Nutrient Management over Extended Cropping Periods in the Shifting Cultivation System of south-west Côte d'Ivoire

Promotor: dr ir A. Van Diest
emeritus hoogleraar in de bodemvruchtbaarheid en bemestingsleer
Co-promotor: dr ir B.H. Janssen
universitair hoofddocent bij de Vakgroep
Bodemkunde en Plantevoeding

Nutrient Management over Extended Cropping Periods in the Shifting Cultivation System of south-west Côte d'Ivoire

H. Van Reuler

Proefschrift

ter verkrijging van de graad van doctor
in de landbouw- en milieuwetenschappen
op gezag van de rector magnificus
dr C.M. Karssen
in het openbaar te verdedigen
op woensdag 17 januari 1996
des namiddags te vier uur in de Aula
van de Landbouwuniversiteit te Wageningen

CIP-DATA KONINKLIJKE BIBLIOTHEEK, DEN HAAG

Reuler, H. van

Nutrient management over extended cropping periods in the shifting cultivation system of south-west Côte d'Ivoire
/ H. Van Reuler. - [S.l. : s.n.]
Thesis Landbouw Universiteit, Wageningen. - With ref. -
With summary in French and Dutch.
ISBN 90-5485-486-3
Subject headings: nutrient management; Ivory Coast/
shifting cultivation; Ivory coast.

The following chapters of this thesis are based on published or submitted manuscripts:

Chapter 2.3 - Van Reuler H, N'Goran K et Wessel M 1994 L'Agriculture. *Dans*: Le Parc National de Taï, Côte d'Ivoire. I. Synthèse des Connaissances. Eds. E P Riezebos, A P Vooren et J L Guillaumet. pp. 133-142. Tropenbos Series 8. Fondation Tropenbos, Wageningen, Pays-Bas.

Chapter 3 - Van Reuler H and Janssen B H 1993a Nutrient fluxes in the shifting cultivation system of south-west Côte d'Ivoire I. Dry matter production, nutrient content and nutrient release after slash and burn for two fallow vegetations. Plant and Soil 154, 169-177.

Chapter 4 - Van Reuler H and Janssen B H 1993b Nutrient fluxes in the shifting cultivation system of south-west Côte d'Ivoire II. Short-term and long-term effects of burning on yield and nutrient uptake of food crops. Plant and Soil 154, 179-188.

Chapter 5 - Van Reuler and Janssen B H 1996 Comparison of the fertilizing effects of ash from burnt secondary vegetation and of mineral fertilizers on upland rice in south-west Côte d'Ivoire. Accepted for publication in Fertilizer Research.

Chapter 6 - Van Reuler H and Janssen B H 1989 *In* Mineral Nutrients in tropical Forest and Savanna Ecosystems. Ed. J Proctor. pp 371-382. Special Publication number 9 of The British Ecological Society. Blackwell Scientific Publications.

Chapter 7 - Van Reuler H and Janssen B H subm. a The influence of soil P, pH and texture on the uptake of P from soil and fertilizer by upland rice in the shifting cultivation system of south-west Côte d'Ivoire. Submitted to the Netherlands Journal of Agriculture.

Chapter 8 - Van Reuler H and Janssen B H subm. b Soil fertility dynamics along a catena in south-west Côte d'Ivoire I. The relations between soils, nutrient uptakes and yields of upland rice during the first season after clearing. Submitted to Plant and Soil.

Chapter 9 - Van Reuler H and Janssen B H subm. c Soil fertility dynamics along a catena in south-west Côte d'Ivoire II. Yields and nutrient uptakes in subsequent seasons. Submitted to Plant and Soil.

Chapter 10 - Van Reuler H and Janssen B H subm. d Optimum P management over extended cropping periods in the shifting cultivation system of south-west Côte d'Ivoire. Submitted to the Netherlands Journal of Agriculture.

NN08201, 2039

Stellingen

1. De sleutel tot behoud van het Nationale Park Taï ligt niet in intensivering van het onderzoek in het Park zelf, maar in intensivering van de landbouw in de zone rondom het Park.

2. Intensivering van de landbouw in zuid-west Côte d'Ivoire is alleen mogelijk wanneer nutriënten van elders worden aangevoerd.

   Dit proefschrift

3. Kennis omtrent gebruiksefficiënties van nutriënten die door de plant zijn opgenomen is noodzakelijk voor een inzicht in de bodem-plant relaties.

   Dit proefschrift

4. Omdat in bodems met veel grind de chemische bodemeigenschappen uitgedrukt per massa-eenheid "fine earth" (fractie < 2 mm) een te optimistisch beeld geven van de bodemvruchtbaarheid, is het aan te bevelen deze grootheden uit te drukken per volume-eenheid van de totale grond inclusief de fractie > 2 mm.

   Dit proefschrift

5. Bodems met een hoog grindgehalte dienen niet op voorhand negatief gewaardeerd te worden. Bij een gunstige regenval worden in het Taï gebied op grindhoudende bodems hogere opbrengsten behaald dan op bodems zonder grind.

   Dit proefschrift

6. De oorzaak van de opbrengstdaling in een verlengde teeltperiode in gebieden met zwerflandbouw is minder gelegen in een achteruitgang van de hoeveelheden beschikbare nutriënten, dan in een slechtere benutting van de opgenomen nutriënten.

   Dit proefschrift

7. Teeltsystemen zijn gebaseerd op lokale kennis van de boeren. Omdat deze kennis ontbreekt bij immigranten heeft hun manier van werken vaak negatieve gevolgen voor het ecosysteem.

8. Voor een zinvolle discussie over duurzame landbouw is een kwantitatief inzicht in het nutriëntenbudget van essentieel belang.

   Smaling E M A 1993 The soil nutrient balance: an indicator of sustainable agriculture in sub-Saharan Africa. The Fertiliser Society Proceedings no. 340, 1-18.

9. De huidige kritische mening over agroforestry staat in schril contrast met de hoge verwachtingen uit de jaren zeventig.

   Koninklijk Instituut voor de Tropen 1979 Agroforestry: Proceedings of the 50th "Tropische Landbouwdag". Department Agricultural Research of the Royal Tropical Institute no. 303. 47 p.
   Sanchez P A 1995 Science in agroforestry. Agroforestry Systems 30, 5-55.

10. De hoeveelheid geïnfecteerde wortels wordt in fosfaatarme bodems gebruikt als criterium voor de positieve bijdrage van mycorrhiza's aan de fosfaatvoeding van de waardplant. Het is de vraag of dit criterium ook bruikbaar is voor fosfaatrijke bodems.

11. De uitbreiding van de winkelopeningstijden zal leiden tot hogere prijzen voor de consument.

12. Thuiswerken wordt door mensen met een baan heel anders ervaren dan door mensen zonder baan.

13. Oerwoudgeluiden kunnen het best bestreden worden met goed voetbal.

H. Van Reuler
Nutrient Management over Extended Cropping Periods in the
Shifting Cultivation System of south-west Côte d'Ivoire
Wageningen, 17 January 1996

Propositions

1. The key to protection of the Taï National Park is not to be found in intensification of the research within the Park but more so in intensification of the agriculture in the zone bordering the Park.

2. Intensification of the agriculture in south-west Côte d'Ivoire is only possible with inputs of nutrients from elsewhere.

   This thesis

3. Knowledge of the efficiency of utilization of absorbed nutrients is essential for a proper understanding of the soil-plant relationship.

   This thesis

4. In gravelly soils the values of the chemical properties expressed per unit of mass of the fine earth fraction (< 2 mm) give an overly optimistic view of the fertility of these soils. It is therefore recommended to express these values per unit of volume of the total soil including the fraction > 2 mm.

   This thesis

5. Gravelly soils should not in the first instance be negatively evaluated. In case of a well distributed rainfall in the Taï region crop yields on the gravelly soils are higher than on the non-gravelly soils.

   This thesis

6. The yield decline over an extended cropping period in shifting cultivation areas is not so much caused by declining amounts of nutrients as well by a lower efficiency of utilization of absorbed nutrients.

   This thesis

7. Cropping systems are based on indigenous knowledge of farmers. Immigrants lack this knowledge and consequently their practices often have negative effects on the ecosystem.

8. For a meaningful discussion on sustainable agriculture quantitative knowledge of the nutrient budget is essential.

   Smaling E M A 1993 The soil nutrient balance: an indicator of sustainable agriculture in sub-Saharan Africa. The Fertiliser Society Proceedings no. 340, 1-18.

9. The present critical evaluation of agroforestry stands in sharp contrast to the high expectations in the seventies.

   Koninklijk Instituut voor de Tropen 1979 Agroforestry: Proceedings of the 50th "Tropische Landbouwdag". Department Agricultural Research of the Royal Tropical Institute no. 303. 47 p.
   Sanchez P A 1995 Science in agroforestry. Agroforestry Systems 30, 5-55.

10. The quantity of infected roots in soils low in phosphorus is used as criterion for the positive contribution of mycorrhiza to the phosphorus supply of the host plant. It is questionable whether this criterion can also be used for soils rich in phosphorus.

11. Extending the opening hours of shops will lead to higher prices for the customer.

12. Working at home is differently experienced by people with than by people without a job.

13. Jungle noises can best be overcome by good football.

H. Van Reuler
Nutrient Management over Extended Cropping Periods in the Shifting Cultivation System of south-west Côte d'Ivoire
Wageningen, 17 January 1996

Abstract

Van Reuler, H.,1996. Nutrient management over extended cropping periods in the shifting cultivation system of south-west Côte d'Ivoire. Doctoral thesis, Wageningen Agricultural University, Wageningen, The Netherlands. 189 p., with English, French and Dutch summaries. Also published in the series Tropical Resource Management Papers, No.12, Wageningen Agricultural University, ISSN 0926-9495; no.12

Intensification of food crop production in shifting cultivation systems can contribute to protection of tropical forest. For such an intensification knowledge of soil fertility and its dynamics is essential. It was tested whether intensification could be achieved by extending the cropping period in on-farm field trials with controlled management. These trials were conducted on locations along catenas ranging from the crest to the fringe of the valley bottom. On the (moderately) well drained soils P proved to be the yield-limiting nutrient. In extended cropping systems with alternately rice and maize, applications of N, P and K were not sufficient to maintain the yield level obtained in the first season after clearing. Yield decline was much less pronounced for maize than for rice. In the eighth season after clearing yields of over 4 ton of maize per ha were still obtained. Data on the efficiency of utilization of absorbed P indicate that factors other than P deficiency caused the yield decline. A probable cause is deterioration of soil physical properties. Fertilizer recommendations (N,P,K) are formulated for the well drained soils of the upper/middle slopes and for the moderately well drained soils of the lower slope.

Additional keywords: apparent recovery fraction, ash, efficiency of utilization of absorbed nutrients, fertilizer application, nutrient dynamics, nutrient uptake, maize, slash-and-burn agriculture, upland rice.

This thesis
is dedicated
to my mother

Aperçu

Van Reuler, H.,1996. Nutrient management over extended cropping periods in the shifting cultivation system of south-west Côte d'Ivoire. Thèse de l'Université Agronomique de Wageningen, Wageningen, Pays-Bas. 189 p. Résumés en français, anglais et néerlandais. Cette thèse a été publiée également dans la série Documents de la Gestion des Ressources Tropicales, No.12, Université Agronomique de Wageningen, ISSN 0926-9495; no.12

L'intensification de cultures vivrières dans les systèmes d'agriculture itinérante peut contribuer à la protection de la forêt tropicale. Des connaissances sur la fertilité du sol et ses dynamiques sont essentielles pour une telle intensification. Dans cette thèse l'intensification par une prolongation de la période de culture a été étudiée dans des essais "on-farm" avec une gestion contrôlée. Ces essais furent exécutés sur des sites différents d'un "catena" représentatif pour le Sud-Ouest de la Côte d'Ivoire. Sur les sols avec un drainage modéré et normal le P apparût comme étant l'élément nutritif le plus important pouvant limiter le rendement. Dans les systèmes de cultures prolongées avec alternativement du riz et du maïs, les applications de N, P et K n'étaient pas suffisantes pour maintenir le niveau de rendement obtenu dans la première saison après défrichement. La diminution du rendement était beaucoup moins prononcée pour le maïs que pour le riz. Dans la huitième saison après défrichement, des rendements de plus de 4 tonnes de maïs par ha furent encore obtenus. Les données sur l'efficacité de l'utilisation du P absorbé montrent que d'autres facteurs que la déficience en P avaient causé la diminution du rendement. Une cause probable est une dégradation des caractéristiques physiques du sol. Des recommendations pour l'application d'engrais (N, P, K) sont formulées pour les sols avec un drainage normal du haut-de-versant/mi-de-versant et pour les sols avec un drainage modéré du bas-de-versant.

Mots-clés supplementaire: absorption d'éléments nutritifs, application d'engrais, culture sur défriche-brûlis, cendres, dynamique des éléments nutritifs, efficacité de l'utilisation du nutriments absorbé, maïs, rendement en éléments des engrais, riz pluvial

Preface

From December 1986 to May 1991 I was assigned as a soil scientist with the project "Analysis and Design of Land-use systems for the Taï region in south-west Côte d'Ivoire". Within this project I studied the intensification of food crop production in the shifting cultivation system of south-west Côte d'Ivoire. On-farm field trials with controlled management were conducted. The results of these experiments are presented in this thesis. Many people have supported me during the various stages of the research.

My promotor Prof. Dr. A. Van Diest has always shown great interest in the research. His critical reading of the different manuscripts is gratefully acknowledged.

I am very much obliged to Dr. Bert Janssen, my co-promotor. He initiated this project and provided the day-to-day guidance. His visits to Côte d'Ivoire were always very stimulating. After my return to Wageningen we had numerous meetings and discussions. Sometimes he may have wondered whether this thesis would ever see the daylight, but here it is!

The Ministry of Scientific Research and Higher Education (le Ministère de la Recherche Scientifique et de l'Enseignement Supérieur Professionelle et Technique) in Côte d'Ivoire is acknowledged for granting permission to conduct out the study.

In the Taï region, the staff members of the field station of the "Institut d'Ecologie Tropicale are thanked for their assistance. Especially Sio is thanked for his help and pleasant company.

I owe a lot to the local farmers without whom the research would have never been executed. Their hospitality and tolerance of outsiders who want to conduct experiments on their fields is gratefully acknowledged. The locally employed workers Dominique and Lassiné are thanked for their hard dedication.

Many students participated in this research. I am thankful to Mildred Berenschot, Janette Bessembinder, Gerard Hazeu, Robert-Jan Hijmans, Helma Ilbrink, Quirine Ketterings, Chris Koopmans, Martin Muilenburg, Romke Postma, Rob Schippers, Steven Starmans, Jeroen Thijssen, Angelo Tjhie, and Kees Verschoor for their very useful contributions to this thesis.

The assistance of Hans Van Amsterdam, Hans Van Der Linden, Gerrit-Jan Van Herwaarden, Annemarie Van Der Velden, Hans Vellema and Romuald Te Molder in characterizing the experimental sites is highly appreciated.

After his return to Wageningen Kees Verschoor provided much logistical support when being employed as a part-time project assistant.

A special word of thanks goes to Gerard Hazeu who came to Côte d'Ivoire three times, first as a student, then as a student-assistant and after his graduation as my successor after my final departure.

My colleagues of the former Centre Néerlandais in Adiopodoumé are thanked for their collaboration. Special thanks are due to Anneke De Rouw, Joep Slaats, Jetse Stoorvogel and Fred Vooren.

Mr. Roger Diallo of WARDA is thanked for his advice on the rice variety to be planted. The planting material was in the first year provided by Mr. Clement and later by Mr. Vernier, both of IDESSA.

I wish to thank Dr. Otto Spaargaren, at that time Director of IBSRAM-Côte d'Ivoire, for providing administrative support. The discussions we had in Grand-Bassam and later in Wageningen were very stimulating.

In Wageningen numerous soil and plant samples were analyzed in the Department of Soil Science and Plant Nutrition. Some samples were analyzed several times and I thank the staff for their persistence. I am grateful to the staff of the Department of Soil Science and Plant Nutrition for the many discussions and for their help.

I thank Gerrit Gort for his advices on statistical data treatment and Dr. Patrick Hommel for his help with interpretation of the weed data.

The discussions with Joep Slaats about our work in the Taï region were very stimulating and are highly appreciated.

Peggy Van Reuler-Petersen and Marieke Sassen are thanked for producing the French summary.

Finally I wish to thank Peggy, Elleke and Liesje for their patience when coping with a husband and father who was for a long time busy with a 'Ta(a)ï' subject.

Contents

Part I

General introduction

Chapter 1

Introduction

1.1 Agricultural production and food requirements

The present world population amounts to 5200 million people and will exceed 6000 million by several hundreds of millions in the year 2000. Yet, at a global level the growth of food production has so far outpaced the growth of world population, mainly through important technical improvements. Examples are the use of fertilizers, high yielding and pest-and disease resistant varieties, irrigation, pesticides, and improved agricultural practices (Pinstrup-Andersen and Pandya-Lorch,1994) In developed countries, however, food production increased three times faster than in developing countries. Contrary to the rest of the world where the annual growth rate of the population is either stabilizing or even declining, in Sub-Saharan Africa (SSA) the annual growth rate is still increasing: from 2.6% in the 1960s to 3.1% in the 1980s (World Bank,1989). The SSA population increased from about 200 million in 1960 to nearly 500 million in 1990 and is projected to amount to 677 million in the year 2000 (World Bank,1989). In SSA, population growth has overtaken the growth of food production and to cover the gap, the continent relies on the availability of up to now relatively cheap food grains on the world market.

Since in nearly all SSA countries the staple food consists of grains, food needs are usually measured in terms of food grains, although it should be kept in mind that grain meals are often supplemented or, when grains are short, even substituted by starchy staples, such as cassava. The minimum annual grain requirements per person, as specified by different countries, may vary, but generally the total food grain needs are estimated at approximately 180 kg per head per year.

Food shortages are common in large areas of SSA. Sometimes famines are caused by catastrophic climatic events such as prolonged droughts, sometimes by civil wars or social upheavals. Apart from these events, there has been a structural decrease in food production per capita in SSA during the past decade, such in contrast to all other developing areas. During the past thirty years agricultural production has increased by only 2 % per year in SSA, while an annual increase of 4% would have been necessary to keep up with population growth (World Bank,1989).

The options to increase agricultural production are to extend the area under cultivation or to increase the productivity of the area already under cultivation.
In SSA, the increase in cereal production between 1961 and 1990 was approximately equally divided between area extension and increase of yield per ha (Table 1.1), in contrast to other regions where the increase in production was mainly due to higher yields per ha, i.e. to intensification.

Table 1.1 Contribution of increase in areas and in yields to the growth of cereal production in developing countries and in high-income countries, 1961-1990 (World Bank,1992).

Country group	Current production (1988-1990 average 10^6 t)	Increase since 1961-1963 (%)			Current yield 1988-1990 (t ha^{-1})
		Total	Attributable to increased area	Attributable to increased average yields	
Developing countries	1,315	118	8	92	2.3
Sub-Saharan Africa	57	73	47	52	1.0
East Asia	499	189	6	94	3.7
South Asia	261	114	14	86	1.9
Latin America	105	111	30	71	2.1
Middle East and North Africa	41	68	23	77	1.4
Europe and former USSR	336	76	-13	113	2.2
High-income countries	543	67	2	98	4.0
World	1,858	100	8	92	2.6

The possibilities to extend the area of useful agricultural soils are limited, since the best land is already cultivated. Only marginal land and forested land remain, and for ecological reasons it is better to leave these untouched. Therefore, increasing the production per ha constitutes the best option for feeding a growing population (Van Reuler and Prins,1993).

1.2 Shifting cultivation

Shifting cultivation can be defined as an agricultural system in which temporary clearings are cropped for fewer years than they are allowed to remain fallow (Sanchez,1976). Due to yield decline during the cropping period, fields are abandoned and new fields are cleared as indicated by the word shifting. Many names exist for the same system. Another common name is slash-and-burn referring to the way of clearing. It is practised in areas with a low population density where power implements and fertilizers are not available (Sanchez,1976). Although minor differences exist, the principle of shifting cultivation is universal (Nye and Greenland,1960). It is estimated that about 250 million people produce their daily food through this system (Robison and McKean,1992).

One way to subdivide shifting cultivation systems is on the basis of the natural vegetation before clearing: e.g. shifting cultivation in forest areas and in savanna areas. More detailed subdivisions are given by Greenland (1974) and Ruthenberg (1980). We confine ourselves to shifting cultivation in humid forested areas, with special reference to West Africa.

The dominant soil types in non-volcanic regions of the humid tropics are Oxisols and Ultisols (Soil Survey Staff,1990) or Ferralsols and Acrisols in the FAO (1988) classification. They are chemically poor, main constraints for crop growth being low nutrient reserves, aluminum toxicity, high P fixation by Fe oxides, acidity without aluminum toxicity and low CEC (Sanchez and Logan, 1992). On such soils, the ash of the burnt vegetation is an important source of nutrients for the crops to be grown. Upon ash application the pH increases and consequently aluminum toxicity and other acidity problems are alleviated. Other beneficial effects of the burn are killing of seeds present in the topsoil and of stump sprouts which would shade out crop species, removal of twigs and branches which would hamper planting, reduction of the cover in which crop consumers may hide, and partial sterilization of the soil (Nye and Greenland,1960; Bennett et al., cited in Jordan,1985).

After the burn, crops are planted. A common cropping sequence is that of a cereal, cassava, plantain. During the cropping period new seeds of weedy species arrive and seeds which survived burning germinate and consequently weed infestation increases. Therefore, cassava and plantain, which require less nutrients and are more weed competitive than cereals, are planted as second and third crop (Sanchez,1976). During the cultivation period yields decline. In Latin America farmers shift to a new field when yields are expected to be less than half of the yield in the first season after clearing (Sanchez,1976). Farmers in south-west Côte d'Ivoire use the same criterion (De Rouw,1991a). In Africa, weed infestation is reported as main reason for yield decline (Nye and Greenland,1960; Jurion and Henry,1969). Sanchez (1976) differentiates according to the fertility level of the soil: on fertile soils weed infestation is the main reason and on less fertile soils nutrient depletion. In the forested humid tropics low-base-status soils dominate and consequently nutrient depletion must be considered as main reason to abandon a field.

After fields have been abandoned forest regrowth can start. During the fallow period nutrients accumulate in the vegetation and are released when the vegetation is burnt for the next cropping period. The length of the fallow period varies from 4 to 20 years (Sanchez,1976).

Shifting cultivation is a dynamic system and may be adapted according to the prevailing conditions. Ruthenberg (1980) states that shifting cultivation is an expression of a certain stage in population density and price relations. A major reason for adapting the system is the scarcity of new land resulting from an increasing population density as is found in the major part of the shifting cultivation areas of the world.

1.3 Alternatives for shifting cultivation

Agronomic alternatives for shifting cultivation generally reported are cattle ranching, perennial crop plantations, agroforestry and intensification in cultivated agricultural systems (Ruthenberg,1980; Harwood,1994). The relevance of the alternatives depend on the ecological and socio-economic conditions. Conversion of forest to pasture for cattle ranching is important in Latin America but not in West Africa because of tsetse fly infestation. Establishment of tree crop plantations is practised on a large scale in West Africa. For the development of healthy plantations remunerative markets need to be available.

Food crops may be cultivated in agroforestry systems or in intensified shifting cultivation systems.

