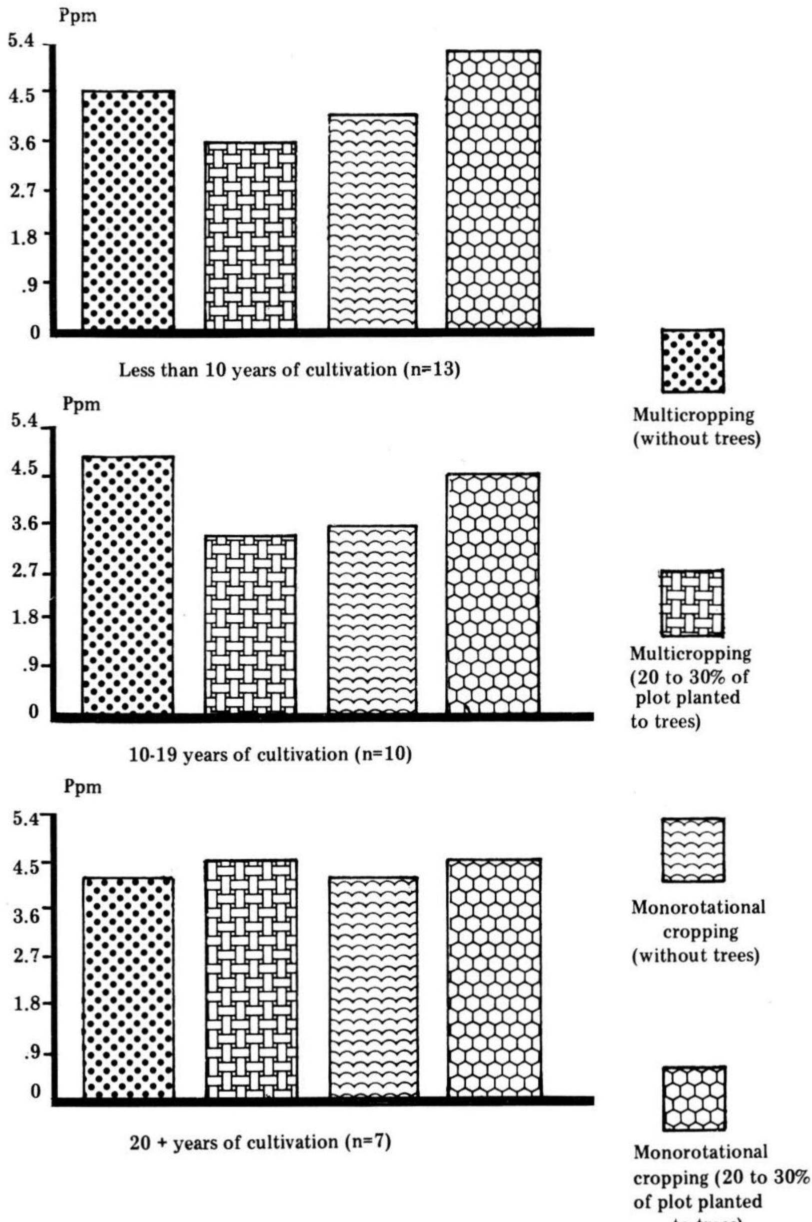


Figure 7. Available boron level (in parts per million) under various cropping systems and extent of tree cover.

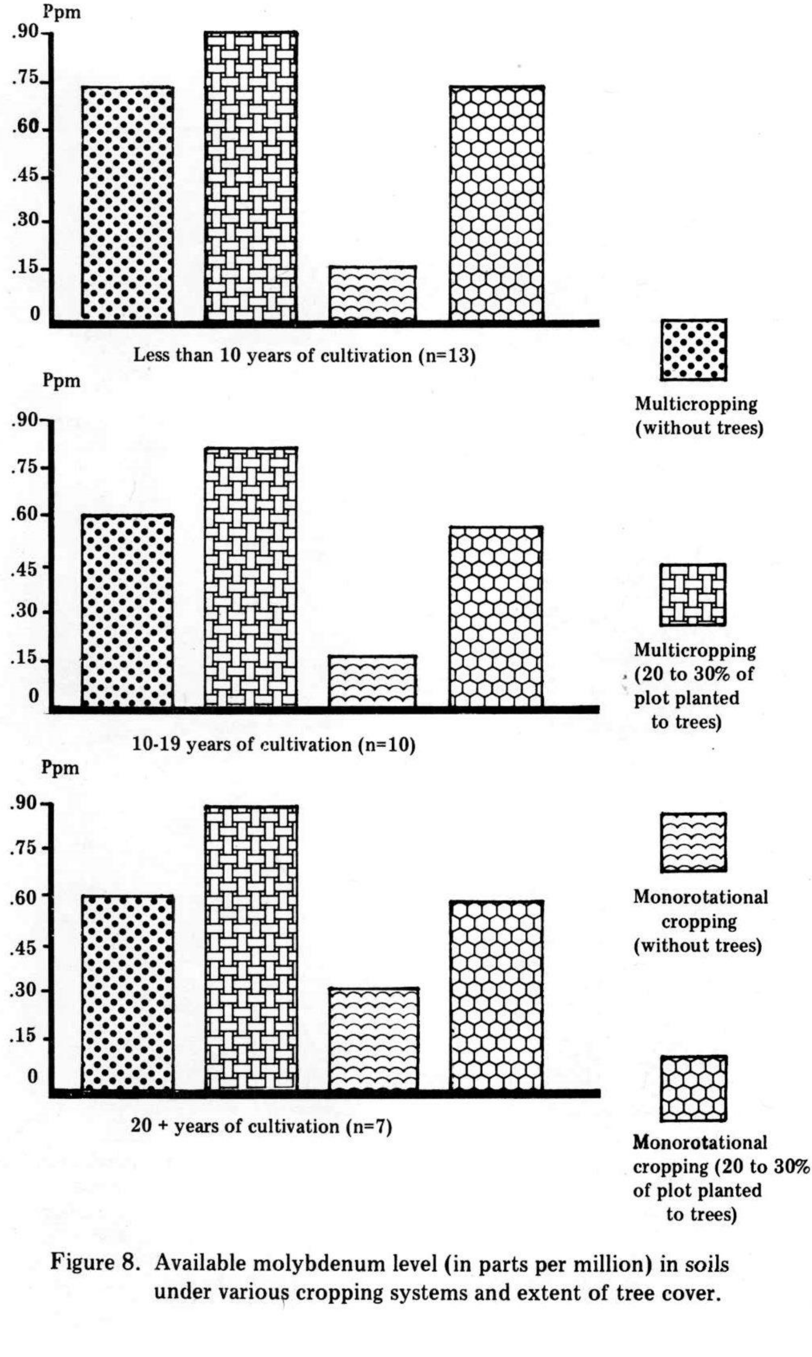


Figure 8. Available molybdenum level (in parts per million) in soils under various cropping systems and extent of tree cover.

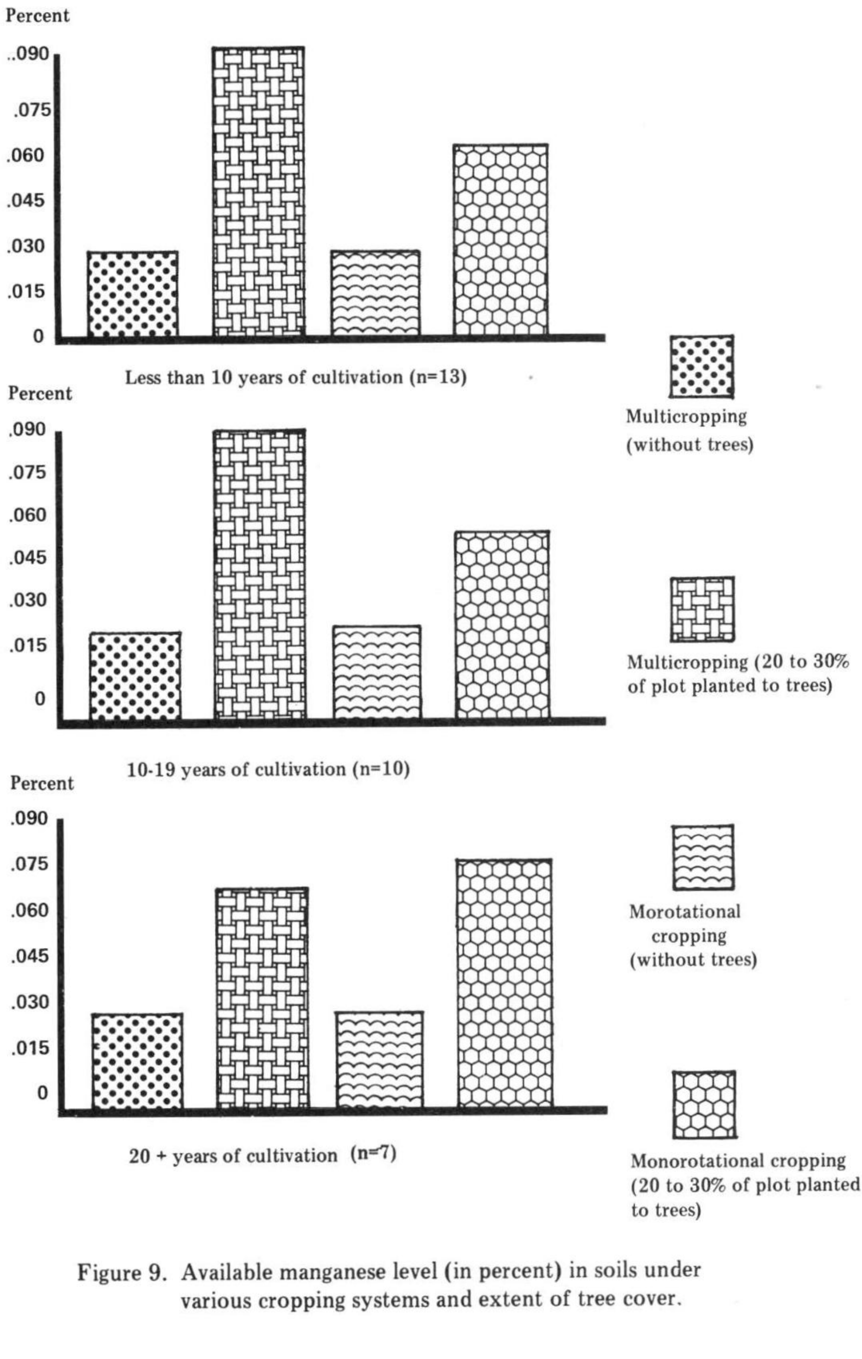


Figure 9. Available manganese level (in percent) in soils under various cropping systems and extent of tree cover.

study makes the data less useful for drawing generalizations, the data themselves provide good indications of the conservative and the ameliorative function of social forestry as a whole on the soil conditions of the farms. The study suggests:

1. a systematic and logitudinal monitoring of soil nutrients be implemented on the following situations:

   a. On farms under various cropping systems and cropping mixtures.

   b. On farms under various degrees of tree cover.

2. a systematic and longitudinal monitoring of production data as proxy information for soil ameliorating functions of social forestry considering that plants and crops react in totality to soil conditions rather than to individualized soil nutrients. Crop performance will, therefore, provide a more comprehensive data base on the nutritive condition of the soil.

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III.

Management Strategies to Enhance Soil Conservation and Productivity

Agroforestry systems normally include annual and perennial crops arranged either spatially or temporally. At times livestock form an important component. These biological elements, together with physical components (land, water, climate), are manipulated, allocated, mixed, and combined in some manner to achieve the farmers' goals of producing food, fodder, green manure, fuelwood, and small timber for local construction on a continuing basis. The range of possible approaches for human manipulation of, and intervention in, the relationships among agroforestry components to attain given objectives are collectively referred to as management strategies.

As in all other undertakings, there exists a wide variety of management options from which the resource manager could select the most appropriate. The selection process is influenced heavily by the goals to be achieved and by the biophysical and socioeconomic conditions obtaining in the locality.

The five papers presented under this section do not pretend to have selected the optimum option in all situations. Rather, they merely illustrate how, under given conditions, certain candidate management approaches have been selected for further testing. It goes without saying that the eventual selection and final adoption of an option will depend on its performance compared with those of the other alternative management strategies.

VEGETATIVE AND TILLAGE STRATEGIES FOR EROSION CONTROL IN NORTHERN THAILAND

by

K.T. Ryan and S. Boonchee[1]

ABSTRACT

Mulching, strip cropping, and reduced tillage are used in various combinations with cereal-legume rotations to suit the range of soil fertility and climatic regions of the uplands of northern Thailand. The use of relay cropping of peanut-pigeon pea and corn-blackbean or other suitable legumes and the use of a live mulch such as stylo showed the best results of preventing soil erosion and maintaining soil fertility. Strip cropping and mulching have decreased the dependence on structural earthworks to control erosion. The use of perennial plants as contour hedgerows was effective for erosion control but reduced the production of interplanted annual crops by occupying 15 to 20 percent of the land that could have been used for crops.

INTRODUCTION

Intensive cultivation of the low and middle terraces of northern Thailand using traditional practices and cropping systems is leading to serious erosion. Coupled with degradation of both soil structure and fertility, this is resulting in an unacceptable decline in production potential.

[1]Soil Conservation Research Advisor and Chief of Technical Section Region 6, respectively, Thai-Australia-World Bank Land Development Project, *Chiang Mai, Thailand.*

The Thai-Australia-World Bank Land Development (TAWLD) Project undertook a research program to select vegetative and tillage strategies that would control both soil erosion and degradation in the northern uplands of Thailand.

From the cropping systems research, crop rotations and relays that maintained or increased production were developed. The soil conservation research developed land managements that combined the advantages of the cropping systems research results with soil conservation practices such as mulching, strip cropping, and reduced tillage.

The project is located in the northern region of Thailand covering an area of about 170,000 km^2. The uplands comprise older alluvial deposits that occur as a series of terraces to about 500 m above sea level. This zone's topography is undulating to hilly and includes dissected erosion terraces. The higher terraces are made up of gravelly red-yellow podzolic (ultisols) and loamy red latosols (alfisols), grading to loamy grey podzolic soils (ultisols) at the lower levels. Most soils are relatively infertile.

Most of the area has a warm, wet season of approximately six months (May-October) with a pronounced bimodal distribution and a cool dry season. The average annual rainfall over the region is about 1200 mm, but there are wide variations within the region ranging from 950 mm in the south to about 1745 mm in the north. Ninety percent or more of the annual rainfall occurs during the wet season. High intensity rain occurs throughout the wet season but is concentrated during the August-September period when rainfall erositivity values also exceed 2000 mt/ha (AIT, 1983).

VEGETATIVE STRATEGIES

The vegetative strategy adopted by the project is using as mulch either crop canopy or crop residue, or a combination of canopy and mulch. Continuous rice cropping leaves the soil prone to erosion. Initially, a peanut-and-rice rotation was tried, but after 10 years it became obvious that this simple rotation was not preventing declines in crop yields. However, this simple rotation had a higher rice yield than monocropping (Buddee, 1985).

Buddee (1985) demonstrated that the increase in rice yield was due to the improved soil conditions after mulching with soybean residue rather than by just an increased nitrogen supply. Pintarak et al. (1982) reported that out of a range of green manure and grain legume crops, blackbean gave the most consistent yield increase of rice in the following year, and multiple cropping systems that used more than one legume showed promise as well.

Peanut followed by mung bean or redbean gave yields of rice approximately 80-100 percent of those following blackbean. Corn/mung bean and corn/redbean systems were most successful when gross returns were evaluated for each system.

Although these cropping systems appeared to be promising, a number of factors limited their usefulness; thus, refinements were considered necessary.

Peanut-mung bean sequential arrangement presents management problems and a relatively high erosion risk. Peanut is harvested in mid- to late August with substantial soil disturbance. In northern Thailand, late August rainfall is highly erosive and peanut harvesting produces high soil loss. Figure 1 illustrates the increase in soil loss following harvest of peanut crop and during sowing and establishment of mung bean crops compared with corn/blackbean. There are slight increases in the distribution of soil loss for corn/blackbean and peanut/pigeon pea relays but they are not as great as the increase for the peanut-mung bean sequential.

If cultivation is needed to control weeds and to plant a second crop, the erosion hazard is increased. Grass weeds, particularly *Digitaria adscendens,* flourish after a peanut crop, and weed control is difficult. Herbicide use is expensive and the second crop may not recover this input expense. By peanut's harvest time, *D. adscendens* has set a large amoung of seed and a later weeding is usually needed. Cultivation to control weeds is difficult and often not possible due to wet conditions during mid- to late August. Any delay in planting the second crop leads to a high failure risk due to dry conditions in October. A drought-resistant relay crop, such as pigeon pea planted well before peanut harvest, has obvious advantages in both crop production and soil conservation.

Second cropping after corn presents fewer weed problems and, if sown without tillage, virtually has no erosion hazard. While sequential cropping is possible, relay intercropping maximizes the use of available moisture and light and minimizes weed and soil erosion problems. The project's research program concentrated on cropping systems embodying these factors (Buddee, 1985).

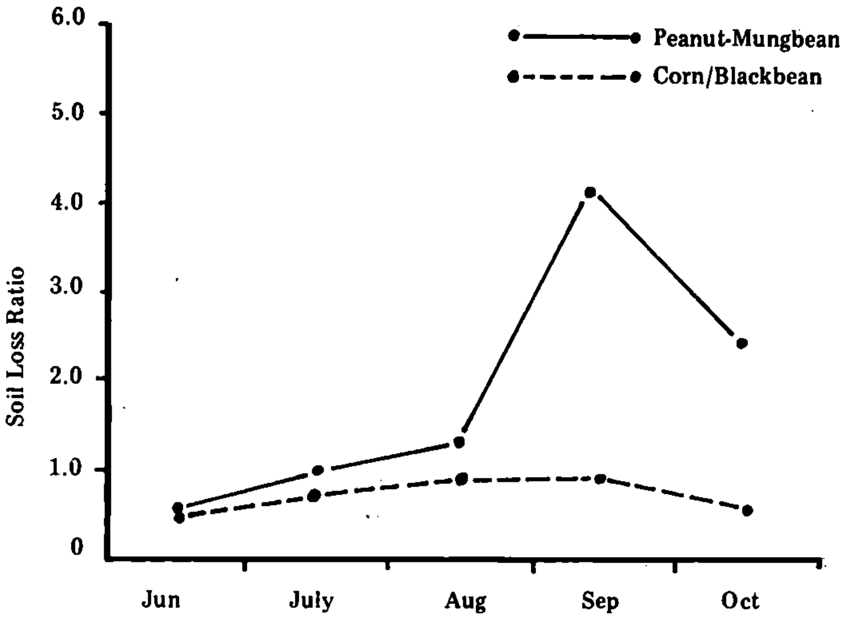

Figure 1. Distribution of ratios of soil loss from peanut-mungbean sequential, and corn/blackbean relay to soil loss from rice. d Data from trials at Hang Chat Station (Buddee, 1985).

Corn/Blackbean Relay Cropping System

Corn is sown on 0.75 m x 0.25 m spacing in May. Blackbean is intersown as a relay crop on 0.75 m x 0.25 m spacing without tillage, 60-70 days later. The influence of planting date on blackbean yield is shown in Table 1.

Yield of rice planted without tillage into trash of the previous year's blackbean was reduced significantly where the trash was less than approximately 300 kg/rai. There was no significant response of rice to 3 kg N/rai applied as ammonium sulphate at maximum tillering. Mung bean is also being tested, although blackbean is clearly superior as a cover crop.

Table 1. Influence of blackbean planting date on yield of blackbean and of a following upland rice crop.

Time of Planting Blackbean	Yield of Blackbean (kg/rai)		Yield of Rice (kg/rai)		
	Bean	Stover	N_0	N_3	Mean
22/6	132 bc	430	222	225	224
7/7	140 bc	1000	204	213	208
22/7	175 abc	760	164	235	199
6/8	135 bc	640	228	203	216
23/8	185 a	480	194	196	195
7/9	110 c	290	191	225	208
22/9	10 d	30	64	91	77
7/10	29 d	40	146	98	121
	DMRT 5%		LSD 5% = 64		
		Mean	177	186	
			LSD 5% = 21		

Source: Buddee (1985).

Peanut/Pigeon Pea Relay Cropping System

Peanut is an important cash crop in the uplands of northern Thailand. A second crop of mung bean or cowpea may be planted after peanut but, as outlined previously, this presents problems of weed control, land preparation, and soil erosion. A relay crop of pigeon pea, sown into the peanut crop at 10-20 days after sowing, has shown promise as a post-peanut cover/cash crop. Pigeon pea produces good yields of grain (100-200 kg/rai) or of forage as well as providing ground cover, weed smother, and mulch for the next season's crop.

Dwarf varieties of pigeon pea do not significantly reduce yields of intercropped mung bean and peanut (Buddee, 1985). However, giant pigeon pea provides better soil cover, higher organic matter production, and better drought resistance than do dwarf cultivars.

Rainfall distributions in northern Thailand are such that planting later than mid-June carries an unacceptable risk of crop failure due to dry conditions in July. Thus peanut or mung bean is planted in mid- to late May and pigeon pea intersown in early to mid-June (approximately 10-20 days later).

Another advantage of pigeon pea is the effect of its mulch on the subsequent corn crop. Under pigeon pea mulch, weed count is lower and emergence of no-tillage sown corn is markedly better than under a weed mulch, which usually follows peanut or mungbean (Table 2). Further work by Buddee (1985) indicated that the increase in yield is due to physical conditions rather than just improved fertility.

Table 2. Emergence and weed numbers after pigeon pea based cropping systems.

Cropping Systems	Corn Establishment per rai	Weed Numbers ($x10^3$/rai)	
		Narrow Leaf	Broad Leaf
Peanut monocrop	7000	309	93
Mung bean monocrop	5000	970	10
Peanut/pigeon pea	9000	160	12
Mung bean/pigeon pea	8300	94	34
Pigeon pea monocrop	7100	83	10
LSD 5%	1600	245	38
1%	2100	337	52

Source: Buddee (1985).

Live Mulch Cropping Systems

Centrosema and stylo grown as ley cover crops have shown increased yields of cereal crops (Pintarak et al., 1982; Jones et al., 1983).

Stylo has been observed not to compete with rice or corn and to establish well post-harvest to give cover similar to that achieved the previous year. This favors stylo as a potential low-cost, self-regenerating, post-harvest cover crop.

Alley Cropping

Alley cropping has been recommended by Kang et al. (1984) as an alternative to the bush fallow system. Advantages of alley cropping include biological recycling of nutrients and soil conservation, suppression of weeds, and rapid production of by-products such as stakes and firewood. The project's research results on alley cropping to date have not been encouraging.

Pintarak and Sawbankam (1982), using *Leucaena leucocephala,* reported that yields of rice, peanut, and sequential mung bean were decreased when grown between rows of *Leucaena,* and attributed the yield decrease to soil moisture competition.

An increase in rice yield was observed but was insignificant, when *Leucaena* cuttings were used as mulch and green manure.

TILLAGE STRATEGIES

The tillage strategy adopted by the TAWLD Project was to minimize soil erosion while maintaining or improving productivity. Techniques that minimize aggregate degradation and maintain soil surface protection have been researched to enable local adoption (Buddee, 1985). These techniques include alternatives to soil conservation contour banks, no-tillage, reduced tillage, and mulching.

Alternatives to Contour Banks

Earthworks used in project areas to reduce soil erosion are costly to build and maintain and occupy about 10-15 percent of usable land. Replacement of alternate contour banks with a grass and *Leucaena* strip was found to be ineffective (Table 3).

Table 3. Runoff and soil loss for land management practices, (3-year average).

Treatment	Runoff (m^3/ha)	Soil Loss (t/ha)
Double-spaced bank	2318	4.3
Single-spaced bank	1706	3.0
Strip cropping	1851	3.3
Single-spaced grass strip	7149	6.6

Source: Buddee (1985).

The use of alternate 10-m strips of cereal and legume (rice and peanut) between double-spaced contour banks is as effective as using normally spaced contour banks. All soil loss figures were quite low, due in part to the use of no-tillage to sow the crops in the third year.

Double-spaced banks with strip cropping reduce the cost of development, increase available cropping area, and facilitate cereal-legume rotation.

Tillage Practices

Tillage is primarily used for seedbed preparation and weed control. However, tillage can cause severe soil degradation and increase the erosion hazard of crop land. In project areas, cultivation amounts to approximately 30 percent of all non-labor inputs for corn and rice. Reducing tillage to one cultivation decreases this percentage to around 17 percent.

Reducing the number of tillage operations from two passes to one pass with the disc plow has decreased the amount of soil loss by 13 percent under peanut and by 29 percent under rice (Figure 2). Runoff is also decreased as the number of cultivations is decreased. Figure 2 shows a runoff reduction of 19% under rice. The reduction, both in soil aggregate degradation and runoff due to greater surface storage, combines to decrease soil loss.

The extra soil moisture and more favorable soil physical conditions have shown a positive effect on both rice and peanut yields. Table 4 presents two-year averages for both crops under different crop managements. Rice yield doubled and peanut yield increased by 15 percent by reducing the cultivations from two to one pass with a disc plow.

Table 4. Average rice and peanut yields from different crop management practices.

Treatment	Rice (t/ha)	Peanut (t/ha)
1 cultivation	0.9	1.5
2 cultivations	0.4	1.3
1 cultivation + mulch	1.6	2.0
No-tillage + mulch	0.8	1.4

Source: Buddee (1985).

No-tillage produces reductions in soil loss in the order of 74 percent for peanut and 78 percent for rice (Figure 2), but unfortunately prolonged no-tillage has produced low crop yields on upland soils due to management problems associated with weed control. The use of cover crops to smother weeds and provide a mulch is considered necessary for the success of no-tillage.

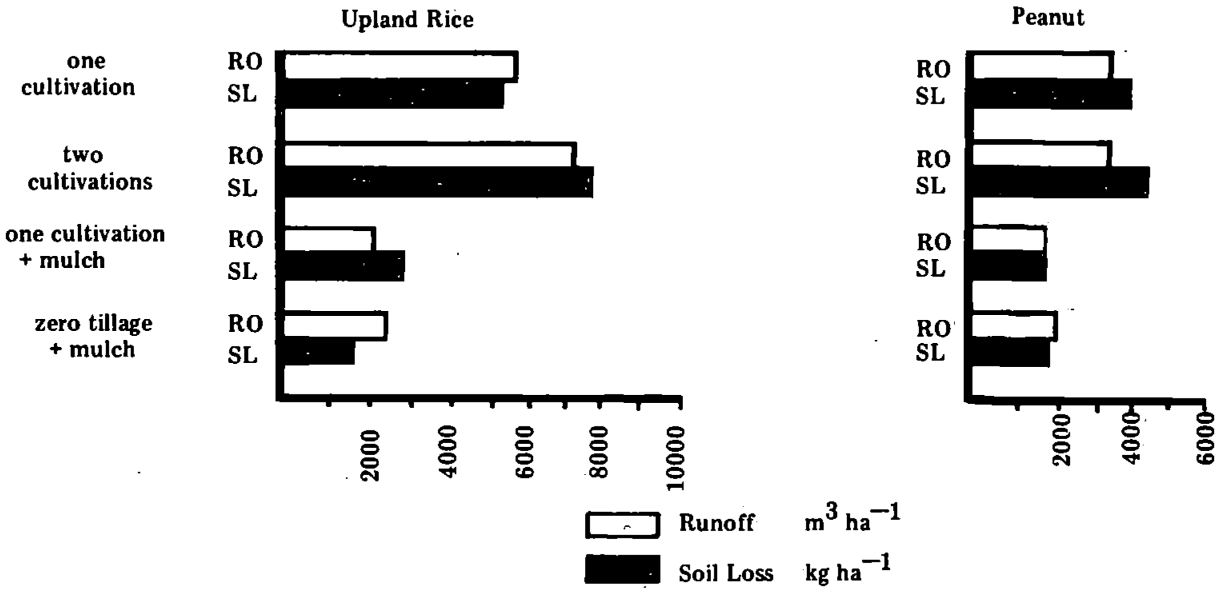

Figure 2. The effect of crop management on soil erosion and runoff for upland rice and peanut (Buddee, 1985).

