PN-ABG-842
69487

Final Report

Covering Period: July 1, 1988 - Dec. 31, 1990

Submitted to the Office of the Science Advisor
U.S. Agency for International Development

SOIL PHOSPHORUS MOBILIZATION AND INCREASED CROP PRODUCTIVITY WITH AGRO-FORESTRY IN THAILAND

Principle Investigator: Dr. Carl F. Jordan
Institute of Ecology, University of Georgia,
Athens, GA 30602

Collaborator: Dr. Jiragorn Gajaseni
Biology Dept, Faculty of Science,
Chulalongkorn University, Bangkok 10500, Thailand

Project Identification No.: 7.109

Grant No. DPE-5542-G-SS-8005-00

A.I.D. Grant Project Officer: Dr. John L. Malcolm

Project Duration: July 1, 1988 - Dec. 31, 1990

Table of Contents

Executive Summary 2

Research Objectives 3

Methods and Results 3
- Agroforestry 3
  - Presentations & Pubs. 5
- Phosphorus Mobilization 7
  - Presentations & Pubs. 8

Impact, Relevance, & Tech. Trans. 9
Project Productivity 9
Future Work 10
Figures 11

Appendix
- Letters from outside reviewers with comments on project
- Publications
  - Decline of Teak Yield in Northern Thailand: Effects of Selective Logging on Forest Structure
  - Interplanting of *Tamarindus indica* L. in Teak Plantations
  - Phosphorus Adsorption by Highly Weathered Soils: Effects of C, N, P, and Biocides.
  - Soil Organic Matter and Phosphorus Availability in Highly Weathered Soils
- Symposium Program
- Book Proposal
- [redacted]

Executive Summary

For over 20 years, the Forest Industry Organization of Thailand has sponsored reforestation of teak in Northern Thailand, within the context of a "Forest Village System", a type of social forestry for landless peasants. Workers are hired to plant the teak, and are allowed to cultivate subsistence crops between the teak for the first two years of the plantation. While the system has been successful, there is room for improvement, both economically and ecologically. Part of this project was concerned with initiating experimental plantations with a higher diversity. Economically, this can provide an income between the second year, when corn and rice cultivation ceases, and 30-60 years, when the teak is harvested. Ecologically, a higher diversity system should more efficiently utilize environmental resources, resulting in a higher net productivity. At the end of the second growing season after establishment of the plantations, there was already noticable differences between experimental treatments.

A second objective was to investigate the role of decomposing litter in solublizing phosphorus bound by iron and aluminum in the soil, and rendering the phosphorus available for uptake by plants. In acid, tropical soils, fixation of P is a common limitation to crop and plantation productivity. If, as hypothesized, decomposing mulch is important in mobilizing bound P, then agroforestry systems in which trees provide mulch could have another advantage over conventional systems of annual monocultures. Results clearly showed that products of organic matter decomposition reduced fixation of soluble P by iron and aluminum. Experiments designed to determine whether organic acids produced by soil microbes could solubilize P already bound also produced positive results. However, we were not able to control the effect of pH. Other researchers have recently found that the process of ligand exchange in acid soils results in an increase in soil pH. This factor confounded the results of the our latter experiments.

A major emphasis of the project was to interact with leaders of the Forest Village System in Northern Thailand. During the course of the project, several workshops and meetings were held, in which the idea of more diverse plantations was introduced. Leaders were receptive, and suggested a wide variety of species that could be incorporated into the plantation system.

The project resulted in a symposium at the Vth International Congress of Ecology, at Yokohama, Japan, August, 1990. The proceedings of the symposium will be published in book form by Commonwealth Agricultural Bureaux.

Work at the Forest Village Plantations will continue, with students under the direction of Gajaseni, the co-P.I. of this project.

Research Objectives

1. To initiate experimental plantations, within the framework of the Thailand Forest Industry Organization "Forest Village System", that could improve the System ecologically and economically.

2. To investigate the role of decomposing litter in solublizing phosphorus bound by iron and aluminum in the soil, and rendering the phosphorus available for uptake by plants.

Methods and Results

This section is divided into two parts. The first deals with the innovative agroforestry system which was initiated as part of the A.I.D. sponsored project. The second concerns the work that tested the hypothesis that addition of organic matter to iron- and aluminum- rich soils can solubilize the iron- and aluminum- phosphates, and render the phosphorus more available for plant uptake.

I. Agroforestry

This research was undertaken to improve the system of agroforestry that has been employed by the Forest Industry Organization (FIO) of Thailand over the past two decades. The system is locally called "taungya". In this system, a teak plantation is established under the auspices of FIO, and peasant workers are employed to plant the seedlings. The peasants are allowed to grow subsistence crops between the teak seedlings for two years, until the teak canopy begins to close.

This system was established to solve several economic and social problems facing Thailand. First there was the problem of landless peasants, and their destructive slash and burn agriculture on government land. The second problem was the depletion of the teak forests, and the diminishing income due to teak. Teak is one of the most important generators of foreign exchange in Thailand. The taungya system gives employment and some subsistence to the peasants, and re-establishes the teak forests for future harvest.

Although the taungya system is a benefit to both the peasants and to the FIO, nevertheless, there are problems associated with the system. One problem is that the time period for a teak rotation is 30 - 60 years, while the length of time that peasants can crop the fields is only two years. This results in a long period of time without income production for a piece of land, and necessitates that peasants continually move, in order to crop newly established plantations. The second problem is ecological. Even-aged monocultures are less than ecologically ideal, in that the trees occupy one particular niche, and leave the rest vacant. Thus there is intense competition for light at one canopy level, but much available light at different levels. There is much competition between

roots and water at one soil depth, but little at other depths. This problem is often partially overcome through thinning, but this is an expensive operation, and is wasteful in that the trees that are thinned are teak that have been planted and cared-for.

The agroforestry experiment carried out as part of the AID-sponsored program was to establish experimental plots in which teak was planted farther apart, and economically valuable fruit trees planted in-between. This is in addition to the rice and corn planted the first two years. The fruit trees would begin producing fruit after 2-3 years, about the time that rice and corn cultivation ends. This would benefit the peasants in that it would give them an extended period of time in which to derive income or subsistence from the plots - up to 15 years. The fruit trees also are ecologically beneficial. First of all they produce side-shade, so that the teak grows tall, and has a good shape without lower branches. Then, after about 15 years, the teak overtops the fruit trees, shades them out, and kills them. Thus, thinning should be unnecessary. The fruit trees also exploit a variety of niches. They have different shaped leaves, different level of canopy, a different type of root network, and a different nutrient demand. Leguminous trees could fix nitrogen.

In March, 1989, prior to the first planting season, the two principal investigators of the project, C.F. Jordan and J. Gajaseni arranged a two-day workshop on ecological principles applied to taungya agroforestry. The workshop was coordinated through the Forest Industry Organization of Thailand, and was held at the FIO headquarters in Lampang, Thailand. The meeting was attended by leaders of approximately 25 forest village projects in Northern Thailand. Representatives of the Royal Forestry Department also attended. Photos taken during the workshop are presented in Fig. 1.

The forest village leaders were very interested in the idea of diversifying the taungya system, and they suggested that other fruit trees be tried, in addition to Tamarindus indica which was originally the only additional species contemplated. Therefore, in May, at the beginning of the 1989 growing season, a variety of species were interplanted in the new teak plantations. A diagram showing the experimental plots is given in Figure 2. The plots are part of the land belonging to the Forest Village project at Mae Moh, in the Mae Moh valley near Lampang, northern Thailand.

In plot A is the teak (Tectona grandis) interplanted with tamarin (Tamarindus indica) as originally planned. In plot B, the teak is interplanted with a fast-growing tree valuable for paper pulp, Gmelina arborea. In plot C, the teak is planted alone, and will be thinned at the appropriate time. This plot will give data as to how teak production on an area basis will be affected by interplanting. In plot D, teak and tamarin are planted together with Jack fruit, Artocarpus heterophyllus. In plot E, cashew, Anacardium occidentale was added to the previous three species.

In plot F, there were already teak trees of various ages, remnants of the original forest. This plot was maintained, in order to compare an uneven-aged teak plantation with conventional even-aged plots. New teak seedlings were planted within this uneven-aged plantation. In plot G, tamarind, jackfruit, and cashew, in addition to teak, were planted within an uneven-aged stand.

In plot H and I, trees were not planted. These plots were used to evaluate the production of annual crops in the absence of tree seedlings.

At the end of the first growing season, virtually all seedlings had become established. There was very little mortality. There were, however, differences in growth between species. The teak established normally, from the small cuttings transplanted from the forest village nursery garden. The tamarin established, but showed little growth. However, this is normal for the first year. The cashew seedlings immediately began a vigorous growth, while the jack fruit barely survived. Corn and rice did poorly, because of a relatively dry growing season.

In June, 1990, shortly after the beginning of the second growing season, the plots were surveyed again. The initial growth patterns were continuing, with the exception of the tamarin, which began a more rapid growth. The teak continued normally, the cashew was growing well, and the jackfruit poorly. Corn and rice grew better than in 1989, due to more rains. Measurements of total production is scheduled to take place late in 1990, after the end of the rainy season.

Presentations and Publications

Prior to the establishment of the AID-supported project, Gajaseni had carried out an analysis of a native teak forest near Lampang, Thailand, in order to better understand the structure of the forest. This study gave rise to the idea that it would be worthwhile to try a multi-aged plantation of teak as part of the experiment, instead of merely even-aged plantations. When the A.I.D. sponsored project began, Jordan suggested that a survey of the remaining stumps on the forest could give an indication of the effect of logging on the forest. This was carried out, and the data from both studies were combined and published. The article is:

Gajaseni, J. and C.F. Jordan. 1990. Decline of teak yield in Northern Thailand: effects of selective logging on forest structure. Biotropica 22: 114-118.

A reprint of this article is included as part of this report.

In Septermber, 1989, Dr. J. Gajaseni presented a paper entitled "Diversified Agroforestry Systems" at the Symposium on Agroforestry Systems and Technologies, Bogor, Indonesia,, sponsored by SEAMEO and BIOTROP.

In Oct. 1989, Dr. C. Jordan presented a plenary paper at the International Conference on Fast Growing Trees and Nitrogen Fixing Trees, in Marburg Germany. The symposium was sponsored by the Organization for oEconomic Cooperation (Paris). The title of Jordan's talk was "Interplanting of Tamarindus indica in Teak plantations.

In Dec. 1989, Dr. J. Gajaseni presented two papers to the 15th National Science Foundation of Thailand. The titles of the presentations were "Biogeochemical Rationale of Traditional Agriculture", and "Diversivication of Agroecosystems in Thailand."

A major presentation resulting from the A.I.D. sponsored progra was an entire symposium held as part of the Vth International Congress of Ecology, held at Yokohama, Japan, August 23-30, 1990. The program for the Symposium is included as part of thi report. A major focus of the symposium was the taungya system in Northern Thailand, its strengths and weaknesses, and the possibilities of success of the experimental system, initiated as part of the A.I.D. sponsored program. In addition, there were also papers describing taungya in other regions, as a basi on which to compare the Thai system. The symposium was very successful. There was a good group of attendees, and after every paper there was extensive discussion that was helpful to both the participants in the symposium, and the audience.

As a result of the Symposium, we were invited by a representative of the Commonwealth Agricultural Bureaux to submit a proposal for a book, based on the proceedings of the symposium. That proposal has already been submitted, and a cop is included as part of this report.

Throughout the project in Thailand, we kept in close contact with the A.I.D. mission, particularly with Mr. William Knowland who was very helpful in making us aware of other A.I.D. sponsored projects in Thailand that were relevant to our work. We had invited Knowland to participate in the symposium, but unfortunately at the last moment, he could not attend.

II. Phosphorus mobilization.

One of the hypothesized advantages of agroforestry over conventional cultivation and monoculture plantations in the tropics is the greater production of leaf litter, which results in greater amounts of leaf mulch and soil organic matter. As part of the A.I.D. sponsored work, we carried out a series of experiments designed to test the hypothesis that decomposition of soil organic matter results in increased mobilization of iron- and aluminum- bound phosphorus, thereby resulting in increased plant growth. Overcoming phosphorus limitations is a important consideration in much of the tropics. Much of the total soil phosphrous in acid tropical soils is bound by iron and aluminum.

The first experiment carried out as part of this project is entitled: "Phosphorus adsorption by highly weathered soils: Effects of C, N, P, and biocides" (attached). The results indicated that addition of carbon compounds reduced phosphorus adsorption by acid, weathered soils. The proposed mechanism is that organic ligands, produced by microbes feeding upon the organic compounds, chelated soluble iron and aluminum, and reduced adsorption sites for phosphate, thereby increasing the amount of P remaining in solution. The results suggest that in highly weathered soils, low in available P and high in exchangeable Al, cultivation techniques which increase soil organic matter will also result in higher levels of plant-available P. The increased soil organic matter reduces fixation of phosphorus entering the soil, either from inorganic fertilization, or from decomposition of superficial mulch.