1.3.1 Agroforestry

Agroforestry is a collective name for land use systems and technologies where woody perennials are grown in association with agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In such a system there are both ecological and economical interactions between the different components (Lundgren and Raintree,1982). The mixture is environment-specific. An example of agroforestry is alley cropping in which N-fixing trees are integrated in food cropping. The trees reduce soil erosion and leaching of nutrients, thus contributing to the restoration and maintenance of soil fertility, and provide timber and fuel wood. In West Africa extensive research has been carried out on alley cropping by the International Institute of Tropical Agriculture (IITA) at Ibadan, Nigeria.

Most data from the humid zone refer to nonacidic soils, mainly Alfisols (or Luvisols in the FAO system). Trees have problems to root in the acidic subsoils of Ultisols/Acrisols. Even tree species tolerant of a high acidity, root in the relative nutrient-rich topsoil (Juo and Kang, 1989). These authors suggest that for the establishment of suitable woody species on such soils, fertilizer application and subsoil liming during two years may pay in the long run. The nutrients applied contribute to the establishment of a nutrient recycling system involving tree pruning, cropping and periodic fallowing. It is obvious that such investments are not very attractive to shifting cultivators. Moreover, alley cropping requires more labour than food crop cultivation in shifting cultivation systems.

1.3.2 Intensification of shifting cultivation

Shifting cultivation systems can be intensified by extending the cultivation period or shortening the fallow period. The latter may negatively influence yields in two ways: a reduction in the amount of nutrients accumulating in the standing biomass and an increase in the quantity of seeds of weedy species remaining. Moreover, more time is required for clearing a young fallow vegetation than for clearing an older vegetation.

To increase the nutrient content of the fallow vegetation the natural vegetation may (partly) be replaced by planted legumes. Although this method has proven to be a technical success in a number of cases (Ruthenberg,1980), the practice has rarely been adopted by farmers probably because of the labour requirements and the low benefits. Jaiyebo and Moore, cited in Sanchez (1976), however, found no difference in the amounts of nutrients accumulated in natural fallows and in various planted fallows, neither in the yields of maize grown after clearing the fallows.

Sanchez et al. (1982) report that continuous cultivation is possible on acid, infertile Ultisols of the Amazon Basin provided fertilizer application is adequate. In the Yurimaguas area in Peru during a cropping period of 8 1/2 years, 21 crops were grown on the same field, with an average grain yield of 7.8 t ha^{-1} $year^{-1}$ (Fig.1.1). The fertilizer requirements are presented in Table 1.2. During the cultivation period soil properties improved. Weed, insect and disease attacks were alleviated by crop rotation, selection of varieties, and judicious use of insecticides and herbicides. On the nearly level soils of the study area, where erosion hazards were absent, this 'Yurimaguas' technology proved to be agronomically and socio-economically feasible.

In Table 1.3 the results of another long-term experiment in Latin America are presented (Janssen and Wienk,1990). On Oxisols/Ferralsols in Suriname similar yields and fertilizer recommendations were reported. In this experiment, groundnut was the only crop of which cultivation was found profitable.

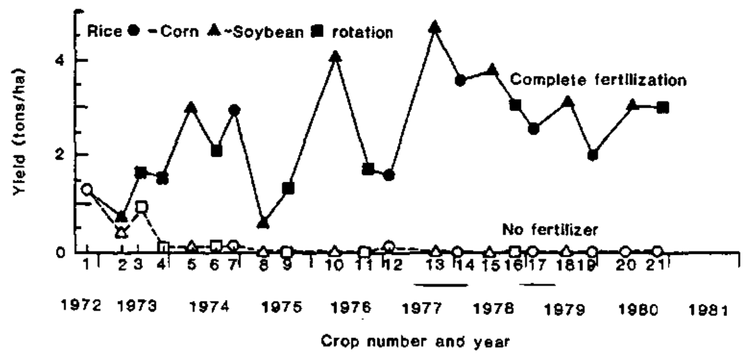


Fig.1.1 Yield record for a continuously cultivated plot at Yurimaguas, with and without fertilization (Sanchez et al.,1982).

Table 1.2 Fertilizer requirements for continuous cultivation of annual rotations of rice, maize, and soybeans or rice, peanuts, and soybeans on an acid Ultisol in Yurimaguas (Sanchez et al.,1982).

Input[a]	kg ha^{-1}	Frequency
Lime	3000	once every 3 years
N	80-100	maize and rice only
P	25	every crop
K	80-100	every crop, split application
Mg	25	every crop[b]
Cu	1	once a year or once every 2 years
Zn	1	once a year or once every 2 years
B	1	once a year
Mo	0.02	mixed with legume seeds only

[a] Ca and S requirements are satisfied by lime, superphosphate, and Mg, Cu and Zn carriers
[b] unless dolomitic lime is used

It is unlikely that the majority of shifting cultivators can readily switch to continuous production. Intermediate production systems of low-cost and low-input technology may be useful as a first step of intensification (Sanchez and Benites,1987). In low-input systems for acid soils, plant species are grown that are well adapted to the main soil constraints, use of external inputs is minimized, and nutrient cycling is maximized (Sanchez and Salinas,1981; Sanchez and Benites,1987).

This low-input system was also tested in the Yurimaguas area (Sanchez and Benites,1987). On an Ultisol (pH 4.5) cleared from 10-year-old secondary forest, the first six crops (rice-rice-cowpea-rice-cowpea-rice) grown did not respond to fertilizer application, but the seventh crop (rice) did. Weeds were controlled with locally available herbicides.

Table 1.3 Target grain yields (t ha^{-1}), required fertilizer applications (kg ha^{-1}) per season, and optimum pH-H_2O for some crops on low fertility acid soils in Suriname (based on Janssen and Wienk,1990)

	Maize	Sorghum	Soybean	Groundnut	Cowpea
Target yield	4.5	3.5	2.5	4.0	1.25
N	170	140	none	none	none
P	40	20	40	20	10
K	100	80	120	60	40
Mg	30	none	15	30	none
pH-H_2O[a]	<- 5.0 to	5.6->	<--- 5.2	to	6.0--->

[a] in order to maintain the indicated pH, 1 t $CaCO_3$ ha^{-1} should be applied annually, preferably before planting groundnut or soybean

The eighth to tenth crops were cowpea, rice and cowpea. Rice received 30 kg N, 22 kg P and 48 kg K ha^{-1}. Due to the changing weed composition a weed control variable was introduced: full weed removal at economically unrealistic levels versus the conventional treatment. Full weed removal appeared to be necessary for obtaining acceptable yields and it is clear that under zero-tillage weed control is a major constraint.

In the low-input system six crops were grown without fertilizer application. This is in contrast to the continuous-cropping experiment discussed above where the yield of the no-fertilizer treatment was about zero after the third crop (Fig.1.1). Sanchez and Benites (1987) ascribed the difference to the use of aluminum-tolerant cultivars, zero tillage and maximum residue return.

Sanchez and Benites (1987) concluded that farmers practising low-input agriculture after six crops have four options: (i) to establish pastures, (ii) to use an agroforestry system, (iii) to change into continuous cropping (to plough, lime, fertilize and rotate crops intensively), (iv) to plant a managed fallow and start a new cropping cycle. In option (iv) a fallow of kudzu (*Pueraria phaseoloides*) was planted and after one year slashed and burnt. Thereafter a new cropping cycle was started. Kudzu proved to be able to suppress weed growth and to replace a natural fallow of about 25 years (Sanchez et al.,1982). Although good results were obtained in a second cropping cycle no data are yet published on how this option develops in the long run. In order to study whether the kudzu option is feasible in other regions, a network of validation trials needs to be established.

Summarizing, it can be stated that shifting cultivation is an ecologically sound system in areas with a low population density. When the population density increases, it is necessary to intensify the cultivation system. The change from shifting cultivation to permanent agriculture is an enormous step. In Europe such a transition has taken centuries. In areas where shifting cultivation is practised today, however, such a long time is not available. Research has made clear that permanent cultivation on low-fertility soils is technically possible. For a major part of the shifting cultivators an intermediate production system may be more appropriate than a highly sophisticated and intensive cropping system.

Anyhow, intensification of agricultural production must be practised in a sustainable way. The terms used to express the ecological risks changed from desertification in the 1970s to deforestation in the 1980s and global warming in the 1990s, as was noticed by Robison and McKean (1992), when compiling their bibliography.

1.4 Aim and contents of this thesis

Aim of this thesis was to study the role of plant nutrients when the period of food crop cultivation in the shifting cultivation system of the Taï region is extended. Therefore in the period 1987-1991 on-farm field experiments with controlled management were conducted near the village Taï. The results of these experiments are presented in this thesis.

In south-west Côte d'Ivoire the Taï National Park (340,000 ha) is situated. Recently the population has increased enormously due to immigration. Forest to be cleared outside the boundaries of the Park has become more and more limiting, and the Park itself is threatened. Intensification of the shifting cultivation system will contribute to the increase in food production and through that to the protection of the Park. For such an intensification knowledge on nutrient dynamics is essential. The research presented in this thesis was part of a multidisciplinary project executed by the Agricultural University of Wageningen titled 'Analysis and design of land use systems in the Taï region, south-west Côte d'Ivoire'.

In Chapter 2 the geography and agriculture of the Taï region are discussed. Already for a long time, this region has been a centre for agricultural and biological research and the results in the field of agronomy are summarized.

Chapter 3 and 4 present data on nutrient fluxes in the traditional shifting cultivation. At two sites with 4- and 20-year-old fallows, respectively, the vegetation was slashed, dried and burnt according to local practices. Next, three crops were grown consecutively. Nutrient contents in the fallow vegetations, ash and crops gave a hindsight in the effect of burning on nutrient fluxes. The fertilizing effects of ash were compared to those of mineral fertilizers (Chapter 5).

To identify the most severe nutritional constraints and the soil characteristics to which they were related at six sites with well drained to imperfectly drained soils, the responses of upland rice to fertilizer N, P, K and lime were studied in 2^4 factorial experiments (Chapter 6 and 7).

The research made clear that soils in the Taï region differ strongly in inherent fertility and responses to fertilizers. The soils are characteristically found in so-called catenas. At five locations along a representative catena, experiments were conducted to study the fertility dynamics of the different soils during five seasons. Because phosphorus proved most limiting, more detailed experiments were carried out with increasing rates of fertilizer P at two other sites during six seasons. Also in these experiments the dynamics of soil fertility could be studied (Chapter 8, 9 and 10).

In Chapter 11, the results of this study are synthesized into recommendations for measures to be taken to successfully extend the cultivation period in the shifting cultivation system of the Taï region.

Chapter 2

Study area

2.1 Introduction

The study area is situated between the western boundary of the Taï National Park and the Cavally river. All experiments described in this thesis were conducted in an area ranging from 20 km north to 10 km south of the village Taï. In the following this area is referred to as the Taï region. Administratively the area is located in the sous-préfecture (district) Taï, which is part of the Préfecture (Province) Guiglo.

2.2 Demography

The indigenous population of south-west Côte d'Ivoire, is formed by the Oubi and Guéré which belong to the Krou. Part of this ethnic group also lives in Liberia.

Since the mid-1960s many immigrants have arrived in the south-west. Immigration increased for four reasons (Guillaumet et al.,1984): crop failure due to extreme drought in the Sahelian zone (1966-1973), possibility of landownership for foreigners, official Government policy to develop the south-west, increasing cacao and coffee prices in the years 1972-1976. Part of the Government policy to develop the south-west was the migration of about 75,000 people (Baoulé) from central Côte d'Ivoire, who had to move because of construction of a dam for hydro-electric power. The development of the population in the sous-préfecture Taï is presented in Table 2.1. In 1975 about 45% of the total population were immigrants (Lena,1984).

Table 2.1 Development of population density (persons km^{-2}) in the sous-préfecture Taï (adapted from Kientz,1992 and Koch,1994).

	1965	1975	1988
Sous-préfecture Taï	3,600	6,865	30,039
Population density	0.9	1.8	7.7
Population density[a]	4.1	7.8	34

[a] excluding protected forest areas

According to the 1988 population census the indigenous population amounted to 18%, the other Ivorians to 34% and non-Ivorians to 48% of the total population (Kientz,1992). This means that more than 80% of the total population originated outside the sous-préfecture.

Since 1989, also Liberian refugees, fleeing the civil war in that country, have invaded the region. According to Kientz (1992), in August 1992 the number of refugees in the sous-préfecture Taï was 15,686. It is not known how long these refugees will stay and how long food support will be provided by relief agencies. In early 1995, the total population of the sous-préfecture was estimated at 50,000 people.

2.3 Physical environment

2.3.1 Climate

In south-west Côte d'Ivoire the total amount of rainfall increases in NE-SW direction going from the interior to the coast. The area has an Aw climate according to the Köppen classification. In the Taï region the mean annual rainfall amounts to 1885 mm with a standard deviation of 338 mm (Collinet et al.,1984). According to Fritsch (1980), four seasons can be distinguished:

(1) a long rainy season from March to July accounting for 45% of total rainfall;
(2) a short relatively dry season from July to September;
(3) a short rainy season from September to November accounting for 30% of total rainfall;
(4) a long dry season from November to March in which potential evapotranspiration exceeds rainfall.

Mean monthly temperatures vary from 24.7 °C to 27.4 °C. Diurnal changes are small, except in the main dry season when the Harmattan winds blow. The Harmattan brings dry and dusty air from the Sahara desert (Stoorvogel,1993). Mean monthly global radiation varies from 1100 to 1800 J cm^{-2} day^{-1} (Monteny, cited in Collinet et al.,1984).

2.3.2 Flora and fauna

Following the UNESCO (1973) world classification, Vooren (1985) classified the natural vegetation as tropical lowland evergreen seasonal forest. In the forest over 150 endemic woody species occur. The biomass varies from 350 t ha^{-1} in the valley bottoms to 560 t ha^{-1} on the higher parts of the slopes (Huttel,1977). Van Rompaey (1993) reports gradients in the numbers of large trees and tree species; both are decreasing from north-east to south-west, following the rainfall gradient.

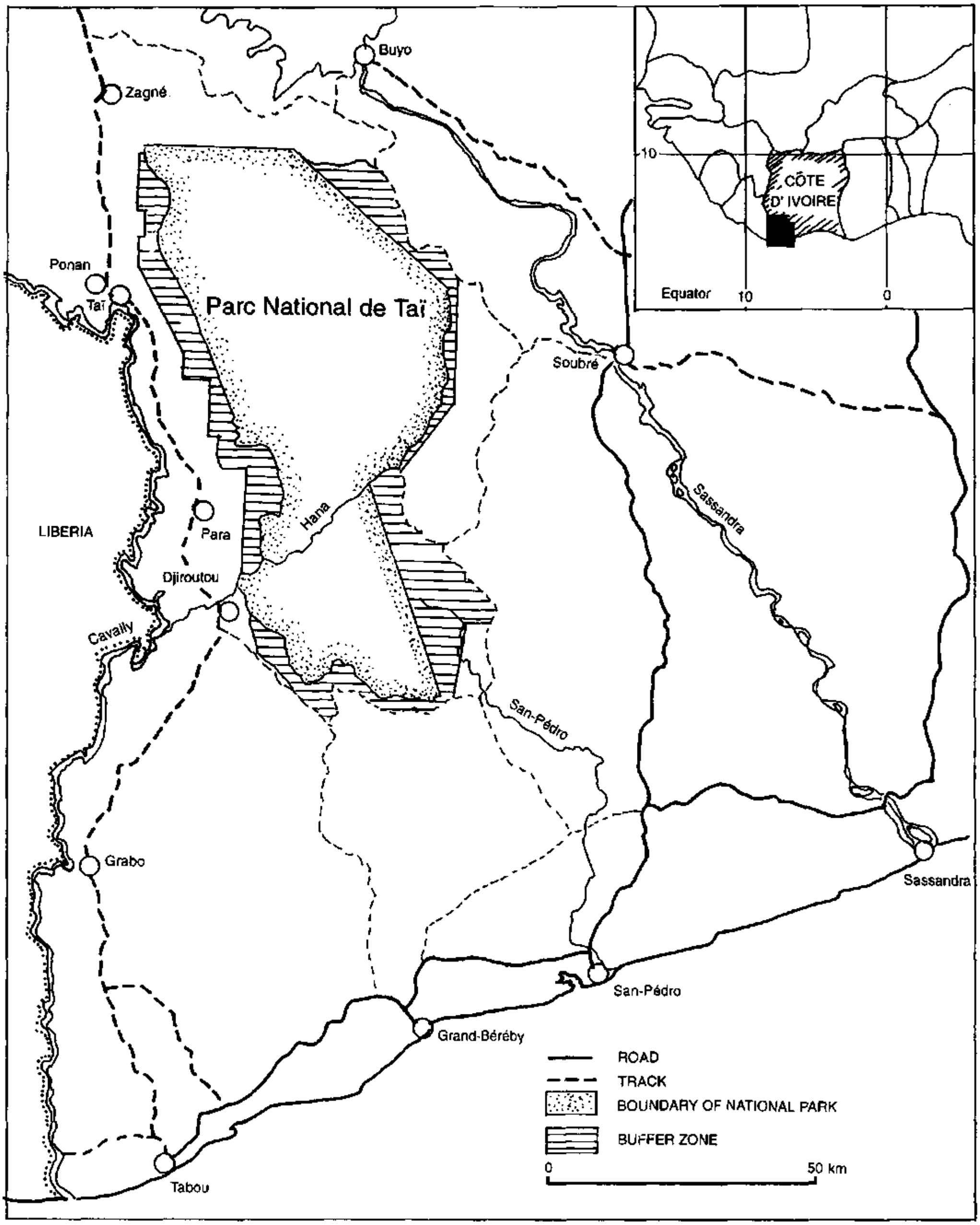


Fig. 2.1 Map of south-west Côte d'Ivoire

The Taï National Park is the last extensive area with undisturbed forest west of the Dahomey gap. It has the status of Biosphere Reserve and of World Heritage Site. Studies on its flora have been summarized by Guillaumet (1994), and those on its fauna by Allport et al. (1994). The Park is especially known for its great variety of monkeys as well as chimpanzees. The latter have been studied extensively by Boesch and Boesch (1989).

2.3.3 Geology and geomorphology

The major part of the underlying rocks of south-west Côte d'Ivoire belongs to the Precambrian Basement Complex consisting of granites and associated metamorphic rocks, mainly of gneissic character. These metamorphic rocks are often indicated as migmatites. The migmatites are characterized by lithological differences over short distances due to different intensities of metamorphism and granitization. Bos (1964) characterized the migmatites of the study area as heterogeneous. The gradual transitions in lithology and scarcity of rock outcrops have resulted in discrepancies between the results of different geological inventories (De Rouw et al.,1990).

Over 80% of the study area consists of a dissected peneplain with remnants of an ironstone crust on the highest terrain positions. Such a landscape can be characterized by catenas or toposequences which are defined as sequences of soils of about the same age, derived from similar parent material, and occurring under similar climatic conditions, but having different characteristics due to variations in relief and drainage (Soil Science Society of America,1973). Along such a catena five sub-elements can be distinguished: crest, upper slope, middle slope, lower slope and valley bottom.

The major part of the study area is situated between 100 and 250 m above sea level. The relief is undulating to rolling, and the slopes tend to be long and are mostly convex. The valleys are relatively narrow and the streams have few meanders. The average local relief is 20 to 25 m.

2.3.4 Soils

Within the framework of the development of south-west Côte d'Ivoire, the Development and Resources Corporation (1967) made an inventory of the soil and forest resources. A soil map at a scale 1:200,000 was published with associations of soil series as mapping units. The study area falls completely within mapping unit K, which has an extent of 357,900 ha. Van Kekem (1984) translated the legend of this map into French and made a correlation with the FAO-UNESCO legend of the soil map of the world (FAO-UNESCO,1974).

Fritsch (1980) mapped an area of 1,600 ha situated in the National Park at a scale 1:15,000. Six types of catenas were distinguished with minor differences in slope form and elevation. In Collinet et al. (1984), the work of Fritsch is summarized. Vellema (unpublished) prepared a physiographic soil map of an area of about 20,000 ha around the village Taï. In this survey the main catena distinguished by Fritsch (1980) appeared to be representative of the entire area of 20,000 ha.

The above data have been incorporated in a land unit survey of about 90,000 ha, roughly situated between the villages Taï and Para (De Rouw et al.,1990). The land units have a characteristic combination of landform, vegetation, lithology and hydrology.

The study area dealt with in this thesis belongs to mapping unit Unm2 of the land unit survey. U stands for Upland, a major geomorphic unit; n for northern vegetation/rainfall zone; m for migmatite/gneiss (lithology); and 2 for drainage intensity class 2. In this survey the catena that is representative of this mapping unit is indicated as migmatite catena. This catena basically resembles the main catena distinguished by Fritsch (1980). The mapping unit Unm2 covers 26,650 ha, i.e. 30% of the survey area.

In the migmatite catena the crest and upper slopes occupy 30-50% of the surface area, the middle slopes 20-30%, the lower slopes 25-30% and the valley bottoms about 15% (De Rouw et al.,1990).

2.4 Agriculture and agricultural research

2.4.1 Introduction

The main components of the local farming systems are forest, food crops and tree crops. The cultivation of irrigated rice in valley bottoms has recently become an important activity.

In the system with food crops, short cropping periods alternate with shorter or longer fallow periods. Fields are abandoned when yields decline due to soil fertility depletion and weed infestation. The lengths of the cropping and fallow periods are related to soil properties and population density. In case tree crops, such as cacao, coffee or rubber, are planted, the forest is replaced permanently.

The relative and absolute values of the various components are strongly related to the availability of land and labour and to feeding habits, which vary among the ethnic groups to which the farmers belong. To give an example, in the village Ponan the Guéré have on average a farm of 20 ha, whereas the farms of the Baoulé and Burkinabé are 8 and 10 ha, respectively. The Guéré have only 30% of their land converted to tree crop plantations (cacao and coffee), and the Baoulé and Burkinabé about 80-90% (Slaats,1995).

2.4.2 Present agriculture

Three main farming systems may be distinguished according to the ethnic groups: indigenous population (Oubi and Guéré), Baoulé and Burkinabé.

2.4.2.1 Indigenous farming system

The traditional farming system of the indigenous population (Oubi and Guéré) is shifting cultivation. A patch of forest of about one ha is cleared and upland rice grown. In case forest is amply available, the main determinants for selection of a site to be cleared are age and quality of the forest, and soil quality (De Rouw,1991a). Locations near the village are preferred.

The development of a fallow vegetation is characterized by two periods of natural decline. After 7-10 years the two dominant pioneer trees *Macaranga hurifolia* and *Harungana madagascariensis* die and after 16-20 years other tree species die (Collinet et al.,1984). Farmers can save much work by choosing one of these periods for field clearing. Because still many weed seeds are present in fields cleared after 7-10 years of vegetation regrowth, farmers prefer sites with 16 to 20-year-old vegetation. Older secondary forests and primary forests are more difficult to fell because trees are thicker and the wood is harder. Also some selected tree species are not slashed for a number of reasons (De Rouw,1987).

Forest quality is assessed by the occurrence of certain species, and soils are judged by the colour and texture of the topsoil (De Rouw,1991a). However, it was not possible to establish a relation with chemical soil properties (De Rouw et al.,1990).

The forest is slashed, dried and burnt. In between the non-burnt vegetation parts farmers grow upland rice of various varieties over a period of one or two seasons (De Rouw,1991a). Crop management is poor and yields vary from 0.7 to 1.5 t ha^{-1}. Next the fields are abandoned and left fallow for at least five years but often for much longer periods (Moreau and De Namur,1978). De Rouw (1991a) reports a

16-year fallow period.