Figure 2 shows that runoff is reduced by 70 percent for rice and 53 percent for peanuts when single tillage with mulch is used; this practice yielded higher crops than no-tillage (Table 4). No-tillage has shown a marked effect on runoff control for some events, as evidenced by reduced peak discharges and increased flow durations of hydrographs (Buddee, 1985).

Mulch

Soil erosion hazard is greatest when the soil is bare and cultivated. Raindrop impact degrades exposed soil aggregates resulting in increased runoff and soil loss. Surface cover to protect soil from raindrop impact and to reduce soil aggregate degradation and associated runoff and soil loss can be provided by a mulch, either as crop residue or as live cover crops.

The capacity of crops to develop and maintain a canopy and the value of their stover as mulch varies – an important factor in the erosion potential of cropping systems.

Upland rice does not provide sufficient ground cover (3 t dry matter/ha) until 20-30 days after sowing. If the stover is burned or collected for other use, ground cover is inadequate from harvest until 20-30 days into the following wet season. In this period severe erosion can occur. Rice straw at 3 t/ha has shown a reduction of soil loss under rice by 70 percent and under peanut by 60 percent. At 5 t/ha, reductions of 85 percent have been recorded.

Increased moisture retention under mulch results from reduced runoff (increased infiltration) and from the shading effect of mulch (Figure 3). The more favorable moisture conditions and reduction in weed competition are reflected in correspondingly higher yields of rice and peanut with mulch, as shown in Table 4.

THE TOTAL STRATEGY

The need to develop conservation cropping strategies for a range of soil types with varying degrees of structural and nutritional degradation and under different climatic conditions, resulted in combinations of the vegetative and tillage strategies mentioned earlier.

To minimize erosion and contour bank construction, crop rotations should be grown in 10-m wide strips between widely spaced contour banks on all soils.

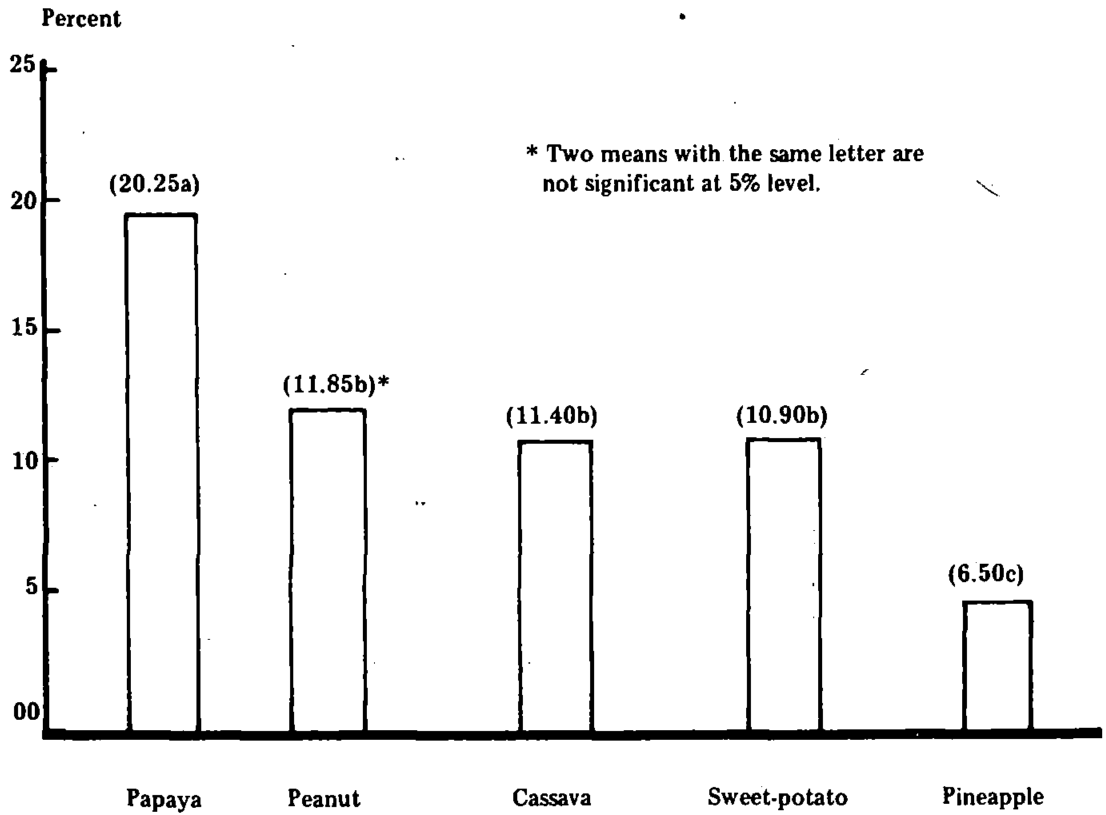

Figure 3. Percent contribution of individual crop to the gross income derived from their market values.

On better soils in areas of more reliable rainfall, corn-based cropping systems are favored. The corn-blackbean relay system, with corn sown with no-tillage into the preceding years' blackbean mulch and the blackbean sown with no-tillage into the blackbean mulch and the rice straw used as a mulch for the no-tillage sown corn, is found to be productive.

On poorer soils, or soils with long histories of cropping, the peanut-pigeon pea system is favored. For acceptable peanut and pigeon pea establishment one cultivation with disc plow, a pre-emergence herbicide to control weeds, and a mulch of rice straw are necessary. The pigeon pea cover crop, sown with no-tillage 10-20 days after sowing the peanuts, should provide the weed cover and mulch to allow a successful no-tillage crop of corn the following year. Blackbean, sown with no-tillage into the corn, should further provide cover and mulch for a following no-tillage upland rice crop. The peanut-pigeon pea combination would then be sown the following year.

On poor soil or degraded land, a stylo ley may be necessary, followed by no-tillage cropping after one or two years. Depending on rainfall patterns, corn, rice, kenaf, or cassava could be planted into the stylo after 2.4-D chemical knockdown. If grasses are present with the stylo, *Roundup* may be used with the 2.4-D. Depending on the extent of soil degradation, a stylo ley may be needed in alternate years. On better soils with more reliable rainfall, cropping each year may be possible with stylo re-establishing after harvest of the crop. In areas of unreliable rainfall, the stylo ley combined with some form of animal production gives a measure of insurance against drought. These crop rotations are shown in Table 5.

Research conducted by the project has established the effectiveness of the first two rotations, i.e., (1) corn/blackbean-upland rice and (2) peanut/pigeon pea-corn/blackbean-upland rice. The stylo-based rotations are the subject of further development.

CONCLUSION

The TAWLD Project aims to prevent soil degradation and improve productivity of the northern uplands of Thailand. By using vegetative and tillage strategies that maximize the period the soil surface is protected, and maximize organic matter addition to the soil and decrease runoff and soil loss, the project is able to achieve these aims.

Table 5. **Promising conservation crop rotations, northern Thailand.**

Soil Fertility	**Good**		**Poor**		**Very Poor**	
Rainfall	**Reliable**	**Unreliable**	**Reliable**	**Unreliable**	**Reliable**	**Unreliable**
Cropping System	**Corn**	**Peanut/Pigeon Pea**	**Peanut/Pigeon Pea**	**Stylo/Crop**[a]	**Stylo/Crop**	**Stylo**[b]
Year 1	Corn/blackbean Lab lab or *Mimosa* *	Peanut/Pigeon pea	Peanut/pigeon pea	Stylo	Stylo	Stylo
Year 2	Upland rice	Corn/blackbean	Corn/blackbean	Crop/stylo	Crop/stylo	Crop/stylo
Year 3	Corn/blackbean	Upland rice	Upland rice	Crop/stylo	Crop/stylo	Stylo
Year 4	Upland rice	Peanut/pigeon pea	Peanut/pigeon pea	Crop/stylo	Crop/stylo	Crop/stylo

a Crops: corn, rice, kenaf, or cassava.

b *Stylosanthes hamata* (a cover crop legume).

* Volunteer cover crop.

Source: *Buddee* (1985).

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TAUNGYA AND SOIL MANAGEMENT DURING THE ESTABLISHMENT PHASE OF FOREST PLANTATIONS IN KERALA, INDIA

by

T. G. Alexander[1]

ABSTRACT

Taungya has been widely used as a low-cost means for establishing forest plantations in Kerala, India. The site shock, including accelerated erosion, generated during the establishment phase by land clearing and preplanting operations can be counteracted though protective and ameliorative measures provided by ground cover. Taungya provides an early soil cover with trees and annual crops badly needed under the highly erosive rains, thus minimizing nutrient loss. However, its effectiveness depends on the nature of crops and cultural practices. Among the common taungya annual crops of rice, tapioca, ginger, turmeric, and sesame, site disturbance is least for rice. A case study involving rice, tapioca, rice-rice, and rice-tapioca sequences reveals that changes in soil properties are minimum under the first crop of rice.

INTRODUCTION

Kerala, which lies in southwest India, has a total land area of 9400 km^2, 24 percent of which is under forest cover. Tree plantations are spread over 1550 km^2. *Tectona grandis* is the major species, whereas *Eucalyptus tereticornis, E. grandis, Bombax ceiba, Ailanthus triphysa,* and *Albizia falcataria* are next in importance (FAO, 1984). Broadly, soils in plantations are Eutric-Dystric Nitosols with associated Ferralsols, Luvisols, and Acrisols (UNESCO, 1977). Plantations are located on level to gently undulating, rolling to hilly, and steeply dissected to mountainous landscapes.

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[1] Scientist-in-Charge, Division of Soil Science, Kerala Forest.

Taungya has been used in establishing forest plantations with no-cost farm labor in Kerala since the 1920s. Experience has shown that this agroforestry and complementary land use is effective in low-input plantation forestry. Taungya is practiced during the first two years where the farmer simultaneously plants tree seedlings and food crops, and undertakes maintenance operations such as weeding, tending, fire protection, and replanting. Where taungya is not practiced (i.e., where only tree seedlings are planted), four to six weedings are carried out as separate and expensive operations during the first two years.

Various aspects of taungya in Kerala and elsewhere have been covered in recent publications (FAO, 1981 and 1984; Halsworth, 1982; King, 1979; MacDonald, 1982; Wiersum, 1982), and Mongi and Huxley (1979) have discussed research strategy for soils with emphasis on the physical, chemical and biological properties in agroforestry systems. Two projects in Kerala Forest Research Institute are being carried out to relate taungya with soil management (Alexander et al., 1980; Alexander and Thomas, 1982). The paper appraises taungya and its site protective and ameliorative roles during the establishment phase in forest plantations.

WHY TAUNGYA

Land clearing and site preparation that bare and disturb the soil subsurface are necessary before seedlings can be planted. Soil loss increases proportionally with the exposed soil surface, as would soil detachment and splash erosion caused by raindrops. Available literature indicates the importance of ground cover in erosion control (Lal, 1984). Before the tree canopy closes, maintenance of vegetative or residue cover on the soil surface is essential. This is the period when taungya with its low-level annual crops fits in ideally. The combination of trees and food crops grown simultaneously provides vegetative cover for effective soil protection. The plant combination not only prevents erosion and loss of nutrients through leaching but also makes an efficient use of land surface, solar energy, and vertical space. Consonant with the current concepts of soil management in the tropics, taungya has also a beneficial role in plantation forestry in the sense that weeding and soil conservation benefit the trees as much as the annual crops (Evans, 1982; Lal, 1984; Lundgren, 1980). However, the type of taungya crops and the nature of cultural practices determine whether the advantages will be vitiated by the great disadvantage of accelerated erosion brought about by soil disturbance in cropping.

TAUNGYA CROPS AND CULTURAL PRACTICES

The following taungya crops are cultivated in Kerala: rice (*Oryza sativa*), tapioca (*Manihot esculenta*), ginger (*Zingiber officinale*), turmeric (*Curcuma longa*), sesame (*Sesamum indicum*), horsegram (*Dolichos biflorus*), and finger millet (*Eleusine coracana*).

Although protective cover can be provided by most crops, soil disturbance varies widely depending on cultural practices. Rice culture involves plowing or raking before sowing with minimum soil cultivation in later periods. Harvesting does not disturb the site, and the stubble as well as residues give good cover to the surface. Cultural practices for sesame and horsegram are somewhat similar to those of rice. In the case of tapioca, mounds of 60-cm diameter and 15 to 30 cm height are constructed preparatory to planting representing a heavy soil disturbance. During harvest, soil loosening occurs once more when the tubers are lifted. Ginger and turmeric are rhizomatous crops grown in raised beds of 80 cm^2 and 10 to 15-cm height. Though green leaves are used for mulching, soil is dug up and loosened during intercultivation and harvesting. Thus, among these annual crops, rice entails the least soil disturbance during the site preparation and harvesting operation.

SOIL CHANGES DURING TAUNGYA CROPPING

Although only rice, horsegram, and finger millet cultivations were originally selected for taungya intercropping, food shortages in the 1940s followed by unprecedented expansion of plantation activities during the 1960s, necessitated the inclusion of erosion-inducing crops such as tapioca and ginger.

The data from a study in six Kerala sites indicated minimal changes of soil properties in rice than in rice-rice, rice-tapioca, and tapioca sequences (Table 1). As two seasons of cropping are unlikely to cause much effect on soil properties, the changes are attributed to disturbances caused by preplanting tillage, intercultivation, and harvesting operations. Field observations and data indicate that erosion is a problem and subsurface horizons show up in most sites. Any generalization based on the data is tentative because the impact of taungya operations upon runoff and soil loss is further influenced by topography, slope, and rainfall.

Table 1. Effect of taungya cropping on soil properties.

Treatment	Month & year of sampling	Sand	Silt	Clay	Organic Carbon	pH in water (20:40)	Exchange acidity	Exchangeable bases
		(.........	....	%.........	.........)		(.........%...	.........)
1	2	3	4	5	6	7	8	9
Rice sequence — 1								
before rice	Feb. 77	71	16	13	1.63	6.2	3.0	17.7
		3.4	1.4	3.1	.31	.3	1.0	2.8
after rice	Nov. 77	73	15	12	1.44	5.1	3.5	15.3
		3.2	1.5	2.3	.24	.2	.4	2.4
Rice sequence — 2								
before rice	Apr. 77	83	11	6	1.99	5.5	3.7	12.2
		1.4	1.1	1.0	.21	.1	.7	3.7
after rice	Nov. 77	81	11	8	1.77	5.1	4.2	10.9
		1.8	1.6	1.4	.25	.2	.7	1.6
Rice-rice sequence — 1								
before rice	Mar. 77	76	11	13	2.01	5.7	5.0	13.4
		7.3	3.4	4.0	.47	.2	1.1	3.7
after first rice	Nov. 77	77	10	13	2.17	4.8	4.6	14.5
		6.0	3.0	3.3	.38	.1	1.1	2.8
after second rice	Dec. 78	73	11	16	2.21	5.8	4.4	14.4
		7.0	3.2	4.0	.47	.1	.7	3.2

Rice-rice sequence – 2								
before rice	Mar. 77	71	17	12	1.64	5.6	3.0	16.6
		9.5	6.7	3.0	.34	.2	1.3	11.8
after first rice	Nov. 77	70	17	13	1.80	5.1	4.2	14.4
		6.0	4.7	1.6	.38	.3	.6	2.7
after second rice	Dec. 78	67	16	17	1.77	5.7	4.4	13.8
		8.0	6.0	2.9	.35	.3	.6	3.0
Rice-tapioca sequence								
before rice	Mar. 77	75	13	12	2.04	5.3	7.6	12.2
		4.4	2.7	2.2	.34	.3	.8	3.0
after rice	Nov. 77	73	14	13	2.28	4.2	8.3	11.1
		1.6	1.6	2.1	.24	.3	1.1	1.7
after tapioca	Apr. 79	70	14	16	2.01	5.7	8.5	8.4
		2.1	1.2	2.5	.34	.2	.8	1.0
Tapioca sequence								
before tapioca	July 77	80	10	10	1.35	5.4	4.6	10.3
		3.9	2.0	2.9	.18	.1	.6	2.8
after tapioca	Oct. 78	75	10	15	1.53	5.6	4.7	9.9
		3.8	1.9	2.5	.30	.3	.9	2.1

Source: Alexander et al., 1980; each value was derived from 12 different stratified samples (0 – 20 cm) taken from 0.4 – 2.0 ha; upper value is the mean and lower value the standard deviation; the methods of analysis were: sand, silt, clay by hydrometer; organic carbon by Walkley-Black; exchange acidity by 0.5 N Barium acetate; and exchangeable bases by 0.1 N Hydrochloric acid.

CONCLUSION

An appraisal of taungya and its site protective-ameliorative roles during plantation establishment indicates that it is an appropriate complementary land-use system. Taungya crops and cultural practices must be selected to minimize runoff and soil loss in plantations. Taungya crops that require minimum tillage should be favored. Erosion-promoting crops such as tapioca, ginger, and turmeric require erosion control measures when used as taungya crops. Conservation-oriented taungya and soil management during the plantation establishment phase are crucial for better and continued productivity in plantations.

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LAND REHABILITATION WITH AGROFORESTRY SYSTEMS IN JAVA, INDONESIA

by

S. Wiradinata and E. Husaeni[1]

ABSTRACT

Land rehabilitation activities are being carried out in eroded forest lands as well as in nonforest areas in Java. Inside forest lands, the *tumpangsari* (intensified taungya), the Ma-Ma project, and others are practiced while in nonforest areas, agroforestry practices are employed. Land rehabilitation inside and outside forest lands is carried out with the joint participation of government agencies and local farmers. The activities are intended to gradually bring about a healthier environment and improve the socioeconomic conditions of rural communities.

INTRODUCTION

Indonesia is a tropical archipelago with a land area of 190.5 million ha and a population of 165 million that grows at the rate of about 2 percent a year. The high population problem is complicated by its uneven distribution. Java, with 6.5 percent of the total land area, is inhabited by almost 110 million people (about 65 percent of the total). Approximately 80 percent of the population is living in the rural areas, 70 percent of which is dependent on agriculture for a livelihood.

Java (including the island of Madura) has a total land area of 13.47 million ha. With 110 million people living on this small, although fertile, island, population density and landownership are major problems. In many rural areas a density approaching 1,000

[1]Both with the Faculty of Forestry, Institut Pertanian Bogor (IPB), Bogor, Jabar, Indonesia.

persons/km^2 is not uncommon. About 37 percent of the farm population is landless. Average landownership is small (0.10-0.20 ha/capita). Consequently, the average income is low.

The extent of eroded and denuded areas, inside and outside forest areas in Indonesia, is approximately 42 million ha and expanding at about 1 million ha annually (DITSI, 1978). The main causes are shifting cultivation, excessive timber exploitation, unwise transmigration schemes, and poor agricultural practices on dry land. Critical lands in Java are estimated at 4 million ha or more than 30 percent of the land area. Studies by Mahbub (1978) showed serious erosion in many watersheds.

Because forest lands are facing pressures from various directions and erosion in many areas is generally severe, attempts at discovering agricultural land-use patterns inside and outside forest boundaries that offer a hope for the future are worthwhile. Besides inappropriate cultivation techniques employed on dry lands, there exist sustainable traditional agricultural practices which lie in the realm of agroforestry. A closer look reveals conditions and problems with wide opportunities for development. Besides, agroforestry can also be applied as remedial measures to enhance land rehabilitation.

BACKGROUND INFORMATION

Soil Erosion and Research in Indonesia

Before World War II, the Forest Service carried out long-range investigations in Java on the influences of forests, more specifically on the hydrological and orological functions of forest cover (Sudarma et al., 1979). With a population of about 30 million at that time, research needs on erosion were not so pressing. Although studies by Coster (1938, 1941) indicated an alarming erosion intensity of 50 t/ha/yr, the situation was still considered under control.

After the war, the rapidly increasing population pressure on land had extended agriculture into steep sloping forest lands. Inappropriate cultivation practices in the rural areas, attributed mainly to ignorance and lack of capital, caused accelerated soil degradation.

Government agencies such as the Soil Research Institute, Forest Research Institute, and universities contributed to soil erosion research. The UNDP/FAO, in cooperation with the Directorate General of Forestry, conducted watershed and soil erosion research in the Upper Bengawan Solo Basin, Central Java. In the 1970s, agroforestry added new dimensions to erosion research.

Magnitude and impacts of erosion. The Soil Research Institute at Bogor developed a land capability appraisal (Harrop, 1974). As shown in Table 1, about 67 percent of lands under Classes VI and VII in Indonesia should be under permanent protection cover. In Java, this percentage should be 50 percent, but Harrop (1974) indicated that the protection cover is only 40 percent. This extent of protection cover in Java is composed of forest lands, 22 percent; estate crops, 4 percent; and gardens, 14 percent. Most of the gardens occupy the flat and gently sloping areas rather than the steep slopes.

Mahbub (1978) gives comparative figures on annual denudation of various watersheds in Indonesia (Table 2). Severe erosion occurs in many watersheds such as the Cacaban subwatershed with 23 mm/yr or 368 t/ha/yr. Muljadi (1981) found that erosion rates of as much as 151 to 421 t/ha/yr occur in several places in Java (Table 3). However, the use of mulch on soybean, bean, and groundnut reduces erosion to a considerable extent (Table 4). John and Van de Goot (1976) reported an erosion rate from 375 to 600 t/ha/yr in the Upper Bengawan Solo Basin during one rainy season. This was the result of experiments on flat to sloping land with light forest cover, sparsely covered with grass, and on bare, uncultivated land.

In the Upper Solo River Basin, McComb and Zakaria (1972) observed a soil loss of 8.6 million tons within a period of five months or an equivalent of 133.4 t/ha/yr. This means that in 20 years, a depth of about 17 cm of soil will be lost. Sudarna et al. (1979) estimated that the average erosion rate in Java was 4.14 mm/yr in 1985 (based on 1938 conditions). In the year 2000, the average soil loss would be 10.4 mm/yr or even higher due to population pressure, dwindling forest resources, and greater demand on land for cultivation, housing, and infrastructure.

Soil Erosion Control Programs

Programs of land rehabilitation inside and outside forest lands in Java began as early as 1961. Large-scale programs of reforestation and greening were launched in 1966. The government has set up a specific program called the "Program Penyelamatan Hutan, Tanah dan Air" or PHTA (program on safeguarding forest, land, and water). The program's coverage is sectoral and regional. It deals with reforestation, afforestation or greening movement (i.e., "penghijaunan"),

Table 1. Distribution of land capability classes for upland crop cultivation in Indonesia showing breakdown by region (000 ha).

Region	Class II		Class III		Class IV		Class V		Class VI		Class VII	
	a*	b**	a	b	a	b	a	b	a	b	a	b
Sumatra	454	1.0	9843	21.5	2577	5.6	12143	26.5	11169	24.4	9587	21.0
Kalimantan	104	0.2	2142	4.0	4265	8.0	8205	15.3	18183	34.0	20561	38.5
Java and Bali	482	3.3	3862	62.4	3021	20.7	–	–	4443	30.4	2803	19.2
Sulawesi	–	–	1561	8.5	1074	6.0	393	2.5	3122	17.0	12162	66.0
Nusa Tenggara	–	–	244	3.5	293	4.2	–	–	2587	36.8	3891	55.5
Irian Jaya	–	–	4012	9.6	5317	12.6	13158	31.3	4520	10.7	15092	35.8
Maluku	–	–	1420	18.0	168	2.1	–	–	1328	16.9	4964	63.0
Indonesia	1040	0.6	23084	18.2	16,715	8.5	33899	10.8	45352	24.3	69060	42.7

* Area (000 ha).

** Percent of regional area.

Explanation: Classes II and III = Suitable for agricultural uses.

Classes IV to VII = Advisable for permanent cover; in case agricultural uses are applied, conservation practices are strongly recommended; Classes VI and VII are for permanent cover only.

Source: Harrop (1974).

Table 2. Erosion intensity in some watersheds in Java.

Watershed/ Subwatershed	Erosion Rate (mm/yr)	Date
Cimanuk:	6.00	1948-1969
Cipeles	3.80	–
Cilutung	9.20	–
Cikeruh and Cirangam	8.60	–
Citanduy:		
Cimuntur	2.90	1973-1974
Cijolang	2.30	–
Cikawung	2.70	–
Ciseel	1.10	–
Citarum, before entering the dam	0.70	1974
Ciliwung	0.10	1964
Cisanggarung	8.00	1974
Pemali-Comal:		
Kabuyutan	7.80	1974
Pemali	7.00	1974
Cacaban	23.00	1974
Rambut	0.42	1949
Comal	7.00	1974
Jratunselana:		
Jragung	2.10	–
Tuntang	2.50	–
Serang	2.50	–
Lusi	1.00	–
Serayu	1.60	1974
Progo	0.70	1971
Oyo	1.70	1971
Solo	1.80	1952-1971
Madiun	1.60	1951-1971
Brantas	0.56	1951-1970
Wampu	0.03	1939-1970
Asahan	0.28	1970-1976
Sekampung	0.87	1973-1976

Source: Mahbub (1978).

Table 3. Annual rates of soil erosion on bare lands in Java.

Location	Soil Type	Slope[b] (%)	Period[c]	Rainfall (mm)	Erosion[a] (t/ha)
Dramaga (West Java)	Oxisol	15-22	1976-77	3797	382
Citayam (West Java)	Ultisol	14	1977-78	2045	421
Putat (Central Java)	Alfisol	9	1975-76	1630	304
Punung (East Java)	Alfisol	10	1975-76	1428	211
Jegu (Central Java)	Vertisol	7	1975-76	1245	151

[a] Maximum erosion tolerance value = 12.5 t/ha/yr.

[b] Length of plot = 22 m.

[c] Rainy season period.

Source: Muljadi (1981).

Table 4. Effects of mulch on soil erosion, Java.

Location	Slope (%)	Rainfall (mm)	Crop	Mulch	Erosion (t/ha)
Citayam (West Java)	14	1117	Bare/no crop	Without mulch	164.2
			Soybean	Without mulch	91.5
			Soybean	Rice straw at 4 t/ha	18.7
			Soybean	Rice straw at 6 t/ha	7.1
			Soybean	Crop waste	15.4-38.9
Citaman	14	546	Bean	Without mulch	64.2
			Bean	Rice straw at 6 t/ha	0.5
		1005	Groundnut	Without mulch	28.4
			Groundnut	Rice straw at 6 t/ha	0.9

Source: Muljadi (1981).

and soil and water conservation practices such as constructing terraces, diversion ditches, gully plugs, contouring, crop rotation, check dams, and fertilizer application.