A second experiment carried out as part of this project is entitled : "Mobilization of Phosphorus by Naturally Occurring Organic Acids in Oxisols and Ultisols". The previous experimen showed that products of organic matter decomposition could reduce fixation of P, in iron- and aluminum- rich soils. This experiment showed that in addition, products of organic matter decomposition, or microbial activity resulting from decomposition, have the capability to solubilize phosphate already bound by the iron and aluminum which constitute the cla structure of the soil. A manuscript describing this experiment is in preparation.

This second experiment showed that organic acids liberated from decomposing organic matter could solublize P bound in the soil. However, the question remains, will this newly solubilized P be available for plant uptake? To answer this question, a third experiment was carried out. Results showed that Manihot esculenta, a typical tropical subsistence crop, is capable of taking up P released through the action of citric acid, a typical product of litter decomposition. The results are described in the attached manuscript, "Soil Organic Matter and Phosphourus Availability in Highly Weathered Soils"

As part of the phosphorus mobilization project, there were two exchanges between institutions in Thailand, and the Institute of Ecology, University of Georgia. From November through December 1988, Nantana Ajchariyanivich of the Biology Dept., Chulalongkorn University attended a laboratory training workshop at the University of Georgia. The workshop was concerned with teaching methods of fractionation for analysis of soil phosphorus. The method was a principle tool used in the phosphorus mobilization project. Several improvements in the method were established, during the course of the project.

In the other exchange during the program, Miss Pornpimorn Vongsunsunee from the Soil Analysis Division, Land Development Department, Ministry of Agriculture and cooperatives, Bangkok carried out research and studies at the Institute of Ecology, University of Georgia. Her major project was to analyze changes in soil that occur during growth of a teak plantation. She found that following clearing of a site, and during the first two years of annual cropping, there was an increase in labile phosphorus in the soil. However, in the older plots, there was a gradual but steady decrease in available P, indicating that the teak was taking up P faster than the P was naturally replenished. As the trees get large, P could be a limiting factor. This is an important reason that teak plantation management should be modified, from the even-aged closely spaced plantations now generally established.

The effect of soil organic matter on P availability vis a vis the effect of changes in soil pH was an issue addressed as part of this project. Results of that study are included in the attached manuscript entitled "Soil Organic Matter and Phosphorus Availability in Highly Weathered Soils".

It is our conclusion that the more diversified systems established in the experimental plots described under "Agroforestry" above, will help alleviate a phosphorus deficiency. Improvements can come about both through the effects of organic matter on P availability, and increased soil pH. Long term-studies at the site by Gajaseni and his students will answer this question.

Presentations and Publications

Results of the phosphorus studies have been presented at the First International Symposium on Environmental Studies on Tropical Rain Forests, Manaus, Brazil, Oct. 7-13, 1990. A manuscript entitled "Soil Organic Matter and Phosphourus Availability in Highly Weathered Soils" will be published in the proceedings of that symposium.

A manuscript entitled "Phosphorus Adsorption by Highly Weathered Soils: Effects of C, N, P, and biocides" is undergoing revision for publication.

Impact, Relevance, and Technology Transfer

In the 22 years that the Forest Village System has been in existence in Northern Thailand, it has made significant progress in: reforesting degraded lands with economically valuable teak; providing employment and opportunities for subsistence cropping for landless peasants. Peasants, cooperating in the Forest Village System, are hired to establish teak plantations. These same people are allowed to plant subsistence crops between the teak for the first two years of the plantation.

Despite the progress, improvements in the system seem possible. This project established a series of plantations with a higher diversity of crops. This will result in a more sustainable economic income throughout a rotation of the plantation, and better ecologic utilization of environmental resources, with a possibly an increase in net primary productivity. As a result of workshops and meetings within the framework of the Forest Industry Organization, awareness of these ideas has been promoted.

The scientific capability in the laboratory of the Co-P.I., J. Gajaseni, has been improved. He was able to equip his laboratory in the Biology Dept., Chulalongkorn University, in Bangkok, and to hire a technician, and train the technician in P analysis. The project has facilitated future studies of the effect of agroforestry systems on economic and ecologic conditions.

Project Productivity

The project successfully completed the goal of establishing plantations with a greater diversity of interplanted crops amongst the principle species, teak. The project also was successful in disseminating this idea, through a series of workshops and a symposium.

The project also was successful in showing that products of organic matter decomposition are effective in preventing fixation of soluble P by iron and aluminum in the soil. However, we were not completely successful in establishing the cause of solublization of P already fixed, following addition of products of organic matter decomposition.

Future Work

Jiragorn Gajaseni, the co-P.I. on the project, now has the opportunity to follow the growth of the plantations through a normal rotation, which is 30-60 years. He will have a series of students from Chulalongkorn University carry out dissertation and thesis research on various aspects of the plantation ecology, during his career as University Professor in Thailand.

Through the workshops organized as part of this project, the Royal Foresty Dept. of Thailand has been brought into closer cooperation with the Forest Industry Organization. Gajaseni will continue to promote this interaction. Such cooperation will be highly beneficial, in as much as the Royal Forestry Dept. is highly interested in the social aspects of forestry, and can complement the commercial orientation of the Forest Industry Organization.

Literature Cited

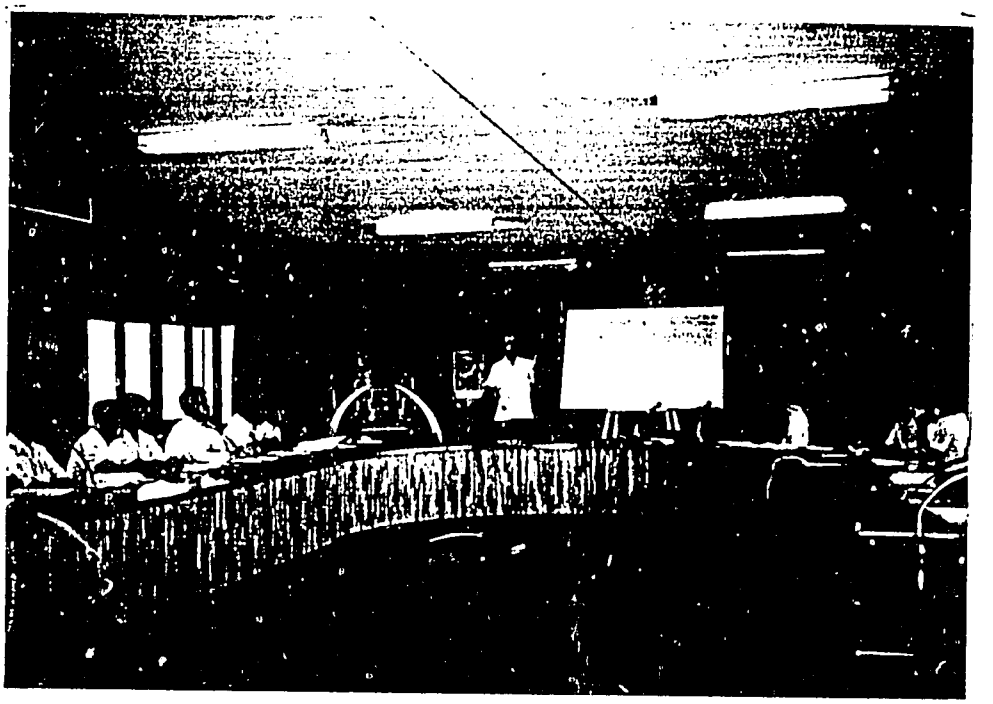
Literature relevant to this report is included in the citations of the attached manuscripts.

Figure Captions

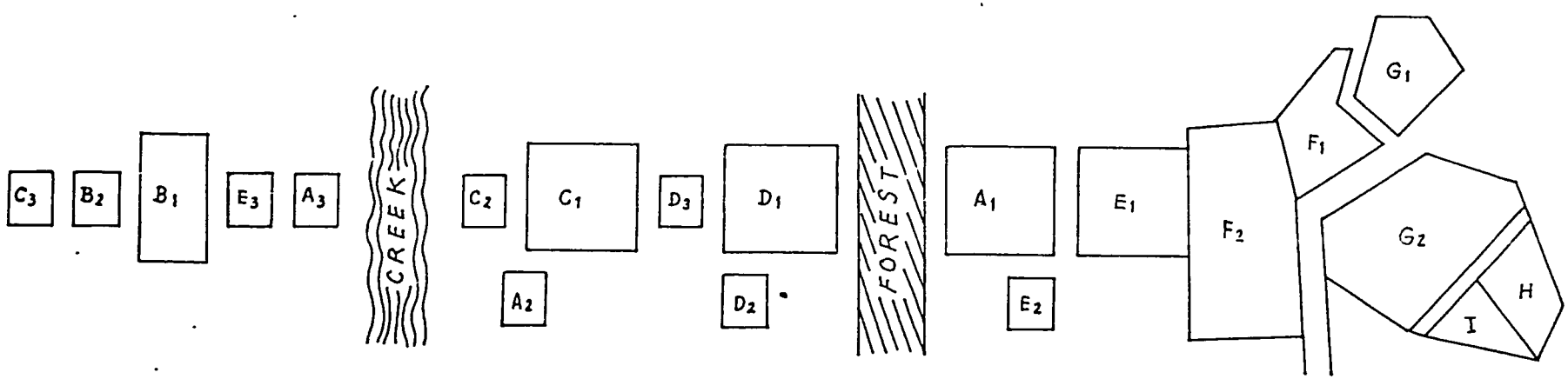
Fig. 1. Photos taken at the workshop on ecological principles applied to taungya agroforestry, March 1989, Lampang, Thailand. Top photo: Top photo; Jordan lecturing. Bottom photo; assembled group of forest village leaders (Gajaseni seated immediately to Jordan's right).

Fig. 2. Map of the experimental site at the Forest Village taungya site, Mae Moh valley, Thailand.

Original figures are in color. See first copy of report for color figures.



A = Tectona grandis + Tamarindus indica
B = Tectona grandis + Gmelina arborea
C = Control (Tectona grandis)
D = Tectona grandis + Tamarindus indica + Artocarpus heterophyllus
E = Tectona grandis + Tamarindus indica + Artocarpus heterophyllus + Anacardium occidentale
F = Multi-age teak plantation
G = Multi-age teak + Tamarindus indica + Artocarpus heterophyllus + Anacardium occidentale
H = Corn + Upland rice
I = Corn



Scale 1:2000

Appendix

Letters from outside reviewers with comments on project
Publications
- Decline of Teak Yield in Northern Thailand: Effects of Selective Logging on Forest Structure
- Interplanting of *Tamarindus indica* L. in Teak Plantations
- Phosphorus Adsorption by Highly Weathered Soils: Effects of C, N, P, and Biocides
- Soil Organic Matter and Phosphorus Availability in Highly Weathered Soils

Symposium Program
Book Proposal
Financial Report

BANARAS HINDU UNIVERSITY
Centre of Advanced Study in Botany
Varanasi-221005, India

K. P. SINGH PhD

Tel.: Off. (0542)310291 Ext 352
Res. (0542) 311600
Telex 545 304 BHU IN

7.109

Experimental Taungya Project in Thailand

The symposium on Taungya in South-east Asia, organised as a part of the V Ecology Congress at Yokohoma (1990), served dual purposes; firstly, it attempted a synthesis of the historical, socio-economic-political and silvi-agricultural problems and perspectives of taungya per se, and secondly, brought out the need to improving the taungya system in view of changing societal aspirations and requirements. The presentations of Carl F. Jordan and Jiragorn Gajaseni, based mainly on their experimental taungya project, evoked much response amongst the participants, and my own reaction is summarized below.

Discussing various socio-economic aspects, Gajaseni rightly emphasized to make the taungya system not only ecologically valid but also economically feasible and socially acceptable. Since rice yield in teak-rice taungya is only about one-half of that when planted alone, the economic return to the farmers should be increased to prevent their migration. In its present form taungya agriculture is considered non-sustainable in Indonesia, for instance. Ameleorative measures should include, as Gajaseni suggested: accelerating land development programmes and permanent settlements; increasing the settlers participation in those programmes, and improving the access of poor families to such basic services as education, health care and housing. It is indeed important that taungya families receive benefits of development yet contribute effectively as an integral component of the system.