After fields have been abandoned, the remaining trees combined with the short cropping period with only minor disturbances of the topsoil facilitate forest regrowth. Before the introduction of coffee in the 1950s, the indigenous population cultivated small plots of rice in the valley bottoms during the dry season. Preparation of these fields coincided with the coffee harvest and due to labour constraints this type of rice cultivation has been discontinued.

2.4.2.2 Baoulé farming system

Since the end of the 1960s, Baoulé indigenous in Central Côte d'Ivoire have migrated to the south-west. There is a relation between the size of their holdings and the time of arrival in the region, as was illustrated for the village of Djéré-Oula by Budelman and Zander (1990). The farms of the Baoulé who arrived before 1980 have an average size of 14 ha, whereas the farm size is 8 ha for the Baoulé who arrived later.

In the Baoulé farming system cacao is a prominent crop. For planting cacao, deep clayey soils are preferred but if they are not available, less suitable soils are used as well. It can be stated that in general the soils in the region are not well suited for cacao. Consequently yields are low.

During establishment of the plantations the young cacao is intercropped with food crops. The characteristic crop for the Baoulé is yam. It is cultivated in mounds (about 5,000 ha^{-1}), and the average yield amounts to 7 t ha^{-1}. In between the yam mounds, cacao seedlings are planted at a very high density.

Baoulé farmers clear the forest completely. Large trees are not slashed but burnt. Yam mounds are made by scraping the topsoil together. In this way every year one to four ha are cleared till the complete holding is planted.

2.4.2.3 Burkinabé farming system

The majority of the non-Ivorian immigrants arrived after the Baoulé, and the influx continued when that of the Baoulé had stopped. Many arrived without any capital, and started working in saw mills, for indigenous farmers, or on commercial rubber plantations. In this way capital was gained for the purchase of forest to start farming.

The agricultural practices resemble those of the Baoulé: cacao seedlings are planted between food crops, preferably rice or maize but also yam and cassava. Burkinabé farmers also clear the forest completely.

When the Burkinabé farmers are running out of land, abandoned rice fields of the indigenous population are rented for food crop cultivation. The need for land explains why the Burkinabé also grow food crops on these fields invaded by the shrub *Chromolaena odorata*. Due to lack of labour or because better land is available, farmers of other ethnic groups are not interested in these fields.

Immigrant farmers convert more forest into tree crop plantations than the indigenous population. In this way land is permanently withdrawn from the shifting cultivation cycle and the pressure on the remaining is increased.

2.4.3 Recent developments and agricultural research

2.4.3.1 Fallow vegetations and weeds

In villages on the western side of the National Park many immigrant farmers grow maize one or two years, followed by fallow period of two to four years. The fallow vegetation is dominated by *Chromolaena odorata*. This shrub covers the surface quickly and hinders the development of other weed species. Growth is abundant and through the produced litter nutrients return to the soil. Chromolaena produces much seed which germinates during the cropping period and necessitates weeding.

It is to be expected that the practice of food crop cultivation periods alternating with short fallow periods will extend to other areas in Côte d'Ivoire. Slaats (1992,1995) studied the use of Chromolaena as fallow vegetation. He found a positive effect of the length of the fallow period (2 and 4 years) on maize yields in the first season after clearing, both with and without fertilizer application. In the second and third seasons, yields after both fallow periods decreased and became about similar. For maize one weeding at 3 to 4 weeks after planting was sufficient, but rice required at least two rounds of weeding. Because the indigenous farmers do not have sufficient labour for the required weeding, they do not cultivate Chromolaena-infested fields.

The role of weeds in rice cultivation has been studied extensively in the Taï region. The influences of burning, and of the length of the fallow and the cropping periods on weed development received attention, as well as the effects of weeds on rice yield. The length of the fallow period proved to be inversely related with the number of weeds during the cropping period (De Rouw,1991a).

Burning the slashed vegetation reduced the number of weed seedlings from about 2000 to 1000 m^{-2} (De Rouw and Van Oers,1988). De Rouw (1991a,1992) quantified the influence of weeds on the yield of the traditional rice variety 'Demandé'. In the absence of 'stress' by weeds during the vegetative phase of rice, tillering was maximum and the yield was 1.6 t ha^{-1}. In case of moderate 'stress', the number of panicles dropped, but weeding during the reproductive phase compensated for the weak tillering by an increased grain weight, and yield was 1.4 t ha^{-1}. For the farmers this yield decrease from 1.6 to 1.4 t ha^{-1} is acceptable, because less labour is required for weeding and harvesting. However, in case of severe 'stress' during both the vegetative and reproductive stages, yields dropped to a very low level of 0.3-0.4 t ha^{-1}.

The negative effect of weeds on the yield of the rice variety 'Demandé' increased with the length of the cropping period. De Rouw (1991a) reports that in the first year after clearing rice grew at the same rate as weeds, both reaching heights of up to 1.70 m. It is also stated that in the second year due to reduced soil fertility, rice reached a height of only 1.20 m while the number and height of weeds increased considerably. The weeds produced many seeds at the end of the second season, thus making it impossible to grow rice in a third season.

Because modern rice varieties are short, they are less weed-competitive than the traditional ones and require more weeding. Slaats (1992) found a yield increase of about 1.5 t ha^{-1} when the short, modern variety IDSA 6 was weeded twice instead of once.

When the cropping period is extended, the botanical composition of the weed vegetation changes. In the first year after clearing, the weed vegetation consists mainly of woody species which cause less trouble than the shrubs dominating in the second year. At such sites with a monospecific stand of Chromolaena, forest regrowth is hampered because the seed stock of woody species is getting depleted. Indigenous farmers are not interested in using these fields because of the labour requirements for clearing and weeding during cropping.

Chromolaena was observed in the south-west for the first time in 1980, and fields became infested from 1984 onwards (De Rouw,1991b). The studies of De Rouw show that the key prerequisites for the traditional cultivation of upland rice are:
1. a fallow period of at least 16 years followed by slashing and burning and crop cultivation during one season, 2. the use of tall varieties and 3. weeding before the reproductive stage.

2.4.3.2 Rice cultivation in valley bottoms

Rice cultivation in valley bottoms has revived due to immigrants being familiar with this practice. At present, rice is grown not only in the dry season but throughout the year. Near the village of Taï the revival started in 1990, but in Djiroutou (100 km south of Taï) it already began in the early 1980s. In this region, rice cultivation is stimulated by the 'Compagnie Ivoirienne pour le Développement des Cultures Vivrières' (CIDV). This organization selects the valley bottoms, supplies seed and fertilizers, and advises on irrigation matters. For being eligible for CIDV support, the area needs to be at least 14 ha in size and must be cultivated by a group of farmers.

A study by Elie (1991) including 9 farmers in Djiroutou revealed a relation between the year of arrival in the region and the area of available land. The only indigenous farmer included in this study owned about 55 ha of which only a few hectares were cultivated. The three immigrants who arrived before 1980 owned about 20 ha each of which a large part had been converted into tree crop plantations. Immigrants who arrived later had to be satisfied with much smaller areas. The two farmers who arrived second last and last only had fields of 0.5 and 0.3 ha, respectively, at their disposal. The sizes of the rice fields varied from 0.2 to 1.0 ha, and according to farmers' information yielded from 1.5 to 6.0 t ha^{-1}.

Suitable valley bottoms on the western side of the National park have not yet been surveyed, but their extent was estimated to be less than 15% of the total surface area. Near the village of Taï the pedological aspects of the valley bottoms have been studied by Van Der Gaag (1989) and Zeeman (1989) and the agronomic aspects by Elie (1991).

In the swampy area between Sakré and Zrigolo De Rouw et al. (1990) report an intermediate form of cultivation of upland rice and wetland rice. Farmers plant according to the upland method, but during the advancing rainy season the fields become inundated. This system requires a fallow period of about 6 years.

2.4.3.3 Perennial crops

Coffee

Robusta coffee cultivation has started in the 1950s. Generally it can be stated that the ecological conditions for coffee are good. Since 1971 the 'Institut de Recherche pour Café, Cacao et autres Stimulantes (IRCC)' has conducted trials at a small experimental station in Zagné. Based on these experiments crop management advices have been developed for the region. At this station, where coffee was planted at a density of 1,333 trees ha^{-1} (3*2.5 m) yields amount to 1.2 and 2,3 t ha^{-1}, without and with fertilizer application, respectively (IRCC,1987-1990).

Usually rice, groundnut or yam is planted in between the coffee during the first two years. When the coffee is planted at wider distances (10*16 m) food crops can be interplanted permanently. However, according to Leduc (1984) it is characteristic of the Ivorian forest zone that after a few years weed infestation and nutrient deficiencies constitute problems.

The first established coffee plantations are now 40 years old and need to be replaced. Due to the low coffee prices the willingness of farmers to invest in plantations is not high.

Cacao
Since the end of the 1960s cacao plantations have been established on a large scale by Baoulé and Burkinabé immigrants. Despite the presently low prices, these plantations have become the main source of income for the immigrants. In spite of low soil suitability, the climatic conditions of the south-west are favourable for growing cacao. In the sous-préfecture of Taï the average yield amounts to 0.2 t ha^{-1}, while the national average is 0.4 t ha^{-1} (Ministère de l'Economie et des Finances,1988). At the experimental station in Zagné yields of 1.5 to 2.0 t ha^{-1} are obtained with fertilization (IRCC,1987-1990).

Cacao needs a well drained, deep, clayey fertile soil. In general it can be stated that cacao is a more demanding crop than coffee, rubber and oil palm. Most soils on the western side of the National Park are gravelly and have a low inherent soil fertility. Experiments conducted at the IRCC station in Zagné confirmed the low potential, especially without fertilizer application.

Low yields are also caused by low quality of planting material and insufficient phytosanitary measures. The need for rapid extension of the plantations has led to application of direct sowing techniques instead of planting seedlings, often with material originating from neighbouring plantations of which the genetic potential is poorly known, instead of using released hybrids. Protection of young cacao trees against pests and diseases is often neglected. Plantain, and other crops or trees like *Trema guinensis* which are sometimes used are not a guarantee for protection against insects, like *Earias biplaga* and thrips (Lachenaud,1987). In adult cacao plantations measures against damage by mirids are also insufficient. The mirid lesions cause wilting, early ageing, and lower yields.

Under these circumstances it is to be expected that 10 years from now only half of the present area will be still in production. This prediction is not valid for the plantations south of Para and at the eastern side of the Park. In these areas soil conditions and crop management are much better. Price increases will lead to extension of the plantations.

Rubber and oil palm

During the last 20 years the cultivation of rubber and oil palm has extended substantially. In 1990 about 16,200 ha in the south-west were planted to rubber, 5,000 ha north of Taï, 3,000 ha on a commercial plantation and 2,000 ha by smallholders. Plantations established by smallholders are a recent development. Farmers are stimulated by extension workers to plant 1 ha with 16-m row intervals so that food crops can be grown between rows. These rubber plantations are not yet in production but in other regions production levels of 1 to 1.5 t ha^{-1} are obtained versus 2.3 t on commercial plantations.

Oil palm plantations are found south of Djiroutou. In 1989 the extent was 22,000 ha, of which 10,000 ha by smallholders with yields of 10 to 12 t ha^{-1} versus 20 t on commercial plantations.

Due to low soil suitability, farmers in the Taï region have rubber as an alternative for cacao, while in areas with more than 2,000 mm of rainfall oilpalm is an alternative.

Agroforestry and forest tree cultivation

In the past several authors proposed agroforestry as one of the possibilities for reafforestation (Catinot,1984; FAO,1984). These techniques are thought to be especially suitable for areas in the buffer zone which are now used for agricultural purposes. Vooren (1986) proposed the use of the ecological cycle of forest trees for agroforestry purposes. Bonnéhin (1988) studied the problems of the buffer zone on the eastern side of the Park and concluded that agroforestry is a better approach than moving people out by force.

The combination of trees and food crops might well be suitable for the Taï region. In fact the traditional system may be considered as agroforestry because woody plants and herbs, wild or cultivated, annual or perennial, are grown in combinations. Up to now one aspect of agroforestry has been studied. Budelman (1990) studied the use of woody species as live support system in yam cultivation. When *Gliricidia sepium* was used, a yam yield of 10 t ha^{-1} was obtained versus 7 t ha^{-1} in the traditional system. Despite this increase, the practice has sofar not been adopted by local farmers because of the labour required for additional work, especially the need for pruning the trees. Generally agroforestry systems require more labour compared to traditional farming systems and are only adopted when the benefits are evident. Another study regarding trees but strictly speaking not in the field of agroforestry is the cultivation of trees which are highly appreciated by the local population for their wood and other products. In an on-going project Bonnéhin studies two species: *Tieghemella heckelii* (Makoré) appreciated for its fruits and wood and *Coula edulis* whose nuts are edible and can be commercialized. This study is a follow-up of research by Bonnéhin (1992) and Van Der Put (1990).

Part III

Nutrient release from burnt fallow vegetations

Chapter 3

Dry matter production, nutrient contents and nutrient release after slash and burn for two fallow vegetations

Key words: ash composition, ash production, burning, Côte d'Ivoire, fallow vegetation, nutrient content, shifting cultivation, temperature recording, Taï National Park

Abstract

At two sites in the Taï region of south-west Côte d'Ivoire, one with a 4-year (4-Y) and the other with a 20-year (20-Y) old fallow vegetation, dry matter and nutrient contents of the different parts of the vegetation were studied. The vegetation was slashed, dried and burnt according to the local system. During the burn the temperature was recorded as well as the amount of ash produced. At soil surface, temperatures above 500 °C were found. At 0.5-cm and 1.5-cm depth, temperatures above 260 °C and 150 °C, respectively, were rare. Because slashed vegetation could dry only during a short period, not more than 45% of the 56.1 ton dry matter was burnt on the 4-Y site and not more than 15% of the 117.4 ton dry matter on the 20-Y site. Plant parts burnt consisted mainly of smaller sized fractions: litter, dead wood, leaves and wood < 5 cm ø. Variability of ash data was high. Ash production amounted to approximately 2.5 ton ha^{-1} at both sites. Nutrient contents of ashes were also about equal at both sites. An exception was K content, being higher in ash from a 4-year-old vegetation.

3.1 Introduction

Shifting cultivation can be defined as an agricultural system in which temporary clearings are cropped for fewer years than they are allowed to remain fallow (Sanchez,1976). In the forest zones the vegetation is slashed, dried and burnt. Burning results in, among other things, release of nutrients. After a cropping period the land is abandoned and will be recultivated after its fertility is judged to be restored, or sooner if other land is not available for use (Greenland,1974). In many parts of the world, due to increasing population the latter is the case. In such areas intensification of the extensive shifting cultivation system is necessary to produce enough food.

Many studies of one or two aspects of the shifting cultivation system have been reported from all over the world. E.g. nutrient contents of fallow vegetations in West and Central Africa have been studied by Bartholomew et al. (1953) in Yangambi, Zaïre, by Greenland and Kowal (1960) in Kade, Ghana, and by Jaffré (1985) in Taï, Côte d'Ivoire. Quantity and composition of ash produced through burning were determined in some countries in tropical America. Tables 3.1 and 3.2 present some of the collected data. The results by Jaffré (Table 3.1) show that dry matter and nutrient contents increased about threefold in the period between 4 and 15 years. Ash production is not proportional to amount of dry matter in the vegetation (Table 3.2). Nutrient contents in ash were considerably lower in Suriname than in Costa Rica and Peru, mainly due to the fact that in Suriname ash was sampled one month after burning and in Peru unburnt parts of the vegetation were included in the ash. Also differences in soil fertility may have played a role.

Temperatures reached during the burn are highly variable and depend on nature, amount and moisture content of the slashed vegetation (Ewel et al.,1981). Reported temperatures reached at soil surface range from 100-150 °C in Brazil (Brinkmann and Vieira,1971) to 650 °C in Thailand (Zinke et al.,1978). At higher temperatures, ash production decreases due to more complete combustion, and consequently nutrients, except N, become concentrated in the ash. In the temperature range from 200 to 350 °C, a gradual decrease in N content is found, and at higher temperatures all N is lost (Andriesse and Schelhaas,1987). Temperatures recorded at 1-cm soil depth were 74 °C in Nigeria (Lal and Cummings,1979), and 100 °C in Costa Rica (Ewel et al.,1981). In Brazil, temperatures of 95 to 125 °C were found at 2-cm soil depth (Brinkmann and Vieira,1971), and in Thailand a temperature of 70 °C at 2-3 cm depth (Zinke et al.,1978). At 5-cm depth, temperatures of 150-250 °C were measured when much dry matter had piled up (Andriesse and Schelhaas,1987). As shown for the Taï region in Côte d'Ivoire by De Rouw and Van Oers (1988), heating killed part of the seeds present in the topsoil which was reflected in weed growth during the cultivation period.

Research covering the complete cycle of the shifting cultivation system is rare. Therefore a study on nutrient fluxes in the traditional shifting cultivation system was set up in the Taï region of south-west Côte d'Ivoire. Its objective was to provide information for the development of a more intensive agricultural system. The study included nutrient contents of the vegetation to be slashed and burnt, amounts of ash produced as well as its chemical composition, influences of burning on crops to be grown, on weed development and on soil properties.

Table 3.1 Above-ground dry matter (t ha^{-1}) and nutrient contents (kg ha^{-1}) of two fallow vegetations in the Taï region, Côte d'Ivoire (Jaffré,1985; Jaffré and De Namur,1983).

	Dead wood	Wood	Lianes	Marantaceae and Zingiberaceae	Leaves	Total
4-year-old vegetation						
Dry matter	2.1	17.2	1.7	1.3	1.3	23.8
N	nd [a]	64.6	25.6	18.1	32.8	141.0
P	nd	5.6	1.9	1.1	2.0	10.5
K	nd	89.7	33.9	35.9	16.9	176.4
Ca	nd	94.6	33.8	6.2	17.4	151.9
Mg	nd	21.5	4.9	3.4	4.1	33.9
15-year-old vegetation						
Dry matter	5.1	63.3	10.5	-	3.9	82.8
N	nd	291.1	76.7	-	97.0	464.9
P	nd	12.7	4.2	-	3.9	20.7
K	nd	158.7	64.1	-	51.6	273.9
Ca	nd	297.5	119.8	-	44.3	461.6
Mg	nd	50.6	16.8	-	16.6	84.0

[a] not determined

Table 3.2 Ash production and nutrient mass fractions in ashes from burnt vegetations in Costa Rica (Ewel et al.,1981), Peru (Seubert et al.,1977) and Suriname (Boxman,1990).

	Costa Rica (± s.d.)	Peru (CV %)	Suriname (range)
Age of vegetation years	7 -8	17	primary forest
Dry matter (t ha^{-1})	53.4	-	450
Ash (t ha^{-1})	6.7 ± 2.06	3.97 (15)	10 [a]
Nutrient mass fractions (g kg^{-1})			
N	14.3 ± 4.68	17.2 (21)	4.9 - 15.5
P	2.3 ± 1.3	1.5 (30)	0.3 - 0.9
K	28.3 ± 21.1	9.7 (47)	1.2 - 7.3
Ca	82.8 ± 41.0	19.1 (36)	8.5 - 22.0
Mg	15.9 ± 7.2	4.1 (36)	1.2 - 7.4
Mn	nd.[b]	1.9 (32)	nd
Fe	nd	1.9 (39)	nd
Cu	nd	0.08 (17)	nd
Zn	nd	0.14 (31)	nd

[a] amount of ash estimated and sampled one month after burning

[b] not determined

The present paper deals with the relation between amounts and nutrient contents of fallow vegetations and on amounts and chemical compositions of the ashes produced from it.

3.2 Materials and methods

3.2.1 Study area

The study area lies between the Taï National Park and the Cavally river which forms the boundary with Liberia (Fig. 2.1). This Park is the last extensive area (340,000 ha) with undisturbed forest in West Africa. Since the mid 1960's the population has increased enormously due to immigration. In the present agricultural system forest is slashed, burnt and food crops are planted. After one or two seasons the fields are abandoned or tree crops are planted. Due to these developments the forest to be cleared for agricultural purposes is almost exhausted outside the Park boundaries and the Park itself is threatened. Average annual rainfall amounts to 1885 mm with a standard deviation of 338 mm (Collinet et al.,1984). A pronounced dry season occurs from November to March.

The region consists of uplands (up to 200 m altitude) with an undulating relief. The main rock type is migmatite, rich in biotite (Papon,1973). The soils are chemically poor, P being the most limiting nutrient on the well drained soils (Van Reuler and Janssen,1989). According to Vooren (1985) the natural vegetation can be classified as tropical lowland evergreen seasonal forest in the UNESCO world classification system (1973). The biomass varies from 350 t ha^{-1} in the valleys to 560 t ha^{-1} on the higher part of the slopes (Huttel,1977, cited in Jaffré and De Namur,1983).

Two sites were selected approximately 9 km south of the village Taï. The secondary vegetations at the sites were 4 and 20 years old according to local information. The sites will further be referred to as the 4-Y site and 20-Y site. According to the FAO (1988) the soils of both sites can be classified as Xanthic Ferralsols. In the Soil Taxonomy (Soil Survey Staff,1990) the soil of the 4-Y site is classified as a loamy acid Typic Kandiudult and the soil of the 20-Y site as a loamy-skeletal acid Typic Kandiudult. Both soils are representative of the region (De Rouw et al.,1990). In 1989, an area of 30 * 30 m was completely felled at the 20 Y-site. The above-ground phytomass was weighed. Litter mass was measured at ten 1-m^2 spots. Samples were taken for determining dry weight and for chemical analysis.

In 1990, 10 plots of 5 * 5 m at the 4-Y site were felled completely. The above-ground phytomass and the litter were weighed and sampled. At both sites, the diameters at breast height (DBH) or slightly lower were measured of all trees with a diameter > 5 cm. In February/March 1990, at both sites, fields of approximately 1 ha were cleared for agricultural purposes by local farmers using axes and machetes. After 15 days at the 4-Y site, and after 30 days at the 20-Y site, the farmers wanted to set fire to the dried slashed vegetation. At both sites the fire was

lit in the early afternoon, as is customary in the region because around that time there normally is some wind. At the day of the burn, 5 plots of 5 * 5 m were chosen at random at both sites. The plots were subdivided into 25 1-m^2 subplots, and in the centre of each subplot a small metal tin (surface area 20 or 28 cm^2) was placed, in such a way that its upper rim was at the boundary of litter and mineral soil surface. In each 25-m^2 plot the temperature during the burn was recorded at 0.5-cm depth near 6 or 7 randomly chosen tins and near at least 2 of them also at 1.5-cm depth. For lower temperatures use was made of small round stickers (Thermindex) turning black when a certain temperature had been reached (49, 99, 149, 199 and 260 ^{0}C). For higher temperatures, three waxes (Thermochrom) melting at respectively 320, 375 and 500 ^{0}C were used. Both materials were attached to small glass slides (22 * 75 mm), the round stickers in the centre and the waxes in thin bands parallel to the short axis. The slides were placed in such a way that the centre of the short axis was at the intended depth. The day after the burn, in each of the plots the unburnt material was weighed.