Independent rehabilitation efforts were started in upper regions outside the forest lands of some watersheds in Java. In the Upper Bengawan Solo watershed, a comprehensive watershed development plan was initiated in 1973. The first phase of the project (a joint effort between UNDP and the Indonesian government), which ended in 1978, was not considered a success due to lack of people's participation. The second phase (1978-84), with its program on watershed management through people's participation and income generation, proved more successful.

In the Citanduy-Cisanggarung watersheds, the demonstration plot (demplot) terracing and more recently the model farm system have been developed with satisfactory results. The program is centered on the sustenance of the environment and the increase of farmers' income through participatory planning, actuating, and monitoring. Impact areas around the demplots have evolved significantly, in many cases up to twentyfold, with minimal government subsidies. In the Konto watershed in East Java, activities are focused on developing a masterplan for watershed development.

In 1974, the state forest enterprise Perum Perhutani started the so-called "prosperity approach" program for inside forest areas as well as adjacent areas. The activities of the program were intended to sustain the environment and at the same time geared toward income generation in rural communities. A variety of undertakings were carried out, such as intensified taungya ("tumpangsari"), beekeeping, planting elephant grass, constructing check dams, and greening movements in villages adjacent to forest lands. In 1982, the PMDH ("Pembinaan Masyarakat Desa Hutan," meaning "guidance of rural communities adjacent to forest lands") program was initiated. The program contained the "prosperity approach" principles and was invigorated with a new basis, that is, the PMDH should be the trigger of a multiplier effect to surrounding villages.

AGROFORESTRY PATTERNS IN REHABILITATION PROJECTS

Four agroforestry patterns are traditionally practiced by Indonesian farmers. They have great potential as strategies for site rehabilitation and maintenance.

The Tropical Mixed Garden

Mixed gardens consist of land around the farmer's house planted to an assortment of vegetables, herbs, and trees such as palms and bamboos. The primary function of the mixed garden is to cushion the impact of hard times (periods of scarcity). In West Java, for instance, about 26 percent of the average family cash income in the rural areas is derived from the mixed garden. Cash income generation from mixed gardens occurs before the rice harvest. During rice harvest time, only 6 percent of such cash receipts are obtained from the mixed garden, because most of the garden products are consumed by the family. The pattern of the mixed garden may differ depending upon natural factors (e.g., location, climate) and cultural, political, psychological, and socioeconomic circumstances.

The mixed garden offers nutritional support (vegetables, edible herbs and fruits), medicinals, and materials for houses and fences. The garden also provides firewood and ornamental plants that give a more pleasant atmosphere. The microclimate around the house is also improved.

Besides the mixed garden, other familiar features near the house are the shed for livestock (such as cattle, sheep, goat, and buffalo) and the fishpond that complete the picture of agroforestry. In West Java the houses in the rural areas are mostly on stilts and the space below offers a convenient shelter for chickens. Fishponds depend on availability of water. During the rainy season a small fishpond may provide a sizable cash income. Revenues from fishponds can be higher and more prolonged with the presence of irrigation.

In terns of temporal arrangements of the mixed garden, the vegetable tubers remain underground during the dry season while banana, papaya, and other fruit trees continue to grow. The spatial arrangement can be considered highly efficient with regard to sunshine and moisture utilization. Under the dominant trees grow other economic plants optimally using available water and light. The multilayered canopy arrangement is also effective in preventing erosion.

The Village Forest

The existence of the village forest (*hutan rakyat*) is not very widespread; it can be found only in West Java. The general feature of a village forest is the large proportion of trees intended to be harvested for their wood, resin, or other forest products and not especially for their fruits. Village forests in West Java are generally located in the vicinity of rural villages. Nearby industrial centers serve as markets and have therefore helped to promote the existence of the village forest. Besides providing cash income from harvested products, the village forest also offers job opportunities for the rural populations.

Village forests in West Java are mostly monocultures of *Albizia falcataria*. *Albizia* provides material for packaging (wooden boxes), building material for houses in the rural areas, lumber for cheap furniture, firewood for rural households, and leaves for fodder and green manure. At the harvestable age of four years the *Albizia* trees can reach a height of 20 m or more with a diameter breast-high (dbh) measuring over 40 cm. In several cases the trees are sold as standing stock, which provides the small farmer with good income. Underneath *Albizia* the leaf-fertilized soil can be planted to cash crops due to the light foliage of the towering trees. Such crops are vegetables, cassava, banana, papaya, and other annuals.

The Village Forest Garden (*Talun*)

The village forest garden or *talun* is usually located at some distance away from the village. The *talun* consists of a piece of secondary forest with or without trees planted for special purposes such as fruit trees, timber, or coffee.

Originally the *talun* was a plot of forest land, the trees of which were cut down under shifting cultivation. After several years of planting dryland rice and other crops, the area is left behind. Generally the *talun* resembles a secondary forest, which, after some years of fallow, may be cleared again for *ladang* (swidden agriculture). In many cases the farmer who owns the plot plants one of the special purpose trees.

Shifting Cultivation (*Ladang*)

In South Banten (West Java) a specific tract of forest land has been designated for *ladang* purposes since preworld war times. A special feature of shifting cultivation as a sustained form of agroforestry still exists in the Baduy area, also in South Banten. The Baduys adhere to dry land farming, while rice fields are considered taboo. Animal husbandry is restricted to keeping chickens.

LAND REHABILITATION

The Greening Movement

The Greening (also referred to as regreening) Movement comprises the rehabilitation efforts on privately owned dry agricultural lands outside forest areas. It is sponsored by the Directorate General of Reforestation and Land Rehabilitation. Greening is of relatively recent origin; two decades ago the first attempts were initiated on a modest scale, gradually extensing into million-dollar projects.

The goal of the Greening Movement is simultaneously of a physical, social, and economic nature. It is intended to improve the standard of living of the rural poor, while checking erosion and enhancing productivity. In Greening three main methods or approaches can be distinguished:

1. *The comprehensive rural development plan,* also known as the Kali Samin (Kali Samin means Samin river, the name of a subwatershed in Central Java) plan, is the result of an intensive study by UNDP from 1972 to 1978 in cooperation with the government of Indonesia. The plan demands large expenditures, in many cases exceeding an average of US$1,500 per hectare.

2. *The demonstration plot method* calls for terracing and tree planting. In terracing, one demonstration plot covering approximately 10 ha is laid out in each appointed location. A similar approach is followed in tree planting. In various areas elephant grass is planted underneath the forest trees for cattle fodder.

3. *Talagasari method* (based on the name of a village in West Java). In contrast to the first two methods, the Talagasari method is not subsidized by the government.

With a total area of 600 ha and a population of approximately 6000 people, Talagasari was a poor village a decade ago. The uphill areas are planted to citronella. Water was not always available in sufficient quantities and wet ricefields yielded one crop annually. The village chief, who is the trigger and leader of rehabilitation using agroforestry, changed all this. Although opposed by their owners, the citronella plantations in the hills were converted into clove and tree crop plantations. After several years water became abundant, making possible two crops of rice annually. Fishponds became widespread and clove trees generated sizable family incomes.

Reforestation

Rehabilitation of eroded land inside forest areas is generally carried out using the taungya method. Taungya in its traditional form is an agroforestry technique of the temporal rotation rather than the spatial type. For about two years farmers plant cash crops while establishing a forest plantation. In its original form, taungya uses no fertilizers and pesticides.

Gradually intensified taungya (in Indonesia called *INMAS tumpangsari*) is applied to increase the agricultural produce. Income derived from the new method can be as high as four times the output from the original taungya (Kartasubrata, 1982). The average total workload for traditional taungya is about 130 man-days/ha and for INMAS tumpangsari, 229 man-days/ha.

The Ma-Ma project (Ma-Ma is the abbreviation for Malang-Magelang, the two forest districts where the activities originally were tried out) provides permanent, improved taungya cultivation for selected farmers. The site of reforestation consists of six strips, each generally 50 m wide, laid out along the contour. The first strip is cultivated with food crops for a duration of five years, while the main (forest) crop – for instance, *Pinus merkusii* – is planted. After five years the farmers move to the next (adjacent) strip, which is cultivated likewise for the next five years. Gradually all strips are reforested, resulting in an unevenly aged plantation with a consecutive five-year difference. At the end of five years at the sixth strip, the reforested areas (strips) would be respectively 30, 25, 20, 15, 10, and 5 years of age. At that time, the first strip can be harvested, after which the strip is again available for reforestation using the taungya system. The Ma-Ma project can be modified according to the rotation of the forest crop: the number of strips or the duration of cultivation at each strip or both may be altered.

The PMDH Program

PMDH is an acronym for a program that means "guidance for rural communities adjacent to forest lands." PMDH aims at increasing the standard of living in the rural areas adjacent to forest land. The efforts for reaching its objectives are varied: beekeeping, planting medicinal herbs, establishing the so-called "living store," containing plants with leaves and fruits of high nutritional value. PMDH also assists the rural people in obtaining credit from local banks. Thus, it can be said that land rehabilitation forms a small part of PMDH activities.

The Inpres Program

Land rehabilitation on privately owned land is financed by the Inpres program (Inpres means presidential instruction) to ensure a smooth cash flow. The program has a dual purpose: ecologically improve the environment and socioeconomically increase farmers' standard of living in the rural areas. A watershed, or a grouping of several watersheds, forms a land rehabilitation unit.

Technically two groups of activities can be distinguished: model farm or demonstration plots on slopes below 50 percent and "agroforestry" on land with 50 percent slope and over. Both are carried out by the farmers who own the land under the guidance of forest extension workers.

Land below 50 percent slope are usually terraced. Four types of terracing are in use, bench terracing being the general feature. Cropping pattern is varied from upland rice to perennials. The mounds of the terraces are usually planted to grass for cattle fodder.

On the "agroforestry" areas (50 percent slope and over) a permanent cover is more dominant, consisting of deep-rooted tree species, the wood of which should preferably be suited for construction, fuelwood, charcoal, packaging, and the leaves may serve as fodder. Nitrogen fixing species are preferred for improving soil fertility. Underneath the trees grass can be planted.

Of great importance are the impact areas surrounding demonstration plots, which are spontaneously converted to agroforestry by the farmers with minimal government subsidies. The extent of these impact areas is in many cases twentyfold to thirtyfold or more, compared to the original 10-ha model farm.

A point worth mentioning is the socioeconomic aspect of land rehabilitation. The inputs per hectare range from $150 to $250, excluding land terracing. From this the farmer may obtain net benefits of $50 to $150 for three to four months of work. Since the average farmer owns less than 0.50 ha, the income derived from his land can still be considered minimal or perhaps below subsistence level for a family of five.

CONCLUSIONS

Soil erosion in Java is caused mainly by excessive population pressure and the ensuing inappropriate cultivation practices on dry lands. The increased demand for land and the population's need to survive create environmental problems that are difficult to overcome.

Land rehabilitation has evolved into million-dollar projects that aim to gradually achieve a healthier environment while improving living standards in the rural areas. The problems encountered are in terms of technical, socioeconomic, and philosophical considerations. Huge efforts by the government with rural community participation offer a hope for the future.

The basic underlying factors which should be considered in attempting to overcome the problems regarding land rehabilitation in Java, are the level of education, poverty, and landownership in the rural areas. In general, rural farmers receive minimal education; many of them are illiterate. The farmer's methods of agricultural cultivation have been handed over to him from generation to generation.

Poverty and landownership are closely related. Because he is poor, the farmer owns only a small piece of land. The reverse is also true. Due to his lack of capital he mainly relies on his muscles. The use of muscles will become more pronounced for the landless farmer. The lack of capital also affects the income the farmer can derive from his agricultural produce. In general, marketing his agricultural yields is done through middlemen. The farmer receives less for his produce than what is actually due him, while he buys his necessities at a price higher than what he can get when he buys them himself. The rural farmer has very little bargaining power.

Cooperatives have the capacity to improve the bargaining position of the rural farmer. The government has been advocating cooperatives for decades. However, due to certain shortcomings, technical as well as managerial, many of the cooperatives proved to be failures. Consequently, the farmer is not too enthusiastic about joining the cooperative, even if it has the potential to improve his livelihood.

We have mentioned how capital from town merchants affects the rural farmer through the use of middlemen. Another feature should also be mentioned, that is, buying up of land by absentee owners living in the cities. In many cases, the rural farmer is compelled to part from his land due to large capital pressures, thus resulting in an increase of landless farmers. In several cases, the rural farmer himself has offered his piece of land for sale, becoming laborers instead of landowners.

Although the mixed garden, the village forest, and the village-forest-garden are ecologically sound, marketing the products remains a problem due to the underlying factors mentioned above. Innovations of cultivation methods are generally few and progress is slow.

Many rural farmers, if not most of them, have not been touched by the introduction of high-yielding tree varieties. Improvement is occurring, although the pace is not fast enough. INTAP (intensification of homegardens) has been successful in many areas to make fuller use of the homeyard by introducing what is called the living store (by planting various vegetables and edible herbs) and the living pharmacy (by planting medicinal herbs). The basic problem of marketing, however, remains unsolved. Alleviating poverty in the rural areas remains a problem.

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GOAT RAISING IN A PINE FOREST: A CASE OF A VIABLE AGROFORESTRY SYSTEM

by

Samuel R. Peñafiel and Vicente P. Veracion[1]

ABSTRACT

Goat integration for cash income in a Benguet pine (*Pinus insularis*) forest was investigated. A stocking rate of four goats/ha hectare did not cause significant soil loss nor disturbance on soil bulk density, compaction, and infiltration rates. Thinning or reducing crown density of the pine stands increased tree growth as well as forage production. Goat weight gains were impressive, which averaged 99 to 129 g/day. Benguet pine-goat combination shows an ecologically and economically viable farming practice for the forest dwellers.

INTRODUCTION

The only commercial natural stands of *Pinus insularis* Endl. (syn *P. kesiya* Roye ex Gordon) in the Philippines are found in the central Cordillera Mountain ranges of northern Luzon where the climate is cool, with temperatures ranging from 10 to 20 degrees centigrage. The pine forest dominates the watersheds of 3 important river systems: Agno, Abra, and Chico Rivers. These watersheds are the sites of several development projects that serve the agricultural and industrial needs of the outlying regions. Due to excessive land pressures, management of these watersheds has been difficult. Communities exist in the watersheds and the inhabitants claim ownership of the areas as tribal and ancestral lands. Mountain slopes have been cleared and cropped. Government reforestation and conservation

[1]Senior Science Research Specialist and Research Center Director, respectively. West Central Luzon Forest Research Center, Forest Research Institute, Loakan Road, Baguio City, Philippines.

programs were met with skepticism by the inhabitants, hence, the support for such programs has been minimal. Consequently, the relationship between the forest dwellers and forestry workers was at times acrimonious.

One strategy that is being evolved to benefit the inhabitants while helping the government in conservation and management is the integration of animal and forest crop production. The use of goats in a tree-animal agroforestry concept has been started. Goat is an important component of small farm systems in the Philippines. It has high fertility and short generation interval. Although a small-sized animal, it is highly resistant to pests and diseases and is relatively inexpensive to stock.

The following discussion presents the results of a study designed to determine the effect of goat grazing in a 15-year-old second growth natural Benguet pine stand with different densities. Other parameters include surface runoff, soil loss through erosion, infiltration, soil compaction, changes in some soil physical and chemical properties, tree growth, weight gain of grazing animal, understory forage production and vegetation, and injuries to regeneration.

MATERIALS AND METHODS

The Study Area

The study area is a part of a 15-year-old second growth natural *Pinus insularis* stand located in Loakan, Baguio City. The forest stand was previously thinned for an earlier study to stocking density ranging from 176 to 688 trees/ha (Veracion, 1982). The understory is dominated by grass-herbaceous species such as *Themeda triandra, Ischaemum polystachyon, Imperata cylindrica,* and *Gleichenia hirta.*

The site is dry from November to April and rainy during the rest of the year. The mean annual rainfall is 3415 mm, 85 percent of which falls in July and August. The average atmospheric temperature is 20.4°C and the relative humidity is 83 percent. The elevation of the experimental site is 1750 m with a mean slope of 25-33 percent. The experimental plots are oriented in a westerly aspect.

Experimental Treatment

The *Pinus insularis* stand was thinned in 1979 to reduce the basal area by the following rates: 30 percent (light thinning), 50 percent (intermediate thinning), and 70 percent (heavy thinning). These were then used as treatments in studying the hydrometeorology of the pine stand. Three blocks each containing the three thinning levels and an unthinned (control) plot were laid out in a Randomized Complete Block Design (Figure 1). Each thinned plot with dimensions of *25 m x 25 m* was fenced with three strands of barbed wires to avoid plot disturbances.

Within each plot, a 4 m x 8 m surface runoff plot with galvanized iron sheets as plot borders was installed. Lengthwise, the plots were laid perpendicular to the slope. Surface runoff was conveyed through a galvanized iron sheet downspout to a concerete tank located at the base of the plot (Figure 2).

One native goat (or a stocking rate of 4 goats/ha) was allowed to graze in each of the thinned plots. Unthinned plots were designated as ungrazed plots. The animals were withdrawn from the plots when 40 percent of the forage was grazed. The animals were then rested for 20 to 50 days and allowed to graze in adjacent areas where the forage composition was similar to that of the study plots.

Data Collected

1. Tree growth: Diameter (stem and crown) and height (total and marketable) of the experimental trees measured every year.
2. Animal weight gain: The daily weight gains of the goats were determined by taking the weights of the animal before and after each grazing period, divided by the total number of days in a period.
3. Surface runoff and sediment yield: After each rainy day, the height of water collected in each tank was measured by a calibrated stick and used as the basis in determining the volume of surface runoff. After measurement of water level, the surface runoff was thoroughly agitated and a 1-liter aliquot sample was taken and subjected to evaporation. The sediment was then weighed and analyzed. Rainfall was measured from a standard rain gage installed in an open area about 20 m away from the experimental site.
4. Forage production: The net primary production of the grass sward was estimated from 5 caged plots, each with an area of 1 m^2. Harvesting was done every 90 days. Light trans-

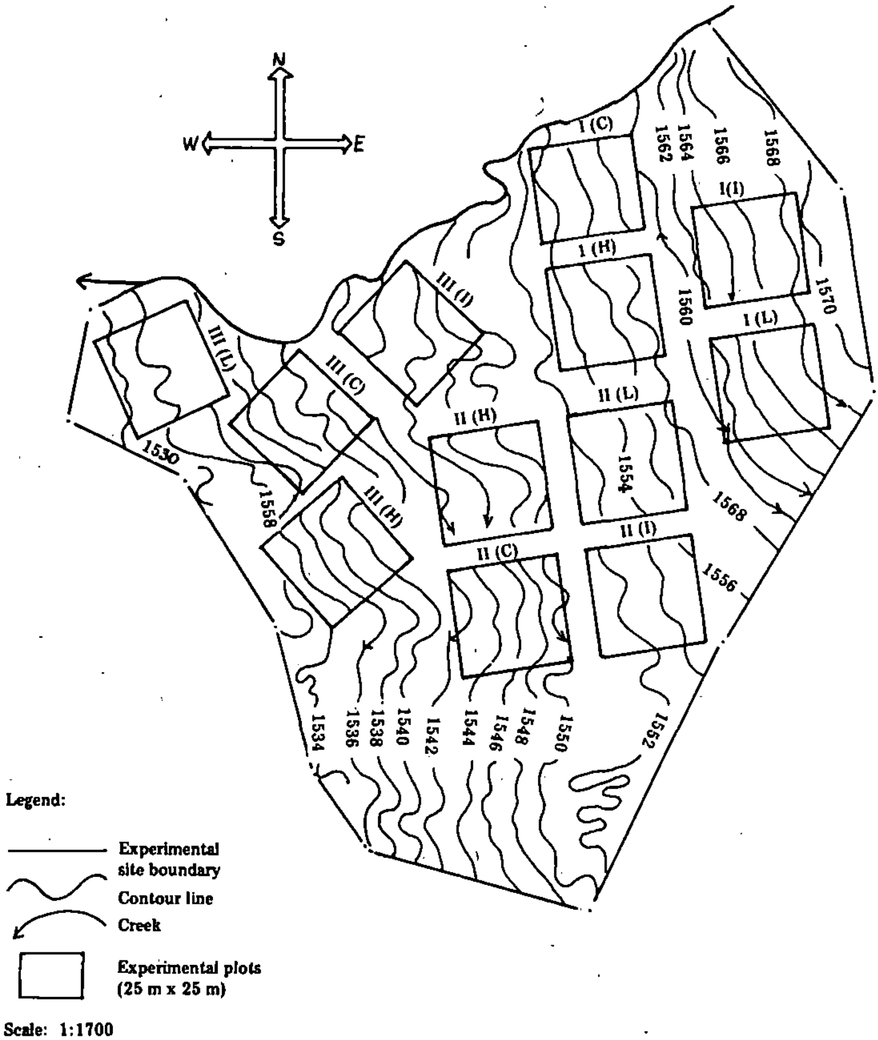

Figure 1. Topographic map of the experimental site.

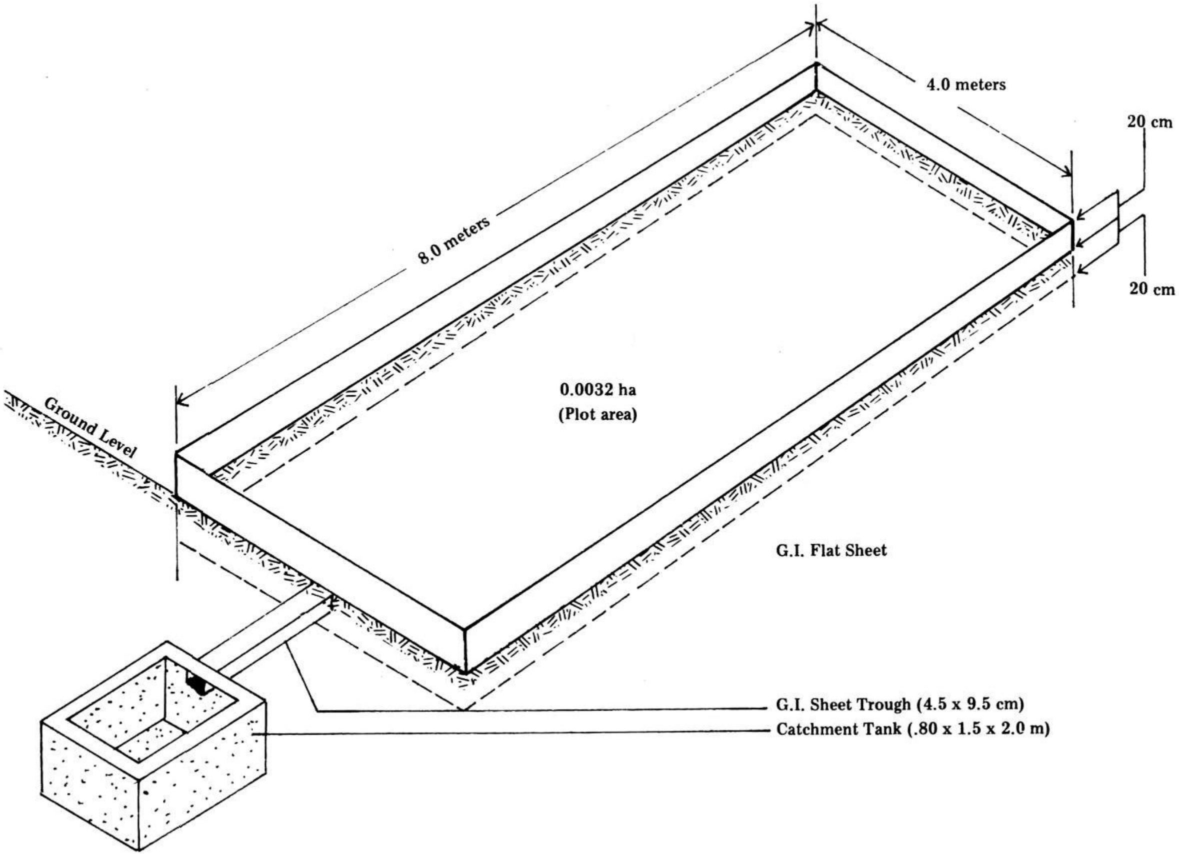

Figure 2. Plan of surface run-off plot installation.

mission just above grass sward level was taken at five points within each plot and in open areas using a sekonic light meter.

5. Soil infiltration rate, compaction and bulk density: A double-ring infiltrometer was used to determine the infiltrating capacity of the soil in all plots after each grazing period. Soil density was taken at five different points in every plot using a pocket penetrometer and supplemented by soil core samples.

6. Soil chemical properties: Soil samples were taken from each plot two times a year to determine changes in N, P, K, organic matter, and pH levels.

7. Forms of injury to regeneration: Natural pine regenerations in the plots were marked and the forms of any injury caused by the goats were described.

8. Understory vegetation composition: The line-intercept method using ground cover as a parameter was adopted to determine possible changes in the percent composition of palatable species.

RESULTS AND DISCUSSION

Tree Growth

The growth response of Benguet pine to thinning is presented in Table 1. The greatest growth rate of tree diameter resulted from heavy thinning, with 2.54 cm/yr. Correspondingly, heavy thinning showed the most increase of tree stem basal area.

The statistical analysis of the tree growth data showed that heavy thinning had significantly higher increases in stem basal area than those of the light thinning and control plots. The stem basal area increase was not significantly different between the heavy and intermediate thinning plots and between the light thinning and control plots.

Forage Production

The mean dry matter yield of palatable species under the pine forest was 2.95 tons/ha/yr. This value was lower than that obtained from open *Imperata-Themeda* grasslands, which was 3-8 tons/ha/yr

Table 1. Average tree stem annual diameter growth and total stem basal area increase in thinned-grazed and control plots.

Plot	Diameter Growth (cm)		Stem Basal Area
	Total	Annual	(%)
Unthinned, no grazing	4.16	1.39	78[b]
Light thinning with grazing	5.28[ab]	1.76	88[b]
Intermediate thinning with grazing	5.46[ab]	1.87	106[ab]
Heavy thinning with grazing	7.62[a]	2.54	153[a]

Note: Same letters indicate insignificant differences at 5% level of significance.

(Peñafiel, 1980) and was higher than that produced from a 40-year old pine stand, which was 1.92 tons/ha/yr (Peñafiel, 1979).

The reduction of total crown cover correspondingly caused an increased dry matter production in the understory plants. The heavy and intermediate thinning plots allowed the understory plants to produce as much as 1036 kg/ha/120 days and 1087 kg/ha/120 days of dry matter, respectively (see Table 2).

There were no significant variations between plots in terms of the dry matter production. The higher dry matter production in the heavy and intermediate plots could be due to the lower tree crown cover, which increased the amount of incident sunlight that reached the understory vegetation.

The goats generally preferred *Ischaemum polystachyon* (a creeper), *Themeda triandra,* and *Caelorachis cancellata,* in that order. But when many grasses became dry in the summer, *Imperata cylindrica* regrowths became the favorite of the goats.

Understory Plant Cover

As a result of browsing, the post-grazing understory cover decreased to 52, 56, and 58 percent for the light, intermediate, and heavy thinning plots, respectively (Table 3). Similarly, the palatable plant cover decreased, which was attributed mainly to goat grazing.

Table 2. Forage production, tree crown cover and light transmission in thinned-grazed and control plots.