A significant, bold new approach in taungya management, based on theoretical ecological considerations, was outlined by Jordan. In northern Thailand in teak taungya, having corn and rice crops in initial years, weed control in post-cultivation period, teak thinning a decade later and economic stagnation while the teak matures are major problems. Recognising that increased species diversity and structural diversity may improve ecosystem performance, by reducing competition and increasing efficiency of habitat resorces utilization, a taungya research project was launched with more widely spaced plantings of teak (2-3 times greater than the usual 4m x 4m) with interplantings of fast growing commercial legumes (eg. tamarind). Besides providing economic returns for a decade or more, the ecological implications of tamarind include shade control of teak form and soil fertility improvement, which in turn may promote teak growth. Eventually teak should overtop tamarind establishing a good canopy without requiring expensive thinning.

BANARAS HINDU UNIVERSITY
Centre of Advanced Study in Botany
Varanasi-221005, India

K. P. SINGH PhD

Tel.: Off. (0542)310291 ~~54291~~ Ext 352
Res. ~~07000~~ (0542)311600
Telex 545 304 BHU IN

The above assumptions on teak-tamarind interactions sound logical enough and can be easily verified experimentally. It will of course, need setting up sufficiently long term experiments analysing ecosystem functioning and ecological economics of such taungyas. From silvicultural considerations there is a high probability that such mixed species taungyas will be successful.

8 October 1990

K.P. SINGH
Professor of Botany
Banaras Hindu University

Comments on Experimental Taungya Project carried out Prof. C.F. Jordan and Dr. J. Gajaseni in Thailand

1) About the word of taungya

Taungya method is certainly one of the most important reforestation measure to rehabilitate large land areas abandoned after over-use, i.e. shifting cultivation or overlogging in southeast Asian countries. However, taungya is usually refined as a reforestation method in which tree saplings and agriacultural crops are simultaneously planted at the initial stage of reforestation and later only trees are left to complete reforestation.

In the experimental taungya project, cashewnut, jackfruit and tamarind, etc., are mixed-planted within main trees Teak. Following the definition, the experimental taungya may probably called as "homegarden". Further consideration, whetehr use of word"taungya" in this poject is adequate or not, is required.

2) About mix-planting

In the taungya, usually only one tree species is chosen, however, in this experimental taungya several trees as mentioned above are planted with teak. The trial of mixed-planting is highly evaluated. However, it is said that mix-planting have some disadvantage, i.e. various kinds of products can harvest but each are little in quantity.

It is probably necessary to clarify advantages and disadvantages of mix-planting from viewponts of both ecology and economy. Particularly, analysis of cost-benefit is needed.

3) About necessity of long term research

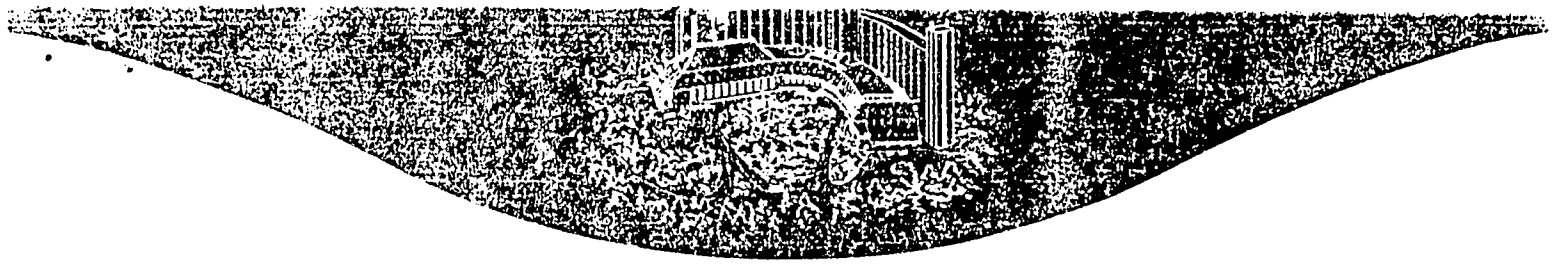
Reforestatin by taungya method will be established after long years. From this reason, it is surely recommended that this experimental taungya project continue as a longterm one because the results to be obtained become much valuable.

August 28, 1990

Hiroyuki Watanabe

Professor of Tropical
Forest Ecology,
Kyoto University,
Kyoto, Japan

Based on the FIO Forest Village Program, the experimental Taungya Project about the suitable or optimum combinations of tree species and agricultural crops in teak plantations carried out by Jiragorn Gajaseni and Carl Jordan has addressed an important problem in taungya agriculture. During the early stage, the project produces income and reduces labor cost which is the major cost item in plantation establishment by means of growing agricultural and horticultural crops. The project took a logical approach to solve the problem of high labor costs. For example, in the teak taungya of northern Thailand, corn and rice cropped during the first two years is a source of subsistence and income for the peasant farmers. Cropping also helps weed control. Moreover, the investigators used ecological principles suggesting improvements for the experimental Taungya Project. For instance, increased species diversity and structural diversity may improve the ecosystem performance, by



reducing competition and increasing efficiency of niche and habitat utilization. In order to test these idea, teak is planted at intervals two or three times greater than the traditional 4×4 m, and is interplanted with fast growing, commercially valuable legum such as tamarind. The legume provides shade to give the teak good form, and to suppress weeds. Meanwhile, it provides economic income for more than one decade. Eventually, the tamarind is overtopped by the teak and is shaded out, eliminating expensive thinning. In my opinion, there is a high probability of success of the Teak Taungya Project that is being tried. other factors such as soil fertility dynamics and its maintenance by means of chemical fertilization, green manure crops or some other ways should be considered in future work in this approach to taungya system.

Huo Yingqiang

Huo Ying-Qiang
Senior Engineer (Professor)
Forest Research Institute of Guangdong Provi
Shahe, Guangzhou 510520
Guangdong, PR China

Yokohama PRINCE HOTEL
13-1 Isogo 3-chome, Isogo-ku, Yokohama-shi, Kanagawa 235, Japan Phone:(045)751-2111 Facsimile:(045)755-8811

SOIL ORGANIC MATTER AND PHOSPHORUS AVAILABILITY IN HIGHLY WEATHERED SOILS

C. F. Jordan, X. Han, R. L. Potter, H. Yingqiang, and G.J. Batmanian.

Introduction

Phosphorus frequently is a factor limiting plant growth on Oxisols and Ultisols of the tropics and sub-tropics (Olson and Engelstad 1972, Stevenson 1986). To overcome phosphorus limitations, agronomic recommendations frequently include addition of superphosphate or rock phosphate (Fox and Searle 1978). While these measures can be effective in the short term, they are often prohibitively expensive in developing tropical countries.

The phosphorus limitations often are not due to lack of phosphorus in these highly weathered soils, but rather to its availability. A large proportion of the total P is bound in insoluble forms by iron and aluminum, or by their oxides in the clay minerals of the soil (Brady 1974, Uehara and Gillman 1981). Raising the pH of these soils through liming increases the proportion of soil phosphorus that is soluble, and thus can be taken up by plants. Raising soil pH also benefits plants through decreasing the solubility of aluminum, which can inhibit their growth (Sanchez 1976). However, lime, like P fertilizer, is often not practical in remote tropical regions. Inexpensive management techniques that mobilize bound phosphorus could benefit farmers without access to capital investment.

*Institute of Ecology, University of Georgia, Athens, Georgia, U.S.A.

REVIEW OF PAST WORK

Our interest in P availability in tropical soils began with studies of the effect of slash and burn agriculture on nutrient availability in an Oxisol in the Amazon Territory of Venezuela (Jordan 1989). We tested the following hypotheses:

1. The ash which results from burning increases nutrient availability, and results in good growth of crops for a few years.
2. Decrease in crop growth results from rapid loss of the nutrients from the soil.

We found that slash and burn did increase the stocks of cations and available P in the soil, but that crop growth declined, even though calcium, potassium, and magnesium levels in the soil remained high. Nitrogen levels in the soil also remained high. The decrease in crop growth seemed to be due to a decrease in available phosphorus. Since P availability in acid tropical soils is pH dependent (Sanchez 1976), leaching of calcium from the soil, with consequent decline in pH and fixation of soluble P could have been the cause.

However, we noticed that local peasant farmers often raked leaf litter and other organic debris around the base of their crop plants during the second and third year of cultivation (Jordan 1989). This technique prevented decline in crop growth. Plants were as vigorous as during the first year. This stimulation of growth, without an increase in soil pH, suggested that other mechanisms could be involved in maintaining or increasing levels of available phosphorus.

We carried out two field experiments, to determine if land management techniques which conserve soil organic matter and increase surface mulch result in better plant productivity, because of greater

phosphorus availability. Different amounts of mulch were applied to the soil, and growth of trees was monitored, on Ultisols in Georgia, U.S.A. (Potter et al 1990a) and near Maraba, Pará, Brazil (Batmanian 1990). In both cases, tree growth was better and P availability higher in sites with higher amounts of mulch on the soil surface. We were not able to determine if the increase in available P came from the mulch itself, or through the solubilization of iron and aluminum phosphates in the soil.

Other workers have shown that fixation of soluble phosphorus in iron and aluminum-rich soils can be decreased by naturally occurring organic acids (Lopez Hernandez et al 1986, Nagarajah et al 1968, 1970). The competition between organic acids and phosphate on iron and aluminum binding sites results in lower fixation of dissolved phosphorus.

We carried out an experiment in which we showed that addition of glucose to a Ultisol resulted in increased microbial activity, and decreased adsorption of phosphate added to the soil (Lee et al 1990). We concluded that the reduced adsorption was due to the chelation of iron and aluminum by organic acids produced by microbial activity. Chelation by organic acids prevented some of the dissolved phosphate from reacting with the iron and aluminum.

Reduction of adsorption of dissolved P could be an important reason that plantation trees in our studies grew better in sites with larger amounts of mulch. Organic acids released from the decomposing mulch, or from the microbes that decomposed the mulch, prevented some of the phosphate from being adsorbed, and maintained it in a state more available for uptake by plants. However, the experiments did not show that the organic acids could mobilize any of the P already bound by

iron and aluminum hydroxides in the soil.

Our next experiment was to determine whether organic acids released from decomposing organic matter, or as a result of microbial metabolism had the capability of solubilizing P bound as iron and aluminum phosphates. We carrried out an experiment in which two products of decomposition, citric and malic acids, were added to an Ultisol, and the soil was shaken end-over end for 24 hours. Concentrations of acids ranged from levels normally found in soils, to 100 times that level. Results showed that these acids increased soluble phosphorus. The increase came at the expense of iron and aluminum-bound phosphorus (Han 1989).

With evidence that products of organic matter decomposition could increase P availability *in vitro*, our next question was, can plants in an *in vivo* experiment benefit from such solubilization. Can addition of organic acids at naturally occurring levels solubilize P bound by iron and aluminum hydroxides, and results in increased P uptake, and increased growth by plants?

METHODS

To test the hypothesis that treatment with organic acids would decrease the iron and aluminum bound fraction of P, increase the labile P, and stimulate plant growth, we carried out a pot study in which the material balance of phosphorus was determined. We analyzed the fractions of plant-available phosphorus in the soil, the effect of treatment on the stocks of P in these fractions, and plant growth and uptake of P by manioc (*Manihot esculenta* Crantz).

Soil Description

Soil was collected near Athens, Georgia, in the Piedmont region. The soil has been classified as a clayey, kaolinitic, thermic typic hapludult (USDA, 1968). To minimize organic matter content, topsoil was not included. Sand, silt, and clay were respetively 46%, 12%, and 42%. KCl extractable Al was 0.14 cnol kg^{-1} soil, and Fe extractable in dilute HCl + H_2SO_4 was 0.15 cmol kg^{-1}. Total C was 5.4 g kg^{-1} soil, and N was undetectable by CHN analyzer.

Cultivation of Manihot

Manihot was grown from stem cuttings. For each block, all cuttings were from the same plant. Care was taken to ensure that the size and condition of the cuttings in each block were as similar as possible. Upon appearance of the first leaves, the cuttings were transplanted to pots containing 17.5 kg soil, dry weight. Three blocks were planted in Mid-April, and harvested in mid-August, 1990. A fourth block was planted and harvested two weeks later.

Two liters of a complete nutrient solution minus phosphorus (Clark 1982) were added approximately every 10 days to the pots during the experiment.

Treatments, and Statistical Design

There were four plants in each of the four blocks. There were four treatments, thus each plant in each block received a different treatment. The four treatments were: control; addition of .001 M solution of citric acid (two liters) every 10 days; addition of KH_2PO_4 at the beginning of the experiment to raise the P concentration in the soil 20 ppm; addition of citric acid and KH_2PO_4. The plus P treatment was included to stimulate growth,

which might result in more rapid mobilization of insoluble phosphorus compounds.

The citric acid solution was buffered. Application at the above-described rate did not change the pH of the soil, as determined by a separate test in containers without plants.

Analysis

At the end of the experiment, plants were harvested, and separated into tuber, fine roots, stems, leaves, original cutting, and leaves shed during the experiment. Parts were oven dried, weighed, and digested in H_2SO_4/H_2O_2 (Thomas et al 1967) for total P.