Moisture contents of the vegetation samples were measured by 24-h drying at 70 ^{0}C. Thereafter samples were ground. Ash samples were analyzed as plant material. After digestion in a H_2SO_4-Se-salicyclic acid mixture with addition of H_2O_2, total N, P, K, Ca, Mg, Mn and Zn were measured: N and P by absorption spectrophotometry (indophenol blue method for N, molybdenum-blue method for P), K and Ca by flame photometry, Mg, Mn and Zn by atomic absorption spectrometry.

3.3 Results

3.3.1 Dry matter productions and nutrient contents of the fallow vegetations

The 4-Y and 20-Y fallow vegetations had basal areas (sum of the stem surfaces measured at breast height of all trees > 5 cm ø) of 16 m^2 and 24 m^2, respectively. In Table 3.3, nutrient mass fractions are presented and in Table 3.4 dry matter yield and nutrient content. Mass fractions of N, Ca and Mg in wood < 5 cm ø and of N in leaves were higher in the 20-Y vegetation than in the 4-Y vegetation. The mass fractions of the other nutrients in the 20-Y vegetation are equal to or lower, especially of K, than those in the 4-Y vegetation. The smaller materials (leaves and

Table 3.3 Mean values and standard deviations of nutrient mass fractions of the fallow vegetations.

	Litter	Dead wood	Wood			Lianes	Leaves
			< 5 cm ø	5-15 cm ø	>15 cm ø		
4-Y vegetation							
N (g kg^{-1})	13.7 ± 4.0	nd[a]	3.8 ± 1.5	3.7 ± 1.5	3.1	-	21.6 ± 7.1
P	0.6 ± 0.3	nd	0.2 ± 0.1	0.2 ± 0.1	0.1	-	1.0 ± 0.4
K	6.7 ± 2.8	nd	4.0 ± 1.9	4.5 ± 1.8	4.5	-	12.7 ± 4.2
Ca	10.0 ± 3.7	nd	3.8 ± 1.1	3.1 ± 1.8	2.4	-	10.0 ± 3.0
Mg	3.2 ± 1.1	nd	0.8 ± 0.3	0.9 ± 0.5	0.5	-	3.6 ± 1.3
Mn (mg kg^{-1})	477 ± 203	nd	39 ± 20	46 ± 29	35	-	315 ± 217
Zn	37 ± 22	nd	8 ± 7	7 ± 4	9	-	27 ± 21
20-Y vegetation							
N (g kg^{-1})	11.3 ± 1.3	2.1	7.7 ± 2.9	2.9 ± 0.7	2.6 ± 1.6	6.4	23.2 ± 3.3
P	0.3 ± 0.1	0	0.2 ± 0.1	0.04	0.04	0.1	0.9 ± 0.2
K	0.9 ± 0.2	1.0	2.2 ± 0.9	1.2 ± 0.3	1.3 ± 0.8	2.6	9.1 ± 1.9
Ca	10.4 ± 2.6	0.8	5.0 ± 2.0	2.4	2.3 ± 1.1	12.0	10.0 ± 2.8
Mg	2.2 ± 0.3	0.5	1.0 ± 0.7	0.5	0.3 ± 0.2	1.3	4.6 ± 1.3
Mn (mg kg^{-1})	nd	nd	nd	nd	nd	nd	nd
Zn	nd	nd	nd	nd	nd	nd	nd

[a] not determined

Table 3.4 Average values and standard deviations of dry matter yield, and nutrient contents of the fallow vegetations.

	Litter	Dead wood	Wood < 5 cm ø	Wood 5-15 cm ø	Wood >15 cm ø	Lianes	Leaves	Total
4-Y vegetation								
Dry matter (t ha^{-1})	6.4 ± 2.1	0.6[a]	12.3 ± 2.4	26.8 ± 25.4	6.1 ± 2.1	-	4.5 ± 3.9	56.1
N (kg ha^{-1})	89.7	1.3	46.7	99.2	18.9	-	97.2	351.0
P	3.8	0	2.5	5.4	0.6	-	4.5	16.8
K	42.9	0.6	49.2	120.6	27.5	-	57.2	297.8
Ca	64.0	0.5	46.7	83.1	14.6	-	45.0	253.9
Mg	20.5	0.3	9.8	24.1	3.1	-	16.2	74.0
Mn	3.1	nd.[b]	0.5	1.2	0.2	-	1.4	6.4
Zn	0.2	nd	0.1	0.2	0.1	-	0.1	0.7
20-Y vegetation								
Dry matter (t ha^{-1})	5.7	7.3	12.6	28.6	56.0	1.8	5.4	117.4[c]
N (kg ha^{-1})	64.4	15.3	97.0	82.9	145.6	11.5	125.3	542.1
P	1.7	0	2.5	1.1	2.2	0.2	4.9	12.7
K	5.1	7.3	27.7	34.3	72.8	4.7	49.1	201.1
Ca	59.3	5.8	63.0	68.6	128.8	21.6	54.0	401.2
Mg	12.5	3.7	12.6	14.3	16.8	2.3	24.8	77.8
Mn	nd	nd	nd	nd	nd	nd	nd	nd
Zn	nd	nd	nd	nd	nd	nd	nd	nd

[a] dry matter is estimated, mass fractions of 20-Y sample are used

[b] not determined

[c] excluding 3 oilpalms in the 30 * 30 m plot, of which dry weight is estimated at 6 t ha^{-1}

litter) have the highest and the coarser materials (wood 5-15 cm ø and > 15 cm ø) the lowest nutrient mass fractions. The 20-Y vegetation contains more N, Ca, and less P and K than the 4-Y vegetation, while they are equal in Mg. The mass ratios of N, P and K in leaves may be used as an indication of the relative availability of these nutrients in the soil. At both sites the N:P ratio is well over 15 and the K:P ratio over 10. Compared to the values for perennial crops at optimum nutrition, the ratios point to shortage of P (Van Reuler and Janssen, 1989).

3.3.2 Temperature during burning

The results of the temperature recordings are presented in Table 3.5. At both sites the fire lasted approximately 2 hours and was judged as successful by the farmers. Some isolated spots were still smoking after 24 hours. Temperatures reached were highly variable. At both sites, surface temperatures of over 500 °C were recorded. At 0.5 cm, temperatures above 260 °C and at 1.5 cm above 150 °C were rare. The frequency distribution of the temperatures indicate that the burn was more intense on the 4-Y site than on the 20-Y site.

Table 3.5 Frequencies of the maximum temperatures reached during the burn at soil surface, 0.5 and 1.5 cm depth.

T (°C)	4-Y vegetation Depth (cm)			20-Y vegetation Depth (cm)		
	0	0.5	1.5	0	0.5	1.5
< 49		2		9	8	6
49 - 99		10	10		5	3
99 - 149		16	3		8	
149 - 199		5	1		5	
199 - 260		3			3	1
260 - 320					2	
320 - 375	1			1		
375 - 500	17			7		
>500	18			14		

3.3.3 Amount and chemical composition of ash

Nutrient contents of ash are presented in Table 3.6. Ash production differed greatly from spot to spot as is reflected in the standard deviations, but there was no difference between the 4-Y and 20-Y sites. One of the 5 observation plots at the 20-Y site burnt only half, due to the presence of many palm leaves. If the not-burnt part is left out of consideration, the ash production at the 20-Y site amounted to 2727 kg ha^{-1}. Table 3.6 shows that about 25 kg N was applied with the ash, such in contrast to reports (e.g. Nye and Greenland,1960) that through burning all N is lost. The ash of the 4-Y fallow contained more K than the ash of the 20-Y fallow. The 4-Y vegetation had a higher K content than the 20-Y vegetation (Table 3.3). Another reason is the higher percentage of burnt vegetation at the 4-Y site. Fig. 3.1 shows that wood > 15 cm ø did not burn at all. At the 4-Y site, litter and leaves burnt completely, dead wood for 80%, wood < 5 cm ø for 60%, wood between 5 - 15 cm ø for about 50%. At the 20-Y site the litter, dead wood and leaf fraction burnt for 90%, wood < 5 cm ø, and wood 5 - 15 cm ø and lianes for 20%.

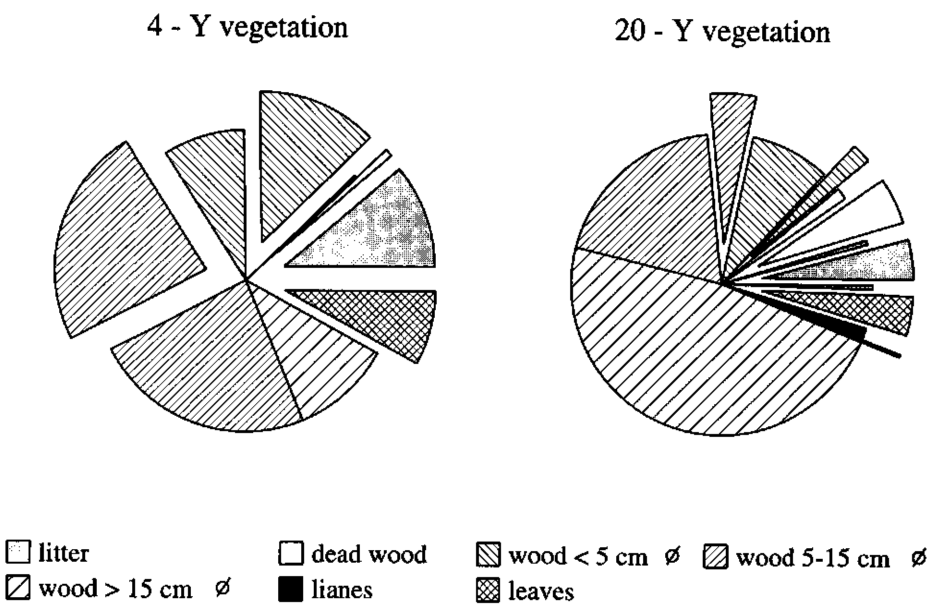


Fig. 3.1 Compositional partition of the 4-Y and 20-Y fallow vegetations. The exploded parts represent the fractions burnt.

3.4 Discussion

3.4.1 Dry matter productions and nutrient contents of the fallow vegetations

A comparison of Table 3.1 with Table 3.4 makes it clear that dry matter productions of fallow vegetations were higher in our study than in the study by Jaffré (1985), and that the basal areas found were higher than the estimates reported by De Namur (1978), 12 m^2 for a 4-year-old fallow and 23 m^2 for a 20-year-old one. For the youngest fallow, a part of the difference can be ascribed to the method of clearing and to composition of the vegetation. Usually some selected tree species are not felled or burnt during clearing of primary forest or old secondary forest, for a number of reasons (Moreau and De Namur,1978; De Rouw,1987). In our study, however, the vegetation at the 4-Y site was felled completely including remaining trees of former primary or old secondary forest. De Namur (1978), Jaffré and De Namur (1983) and Jaffré (1985) excluded such trees from their observations and studied the real forest regrowth on abandoned cultivation sites. Assuming that in our study trees with a diameter > 15 cm were older than 4 years, the basal area is reduced from 16 to 13 m^2 and the dry matter of the vegetation accordingly from 56.1 to 43.7 t ha^{-1}. Although the fallows compared bear the same age, the species compositions are completely different. The biomass of the 4-year-old secondary regrowth consisted for 75% of *Macaranga hurifola* in the studies of Jaffré and De Namur (1983) and Jaffré (1985), and for only 5% in our study. At our 4-Y site, *Anthocleista nobilis* made the highest single-species contribution, viz. 29%.

Table 3.6 Averages and standard deviations of nutrient mass fractions measured and calculated nutrient contents of the ash. Total production was 2535 ± 2139, and 2459 ± 2081 kg ha^{-1}, at the 4-Y and 20-Y sites, respectively.

	4-Y site			20-Y site		
	mass fraction	nutrient content ($kg\ ha^{-1}$)		mass fraction	nutrient content ($kg\ ha^{-1}$)	
	($g\ kg^{-1}$)	measured	calculated[a]	($g\ kg^{-1}$)	measured	calculated
N	10.1 ± 5.1	26	264	11.1 ± 5.8	27	223
P	4.4 ± 2.2	11	13	3.1 ± 1.5	8	7
K	49.1 ± 28.5	124	190	28.6 ± 17.9	70	69
Ca	49.3 ± 22.7	125	179	48.2 ± 21.4	118	138
Mg	16.5 ± 7.3	42	55	19.1 ± 9.7	47	43
Mn	2.0 ± 1.2	5	5	2.6 ± 1.1	6	nd[b]
Zn	0.14 ± 0.06	0.3	0.5	0.11 ± 0.05	0.3	nd

[a] burnt fraction of vegetation times nutrient mass fraction
[b] not determined

3.4.2 Temperature during burning, ash quantity and composition

Temperatures recorded in our study concur with data reported in the literature. Burning may have locally influenced some chemical properties and microflora of the upper 2 cm of the soil (Andriesse and Koopmans,1984; Dunn et al.,1979). Also some seeds present in this zone proved to have been killed (Van Reuler and Janssen, 1993b). At the 4-Y site approximately 50% of total dry matter was burnt and at the 20-Y site only 15%. The major part of the vegetation at the 4-Y site consisted of relatively small-sized pieces, which consequently dried fast and burnt easily. At the 20-Y site, about 50% of total dry matter was composed of wood > 15 cm ø, and that did not burn easily. Moreover, the many trees > 15 cm ø might have formed physical barriers to spreading of the fire.

By means of ash, nutrients are added to the soil. Of these nutrients P is the most important one regarding crop production in the Taï region (Van Reuler and Janssen, 1989). The original nutrient contents of the burnt parts were higher at the 4-Y site than at the 20-Y site. The calculated amounts of nutrients which could have been released by the burn deviate from the measured average values (Table 3.6). For N only 10% was found back; apparently the major part was lost by volatilization. For the other nutrients variability was high enough to explain the differences between measured and calculated means. It is difficult to draw conclusions from a comparison of our data with those of Table 3.2 because of the large variability of the data. This variability is a result of the many variables affecting the success of burning and burning temperatures, and the often heterogeneous conditions in the field.

3.5 Conclusions

In the shifting cultivation of the Taï region, south-west Côte d'Ivoire, only the smaller-sized components of the slashed vegetation are burnt. The moisture content of the coarser-sized components is generally too high due to the short drying period.

Quantity and chemical composition of ash are highly variable. Both are influenced by the portion of finer vegetative particles. These particles also affect temperatures reached during fire, and temperature in turn affects the amount and chemical composition of ash. Despite differences in dry matter content of the two fallows, the amount of ash produced as well as the amount of N, P, Ca and Mg added to the soil in the form of ash did not differ much. Only for K a difference was found between the 4-Y and 20-Y fallow vegetation.

For agricultural purposes forest is slashed and burnt. Through burning considerable amounts of N are lost and part of the seeds present in the topsoil are killed. However, in the traditional shifting cultivation system the elevated temperatures are limited to the upper few centimeters and stumps are not killed. Moreover a number of big trees is not slashed and the clearings have a limited size. These combined factors facilitate forest regrowth after the fields have been abandoned.

Chapter 4

Short-term and long-term effects of burning on yield and nutrient uptake of food crops

Key words: ash, burning, Côte d'Ivoire, efficiency of utilization of nutrients, maize, nutrient uptake, residual effects, shifting cultivation, Taï National Park, upland rice, weed growth

Abstract

At two sites, one with a 4-year-old (4-Y) secondary vegetation and the other with a 20-year-old (20-Y) vegetation, the influence of burning slashed vegetation on crop performance was studied during three seasons. In the first season after clearing, also the influence on weed growth was studied. At both sites, burning significantly decreased the number of weed seedlings. The lowest number of seedlings was found on the burnt plots of the 20-Y site. Burning increased yield and nutrient uptake significantly in the first and second season after clearing. In the third season after burning, only at the 4-Y site a significantly higher yield and nutrient uptake were found. At the 20-Y site the effect had disappeared. Calculations of efficiency of utilization of absorbed N, P and K indicated that P was the least available nutrient, also after burning. At both sites three consecutive crops absorbed approximately 40% of P applied in ash, while the cumulative recovery of K was at least 36% at the 4-Y site and at least 59% at the 20-Y site. On non-burnt plots, yields were not lower in the third season than in the first season after clearing, thus indicating that the inherent soil fertility did not decrease. Hence, yield decline on the burnt plots could be ascribed to ash depletion. It was concluded that in the local shifting cultivation system, the combination of ash depletion and infestation of weeds are the main reasons for abandoning the fields.

4.1 Introduction

Burning is part of shifting cultivation systems, except in extremely humid areas. The main benefits of burning reported in the literature are:

1. Killing of stump sprouts which otherwise would shade out crop species
2. Killing of seeds of some weedy species that would compete with crops for nutrients and water
3. Conversion of dry leaves and part of wood into ash, thereby increasing the amount of nutrients immediately available for the first crop

4. Removal of most twigs and small branches which form a dense cover hampering planting
5. Reduction of the cover in which insects, mammals, birds and other crop consumers may hide
6. Partial sterilization of the soil although microbial populations rapidly increase again (Nye and Greenland,1960; Bennett et al.,1974 cited in Jordan,1985).

After the burn crops are cultivated over a varying period. During that period, yields gradually decline. This decline is the reason why fields are abandoned. According to Sanchez (1976), farmers in Latin America abandon their fields when they cannot expect the yield of a subsequent crop to be more than 50% of the first crop. The same value is reported for the Taï region, south-west Côte d'Ivoire
(De Rouw,1991a). The two main causes for yield decline are weed infestation and soil fertility depletion. In Africa, weed infestation is considered as the main reason by Nye and Greenland (1960), and Jurion and Henry (1969). A differentiation according to the fertility level of soils is made by Sanchez (1976): on fertile soils the main reason for shifting to another field is weed infestation, and on less fertile soils it is nutrient depletion.

In the traditional shifting cultivation system of the Taï region upland rice is grown in the first season after clearing. Yields amount to 1 t ha^{-1} and fields are abandoned after one or two seasons. As main reasons for abandoning are suggested weed infestation and lack of soil nutrients because of a diminishing effect of burning and nutrient immobilization by weeds (De Rouw,1991a).

Part I of this series of papers dealt with dry matter production and nutrient content of a 4-year-old and a 20-year-old fallow vegetation, and with amount and chemical composition of ash produced by burning the slashed vegetation (Van Reuler and Janssen, 1993a). The aim of the present study is to quantify the economy of nutrients on burnt and non-burnt fields in the first three cropping seasons after clearing. For proper interpretation of uptake data, the concept of efficiency of utilization (EU) of absorbed nutrients will be used. EU is defined as grain yield (14% moisture) per unit nutrient absorbed by the crop. EU is an indication of the availability of a nutrient relative to other growth factors. According to Van Keulen and Van Heemst (1982), grain yield of small cereals maximally increases by 70 kg per kg N absorbed, by 600 kg per kg P and by 55 to 100 kg per kg K absorbed. Janssen et al. (1990) report for maize maximum values of 70 kg per kg N, 600 per kg P and 120 kg per kg K absorbed. Minimum values, indicating accumulation in the crop are 30, 200, and 30 kg grain per kg N, P and K, respectively.

4.2 Materials and methods

The study was carried out in the Taï region, south-west Côte d'Ivoire. Location and environmental characteristics were described in Part I of this paper. One field was cleared from a 4-year-old (4-Y) and the other from a 20-year-old (20-Y) fallow vegetation. At each site an area of approximately 1 ha was cleared by local farmers with axes and machetes. In the centre of the cleared fields, approximately 350 m^2 were selected for experimental purposes. Half of this area was protected from burning by removing all litter and slashed vegetation from a surrounding 1-m wide corridor. The other half was burnt just like the rest of the 1-ha field. After the burn, the non-burnt wood in the experimental area was cut into pieces with a chain saw and removed by hand in order to facilitate the experimental work and to increase the net area to be planted. Also the logs present in the non-burnt half of the experimental area were cut and removed. In this part the litter layer was not disturbed. In both parts, five or six experimental units of 4 * 5 m^2 each were laid out. The area to be planted was fenced in.

Three crops were grown: upland rice from April-July, 1990 (1990-1), maize from August to November, 1990 (1990-2) and again upland rice from April to August 1991 (1991-1). Upland rice (*Oryza sativa*, cultivar IDSA 6) was sown in the traditional way with a planting stick or machete. Average density of plant holes was 100,000 ha^{-1} with five to ten grains per hole. Maize (*Zea mays*, Pioneer 3246) was sown in rows with a density of 55,555 plants ha^{-1} (60 * 30 cm). In both seasons, rice was harvested after 120 days. Maize was harvested after 103 days. Harvested plot size was 3 * 4 m. At each harvest, all above-ground plant parts were removed from the plots.

During each cropping season, fields were weeded twice by hand, with weeds left in the field as surface mulch. Maize was sprayed regularly with insecticide (Decis) against stalk borers. A detergent was added to increase the efficiency. During maturing, rice fields were guarded against bird damage and maize fields against monkey damage. In the first season (1990-1), 25 main stems of rice were sampled in each experimental unit at 45 and 70 days after sowing (DAS), i.e. at the stages of mid-tillering and panicle initiation, respectively. Further plant samples (grain, panicle and straw) were collected in 1990-1 and 1991-1. In season 1990-2 maize grain samples were collected at harvest and straw samples somewhat later.

At 28 DAS in the first season, weed species and weed densities were recorded in 10 randomly chosen 1-m^2 plots in the non-burnt as well as on the burnt part of each site.

Data on weed development were processed in two ways. Firstly, a tabular comparison of plot data was made to study the effects of burning and age of regrowth on the occurrence of separate species. Secondly, the effect on species composition as a whole was studied by Detrended Correspondence Analysis (DECORANA; Hill,1979). The resulting ordination diagram visualizes similarities in species composition of the sample plots and enables a correlation with environmental factors.

Moisture contents of plant samples were measured by 24-h drying at 70 ^{0}C. Thereafter samples were ground. Grain samples were also dried at 105 ^{0}C. After digestion in a H_2SO_4-Se-salicyclic acid mixture with addition of H_2O_2, total N, P, K, Ca, Mg, Mn and Zn were measured: N and P by absorption spectrophotometry (indophenol blue method for N, molybdenum-blue method for P), K and Ca by flame photometry, Mg, Mn and Zn by atomic absorption spectrometry. Per site the effect of burning on various characteristics was analyzed by means of Student's t test. The plots in the non-burnt and burnt parts of a site were considered as being at random drawn samples without replacement from the two populations.

4.3 Results

4.3.1 Yields

Rice yields on individual non-burnt plots varied from 0.65 to 1.02 t ha^{-1} in 1990-1 and from 0.95 to 1.43 t ha^{-1} in 1991-1. Averages are presented in Table 4.1.

Table 4.1. Average yields of grain (t ha^{-1}, 14% moisture), straw and panicle or cob+husk (kg ha^{-1}, dried at 70 °C) obtained at the non-burnt (NB) and burnt (B) plots of the 4-Y and 20-Y sites in 1990-1, 1990-2 and 1991-1.

			4-Y site		20-Y site	
Season	Crop	Plant part	NB	B	NB	B
1990-1	rice	grain	0.93	1.64***	0.82	1.72***
		straw	1.85	2.83***	1.55	2.65**
		panicle	0.23	0.38*	0.31	0.31
1990-2	maize	grain	0.49	1.61***	0.29	1.42***
		straw	0.77	1.13**	0.44	1.04***
		cob+husk	0.27	0.63***	0.19	0.44**
1991-1	rice	grain	1.16	1.54**	1.26	1.24
		straw	1.77	2.48***	1.81	1.70
		panicle	0.18	0.14	0.14	0.17

*, **, *** significant difference between NB and B per site at 0.05, 0,01 and 0.001 level, respectively

The Harvest Index (HI) is defined as the ratio of grain mass to total above-ground dry mass. Here dry mass means dried at 70 ^{0}C instead of dried at 105 ^{0}C. At both sites, HI was 0.3 in 1990-1 and 0.4 in 1991-1. Maize yields on individual non-burnt plots varied from 0.12 to 0.58 t ha^{-1} in 1990-2, with lower yields at the 20-Y site than at the 4-Y site. HI was 0.3 at both sites.