Plot	Forage Production (kg/ha/120 days)	Crown Basal Area (m^2)	Crown Cover (%)	Light Transmission (%)
Unthinned, no grazing	899.72[a]	506.18[a]	81	21
Light with grazing	915.15[a]	519.77[ab]	83	23
Intermediate with grazing	1,087.31[a]	363.34[b]	58	47
Heavy with grazing	1,035.59[a]	386.69[b]	46	47
Mean	984.19 (2.95 tons/ha/yr)			

Note: Same letters indicate insignificant differences at 5% level of significance.

Table 3. Comparative pre- and post-grazing plant understory covers.

Plot	Palatable Cover (%)		Understory Cover[a] (%)	
	Pre-grazing	Post-grazing	Pre-grazing	Post-grazing
Heavy thinning (grazed)	86.83	46.75	96.13	57.67
Intermediate thinning (grazed)	73.50	45.34	95.27	56.04
Light thinning (grazed)	79.23	50.35	86.93	51.83
Unthinned (ungrazed)	60.32	50.44	87.68	86.00

[a]At 1.5 years after goat grazing.

Goat Live-weight Gains

The daily live weight of goats based on five grazing trials is shown in Table 4. The mean rate for all trials was 110.95 g/day at a stocking rate of 4 goats/ha. The goats in heavy thinning plots averaged a live-weight gain of 99.14 g/day, which is lower than the 104.43 g/day gain from the intermediate thinning plots. The highest average live-weight gain was obtained in the light thinning plots at 129.14 g/day. These values are lower than the live-weight gains obtained by Hussain et al. (1979), which was 154 g/day but higher than that found by Devedra (1984), which was 43.2 g/day at stocking rates of 20 goats/ha.

Table 4. Average daily live-weight increase of goats grazed in Benguet pine stands (g/day).

Plots	Trials							Mean
	1	2	3	4	5	6	7	
Heavy	167	125	83	91	50	74	104	99.14[a]
Light	104	167	138	75	116	148	156	129.14[a]
Intermediate	167	83	166	37	116	37	125	104.43[a]
All plots								110.95

Note: Same letters indicate insignificant differences at 5% level of significance.
Grazing period in each trial ranged from 30 to 45 days.

The live-weight gains did not follow the general trend in forage production. Although forage dry matter yield was higher in the heavy and intermediate plots, it did not cause a corresponding increase in animal weight. One reason for this inverse result could be that the feed was not limiting.

During each grazing period the animals were withdrawn as soon as forage utilization reached 40 percent and therefore, with this amount of forage still left in the plots, the animals were well fed. The variation in animal weight gains could also be due to the sex and body size.

Effect of Grazing on Soil Hydrologic Properties

Some reasons why grazing is often excluded from watershed areas are soil compaction effects and the corresponding reduction in vegetation cover that causes soil erosion. Table 5 and Figure 3 show the amount of surface runoff in relation to total rainfall for a two-year period and the sediment yield in all grazed and ungrazed plots. In 1983, a cumulative volume of surface runoff of 1742.884 liters was collected in the grazed-thinned plots and 953.4017 liters came from the unthinned-ungrazed plots. In 1984, the same trend was observed.

Table 5. Average surface runoff (liters/plot) and sediment yield (t/ha) in control and grazed plots.

Parameter	Year	Total Rainfall (mm)	Grazed	Control	Test of Significance
Surface runoff	1983	2,214.5	1,742.884	953.4017	NS
	1984	3,789.8	1,493.74	1,077.14	NS
	Mean		1,574.63	1,033.47	NS
Sediment yield	1983	2,214.5	1.1612	0.4797	NS
	1984	3,789.8	0.6562	0.4456	NS
	Mean		0.9891	0.4576	NS

Soil Texture: Clay (41-58%).

In terms of soil loss, 1.1612 tons/ha of soil were moved by the surface runoff from the grazed plots compared to only 0.4797 tons/ha of soil loss from the control plots. This soil erosion rate was much lower than that obtained by Lopez (1985) where overgrazing (cattle) in pine-grasslands caused a soil loss of 23.11 tons/ha. The test of significance for all data showed insignificant differences between the grazed and ungrazed plots, suggesting that goat grazing may not be the single contributor to soil erosion.

Goat grazing did not have a dramatic effect on soil loss and surface runoff (Table 6). Although lower values were obtained in the ungrazed plots than in the grazed plots, the movement of the goats in the plots did not cause significant changes in soil bulk density, compaction, and infiltration rate. This can be attributed to the small size and light weight of the goats.

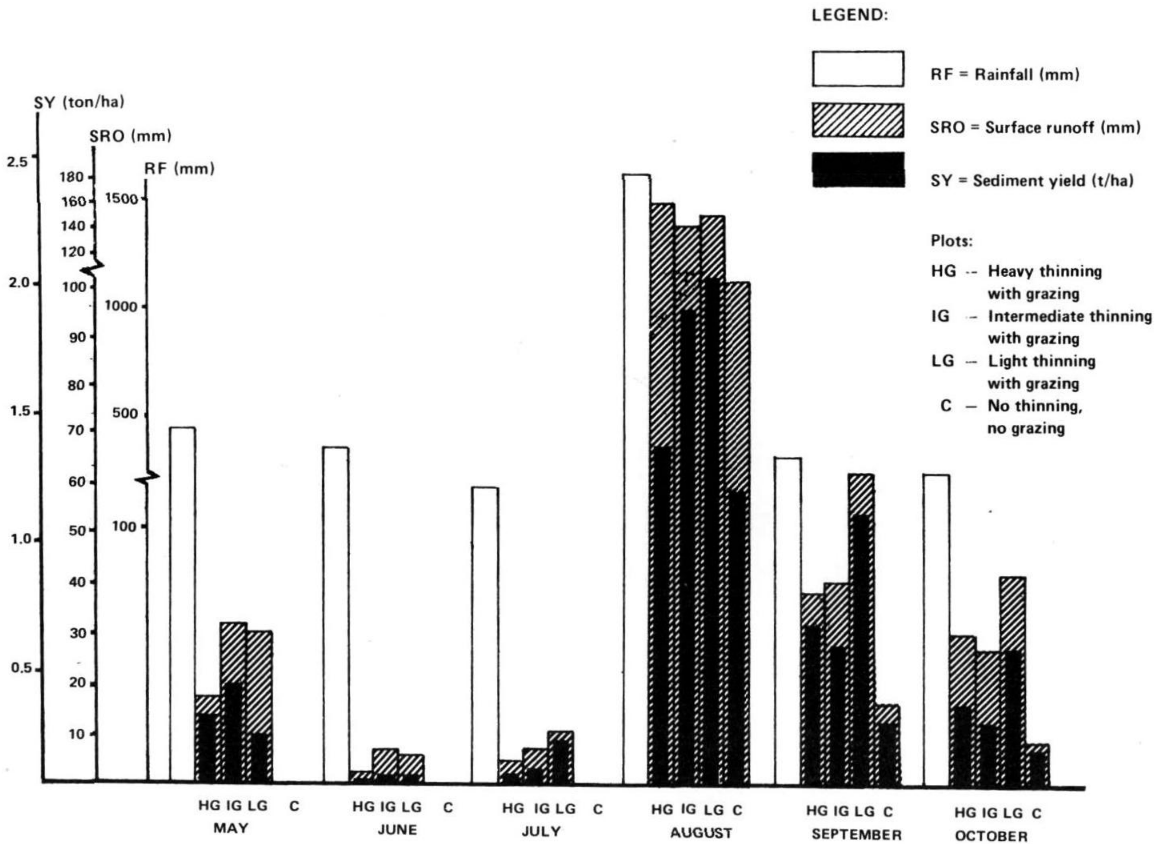

Figure 3. Monthly distribution of surface runoff and sediment yield in relation to total rainfall in grazing plots (1984).

Table 6. Average soil bulk density, infiltration rate, and soil compaction in all plots.

Plots	Bulk Density (g/cm^3)	Soil Compaction (kg/cm^2)	Infiltration Rate (mm/min)
Control (ungrazed)	0.91	1.51	73.83
Heavy (grazed)	0.94	2.85	49.30
Intermediate (grazed)	0.96	2.95	47.82
Light (grazed)	0.97	2.91	81.78

Note: All means are not significant at 5% level of significance.

Goat browsing did not cause significant soil nutrient drain (Table 7). This is expected because the animals, while grazing, scattered their feces and urine in the plots. Moreover, litterfall contributed nutrients to the soil. After the grazing tests, a decreasing trend of N, P, and K levels was observed in all the trials.

Injuries and Damages on Pine Regenerations

Goats are known to eat various plants and plant parts, which is considered as a constraint to the integration of goats into tree farms.

The observations on the damages and injuries on young Benguet pine seedlings (0-2 yrs) show that goats did not cause the seedlings' death. The common damages were caused by the goats' browsing on pine needles, trampling on smaller seedlings, and limited gnawing on the main stem of the seedlings (Table 8). Of the total 67 pine regenerations in the experimental plots, the goats browsed 8, trampled 2, and bit 1. Only 16 percent of the seedlings were injured, but the degree of damage was not so severe as to affect adversely tree growth and development.

The noninjurious effects of goat grazing on the pine regenerations could be attributed to sufficient available forage, low stocking rate, and their withdrawal from the plots when the prescribed forage utilization was attained. The observations of the study contradict the report of Yokom (1967) that goats are destructive animals. Thus, the question of "When is goat not destructive or destructive?" may depend on some factors such as stocking rate, frequency and intensity of grazing, and type of vegetation browsed.

Table 7. Comparative status of some chemical characteristics in the thinned (grazed) and unthinned (ungrazed) plots.

Thinning Plot		Year	N(%)	P (ppm)	K (mg/100g)	CEC (me/100g)	pH	OM (%)
Heavy	pre-grazing	(1982)	0.35	2.46	0.22	–	4.95	9.06
	post-grazing	(1985)	0.21	3.28	0.17	23.23	5.2	9.54
Intermediate	pre-grazing	(1982)	0.26	2.79	0.15	–	5.0	9.16
	post-grazing	(1985)	0.17	3.51	0.12	21.96	5.2	8.28
Light	pre-grazing	(1982)	0.27	2.67	0.17	–	4.95	8.50
	post-grazing	(1985)	0.18	3.63	0.15	24.43	5.2	8.03
Control (no grazing)		(1982)	0.32	2.28	0.20	–	4.95	9.79
		(1985)	0.21	3.74	0.15	26.49	5.1	9.06

Table 8. Number of *Pinus insularis* natural regeneration and forms of injury caused by grazing goats in grazed plots.

Grazed/Thinned	No. of Seedlings 1982	1985	Total Injured	Forms of Damage/ Injury
Light	17	16	3	Trampling; bark scratches
Heavy	36	35	4	Browsing
Intermediate	18	16	4	Browsing
Total	71	67	11	

Note: Death of seedlings was not caused by the animals.

Economic Benefits of Goat Production in a Pine Forest

In the hilly rural areas of the Philippines, goat is fast becoming an important source of cash income of small farmers. The Philippine native goat used in the study usually has a gestation period of five months (150 days), with one to three kids per litter. Thus, with two litters, a farmer could have an average of six kids in two years. In 1984, the farm gate price of goats (25 kg body weight) was about ₱420; if the six goats were sold one year later, the farmer could expect ₱2,520 (US$136). Native goats are easy to handle and require only minimal labor input.

Forest dwellers can derive benefits from pine plantations if they are allowed to raise goats. The national forest agency can also benefit from this system because grazing can minimize forest fires through reduction of potential fire hazards such as dry grass.

Thinning of the plantation could also increase the farmer's income. The farmer can generate an additional income of ₱908.56/ha from the sale of 4.432 m^3 of fuelwood obtained from thinning the pine stands (Table 9). Both the thinning products and the goats are sources of immediate cash while the farmer waits for the main harvests of sawlogs or pulpwood products.

Table 9. Average volume and total market value of thinned products (1984).

Plot	Volume Removed (m3/ha)	Market Value if Sold as Fuelwood[a] (P)
Intermediate thinning	3.300	676.50
Heavy thinning	7.052	1445.66
Light thinning	2.944	603.52
Average	4.432	908.56

[a]Price of fuelwood is P205/m^3; US$1 = P18.50 (1984 exchange rate).

CONCLUSIONS AND RECOMMENDATIONS

In the mountainous pine region watersheds of Luzon, a tree-goat agroforestry system could be a potential solution to reconcile the conflicting interests of national forestry programs and the forest dwellers. Goat production is more promising than cattle or slope farming in these areas in terms of conservation and economic objectives.

The study results show that goats are not destructive and could be compatibly raised with pine trees. Thinning the pine stands improve not only the tree growth but also forage production. The shorter gestation period and higher birthrates of goats could provide immediate additional income and source of protein to forest dwellers. The assistance of government agencies, such as the Bureau of Forest Development and the Bureau of Animal Industry, is necessary to effectively radiate and spread among forest inhabitants the pine-goat agroforestry practice in the pine forests of the country.

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SILVIPASTORAL FARMING FOR INCREASING PRODUCTIVITY OF FORAGE, FUEL, AND FODDER IN INDIAN WASTELANDS

by

R. Deb Roy and B.D. Patil[1]

ABSTRACT

The results of silvipastoral research studies conducted at the Indian Grassland and Fodder Research Institute (IGFRI) in Jhansi, India, are reviewed. The performance of selected grass and tree species suitable for silvipastoral farming on degraded wastelands based on the Institute's experiments, is detailed.

INTRODUCTION

Overgrazing of India's rangeland and cutting of trees and shrubs denude the countrysides causing erosion and desertification and other ecological imbalances. Demand for forage and fodder comes not only from livestock but also from wildlife. In addition, the human population demands fuelwood. Utilization of some of India's 75 million hectares of wastelands through silvipastoral farming would be an answer to some of the country's rural problems. Growing of dual or multipurpose trees and shrubs in association with grass and grass legume mixtures simultaneously on the same land would meet some of the fuel and fodder demands (Deb Roy and Pathak, 1983; Deb Roy and Patil, 1978; Deb Roy et al., 1980a, 1982b; Deb Roy, 1985b).

The role of fodder trees and shrubs in providing highly nutritious green leaf fodder is of great importance to livestock production, especially during the crucial lean period when grasses are either

[1]Sr. Scientist/Head of Agrosilvipasture Division and Ex-Director, respectively, Indian Grassland and Fodder Research Institute, Jhansi, India.

grazed or become very rough and unpalatable (Deb Roy et al., 1980c; Deb Roy et al., 1982a; Deb Roy, 1985a; Singh, 1982; Wilson, 1969; Torres, 1983). The importance of fodder trees and shrubs under the silvipastoral system of farming as well as under pure tree plantation, has been emphasized by Deb Roy and Pathak (1973, 1983), Deb Roy et al. (1978, 1980b, 1982b), Deb Roy (1979b, 1985a) Patil et al. (1982), Muthanna and Shankarnarayan (1978), Shankar (1981), and Torres (1983).

Information on silvipastoral system studies at the Indian Grassland and Fodder Research Institute (IGFRI) in Jhansi, India, with emphasis on the growth and production of forage, fuel and top feed under silvipastoral farming, is discussed in this chapter.

METHODS AND DISCUSSION

Location, Soil, and Climate

The experimental area is an undulating plateau with rocky outcrops at an elevation of 275 m. The soils are reddish-brown, shallow, and with 7-8.5 pH. The climate of Jhansi is typically monsoonic and is characterized by long and intense hot summers, low and erratic rainfalls, and short mild winters.

Seedling Establishment

Seedlings of *Acacia tortilis* and *Leucaena leucocephala* were planted in 1971 in pits measuring 45 cm^3 and in association with *Cenchrus* species. *Leucaena* was severely affected by grazing and termite attack while *A. tortilis* was not.

In 1973 *Albizia amara* and *Hardwickia binata* were established in association with *Cenchrus ciliaries* and a mixture of *Chrysopogon fulvus* and *Sehima nervosum.* In spite of the low rainfall (586 mm) during the year of establishment followed by very high temperatures and low rainfall in the following year, both tree species recorded 90 percent survival rate in the third year (Deb Roy and Pathak, 1973).

A large number of fodder-fuel trees (*Albizia lebbek, A. procera, L. leucocephala, P. juliflora, A. tortilis, Bauhinea alba*) were planted with different grass legume mixtures in 1976. The survival establishment of the tree species varied from 83 percent in *A. procera* to above 90 percent in *A. tortilis* (Deb Roy et al., 1977).

For the purpose of tree establishment, 4-5-month-old tree seedlings were planted in 45 cm^3 pits during monsoon periods. In 1971, 1-year-old *A. tortilis* seedlings were used.

Recently five selected tree species (*A. tortilis, Albizia amara, A. lebbek, L. leococephala,* and *H. binata*) were further established under silvipastoral systems under an IDRC Operational Research Project. Percentage survival of 1-year-old seedlings under a silvipastoral system is presented in Table 1. *A. tortilis* and *A. amara* exhibited more than 80 percent, followed by 75 percent in *A. lebbek* and 56 percent in *L. leococephala,* and the least in *H. binata.*

Table 1. Percentage survival of different fodder trees under a silvipastoral system in Jhansi.

Species	Sept./Oct. 1982	Dec. 1982	Mar. 1983	Jun. 1983
Acacia tortilis	89.6	89.6	87.3	85.8
Albizia amara	87.5	87.5	86.4	65.2
Albizia lebbek	78.2	75.8	65.4	63.8
Leucaena leucocephala	68.2	65.7	62.8	55.7
Hardwickia binata	48.7	43.6	41.7	37.1

Source: Patil et al. (1982-83).

Grass and Legumes Establishment

In order to hasten establishment and also to boost pasture production, it is advocated that 40 kg P_2O_5 and 20 kg N/ha be applied at the time of land preparation. Immediately after tree planting, grass seed/seedlings may be sown/transplanted in lines 90-100 cm from row to row and 45-50 cm within the row in case of transplanting. In between the lines of grasses, seeds of the legume *Stylo (Stylosanthese hamata)/Siratro (Macroptelium atropurpureum)* may be sown in lines 25-30 cm apart in between the lines of grasses. About 20-30 kg N/ha may be applied one month after sowing/planting in the first year, followed by 30 kg N/ha every year after the onset of the monsoon period.

In barren land with poor vegetation, light harrowing can be done before sowing of grass and legumes. Deb Roy and Pathak (1973,

1983) and Deb Roy et al. (1978b, 1980a) successfully established grasses and legumes under silvipastoral systems. It has also been established that one line of *Stylo* and one line of *Siratro* in between two lines of grasses keep the pasture with less weed, thus resulting in better pasture establishment and subsequent yield.

The introduction and importance of *Stylo* in the tropical pasture have been discussed in detail by Rai (1984) and Deb Roy (1985b). Both *S. hamata* and *Siratro* have been introduced in Indian pasture/silvipasture with success.

Pasture establishment was not affected by the presence of tree seedlings in various silvipastoral systems. Of the various perennial grasses, *Cenchrus ciliaris* was the easiest to establish, followed by *C. fulvus*. *S. nervosum*, because of its specific requirement, is comparatively difficult to establish.

Forage Production

Forage production studies under silvipastoral systems have been ongoing at IGFRI since 1971. Deb Roy and Pathak (1973) reported that a yield of 3.5 to 4.0 t/ha of dry forage from *C. ciliaris* in association with *A. tortilis* can be derived without much affecting the growth of the trees. *C. ciliaris* recorded higher forage production than *C. setigerus*. Forage production of both these species for a period of five years was discussed in detail by Deb Roy et al. (1978-1980) and Deb Roy and Pathak (1983). The data are shown in Table 2.

In another trial, *C. ciliaris* showed higher forage production, both in association with *H. bimata* (3.83 t/ha) and *A. amara* (4.0 t/ha), than a mixture of *C. fulvus* and *S. nervosum* (Table 3). Forage production in general was higher under wider spacing.

Dry forage production varying from 7.4 to 8.71 t/ha of *C. ciliaris* in association with *A. lebbek* was observed in the third year of establishment. This grass in association with *A. lebbek* gave an average green and fry forage production of 26.1 and 7.1 t/ha, respectively. Even with *P. juliflora*, the dry forage production recorded was 6.06 t/ha.

C. ciliaris in association with *L. leucocephala* recorded maximum forage production of 9.5 t/ha whereas *C. fulvus* showed 7.38 t/ha of forage under the same tree. In the same year *S. nervosum* in

Table 2. Forage production (dry) under a silvipastoral system in 1972-76 (in t/ha).

Treatments	1972	1973	1974	1975	1976	Mean
L1 S_1 Cc	4.289	3.103	5.341	5.892	2.732	4.271
L1 S_1 Cs	2.499	2.153	2.149	5.012	2.452	2.853
L1 S_2 Cc	4.025	2.510	4.020	5.472	3.402	3.885
L1 S_2 Cs	2.069	2.548	3.223	5.218	3.905	3.392
At S_1 Cc	3.316	3.113	4.020	4.087	2.990	3.505
At S_1 Cs	2.960	2.801	2.626	5.439	2.690	3.302
At S_2 Cc	4.194	2.326	2.952	5.040	2.990	3.500
At S_2 Cs	1.365	1.374	2.629	4.997	2.997	2.670
Mean	3.090	2.492	3.369	5.144	3.018	3.423
C.D. at 5%	1.164	N.S.	N.S.	N.S.	N.S.	

Index: Cc = *Centrus ciliaris* Cs = *C. setigerus*
L1 = *Leucaena leucocephala* At = *Acacia tortilis*
S_1 = 4 x 4 m spacing S_2 = 4 x 6 m spacing

Table 3. Forage production (dry) as affected by different treatments of silvi-pastoral system (in t/ha).

Grass Species	*Hardwickia binata* 4 x 4 m spacing	*Hardwickia binata* 4 x 6 m spacing	*Albizia amara* 4 x 4 m spacing	*Albizia amara* 4 x 6 m spacing
Cenchrus ciliaris	2.533	3.830	2.554	4.024
A mixture of *S. nervosum* and *C. fulvus*	3.588	3.654	3.084	3.336

association with *A. lebbek* recorded green and dry forage production of 27.57 and 5.66 t/ha (Deb Roy et al., 1978a). Higher forage production during 1978 was associated with good climate condition prevailing during the year. Deb Roy (1985b) discussed in detail the climatic parameters and the forage production under *Albizia-Cenchrus-Stylo* ecosystem. Forage production was significantly affected by the amount of rainfall and the number of rainy days. Ahuja et al. (1978) also reported similar results.

Under severe drought conditions, *S. nervosum* showed higher forage production (3.72 t/ha) than *C. ciliaris* (3.4 t/ha) in association with *A. lebbek* in the fourth year of pasture establishment.

Deb Roy et al. (1980b) did not find much difference in forage production of *C. ciliaris* whether grown in association with *A. tortilis* or without the tree. However, forage production was affected when grown in association with *H. binata* as well as *A. amara*. Muthanna and Shankarnarayan (1978) also did not find a significant difference in forage production under different trees. Shankar et al. (1976) recorded the highest forage production of 2.3 t/ha under *P. cineraria*, followed by *T. undulata, A. lebbek,* and *P. juliflora*, with *A. senegal* recording the least at 0.75 t/ha.

Wood Production

Total wood production was much higher for trees planted in association with pasture than those without pasture. The production varied from 31.0 to 35.1 t/ha. The production was also higher in association with *C. ciliaris* than with *C. setigerus*. Wider tree spacing also showed higher wood production. Total wood production per tree varied from 98 kg to 410 kg. The data on growth parameter and wood production of *A. tortilis* under silvipastoral system at the age of 13 years are presented in Table 4. *A. tortilis,* in combination with *C. ciliaris,* produced the greatest wood yield (93.14 t/ha). Treatments without pasture consistently showed low wood yield. Production was more in the branch wood than in the main bole.

Deb Roy (1985b) studied in detail the various aerial biomass production of 8-year-old *A. procera* and *A. lebbek* under a silvipastoral system. The mean aerial biomass production was higher in *A. procera* than in *A. lebbek,* but the total wood production was higher in the latter (155.0 kg/tree) than the former species (150.3 kg/tree).

Top Feed Production

Deb Roy and Gupta (1984) studied the top feed contribution of *A. tortilis* under a silvipastoral system. The mean production varied from 10.5 kg to 20.2 kg/tree.

Lopping studies on *A. procera* and *A. lebbek* under the silvipastoral system revealed that a two-thirds lopping at an interval of every six months gave an annual green and dry leaf fodder production of 6.24 t/ha by *A. procera* and 2.72 t/ha by *A. lebbek.* In the case of *A. procera,* the highest annual green production of 9.63 t/ha and dry leaf fodder production of 5.28 t/ha were observed at the third annual lopping (Deb Roy, 1985b). Both species gave higher leaf fodder production in summer lopping than in winter lopping, which could help in meeting the acute green fodder scarcity in the summer season.

Cash Crop Production

In the established silvipastoral system, there is scope for producing cash crop occasionally. After growing and utilizing the pasture (grasses and legumes) in the interstrip for a period of 4-6 years, the interspace can be utilized for growing dryland crops such as pigeon pea and cowpea for one year. The side branches of the trees should be lopped for fuelwood and leaf fodder production. Deb Roy et al. (1978b) even reported production of cowpea in the first year, along with trees in the reclamation of wasteland followed by pasture.

Table 4. Values of growth parameters and wood production of 13-year-old *A. tortilis* under a silvipastoral system in Jhansi, India.

Treatment	Height (m)	CD[a] (cm)	DBH[b] (cm)	Wood Production (kg/tree) Main Bole	Branches	Total Wood	Yield (t/ha)
S_1 G_0	8.16	16.09	15.57	36.39	61.78	98.17	37.99
$S_1 G_1$	8.05	18.21	19.03	40.45	71.83	112.28	43.18
$S_1 G_2$	8.88	20.15	25.53	64.85	136.58	201.13	77.47
$S_2 G_0$	8.93	23.95	25.53	77.84	59.15	136.99	35.09
$S_2 G_1$	9.47	25.43	27.92	117.65	245.93	363.58	93.14
S_2 G_2	9.08	21.59	24.60	82.09	114.73	226.82	58.10
Mean	8.60	20.91	19.20	69.88	120.00	189.18	57.50

Index: S_1 = 4m x 4m spacing; S_2 = 4m x 6m spacing; a = Collar diameter (CD); b = Diameter breast-high (DBH)

G_0 = No pasture; G_1 = *C. ciliaris*; G_2 = *C. setigerus*

Source: Deb Roy and Gupta (1984).

Deb Roy and Pathak (1983) reported higher seed production of cowpea and pigeon pea in the plot having *C. ciliaris* in association with *A. tortilis* than in the control plots. Muthanna and Arora (1977) reported increased seed production of cash crops in a lopped area compared to an unlopped one and to the control (no grass).

THE IDRC SILVIPASTURE RESEARCH PROJECT: SOME HIGHLIGHTS

In 1982, the International Development Research Council (IDRC) of Canada sponsored a joint project with Indian Grassland and Fodder Research Institute (IGFRI), Jhansi, India, entitled "Silvipasture Operational Research Project for Bundelkhand Region." The long-term objective of the project is to increase the overall forage and tree crop productivity of degraded grazing lands and other wastelands in the semiarid pastoral areas by interplanting fast-growing and hardy fodder, along with fuel trees and shrubs with promising grasses and legumes that have high potential for animal feeds.