Analysis of soil for P at the end of the experiment was based on the scheme published by Hedley and Stewart (1982), and Hedley et al (1982). Procedures were modified as described by Potter et al (1990b), as follows: Fresh soil was sieved through a 2 mm mesh within four hours after plant harvest. Soils were not dried and ground. Although these procedures increase homogeniety of samples, they may alter labile stocks of P. In addition, microbial biomass was not determined, because chloroform treatment also can affect labile P estimates.

The following plant-available fractions of P were determined: Resin (water soluble); Dissolved organic P; 0.5M $NaHCO_3$ inorganic and organic (labile P). Insoluble fractions not readily available for plant uptake that were determined were: 0.1M NaOH inorganic and organic (P chemisorped to Fe and Al components of soil surfaces); Sonification plus NaOH (P held at internal surfaces of soil aggregates); 1M HCl (occluded P); residual P soluble only in strong acid.

Percent recovery was determined by comparing the sum of the above fractions with the total, as determined by a complete digest of a separate sample taken from the same pot.

Results

Addition of citric acid increased growth of Manihot (Table 1). In treatments to which no P had been added, citric acid increased average final dry weight from 40.72 g/plant to 61.95 g/plant (significant at 95% level of confidence). In treatments to which P had been added, citric acid increased average final dry weight from 145.05 g/plant to 164.73 g/plant, but high variability precluded statistical significance.

Total uptake of phosphorus by Manihot increased as a result of citric acid treatment. The increase was due to greater biomass in the citric acid treated pots. Concentration of P did not increase in plants due to citric acid treatment.

Results of the analysis of phosphorus fractions in the soil at the time the experiment was terminated, are given in Table 2. There was slightly more resin (soluble) P in the citric acid treatments than in the minus citric acid treatments. With one exception, addition of citric acid did not statistically result in any differences in any of the other fractions. The one exception was NaOH-organic, in the minus-P treatments.

Table 1. Dry weight of plant parts in grams, at time of harvest.

Treatment / Plant No.	Original cutting	Tuber	Fine roots	Stem	Leaves	Litter	Total
Control							
1	4.26	2.94	5.19	15.18	10.42	7.22	45.21
2	7.12	0	4.12	10.96	7.48	7.15	36.83
3	6.76	1.95	4.17	10.88	8.82	6.33	38.91
4	0.43	5.23	6.03	10.82	15.12	4.29	41.92
						avg.	40.72
						(se)	(1.83)
Citric Acid							
1	8.37	10.78	7.62	21.52	13.62	13.85	75.76
2	6.54	0	3.86	15.09	10.71	10.07	46.27
3	8.12	8.38	5.55	19.02	13.58	11.28	65.93
4	3.29	4.00	8.69	16.10	16.12	11.60	59.80
						avg.	61.95
						(se)	(6.17)
20 mg P/ kg soil							
1	9.06	21.63	11.36	37.11	29.89	13.97	123.02
2	9.32	35.23	8.15	30.68	22.57	17.61	123.56
3	6.19	31.24	9.48	31.17	28.38	14.76	121.22
4	9.19	60.21	19.21	52.85	46.19	24.73	212.38
						avg.	145.05
						(se)	(22.45)
Acid + 20 mg P							
1	10.15	35.90	10.93	41.51	31.66	13.87	144.02
2	11.88	16.14	13.26	37.49	34.05	13.05	125.87
3	8.50	30.90	10.06	32.60	35.30	10.87	128.23
4	15.03	90.69	17.15	57.95	61.42	18.54	260.78
						avg.	164.73
						(se)	(32.27)

Table 2. Concentrations of phosphorus (ppm) in fractions extracted from soil subjected to experimental treatments. Values are averages from four blocks, with standard error in parenthesis.

Treatment	Control	Citric Acid	P	P + Citric Acid
Fraction				
Resin	0.45 (0.03)	0.50 (0.04)	0.59 (0.04)	0.67 (0.01)
DOP*	0.08 (0.01)	0.08 (0.01)	0.08 (0.01)	0.09 (0.01)
$NaHCO_3$ inorg.	0.00	0.00	0.00	0.00
$NaHCO_3$ org.	0.00	0.00	0.00	0.00
NaOH inorg.	38.21 (0.45)	38.34 (0.49)	41.81 (0.89)	42.31 (1.13)
NaOH org.	5.92 (0.22)	7.41 (0.62)	7.34 (0.17)	7.40 (0.46)
Sonicate NaOH inorg.	7.45 (0.09)	7.86 (0.27)	8.12 (0.19)	8.45 (0.28)
Sonicate NaOH org.	1.31 (0.16)	1.48 (0.08)	1.51 (0.14)	1.53 (0.16)
HCl	1.01 (0.06)	1.06 (0.10)	0.99 (0.06)	1.05 (0.08)
Residual	201.66 (3.70)	213.89 (5.09)	210.54 (1.86)	217.04 (3.44)
Sum	256.09 (3.85)	270.61 (5.14)	270.97 (1.98)	278.52 (4.97)
Total**	268.14 (4.02)	279.95 (3.93)	285.60 (5.08)	293.49 (7.82)
Recovery	95.6	96.7	95.2	95.0
P in plant tissue***	2.09	2.65	8.42	11.74
Total P + P in tissue	270.23	282.60	294.02	305.23

*Dissolved Organic Phosphate
**Obtained by separate digestion of soil without fractionating
***Total P content of plant (values in Table 1 x concentration) divided by dry weight of soil per pot. This is the concentraton of P in the "living plant fraction".

DISCUSSION

Phosphorus Uptake by Manihot

Addition of citric acid increased both uptake of phosphorus and growth of Manihot. The increase was significant only in the treatments in which there was no P added to the soil. In the plus-P treatments, the increase was not significant, due to high values in the fourth block. If we were to eliminate data from the fourth block, on the basis that the initiation and termination of that block was two weeks later than for the other blocks, the difference would become significant at the 95% level.

As would be expected, growth of Manihot in the plus-P treatments was greater than in the minus-P treatments.

Phosphorus Fractions in Soil

At the termination of the experiment, there was slightly more resin P in the plus-citric acid treated soil than in the minus citric acid treatment (Table 1.) The citric acid did not affect levels of dissolved organic P, and other labile P ($NaHCO_3$ extractable) were too low to be detectable.

There is a dynamic equilibrium between the various fractions of P in the soil. An increase in the resin P would have to be compensated for by a decrease in another fraction. Our hypothesis was that an increase in soluble P would come from iron and aluminum phosphates of the clay minerals (NaOH extractable P). However, Table 2 shows no significant decrease in any of the insoluble P fractions due to citric acid treatment. Lack of apparent decrease in insoluble fractions may be because the increase due to citric acid is extremely small compared to

total soil P. In the minus-P treatments, citric acid resulted in a 0.05 ppm increase in resin P and a 0.56 ppm increase in plant P, for a total of 0.61 ppm increase in cycling P, while the soil has a total of about 270 ppm P. In the plus-P treatments, citric acid resulted in a .08 ppm increase in resin P, and a 3.32 ppm increase in plant P, for a total of 3.40 ppm of cycling P.

Evaluation of Fractionation

The sum of the various fractions of soil P was summed, and compared to total P from a separate total digestion of the same soil. The percentage recovery is an estimate of the loss of P during the fractionation procedure. Recovery averaged slightly more than 95% (Table 2). Though soil was homogenized prior to potting, total P varied from 269 to 280 in aliquots of original soil. Differences of this magnitude could mask decreases in insoluble P in the citric acid treatments.

The total P in the soil, plus P taken up by the plant at the end of the experiment, is given on the last line of Table 2. Plant P was converted to the basis of ppm/kg soil, to make data comparable with soil data. Watering probably added about 2 ppm P. In the plus P treatments, the addition of 20 ppm P resulted in original total P concentration of close to 295 ppm.

The minus citric acid treatments had slightly less total P at the termination of the experiment than did the plus citric acid treatments. We think that there may have been a slight leaching loss of P in the minus-citric acid treatments, due to smaller plant size, and less transpiration.

Soil Acidity

The final pH of the soil in the treatments that received citric acid treatment was about 0.5 units higher than those that did not. We have no data that could explain this increase. Tests in which citric acid solution was added to soil without plants showed no effect of the soil pH. There is the possibility that the increase in pH is due to the effect of citric acid which reacted with iron and aluminum, solubilizing some of the P and rendering it available for plant uptake. Ligand exchange of citrate for P followed by adsorption of citrate should result in increased pH (Goldberg and Sposito 1985, Fox *et al* 1990). Also, greater amounts of P resulted in an increased rate of plant growth and increased transpiration, which reduces cation leaching and in turn, and this could have maintained a higher soil pH.

CONCLUSION

Studies of agroforestry in tropical regions suggest that improved growth of crop plants under these type of systems is due to increases in mulch and soil organic matter, which promote improved soil structure, ameliorated microclimate, and increased levels of nitrogen when N-fixing symbionts are part of the agroecosystem. To this list of benefits of mulch and increased soil organic matter in agroforestry systems, we can add the decrease in adsorption of P in the soil by iron and aluminum, and possibly even the solubilization of P fixed by iron and aluminum hydroxides, thereby increasing P available to plants.

ACKNOWLEDGEMENTS

Research supported U.S. Agency for Inter. Devel., U.S.Nat.Sci. Found., UN Development Program, and Companhia Vale do Rio Doce, Brazil.

LITERATURE CITED

Batmanian, G.J. 1990. Reforestation of degraded pastures in the Brazilian Amazon: effect of site preparation on phosphorus availability in the soil. Ph.D. dissertation, Univ. of Georgia, Athens, Ga. U.S.A.

Brady, N.C. 1974. The Nature and Properties of Soils. MacMillan, N.Y.

Fox, R.L. and P.G.E. Searle. 1971. Phosphate adsorption by soils of the tropics. pp 97-119 in Diversity of Soils in the Tropics. Ed. M. Stelly. American Soceity Agronomy, Madison, Wisconsin.

Clark, R.B. 1982. Nutrient solution growth of sorghum and corn in mineral nutrition studies. Journal of Plant Nutrition 5: 1039-1057.

Fox, T.R., N.B. Comerford, and W.W. McFee 1990. Kinetics of phosphorus release from spodosols: effects of oxalate and formate. Soil Sci. Soc. Am. J. 54: 1441-1447.

Goldberg, S. and G. Sposito. 1985. On the mechanism of specific phosphate adsorption by hydroxylated mineral surfaces: a review. Commun. Soil Sci. Plant Anal. 16: 801-821.

Han, X. 1989. The mobilization of aluminum- and iron- bound phosphorus by organic matter decomposition in highly weathered soils. Ph.D. dissertation, Univ. of Georgia, Athens, Ga. U.S.A.

Hedley, M.J. and J.W.B. Stewart, 1982. A method to measure microbial phosphorus in soils. Soil Biol. Biochem. 14: 377-385.

Hedley, M.J., J.W.B. Stewart, and B.S. Chauhan. 1982. Changes in inorganic soil phosphorus fractions induced by cultivation practices and by laboratory incubations. Soil Sci. Amer. Jour. 46: 970-976.

Jordan, C.F. 1989. An Amazonian Rain Forest. Man and the Biosphere Series, Vol. 2. UNESCO. Parthenon Publishing, Carnforth U.K.

Lee, D., X.G. Han, and C.F. Jordan. 1990. Soil phosphorus fractions, aluminum, and water retention as affected by microbial activity in an ultisol. Plant and Soil 121: 125-136.

Lopez-Hernandez, D., G. Siegert and J.V. Rodriguez. 1986. Competitive adsorption of phosphate with malate and oxalate by tropical soils. Soil Sci. Amer. Jour. 50: 1460-1462

Nagarajah, S. A. Posner, and J.P. Quirk. 1968. Desorption of phosphate from kaolinite by citrate and bicarbonate. Soil Sci. Soc. Amer. Proc. 32: 507-510.

Nagarajah, S. A. Posner, and J.P. Quirk. 1970. Competitive adsorption of phosphate with polygalacturonate and other organic anions on kaolinite and oxide surface. Nature 228: 83-85.

Olson, R.A. and O.P. Engelstad. 1972. Soil phosphorus and sulfur. pp 82-101 in Soils of the Humid Tropics. National Research Council, National Academy of Sciences, Washington, D.C.

Potter, R.L., C.F. Jordan, and A.E. Smith. 1990a. Soil P transformations following organic matter additions to an Ultisol in the Southern Piedmont. Agronomy Abstracts. Proceedings of the 1990 meeting of the American Society of Agronomy, San Antonio Texas, Oct 21-26, 1990. American Society of Agronomy, Madison, Wisconsin.

Potter, R.L., C.F. Jordan, R.M. Guedes, G.J. Batmanian, and X.G. Han. 1990b. Assessment of a phosphorus fractionation method for soils: problems for further investigation. Agriculture, Ecosystems and Environment. In Press.