Burning increased rice yields significantly in the first season (1990-1) at both sites. Yields on burnt plots varied from 1.37 to 2.01 t ha^{-1}. The HI was 0.3 at both sites. Burning also increased maize yield significantly at the 4-Y site and at the 20-Y site in the second season (1990-2). Yields varied from 1.11 to 2.11 t ha^{-1}. HI was 0.5 at both sites. In the third season (1991-1), burning resulted in significantly higher yields at the 4-Y site only. Rice yields varied from 0.82 to 1.81 t ha^{-1} in 1991-1. HI was 0.4 at both sites.

4.3.2 Nutrient uptake

Table 4.2 shows that through burning the N content in total above-ground plant parts increased significantly at 45 DAS and decreased significantly at 70 DAS, in straw and in grain.

Table 4.2. Mass fractions (g kg^{-1}) of N, P and K in total above-ground plant parts at 45 and 70 days after sowing (DAS), and in straw and grain at harvest (120 DAS) of upland rice in the first season after clearing (1990-1).

Nutrient	DAS	Plant part	Mass fractions			
			4-Y site		20-Y site	
			NB	B	NB	B
N	45	total	30.8	35.6***	31.0	33.5*
	70	total	21.9	18.0**	23.3	19.6***
	120	straw	10.7	9.2	14.1	11.9*
	120	grain	14.8	13.2*	14.4	13.7*
P	45	total	0.9	1.4***	0.8	1.3***
	70	total	0.5	0.8***	0.6	0.6***
	120	straw	0.3	0.6***	0.4	0.4
	120	grain	1.2	1.6***	1.3	1.3
K	45	total	24.4	30.9***	25.2	31.9***
	70	total	20.6	24.4***	20.8	22.8
	120	straw	15.4	18.4*	18.5	21.2
	120	grain	2.5	2.4	2.4	2.2

*, **, *** significant difference between NB and B per site at 0.05, 0.01 and 0.001 level, respectively.

The P content of total above-ground parts, straw and grain was significantly increased at the 4-Y site, while at the 20-Y site only at 45 DAS and 70 DAS a significant increase was observed. At both sites the K content of total above-ground

Table 4.3. Average nutrient uptake at the non-burnt (NB) and burnt (B) plots of the 4-Y and 20-Y site in the seasons 1990-1, 1990-2 and 1991-1.

Nutrient	Season	Crop	Nutrient uptake			
			4-Y site		20-Y site	
			NB	B	NB	B
N (kg ha^{-1})	1990-1	rice	34.9	49.4**	36.3	55.8***
	1990-2	maize	16.1	27.0***	9.4	30.0***
	1991-1	rice	32.1	36.9*	33.5	31.0
			83.1	113.2	79.2	116.8
P	1990-1	rice	1.8	4.3***	1.8	3.3***
	1990-2	maize	1.5	2.6**	0.7	3.1**
	1991-1	rice	1.5	2.6***	1.9	1.8
			4.8	9.5	4.4	8.3
K	1990-1	rice	32.1	58.6***	32.5	62.4***
	1990-2	maize	9.2	14.9***	3.6	15.4***
	1991-1	rice	29.7	42.5**	27.6	27.3
			71.0	116.0	63.7	105.2
Ca	1990-1	rice	5.5	6.7**	3.6	7.0**
	1990-2	maize	1.8	3.1***	1.6	3.3***
	1991-1	rice	5.6	8.6*	4.8	4.8
			12.9	18.4	10.0	15.2
Mg	1990-1	rice	6.0	8.4**	5.0	9.2***
	1990-2	maize	2.0	3.7***	1.1	3.4***
	1990-1	rice	4.5	6.9**	4.9	5.3
			12.5	19.1	11.1	18.0
Mn (g ha^{-1})	1990-1	rice	898	1249.**	1066	2172.**
	1990-2	maize	na.^{a}	na	na	na
	1991-1	rice	884	1189	912	1072
Zn	1990-1	rice	80	109.**	95	180.**
	1990-2	maize	na	na	na	na
	1991-1	rice	111	130.*	94	99

*, **, *** significant difference between NB and B per site at 0.05, 0.01 and 0.001 level, respectively.
^{a} not analyzed

parts at 45 and 70 DAS was significantly higher on the burnt than on the non-burnt plots. At the 4-Y site also the K content of straw was significantly higher.

Burning increased nutrient uptake significantly in 1990-1 and 1990-2 at both sites (Table 4.3). In 1991-1 a significantly higher nutrient uptake was observed at the 4-Y site only. Nutrient uptake by rice on the non-burnt plots was about equal at both sites, in 1990-1 as well as in 1991-1 (Table 4.3). Exceptions were that at the 4-Y site Ca uptake was higher and Mn uptake lower that at the 20-Y site. In 1991-1 nutrient uptake was equal to or slightly lower than in 1990-1. Nutrient uptake by maize was low (1990-2). The major part of the absorbed K, Ca and Mg is present in the straw and cob + husk, this in contrast to N and P. Therefore the total uptake of K, Ca and Mg was probably underestimated due to the time lag between harvest and straw sampling. The nutrient content of the cob + husk was estimated. At the 4-Y site, nutrient uptakes on the non-burnt plots were higher than on the non-burnt plots of the 20-Y site. On the burnt plots of both sites about equal amounts of nutrients were absorbed. Exception was the higher P at the 20-Y site.

In each season, more nutrients were absorbed on the burnt than on the corresponding non-burnt plots, with the exception of the 20-Y site where the uptakes were equal in the third season (1991-1).

On the burnt plots of both sites, less nutrients were absorbed in 1991-1 than in 1990-1, with the exceptions of Ca and Zn at the 4-Y site. At the 20-Y site the decrease in nutrient uptake was stronger than at the 4-Y site.

The cumulative amounts of nutrients absorbed by the three crops at the 4-Y site are equal to or slightly higher than those at the 20-Y site, on the non-burnt as well as on the burnt plots. Exceptions are the Mn and Zn uptakes.

Table 4.4 Average numbers of weed species and weed seedlings on the non-burnt (NB) and and burnt (B) plots of the 4-Y and 20-Y site 28 days after sowing in 1990-1.

	4-Y site		20-Y site	
	NB	B	NB	B
Total species	9.4	3.3***	9.5	4.7***
Total seedlings	81	12.4**(a)	24.9	10.6**

*, **, *** significant difference between NB and B per site at 0.05, 0.01 and 0.001 level, respectively.
(a) without *Triumfetta rhomboidea*

4.3.3 Weed growth

In the observations made on the 40 sampling plots, 69 different weed species were recorded. Table 4.4 presents the numbers of weed species and seedlings averaged over 10 plots observed per treatment. Burning lowered the number of species as well as the amount of total seedlings significantly at both sites. The number of seedlings was considerably higher at the 4-Y site than at the 20-Y site, on the non-burnt as well as on the burnt plots.

Table 4.5 Frequency of occurrence of differential species over 10 1-m² plots of each of the four treatments, 28 days after sowing in 1990-1. In parentheses, the average density of the species, if present, is given.

	4-Y site				20-Y site			
	NB		B		NB		B	
Group 1								
Geophylla afzelii	7	(18.6)	0 *		6	(3.3)	0 *	
Tetracera potatoria	3	(5.7)	0		3	(2.3)	0	
Scherbournia calycina	4	(4.3)	0 *		1	(3.0)	0	
Borreria scabra	5	(10.4)	1	(2.0)	2	(2.0)	0	
Myrianthus libericus	1	(2.0)	0		3	(1.3)	0	
Baphia capparistifolia	2	(2.5)	0		1	(1.0)	0	
Group 2								
Neuropeltis prevostioides	1	(1.0)	0		5	(3.2)	0 *	
Mildbraedia paniculata	0		0		3	(2.0)	0	
Celastraceae sp	0		0		3	(1.0)	0	
Griffonia simplicifolia	2	(1.0)	0		2	(7.0)	1	(1.0)
Group 3								
Chromolaena odorata	10	(28.1)	0 ***		1	(1.0)	3	(1.0)
Group 4								
Cyperaceae sp	4	(4.3)	2	(26.0)	0		0	
Solanum verbascifolium	2	(9.5)	1	(2.0)	0		0	
Centrosema pubescens	2	(2.5)	1	(2.0)	0		0	
Group 5								
Macaranga barteri	0		0		5	(1.0)	2	(1.5)
Ricinodendron heudelotii	0		0		2	(2.5)	3	(1.0)
Trema guineensis	0		0		3	(1.7)	1	(1.0)
Group 6								
Ceiba pentandra	6	(1.7)	6	(2.0)	8	(1.6)	9	(1.8)
Triumfetta rhomboidea	5	(27.6)	5	(506.2)	7	(1.9)	8	(3.1)
Ipomoea involucrata	6	(3.8)	7	(3.3)	3	(2.0)	2	(1.5)

*, **, *** significant difference between NB and B per site at 0.05, 0.01 and 0.001 level, respectively.

Table 4.5 presents the frequency of occurrence of differential species as well as their average density. Species of Groups 1, 2 and 3 do not tolerate burning. Group 1 contains species not related to the length of fallow and Group 2 those characteristic of the 20-Y site. The abundant occurrence of *Chromolaena odorata* (ex *Eupatorium odoratum*) (Group 3) on the non-burnt plots of the 4-Y site suggests it to be characteristic of this treatment. Species which can tolerate burning and are characteristic either of the 4-Y or the 20-Y site are presented in group 4 and group 5, respectively. Group 6 is composed of so-called constant species which occur regularly and irrespective of the four treatments.

In the ordination diagram of Fig. 4.1, observations on the non-burnt plots are mainly located on the lefthand side of Axis 1 and those on the burnt plots on the righthand side. Thus, Axis 1 (main trend in species composition) is correlated with burning. Along Axis 2, strongly correlated with the age of the two fallow vegetations, 20-Y species are situated in the upper part and 4-Y species in the lower part.

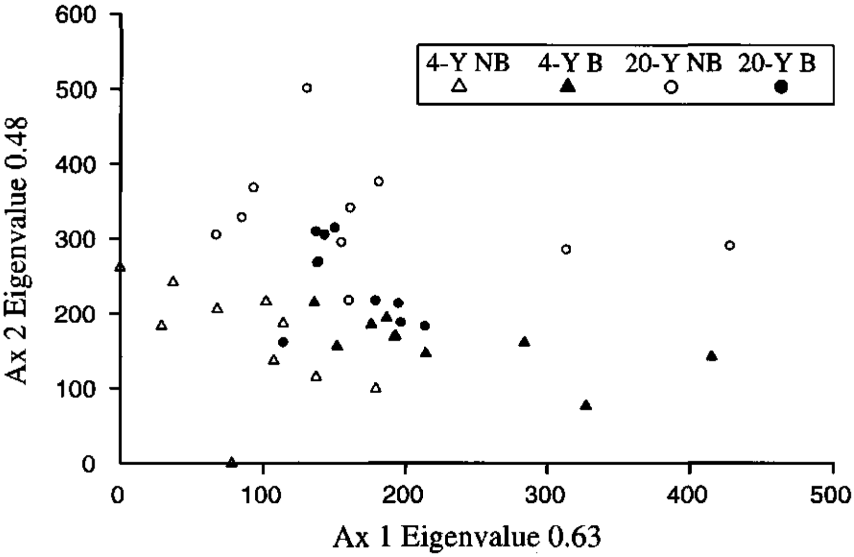


Fig. 4.1 Ordination diagram of the weed composition on the sample plots at 28 days after sowing.

4.4 Discussion

4.4.1 Yield and nutrient uptake

Table 4.6 presents data on the efficiency of utilization (EU) of absorbed nutrients. The values for N and K are near minimum and that of P near maximum on the non-burnt plots of both sites in 1990-1, indicating that P was least available of these three nutrients. Burning the slashed vegetation releases nutrients which can be absorbed by the crops cultivated. Table 4.2 shows that this release resulted in an increase in P mass fractions of total plants in an early stage (45 and 70 DAS). At 120 DAS the effect had disappeared on the 20-Y site but not at the 4-Y site. Due to the improved P status, plant growth was stimulated apparently to such an extent, that the absorbed N was diluted. This explains the lower mass fractions of N in plants on burnt plots than in plants on non-burnt plots, at 70 and 120 DAS. Burning increased the K availability so much that K mass fractions of straw remained higher on the burnt plots than on the non-burnt plots at both sites.

On both burnt and non-burnt plots, EU of P was well below 600 in 1990-1. This can be explained by moisture stress during the flowering period. In this period, rice is extremely sensitive to drought (Jacquot and Courtois,1983). In case of sufficient moisture supply the absorbed P would have been used more efficiently. Yields would have amounted to 1.1 t ha^{-1} on the non-burnt plots and to over 2 t ha^{-1} on the burnt plots of both sites, if the EU of P were 600.

Table 4.6 Average efficiency of utilization (kg kg^{-1}) of the absorbed nutrients on the non-burnt (NB) and burnt (B) plots of the 4-Y and 20-Y site in the seasons 1990-1, 1990-2 and 1991-1.

Season	Crop	Nutrient	Efficiency of utilization			
			4-Y site		20-Y site	
			NB	B	NB	B
1990-1	rice	N	27	33	23	31 ***
		P	511	384 **	454	516
		K	29	28	25	27
1990-2	maize	N	31	60 ***	30	47 ***
		P	336	614 ***	356	458 *
		K	53	108 ***	79	92
1991-1	rice	N	36	42	38	40
		P	751	585 ***	666	673
		K	39	36	46	45

*, **, *** significant difference between NB and B per site at 0.05, 0.01 and 0.001 level, respectively.

In 1991-1, compared to 1990-1 the absolute amount of nutrients absorbed by rice had decreased, except for Ca at the 4-Y site. In 1991-1 moisture supply was sufficient for a more efficient use of the absorbed nutrients, resulting in higher EU's of N, P and K than in 1990-1. The EU values of N and P for maize (1990-2) indicate that the absorbed nutrients were inefficiently used although yields were very low on both sites. The EU of K is probably overestimated. Burning considerably increased the

EU's of all three nutrients for maize, but not for rice. This may be due to the fact that maize is more sensitive to acidity than is upland rice. Burning also resulted in a pH increase. Fig. 4.2 shows the relation between pH (0-10 cm) at the start of the growing season and EU of P, for rice in 1990-1 and for maize in 1990-2. For rice, the EU of P was not influenced by pH, but it was for maize. For maize the positive effect of burning consists of a pH effect and a P effect, and for rice of a P effect only.

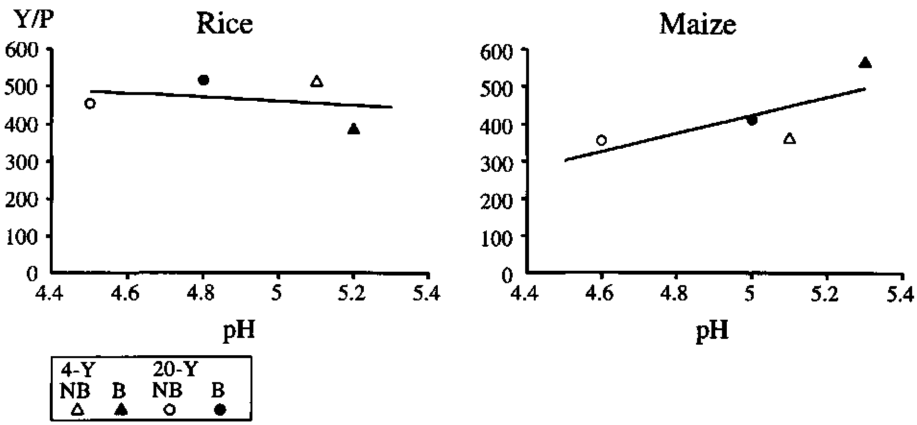


Fig. 4.2 Relation between efficiency of nutrients of absorbed P and pH (0-10 cm) for rice (1990-1) and maize (1990-2).

In Tables 4.7 and 4.8 the differences in uptake of nutrients from the burnt and non-burnt fields are presented, in kg ha^{-1} as well as in percentages of the amounts of nutrients added in ash (Van Reuler and Janssen, 1993a). At the 4-Y site, the differences decrease for N and P from the first to the third season. On the 20-Y site, the trend is rather irregular. Anyway, the difference had practically disappeared in the third season. At both sites, more extra N was absorbed than was added in ash. Apparently burning stimulated uptake of soil-N. The increase in pH due to ash may have increased the mineralization rate of organic matter. Another reason, more important, is that addition of ash stimulated crop growth and, hence, increased the need for N. It is likely that on the non-burnt plots more N was available than could be used by the crop, because of growth being limited by P deficiency. This is reflected in the low EU of N and the high EU of P in the crop. The fractions of P, Ca and Mg absorbed from the ash do not differ among sites. The percentage of K absorbed was higher on the 20-Y than on the 4-Y site because the amount added through ash was lower on the 20-Y site.

Table 4.7 Difference in uptake of nutrients from the burnt and non-burnt plots of the 4-Y site expressed in kg ha^{-1} and as percentage of the amount of nutrients added in ash.

Season	Crop	N	P	K	Ca	Mg	Mn	Zn
1990-1	rice	14.5	2.5	26.5	1.2	2.4	0.35	0.03
1990-2	maize	10.9	1.2	5.7	1.3	1.7	-	-
1991-1	rice	4.8	1.1	12.8	3.0	2.4	0.31	0.02
Total		30.1	4.7	44.9	5.5	6.5	-	-
Ash		26	11	124	125	42	4.97	0.35
Total/Ash %		116	43	36	4	16	-	-

Table 4.8 Difference in uptake of nutrients from the burnt and non-burnt plots of the 20-Y site expressed in kg ha^{-1} and as percentage of the amount of nutrients added in ash.

Season	Crop	N	P	K	Ca	Mg	Mn	Zn
1990-1	rice	19.5	1.5	29.9	3.4	4.2	1.11	0.09
1990-2	maize	20.6	2.4	11.8	1.8	2.3	-	-
1991-1	rice	-2.5	-0.1	-0.3	0.0	0.4	0.16	0.01
Total		37.6	3.8	41.4	5.2	7.0	-	-
Ash		27	10	70	118	47	6.36	0.26
Total/Ash %		139	38	59	4	15	-	-

4.4.2 Weed growth

On the field cleared of 20-year-old fallow vegetation, less weed seedlings were found than on the field cleared of the 4-year-old fallow vegetation (Table 4.4). At the 20-Y site burning diminished the number of weed seedlings significantly. On the burnt plots of the 4-Y site the herb *Triumfetta rhomboidea* (Tiliaceae) occurred abundantly in 5 of the 10 observations (Table 4.5). The irregular distribution of this species may be explained from its seed morphology, viz. round capsules (4-6 mm ø) densely packed with hooked bristles (Akobundu and Agyakwa,1987). The seeds easily attach themselves to e.g. animals. Such a phenomenon was described for a closely related species, *Triumfetta graveolens* by Backer and Van Slooten (1924). Without *Triumfetta rhomboidea* the number of seedlings on the burnt plots of the 4-Y site is 12.4. At both sites burning decreased the number of seedlings significantly. This agrees with the findings of De Rouw and Van Oers (1988) who reported that in the Taï region burning killed about half of the 2000 seeds per m^2 present in the top 10 cm of soil.

Fig. 4.1 shows that the main factor explaining the differences in species composition, is burning. This correlation appeared to be largely due to observations made at the 4-Y site where the difference between the burnt and non-burnt plots is much more evident than at the 20-Y site. Moreover, the ordination diagram shows that the non-burnt plots of the 20-Y site were quite heterogeneous as far as species composition is concerned. Axis 3 (not shown), eigenvalue 0.35, appears to be determined by differences in density of *Triumfetta rhomboidea*, which is assumed to be caused by animal activity.

It is often questioned whether soil fertility depletion or weed infestation is the main reason for farmers to abandon fields after having grown food crops for only one or two seasons. In the traditional shifting cultivation system of the Taï region only one season per year is used for crop cultivation. The average yields obtained by farmers amount to approximately 1 t ha^{-1} in the first year and at best 0.5 t ha^{-1} in the second year (De Rouw,1991a). Expecting such a yield decline, farmers already abandon the fields after one crop. In this study, in the first season after clearing yields of 1.5 t ha^{-1} were obtained on the burnt plots, despite the drought. In case of sufficient moisture supply in 1990-1, yields would have been at least 2 t $ha^{-1.}$ The difference with the farmers is caused mainly by better management of the experimental fields (Van Reuler and Janssen, 1989). On the non-burnt plots, however, yields were upheld in the third season after clearing. With sufficient moisture, yields declined on the burnt plots from approximately 2 t ha^{-1} to 1.5 and 1.2 t ha^{-1} in 1991-1. Therefore, yield decrease on the burnt plots must be attributed to ash becoming depleted of nutrients and not to a declining inherent soil fertility. Thus it is assumed that in the traditional system, at the present management level, ash depletion and infestation of weeds are the main reasons for abandoning the fields.

4.5 Conclusions

Burning slashed vegetation released nutrients resulting in a two-fold to four-fold increase in yield and nutrient uptake, during the first two seasons after clearing. In the third season after clearing only at the 4-Y site an effect of burning was observed. At the 20-Y site the effect had disappeared.

On the non-burnt plots of both sites, nutrient uptake by rice in the third season was equal to that in the first season after clearing.

The values of efficiency of nutrient utilization indicated that P was the yield-limiting nutrient, also after burning. Total nutrient-absorption values for the three seasons were similar for the 4-Y and 20-Y sites. At both sites, the three consecutive crops absorbed approximately 40% of the P, 4% of Ca and 15% of Mg applied with ash. At the 4-Y site, at least 36% of the K applied with the ash was taken up, and on the 20-Y site at least 59%. The effect of burning was stronger on maize than on rice, because maize did and rice did not respond to pH increase. The response manifested itself in a more efficient utilization of absorbed nutrients.

The length of the preceding fallow period strongly influenced the number of weed seedlings during the cultivation period. Burning reduced the number of species and number of seedlings per species. The lowest number of seedlings was found on the burnt plots of the 20-Y site.

In the traditional agricultural system crops are not worth the effort of harvesting when no nutrients are added through burning. Therefore it is concluded that fields are abandoned because of depletion of ashes. A second important reason is weed infestation.