Details of the technical program and the three specific wasteland study sites are given in a report by Patil et al. (1983-84). The three specific study sites represented an undulating terrain, an eroded plain, and ravines. The tree species selected were *A. tortilis, A. amara, A. lebbek, H. binata/D. sissoo, L. leococephala/D. cinerea.* These trees were planted at three spacings in association with grasses such as *C. ciliaris, S. nervosum,* and *C. fulvus* and with the legume *S. hamata/M. atropurpureum* in 64 treatment combinations in a split plot design with three replications. The third (ravinous) site was established in 1984.

A. tortilis and *A. amara* exhibited excellent establishment in all three sites. *D. cinerea,* which was tried only in the ravinous area, also showed very good establishment. *A. lebbek* and *L. leucocephala,* although showing initially good establishment, suffered heavy casualties due to unfavorable weather conditions when extreme temperature reached 48°C in 1984. The same situation occurred with *D. sissoo,* which was planted in place of *H. binata* in one of the sites. *H. binata* exhibited the least establishment survival rate. In site one, *A. tortilis* showed the highest establishment survival rate.

A. tortilis, A. amara, and *L. leococephala* showed better growths both in height and collar diameter (CD) than other species.

However, due to high foliage palatability of *A. amara* and *L. leococephala,* their growth was affected by sporadic browsing of wild animals. In the first study site, *L. leococephala* exhibited the highest annual height and CD increment, followed by *A. tortilis* and then by *A. amara.* The least growth increment was observed in *H. binata* because its initial slow growth needed interculture in the first two years for better establishment and growth.

Seedling growth was much faster in the ravinous area, probably because the barren land had lower competition with local flora than in other sites where seedlings growth was affected by competition from local grasses and other weeds. In such localities, soil working should be more thorough to suppress the local flora in order to introduce successfully the desired pasture (grass and legume). *S. hamata* showed better establishment and subsequent growth and production than *M. atropurpureum.*

Forage production was highest in a mixture of *Sehima-Chrysopogon* with *S. hamata.* The production varied from 3.2 to 5.9 t/ha with legume contributing about 15-20 percent of the total forage.

In the ravinous site, which has a high pH, *A. tortilis, A. amara,* and *D. cinerea* grew very well. *S. hamata* and *M. atropurpureum* grew fairly well although the grass showed comparatively poor establishment.

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IV. Quantification of Some Agroforestry Impacts

Libraries in the tropics have been experiencing a notable increase in available agroforestry literature and an associated expansion in demand for agroforestry information. These trends are consistent with the ground swell of interest in agroforestry as an alternative land-use system for fragile upland sites in the humid tropics.

A close scrutiny of available bibliographic materials reveals that the vast majority are empirically based on, rather than derived from, systematic scientific investigation. Consequently, an equally great proportion of the current literature are qualitative and are severely wanting in hard or quantitative information.

As tools for creating awareness about the strengths and weaknessses of agroforestry systems, and as bases for a broad campaign for the adoption of these sytems to counteract the degradation brought about by intensive cultivation of sloping lands under pure annual crops, the predominantly descriptive type of agroforestry literature may suffice. However, if hard management decisions are to be made, such as when comparing one agroforestry system with others to select the most appropriate one for a given site, many of the current available literature would be almost useless.

Fortunately, many researchers are aware of the large gap in quantitative agroforestry information and are working toward filling this great need. The two papers presented below represent some of the current efforts in Southeast Asia to bridge that gap.

CROPPING MANAGEMENT AND CONSERVATION PRACTICE INDICES IN A TEAK AGROFORESTRY SYSTEM IN JAVA, INDONESIA

by

Djoko Widodo[1]

ABSTRACT

The Universal Soil Loss Equation (USLE) is used in predicting erosion rates as well as the cropping management and conservation practice indices in teak plantations under three age groups. Erosion rate is lowest in young teak plantations (0-5 years old) covered with grass.

INTRODUCTION

The study was conducted in Banyuasin Teak Forest in Kecamatan Widodaren, Kabupaten Ngawi, East Java. The forest is part of the Solo River watershed which has an elevation of about 137 m above sea level. The experiment was conducted to assess the soil erosion rates in teak forest plantations and to determine the cropping management and conservation practice (CP) indices based on the USLE.

[1] Staff member, Watershed Management Technology Center, Indonesia.

METHODS

The treatments considered in the study are different age groups of teak (*Tectona grandis*) plantations with improved grass cover. The age classes in years are 0-5, 5-10, and 10-15. The teak are planted on a 3 m x 2 m spacing distance, while the grass is planted on contour ridging at 3 m intervals.

CP indices are predicted by the USLE developed by Wischmeier and Smith (1978), which is expressed as follows:

$$A = R\,K\,L\,S\,C\,P$$

where:

A = erosion rate (t/ha/yr)
R = rainfall erosivity
K = soil erodibility
L = slope length (m)
S = slope gradient (in degrees or %)
C = cropping management
P = conservation practice

CP is then computed as

$$CP = \frac{A}{R\,K\,L\,S}$$

The parameters A, R, K, and LS were determined in the study.

Erosion Rate (A)

The erosion rate data were derived from the erosion plot over a period of two years (1981-82). The erosion plot was built with an artificially delineated catchment with dimensions of 50 m long and 20 m wide. The outlet was provided with 2 erosion tanks:

Tank I: measurements = 2.5 m x 1.0 m x 1.0 m
Tank II: measurements = 1.4 m x 0.75 m x 1.0 m

The water in the tank was drained by using plastic pipes until only the sediment material was left. Suspended load and bedload samples were analyzed to determine the erosion rate.

Rainfall Erosivity (R)

According to Bols (1978), the formula of rainfall erosivity (EI_{30}) is as follows:

$$EI_{30} = \frac{2.467\ r^2}{0.0727\ r + 0.725}$$

where:

EI_{30} = rainfall erosivity
r = rainfall depth (cm)

Rainfall depth was obtained from a rainfall standard gauge at the research site.

Soil Erodibility (K)

Soil erodibility (K) is affected by the following characteristics:

1. Texture
2. Soil structure
3. Organic matter
4. Permeability

Soil characteristics of the research site were used in determining the K factor with the help of Wischmeier's nomogram (Figure 1).

Slope Length and Gradient (LS)

Slope length and gradient were measured using linear measure and abney level. The LS factor was then determined with the use of the following formula:

$$LS = \frac{m}{22.1} \times [65.41\ \mathrm{Sin}^2 + 4.56\ \mathrm{Sin} + 0.065]$$

where:

LS = slope length (in meters) and slope gradient (in degrees)
m = exponential, such that
m = 0.2, if the slope steepness is less than 1%
m = 0.3, if the slope steepness is 1-3%
m = 0.4, if the slope steepness is 3-5%, and
m = 0.5, if the slope steepness is more than 5%

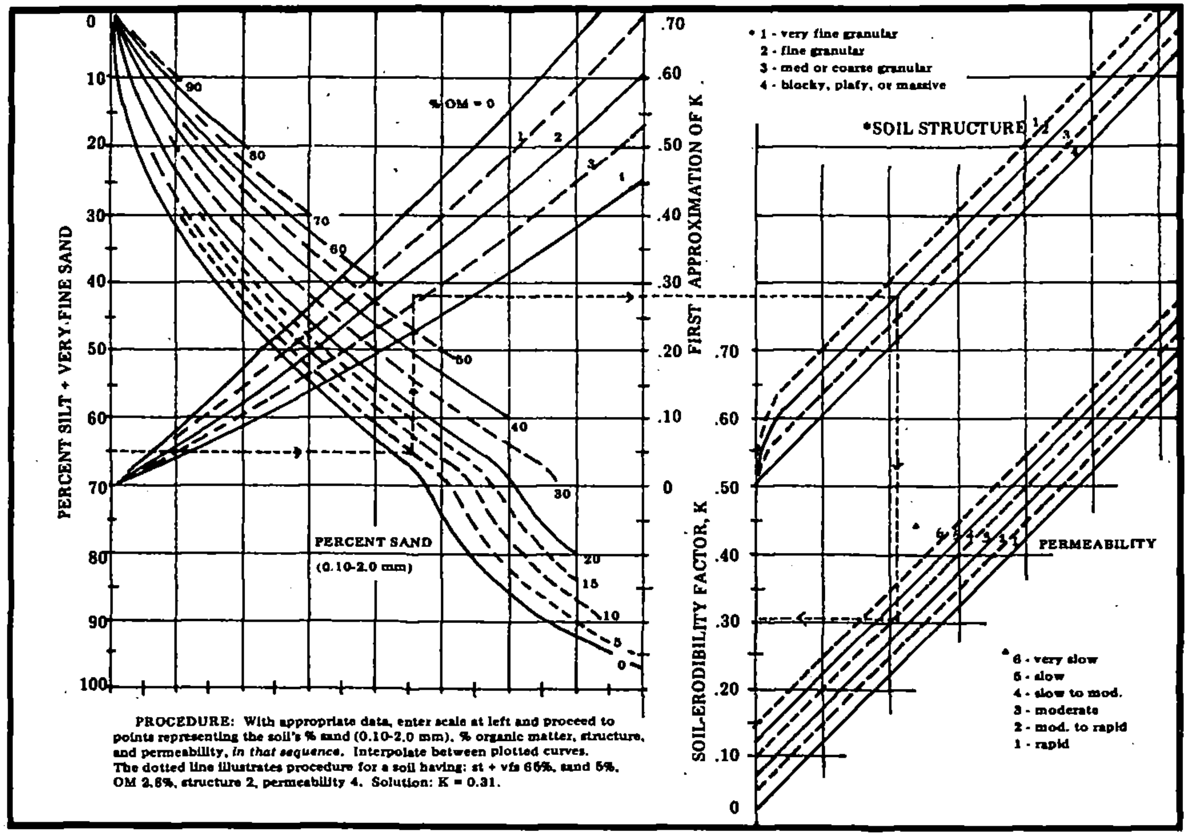

Figure 1. The soil-erodibility nomograph. (Source: Wischmeier and Smith, 1978).

If slope gradient is expressed in percent (%) and m = 0.5, the LS factor can be determined by using the formula:

$$LS = 1.38 + 0.065\,s + 0.138\,s^2$$

RESULTS AND DISCUSSION

Erosion Rate (A) and Rainfall Erosivity (R)

The results of the computations for (A) and (R) factors from the erosion plots are shown in Tables 1 to 6. There is a linear relationship between the (A) and (R) values. A linear regression model was used to predict the erosion rate. The equations for the three replications (plots) are as follows:

Replication I: $Y = 0.3802 + 0.6870\,X$
Replication II: $Y = 0.7605 + 0.7014\,X$
Replication III: $Y = 0.0685 + 0.7636\,X$

where

$Y = A$ = erosion rate (t/ha)
$X = R = EI_{30}$

Based on the linear regression models from Tables 1 to 6, the erosion rate of each plot was determined. The results were then converted into t/ha/yr (Table 7).

Soil Erodibility (K)

Based on a soil sample analysis from the Department of Ilmu Farah Fakultas Pertanian, Universitas Gadjahmada, the five soil characteristics were described. Using the Wischmeier nomogram, the K factor was determined (Table 8).

Slope Length and Gradient (LS)

Slope length and gradient were measured in the study area. Using the LS formula, the results are shown in Table 9.

Cropping Management and Conservation Practices (CP)

Table 10 shows the CP results based on the CP formula. The average annual erosion rate and the CP index values are as follows:

1. Treatment I: Teak plantation under 0-5 years with grass cover

   1980-81: erosion rate = 7.82 t/ha/yr
   CP index = 0.21

   1981-82: erosion rate = 6.21 t/ha/yr
   CP index = 0.17

2. Treatment II: Teak plantation under 5-10 years with grass cover

   1980-81: erosion rate = 8.21 t/ha/yr
   CP index = 0.21

   1981-82: erosion rate = 11.27 t/ha/yr
   CP index = 0.31

3. Treatment III: Teak plantation under 10-15 years with grass cover

   1980-81: erosion rate = 7.38 t/ha/yr
   CP index = 0.26

   1981-82: erosion rate = 7.69 t/ha/yr
   CP index = 0.29

Table 1. Erosion and EI_{30} analysis results of Replications I, II, and III.

No.	EI_{30}	Erosion Rate (kg) Replication I	Replication II	Replication III
1.	3.903	2.6988	2.0343	2.2809
2.	2.528	1.2089	0.3910	0.3709
3.	2.692	1.1020	0.4435	0.4845
4.	1.155	0.3188	–	–
5.	3.518	1.2630	1.8515	–
6.	6.659	3.8038	4.5186	3.8032
7.	6.408	4.3176	4.3443	2.9180
8.	3.093	2.9219	1.1261	1.6526
9.	3.093	1.0373	1.2234	1.0400
10.	1.431	0.4273	0.2034	0.1119
11.	0.718	0.1092	0.1344	0.0848
12.	1.270	0.6958	0.5722	0.0547
13.	6.665	4.4815	3.2381	2.7860
14.	10.370	6.6684	6.6000	6.8119
15.	0.718	0.2823	0.1624	0.4367

16.	2.528	1.1125	1.2693	1.1188
17.	3.708	2.4680	1.5690	1.3629
18.	6.665	4.4570	3.7556	3.4178
19.	28.287	19.9764	19.6692	18.8216
20.	24.946	15.6223	16.0529	15.1538

Source: Proyek P3DAS (1983).

Table 2. Erosion and EI_{30} analysis results of Replications I, II, and III.

		Erosion Rate (kg)		
No.	EI_{30}	Replication I	Replication II	Replication III
1.	3.03	2.7158	2.1768	2.0727
2.	0.18	0.0849	0.8999	0.7085
3.	0.26	0.0819	–	–
4.	2.80	2.0819	1.6292	1.5483
5.	7.59	6.1319	5.7982	5.7909
6.	11.54	–	–	8.6563
7.	0.98	1.0232	1.6438	2.3642
8.	6.74	5.1212	4.0541	–
9.	11.65	9.2499	7.3331	9.2420
10.	2.06	1.9750	0.6338	1.0824
11.	1.97	1.5271	1.6338	2.0955
12.	4.03	3.2175	2.9275	3.2927
13.	11.86	–	9.4904	–
14.	5.24	4.8812	2.6817	3.2100
15.	3.09	–	1.4368	1.4239
16.	8.04	–	–	6.1253
17.	5.46	8.6979	4.3473	4.6595
18.	1.78	10.7795	0.4293	2.2202

Source: Proyek P3DAS (1983).

Mathematical model of linear regression:

Replication I : $Y = 0.1800 + 0.7056\ X$

Replication II : $Y = -0.0265 + 0.6999\ X$

Replication III : $Y = 0.0685 + 0.7636\ X$

Table 3. Erosion and EI_{30} analysis results of Replications I, II, and III.

No.	EI_{30}	Erosion Rate (kg)		
		Replication I	Replication II	Replication III
1.	3.518	2.2183	–	–
2.	2.528	0.7174	1.0355	1.0303
3.	2.692	0.9842	1.1300	1.0360
4.	1.155	0.1356	0.2466	0.6240
5.	3.518	0.0709	2.0447	3.2903
6.	11.340	–	–	6.8405
7.	11.340	–	8.8099	–
8.	0.810	0.0645	0.0127	0.0196
9.	13.829	7.2046	–	7.4457
10.	0.810	0.1417	0.0672	0.0666
11.	0.359	–	0.1490	0.3333
12.	21.228	12.7634	15.4287	14.2748
13.	19.135	11.6630	12.4374	11.3394
14.	2.692	1.7565	0.6161	0.5354
15.	19.135	10.7132	11.6489	10.7256
16.	3.708	–	2.1157	2.0796
17.	3.518	1.4341	3.4576	1.9142
18.	3.708	1.0430	3.6659	1.8304

Source: Proyek P3 DAS (1983).

Mathematical model of linear regression:

Replication I : $Y = -0.5689 + 0.6101X$

Replication II : $Y = -0.2533 + 0.7122\ X$

Replication III : $Y = -0.5191 + 0.6217\ X$

Table 4. Erosion and EI_{30} analysis results of Replications I, II, and III.

No.	EI_{30}	Erosion Rate (kg)		
		Replication I	Replication II	Replication III
1.	3.093	0.6668	1.5480	1.5780
2.	6.655	0.9321	–	–
3.	2.016	–	1.1812	–
4.	2.016	0.2760	0.3675	–
5.	3.093	1.9612	1.3370	–
6.	4.374	1.8968	2.8951	2.0375
7.	6.655	3.3014	2.9636	3.2010
8.	30.855	14.5687	16.2863	14.0437
9.	3.093	1.6681	1.0141	1.2925
10.	4.374	3.3559	2.1902	1.3668
11.	7.507	3.6641	1.9814	4.0330
12.	1.558	0.8109	1.6020	0.4095
13.	2.016	–	0.0842	0.2035
14.	0.810	0.2350	0.1583	0.1815
15.	3.708	0.2430	1.1775	–
16.	43.961	27.1120	24.6964	31.8767
17.	3.093	3.5751	1.9627	2.4835
18.	0.523	0.2535	0.5475	–
19.	42.236	26.4025	19.7681	22.3885
20.	15.798	7.1801	6.7842	8.4597
21.	27.843	26.0026	23.1794	23.9978
22.	0.523	0.8475	1.2000	0.6608
23.	33.977	19.1115	22.5143	22.4499
24.	3.093	0.6280	0.3910	–
25.	5.087	4.2569	2.3708	1.3145
26.	5.087	3.6365	1.5295	–
27.	17.004	8.2804	8.6103	10.4112
28.	70.347	37.5686	36.2996	31.3319
29.	22.170	13.5920	13.7411	20.1972
30.	3.093	1.1280	0.4018	–
31.	4.374	1.0787	0.6862	–

Source: Proyek P3DAS (1983).

Mathematical model of linear regression:

Replication I : $Y = -0.3071 + 0.5888\ X$
Replication II : $Y = -0.4062 + 0.5582\ X$
Replication III : $Y = -0.4948 + 0.5769\ X$

Table 5. Erosion and EI_{30} analysis results of Replications I, II, and III.

No.	EI_{30}	Erosion Rate (kg) Replication I	Replication II	Replication III
1.	7.682	11.2732	11.4977	9.4866
2.	1.558	0.6885	9.6517	0.4322
3.	34.775	40.4885	37.7149	35.8573
4.	15.443	17.6927	14.3928	14.6133
5.	11.337	12.8492	10.5747	8.3982
6.	12.396	13.9625	12.5889	8.8784
7.	7.161	9.9399	9.7783	7.1736
8.	16.517	17.7180	18.2045	12.3883
9.	17.004	21.6842	19.3704	18.7386
10.	8.959	9.6868	9.4567	10.3001
11.	3.394	1.6744	1.5633	–
12.	41.043	40.1628	39.7783	37.0809
13.	26.380	22.6314	22.6889	19.9798
14.	2.265	0.8490	0.8940	–
15.	49.816	–	51.7820	48.8809
16.	15.798	21.1020	18.8443	17.9388
17.	27.843	34.1538	30.9830	26.3954
18.	23.543	23.6345	22.9000	21.6969
19.	0.498	0.6384	0.3665	–
20.	41.725	37.3805	39.4339	39.0960
21.	23.543	26.2557	27.3091	25.7492
22.	10.218	9.3541	8.9654	7.2707
23.	45.710	51.4573	50.7908	48.0897
24.	32.403	43.5875	37.2494	35.7539
25.	32.403	–	–	–
26.	0.449	0.3030	0.1586	–

Source: Proyek P3DAS (1983).

Mathematical model of linear regression:

Replication I : $Y = 0.5152 + 1.0682\,X$

Replication II : $Y = -0.0249 + 1.0442\,X$

Replication III : $Y = -1.1514 + 1.0115\,X$

Table 6. Erosion and EI_{30} analysis results of Replications I, II, and III.

No.	EI_{30}	Erosion Rate (kg)		
		Replication I	Replication II	Replication III
1.	6.655	1.7772	2.5761	1.2370
2.	3.093	0.4397	0.6750	0.3855
3.	4.374	1.8115	1.6462	0.5671
4.	6.655	2.1825	1.2012	1.980
5.	6.655	3.1733	2.9022	2.80
6.	19.521	13.4793	15.1037	12.3731
7.	33.977	21.4027	22.4119	24.04
8.	5.848	3.0668	3.190	2.72
9.	5.087	3.9620	2.655	4.90
10.	4.374	3.4250	2.185	2.31
11.	3.093	0.9125	0.6388	0.7035
12.	6.655	1.820	4.4887	3.680
13.	5.087	1.930	2.7542	1.705
14.	62.413	44.8068	43.772	42.7258
15.	1.558	0:8750	1.182	1.230
16.	2.016	1.3230	1.130	1.180
17.	49.274	32.4225	33.8372	31.9056
18.	3.708	1.6687	2.130	2.145
19.	49.274	41.2072	40.7965	43.1446
20.	3,708	1.9142	1.1745	2.1525
21.	76.483	52.5930	53.2806	51.8159
22.	3.093	0.7975	0.5648	0.611
23.	42.236	23.2213	24.2735	23.9381
24.	3.708	1.2425	1.965	1.5275
25.	9.339	6.740	8.572	7.293
26.	120.838	–	–	–
27.	51.089	33.1174	34.5747	33.9721

Source: Proyek P3DAS (1983)

Mathematical model of linear regression:

Replication I : $Y = -1.2118 + 0.7097\ X$

Replication II : $Y = -1.0320 + 0.7174\ X$

Replication III : $Y = -1.1390 + 0.7093\ X$

Table 7. Erosion rate results (t/ha/yr).

Year	Treat-ment*	Repli-cation	Y = a + bX	R	Erosion Rate (A)	
					In Plot (kg/ha)	Per Ha (t/ha)
1980-81	A	I	Y = 0.3802 + 0.6870 X	1140	783	7.83
	A	II	Y = 0.7605 + 0.7014 X	1140	799	7.99
	A	III	Y = 0.9088 + 0.6724 X	1140	765	7.65
	B	I	Y = 0.180 + 0.7056 X	1140	804	8.04
	B	II	Y = –0.0265 + 0.699X	1140	798	7.98
	B	III	Y = 0.0685 + 7636 X	1140	871	8.71
	C	I	Y = –0.5689 + 06101 X	1140	695	6.95
	C	II	Y = –0.2533 + 0.7122 X	1140	812	8.12
	C	III	Y = –0.5191 + 0.6217 X	1140	708	7.08
1981-82	A	I	Y = –0.3071 + 0.5888 X	1082	637	6.37
	A	II	Y = –0.4062 + 0.5582 X	1082	603	6.03
	A	III	Y = –0.4948 + 0.5769 X	1082	624	6.24
	B	I	Y = 0.5152 + 1.0682 X	1082	1157	11.57
	B	II	Y = –0.0249 + 1.0442 X	1082	1130	11.30
	B	III	Y = –1.1514 + 1.0115 X	1082	1093	10.93
	C	I	Y = –1.2118 + 0.7097 X	1082	767	7.67
	C	II	Y = –1.032 + 0.7174 X	1082	775	7.75
	C	III	Y = –1.139 + 0.7093 X	1082	766	7.66

*Treatment A: teak plantation (*Tectonia grandis*) under 0-5 years.
B: teak plantation (*Tectonia grandis*) under 5-10 years.
C: teak plantation (*Tectonia grandis*) under 10-15 years.

Table 8. K factor determination results.

Treatment	Replication	Soil Particle (%) 0.002-0.1 mm	Soil Particle (%) 0.1-2 mm	Organic Matter (%)	Structure	Permeability (cm/hr)	K Factor
A	I	20.1	16.8	2.55	2	21.58	0.03
A	II	18.6	2.5	1.31	2	16.78	0.02
A	III	21.6	16.3	2.81	2	44.40	0.04
B	I	25.2	16.3	1.66	2	9.84	0.09
B	II	21.5	3.9	0.71	2	9.23	0.06
B	III	14.8	2.7	1.77	2	6.27	0.05
C	I	23.1	4.6	1.40	2	10.1	0.05
C	II	21.5	3.9	0.71	2	9.23	0.06
C	III	16.5	7.7	2.03	2	58.03	0.04

Table 9. LS factor results.

Treatment	Replication	Slope Length (m)	Slope Gradient (%)	LS Factor
A	I	50	10.5	1.2215
A	II	50	11	1.3287
A	III	50	9	0.9292
B	I	50	6.5	0.4179
B	II	50	5.5	0.5396
B	III	50	7	0.6078
C	I	50	5	0.3644
C	II	50	6.5	0.5396
C	III	50	7	0.6078

Table 10. CP factor results.

Year	Treatment	Replication	A t/ha/yr	R	K	LS	CP
1980-81	A	I	7.83	1140	0.03	1.2215	0.18
	A	II	7.99	1140	0.02	1.3287	0.26
	A	III	7.65	1140	0.04	0.9292	0.18
	B	I	8.04	1140	0.09	0.4179	0.16
	B	II	7.98	1140	0.06	0.5396	0.21
	B	III	8.71	1140	0.05	0.6078	0.25
	C	I	6.95	1140	0.05	0.3644	0.33
	C	II	8.12	1140	0.06	0.5396	0.21
	C	III	7.08	1140	0.04	0.6078	0.25
1981-82	A	I	6.37	1082	0.03	1.2215	0.16
	A	II	6.03	1082	0.02	1.3287	0.20
	A	III	6.24	1082	0.04	0.9292	0.15
	B	I	11.54	1082	0.09	0.4179	0.28
	B	II	11.30	1082	0.06	0.5396	0.32
	B	III	10.93	1082	0.05	06078	0.33
	C	I	7.67	1082	0.05	0.3644	0.38
	C	II	7.75	1082	0.06	0.5396	0.22
	C	III	7.66	1082	0.04	0.6078	0.29

SUMMARY AND CONCLUSION

The USLE was used to predict annual soil erosion rates under three age groups of teak plantations with grass covers. The CP indices were computed for the teak-grass combination. In summary, the results are as follows:

Treatment	Erosion Rate (t/ha/yr)		CP Index	
	1980-81	1981-82	1980-81	1981-82
A	7.82	6.21	0.21	0.17
B	8.24	11.24	0.21	0.31
C	7.38	7.69	0.26	0.29

Note: Treatment A: 0-5 years old teak plantation with grass cover.
" B: 5-10 "
" C: 10-15 "

Erosion was reduced in soils under the youngest teak-grass combination (0-5 years old); the CP index decreased from 0.21 in 1980-81 to 0.17 in 1981-82. On the other hand, the more mature plantations showed increased erosion rates and CP indices.

The experiment illustrates how effects of conservation measures can be quantified. The USLE is a useful tool in predicting soil loss that can help in implementing agroforestry measures.

Agroforestry system in teak forest plantations can be practiced for area development as a technique for soil conservation and for increasing crop production.

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SOIL EROSION AND AMELIORATION RATES IN SWIDDEN CULTIVATION, PERMANENT AGRICULTURE, AND FORESTRY IN NORTHERN THAILAND

by

K.T. Ryan and U. Taejajai[1]

ABSTRACT

The Universal Soil Loss Equation (USLE) was used to model soil losses from swidden, continuous rice cropping, recommended cropping system, dipterocarp forest, introduced evergreen forest, and teak plantation in two sites in northern Thailand. The cropping system recommended by the Thai-Australia-World Bank Land Development Project and the establishment of woodlots produced less soil loss than the present management of the uplands.