Sanchez, P.A. 1976. Properties and Management of Soils in the Tropics. Wiley. N.Y.

Stevenson, F. J. 1986. Cycles of Soil Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients. Wiley, N.Y.

Thomas, R.L., R.W. Sheard, and J.R. Moyer. 1967. Comparison of conventional and automated procedures for N, P, and K analysis of plant material using a single digestion. Agronomy Jour. 59: 240-247.

Uehara, G. land G. Gillman. 1981. The Mineralogy, Chemistry, and Physics of Tropical Soils with Variable Charge Clays. Westview, Boulder Colorado.

USDA 1968. Soil survey, Clarke and Oconee Counties, Georgia. United States Dept. Agriculture, Washington, D.C.

PROGRAM

of

V INTERNATIONAL CONGRESS OF ECOLOGY

Yokohama, August 23～30, 1990

Development of Ecological Perspectives for the 21st Century

Yokohama, 1990

S3-1-02 : Taungya Agriculture in Southeast Asia: Ecologic and Economic Aspects

Organizers : Jordan, C. F., Watanabe, H.

Aug. 28 (Tue.) (10:00–13:00/15:00–19:00) Room No. 506

Historical Perspective

01 Huo, Y.
The History and Present Situation of Some Taungya Agroforestry Systems in China: Present-Day Perspective

02 Gajaseni, J.
Socio-Economic Paradigms of Taungya Agriculture.

03 Phothitai, M.
Agroforestry in Thailand: Perspective of Forest Industry Organization (FIO).

04 Priyakraisorn, O.
Title Undecided

05 Knowland, W.
Perspective of an International Development Agency. Ecological Aspects

06 Kyuma, K.
Soil Fertility Problems in Taungya Agriculture.

07 Watanabe, H.
Competition between Trees and Crops in Taungya in Southeast Asia.

08 Jordan, C. F.
Ecological Theory and Taungya Agriculture.

09 Bruijnzeel, L. A.
Nutrient Dynamics of Moist Tropical Forest Land: Forest Response to Disturbance.
Taungya in Other Regions

10 Simon, H., K. F. Wiersum.
Taungya Cultivation in Indonesia: Agrisilvicultural and Socio-Economic Aspects.

11 Batmanian, G. J.
The Use of Taungya Systems in the Brazilian Rain Forest.

12 Singh, K. P., O. N. Pandey.
Taungya in India: Agri-Silvicultural, Socio-Economic and Ecological Aspects.

Proposal to Commonwealth Agricultural Bureaux
for preparation of a book entitled

Taungya in Southeast Asia

Proceedings of a Symposium held on August 28, 1990
as part of the Vth International Congress of Ecology
Yokohama, Japan

Edited by

Jiragorn Gajaseni[1], Hiroyuki Watanabe[2],
and Carl F. Jordan[3]

1. Faculty of Science, Chulalongkorn University, Bangkok 10500, Thailand

2. Laboratory of Forest Resources, Faculty of Agriculture, Kyoto University, Kyoto, 606, Japan

3. Institute of Ecology, University of Georgia, Athens, Georgia, 30602, U.S.A.

Each chapter is envisioned to be about 10 -15 manuscript pages, plus figures, tables, and literature cited. The book is meant to be an overview, rather than an outlet for original data. Synoptic material is welcome. Original data should be cited in the literature.

Section One

Historical Perspective

Chapter 1. Origins of Taungya in Burma
Shinya Takeda. Laboratory of Forest Resources, Faculty of Agriculture, Kyoto University, Kyoto Japan

Section Two

Social, Economic and Cultural Perspectives

Chapter 2. Socio-economic Paradigms of Taungya Agriculture
Jiragorn Gajaseni. Faculty of Science, Chulalongkorn University, Bangkok, Thailand

Chapter 3. Cultural Paradigms in Taungya Agriculture
Garo Batmanian. World Wildlife Foundation, Washington D.C., U.S.A.

Section Three

Regional Perspectives

Chapter 4. Taungya in Thailand: Economic Perspective
Montee Phothitai. Forest Industry Organization, Bangkok, Thailand

Chapter 5. Taungya in Thailand: Social Perspective
Ob Preeyagrysorn. Payap University, Chiangmai, Thailand

Chapter 6. Taungya in the People's Republic of China
Huo Yingqiang. Forest Research Institute of Guangdong, Guangzhou, P.R.C.

Chapter 7. Taungya in Indonesia.
Hasanu Simon, Forestry Faculty, Gadjah Mada University, Bulaksumur, Yogykarta, Indonesia, and K.F. Wiersum, Dept. of Forestry, Wageningen Agricultural University, The Netherlands.

Chapter 8. Taungya in India
K.P. Singh, Dept. of Botany, Banaras Hindu University, Varanasi India, and O.N. Pandey, Faculty of Forestry, Birsa Agricultural University, Ranchi, India.

Chapter 9. Taungya in Nepal
Jay B.S. Karki. International Rice Research Institute, Manira, Philippines

Ecological and Agronomic Aspects

Chapter 10. Soil Fertility Problems in Taungya Agriculture
Kazutake Kyuma. Faculty of Agriculture, Kyoto University, Kyoto 606, Japan

Chapter 11. Competition between Trees and Crops in Taungya Agriculture Hiroyuki Watanabe. Faculty of Agriculture, Kyoto University, Kyoto 606, Japan.

Chapter 12. Nutrient Losses during Plantation Harvest: Implications for Regeneration of the Forest.
L.A. Bruijnzeel. Institute of Earth Sciences, Vrije Universiteit. Amsterdam, The Netherlands.

Chapter 13. Ecological Aspects of Taungya Agriculture.
Carl F. Jordan. Institute of Ecology, University of Georgia, Athens Georgia 30602, U.S.A.

Future Directions

Chapter 15. Toward an Improved Approach to Taungya
Carl F. Jordan, U.S.A., and Jiragorn Gajaseni, Thailand.

Preceding page

11 Text Pages

3 Figures

Running title: P sorption: effect of C, N, P, biocides

40

Phosphorus adsorption by highly weathered soils: Effects of C, N, P, and biocides

DOWON LEE[1] and CARL F. JORDAN[2]
Institute of Ecology, University of Georgia, Athens, GA 30602, U.S.A.

[1]Dept. of Environmental Science, Hankuk Univ. of Foreign Studies, Yongin-Gun Gyungkee-Do 449-850, South Korea

[2]Corresponding author

Key Words: adsorption, chelation, microbial activity, phosphorus, sorption, soil organic matter, soil phosphorus, ultisol.

41

Abstract

Adsorption experiments were carried out on two highly weathered soils, to determine the effect of C, N, P, and biocides on P adsorption. C and N additions generally decreased P adsorption. These additions stimulated microbial activity, which reduced adsorption, probably through chelation and nitrification. Addition of P initially decreased P adsorption, probably through blockage of adsorption sites. Biocides generally decreased adsorption, probably because the microbes that survived the biocides grew and metabolized rapidly using the remains of the microbes that had been killed. Soil 2 with naturally higher levels of C had lower adsorption than soil 1.

These results suggest that in highly weathered soils, low in available P and high in exchangeable Al, cultivation techniques which increase soil organic matter will also result in higher levels of plant-available P.

Introduction

Alternative management techniques such as minimum cultivation and agroforestry are becoming more common (National Research Council 1989), especially on highly weathered tropical and subtemperate soils (Wiese 1983).

In minimum cultivation, organic matter input into the soil is often increased. The benefits of increased levels of soil organic matter include: 1) improved soil structure; 2) increased water holding capacity; 3) as a source and sink for plant nutrients; and 4) increased cation exchange and buffer capacity (Tate 1987).

In regions with low average temperatures where decomposition is slow, minimum tillage may result in an accumulation or "loading" of soil organic matter, with a concomitant immobilization of nutrients. This has been attributed to: 1) greater physical occlusion of soil organic matter (Tiessen et al. 1984a); 2) lack of tillage which enhances microbial degradation (Doran et al 1987); and 3) dominance of fungi which have slower nutrient turnover and lower growth efficiency than bacteria (Holland and Coleman 1987, Hendrix et al 1987).

In highly weathered acid soils of warmer climates, aluminum toxicity and phosphorus availability are often greater problems than slow decomposition. Reduced aluminum toxicity (Hargrove

and Thomas 1981) and improved phosphorus availability (Lee et al. 1990) are two benefits frequently associated with increased soil organic matter in tropical and sub-temperate regions. These effects are extremely important in alleviating plant stresses associated with what are considered to be the leading constraints to agronomic production on soils classified as Oxisols and Ultisols: aluminum toxicity and phosphorus deficiency (Olson and Engelstad 1972; Stevenson 1986).

Several mechanisms have been suggested to explain how organic matter enhances availability of soil phosphorus to plants. The mechanisms include solubilization by weathering (Johnson et al 1977, Kucey 1983, Tate 1984, Thomas et al 1985, Lopez-Hernandez et al 1986, Nagarajah et al 1968, 1970, and competition by organic ligands for adsorption sites on soil minerals (Sibanda and Young 1989, Traina et al 1986, Young and Bache 1985). Organic matter can also decrease the availability of P through adsorption, but desorption frequently also is important, and the net result of higher soil organic matter may be increased P availability (Harter 1969, Tiessen et al 1984b, Le Mare 1982).

In previous work (Lee et al 1990), we found higher levels of microbial activity caused by higher levels of C in soil result in less sorption of P, as determined by fractionation of soil P. In this work, the objective was to determine the effect of C on P availability using adsorption tests.

Other objectives were to evaluate interactions of C with inorganic N and P additions, and also biocides. Initial status of soil N and P may influence the P adsorption/desorption processes (Lee et al 1990). Transformation of N in soil is an important factor influencing P adsorption processes by altering the concentration of the hydrogen ion in soil solution. Nitrification can influence P availability since it leads to acidification of soil (Van Miegroet and Cole 1985). Denitrification can be coupled to solubilization of iron-phosphate due to chemical reduction of Fe^{+++} to relatively mobile Fe^{++} under reducing conditions (Jansson 1987). Biocides were included in the experiments to compare the influence of fungi vs. bacteria in influencing adsorption/desorption. Combinations of biocides may elucidate interactions of several biotic groups (Ingham et al 1985).

Because soil type strongly influences P adsorption and desorption characteristics (Lajtha and Bloomer 1988), we compared adsorption on two Ultisols, one higher in Al and lower in C than the other.

Methods

Soil Types

Soils were taken from the B horizon, below the rooting zone of trees, to minimize organic matter content. Soil 1 was a Madison sandy clay loam, a clayey, kaolinitic, thermic typic hapludult (USDA, 1968) collected in Clarke County Georgia.

Sand, silt, and clay were respectively 46.2%, 12.3% and 41.5%. KCl extractable Al was 0.14 cmol kg^{-1} soil, and Fe extractable in dilute HCl + H_2SO_4 was 0.15 cmol kg^{-1}. Total C was 5.4 g kg^{-1} soil, and N was undetectable by CHN analyzer. Water soluble inorganic P was ≤ 1 ppm.

Soil 2 was collected near Marabá, Pará, in the Amazon Basin of Brazil. It has been classified by the Brazilian system as Podizolico Vermelho Amarelo Alico (Red Yellow Podzolic). This is a type of Ultisol in the U.S. Soil Taxonomy (Sanchez 1976). Sand, silt, and clay were respectively 12%, 71%, and 17%. Al was .01 cmol kg^{-1}, C was 15.0 g kg^{-1} soil, and N was .08 g kg^{-1} soil.

Experimental Design and Treatment

Twenty grams of soil (oven dry basis) were placed in ten dram vials. Soils were treated in three blocks, with two replicates for soil 1, and three replicates for soil 2. For soil 1, N was added to the columns in one block at the rate of 0.1 g NH_4NO_3 - N kg^{-1} soil. In a second block, 0.05g KH_2PO_4 - P kg^{-1} soil was added. There were no additions of N nor P in the third block.

Within each block there were four treatments: C as 1 gram of glucose - C kg^{-1} soil, to stimulate microbial activity; C plus bactericide; C plus fungicide; C plus bactericide plus fungicide. Bactericide was streptomycin, added at a rate of 3 g/kg soil. Fungicide was cycloheximide, added at 1 g/kg soil.

There were two control columns that received no additions, two in the N block that received only N, and two in the P block that received only P.

Soil 2 was used as a comparison for soil 1, to determine P adsorption differences in a soil with naturally higher levels of C and lower levels of Al, and to confirm any effects of N addition on P adsorption observed in soil 1. Since the soils differed in other ways also, the comparison is not ideal, yet it was felt that using soils with naturally different levels of C might yield information not obtainable through experiments in which soil C was manipulated with additions of glucose C. Soil 2 had the following treatments: additons of N; bactericide (B) only; N + B; fungicide (F) only; N + F; B + F; N + B + F; control with no additions. One gram cellulose - C kg^{-1} soil was also included as a treatment.