Chapter 5

Comparison of the fertilizing effects of ash from burnt secondary vegetation and of mineral fertilizers on upland rice

Key words: ash, Côte d'Ivoire, lime, mineral fertilizers, soil pH, apparent recovery fraction, relative effectiveness, shifting cultivation, substitution rate or value, Taï National Park, upland rice

Abstract

An important reason for burning the slashed vegetation in shifting cultivation systems is the release of nutrients. In an experiment in the Taï region, south-west Côte d'Ivoire the fertilizing effects of ash and mineral fertilizers were compared. The ash was derived from a 20-year-old secondary forest which was slashed, dried, piled and burned. The nutritional value of ash was compared with that of N, P, K fertilizers and lime in a field trial consisting of a "fertilizer" and an "ash" part. The experimental design of the fertilizer part was a 3^4 factorial. The application rates per ha were 0, 50, 100 kg N (urea); 0, 12.5, 25 kg P (triple superphosphate); 0, 50, 100 kg K (KCl); 0, 400, 800 kg $Ca(OH)_2$. The 81 treatment combinations were divided over nine subblocks. To each of these subblocks three experimental units were added. In six of them ash was applied at rates of 0, 4000 and 8000 kg ash ha^{-1}. With 4000 kg ash ha^{-1} 31 kg P, 264 kg K, 915 kg Ca, 150 kg Mg, 10 kg Na, 10 kg Mn, 2.6 kg Zn and 32 kg S were applied. Upland rice (cultivar IDSA 6) was grown as test crop. The grain yields on individual experimental units varied from 1.2 to 3.2 t ha^{-1}. In the 3^4 trial, N and P application significantly affected the yields of grain and straw. P application increased the uptakes of N, P, K, Ca and Mg significantly. N uptake was also significantly increased by N application and liming. There was a significant negative quadratic P effect on grain and straw yield, and uptake of nutrients, indicating that higher application rates did not result in higher yields and uptake of nutrients. Ash application significantly increased the yields of grain and straw and the uptakes of N, P, K and Mg, but not of Ca. It was concluded from the two trials that the response to ash application was mainly a P effect. The recovery fractions of P at about the same P applications rates were 7.4% and 11%, in the ash and 3^4 trial, respectively. Hence, the relative effectiveness of ash-P was 0.67 or 67%, and the substitution rate 1.5. This implies that for the uptake of a unit of P about 1.5 times as much ash-P as fertilizer-P should be applied. The effectiveness of ash as liming material was 0.59 compared to $Ca(OH)_2$, hence 1.7 times as much ash as $Ca(OH)_2$ is needed to establish a same increase in pH. The CaO equivalent of ash

proved to be 44% and the $CaCO_3$ equivalent 78%. In the ash trial a higher efficiency of utilization of absorbed P was found than in the 3^4 trial. Several possible causes of this difference are discussed but no conclusive answers could be given.

5.1 Introduction

Shifting cultivation is judged to be a sound agricultural system in areas with a low population density (Sanchez,1976). In many areas, however, the population density has increased and the system is under pressure to change.

In south-west Côte d'Ivoire, shifting cultivation is the traditional land use system of the indigenous population, belonging to the ethnic groups of Oubi and Guéré. Since the mid-1960s the population density has increased enormously through immigration (Dosso et al.,1981). The immigrants are used to planting perennial crops, such as coffee, cocoa or rubber, after food crops. Because of the revenues involved, this practice is followed nowadays by the Oubi and Guéré.

In 1972 the Taï National Park (340,000 ha) was established (Fig. 2.1). As a result, the forested area outside the Park boundaries available for clearing for agricultural purposes diminished rapidly, and the Park itself became endangered. For the protection of the Park, it became necessary to intensify agricultural production in the surrounding areas. A research programme to study the possibilities of agricultural intensification was set up by the Wageningen Agricultural University. The programme included investigations of nutrient fluxes in the traditional system of food crop production.

It was found that burning the slashed vegetation doubled yields of upland rice compared to the yields on non-burnt fields, i.e. an increase of about 0.7 ton per ha, in the first season after clearing. This increase could be ascribed to the addition of P with the ash (Van Reuler and Janssen,1993b). Nevertheless, P still remained the yield-limiting nutrient on burnt fields at well drained sites (Van Reuler and Janssen,1989;1993b).

The objective of the present experiment was to compare the fertilizing effects of ash and mineral fertilizers on the yields and nutrient uptakes of upland rice. The effect on soil pH was also studied.

The fertilizing value of a certain nutrient source can be judged by comparing it with the fertilizing value of a reference nutrient source. For that purpose a so-called relative effectiveness (RE) has been defined, being the ratio of the instantaneous slopes of the application - yield or application - uptake response curve, found for the source being tested and the reference nutrient source (Barrow,1985). The inverse of the RE, known as substitution rate or substitution value, indicates how many nutrient units of the source under examination are needed for bringing about the same response as one nutrient unit in the reference fertilizer. Both expressions are used in this paper.

5.2 Materials and methods

5.2.1 Study area

The study site was located at approximately 1 km north of the village of Taï (Fig. 2.1). Mean annual rainfall amounts to 1885 mm with a standard deviation of 338 mm (Collinet et al.,1984). A pronounced dry season occurs from November to March. The natural vegetation can be classified as lowland evergreen seasonal forest (Vooren,1985) in the UNESCO classification (UNESCO,1973).

The field experiment was carried out on the lower part of a catena representative of the region (Fritsch,1980; Van Kekem,1986; De Rouw et al.,1990). Soils in this physiographic position are classified as Dystric Regosols (FAO,1988) and as Typic Troporthents (Soil Survey Staff,1990). The topsoil (0-20 cm) data presented in Table 5.1 show that the inherent soil fertility was low.

Table 5.1 Soil analytical data (0-20 cm) of the experimental site.

sand (%)	80	Exch. cations[c]	
silt	9	Ca (mmol+ kg^{-1})	9.9
clay	10	Mg	3.5
		K	1.2
pH-H_2O[a]	5.18	Na	0.1
		Al	6.0
Org. C (g kg^{-1})	1.2	Mn	0.4
Org. N	0.08		
		ECEC (mmol+ kg^{-1})	21.0
Total P (mg kg^{-1})	88		
P-Dabin[b]	10.0		
P-Olsen	3.3		

[a] average of 108 samples, other data are the average of 27 samples
[b] modified Olsen extraction (0.5 M $NaHCO_3$+0.5 M NH_4, pH 8.5)
[c] $BaCl_2$ extraction

The field had been cultivated for one season one year and six years before the present trial started. The almost one-year-old secondary vegetation was slashed and removed from the field. It was not burnt to avoid interference with the experimental treatments.

5.2.2 Experimental design

The nutritional value of ash was compared with that of N, P, K fertilizers and lime in a field trial consisting of a "fertilizer part" and an "ash part". The experimental design of the fertilizer part trial was a 3^4 factorial. In order to reduce uncontrollable variance the block size was reduced from 81 to nine subblocks by confounding three-factor interactions (Cochran and Cox,1957). To each of these nine subblocks three experimental units were added, bringing the total number to 9 * 12 = 108 units. An experimental unit measured 4 * 5 m.

The application rates in the factorial experiment were 0, 50 and 100 kg N ha^{-1} applied as urea (46% N), 0, 12.5 and 25 kg P ha^{-1} applied as triple superphosphate (20% P), 0, 50 and 100 kg K applied as potassium chloride (50% K), and 0, 400 and 800 kg $Ca(OH)_2$ ha^{-1} (according to product information the liming material contained 96.5% $Ca(OH)_2$ and the CaO equivalent was guaranteed to be 74%).

In six of the nine subblocks the ash trial was conducted. The application levels were 0, 4,000 and 8,000 kg ash ha^{-1}. Such high rates, far above normal, were used to be sure that the effect of ash could show up. The amounts of nutrients applied with the ash are presented in Table 5.2. The ash was derived from a 20-year-old secondary vegetation described by Van Reuler and Janssen (1993a). For the present experiment the vegetation of a 30 * 30 m section of the forest was slashed, dried, piled and burnt very intensively. In this way about 2 t ash ha^{-1} was produced.

The remaining experimental units in the other three subblocks were used for another purpose, not dealt with in this paper.

Table 5.2 Nutrients applied with the ash. All data in kg ha^{-1}.

Ash rate	N	P	K	Ca	Mg	Na	Mn	Zn	S
4,000	0	31	264	915	150	10	10	2.6	32
8,000	1	62	528	1830	300	19	20	5.1	63

5.2.3 Crop cultivation

Upland rice (*Oryza sativa*, cultivar IDSA 6) was grown between April and August 1989. The rice was sown in the traditional way with a planting stick or machete. The average density of plant holes was 100,000 holes ha^{-1} with five to ten seeds in each hole. Ash, mineral fertilizers and lime were broadcast one day after planting. The field was fenced to limit damage by rodents. During the growing season, the field was weeded when necessary, leaving the weed remains as surface mulch. During the ripening stage, the rice field was guarded against bird damage. After 130 days the rice was harvested, net plot size being 3 * 4 m. Grain and straw samples of all treatments and some panicle samples were collected for chemical analysis. All above-ground crop residues were removed from the field. The yield data refer to grain with a moisture content of 14%.

5.2.4 Interpretation of yield and nutrient uptake data

The relation between nutrient application and grain yield can be split into the relation between nutrient application and nutrient uptake and the relation between nutrient uptake and grain yield. This so-called three-quadrant method was introduced by De Wit (1953) and applied by, among others, Van Keulen and Van Heemst (1982) and Van Keulen (1982).

The apparent fertilizer recovery fraction (RF) is the fraction of a nutrient applied by fertilizer that is absorbed by the crop.

The efficiency of utilization (EU) is defined as grain yield per unit of nutrient absorbed. The EU is an indication of the availability of the particular nutrient in relation to other growth factors. According to Van Keulen and Van Heemst (1982), grain yield of small cereals maximally increases by 70 kg per kg N absorbed, by 600 kg per kg P and by 55 to 100 kg per kg K absorbed. Janssen et al. (1990) report for maize maximum values of 70 kg per kg N, 600 per kg P and 120 kg per kg K absorbed. Minimum values, indicating accumulation in the crop are 30, 200 and 30 kg grain per kg N, P and K, respectively.

5.2.5 Soil, plant and ash samples

Before planting, per subblock three composite soil samples (0-20 cm), totalling 27 samples were collected. The samples were analyzed according to Houba et al. (1989). In addition, composite soil samples for pH-H_2O (1:2.5) measurement were taken at 0-5 cm, 5-10 cm and 10-20 cm depth in each experimental unit, and at 40-50 cm depth in some units. This sampling was repeated 144 days after ash and $Ca(OH)_2$ application.

Moisture contents of plant samples were determined by 24-h drying at 70 ^{0}C.

Thereafter samples were ground. Grain samples were also dried at 105 ^{0}C. The yield data refer to grain with a moisture content of 14%. Plant and ash samples were analyzed according to Walinga et al. (1989).

5.2.6 Statistical analysis

For quantitative statistical analysis the SAS programme was used (1989). In the regression model for the 3^4 experiment N, P, K, and L, their quadratic terms and two-factor interactions were included. The model for the ash trial consisted of ash and ash * ash. The General Linear Model (GLM) procedure was used to estimate the regression coefficients for each term. The quadratic terms and two-factor interactions were deleted from the model one by one until the ones remaining in the model were significant at $P < 0.1$. At each step, the variable showing the smallest contribution to the model was deleted. The response to nutrient or ash application can be predicted by multiplying the relevant regression coefficient by the application rate (0, 1 or 2). The R-squared value provides a measure of how much of the variability in the observed data can be explained by the model.

5.3 Results and discussion

5.3.1 Yields and nutrient uptake data

Grain yields on individual experimental units varied from 1.2 t ha^{-1} to 3.2 t ha^{-1}. Main treatments average values of grain yields, straw yields and uptakes of N, P, K, Ca and Mg (uptake refers to the quantities of nutrients in all above-ground plant parts, grain, straw and panicle) are presented in Table 5.3, and the results of the statistical analysis of the 3^4 and the ash trial, in Table 5.4 and Table 5.5, respectively. About 37 and 41% of total variation in grain and straw yield, respectively, was explained by the statistical models in the 3^4 trial, although N and P significantly affected grain and straw yields. Highest values of total R^2 were obtained for nutrient uptakes, with the maximum of 73% for P uptake (Table 5.4). N, K, Ca and Mg uptakes significantly increased as well as a result of P application, all again pointing to P as being the primary growth-limiting nutrient. The significant negative quadratic P effect indicates that at higher application rates yield and nutrient uptakes will not increase. Highest yields were obtained at P1 (12.5 kg P ha^{-1}), but highest P uptake at P2 (25 kg P ha^{-1}). N as well as P significantly stimulated N, K and Ca uptake.

Table 5.3 Grain yield, straw yield and total nutrient uptake of the main and of some selected treatments of the 3^4 and ash trials.

Treatment	Yield (t ha^{-1})		Total uptake (kg ha^{-1})				
	Grain	Straw	N	P	K	Ca	Mg
Control[a]	1.61	1.99	43.2	2.6	29.9	5.1	3.9
Ash1	2.38	2.89	56.3	4.8	50.6	7.0	6.4
Ash2	2.79	3.41	67.1	6.9	66.4	7.7	7.8
N0	1.89	2.51	46.2	4.4	38.6	6.3	5.2
N1	2.10	2.78	57.4	4.6	44.3	7.5	6.1
N2	2.02	2.96	65.0	4.6	49.0	8.2	6.6
P0	1.83	2.41	51.9	3.0	38.8	6.1	5.0
P1	2.12	2.91	59.8	4.8	46.3	8.0	6.5
P2	2.05	2.94	56.7	5.8	46.7	7.9	6.4
K0	1.97	2.51	54.6	4.3	41.6	6.9	5.6
K1	2.05	2.86	58.9	4.9	46.1	7.9	6.3
K2	1.99	2.89	54.8	4.4	44.2	7.2	6.0
L0	1.92	2.64	52.7	4.4	41.7	6.6	5.5
L1	2.05	2.84	56.5	4.6	44.5	7.7	6.2
L2	2.03	2.77	58.9	4.6	45.7	7.6	6.2
-N +P +K +L	1.96	2.89	49.0	5.4	42.7	7.1	5.7
-N -P +K +L	1.57	1.94	36.0	2.3	25.9	4.4	3.5
-N +P -K +L	2.17	2.49	50.8	5.6	45.5	6.2	6.0
-N +P +K -L	1.86	2.95	52.1	7.4	47.3	8.0	6.1

[a] average of 7 experimental units, one from the 3^4 trial and six from the ash trial

Table 5.4 Estimated regression coefficients for N, P, K and lime and significant terms in equations describing the yields and nutrient uptakes in the 3^4 trial. The variance explained by the models is indicated by R^2 (%).

Parameter	Yield (t ha^{-1})		Total nutrient uptake (kg ha^{-1})				
	Grain	Straw	N	P	K	Ca	Mg
N	0.36^{**}	0.23^{***}	9.4^{***}	0.04	5.22^{***}	0.95^{***}	0.16
P	0.48^{***}	0.74^{***}	13.7^{***}	2.30^{***}	3.94^{***}	2.93^{**}	2.18^{***}
K	0.01	0.19^{***}	8.5	0.96^{**}	1.31	0.13	0.13
L	0.06	0.07	2.8^{*}	0.14	1.97	0.51	-0.21
N*N	-0.15^{**}						
N*L							0.59^{**}
P*P	-0.19^{***}	-0.23^{**}	-5.5^{**}	-0.45^{**}		-1.00^{*}	-0.78^{*}
K*K				-4.3^{*}	-0.47^{**}		
R^2	37	41	54	73	39	26	41

*, **, *** significant at $P < 0.1$, $P < 0.05$ and $P < 0.01$

Ash significantly increased grain and straw yields and nutrients uptakes, except, surprisingly enough, Ca uptake. Also here the highest R^2 was found for P uptake, allowing the conclusion that response to ash was mainly a response to P. In view of the large yield difference between Ash1 and Ash2 in the ash trial, it is possible that higher rates of ash could have resulted in yields higher than 2.8 t ha^{-1}.

Table 5.5 Estimated regression coefficients for ash in equations describing the yields and nutrient uptakes in the ash trial. The variance explained by the models is indicated by R^2 (%).

Parameter	Yield (t ha^{-1})		Total nutrient uptake (kg ha^{-1})				
	Grain	Straw	N	P	K	Ca	Mg
Ash	0.57^{***}	0.65^{*}	11.1^{***}	2.11^{***}	17.1^{***}	1.14	1.96^{**}
R^2	85	66	64	87	82	23	53

*, **, *** significant at $P < 0.1$, $P < 0.05$ and $P < 0.01$

5.3.2 Relations between nutrient application and nutrient uptake; fertilizing and liming value of ash

5.3.2.1 Phosphorus

Fig. 5.1 shows the relations between P application, P uptake and yield in a three-quadrant diagram. The slope of the line in Quadrant IV represents the apparent recovery fraction (RF). RF was 14.5% between P0 and P1, and 7.6% between P1 and P2. The calculation of the recovery of ash-P is more complicated, because ash contains other nutrients besides P. Theoretically, equal quantities of these other nutrients should have been applied at all ash levels including Ash0, but it is impossible to achieve this in practice. Besides P, also K and Ca were applied with ash. Therefore, as approximation to the P uptake at Ash0, the average P uptake of the -N-P+K+L treatment combinations (N0P0K1L1, N0P0K2L1, N0P0K1L2, N0P0K2L2) of the 3^4 trial should be used (Table 5.3), considering the K and Ca supplies with these treatments as the best possible approximations of those at Ash1 and Ash2. However, the average P uptake on the -N-P+K+L plots (2.3 kg) does not differ significantly from the average P uptake (2.6 kg) on the seven control plots. Therefore for the P uptake of Ash0 the average of both treatment combinations was used, i.e. 2.5 kg P ha^{-1}. The recovery of ash-P was 7.4% between Ash0 and Ash1, and 6.7% between Ash1 and Ash2. Thus, the P-recovery from ash seems much lower than that from TSP, but the comparison is hampered by the fact that with ash more P was applied than with TSP. At Ash1 and P2 (in the 3^4 trial), about equal quantities of P (31 and 25 kg) were applied and the P-recovery fractions were 7.4 and 11.0%, respectively. Hence, the relative effectiveness of ash-P is estimated to be 7.4/11.0 =

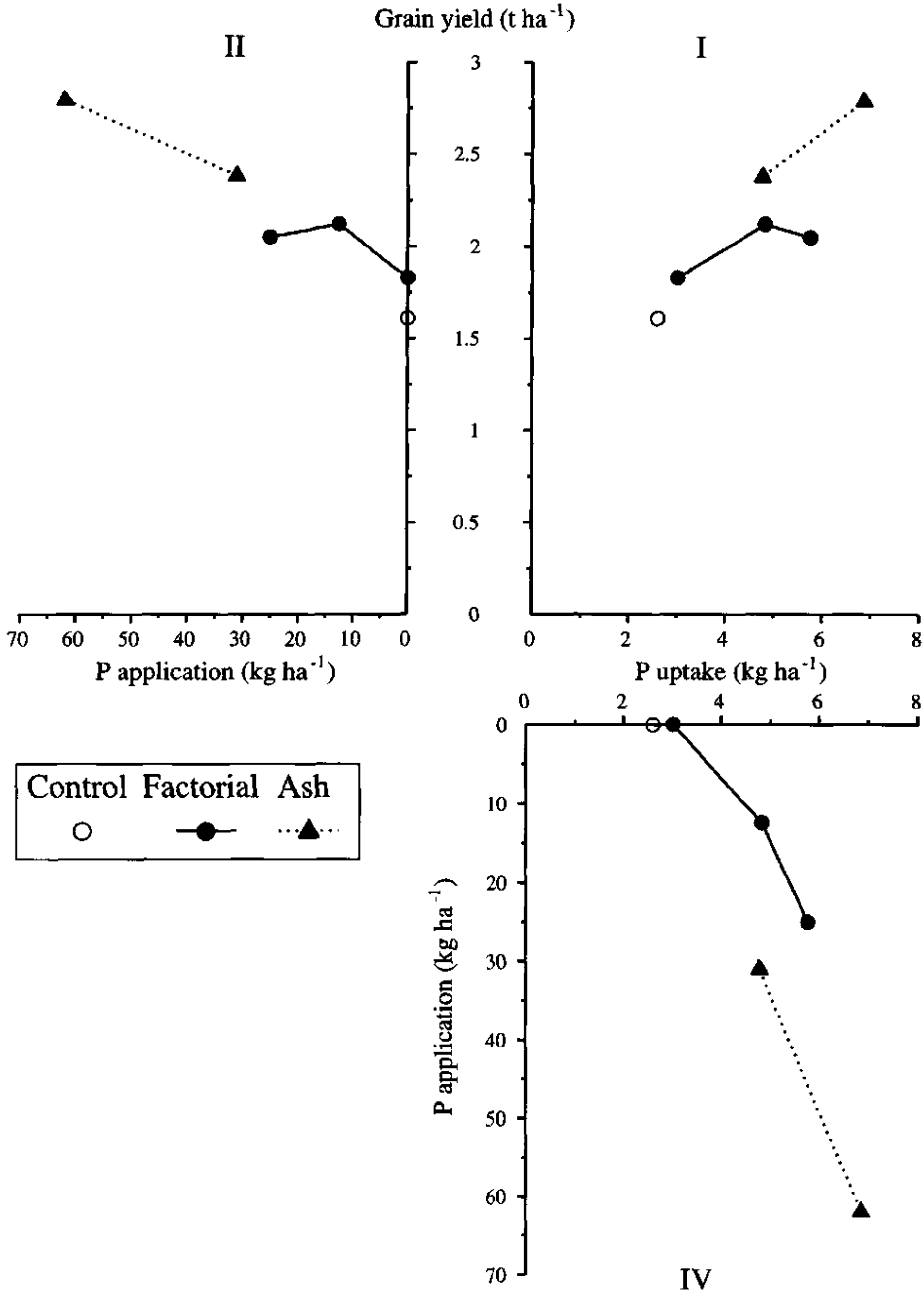


Fig. 5.1 The relations between P application, P uptake and rice grain yield in the 3^4 (main P treatments) and ash trials.

about 0.67 or 67%, and the substitution rate 11.0/7.4 = 1.50. This implies that for a same uptake of P, about 1.5 times more ash-P than TSP-P should be applied.

5.3.2.2 Potassium

As approximation for the K uptake at Ash0, the average K uptake of the -N+P-K+L treatment combinations (N0P1K0L1, N0P2K02L1, N0P1K0L2, N0P2K0L2) of the 3^4 trial was used, considering the P and Ca supplies of these treatments as the best possible approximations of those at Ash1 and Ash2 (Table 5.3). The K uptake thus found was 45.5 kg ha^{-1}, being significantly higher than the average uptake (29.3 kg) in the control plots. The recovery of ash-K would be strongly overestimated when the control plots were to be used as reference. The recovery of ash-K was 1.9% between Ash0 and Ash1, and 6.0% between Ash1 and Ash2. The relative effectiveness of ash-K is difficult to assess for two reasons. One reason is that the application of KCl in the 3^4 trial did not result in a significant increase in K uptake, and the other is that far more K was applied with ash than with KCl. From the uptake data in Table 5.3, the recovery fraction of K from KCl may be estimated at 9.0% between K0 and K1, and at 2.6% between K0 and K2. Hence, the relative effectiveness of ash-K would lie somewhere between 1.9/9.0 = 0.21 and 6.0/2.6 = 2.29. This range is so wide that such an answer cannot be considered as conclusive. The most concrete statement that can be made is that there is no reason to assume that ash-K is less available to the crop than KCl-K. Since under the prevailing conditions of high rainfall and low soil-ECEC K-leaching is a serious risk, such a reduced solubility may be looked upon as an asset. Exchangeable K is about 1.2 mmol kg^{-1} and ECEC 21 mmol(+) kg^{-1} (Table 5.1) and, hence, the relative K saturation is about 6%. In the 3^4 trial, maximum K uptake was obtained at K1, i.e. at an K application of 50 kg ha^{-1}. If the added K is retained as exchangeable K in the topsoil of 3 million kg, the added 50 kg of K would increase exchangeable K by 0.43 mmol K kg^{-1}. The relative K saturation would then rise from about 6 to about 8%. It is questionable whether the soil can maintain such a high value. The data of Table 5.3 suggest that the soil itself can supply about 40 kg K per ha per season, which is roughly 30% of exchangeable soil K. Assuming that the same recovery value holds for fertilizer K that is retained as exchangeable K, and taking into account that 9% of fertilizer K was recovered by the crop, it follows that 9/30 = 0.3 or 30% of the applied K was present as exchangeable K in the topsoil. The remainder of applied K may have moved to deeper soil layers and/or may have been incorporated into soil minerals, thus becoming unavailable to the crop.