INTRODUCTION

Thailand's agricultural economy is being confronted with a growing rural population and the consequent increases in the demand for additional land. Since most of the useful lowlands is already occupied, this demand has been accommodated by increased utilization of the uplands where the soils are fragile and erosion prone. The intensive cultivation of these uplands is degrading the soil, which causes declines in crop production.

The objective of the Thai-Australia-World Bank Land Development (TAWLD) Project is the development and stabilization of rain-fed agricultural areas. These areas on the low and middle terraces of northern Thailand are currently being cropped either intensively or irregularly by slash-and-burn or swidden agriculture. The current

[1]Soil Conservation Research Advisor and Agricultural Scientist, respectively, Thai-Australia-World Bank Land Development Project, Chiang Mai, Thailand.

program includes a land development component involving the clearing by heavy equipment of natural vegetation, which consists mainly of dipterocarp-bamboo secondary regrowth. Stumps and roots are removed and soil conservation structures such as contour banks and gully control structures are constructed. This is supported by a wide range of research and advisory programs that include cropping systems and soil conservation to develop acceptable, practical, and stable farming practices (Buddee, 1985).

METHODS

Wischmeier and Smith (1978) describe the USLE as an erosion model designed to predict the long-time average soil losses through runoff from specific field areas under specified cropping and management systems. Although not developed in tropical conditions, the model has been suggested for use in management decisions by supplying relative data on soil losses for various types of land management (Srikhajon et al., 1984).

Because long-term averages are used as bases of the parameters in the USLE, the equation may not estimate short-term or annual values of soil loss as accurately as for the long-term ones. This is due to the seasonal and annual fluctuations in the actual values of the parameters in the short term. Despite this shortcoming, the USLE is probably more accurate than other models when the simplicity of required inputs is taken into consideration.

The use of local data to refine the USLE parameters can further increase the suitability of the model to most localities. This work has already begun in Thailand (Srikhajon et al., 1984).

The soil loss equation is represented by

$$A = R\,K\,L\,S\,C\,P$$

where

- A = computed soil loss per unit area
- R = erosivity factor, rainfall and runoff factor
- K = erodibility factor, soil factor
- LS = topographic factor, slope length and steepness factor
- C = cover and crop management factor
- P = support practice factor

The value for each of the parameters used in this study is discussed below.

Erosivity Factor (R)

At this stage, sufficient and accurate data are not available to obtain the values of this parameter. The Asian Institute of Technology (1983) has made reasonable estimates of annual erosivities for parts of Thailand. These data were used, along with average annual rainfall, to predict annual erosivity indices at other sites in northern Thailand (Ryan, 1985).

Two sites, Rong Kwang and Chiang Rai, were selected to represent the range of rainfall regimes in northern Thailand where the Project operates. An 11-year period was selected from the available rainfall data, and erosivity indices were then calculated for each year at both sites (Table 1).

Erodibility Factor (K)

Srikhajon et al. (1984) report the ranking of erodibility factors for soils in Thailand by the soil texture, region, and topographic location. The soils at Rong Kwang and Chiang Rai have a texture of sandy clay loam. The erodibility factor has been determined to be 0.21, which was then adjusted to 0.23, following local data evaluation (Ryan, 1985).

Topographic Factor (LS)

The relationship between slope length and slope steepness as discussed by Wischmeier and Smith (1978) was assumed to hold. Factors for 9 percent and 13 percent slopes were derived for slope lengths 60, 44 and 40 m. The first length, 60 m, was used for all land management, excluding contour banks. The other two elements were used for management with contour banks for 9 percent and 13 percent slopes, respectively. Table 2 lists the topographic factors for each slope-length combination.

Cover and Crop Management Factor (C)

The types of management evaluated in this study are:

1. Swidden: cropped once in 10-year rotation
   cropped once in 5-year rotation
   cropped once in 2-year rotation.

Table 1. Rainfall and erosivity index data for Rong Kwang (1973-1983 and Chiang Rai (1972-1982).

	Year	Annual rainfall (mm)	Annual Erosivity Index
Rong Kwang	1973	1167	793
	1974	960	528
	1975	1237	883
	1976	1039	629
	1977	809	334
	1978	1734	1520
	1979	753	262
	1980	1050	643
	1981	1239	885
	1982	824	353
	1983	1233	878
Chiang Rai	1972	1663	1429
	1973	1601	1349
	1974	1538	1269
	1975	2019	1885
	1976	1562	1299
	1977	2013	1884
	1978	2177	2088
	1979	1375	1060
	1980	1794	1597
	1981	2042	1915
	1982	1604	1353

Table 2. Topographic factors (LS) for slope-length combination.

Slope length (meters)	Slope (9%)	Steepness (13%)
60	1.65	2.4
44	1.40	–
40	–	2.3

2. Continuous rice
3. Rice-peanut system with reduced cultivation and mulch added (as recommended by the Project)
4. Forest: dry dipterocarp
   dry evergreen
   teak plantation

The swidden management duration is for the periods of 10, 5 and 2 years to show the effect of increasing population on the frequency of rice growing. It is assumed that when rice is not sown, dry dipterocarp forest management would apply.

The continuous rice management represents a situation when swiddening can no longer be practiced and farmers are forced to grow rice regularly at the same site.

Only the Project management uses soil conservation contour banks. The banks are installed at twice the bank-spacing interval (Buddee, 1985), and rice and peanut are sown in alternate 10-m strips between the banks. Rice straw mulch is applied after sowing of both crops to protect the soil until sufficient canopy can protect the soil. Cultivation prior to sowing is kept to a minimum of only one pass of a disc plow.

Forest management has been divided into two groups. One group consists of the dry dipterocarp forest to represent the vegetation prior to clearing and development and to represent the forest fallow in the swidden rotations. The other group is the dry evergreen forest representing the sown woodlot management of the Project and the teak plantation, an alternative commercial use of the land.

The cover and crop management factors for each of the 11-year study period and the source of the factor values are shown in Table 3.

Support Practice Factor (P)

The Project management is the only management in which this factor varies from 1.0. Ryan (1985) reports that the combination of the sowing of rice and peanut and alternate 10-m strips between contour banks reduces this factor to 0.08 at 4-5 percent slope. To adjust this value to 9 percent and 13 percent slope, 0.08 was multiplied by 1.2 and 1.6, respectively (Wischmeier and Smith, 1978). Thus 0.0096 and 0.128 factors were used.

Table 3. Cover and crop management factors (C) for the year-11 study period.

Management	Year										
	1	2	3	4	5	6	7	8	9	10	11
Swidden											
1 in 10 years[a]	0.280	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.280
1 in 5 years	0.280	0.064	0.064	0.064	0.064	0.280	0.064	0.064	0.064	0.064	0.280
1 in 2 years	0.280	0.064	0.280	0.064	0.280	0.064	0.064	0.064	0.280	0.280	0.280
Continuous rice[a]	0.280	0.280	0.280	0.280	0.280	0.280	0.280	0.280	0.280	0.280	0.280
Project[b]	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095
Forest[a]											
Dry dipterocarp	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064
Dry evergreen	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Teak plantation	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088

[a] From Srikhajon et al. (1984).

[b] From Ryan (1985).

Illustrative Computation

Using these values, the following calculation shows how the soil loss quantities in Tables 4 and 5 were determined. At Rong Kwang in 1973, for example, the following values are obtained:

R = 793 - - -	(From Table 1, Row 1)
K = 0.23 - - -	(Adjusted; from Ryan, 1985)
LS = 1.65 - - -	(at slope length of 60 m and 9% slope steepness; from Table 2)
C = 0.095 - - -	(For Project-recommended cropping, i.e., rice-peanut system with reduced cultivation and mulch added; from Table 3 at Year 1)
P = 0.0096 - -	(For a 9% slope steepness; project-recommended cropping system)

Substituting these values into the USLE

$$
\begin{aligned}
A &= R\ K\ LS\ C\ P \\
&= 793 \times 0.23 \times 1.65 \times 0.095 \times 0.0096 \\
&= .27
\end{aligned}
$$

This A value can then be converted easily into a quantity of soil loss per hectare once the area of the experimental plot is known.

RESULTS AND DISCUSSION

The USLE was applied using the factors shown in Table 3 for each of the 8 types of land management and for a period of 11 years. The cumulative soil losses are presented in Table 4 for Rong Kwang and Table 5 for Chiang Rai. The average soil losses are shown in Figure 1 for both sites.

Trends in soil losses from different land management types are the same at both Rong Kwang and Chiang Rai. Chiang Rai soil loss values are approximately double that of Rong Kwang as would be expected from the erosivity index values. The cumulative soil losses for the continuous rice management are highest at both sites. The values are not entirely unrealistic as soil losses of this order have been monitored on less erodible soil and flatter slope (Buddee, 1985).

The effect of shortening the swiddening rotation from once in 10 years to once in 2 years is shown in a 1.6 increase in soil loss at Rong Kwang and 1.8 increase at Chiang Rai. The difference in the

Table 4. Cumulative soil losses at Rong Kwang (ton/ha).

		Swidden			Continuous Rice	Project Cropping System	Forest		
		Once in 10	Once in 5	Once in 2			Dry Dipterocarp	Dry Evergreen	Teak Plantation
Slope 9%									
Year:	1973	84	84	84	84	2	29	6	26
	1974	97	97	97	140	4	32	10	44
	1975	119	119	191	234	6	54	16	74
	1976	134	134	206	301	8	69	20	95
	1977	142	142	242	337	9	77	23	106
	1978	179	303	279	498	14	114	34	157
	1979	185	310	306	526	15	120	36	165
	1980	201	325	322	594	16	136	40	187
	1981	222	347	416	688	19	157	47	216
	1982	231	355	425	726	20	166	49	228
	1983	324	449	518	819	23	187	56	257
Slope 13%									
Year:	1973	123	123	123	123	5	28	8	39
	1974	141	141	141	204	8	47	14	64
	1975	172	172	278	341	14	78	23	107
	1976	195	195	300	438	18	100	30	138
	1977	206	206	352	489	15	112	33	154
	1978	260	441	405	724	30	166	49	228
	1979	269	451	446	765	32	175	52	240
	1980	292	473	468	864	36	196	59	272
	1981	323	505	605	1001	42	229	68	315
	1982	336	517	618	1056	44	241	72	332
	1983	472	653	753	1191	50	272	81	374

Table 5. Cumulative soil losses at Chiang Rai (ton/ha).

		Swidden			Continuous Rice	Project Cropping System	Forest		
		Once in 10	Once in 5	Once in 2			Dry Dipterocarp	Dry Evergreen	Teak Plantation
Slope 9%									
Year:	1972	152	152	152	152	4	10	35	48
	1973	185	185	185	295	8	20	67	93
	1974	215	215	319	430	12	29	98	135
	1975	261	261	365	630	17	43	144	198
	1976	293	293	503	768	21	52	176	241
	1977	339	493	549	969	27	65	221	304
	1978	389	544	771	1190	33	81	272	374
	1979	415	569	797	1303	36	88	298	410
	1980	454	608	966	1473	41	100	337	463
	1981	500	655	1013	1676	46	114	383	527
	1982	644	798	1157	1820	50	124	416	572
Slope 13%									
Year:	1972	221	221	221	221	9	15	50	69
	1973	269	269	269	429	18	29	98	135
	1974	313	313	465	626	26	42	143	197
	1975	380	380	531	917	38	62	210	288
	1976	426	426	732	1118	47	76	255	351
	1977	492	717	799	1409	59	96	322	433
	1978	566	791	1121	1732	72	118	396	544
	1979	604	828	1159	1895	79	129	433	596
	1980	660	885	1406	2142	89	145	490	673
	1981	728	952	1473	2438	101	165	557	766
	1982	937	1161	1682	2647	110	180	605	832

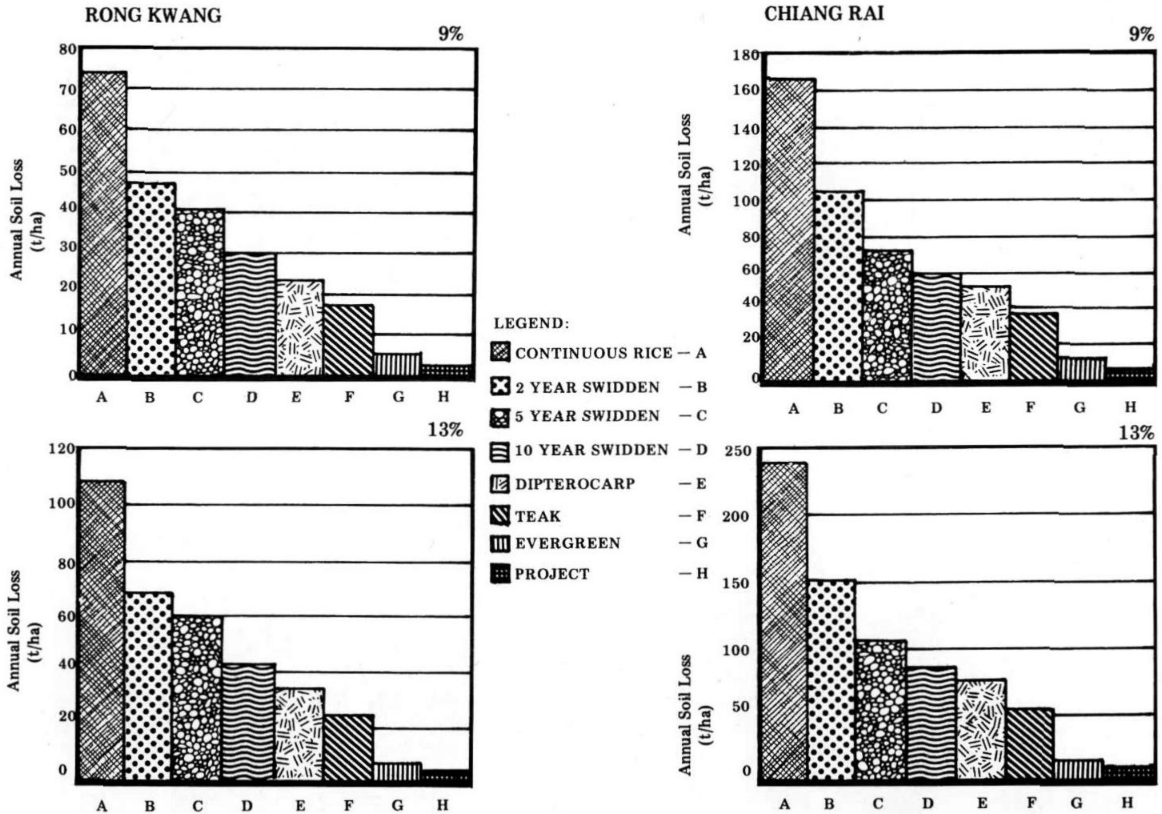

Figure 1. Average annual soil losses at Rong Kwang and Chiang Rai on 9% and 13% slopes for different land managements.

increases is due to the difference in the periods of erosivity used at each site. The soil losses from forest management were less than those from swiddening and continuous rice cropping. The effect of producing one crop of rice every ten years increased the soil loss by 1.5-1.7 times compared to that of a dry dipterocarp forest. The range is again due to differences in modeled periods at each site.

Using the C factors from Srikhajon et al. (1984), the land was placed under a dry evergreen forest, such as *Eucalyptus*, instead of placing it under dry dipterocarp forest. The land management that produced the least amount of soil loss was the Project-recommended rice-peanut cropping system. The lower soil losses indicate that a combination of crop and soil conservation earthwork measures is required to manage soil conservation adequately in these upland areas.

The soil losses that would occur in the clearing and development of the land to the required level for each of the management system modeled were not considered; however, this important area is receiving attention in the Project research program (Buddee, 1985).

CONCLUSION

The USLE was used to model soil losses from swidden, continuous rice cropping, Project-recommended cropping system, dipterocarp forest, introduced evergreen forest, and a teak plantation at two sites in northern Thailand. The two sites represented a low and high rainfall regime.

For the two slopes modeled, 9 percent and 13 percent, soil loss rankings for both sites are as follows (in the order of least to greatest soil loss contribution): project cropping system, evergreen forest, dipterocarp forest, teak plantation, swidden, and continuous rice.

The cropping system recommended by the Project and the establishment of woodlots will result in lower soil losses than from the present land management of the uplands.

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V.
Some Models of Agroforestry Systems

With the vast number of potential plant and animal species that could be put together in various types of combinations, there is an almost infinite number of agroforestry systems that could be theoretically set up. This vast number can be whittled down to a more manageable size when such considerations as farmers' preference for certain crop species, compatibility among species that are to be combined, and suitability of the preferred species to on-site soil and climate are taken into account. The number of candidate agroforestry systems may further decrease when tested for social acceptability and economic viability.

The two papers selected for this section were drawn from two models that were successfully introduced to and adopted by farmers in the southern Philippines, and for which one of the innovators (who is also one of the authors) received the prestigious Ramon Magsaysay Award for 1985. These models are not to be taken as universally applicable to the tropics. The objective of presenting them here is to examine in greater detail what elements these models possess that enable them to achieve the twin goals of site protection and amelioration, and which make them highly acceptable to hill farmers. It is anticipated that lessons could be drawn from them in designing other models for application to other types of situations.

SLOPING AGRICULTURAL LAND TECHNOLOGY: AN AGROFORESTRY MODEL FOR SOIL CONSERVATION

by

H.R. Watson and W.A. Laquihon[1]

ABSTRACT

The Mindanao Baptist Rural Life Center (MBRLC) developed and spread the agroforestry system termed "Sloping Agricultural Land Technology " (SALT) to help the small hillside farmers of Mindanao. The model has been tested both in demonstration and farmers' plots and has proved to be an appropriate land-use system, which the farmers can adopt to conserve their farms' topsoil and at the same time to generate steady income. The model's development from its initial conception to the present status is detailed in this discussion.

DEVELOPMENT OF SALT AT THE MINDANAO BAPTIST RURAL LIFE CENTER

Background of SALT

SALT grew out of problems that farmers expressed to the MBRLC staff in formal meetings, as well as during on-the-farm visitations.

Low and declining farm yields were the foremost problems mentioned. Corn production on hillside farms had dropped in ten to twelve years from 3.5 to .5 tons/ ha/cropping. Yields of other crops such as banana, coffee, coconut, and fruit trees had also dropped 100-200 percent over the same period. The farmers stated the main reason for low yields was soil erosion. They also expressed the need for better income distribution throughout the year. There were times during the year when a family had no money or food since they

[1]Director and Assistant Director/Supervisor, Training and Extension, respectively, Mindanao Baptist Rural Life Center, Bansalan, Davao del Sur, Philippines.

depended on a one-crop farming system. Another problem was a lack of ready cash for fertilizers, insecticides, and seeds of improved varieties of corn and other crops.

Recognizing these problems, the MBRLC developed SALT to help the upland farmers of Mindanao. SALT is conceived to (1) conserve the soil, (2) rebuild the soil, (3) increase crop yields, and (4) be simple enough for the average Mindanao farmer to employ on land with a 5-25° slope. It is basically a method of growing field and permanent crops between 3-m to 5-m wide contoured rows of *Leucaena*. *Leucaena* seeds are thickly planted in double rows to make hedgerows. When a hedge is 1.5-2 m tall, it is cut down to about 40 cm, and the cuttings (tops) are placed in alleyways to serve as organic fertilizers.

SALT is a diversified farming system which can be considered agroforestry. Rows of coffee, banana, and citrus are dispersed throughout the farm plot. The strips not occupied by permanent crops are planted to annuals such as corn, soybean, peanut, or mung bean and then again to corn. This cyclical cropping provides the farmer some harvest almost year-round. The average income from a hectare of SALT farm worked on by one family is approximately ₱1,000 per month if the farmer follows instructions carefully.

A farmer can grow varieties of crops that he is familiar with on the SALT farm. New farming techniques can be adapted to SALT. If farmers leave land fallow, the *Leucaena* will continue to grow which may later be harvested for firewood or charcoal (see Figure 1).

The advantages of SALT are that it is a *simple, applicable, low-cost,* and *timely* method of farming hilly lands. It is a technology developed for farmers with few tools, little capital, and little training in agriculture. Contour lines are run by using an "A" frame transit that any farmer can learn to make and use. *Leucaena* seeds can be collected from roadsides or other places in the village. Old farming patterns can be utilized in the SALT system.

The MBRLC is basically a training center for small hillside farmers; research and testing are not major emphases of the Center. The testing and research conducted by the Center are mainly for the purpose of guiding the staff in developing projects for the farmers.

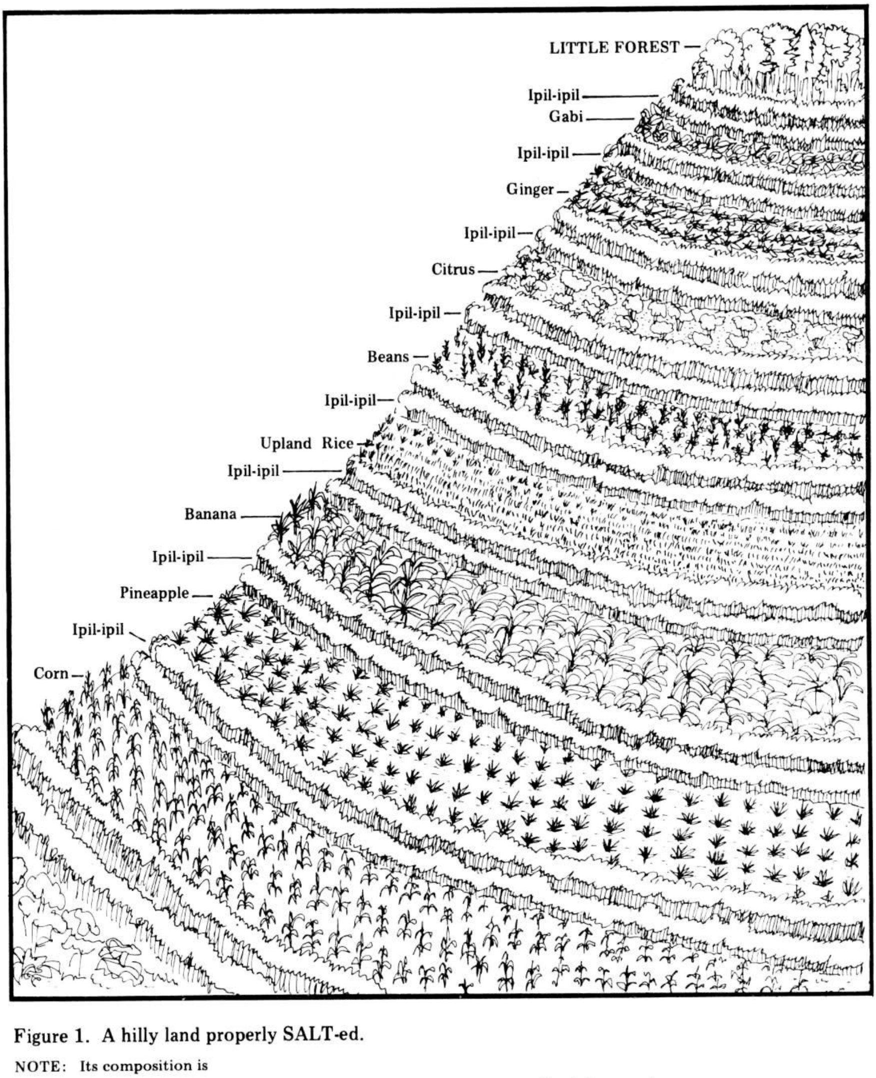

Figure 1. A hilly land properly SALT-ed.

NOTE: Its composition is

(1) 20% *Leucaena* planted in double lines on contours distanced at 4-6 m apart,
(2) 25% permanent crops planted in every third strip, and
(3) 55% nonpermanent crops planted between strips of permanent crops.
All food crops are only suggestive.

The First SALT model

The criteria for creating and establishing the model are the following:

1. Adequately controls soil erosion.
2. Helps restore soil structure and fertility.
3. Efficient in food crop production.
4. Applicable to at least 50 percent of hillside farms.
5. Can be duplicated readily by hillside farmers with the use of local resources and preferably without making loans.
6. Culturally acceptable.
7. Has the small family as the focus, and food production as the top priority; fruit trees, forest, and others are secondary priority.
8. Must be workable in as short a time as possible.
9. Should require minimal labor.
10. Economically feasible.

In 1978 a hectare of land was selected as a test site at the MBRLC. It is typical of the surrounding farms: slope steeper than 15°; has been farmed for five years or more; soils similar to those of most farms in the area. Contour lines were established carefully and then alternating strips were planted to corn, leaving every other strip uncultivated to help control soil loss until the ipil-ipil was large enough to hold the soil. The first crop of corn was harvested in late 1978.

Empirical Observations from the First SALT Model

Corn yields of the model and local farms were compared. Labor inputs and soil loss were also monitored (Table 1).

As indicated in Table 1, SALT requires more labor than conventional farm methods, but the increase in yields compensates for this additional labor. Furthermore, the use of 100 percent of annual work hours for SALT farm can be viewed positively as increased employment for farmers. The tools needed to cultivate the SALT farm are the same as those used by the local farmer: carabao, plow, harrow, and long knife for cutting grasses. The hoe was introduced into the SALT system.

Table 1. Comparison of SALT model with a local farming system (1 ha).

Item	SALT Model	Local Farm
Labor (1 year)	100% of work hours	50% of work hours
Corn yields (2 crops per year)	2000 kg/crop[a]	500 kg/crop[b]
Soil loss	Slight	Severe

[a]Only leaves from *Leucaena* in hedgerows were used for fertilizer.

[b]The local farmer used neither commercial fertilizer nor *Leucaena* green manure.

Soil loss was measured simply by placing stakes along contour lines. The loss from the upper side of the alley and the accumulated soil on the lower side were measured. The amount of accumulated soil on the lower side was subtracted from the amount lost on the upper side; the difference is the amount of soil lost in the alley. On the local farm, the amount of topsoil that remained and in some cases coconut trees that grew in the field indicated how much soil had been lost.

By 1980 the MBRLC felt that SALT could adequately fulfill the following guidelines:

1. Simple enough for any hillside farmer in Mindanao to follow.
2. Applicable to at least 50 percent of hillside farmers in Mindanao.
3. Low cost in comparison with making bench terraces or conventional terraces.
4. Timely to save what little topsoil that remains.

Refining the Testing Program for SALT

The first few years of the SALT model, which later became known as Demonstration SALT, were spent in checking for adaptability of crops, and crop yields and did not emphasize profitability. In 1982 farm income was emphasized in the Demonstration SALT, and crops that would yield the greatest financial returns were tested.

By 1984 several test plots were already established: a Test SALT, a Hedgerow Test SALT, and an Animal Test SALT. These projects are described as follows:

1. **Demonstration (Model) SALT-1 ha (established in 1978)**
   a. Employs one worker.
   b. Uses minimal tillage (except in unusual situations).
   c. Uses hoe as the main tool for weeding.
   d. Costs and returns recorded on a monthly and annual basis.
   e. Open for visitation by farmers, agricultural technicians and other interested persons.

2. **Experimental SALT – .5 ha (established in 1980)**
   a. Corn is tested to learn the effect of various levels of *Leucaena* vs. commercial fertilizer on yields.
   b. Permanent crops with some improved practices are evaluated.
   c. Varieties of permanent and row crops in the SALT system are tested.
   d. Various ways of using crop residue to aid in controlling soil loss are tried.
   e. Pests and diseases in various crops are monitored.
   f. Soil loss is monitored.