Incubation

The soil in each vial was adjusted to 43% soil moisture, which represented approximate field capacity. Vials were incubated at 25°C for four weeks for soil 1, and six weeks for soil 2.

Phosphorus Adsorption Test

Procedures were a modification of those described by Fox and Kamprath (1970). After incubation, soil was air-dried, ground,

and passed through a 0.5 mm seive. One-half gram of soil sample was placed in 25 ml of a 0.01 M $CaCl_2$ solution containing 1, 20, and 100 mg KH_2PO_4-P l^{-1} solution. For soil 2, only P at 20 mg l^{-1} concentration was used. The soil and phosphorus mixture was continually shaken end-over-end for 24 hours. Five ml subsamples were pipetted from the mixture after 0.5, 3, and 24 hour reaction times. These suspensions were centrifuged for 10 minutes at 10,000 rpm at 0° C, and the supernatant was passed through a Whatman No. 42 filter. The filtrate was stored at 4°C and inorganic P was determined by the molybdenum blue method, adapted for the Technicon Auto Analyzer (Allen et al 1974).

Adsorbed P was calculated as the difference between initial and final P concentration.

Results and Discussion

Effects of Carbon

Adsorption of P after 0.5 hours for the 1 and 20 mg l^{-1} solution was lower in soil to which C had been added than in the controls (Fig. 1), with one exception. Lower adsorption occurred in all blocks and all treatments. This tends to confirm the hypothesis that soils with higher levels of organic matter adsorb less P. The result may have been an indirect effect of the glucose addition. Glucose probably stimulated

microbial growth, and lowered adsorption may have been partly a result of microbial activity. Organic ligands produced by microbial activity may have reacted with iron and aluminum, thereby decreasing adsorption sites available for P reactions. Increased microbial biomass also may have been partly responsible. P may have been adsorbed directly by microbes, where it would be more readily desorbed than had it been adsorbed to clay minerals.

Of the 24 glucose-treated samples, only the C + P + B treatment, in the 1 mg l^{-1} P test showed an increase in adsorption (Fig. 1). The high standard deviation suggests that this exception may be due to lack of experimental precision, rather than to real differences.

Adsorption by soil 2 (Fig. 3) with higher total C content was less than by soil 1 (Fig. 2), over all time intervals, for the 20 mg P l^{-1} solution. This again tends to confirm the idea that soils with higher carbon adsorb less P, but other factors may have been involved. For example, soil 2 had less aluminum, and this may have caused part of the difference in P adsorption.

An initial P concentration of 100 mg l^{-1} resulted in no discernible trend (Fig. 1). For this concentration and 0.5 h reaction time, the differences due to C were overshadowed by total adsorption.

Beyond 0.5 h, adsorption of P was less for soil with C added compared to control and to plus-P treatment, for the 20 mg l^{-1} solutions (Figs 2a, 3a), although at 24 hours, differences shown in Fig. 3a are slight. The plus-N treatments are discussed below.

Effect of N and P

For soil 1 at 0.5 hours, addition of N affected very little the adsorption of P compared to the control, but increased slightly adsorption compared to C only and C + N (Fig. 1). However, after 24 hours, addition of N generally resulted in lower P adsorption for the 20 mg^{-1} solution (Fig. 2 a,b,c). In soil 2, addition of N lowered P adsorption, but the effect was clearest at intervals greater than 0.5 hours (Fig. 3). Lowered P adsorption due to N could have resulted from nitrification, or from production of organic acids. Both result from microbes such as nitrifiers and other microscopic heterotrophs.

For solutions of 1 and 20 mg P l^{-1} at 0.5 hours reaction time, addition of P reduced adsorption compared to controls, and addition of C + P reduced adsorption compared to C alone in soil 1 (Fig. 1a,b). Previously added P possibly occupied adsorption sites, thereby reducing adsorption.

Effect of Biocides

If biocides were completely effective, adsorption should have been greater when they were added, since microbial growth would have been less. This seems to have been the result for the C + P + B additions at the 1 and 20 mg P l^{-1} level (Fig 1), but not for the other treatments(Figs. 1,2,3). These results may be explained by the results of Lee et al (1990), using the same soils and biocide levels. They found that bactericide inhibited respiration for one day, but actually stimulated respiration over a longer interval, probably due to growth of microbes that survived the biocide treatment. This may also be the explanation here. Addition of bactericide may have resulted in higher levels of biomass, over the course of the incubation.

Mechanisms

Addition of C, N, and P, singly and in combination, decreased P adsorption by the two soils tested. Presumably, C served as an energy source for microbes, while additions of N and P overcame limiting conditions for metabolism. The increased microbial activity may have included processes such as production of organic acids and nitrification which reduced P adsorption. In addition, P presumably blocked P adsorption sites, thus accounting for the initial lowering of P adsorption.

Biocides also apparently increased microbial growth due to rapid growth of organisms surviving the biocide application (Lee et al 1990).

Because soil organic matter increases exchange surfaces in the soil, soils with higher organic matter could have higher P adsorption. However, in the soils tested here, the soil with the higher levels of C (soil 2) had lower adsorption of P. One reason may be the levels of exchangeable Al in the soils tested. The reaction of P with Al results in a bond which is stronger than the exchange reaction of P on the surface of organic matter. When soil organic matter is higher, more P is adsorped by organic matter, and less reacts with the Al. This P is readily desorped again into solution.

Decrease in net P adsorption with increased organic matter also can be caused by high rates of oxygen depletion during decomposition of organic matter. Phosphorus release from sediment layers can be enhanced by deoxygenation (Syers et al 1973, Carlton and Wetzel 1988). In our experiment, decomposition of organic matter could have depleted oxygen and created anoxic conditions.

An additional factor to explain less P adsorption with higher organic matter is that the organic matter also may have complexed some of the Al, making less available to react with the P. Other characteristics of soil minerals also can influence P adsorption and desorption (Lajtha and Bloomer 1988).

Conclusion

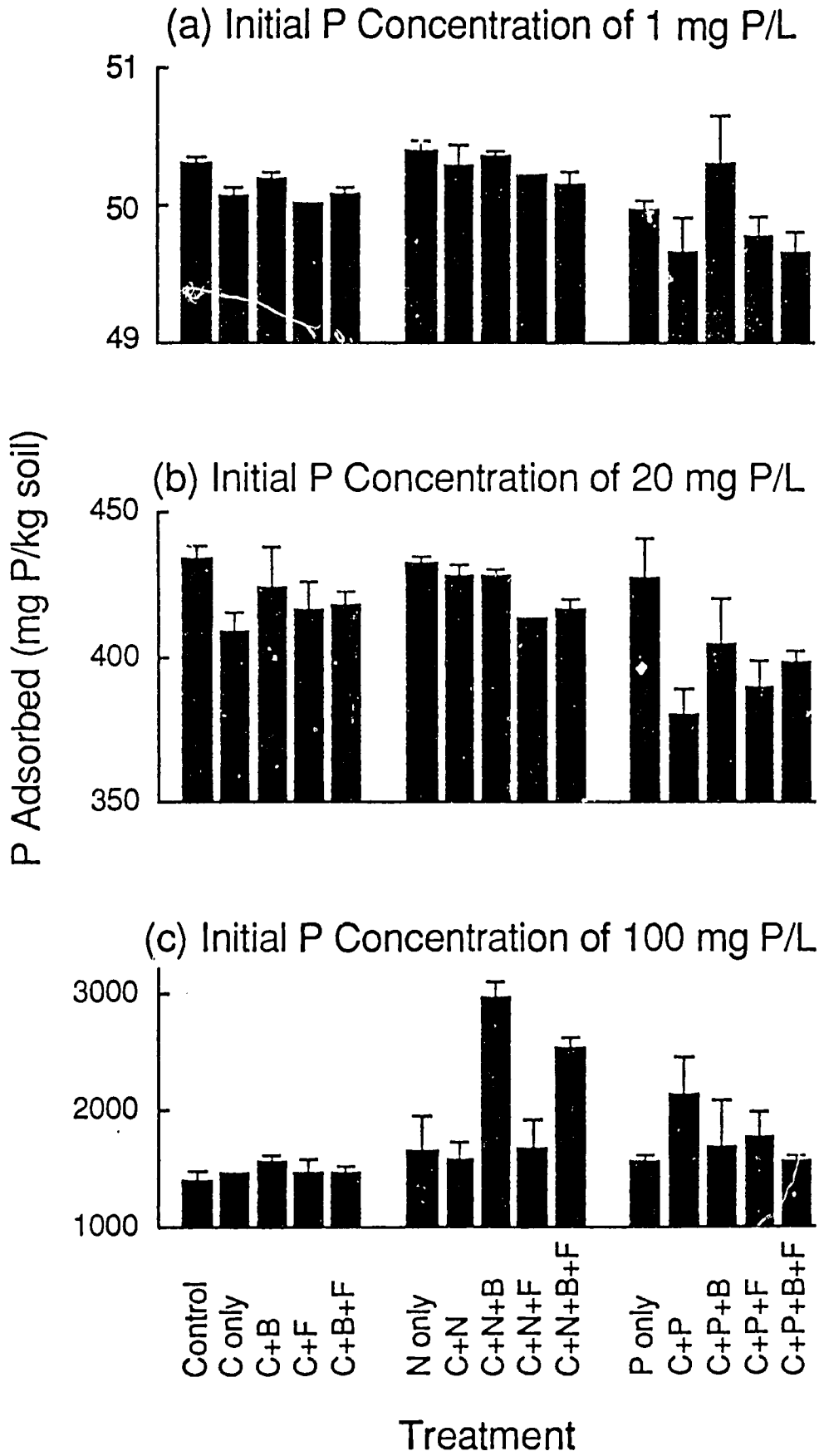
For the soils and conditions tested, an increase in organic matter resulted in a net increase in P availability. The mechanisms of action may involve competition and complexation, although other factors may also be involved. These results suggest that in regions where weathered soils high in Al are common, cultivation techniques which maximize soil organic matter may reduce the need for inorganic applications of phosphate and/or lime.