5.3.2.3 Calcium and liming

In the 3^4 trial as well as the ash trial Ca uptake did not increase significantly upon liming and ash application, respectively. Therefore calculations of the recovery fractions of Ca are not meaningful. The purpose of application of $Ca(OH)_2$ was to increase pH. Assessment of the effectiveness of ash in comparison with $Ca(OH)_2$ should therefore refer to their effects on pH.

Fig. 5.2 shows the effect of $Ca(OH)_2$ and ash application on pH-H_2O (0-20 cm) at the end of the growing season. The ratio of the slope of the ash line between Ash0 and Ash1 to the slope of the $Ca(OH)_2$ line between L0 and L2 amounts to 0.59. This implies that for a same pH increase, the quantity of ash to be applied is 1.7 times as large as the quantity of $Ca(OH)_2$.

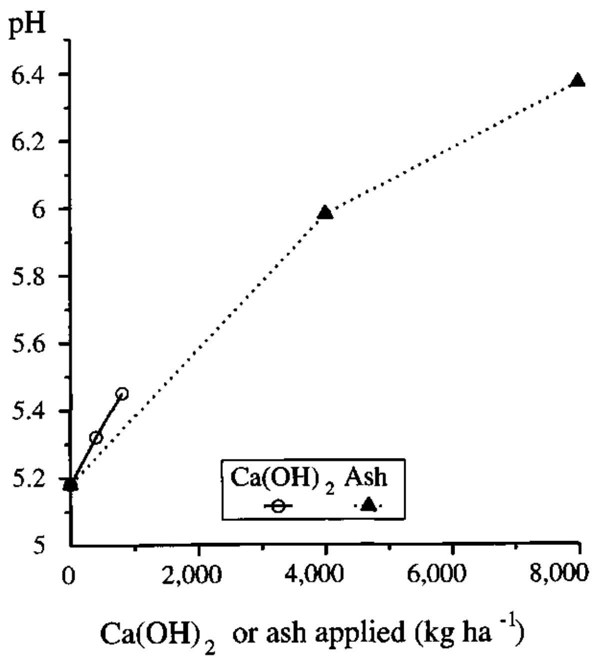


Fig. 5.2 Effect of $Ca(OH)_2$ and ash application on pH.

The effectiveness of liming materials is generally expressed in terms of CaO or $CaCO_3$ equivalent. The CaO equivalent of the applied $Ca(OH)_2$ was 74%, and hence the $CaCO_3$ equivalent was 74 * 100/56 = 132%. Consequently, the CaO equivalent of the ash may be estimated at 0.59 * 74 = 44% , and the $CaCO_3$ equivalent at 0.59 * 132 = 78%.

5.3.2.4 Nitrogen

Although the ash used contained practically no N, it proved to have a significant positive effect on N uptake. The extra N absorbed must have been supplied by the soil. The efficiency of utilization of N (EUN), i.e. the ratio of yield to N uptake, was always closer to 30 than to 70 as can be derived from Table 5.3, indicating that N was never growth limiting (Janssen et al.,1990). The uptake of N was related to crop growth which in turn depended mainly on P availability. Fig. 5.3 shows the relations between N uptake and P uptake. The line for ash lies closer to the line for N1 rather than N0 at higher ash rates, suggesting that in the ash plots the supply of N was about the same as in the N1 plots of the 3^4 trial. In the 3^4 trial liming increased the N uptake significantly ($P < 0.1$). The significant effect of ash on N uptake may be caused by a combined effect of P and Ca applied with ash. This extra uptake may have been derived from increased N mineralization in the ash plots, possibly as a result of the increase in pH in these plots. In the N0 treatment, however, there proved to be no relation between pH and amount of N taken up.

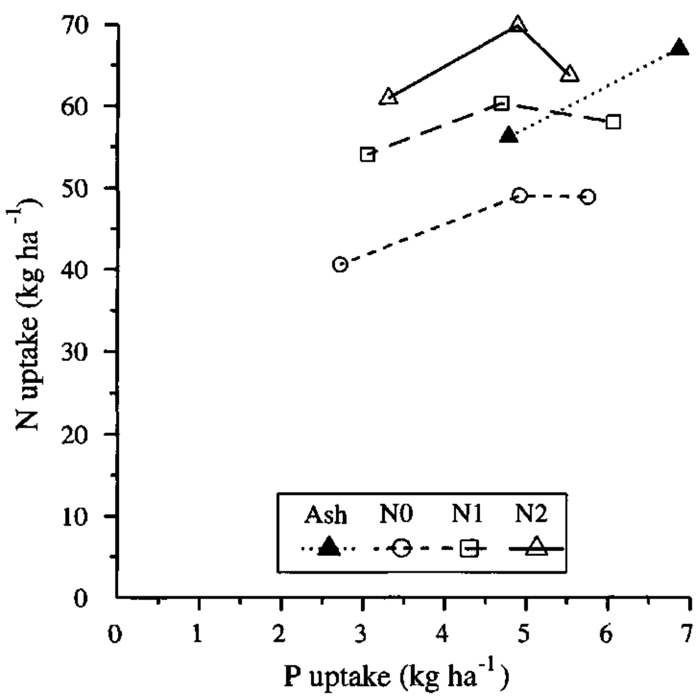


Fig. 5.3 Relations between N and P uptake in the ash and for the three N levels of the 3^4 trial.

Apparently the soil can supply at least 65 kg N ha^{-1} in one growing season. Available N not actually taken up may simply remain in the soil solution, but is usually subjected to processes like leaching, volatilization, denitrification and immobilization. These processes were not measured in Taï. The recovery of fertilizer N was only about 20% and it is likely that leaching played a dominant role in N-losses.

5.3.3 Relations between nutrient uptake and yield; additional ash effect

From the relation between P uptake and grain yield (Quadrant I in Fig. 5.1), it follows that high values, even above 600 for efficiency of utilization (EU) of P, were found on minus-P plots, and that in the ash trial absorbed P was more efficiently used than in the 3^4 trial. Similar conclusions can be drawn from Fig. 5.4, showing the uptake-yield relations for N, K and Ca. In all cases the lines for ash lie above those of the 3^4 trial and the question arises as to which factors, nutrient(s) or others, the better EU's of the crop for P in plots with ash can be ascribed. An obvious hypothesis is that the presence in ash of nutrients other than the ones under study improves the EU.

A greenhouse experiment with the double-pot technique revealed (G.J.F. van Ewijk, personal communication) that ash supplied, in the first place, K and S to the plants, and furthermore small amounts of N, P, Zn and Cu, but no Mg, Fe, B and Mn. These results suggest that the additional beneficial effects of ash could have been caused by S, Zn or Cu. This hypothesis was tested in a field experiment on sites which had been cultivated for six seasons (Van Reuler and Janssen subm.d). Application of S as $CaSO_4$ did not have any positive effect on yield, thus making it unlikely that the additional effect was caused by the sulphur in the ash. Unfortunately, no conclusions could be drawn about the effects of micronutrients because in a similar test for micronutrients the crop was damaged by the foliar application of a solution of these nutrients. On comparable soils with a sandy texture in Ghana, Zn deficiency was common. Unfortunately the length of the cultivation period at this site was not reported (Kang and Juo,1984). Because the cropping history of the present site in Taï was relatively short, Zn deficiency is not yet to be expected.

Soil pH was strongly raised by ash application (Fig. 5.2), but the difference in pH is not a very plausible cause to explain the difference in EUs between the plots with and without ash. Reasons are that no response to liming was observed in the 3^4-trial (Tables 5.3 and 5.4), and that in general in our previous studies the growth of upland rice was not influenced by pH changes (Van Reuler and Janssen,1989:1993b).

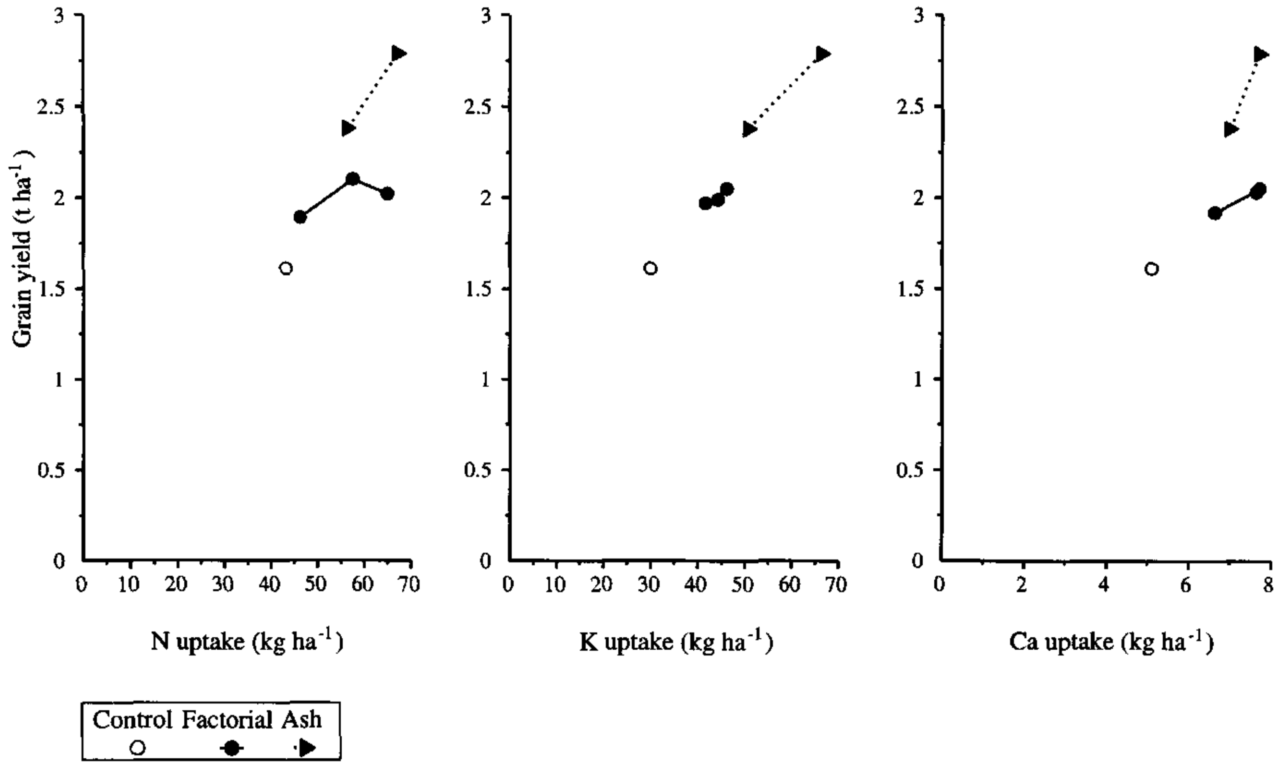


Fig. 5.4 Relation between grain yield and uptakes of N, K and Ca. Uptakes are averaged per application rate of N, K and lime.

Table 5.6 presents the uptakes of the other nutrients for reference values of the uptake of N, P, K, and Ca, respectively. The yields and uptakes were calculated by interpolation of the data of Table 5.3. The reference uptake values were chosen in the overlap of the uptake ranges of the ash and the 3^4 trial. There was, however, no overlap in the case of K, its uptake always being lower in the 3^4 trial than in the ash trial. Therefore, a value between the uptake ranges of the two trials was taken as reference value of K uptake.

Table 5.6 shows that the uptake of K was higher and the uptake of Ca lower in the ash trial than in the 3^4 trial. Hence, the largest difference between the ash and the 3^4 trial is the uptake ratio of K and Ca. The value of K/Ca increases with increasing ash application, being 6.0 on average in the 3^4 trial, 7.2 at Ash1 and 8.6 at Ash2. The ratio K/Ca in ash is 0.3 (Table 5.2). Apparently ash-K is better available to the crop than ash-Ca. Whether the difference in K/Ca is the cause of the better nutrient utilization and higher yields in the ash trial than in the 3^4 fertilizer trial is not clear. In general, K facilitates water uptake by roots and at the same time reduces transpiration losses (e.g. Beringer and Trolldenier,1978), and increases the resistance of plants against pathogens and insects. However, the K content in the 3^4 trial does not point to K deficiency. It cannot be excluded that not K/Ca itself, but another nutrient being correlated with K/Ca, was the main cause of the difference in utilization efficiency between the fields with and without ash. It is not likely that Mg is the other nutrient, as the uptake data (Tables 5.3 and 5.6) show that differences in Mg uptake between the 3^4 fertilizer trial and the ash trial were of minor importance.

The nature of the vegetation that is burnt and the temperature during the burning influence the chemical composition of the ash produced. Ash produced in a different way or from a different vegetation may have other fertilizing and liming values than the 67% for the relative effectiveness of ash-P, and 73% for the $CaCO_3$ equivalent of ash we found. In this trial, ash was produced in a pile, and the burning was much more intensive than it usually is on farmers' fields. Our ash did not contain N. N is entirely lost at temperatures over 350-400 °C (Andriesse and Schelhaas,1987), and therefore we may assume that the temperature in the pile had been at least 350 °C.

Our results may also have been affected by the very high application rates of ash, being 4 and 8 ton ha^{-1}, while the normal rate in Taï is about 2.5 ton ha^{-1} (Van Reuler and Janssen,1993a). As a result, the amounts of P, K and Ca applied through the ash were much higher than those in the 3^4 fertilizer trial, and this difference may have affected the validity of the comparison.

Table 5.6 Comparison of yields (t ha^{-1}), nutrient uptake (kg ha^{-1}) and the ratio of K uptake to Ca uptake in the Ash and 3^4 trial for fixed values (***bold***) of N, P, K and Ca uptakes, respectively.

Trial	Grain yield (t ha^{-1})	Uptake of nutrients (kg ha^{-1})					K/Ca
		N	P	K	Ca	Mg	
Ash	2.52	***60***	5.5	56.0	7.2	6.9	7.8
3^4	2.07	***60***	4.6	45.9	7.7	6.3	5.9
Ash/3^4	1.22		1.2	1.2	0.9	1.1	1.3
Ash	2.42	57.4	***5***	52.3	7.1	6.6	7.4
3^4	2.11	59.2	***5***	46.4	8.0	6.5	5.8
Ash/3^4	1.15	1.0		1.1	0.9	1.0	1.3
Ash	2.24	52.5	4.0	***45***	6.7	5.9	6.7
3^4	2.03	58.2	4.8	***45***	7.7	6.2	5.8
Ash/3^4	1.10	0.9	0.9		0.9	1.0	1.2
Ash	2.42	57.3	5.0	52.1	***7***	6.6	7.4
3^4	1.97	54.1	4.4	42.7	***7***	5.7	6.1
Ash/3^4	1.23	1.1	1.1	1.2		1.1	1.2

5.4 Conclusions

In a 3^4 fertilizer trial the yield of upland rice was increased significantly by application of N ($P < 0.05$) and P ($P < 0.01$). Highest yields were obtained with 50 kg N ha^{-1} and 12.5 kg P ha^{-1}. N application and liming also increased the N uptake, while P application increased the uptake of N, P, K, Ca and Mg.

Also ash application increased the yield and uptake of N, P, K and Mg. The response to ash was mainly a P effect. The apparent recovery fractions of 25 kg fertilizer-P and 31 kg ash-P were 11.0% and 7.4%, respectively. Consequently, the relative effectiveness of ash-P was 0.67 and the substitution rate 1.5. The high N uptake in the ash trial is probably a combined effect of P and Ca applied with the ash.

The efficiency of utilization of absorbed ash-P was higher than of absorbed fertilizer-P. The effect might have been related to the high K content, or to the high K/Ca ratio in ash, but other factors may have been involved as well.

Ash was compared with $Ca(OH)_2$ in their effects on pH. It was found that 1.7 times as much ash as $Ca(OH)_2$ need to be applied for establishing the same pH increase.

In this trial ash had direct effects as P fertilizer and as liming material, and an indirect effect consisting of an improvement of utilization of absorbed nutrients. It is obvious that ash may behave as K fertilizer, and there are indications that it may act as S fertilizer too, but the prevailing soil conditions made it impossible to evaluate these qualities.

Part III

Identification of nutritional constraints and related soil properties

Chapter 6

Nutritional constraints in secondary vegetation and upland rice

Summary

1. The Taï National Park (340,000 ha) in south-west Côte d'Ivoire is the last extensive area with undisturbed forest in Africa west of the Dahomey Gap. The annual rainfall is about 1800 mm.
2. The indigenous people practise shifting cultivation with upland rice as the main food crop. Due to immigration, there is a shortage of land outside the Park and therefore the crop yields need to increase.
3. The nutrient status of secondary vegetation is discussed. Phosphorus is the limiting nutrient.
4. In on-farm trials with rice the effects of nitrogen, phosphorus and potassium fertilizers and lime were studied. The yields varied between sites and treatments from 0.9 to 5.0 ton ha^{-1}. A significant positive response was obtained to phosphorus fertilizers only.
5. The response of upland rice to phosphorus fertilizer application was related to the extractable soil phosphorus concentrations (modified P-Olsen method). An application of 50 kg phosphorus fertilizer resulted in a yield increase of about 600 kg grain.
6. The yields of the plots without fertilizer in the trials were between 1.5 and 3.3 t ha^{-1}, considerably higher than the local farmers' yields (0.8 - 1.0 t ha^{-1}). This was mainly caused by differences in management, including more thorough clearing of the fields, regular weeding, fencing of the fields to limit the damage by rodents, and guarding against bird damage.

6.1 Introduction

The Taï National Park in the south-western part of Côte d'Ivoire is the last extensive area with undisturbed forest in Africa west of the Dahomey Gap. Until the mid 1960's the region was largely uninhabited. The small population living along a few roads and on the coast practised subsistence shifting cultivation. In 1965 the Government decided to develop the region by timber exploitation to be followed by the creation of major agro-industrial projects to provide employment and trade after the timber harvest and the setting up of viable industries to ensure the region's economic development (Dosso et al., 1981).

The Government also aimed to increase the population density by migration mainly from Central Côte d'Ivoire. Additional to the planned development, the region has attracted spontaneous immigration from other parts of Côte d'Ivoire and neighbouring countries such as Burkina Faso and Mali (Dosso et al.,1981). This immigration was enforced by poor climatic conditions in the Sahelian zone (Lena, 1984). The majority of the immigrants settled and started to grow crops, particularly coffee and cocoa. The overall consequence of these developments is that the area of undisturbed forest is decreasing very quickly. To safeguard the forest, the Taï National Park (340,000 ha) was established in 1972. In a few years time the primary forest outside the Park boundaries will have vanished. Each year the farmers have to clear fields with younger secondary vegetation. To safeguard the Park from disturbance, the areas cleared for agriculture outside have to be more intensively farmed.

The Agricultural University of Wageningen, the Netherlands has a project to study this, and work is in progress on forestry, agroforesty, vegetation succession, soils and soil fertility. This paper deals with the nutrients in different landuse systems.

6.2 Physical and biotic environment

The Taï National Park is situated between the Sassandra river in the east and the Cavally river in the west (Fig. 2.1). The study area is located on the western side of the Park.

The yearly rainfall at the village of Taï is 1833 mm with a standard deviation of 338 mm (Casenave et al.,1980). According to Fritsch (1980) four seasons can be distinguished: (i) a long rainy season from March to July accounting for 45% of the total rainfall, (ii) a short relatively dry season from July to September, (iii) a short rainy season from September to November accounting for 30% of the total rainfall, (iv) a long dry season from November to March in which the potential evapotranspiration exceeds the rainfall. The mean monthly temperature varies from 24.7 °C to 27.4 °C. In Fig. 6.1 the average climatic data and the calculated potential evapotranspiration according to the Turc formula are presented.

The rocks in the study area belong to the Precambrium Basement complex (Papon,1973). The main rock type is metamorphic migmatite, rich in biotite. Granite occurs locally. The region consists of uplands (up to 200 m altitude) with an undulating to rolling relief. The slopes tend to be long and are mostly convex. Valleys are relatively narrow and the streams have few meanders. The average local relief is 20 to 25 m.

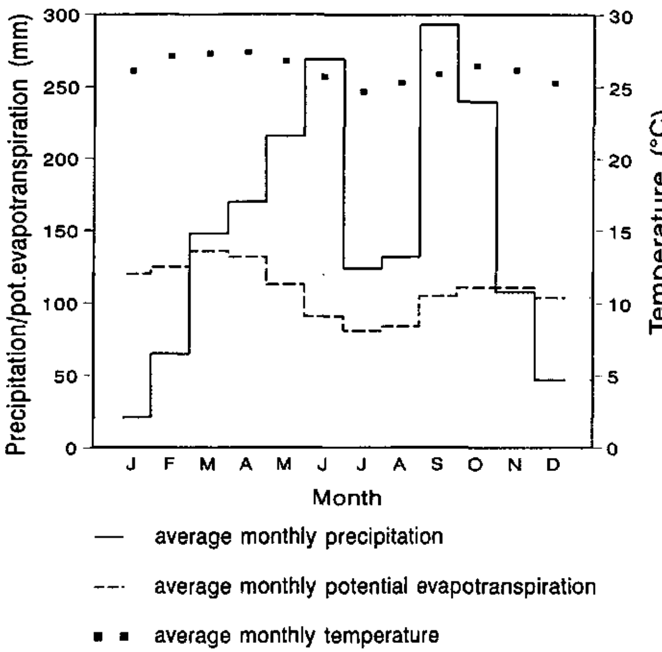


Fig. 6.1 Climatic data of the Taï meteorological station.

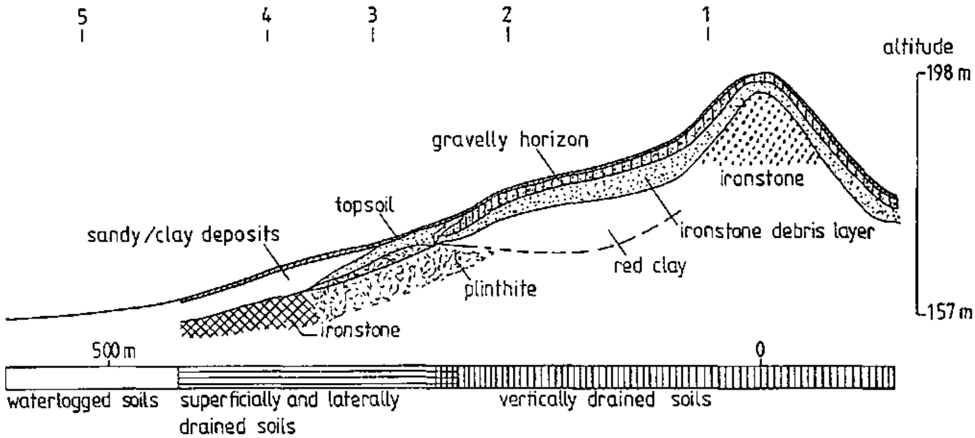


Fig. 6.2 Transect of soils representative of the Taï region (Fritsch,1980; Vooren,1985). Vertical scale is exaggerated. The number refers to the soils analyzed by Fraters (1986) and Borst (1987).