3. **Test SALT – approximately 1/3 ha (established in 1984 and will last for five years)**

   The test area contains two SALT plots and two plots without SALT for comparison in the following areas:

   a. Labor inputs (man-hours per crop per year).
   b. Crop yields.
   c. Net income per year.
   d. Soil loss.
   e. NPK levels and soil pH changes.
   f. Organic matter percentage in the soil.

4. **Hedgerow Test SALT – approximately ¼ (established in 1984)**

   The objectives are the following:

   a. To test the adaptability of various legumes and nonlegume plants in their ability to grow and hold soil in a hedgerow or alley farming system.

b. To test the ability of various selected species to produce green manure or organic fertilizer that could be used in a SALT-type farming system.

c. To provide a seed bank for various types of legumes that have potential use in hillside farming (both animal and crop systems of farming).

5. **Animal SALT– ha (established in 1984)**

The main objective of the Animal SALT Test is to determine the feasibility of growing livestock by feeding the farm produce to animals (marketing grain through animals concept).

Corn Fertility Tests Conducted at Experimental SALT

Most of the tests pertaining to crops are related to corn because corn is the No. 1 food and grain crop of the hillside farmers in Mindanao. *Leucaena* occupies 20 percent in each of the three test areas.

Table 2 shows that there is a significant increase in corn yields when either *Leucaena* or commercial fertilizer is put into the system, although commercial fertilizer is used more efficiently by the corn plant than the *Leucaena*. The *Leucaena* treatments doubled the yield of the control plots.

Table 2. Effect of nitrogen sources on corn production (DMR-2 variety) over 8 croppings, Experimental SALT.

Treatment	Corn Yield (tons/ha)
No fertilizer	1.3
Leucaena leaves from hedgerow	2.7
Commercial fertilizer[a] + *Leucaena*	3.7
Leucaena = commercial fertilizer	2.6
Commercial fertilizer only	3.7
LSD % 5 level	0.7

[a]Commercial fertilizer applied = 100 kg N; 50 kg P/ha.

The two treatments using only *Leucaena* gave the same results because of almost identical inputs of leaf matter. The two commercial fertilizer plots yielded the same (even though one has *Leucaena* input) because 4.0 tons/ha is about the "genetic limit" of DMR-2 production.

The data in Table 3 indicate that there is no significant difference in corn varietal yields between DMR-2 and Tinigib in soils with low fertility. This suggests that it may be more economical for the small farmer to use local varieties until he can begin to afford the cost of using commercial fertilizer.

Table 3. Average yields (six croppings) of two corn varieties in a SALT experiment treated with *Leucaena* as fertilizer.

Variety	Yield (ton/ha)
Tinigib	1.99
DMR-2	2.18
Mean	2.09
LSD (0.05)	0.58

To determine if continuous corn production on the same piece of land using *Leucaena* leaves produced in the hedgerow would eventually deplete the soil of nutrients to the point that corn production would not be feasible, a four-year test was carried out. The analysis showed that there is a slight downtrend in production but it is significant (Figure 2). After ten continuous croppings of corn for 39 months (three crops of corn per year), the yield of March 1985 (which was at the end of the dry season) is slightly lower than the previous yield but significantly higher than the national average of about 1 ton and the local average of 500 kg.

Cost and Return Analysis – Demonstration SALT

The Demonstration SALT plot was in the beginning both a SALT model and a testing and observation project. Table 4 shows the gross incomes, total expenses, and net incomes for the years 1980 through July 1985. The average annual income for hilly land farmers in the area is about ₱4,000 with most farmers farming more than 1 ha of land. A farmer can triple his farm income by adopting the SALT system.

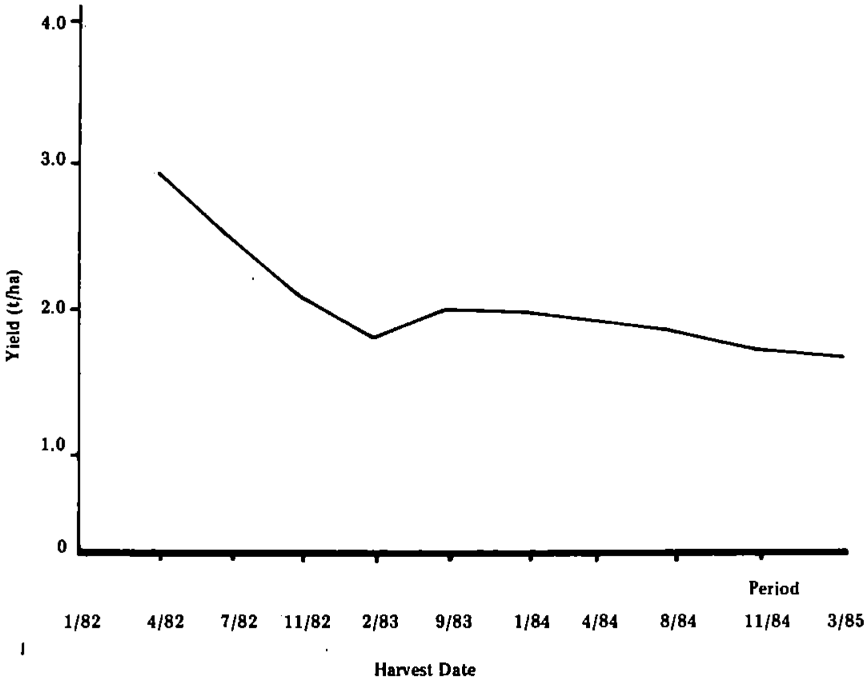

Figure 2. Average yields of continuous corn (DMR-2 variety) cropping with *Leucaena* cut from hedgerows.

Table 4. Costs and returns analysis of the SALT Demonstration Plot, 1980-1985 (in Pesos, ₱).

Year	Gross Income	Total Expense[a]	Net Income	Net Income/mo
1980	5,693.20	1,117.50	4,575.70	381.31[b]
1981	3,055.45	583.25	2,472.20	206.02[b]
1982	9,007.30	1,833.10	7,174.20	597.85
1983	6,471.33	1,228.55	5,242.78	436.90[c]
1984	14,287.36	1,741.75	12,545.61	1,045.47[d]
1985	8,344.95	1,151.31	7,193.64	1,027.66[e]

[a]For seeds, insecticides, fertilizer. No labor expense is included because the farmer used his own labor.

[b]Permanent crops were not yet producing.

[c]A 6-month drought occurred in Mindanao in 1983.

[d]Permanent crops began producing.

[e]From January-July (7 months only).

THE EXPANSION OF SALT

Opening SALT Model to the Public

From 1980 to 1984 the number of persons who visited the SALT project was monitored (Table 5).

Table 5. Number of SALT visitors by group, 1980-84.

Group	1980	1981	1982	1983	1984
Farmers	618	437	1423	874	1473
Technicians	225	60	123	143	169
Students	1329	750	871	771	811
Teachers/govt. officers	40	58	240	117	609
Out-of-school youth, housewives, and others	322	292	310	181	518
Total	2534	1597	2967	2086	3580

The figures in the table do not include casual visitors or those who received SALT training. The calculation is based solely on those who requested permission to visit and see SALT as part of a one-day educational tour to the MBRLC.

SALT Training Program

Three-fourths of a training session at the MBRLC is "HOE" or hands-on-experience, which is based on the principle of "What I do, I know." The "HOE" strategy of teaching seems effective as indicated by a steadily increasing number of SALT trainee-graduates (Table 6).

Teaching aids such as leaflets, manuals, bulletins, flip charts, and slides were developed. In 1980 SALT became one of the 37 training courses available at the MBRLC.

Table 6. Number of SALT trainings and graduates by year.

Year	No. of Training Groups	No. of Graduates
1980	5	79
1981	15	330
1982	24	784
1983	30	640
1984	44	872
Total	118	2705

The numbers in Table 6 do not include the SALT trainings conducted outside the MBRLC or at BOOST (Baptist Outside-Of-School Training) programs. SALT is one of the core courses at BOOST, which are now located in three provinces in Mindanao.

SALT training outside the MBRLC is conducted by the Center's extension workers upon requests of public and private organizations, institutions, and groups. The usual duration of a SALT training is 3-5 days for a group of 15-20 persons. About 80 percent of the SALT trainees were farmers and the rest were technicians, students, government officials, and others.

Developing SALT in Nearby Local Hillside Farms

1. SALT Farmer-Cooperators

In 1981 twelve hillside farmers around the MBRLC became the pioneer SALT farmer-cooperators. Out of thirty who were invited to a one-day SALT training seminar, twelve volunteered to try the SALT idea. Support in terms of seeds and materials worth ₱500 as well as visitations by extensionists were facilitated. In 1982 two dropped out, with transfer of residence and lack of time as the reasons given.

2. Response of Farmers

Thousands of farmers have visited the Demonstration SALT. None of them has criticized the system. On the other hand, not all of these visitors established a SALT project.

Presently there are 32 local hillside farmers near the MBRLC who are using SALT on their farms. Except for the original twelve farmer-cooperators, most of them have received no financial support in terms of seeds or materials from the MBRLC. One young farmer who visited the Demonstration SALT started SALT on his farm with no training at all. After two years, three other farmers adjacent to him put up SALT projects with the assistance of one of MBRLC's extension agents. In most cases farmers need encouragement and a technician must visit their farm and assist in the layout of contour lines.

3. Modifications of the SALT System

A SALT project, which follows the recommendations, will have about 20 percent *Leucaena*, 25 percent permanent crops, and 55 percent nonpermanent crops, based on area (see Figure 1). Several variations have been observed:

a. Row Crop SALT System – The farmer only plants annual crops such as corn, beans, or other row crops in the alleys. This system may be more economical for the farmer in the short run, but the recommended practice is that permanent crops be planted in every third or fourth alley. Some farmers say they do not own the land; hence, they do not want to plant permanent crops.

b. Permanent Crop SALT System – The farmer plants all the alleys to perennials such as banana, coffee, or fruit trees.

c. Almost all SALT projects are some form of variation of the Demonstration SALT at the MBRLC.

4. **Some Common Problems Found in SALT Projects**

a. One line of *Leucaena* in the hedgerow instead of two. Some farmers feel that double rows of *Leucaena* take up too much space and plant only one row in the hedgerow. The MBRLC's experience showed that one hedgerow cannot do an adequate job of holding the soil. Also, the *Leucaena* leaves used for fertilizer are reduced by about 50 percent, which adversely affects crop yields.

b. Some farmers feel that the hedgerows should be spaced over 6 m. Some farmers place the hedgerows 10-20 m apart. The most effective way to overcome this problem is for the extension agent to visit the farmer and review the reasons for close hedgerows, which is related closely to the degree of slope.

c. Hedgerows are not planted along contours; straight lines are run across the hill and the width of the alleyways is uniform.

d. *Leucaena* is not planted densely enough in the hedgerow.

e. Technicians do not understand the SALT system well before teaching farmers or laying out demonstration projects, resulting in poorly constructed SALT projects.

f. Lack of *Leucaena* seeds.

g. Failure to weed and clean around the hedgerow while the *Leucaena* is still young. Young *Leucaena* can hardly compete with some types of weeds and grasses; thus, growth is repressed and productivity of the project is delayed.

h. Stray animals eat the young *Leucaena*. (It is better to have several farmers in a cluster to begin SALT projects rather than one isolated farmer).

i. On very acid soils *Leucaena* does not grow well. The MBRLC is presently testing other legumes and an acid-tolerant *Leucaena*.

j. *Leucaena* does not perform well on heavily eroded clay soil or on soils with a hard plan near the surface. A well-prepared planting furrow sometimes will overcome this problem.

k. Some farmers expect SALT to be a miracle system: little work, high income. Once established, no further work or development is needed.

Difusing SALT Island-Wide

In 1982 SALT was diffused throughout the island of Mindanao. Baptist churches and their entities were made points of entry for SALT. Specific church programs of operationalizing these were:

1. **HELP (Help Eroded Land Produce)** which set up a 1 ha SALT model with qualified cooperators. These SALT demonstration farms were used as training sites for given areas. When fully functional the material aid granted to each farm is worth ₱2,000. Presently there are six HELP cooperators in four provinces.

2. **BOOST-SALT**, which follows up to their home farms the Baptist Outside-of-School Trainees. When qualified, a BOOST trainee graduate can avail of aid grant of *Leucaena* seeds and materials worth ₱500 for establishing a SALT project. Presently there are fifteen BOOST-SALT cooperators in eight provinces.

3. **CFC-SALT**, which sets up SALT, with grant aid of *Leucaena* seeds only worth ₱200, for any qualified member of the Christian Farmers' Club (CFC). There are now 106 SALT cooperators in 163 CFCs throughout Mindanao.

Diffusing SALT Nationwide

Many public and private organizations believe in the potential of SALT for upland development. These organizations voluntarily picked up SALT and diffused it to their clientele. Table 7 shows the organizations and the year their representatives were sent for SALT training at the MBRLC and their present estimated number of SALT cooperators. The Philippine-Australian Development Assistance Program (PADAP) of Zamboanga del Sur, the United States Agency for International Development-Agricultural Education Outreach Project of the Ministry of Education, Culture and Sports (USAID-AEOP-MECS) and the Ministry of Human Settlements' Kilusang Kabuhayan at Kaunlaran (MHS-KKK) were the first three strong implementors of SALT.

Table 7. Organizations that adopted SALT and their SALT cooperators.

Organization	Year	Number of SALT Cooperators
Federation of Free Farmers (FFF)	1981	15
Peace Corps Volunteers (PCV)	1981	30
Bureau of Forest Development (BFD)	1981	15
Southern Philippines Development Authority (SPDA)	1982	5
Ministry of Human Settlements Kilusang Kabuhayan at Kaunlaran (MHS-KKK)	1982	100
Philippine-Australian Development Assistance Program (PADAP)	1982	700
Ministry of Agrarian Reform (MAR)	1982	10
British Volunteers	1982	10
U.S. Agency for International Dev't.– Agricultural Education Outreach Project-Ministry of Education, Culture and Sports (USAID-AEOP-MECS)	1983	150
Farming Systems Development Corporation (FSDC)	1983	10
DMSF	1983	20
FTC-PTC-RD	1983	10
Ministry of Agriculture and Food (MAF)	1984	10
OMF	1984	20
National Electrification Administration (NEA)	1984	5

Internationalization of SALT

Several countries and international organizations are aware of SALT. Representatives from the World Bank, FAO, USAID, and countries such as Nepal, Indonesia, Thailand, Taiwan, Japan, Malaysia, Bangladesh, India, Nigeria, Australia, New Zealand, and the United States have visited SALT projects. Indonesia has translated the SALT manual into Bahasa Indonesia.

Recognition of SALT

Some institutions have documented SALT while others have recognized it. The PCARRD featured SALT in its March 1984 issue. The Ministry of Human Settlements (MHS) produced a video tape of SALT. The MECS, through its Agricultural Education Outreach Project (AEOP) with U.S. AID assistance, produced an excellent set of slides entitled "SALT: AEOP's Commitment to the Hillylands."

In 1984 two national awards were given in recognition of SALT. Barangay Kinuskusan of Bansalan, Davao del Sur – the birthplace of SALT – was adjudged *national* winner in "indigenous technology development" in the MHS-Rotary Club of Makati's "Annual Barangay Kaunlaran Contest." In May 1984 the Crop Science Society of the Philippines (CSSP) in its annual conference held at the Mariano Marcos Memorial State University (MMSU) and the Philippine Tobacco Research and Training Center (PTRTC) in Batac, Ilocos Norte, presented the MBRLC the "Technology Developer of the Year" award for its SALT system.

In 1985 the director of the MBRLC was awarded the 1985 Ramon Magsaysay Award for International Understanding for encouraging SALT use internationally.

CONCLUSIONS

The MBRLC staff concluded from observations, experiences in working with SALT for seven years, and tests conducted at the experimental plots that SALT can adequately reduce soil erosion and can restore moderately degraded hilly lands to a *profitable* farming system operated by a typical hilly land farmer. The holding of topsoil by the hedgerows of *Leucaena* and by permanent and cover crops, the recycling of crop residues, the nutrients furnished (namely, NPK) by the *Leucaena* leaves grown in the hedgerows, and minimum tillage account for the success of SALT.

The MBRLC recognized that SALT is not a perfect farming system. There is not and never will be one system for all farmers. SALT is not a miracle system nor a panacea. To establish a 1-ha SALT requires much hard work and discipline. There is no easy way. It takes three to ten years to deplete the soil of nutrients and to lose the topsoil; no system can bring depleted, eroded soils back into production in a few short years. Soil loss leads to low yields and poverty, but land can be restored to a reasonable level of productivity by using SALT.

Some Suggested Research Projects Related to SALT

1. Proper intervals of contour hedgerows to give adequate soil protection and adequate organic fertilizer.

2. Various tree species of hedgerows for different types of soil and pH range, and for compatibility with different intercropped annuals.
3. Crop yield influence by placing *Leucaena* leaves on top of the soil vs. incorporating leaves in the soil in the SALT system.
4. Tests to determine more accurately soil loss under SALT system vs. no system or other systems of upland farming.
5. Determine optimum cutting of *Leucaena* in hedgerows for use as organic fertilizer on crops.
6. Determine cause of die-back of some *Leucaena* in the hedgerow after six to eight years.
7. Conduct genetic work on the selection of pure cultivars, cultivars suitable for SALT, and cultivars for leaf production.
8. Test feasibility of animal production with crop production in a SALT system.
9. Test feasibility of establishing resettlement areas in denuded areas using SALT in combination with forestry projects.
10. Test feasibility of 1 ha of SALT and 4 ha for tree farming in upland areas (national forests, etc.)
11. Continue to seek better methods of farming upland soils.
12. Test economic feasibility of SALT variations.
13. Research socioeconomic and other determinants of adopting hillside technologies such as SALT.

Recommendations

The nation considers itself in a state of emergency concerning deforestation and soil erosion. Therefore, the MBRLC strongly recommends that:

1. A hillside upland agroforestry research and training center be established in Southeast Asia with a satellite center in each nation. A center of this type seems the only hope for securing hills and forests from destruction.
2. Regional training centers be established in hilly areas with functional models of proven hillside farmers and agroforestry systems.

3. The national government create a committee to assess the present conditions of national forests and land degradation in order to integrate conservation into all levels of society.

FARMERS' INVOLVEMENT AND USE OF SIMPLE METHODS: AGROFORESTRY STRATEGIES FOR WATERSHED PROTECTION AND MANAGEMENT

by

W.G. Granert and W.Q. Sabueto[1]

ABSTRACT

The paper discusses watershed management activities and techniques used as well as problems encountered by the World Neighbors Project in Cebu Province, Philippines. For effective watershed management, it is necessary that the users of the watershed resources, including upland farmers, be directly involved in soil protection and conservation activities both to improve hydrologic conditions in the watershed and to maintain the productive capacity of the upland farms. Simple conservation techniques and tools should be devised and imparted to the watershed inhabitants.

INTRODUCTION

A watershed in composed of many parts, all intertwined to form a complex, functioning system. In the Philippine setting, as in many developing countries, the individual farm has been added to the natural system. These artificial structures or agroecosystems are now replacing much of the natural system that has been in existence over a long period. If watershed amelioration is to take place, these small individual farms must be the starting point for activities that will eventually protect the entire area.

A key to ensuring the regeneration, protection and maintenance in a watershed is to involve the upland farmers and to keep initial activities simple and on a small scale. This means that the implementor has to understand fully why he is undertaking the effort and be able to do it even if all results may not be immediately apparent.

[1]Project Advisor and Project Coordinator, respectively, World Neighbors Soil and Water Conservation Project, Cebu, Philippines.

The following discussion is about the experiences of a non-goverment organization (NGO), the World Neighbors Soil and Water Conservation Project (hereafter referred to as Project), in Cebu, Philippines. The project started in 1981.

WORLD NEIGHBORS EXPERIENCES IN CEBU

Agroforestry Approaches

1. **Hedgerows.** These stuctures are vegetative strips planted across the hillside to slow down water runoff and function as a deposit area for eroded soil. Farmers lay out the contour planting lines, starting at the field's upper limit and continuing to the bottom. The recommended maximum vertical distance is 1.5 m between contour lines. Closer plantings depend on slope; on steeper areas the rows can be 3 to 6 m apart. For hedgerows used to generate fertilizer or animal fodder, five to 5 to 6 m apart is the masimum distance. Hedgerows are constructed with or without a canal.

a. **Species choices for hedgerow planting**

The project in Cebu uses *Leucaena, Gliricidia, Pennisetum,* and is currently testing *Cajanus cajan* and combinations of these species.

b. **Problems in implementation**

- *Wrong planting time.* The onset of the rainy season is the right time to start planting. Poor timing in planting results in stunted plants or poor survival during dry months.
- *Plant competition.* Too many plants per linear meter create competition for nutrients. In very poor soils this competition is magnified. When using *Leucaena* the Project recommends a triangular spacing with 10-25 cm on a side depending on whether it is planted on a slope or a flat area.
- *Lack of weeding.*
- *Seedling wash out.* Heavy rainshowers wash out planted seedlings, especially during early growth when roots are not long enough to hold the plant securely.

- *Failure to replant gaps in the line.*

- *"Contour line" not on the contour.* Farmers sometimes inaccurately mark the contour line which causes water in the canal to flow toward the low area. If enough rainwater accumulates, a breakthrough in the canal wall may occur.

- *Canal maintenance.*

2. **Soil fertility management.** Procedures for composting, green manuring, and nutrient cycling are taught to farmer-participants. Green manuring uses *Leucaena* or *Gliricidia* leaves incorporated into the soil prior to seeding field crops or vegetables. Legume rotation with field crops is also taught.

Understanding nutrient cycling forms an important aspect of the soil fertility management program. Practical application of the principles is demonstrated in establishment of zero-based grazing systems for cows and goats. Manure collected periodically is returned to the fields for use on fodder and food crops. Some farmers estimated that they have reduced the use of commercial fertilizer by as much as 50 percent since contour farming methods have been introduced.

Engineering Approaches

The Project has been relatively successful in implementing the use of simple tools and structures in water and conservation works. These are described below.

1. **Use of simple tools and labor-saving devices.** Transits are precise tools used for establishing level (contour) lines on which contour hedgerows or contour canals are set up to minimize erosion. The A-Frame is a low-cost and simple device that can serve as a substitute and can be easily constructed with three pieces of round wood, a rock, and vines. The instrument is easily calibrated and requires about 15 minutes of basic instruction on how to use it. Two models are locally used: the World Neighbors' model (rock on a string as a plumb bob) and the Baptist Rural Life Center model (using a carpenter's level).

The most common hand tools used in conservation work are *bolo* (machete), *guna* (weeding blade with handle), digging bar, pick mattock, round-point shovel, and narrow- or broad-bladed hoe. The number of tools a farmer owns depends on his financial status and farm plans.

Draft animals such as carabaos and cattle are labor-savers when constructing drainage systems, contour canals, hedgerows, small dams, bench terraces, and in doing contour plowing. Using a carabao, a farmer can construct 67 linear m/day (0.5 m wide x 0.3 m deep); without it only 19 linear m/day can be made.

2. **Contour canals/drainage systems**

a. **Contour canals**

Contour canals form a major portion of the drainage system. They safely allow rainwater removal from sections of a field. The question in construction is: "Does the soil go above the canal or below?" Placing the soil above the canal requires more labor but forms a more permanent structure.

Canals may be joined to one another to form an irrigation system or water can be directed into a hillside fishpond. In areas where the water table is very high or underground seepage occurs, waterlogged soil is planted to field crops (e.g., corn, root crops, upland rice), and canals are constructed to intercept and drain away excess water.

Some farmers place soil traps (sedimentation pits) along a canal. These traps retain more water and settle down suspended sediments. The water in the trap is used to fill spray tanks or to water individual plants. *Azolla* (a green algae known as a rich source of organic fertilizer) may also be grown in the small ponds.

b. **Drainage systems**

Drainage canals are simple but require some labor in digging them. Most farmers excavate a canal (0.5-1.0 m wide and 0.25-0.50 m deep) along the field boundary. The canal follows the boundary regardless of slope. To slow down the water flow a series of check dams are set up at certain intervals in the canal. Napier grass (*Pennisetum purpureum*) or legume trees are planted along the canal sides. At present, the Project is introducing a reverse stair formation for use in uneven areas (Copijn, 1984).

The problems associated with drainage construction are the following:

- **Labor.** A shortage of household labor exists. To overcome this shortage, World Neighbors Project encourages the formation of indigenous work groups called *alayons* in Cebu (Granert, 1984).
- **Lack of maintenance.** Farmers usually do not clean areas behind check dams. The area is filled with soil and the stormwater overflows and carries away silt and organic matter.
- **Poor check dam replacement.** Some farmers lose much soil because of poor replacement of broken or rotten check dams.
- **Gully erosion.** Gullies often form along depressions in an upland and aggravate the erosion problem.

3. **Rock walls.** These structures are built where there is an abundance of rocks. An area about 1 m wide is leveled to provide a good base for the wall. Large rocks and stones are used for the base and wall, while smaller ones are filled in the middle. Farmers usually build rock walls with a 1-m base and a height up to 1 m. The walls taper slightly toward the top, which provide more stability.

Rock wall building is very laborious. The farmers can construct them at a rate of 14 linear m/day (1 m high, 1 m wide) provided the rocks are readily available or just 8 m if the rocks are to be brought in from a distance. Despite high labor input, rock walls are more permanent structures that require minimal maintenance. The rocks used in walls are generally cleared from the nearby fields, making field preparation easier. Also, the trees and grass planted for wall stabilization can be used as animal feed, firewood, fertilizer, and windbreaks.

4. **Check dams.** These simple structures slow down water flow on a hillside. The farmers construct check dams in drainage canals or in areas where gully erosion has begun. The structures are small, generally only 1 m high and up to 3 m long. They are made of tree cuttings and rocks that can stabilize eroding hillside drainage canals.

Check dams are made by driving a row of bamboo stakes or tree cuttings across the canal and then weaving grass or bamboo between the stakes. Brush, stones, or other available materials are piled behind the dam to act as a strainer. Water plows through the structure while silt and soil are retained. Trapped soil is periodically removed and placed back on nearby fields. The distance between check dams varies with slope. Generally 1 in every 5 m of slope distance has proved useful.

5. **Soil traps.** Sometimes called sedimentation pits, these structures also help slow down water flow on a hillside. Soil traps are placed at the bottom of contour and drainage canals at the rate of 1 for every 15-20 m of canals.

Combination of Agroforestry and Engineering Techniques

1. **Hedgerows without a contour canal.** Generally, farmers will plow (or manually prepare) a 1-m wide contour strip. The strip may need three plowings during a one-month period to remove *Imperata* grass. The row is cleared of weeds, holes or furrows dug, and then planted.

2. **Hedgerows with a contour canal.** The canal should be about 0.5 m wide and just as deep. Some farmers reduce the depth to 0.3 m. Canals are made in two ways:

- **Soil below the canal**

  The soil excavated from the canal is placed on the downhill side just below the canal. The mound is them leveled and the seeds, cuttings, or seedlings planted on the level surface. During the second year, when the plants are more mature and can protect the hillside from erosion, the canal is allowed to be filled in. At this time, a second canal is dug below the hedgerow, which will then remain as a permanent structure (World Neighbors, 1983).