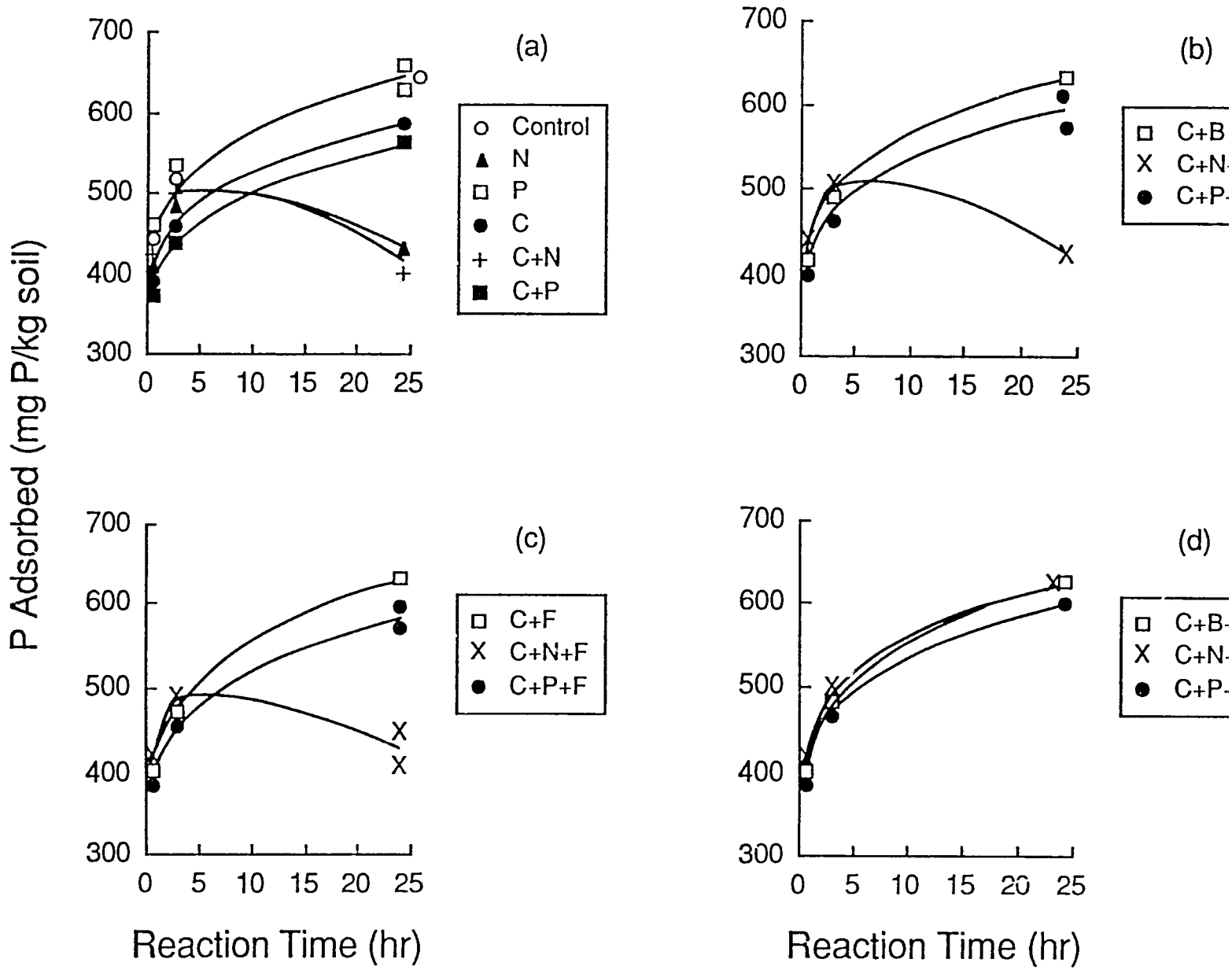
Figure Captions

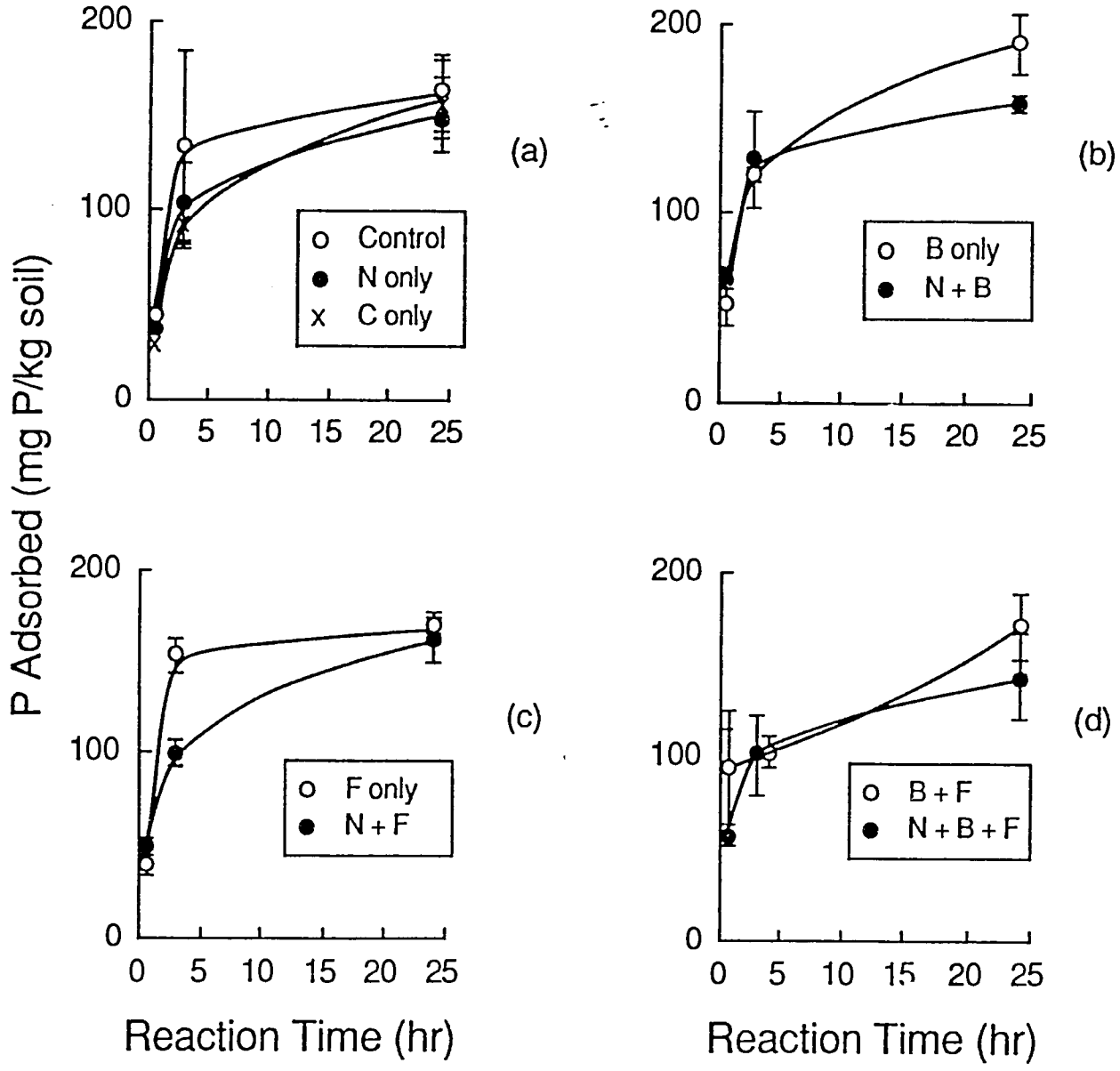
Figure 1. Adsorption of P by soil 1 during 0.5 hr reaction time from solution initially containing three levels of dissolved P. Treatment symbols: C = glucose C; N = ammonium nitrate; P = monobasic potassium phosphate; B = streptomycin; F = cycloheximide.

Figure 2. Adsorption of P by soil 1 at three reaction times from solution initially containing 20 mg monobasic potassium phosphate l^{-1}. Treatment symbols are the same as for Fig. 1. Individual data points are plotted. Where only one point appears for a treatment at a particular reaction time, values were too close to plot separately.

Figure 3. Adsorption of P by soil 2 at three reaction times from solution initially containing 20 mg monobasic potassium phosphate l^{-1}. Treatment symbols are the same as for Fig. 1, except C indicates cellulose. Plotted values are average and standard deviation of three replicates.


(a) Initial P Concentration of 1 mg P/L
51
50
49
(b) Initial P Concentration of 20 mg P/L
450
400
350
P Adsorbed (mg P/kg soil)
(c) Initial P Concentration of 100 mg P/L
3000
2000
1000
Control
C only
C+B
C+F
C+B+F
N only
C+N
C+N+B
C+N+F
C+N+B+F
P only
C+P
C+P+B
C+P+F
C+P+B+F
Treatment


P Adsorbed (mg P/kg soil)
Reaction Time (hr)
(a)
Control
N
P
C
C+N
C+P
(b)
C+B
C+N
C+P
(c)
C+F
C+N+F
C+P+F
(d)
C+B
C+N
C+P


P Adsorbed (mg P/kg soil)
200
100
0
0 5 10 15 20 25
Reaction Time (hr)
(a)
Control
N only
C only
(b)
B only
N + B
(c)
F only
N + F
(d)
B + F
N + B + F

Acknowledgements

We thank A.N. Sharpley, R.L. Potter, and G.J. Batmanian for their criticisms of the manuscript. The research was carried out as part of a study on soil organic matter and P availability, supported in part by U.S. Agency for International Development, and U.S. National Science Foundation.

References

Allen S E, Grimshaw H M, Parkinson J A and Quarmby C 1974 Chemical Analysis of Ecological Materials. Blackwell, Oxford, 565 p.

Carlton R G and Wetzel R G 1988 Phosphorus flux from lake sediments. effect of epipelic algal oxygen production. Limnol. Oceanogr. 33, 562-570.

Doran, J W, Mielke L N, and Power J F 1987 Tillage/residue management interactions with the soil environment, organic matter, and nutrient cycling. INTECOL Bull. 15, 33-39.

Fox, R L and Kamprath E J 1970 Phosphate sorption isotherms for evaluating the phosphate requirements of soils. Soil Sci. Soc. Amer. Proc. 34, 902-7.

Hargrove, W L and Thomas G W 1981 The effect of organic matter on exchangeable aluminum and plant growth in acid soils. In Chemistry in the Soil Environment. Soil Sci. Soc. Am. J. Special pub. no. 40. pp. 151-166. Soil Sci. Soc. Am. Madison, Wisconsin.

Harter, R D 1969. Phosphorus adsorption sites in soils. Soil Sci. Soc. Am. Proc. 33, 630-632.

Hendrix, P F, Crossley Jr. D A, Coleman D C, Parmelee R W, and Beare M H 1987 Carbon dynamics in soil microbes and fauna in conventional and no-tillage agroecosystems. INTECOL Bull. 15, 59-63.

Holland E A, and Coleman D C 1987 Litter placement effects on microbial and organic matter dynamics in an agroecosystem. Ecology 68, 425-433.

Ingham R E, Trofymow J A, Ingham E R, and Coleman D C 1985 Interactions of bacteria, fungi, and their nematode grazers: effects on nutrient cycling and plant growth. Ecol. Monogr. 55, 119-140

Jansson M 1987 Anaerobic dissolution of iron-phosphorus complexes in sediment due to the activity of nitrate-reducing bacteria. Microb. Ecol. 14, 81-89

Johnson D W, Cole D W, Gessel S P, Singer M J, and Meinden R V 1977 Carbonic acid leaching in a tropical, temperate, subalpine and northern forest soil. Arctic Alpine Res. 9, 329-343.

Kucey R M 1983 Phosphate-solubilizing bacteria and fungi in various cultivated and virgin Alberta soils. Can. J. Soil Sci. 63, 671-683.

Lajtha K and Bloomer S H 1988 Factors affecting phosphate sorption and phosphate retention in a desert ecosystem. Soil Sci. 146, 160-167.

Lee D, Han X G, and Jordan C F 1990 Soil phosphorus fractions, aluminum, and water retention as affected by microbial activity in an Ultisol. Plant and Soil 121, 125-136.

Le Mare P H 1982 Sorption of isotopically exchangeable and non-exchangeable phosphate by some soils of Colombia and Brazil, and comparisons with soils of southern Nigeria. J. Soil Sci. 33, 691-707.

Lopez-Hernandez D, Siegert G, and Rodriguez J V 1986 Competitive adsorption of phosphate with malate and oxalate by tropical soils. Soil Sci. Soc. Am. J. 50, 1460-1462.

Nagarajah S, Posner A M, and Quirk J P 1968 Desorption of phosphate from kaoline by citrate and bicarbonate. Soil Sci. Soc. Am. Proc. 32, 507-510.

Nagarajah S, Posner A M, and Quirk J P 1970 Competitive adsorption of phosphate with polygalacturonate and other organic anions on kaolonite and oxide surface. Nature 228, 83-85.

National Research Council 1989 Alternative Agriculture. National Academy Press, Washington, D.C. 448 p.

Olson, R A, and Engelstad O P 1972 Soil phosphorus and sulfur. In Soils of the Humid Tropics. Eds. National Research Council Committee on Tropical Soils. pp. 82-101. National Academy Sciences, Washington, D.C.

Sanchez P A 1976. Properties and management of soils in the tropics. Wiley, New York.

Sibanda H M and Young S D 1989 The effect of humus acids and soil heating on the availability of phosphate in oxide-rich tropical soils. In Mineral Nutrients in Tropical Forest and Savanna Ecosystems. Ed. J Proctor pp 71-83. Blackwell. Oxford.

Stevenson F J 1986 Cycles of Soil: Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients. Wiley. N.Y. 380 p.

Syers J K, Harris R F, and Armstrong D E 1973 Phosphate chemistry in lake sediments. J. Environ. Qual. 2, 1-15

Tate K R 1984 The biological transformation of P in soil. Plant and Soil 76, 245-256.

Tate R L 1987 Soil Organic Matter: Biological and Ecological Effects. Wiley, N.Y. 219 p.

Thomas G V, Shantaram M V, and Saraswathy N 1985 Occurrence and activity of phosphate-solubilizing fungi from coconut plantation soils. Plant and Soil 87, 357-364.

Tiessen H, Stewart J W B, and Hunt H W 1984a Concepts of soil organic matter transformations in relation to organo-mineral particle size fractions. Plant Soil 76, 287-295.

Tiessen H, Stewart J W B, and Cokle C V 1984b Pathways of phosphorus transformations in soils of differing pedogenesis. Soil Sci. Soc. Am. J. 48, 853-858.

Traina S J, Sposito G, Hesterberg D, and Kafkafi U 1986 Effects of pH and organic acids on orthophosphate solubility in an acidic, montmorillonitic soil. Soil Sci. Soc. Am. J. 50, 45-52.

Van Miegroet H, and Cole D W 1985. Acidification sources in red alder and Douglas fir soils - importance of nitrification. Soil Sci. Soc. Am. J. 49, 1274-1279.

67

Wiese A F 1983 No-tillage crop production in temperate agriculture. In No-tillage Crop Production in the Tropics. pp 7-24. International Plant Protection Center, Oregon State Univ., Corvallis.

USDA 1968 Soil survey, Clark and Oconee Counties, Georgia. United States Dept. Agriculture, Washington, D.C.

Young S D and Bache B W 1985 Aluminum-organic complexation: Formation constants and a speciation model for the soil solution. J. Soil Sci. 36, 261-269.

Fast Growing Trees and Nitrogen Fixing Trees

International Conference
Marburg, October 8th–12th, 1989

Edited by
D. Werner and P. Müller

81 figures and 41 tables

SEMPER BONIS ARTIBUS

Gustav Fischer Verlag
Stuttgart · New York · 1990

65

Editors adress:
Prof. Dr. D. Werner
Dr. P. Müller
Philipps-Universität
Fachbereich Biologie – Botanik
Lahnberge
D-3550 Marburg

CIP-Titelaufnahme der Deutschen Bibliothek

Fast growing trees and nitrogen fixing trees : international conference, Marburg, October 8th–12th, 1989 / ed. by D. Werner and P. Müller. [Sponsors Der Bundesminister für Wirtscha Wirtschaftl. Zusammenarbeit (Bonn) via the GTZ (Eschborn)...]. – Stuttgart ; New York : Fischer, 1990
ISBN 3-437-30623-5 (Stuttgart)
ISBN 1-56081-306-7 (New York)
NE: Werner, Dietrich [Hrsg.]
Library of Congress Card-No. 90-3918

© Gustav Fischer · Stuttgart · New York · 1990
This work with all its parts is protected by copyright. Any use beyond the strict limits of the copyright law without the consent of the publisher is inadmissible and punishable. This refers especially to reproduction of figures and/or text in print or xerography, translations, microforms and the data storage and processing in electronical systems.
Printed by: Gulde-Druck GmbH, Tübingen
Bound by: F. W. Held, Rothenburg

66

Interplanting of *Tamarindus indica* L. in Teak Plantations

C. F. Jordan and J. Gajaseni, Inst. of Ecology, Univ. of Georgia, Athens, Georgia, U.S.A.

INTRODUCTION

Teak (Tectona grandis L.) is a valuable timber tree, whose natural range extends through northern Thailand. In native deciduous forests of that region, it frequently is a dominant species (Gajaseni 1988).

Teak has been a traditional export of Thailand, and has made an important contribution to the economic development of Thailand. In recent years however, there has been a dramatic decline in teak harvest. Total yield from throughout Thailand dropped from about 300 x 10^3 m^3 in 1971 to 39 x 10^3 m^3 in 1985 (Royal Forest Dept. 1985). Harvest has been declining because of lower availability of merchantable logs, due to both legal and illegal overharvesting of the native teak forests (Gajaseni and Jordan, In Press).

In an effort to reverse the decline of available teak, and to insure its future importance in the Thai economy, the Forest Industry Organization of Thailand has organized a system of social forestry built around teak plantations. While this system has had partial success since its inception 22 years ago, there have been ecologic problems due to monocultural plantings, and economic problems caused by the long rotation period for teak. In this paper, we report on an experiment in which tamarind (Tamarindus indica L.), a fast growing legume that yields an important economic fruit, has been incorporated into the system in an attempt to overcome these problems.

THE FOREST VILLAGE SYSTEM

The Forest Industry Organization (FIO) of Thailand has set up approximately 30 "Forest Villages" in the Northern region of Thailand. The primary purpose of the villages is to supply labor for establishment and maintenance of teak plantations. Villagers are mainly landless peasants who volunteer to participate in the program. FIO offers subsidized housing, electricity, schools, and other amenities for families, and a small wage to workers. To further encourage families to join the cooperative system, they are allowed to interplant crops, mainly upland rice and corn, between the teak for the first two years of the teak rotation. The crops can be used by the peasants for subsistence, or to sell in the market.

The practice of interplanting crops during early years of teak

plantation has been called "Taungya" agriculture or forestry. A benefit to the FIO of taungya is that the cultivation of crops reduces weed competition with the teak seedlings. The peasants pull weeds as part of their corn and rice cultivation.

PROBLEMS WITH THE FOREST VILLAGE SYSTEM

Families have the privilege to work a plot of land for only two years. Then they must move their subsistence and economic cropping to another plot. This is demoralizing for the peasants, who would like longer-term control over the land. Peasants sometimes leave the village system in search of greater economic reward or land security. Peasants need a greater interval during which they can harvest subsistence crops, due to the decreasing amount of land for new plantations.

Weeding is another problem with the present system. The farmers pull weeds a part of their corn and rice cultivation, but when crops are abandoned after the second year, weeds invade aggressively, and the FIO must then hire crews to weed the plantations.

Thinning of the teak stand also is an expense for the FIO. Teak is planted at 4 x 4 meter intervals. At that density, shade from one tree will be enough to kill the branches and leaves of the adjacent tree, and ensure a clyindrical, clean bole. However, planting at this close interval results in competition for light, nutrients, and water. Effects are first noticable before the plantation is 10 years old, and by the time it is 15, it must be thinned, or growth will stagnate. Trees removed by thinning are too small to have much value.

A third problem that may arise as pure teak plantations mature is deleterious effects on the soil, due to nutrient depletion. Some foresters of the region predict that pure teak can be grown on a site for only two rotations. Following that, a fallow with another species may be required.

TEAK FORESTS AND PLANTATIONS

Teak forests of Northern Thailand are heavily dominated by teak. Near Lampang in the Mae Moh valley, teak biomass constitutes 76 percent of total standing forest biomass in logged-over stands. Based on measurements of stumps in these forests, the standing crop of teak in these forests before logging was estimated to be 400 t/ha, and to represent 89 percent of total forest biomass (Gajaseni and Jordan <u>In Press</u>).

68

It is not clear why teak is so dominant. It may be due in part to the fire resistance of this species. Northern Thailand has a highly distinct 4 1/2 month dry season (Gajaseni 1988). During this season, fires can spread rapidly through native forests, and fire-resistance may favor teak in a competition with other native species. The strong dry season and associated fires also may inhibit pests and parasites of teak. Teak near Lampang appears relatively free of insects and disease when compared to plantations in regions where there is no strong dry season, such as Eastern Puerto Rico (Jordan, Personal Observation). There is also the possibility that teak may have an allelopathic affect against some of the other native plant species.

Although the deciduous forests of northern Thailand are heavily dominated by teak, when dominance is calculated as percent biomass, other species are common in the mature native forest (Table 1).

Table 1. Species composition in a mature mixed deciduous forest with teak, Lampang, Northern Thailand.

Species	Density (no./ha)
Tectona grandis L.	303
Xylia kerrii C.& H.	44
Careya arborea Roxb.	22
Diospyros mollis Griff.	16
Nauclea orientalis L.	16
Terminalia belerica Roxb.	16
Lagerstroemia sp	11
Schleichera oleosa Merr.	5

DIFFERENCES BETWEEN NATIVE TEAK FORESTS AND PLANTATIONS

An important difference between teak in the native forests, and teak in plantations is that in plantations, the trees are all of the same age, while in native forests, they are of mixed age. This difference is important for efficiency of resource utilization. When trees are all of the same age and have been planted at intervals of 4 meters, competition develops during the first decade. The crowns of the trees are all at the same height, and leaves of one tree interfere with light interception by leaves of another tree at that level. Yet considerable light reaches the floor untilized, and provides a resource for weed competition. In even-aged plantations, roots too, are competing for the same nutrients and water since root systems probably are more or less equally developed.

In contrast, in native forests where trees are of differenct sizes and ages, there appears to be more efficient utilization of resources. Leaves form different strata, and light that filters through the canopy is utilized by trees at intermediate and lower strata. The larger trees presumably

have deeper root systems, and can utilize nutrient and water resources at lower levels. When a large old tree dies and falls over, there are usually many younger trees already estabished nearby, that are able to utilize the resources released due to the death of the larger tree.

MULTIPLE CROPPING SYSTEMS

To reduce the economic and ecologic problems of the taungya plantations, we are modifying the system into a type of multiple cropping system. Multiple-cropping agricultural systems are often more efficient, both ecologically and economically, than monocultural systems (Francis 1988), especially where large scale, capital and energy intensive systems are not practical.

Multiple-cropping systems may be ecologically efficient for various reasons. In the lowland tropics, where soils frequently are of low fertility (Sanchez 1976) and fertilizers may be prohibitively expensive, the use of multiple cropping systems may be important. Different species usually require different relative amunts of each nutrient, and multiple-cropping will utilize more completely the complete stocks of all nutrients which become available in the soil. Resistance to pests also may be greater in multiple-cropping systems, because the variety of plant species may make it more difficult for insect predators to locate desirable host individuals. Weed species, too, may be more easily controlled in multiple-cropping systems, because the soil has a more continuous or complete coverage with a variety of crop species than with a single species.

Multiple cropping systems may be more economically efficient, in the sense that a variety of crops will increase stability of income throughout the year. It can buffer the farmer against disaster due to the poor performance or failure of one particular crop. It can also buffer the farmer against vageries of price changes offered for various crops. When multiple cropping systems include a subsistence component, this can further protect the farmer against unfavorable economic conditions.

A multiple cropping system may have advantages over monoculture plantations, as well as over even-aged plantations. In an experiment to exploit the advantages of a multiple cropping system over a monoculture plantation, we are working together with the Forest Industry Organization of Thailand to interplant tamarind (Tamarindus indica) with teak.

10

THE MODIFIED TAUNGYA SYSTEM

In our experimental system, teak is planted at intervals of 12 meters. Tamarinds are planted at 4 meter intervals between the teak trees. Then between the trees, upland rice and corn are cultivated for two years, just as in the taungya system.

The advantage of the modified system begins after several years. Tamarind can begin yielding a harvest after several years. These fruits have a high economic value in the Thai marketplace. The tamarind can supply an economic income to the peasants for perhaps 15 or more years. This would alleviate part of the peasant farmer's problems with the taungya system by allowing them a long-term commitment to a parcel of land.

There are advantages of this system to the FIO also. To ensure good production of the tamarind, the peasants need to weed the plot for many years, thereby decreasing the labor needed to weed the teak. Regarding the problem of ensuring proper form for the teak trees, the tamarinds will shade out the side branches of teak, and ensure good cylindrical growth of the trunk.

Eventually, perhaps after 15-20 years, the teak will overtop and shade out the tamarind. This is another advantage, because in contrast to the pure teak plantation, thinning will not be necessary. The differential structure of teak and tamarind will ensure self-thinning. This should save the FIO additional labor expenses.

Tamarind also may counteract a trend the for the teak to deplete the soil nutrients. We do not know yet if tamarind in this region fixes nitrogen, but we are planning studies to determine this.

TRAINING CAPABILITIES

The experimental modified taungya system will serve as a training and extension center. The project will be a focus for thesis research for Master degree students in the Biology Dept. at Chulalongkorn University. As the program develops a Doctoral degree, the site will be an opportunity for dissertation research.

The research site also provides an oportunity for extension. In March 1989, the project sponsored a workshop for the leaders of the 30 forest villages in Northern Thailand, to explain to them our new system. A major emphasis of the meeting was a series of lectures focusing on ecological principles applied to forest management.

11

PROGRESS

The research site was selected in 1988, and about 10 hectares were prepared for planting between Jan. and March 1989. The planting took place during May of 1989. In one small section of the plantation, the peasant workers substituted Jack fruit (Artocarpus heterophyllus Lam.) for one of the two tamarinds in the interval between teak. As of October 1989, the entire plantation had been successfully established.

IMPLICATIONS

The problems encountered in the teak plantations, such as competition, need for thinning and weeding, and the long time interval until economic income are common problems in monoculture plantations throughout the world. The idea of interplanting fast growing legumes that yield economically valuable fruit between longer-lived trees planted for timber could be tried in many regions throughout the world, and with a variety of species combinatins. It might be anticipated that such combinations might be both ecologically and economically superior to uniform monocultures.

CONCLUSION

In general, native forests appear to utilize light, water, and nutrients more efficiently than plantation forests, due to the diverse sizes and resource requirements of the many species in the native forests. For this reason, we anticipate that the mixed species plantation described here will be more productive at a lower cost than a pure monoculture stand of teak.

REFERENCES

1. Francis, C.A. (1989). Adv. Agr. 42, 1-42.
2. Gajaseni, J. (1988). Ph.D. dissertation, Univ. of Georgia, Athens, Georgia, U.S.A.
3. Gajaseni J. and Jordan, C.F. (In Press). Biotropica.
4. Royal Forest Dept. (1985). Forestry Statistics of Thailand 1985. Royal Forest Dept., Bangkok, Thailand.
5. Sanchez, P.A. (1976). Properties and Management of Soils in the Tropics. Wiley, N.Y.

ACKNOWLEDGEMENT

This project has been supported by the Forest Industry Organization of Thailand, the Biology Dept., Chulalongkorn University, and a grant from the U.S. Agency for International Development.