- **Soil above the canal**

  The excavated soil is placed adjacent to the canal and above it. Grass, or in combination with legumes, is used to stabilize the riser created by the soil mound; otherwise, most soil will eventually fall back into the canal. The Project uses Napier grass with *Leucaena* or *Gliricidia* in various planting schemes. The canal is not redug in the second or third year and requires less cleaning after the riser is stabilized.

The use of canals is definitely more advantageous than no canal at all because (1) the canal (with soil below) can help prevent the washing out of the contour plantings and (2) rainwater caught in the canal can be used to supply moisture to young seedlings or cuttings. The ridge created by placing the soil above the canal forms a holding area that functions as a small canal. This also protects and supplies moisture to seedlings.

3. **Contour plowing with hedgerows.** Contour plowing is difficult; it requires some practice before a farmer learns how to divide his field into manageable sections. General guidelines have been developed to assist a farmer in plowing.

4. **Surface water management.** Rainfall accumulation is done with the use of the following methods:

a. Contour canals with compartments or blocked exits

b. Soil traps or sedimentation pits

c. Organic residues as fertilizers

d. Check dams

e. Cover grass such as *Centrosema, Pureria* (kudzu), *Calopogonium*, and *Desmodium*

f. Mulches (Granert and Cadampog, 1980; Principle, 1976)

g. Hillside fishponds.

LAND TENURE: A KEY TO IMPLEMENTATION

Land tenure is a very important factor in implementing permanent soil and water conservation projects. On public forest lands some farmers are hesitant to plant trees in hedgerows because they are afraid that the forest agency may claim the area or stop them from cutting the trees when they mature or begin to shade the field. Some landlords do not want permanent improvements such as terraces because these will provide evidence of occupancy on which the farmer can base his claim.

CONCLUSION

This paper discussed some activities, techniques, and problems that have been used and encountered since 1981 in the Cebu project of the World Neighbors Soil and Water Conservation Project. A major point to stress is that people must play a major role in watershed protection, soil conservation, and maintenance of productivity. Those individuals who live in the area are closest to the problem. If protection and conservation are to take place, they are the ones to carry out the appropriate activities. Large amounts of capital input, expert planning, and law enforcement will help to do the job, but the major responsibility rests with the smallest unit – the individual upland farmer. As a resource manager, he will rehabilitate degraded areas and protect existing forests while earning an adequate livelihood in the process.

The watershed is the sum of its parts. The individual upland farm is one component. Concurrent with plans made and implemented by individual farmers, efforts should be made to study how adjoining or contiguous groups can cooperate to improve watershed stability and productivity. One cannot assume that farmers' cooperation will automatically take place; supporting policies and economic incentives are needed to enhance farmers' involvement.

At the same time, studies can be initiated to assist in planning overall drainage systems that will receive runoff from many farms, available choices of species for permanent plantings, watershed maintenance (involving farmers in off-farm work), and stabilization methods in uninhabited areas. In all activities, close consultation with the watershed occupants must be maintained.

Much research is still needed to devise systems, components, and methodologies for use by future planners. Some suggestions for research areas are the following:

1. Water infiltration studies, given a specific land-use stabilization method such as contour canals. How much water is actually being retained?
2. Feeding rates for various animals, given different hedgerow planting materials.
3. Techniques for rehabilitation of slopes greater than 45 percent.

4. Soil types versus soil erosion control measures. What techniques can farmers implement with minimum effort?
5. What is the cost of soil conservation to a given farmer? What is the value of 1 m^3 of soil saved?
6. Stabilizing species for terraces, risers, hedgerows, combinations of legumes and nonlegumes – which one in which system?

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VI.
Report of the Working Groups

Two Working Groups were created from among the Workshop participants to devote the last two days of the week (1) to synthesize the myriad of information presented by the authors and (2) to make recommendations for follow-up action regarding the protective and ameliorative functions of agroforestry systems.

WORKING GROUP I REPORT: PROTECTIVE ROLES OF AGROFORESTRY

During the workshop sessions, Working Group I concentrated on discussing problems and issues related to the protective roles of agroforestry as a land-use system. In a brief outline form, Group I enumerates the known attributes that contribute to this important protective function. Also included in the report are a brief listing and assessment of available information on the capacity of agroforestry systems to minimize site degradation, the known information gaps regarding this key role, the recommended areas of research to remedy these knowledge gaps, and the recommendations for establishment of a Regional (Asia-Pacific) Agroforestry Research and Training Center (RARTRAC).

ATTRIBUTES OF AGROFORESTRY LAND-USE SYSTEMS

Structural Attributes

1. Species diversity: Two or more species of plants, one of which is a tree species; this is one reason for the system's ecological stability.

2. Vertical and spatial (horizontal) structures:
   - Two or more canopy layers for greater efficiency in the use of solar energy for photosynthesis.
   - Spatial arrangement of trees and crops for greater efficiency in the use of moisture and nutrients, and therefore, higher productivity.

Functional Attributes (protective)

1. Canopy interception of rainfall, which reduces impact of raindrops on surface soil, thus minimizing soil erosion.

2. Production and accumulation of organic matters that improve soil structure, promote higher rate of infiltration, and reduce surface runoff, thus lessening soil erosion and sedimentation; improve soil water retention, thus conserving water.

3. Better nutrient cycling, thus reducing nutrient loss.

4. Physical barrier to soil erosion, thus minimizing soil erosion, sedimentation, and nutrient loss.

5. Shelterbelt and shading effects, reducing soil moisture loss.

6. Diverse species mix, therefore enhancing pest and disease prevention and control.

ASSESSMENT OF AVAILABLE INFORMATION

The workshop papers from representative Asia-Pacific countries reviewed available literature and presented new information from the authors' own research and extension projects. These were discussed to ascertain what information are now available in the region that are relevant to the protective function of agroforestry systems.

1. Quantitative information is available to a limited degree on erosion, sedimentation, and surface runoff in various tropical moist forests, tree crops, and grasslands; these can serve as benchmark information.

2. Shifting cultivation: Quantitative information is available, which shows that:
   - Intensive cropping (with annual crops) reduces soil fertility due to accelerated soil erosion.
   - Shorter fallow periods result in higher erosion rates and lower fertility and reduce the ability of the site to rehabilitate itself through nutrient pumping and cycling.
   - Cropping patterns and crops grown vary in their effects on soil erosion.

3. SALT (Sloping Agricultural Land Technology): This system, originated by an NGO in the southern Philippines, is observed to reduce soil erosion and loss of nutrients, as evidenced by an increase in crop productivity. No data are presently available to quantify this protective impact.

4. World Neighbor's PEPPER (People Educating People for Proper Erosion Rehabilitation) Agroforestry System: This system, like SALT, is observed to be working quite well in Cebu; no quantitative data are available. Empirical information points out that:
   - *Leucaena* hedgerows and the accompanying drainage canals and rivers reduce soil erosion.
   - *Leucaena* and *Gliricidia* hedgerows could reduce erosion by as much as 4 times the rate in areas without hedgerows (0.4 t/ha

vs. 1.6 t/ha). Surface runoff is 2 times less; there were also positive changes in soil chemical properties such as pH, OM, P, and K.

5. Taungya: Soil erosion rates ranged from 0.63 to 17.37 t/ha/yr. Very little quantified data.

6. Trees + permanent crops: No numerical data; qualitative information only.

7. Shelterbelts: No quantitative data; qualitative information only.

8. Intensive agroforestry: No data on soil erosion rates; CEC increased by 2.25 meq/100 g soil; BD decreased and NPK increased.

9. Bench terraces, contour canals, contour bench, cover crops all show appreciable reductions in soil nutrient losses as well as surface runoff; data not systematically quantified.

10. The incorporation of crop residues and leaves/litter makes soil fertility levels stable.

11. Tree-animal combination:
    - Goat grazing does not accelerate soil erosion, sedimentation, and nutrient loss if maximum stocking density is not exceeded.
    - Forage + tree production, managed on a cut-and-carry system: No data on comparative erosion rates with field grazing system.

12. The following agroforestry systems were observed to work in upland stabilization/rehabilitation and human resources development:
    - Taungya — Burma, Thailand, India
    - SALT — Davao del Sur, Philippines
    - World Neighbors' PEPPER — Cebu, Philippines and Indonesia
    - Trees + permanent crops that include the following tree-crop combinations: giant ipil-ipil + cacao, coffee; *Albizia* + coffee, abaca; *Gliricidia* + coffee, cacao; *Gliricidia* + black pepper; Benguet pine + coffee; *Bauhinia* + orange; *Cunninghania lanceolata* + orange; *Acacia* + tea; coconut + coffee + lansones; coconut + nangka.
    - Trees and forage (India)
    - Benguet pine + goats (Philippines)
    - Shelterbelts: bamboo shelterbelts (Taiwan); *Casuarina* (Taiwan, India); *Leucaena* (Philippines).

INFORMATION GAPS

The current available information, when compared with the information required to make full use of agroforestry systems as a means toward achieving ecological and socioeconomic goals, will indicate the types of information that are found wanting by the working group. Thus, the information gap is ascertained.

1. Soil erosion and deforestation or conversion of forests to other uses are very serious problems in most of the Asia-Pacific region, but quantitative information on the ecological and socioeconomic impacts is lacking in most countries. The lack of systematic assessment of these problems and their proposed solutions is the greatest gap in information that hinders the development of systems to reclaim, rehabilitate, and stabilize degraded uplands.
2. SALT: Numerical information is needed, particularly on the following:
   - Actual soil loss, nutrient loss or gain, pest and disease infestation, soil movement within the SALT area
   - Limitation of SALT with respect to slope
   - Other species suitable to hedgerows
   - Intervals of hedgerows as influenced by biophysical factors.
3. Taungya
   - Soil loss for different slopes, soil types, climate, species, and cultivation practices.
4. PEPPER
   - Soil nutrient loss or gain
   - Hedgerow establishment and management: narrow double hedgerow vs. wide double hedgerow, plant species.
   - Long-term effects of system: topography, soil stabilization, soil movement within the systems.
5. Intensive cropping system
   - Work is being done to monitor the system.
6. Silvipastoral
   - Soil/surface runoff on other systems
   - Tree understorey plant relationship

- Tree-animal relationship
- Nutrient cycling.

7. Trees + perennial crops
   - Soil erosion, sedimentation, runoff, nutrient and soil loss
   - Pest and disease protection
   - Compatibility between trees and crops.
8. Aquasilvicultural: No data
9. Shelterbelts: No data.

RESEARCH RECOMMENDATIONS

In Group I's assessment, important information gaps exist in the protective roles of agroforestry. If such deficiencies are not filled, policymakers, development planners, and land-use managers will face difficulties in formulating plans to use agroforestry as a total tool for ecological stabilization. Thus, the need exists for further research to fill the informational voids.

1. The magnitude and implication of deforestation and soil erosion in each country should be assessed. Areas where these problems are serious should be declared "disaster" areas and be given priorities in instituting rehabilitation programs.

2. A case study of SALT should be undertaken to evaluate the system with respect to its productivity, protection, and amelioration, including socioeconomics: more specifically, hydrometeorological studies; verification and pilot testing of SALT in other areas; hedgerow establishment to include species, distance, slope, and soil type; and pest infestation. This type of study is also recommended for all other systems known to be working in other areas.

3. Taungya
   - Quantification of soil and nutrient losses.
   - Other studies: soil management strategies for different slope groups, crop combination, cost-benefit analysis.

4. PEPPER
   - Case study of the system
   - Verification and pilot testing of SALT in other areas

- Application of other technologies: species; biological and organic fertilizer areas.

5. Intensive cropping system
   - Continue with work
   - Pilot test in other areas.

6. Silvipastoral
   - Hydrometeorological studies as affected by animal stocking rates, tree density, forage, grazing management.
   - Tree stand density and improvement practices to improve forage production: spacing, thinning, pruning.
   - Effects of trees in forage productivity and quality.
   - Effects of trees on animals and vice versa, including tree-animal parasite, tree weeds.
   - Nutrient cycling studies.
   - Economics.

7. Trees + perennial crops
   - Hydrometeorological studies
   - Survey of pest and disease problems
   - Others such as crop compatibility studies
   - Socioeconomics
   - Cultural management.

8. Aquasilvicultural: No information documentation of system and meaning effects on soil erosion, reduction in wind speed.

9. Shelterbelts: See foregoing comment.

RECOMMENDATIONS (DESIGN AND USE OF AGROFORESTRY SYSTEMS)

Implement simple and efficient agroforestry systems, which have the following characteristics:

1. Simple and economically feasible for small hillside farmers.

2. An efficient system to control soil erosion and sustain profitable farming for a long period of time for small hillside farmers.

3. A profitable system to provide an adequate standard of living for the farm family.

4. A simple system that allows the farmer to manage his resources adequately.

5. A system that can be expanded, modified or changed to meet changing situations.

The following research is recommended:

1. A comparative study on a hillside site on the socioeconomic condition of a farm and a community family before and after an agroforestry system.

2. A study on the stabilization effects of an agroforestry system as in-migration of tribal groups in the upland forest and watershed and out-migration to urban areas.

ESTABLISHMENT OF AN ASIA-PACIFIC (ASPAC) AGROFORESTRY RESEARCH TRAINING CENTER (ARTRAC) SPONSORED BY A CONSORTIUM OF FINANCIAL INSTITUTIONS AND FOUNDATIONS

1. Each nation should designate one of its existing institutions as a possible coordinating agency for ARTRAC.

2. ARTRAC should provide assistance to upland farmers on a shared basis.

3. Research programs should be initiated by ARTRAC to develop wasteland (disaster) areas through agroforestry projects.

4. Existing policies on upland development, utilization, and conservation should be evaluated as a basis for formulating more appropriate policies.

5. The East-West Center should support the synthesis of "state-of-the-art" agroforestry in each country in the ASPAC region.

6. The East-West Center should publish a quarterly review of projects and research on agroforestry in Asia and the Pacific.

7. International and regional institutions involved in agroforestry should coordinate their efforts.

8. The East-West Center should initiate the development of mechanisms to facilitate faster exchange of information between and among institutions, researchers, development workers, extension agents, and farmers.

9. Government and other institutions should organize and support periodic meetings among upland workers within the country and between the countries.

10. ARTRAC should initiate the inclusion of forest and soil conservation courses in the elementary, high school, and college curricula.

GENERAL RECOMMENDATIONS

1. In order to facilitate comparison and synthesis of information, it is strongly recommended that each study and project site be characterized as follows:
    - Climatic factors: rainfall, temperature, relative humidity, sunlight.
    - Topographic factors: slope, aspect, elevation.
    - Soil factors: texture, type, physical properties, chemical properties.
    - Socioeconomic factors.

2. Documentation and case study on an existing system should be undertaken.

3. Pilot testing and verification of existing systems in other areas are needed prior to dissemination and adoption.

4. Development of research methods and equipment that are simple, inexpensive, yet sufficient to provide desired information should be given high priority.

5. Assessment of each system in relation to watershed management objectives must be carried out.

GROUP I MEMBERS

Chairman : Marcelino V. Dalmacio

Rapporteur : Elizabeth B. Cruz

Members :

Pao-chang Kuo
T.G. Alexander
Samuel R. Peñafiel
William G. Granert
Harold R. Watson
Sawatdee Boonchee
Gem B. Castillo
Armando M. Palijon
Rogelio Colting
Benjamin B. Dimas
Hoanh Hoang Nguyen
Djoko Widodo

WORKING GROUP II REPORT: AMELIORATIVE ROLES OF AGROFORESTRY

During the workshop sessions, Working Group II reviewed the topics covered and papers presented by the participants and prepared a report related to the ability of agroforestry systems to ameliorate the status of upland sites. The brief, outline-type report is divided into four parts: state of the art on agroforestry's ameliorative roles, the identified research gaps on this aspect of agroforestry, recommended courses of action to narrow or eliminate these gaps, and general recommendations.

STATE OF THE ART

1. Some direct evidence have been presented on the ameliorative roles of some agroforestry systems. In this workshop, Dr. Cadeliña reported that an agrosilvicultural system improved the N, K, Ca, Mo, and soil Ph, but not P. Furthermore, Dr. Nguyen showed that parameters such as organic carbon, N, CEC, available P, exchangeable K, and bulk density were improved under a specific type of agrosilvicultural system. There are also some information on these aspects in existing literature.
2. Some direct evidence of the positive and negative effects of the silvipastoral system on sloping lands and plains are available. In this workshop, Mr. Peñafiel reported that grazing under a pine forest thinned to remove part of the crown and allow grass yields showed improved P, K, CEC, pH, and OM content, except. N. Livestock productivity was reported to be high. In India Dr. Deb Roy presented similar findings for plains under man-made silvipastoral conditions.
3. Most of the ameliorative roles of agrisilviculture, silvipastoral systems as they relate to improvement of soil structure, pest and disease control, reduction of soil temperature, and solar radiation and effects on other microclimatic conditions are presented in literature that are qualitative in nature; quantitative information is still limited.
4. Qualitative and quantitative data on the silvofisheries systems were not presented in the workshop.

RESEARCH GAPS

1. Research Methodology
   - There is a recognized need for standardization of methods of monitoring and analyzing data of agroforestry systems.

2. Ecology of Agroforestry Systems – Much still needs to be done in the following research areas:
   - Nutrient cycling under various agroforestry systems.
   - Beneficial micro- and macro-organisms that can enhance plant growth and productivity.
   - The role of agroforestry systems in improving microclimatic and hydrological conditions.
   - Correlating crop productivity with soil parameters such as nutrients, soil pH, soil structure, and soil temperature.
   - Energy input-output analysis of agroforestry systems.
   - Comparative study of the long-term effects of nonagroforestry and agroforestry systems.

3. Management Schemes
   - Determination of existing cropping patterns under various agroforestry systems and their possible improvements.

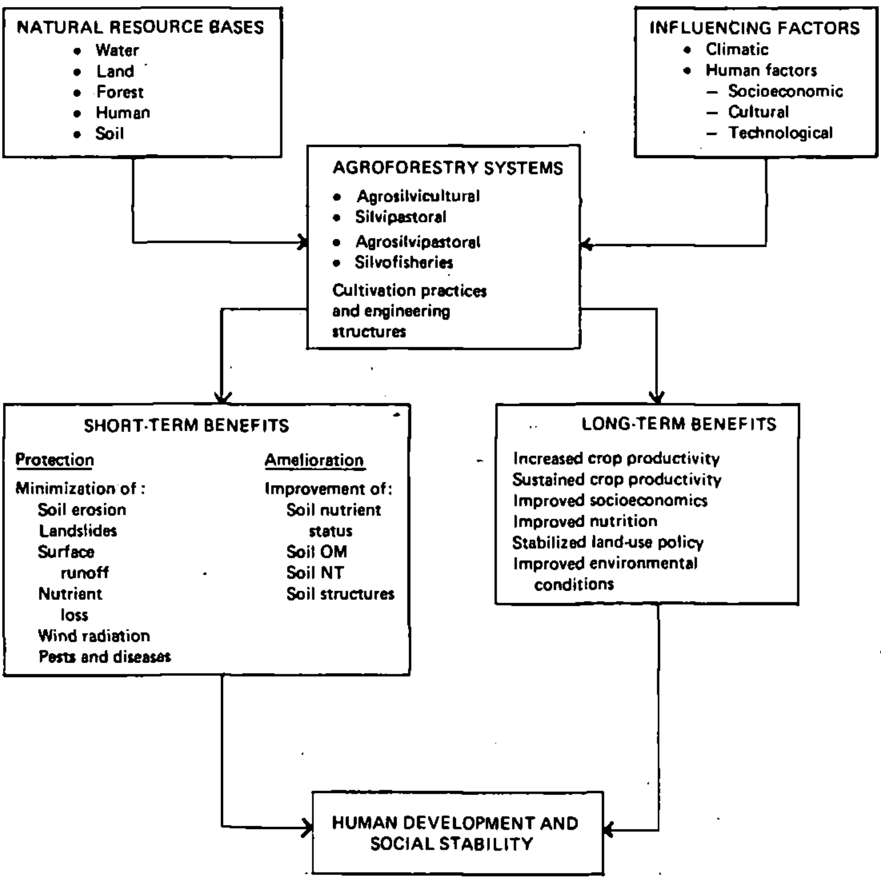
4. Protection
   - Effects of agroforestry systems on pest and disease control.

RECOMMENDED COURSES OF ACTION TO CLOSE RESEARCH GAPS

Research Gaps	Action/Suggestion: What to Do?	Action/Suggestion: How?
1. Standardization of research methodology to analyze agroforestry systems	Workshop on agroforestry research methodologies	Recommend the East-West Center to organize the workshop.
2. Correlating productivity with soil parameters such as nutrients, soil pH, soil structure, and temperature	Each center is encouraged to implement at least one of the research activities identified using standardized research methodology.	Request support from East-West Center, external donor agencies, and in-country research organizations available in the ARTRAC.
3. The effect of agroforestry on pest and disease control	There is a need for a data bank on all research conducted on various agroforestry systems.	Request East-West Center to put up such a data bank.
4. Identification of existing cropping patterns under various agroforestry systems and their possible improvements		

5. The effect of agroforestry systems on improving micro-climatic and hydrological conditions
6. Nutrient cycling under various agroforestry systems
7. Energy input-output analysis under various agroforestry systems
8. Comparative study of the long-term effects of nonagroforestry and agroforestry systems
9. Beneficial organisms that can enhance plant growth

CONCEPTUAL FRAMEWORK FOR THE PROTECTIVE AND AMELIORATIVE ROLES OF AGROFORESTRY



GENERAL RECOMMENDATIONS

1. To develop an agroforestry research network among Asia-Pacific countries with the East-West Center enhancing inter-country collaboration and strengthening donor agency-research network cooperation.
2. To conduct coördinated research within the network on the identified research gaps.
3. To conduct research on harvesting and postharvesting technologies, socioeconomic aspects, marketing strategies, and technology transfer in addition to the ameliorative roles of agroforestry.

GROUP II MEMBERS

Chairman : Reynaldo de la Cruz

Rapporteurs : Mercedes U. Garcia

Agnes C. de Jesus
Anna B. Cabatbat
Feliciano G. Calora, Jr.

Members : Bimal Koirala
A.K.M. Fazlul Huq
Sanusi Wiradinata
R. Deb Roy
Rowe V. Cadeliña
Uthit Taejajai
Samyos Kijkar
Romulo T. Anggangan
Francisco N. Bibal
Verne Obate
Ramon Sonido

VII.
List of Participants

REGIONAL WORKSHOP ON THE ROLES OF AGROFORESTRY IN SITE PROTECTION AND AMELIORATION

Funded by the East-West Center (EWC)

1. Dr. Rowe V. Cadeliña
   Director
   University Research Center
   Silliman University
   Dumaguete City 6501
   Philippines

2. Dr. Marcelino V. Dalmacio
   Chief
   Special Projects Division
   Forest Research Institute
   College, Laguna 3720
   Philippines

3. Mr. William G. Granert
   World Neighbors Project Advisor
   c/o Development Alternatives, Inc.
   Office of the Minister
   Visayas Avenue, Diliman
   Quezon City 3004
   Philippines/USA

4. Dr. Hoang Hoanh Nguyen
   Consultant on Soils and
   Agroforestry
   Forest Research Institute
   College, Laguna 3720
   Philippines/Vietnam

5. Professor Pao-chang Kuo
   Professor of Silviculture
   Forestry Department
   National Taiwan University
   Taipeh, Taiwan 107

6. Mr. Sawatdee Boonchee
Chief, Technical Section
Office of Land Development
Chiang Mai 50000
Thailand

7. Mr. Samuel R. Peñafiel
Senior Science Research Specialist
West Central Luzon Research Center
Forest Research Institute
Loakan, Baguio City
Philippines

8. Mr. Uthit Taejajai
Agricultural Scientist
TAWB Land Development Project
P.O. Box 147
Chiang Mai 50000
Thailand

9. Mr. Djoko Widodo
Watershed Management and Technology Center
Jakarta
Indonesia

10. Mr. Sanusi Wiradinata
Lecturer, Faculty of Forestry
IPB, Bogor, Jabar
Indonesia

11. Mr. Harold R. Watson
Director
Mindanao Rural Life Baptist Center
P.O. Box 94
Davao City
Philippines

Funded by EWC and UNEP

12. Dr. T.G. Alexander
    Scientist in Charge
    Division of Soil Science
    Kerala Forest Research Institute
    Peechi 680 653
    Kerala
    India

13. Mr. Bimal Koirala
    Visiting Professor
    Institute of Forestry
    Tribhuvan University
    Hetauda, Narayani Zone
    Nepal

14. Mr. Somyos Kijkar
    Sector Leader
    Mae Sa Integrated Watershed
    Project
    P.O. Box 200 (Mae Ping)
    Chiang Mai 50001
    Thailand

15. Mr. R. Deb Roy (International
    Development Research Center of
    Canada)
    Head, Agro-Silvipasture Division
    Indian Grassland and Fodder
    Research Institute
    Jhansi 284 003
    India

16. Mr. A.K.M. Fazlul Huq
    (FAO/Bangladesh)
    Community Forestry Project Manager
    and Conservator of Forests
    Bogra
    Bangladesh

17. Ms. Ana B. Cabatbat
    USAID/ASEAN Watershed Project
    UPLB/CF, College, Laguna 3720
    Philippines

18. Mr. Francisco N. Bibal
    Dean, College of Forestry
    MSAC, La Trinidad
    Benguet 0211
    Philippines

19. Ms. Elizabeth B. Cruz
    National Power Corporation
    Quezon Avenue Cor. BIR Road
    Diliman, Quezon City
    Philippines

20. Mr. Benjamin B. Dimas
    Highland Agricultural
    Research Center
    MSAC, La Trinidad
    Benguet 0211
    Philippines

21. Ms. Agnes C. de Jesus
    Watershed Management Coordinato
    Philippine National Oil Energy
    Development Co.
    P.O. Box 1031
    Makati Commercial Center
    Makati, Metro Manila
    Philippines

22. Mr. Armando M. Palijon
    UPLB College of Forestry
    College, Laguna 3720
    Philippines

23. Mr. Avenir Ramil
    Senior Watershed Officer
    Philippine National Oil Energy
    Development Co.
    P.O. Box 1031, MCC
    Makati, Metro Manila
    Philippines

From the Sponsoring Organizations

24. Dr. Cesar C. Jesena, Jr.
    Deputy Director
    SEARCA, College
    Laguna 3720
    Philippines

25. Dr. Celso B. Lantican
    Dean, College of Forestry
    University of the Philippines
    at Los Baños
    College, Laguna 3720
    Philippines

26. Dr. Filiberto Pollisco
    Director
    Forest Research Institute
    College, Laguna 3720
    Philippines

27. Mr. Napoleon T. Vergara
    Research Associate/Agroforestry
    Coordinator
    EAPI, East-West Center
    Honolulu, Hawaii 96848
    U.S.A.

28. Dr. Reynaldo de la Cruz
    Associate Professor
    UP College of Forestry
    College, Laguna 3720
    Philippines

    and

    Research Fellow
    EAPI, East-West Center
    Honolulu, Hawaii 96848
    Philippines

29. Dr. Mercedes U. Garcia
    Associate Professor
    UP College of Forestry
    College, Laguna 3720
    Philippines

Observers from the Philippines:

Romulo T. Anggangan
Gem B. Castillo
Rogelio Colting
Verne Obate
Ramon Sonido