A soil map of south-west Côte d'Ivoire at a scale of 1:200,000 has been prepared by the Development Resources Corporation (1967). Near the village of Taï, more detailed studies have been carried out (Fritsch,1980; Fraters, 1986; Van Kekem, 1986). Fig. 6.2 presents a representative transect near Taï and Table 6.1 shows the soil classification according to different systems. The soils on the slopes are strongly leached and chemically poor. The wet soils in the valley bottoms are presently not used for agriculture.

Table 6.1 Classification of the soils of the transect presented in Fig. 6.2. The soils are classified according to Commission de Pédologie et de Cartographie des Sols (CPCS,1967), FAO-UNESCO (1974), and Soil Survey Staff (1975). After Fraters (1986).

Position on transect	CPCS	FAO-UNESCO	Soil Survey Staff
1	Sol ferralitique fortement désaturé, remanié, modal	Ferric Acrisol	Orthoxic Palehumult
2	Sol ferralitique fortement désaturé, remanié, faiblement appauvi	Ferric Acrisol	Orthoxic Palehumult
3	Sol ferralitique fortement désaturé, à recouvrement plus ou moins appauvi	Ferric Acrisol/ Plinthic Ferralsol	Orthoxic Palehumult/ Plinthic Haplorthox
4	Sol ferralitique fortement désaturé, induré appauvi, hydromorphe	Xanthic Ferralsol	Tropeptic Haplorthox
5	Sol hydromorphe, peu humifère, à amphigley à nappe phréatique	Dystric Gleysol	Tropaquent

According to Vooren (1985) the vegetation type is tropical lowland evergreen seasonal forest in the UNESCO (1973) world classification. In the forest over 150 endemic wooden species occur. The biomass varies from 350 t ha^{-1} in the valleys to 560 t ha^{-1} on the higher parts of the slopes (Huttel 1977). In the Park a great variety of monkeys is found as well as chimpanzees. Other animal species include elephant, pigmy hippopotamus, panther and buffalo.

The indigenous people, Guéré and Oubi, traditionally clear the forest and cultivate the land for one or two crop cycles with upland rice as the main crop. Thereafter the fields are either left fallow for a period of at least 15 years, or cash crops such as coffee and cocoa are planted. Hunting and gathering of forest products are often important activities (Moreau and De Namur,1978; De Rouw,1979). The immigrants, like the Baoulé people, also cultivate food crops after forest clearance, but they always plant coffee or cocoa thereafter.

6.3 Soil nutrients

The soils in the Taï region are chemically poor. Fraters (1986) and Borst (1987) studied soil samples collected under primary forest from the transect presented in Fig. 6.2. Generally the nutrient concentrations of the soils in the positions 1 and 2 are higher than those of the profiles in the positions 3 and 4. It should be taken into account, however, that these data are always determined on the fine earth fraction (< 2 mm) only. In soils with high gravel (> 2 mm) contents the fertility is volumetrically diluted. The soils in the positions 1 and 2 have gravel mass contents of about 75 % by weight. If one corrects the data for this content, the differences in fertility between the soils disappear. Borst (1987) studied these soils in a glasshouse experiment, using the double-pot technique in which plants can take up nutrients from the soil and a nutrient solution simultaneously (Janssen,1974). He found that compared with a set of reference soils, the Taï soils were very low in phosphorus, low to medium in potassium, and medium in magnesium except the valley bottom soil which was low.

Jaffré (1985) studied the forest regrowth on fields abandoned after one crop of upland rice. The above-ground phytomass and its nutrient contents were measured in a rice field at harvest (time 0) and at sites with secondary regrowth at 14, 26, 48, 78 and 180 months. Fritsch (1982) found that the soils at these sites did not differ greatly and when they differed it was mainly in pH and exchangeable bases (Table 6.2). All the soil properties indicate that the chemical fertility of the soils is low.

Table 6.2 Analytical data of topsoil samples (0-20 cm) from sites with secondary vegetation of varying age (after Fritsch, 1982). Gravel content as percentage of whole soil, others of fine earth fraction only.

Age of vegetation months	Gravel (%)	pH-H_2O	Organic C (g kg^{-1})	Organic N	Total P (mg kg^{-1})	P-Dabin[a]	Exchangeable cations Ca (meq kg^{-1})	Mg	K	Na	CEC[b] (meq kg^{-1})
0	4	4.7	9.0	0.7	96	9.0	5.5	3.0	0.7	0.2	37.4
14	1	5.2	10.0	0.9	103	9.5	12.2	4.8	0.7	0.1	41.8
26	7	4.9	11.9	0.9	120	10.0	9.0	4.0	0.4	0.1	50.2
48	7	4.9	10.3	0.9	103	9.5	11.0	3.5	0.5	0.1	48.6
78	1	5.3	11.4	1.0	170	9.5	10.9	8.0	1.0	0.2	43.8
180	20	4.5	13.5	1.1	127	13.5	6.4	3.0	1.0	0.2	56.9
180.[c]			12.2	0.9	114	12.2	5.8	2.7	0.9	0.1	51.2

[a] modified P-Olsen extraction: 0.5 M $NaHCO_3$+0.5 M NH_4F, adjusted to pH 8.5

[b] CEC pH 7.0

[c] corrected data for the percentage gravel on the basis of specific gravity for gravel = 3, bulk density of fine earth = 1.3

Table 6.3 Total above-ground phytomass (t ha^{-1}) of secondary vegetation of varying age, and its contents of nitrogen, phosphorus and potassium (kg ha^{-1}) (Jaffré,1995).

Age of vegetation (months)	Phytomass	N	P	K
0	1.3	21.6	1.56	25.4
14	8.9	78.9	4.59	92.2
26	14.1	97.2	6.88	130.1
48	21.6	141.0	10.53	176.4
78	38.4	236.4	14.37	243.6
180	77.4	464.9	20.71	273.9

Table 6.4 Leaf mass (t ha^{-1}) of secondary vegetation of varying age, leaf concentration of nitrogen, phosphorus and potassium (g kg^{-1}) and the ratios of these concentrations (Jaffré,1985) compared with the nutrient concentrations and ratios in the leaves of primary forest trees on phosphorus-deficient soils in Surinam (Ohler,1980) and in leaves of a number of agricultural tree crops at optimum nutrition (various authors cited by De Geus,1973).

Age of vegetation (months)	Leaf mass	N	P	K	N/P	K/P	N/K
0	0.30	30.4	1.70	21.2	17.9	12.5	1.4
14	1.19	22.9	1.04	13.7	22.0	13.2	1.7
26	1.17	24.9	1.40	15.1	17.8	10.8	1.7
48	1.30	25.2	1.54	13.0	16.4	8.4	1.9
78	1.48	24.8	1.28	14.7	19.4	11.5	1.7
180	3.85	25.2	1.00	13.4	25.2	13.4	1.9
Mean		24.6	1.25	14.0	19.7	11.2	1.8
Suriname primary forest	16.6	13.1	0.77	9.9	17.0	12.9	1.3
Cacao		24	1.8	16	13.3	8.9	1.5
Citrus		27	1.8	17	15	9.4	1.6
Coconut		19	1.25	9	15.2	7.2	2.1
Oil palm		26	1.68	11	15.5	6.5	1.7
Pecan		27	2.1	8.5	13	4.0	3.2
Rubber (Malaysia)					15.1	5.9	2.6
Rubber (Vietnam)					14.4	3.9	3.9

The data in Table 6.3 show that the above-ground phytomass increased more or less linearly with an annual rate of about 5 t ha^{-1}. The rate of increase of the nutrient content of the phytomass was less than linear. This does not necessarily mean that the nutrient uptake rates decreased. The annual uptake of nutrients is equal to the sum of the annual net increase in total nutrient content of the phytomass plus the amount of nutrients returned in the litterfall and decaying roots. Since these returns increase with time, the net increase in nutrient content of the phytomass gradually decreases till it is zero at equilibrium. Then the annual uptake equals the amount of nutrients returned (Noij et al.,1988).

That the availability of nutrients probably did not decrease with time is reflected in the concentrations of nutrients in the leaves (Table 6.4). These were highest initially, but from 14 months onwards there was no consistent change with time.

The ratios of the nutrient concentrations in the leaves were calculated and compared with the ratios found in the leaves of primary forest in Surinam (Ohler,1980) and of a number of agricultural tree crops at optimum nutrition (De Geus,1973). Agricultural research in Suriname showed that after clearing, phosphorus was the major limiting nutrient for agricultural crops on these soils (Boxman and Janssen,1988). Because the N/P and K/P quotients are similar in Taï and Suriname, it is probable that phosphorus is also limiting in the Taï region. This is supported by the comparison with the data for agricultural tree crops in Table 6.4, which all have lower N/P and K/P quotients than the leaves in Taï. This indicates that in the Taï region phosphorus is the least available nutrient and therefore that the rate of forest regrowth may be limited by the availability of phosphorus. No systematic research on the availability of nutrients for agricultural crops had been carried out in the Taï area. Therefore field trials were started in 1987.

6.4 Field trials

6.4.1 Materials and methods

Fertilizer trials with upland rice (*Oryza sativa*, cultivar IDSA 6) were conducted on farms in six fields in an area from 20 km north to 10 km south of Taï in the growing season (March-August) of 1987. The relative position of the fields on the transect in Fig. 6.2 and some characteristics of the topsoil (0-20 cm) before the trials started are presented in Table 6.5. Some data on the vegetation before clearing are given in Table 6.6. The fields were cleared by slash and burn and as much unburnt wood as possible was removed by hand. This resulted in a 5 - 20 % increase in the net surface to be planted compared with the farmers' fields. The rainfall was recorded at or near each site.

The experimental design was a 2^4 factorial in three replicates, that is 48 plots per trial field. Each of the six fields consisted of three blocks, each of sixteen 5 * 4 m plots. The factors investigated were nitrogen, phosphorus, potassium and lime. Application rates were 0 and 50 kg N ha^{-1} as urea ($CO(NH_2)_2$, 46% N), 50 kg P ha^{-1} as triple superphosphate (mainly $Ca(H_2PO_4)_2.H_2O$, 20% P), 50 kg K ha^{-1} as potassium chloride (KCl, 50% K) and 400 kg $Ca(OH)_2$ ha^{-1}.

Table 6.5 The relative position of the trial fields on the transect of Fig. 6.2 and the analytical data of the topsoil (0-20 cm).

Trial field	Position on transect	Gravel	Clay	Silt	Sand	$pH\text{-}H_2O$	Organic C	Organic N	Total P	P-Dabin[a]	Exchangeable cations Ca	Mg	K	Na	CEC[b]
		(%)					(g kg^{-1})		(mg kg^{-1})		(meq kg^{-1})				(meq kg^{-1})
I	4-3	18.9	7.0	70.3	29	3.9	16.1	1.4	73	15	8.7	5.2	2.2	0.3	76.2
II	4	22.8	6.1	67.7	2	4.1	11.2	1.1	98	12	7.7	4.4	2.0	0.2	57.4
III	3-4	21.2	6.6	69.2	4	4.1	9.0	0.9	137	10	6.4	3.5	2.2	0.2	46.6
IV	3-4	14.9	7.5	74.1	20	4.9	11.6	1.3	129	8	15.3	7.3	2.6	0.2	48.9
V	5-4	21.4	8.5	67.3	1	4.4	10.5	1.2	134	25	8.2	6.0	2.3	0.3	56.5
VI	5-4	10.5	10.3	76.9	1	4.3	8.6	0.8	80	11	8.2	4.5	1.2	0.2	34.5

[a] modified P-Olsen extraction: 0.5 M $NaHCO_3$ + 0.5 M NH_4F, adjusted to pH 8.5
[b] pH 7.0

Lime was applied before sowing. The nitrogen and potassium applications were split into two equal parts and broadcast at 9 -14 days and 44 - 54 days after sowing, except at field IV where the applications were made at 30 and 62 days after sowing. Triple superphosphate was placed in holes of 1 cm diameter at a distance of about 7 cm from the plant and at a depth of less than 12 cm, at 9 - 14 days (at field IV, 30 days) after sowing.

The rice was sown in the traditional way with a planting stick or machete. The average density of planting holes was about 90,000 ha^{-1} with five to ten grains in each hole. The fields were fenced and when necessary, weeded by hand, leaving the weed remains as surface mulch. During the maturing stage the fields were guarded against bird damage. The rice was harvested after 114 - 131 days. The harvested plot size was 3 m x 4 m. The yield data refer to grains with a moisture content of 14%.

6.5 Results

Rice yields varied between sites and between treatments from 0.9 to 5 t ha^{-1} on individual plots. The variation in yield between replicates of the same treatment was large. The average yields of the main treatments varied from 1.5 to 4.0 t ha^{-1} (Table 6.6). Each yield figure is the average of 24 items unless indicated otherwise. For example "-N" means the average of all plots that did not receive nitrogen fertilizer irrespective of the application of other nutrients or lime. At all fields, except field V, there was a significant positive response to phosphorus but not to nitrogen, potassium and lime. At field III nitrogen application had a significant negative effect.

The yields on the control plots were about the same as those on the nitrogen-potassium-lime fertilized plots without phosphorus (with again field III as an exception), another indication that the effects of nitrogen, potassium and lime were very small.

It was observed that during the vegetative growth, the rice often responded to nitrogen, provided that phosphorus was also applied. This positive nitrogen-phosphorus interaction did not show up in the final grain yields.

Lowest yields were obtained on fields cleared of primary forest. This is in contrast to the generally accepted assumption that such sites produce more than sites cleared of secondary vegetation due to the higher nutrient content of the primary forest.

Table 6.6 Effects of fertilizer treatments on rice grain yields (t ha^{-1}). The values are the average yields of 24 experimental plots with (+) or without (-) the respective nutrients. Before clearing, the vegetation on fields I and II consisted of primary forest and on the other fields of secondary regrowth of the indicated age. The shade produced by remaining and surrounding trees is also indicated. (**, * significant difference at 0.01 and 0.05 level, respectively

Trial field	Age of regrowth (years)	Shade[a]	Yield								
			-N	+N	-P	+P	-K	+K	-L	+L	No fertilizer[b]
I		++	2.16	2.16	1.63	2.68**	2.13	2.18	2.06	2.26	1.49
II[c]		++	1.66	1.85	1.50	2.10*	1.85	1.66	1.68	1.82	1.55
III	34	+	2.54	2.17**	2.10	2.61**	2.42	2.30	2.36	2.35	2.57
IV	23	0	3.21	3.29	2.70	3.81**	3.22	3.29	3.33	3.17	2.50
V	23	0	3.76	3.99	3.87	3.89	3.75	4.00	3.88	3.88	3.11
VI	1	0	3.15	3.40	3.09	3.46*	3.37	3.16	3.32	3.23	3.14

[a] estimated shade: ++ = much; + = intermediate; 0 = none
[b] average yields of 16 experimental plots
[c] average yields of 3 experimental plots

6.6 Discussion

The results of the field trials confirm the conclusion drawn from the data on the secondary vegetation that phosphorus availability is a major growth-limiting factor.

The rice yields of the -P treatments were clearly related to the extractable phosphorus content at the fields IV, V and VI, but not elsewhere. At similar values of extractable phosphorus the yields of both the -P and +P treatments of fields I, II and III were considerably lower than those of fields IV, V and VI. Compared with the other fields, the following adverse conditions were present in fields I, II and III: a lower pH, more shade, a higher position on the slopes and they had been cleared of an older and probably heavier forest.

A possible negative effect of a low pH seems to contradict the absence of a significant effect of liming. However, the lime was broadcast and not worked into the soil and therefore had probably not yet affected the yields. This hypothesis is supported by the fact that the second crop (maize grown from August to December 1987) showed a positive response to lime, especially on the fields which originally had the lowest pH values.

The higher position on the slope may have negatively influenced the yield via the moisture supply.

The presence of shade might have caused a decrease in solar irradiation but, in view of the yield levels concerned, it is questionable whether this can have played an important role.

The influence of the former forest vegetation is through the quantity and quality of the slashed material and the presence of the remaining roots. The decomposition of woody material results in immobilization of inorganic phosphorus and nitrogen, thus lowering the amounts that are available for uptake by plants (Noij et al.,1988). With the present available knowledge it is difficult to say which factors were most important.

The yields of the plots without fertilizer application were higher than those obtained by farmers, which vary from about 0.8 to 1.0 ton per ha (A. De Rouw, personal communication). There are several reasons for this difference: the experimental plots were almost completely covered by the crop while on farmers' fields a considerable part may be occupied by fallen trees and branches; unlike farmers' plots the experimental plots were fenced (limiting the damage by rodents), regularly weeded and guarded against bird damage at maturing stage of the rice; the farmers' fields may be affected by shade. For a number of reasons some selected tree species are not felled or burnt during the clearing of primary and old secondary forest (De Rouw,1987). As well as trees left in the fields, the surrounding vegetation may produce shade, especially if the clearings are of a limited size. The effect of shade on farmers' fields may be stronger on areas cleared of primary forest where more solid trees occur than in secondary forest.

6.7 Conclusions

An important way of lowering the population pressure on the last remaining forest area in south-west Côte d'Ivoire is to increase the yields of agricultural crops. The results given in this paper indicate that in the Taï area phosphorus can be considered as the major limiting nutrient for the secondary vegetation as well as for upland rice. An application of 50 kg phosphorus to rice resulted in an average yield increase of 600 kg ha^{-1}. With the present prices of rice and phosphorus fertilizer in Côte d'Ivoire this is economically viable. However, further research with varying application rates of phosphorus and other nutrients will be necessary over a number of years to determine the most economic rates.

The results also indicate that the low yields per ha generally obtained in the local shifting cultivation systems are not only due to low soil fertility. Other reasons might be poor management, the fact that the net area planted is relatively small due to fallen trees and branches, and shading.

Chapter 7

The influence of soil P, pH and texture on the uptake of P from soil and fertilizer by upland rice

Key words: Côte d'Ivoire, soil P supply, P uptake, recovery of fertilizer-P, shifting cultivation, soil properties on volume basis, Taï National Park, upland rice

Abstract

In the Taï region of south-west Côte d'Ivoire, shifting cultivation is the standard agricultural practice. A growing population requires an increase in crop production, among others by removing soil fertility constraints. At six sites in 1987, and two sites in 1988, long-term field trials were started to study the supply of nutrients from the soil and the response of food crops to fertilizers. This paper describes the results for P during the first season after removal of the primary or secondary forest vegetation. P rates were 0 and 50 kg ha^{-1} in 1987, and 0, 12.5, 25 and 50 kg in 1988. The application of 50 kg P ha^{-1} resulted in a yield increase of 0.5 to 1.0 t ha^{-1} at five of the six sites in 1987. In 1988, a similar response could be obtained with lower rates of 12.5 or 25 kg P ha^{-1}. At all sites, P application increased P uptake significantly, but the recovery of fertilizer-P by the crop decreased with increasing P-application rates. The supply of P from the soil alone was best described by an equation including P-Dabin (a modified P-Olsen method), total P and pH. The recovery of fertilizer-P could best be described by equations including silt plus clay content, P-Dabin, and/or total P. Since some soils had a high gravel content, soil analytical data, referring to the fine earth (< 2 mm) fraction of the soils and expressed on a mass basis, were translated to values expressed on the basis of volume of total soil. This conversion substantially improved the relations between soil properties and P uptake or fertilizer-P recovery.

7.1 Introduction

Shifting cultivation can be defined as an agricultural system in which temporary clearings are cropped for fewer years than they are allowed to remain fallow (Sanchez,1976). After a cropping period the land is abandoned and will be recultivated after its fertility is judged to be restored, or sooner if other land is not available for use (Greenland,1974). In many parts of the world, increasing population demands an intensification of the extensive shifting cultivation system in order to produce enough food.

In the Taï region of Côte d'Ivoire, the main causes of decreasing yields are depletion of nutrients from the ashes of burnt fallow vegetation and weed infestation (Van Reuler and Janssen, 1993a,b). For the fallow vegetation as well as for the crops during the first season of a cultivation period P was the nutrient limiting yield most (Jaffré,1985; Van Reuler and Janssen,1989).

The present study deals with a search for appropriate soil properties to predict, for the first season of a cultivation period, (i) the soil supply of P to crops, and (ii) the recovery of fertilizer-P to crops. It forms part of a larger research on nutrient management in the shifting cultivation system of south-west Côte d'Ivoire. Only those soil properties were included in the study which belonged to the standard soil analysis package of the former ORSTOM laboratory at Adiopodoumé, Côte d'Ivoire (Gouzy,1973a). First, the gravel content (> 2 mm) and the fine-earth fraction (< 2 mm) were determined, and next, pH-KCl and pH-H_2O, organic C and N, CEC and exchangeable cations, P-Dabin, and total P were determined. P-Dabin is a modified P-Olsen method. It involves extraction with a mixture of 0.5 M $NaHCO_3$ and 0.5 M NH_4F (pH 8.2). In francophone West Africa it is a widely used method (Dabin,1967).

The recovery of applied fertilizer-P by the crop depends on properties of the fertilizer itself, on soil and crop characteristics, and on weather conditions.
Fertilizer-P may react with many soil constituents, among which oxides of iron and aluminum and clay minerals are the most important ones. As a result, fertilizer-P may become unavailable to plants for a shorter or longer time (phosphorus fixation). Sanchez and Uehara (1980) report that for soils with a relatively similar mineralogy soil texture is an important parameter of P fixation. According to Juo and Fox (1977), West African soils have a low to medium P-sorption capacity, when compared to Oxisols and Andepts from South America and Hawaii. They also concluded that P-sorption is related mainly to the extent of reactive surfaces of soil particles.

7.2 Materials and methods

7.2.1 Study area

The study area lies between the Taï National Park and the Cavally river which forms the boundary with Liberia (Fig. 2.1). This Park is the last extensive area (340,000 ha) of undisturbed forest in West Africa. Average annual rainfall amounts to 1885 mm with a standard deviation of 338 mm (Collinet et al.,1984).

The uplands of the Taï region are characterized by a catena which can be subdivided into crest, upper slope, middle slope, lower slope and valley bottom. The soils of the crest, upper and middle slope are well drained. The soils of the lower slope are moderately well and imperfectly drained, while the soils of the valley bottom are poorly drained.

The area where we conducted our fertilizer field trials ranges from 20 km north to 10 km south of the village of Taï. Six locations were selected in 1987 (Sites I - VI) and two in 1988 (Sites VII and VIII). In Table 7.1, the physiographic position of the experimental sites and the vegetation present before clearing are shown. In all following tables, the arrangement of the data is according to this physiographic position of the sites.

Table 7.1 Experimental sites in order of their position at the catena, and age of the vegetation before clearing.

Experimental site	Position at catena	Age of regrowth years
VII	crest - upper slope	25
IV	upper slope	23
I	upper - middle slope	*
III	middle slope	34
II	lower slope	*
VIII	lower slope	1
VI	lower slope - valley bottom	1
V	valley bottom - lower slope	23

* primary forest

7.2.2 Soil and plant analysis

Topsoil samples (0 - 20 cm) were collected before the start of the trials. They were analyzed according to the procedures described by Gouzy (1973a). Since in (very) gravelly soils the volume of soil plants can exploit for water and nutrients is smaller than in gravel-free soils, we considered it more appropriate to express the analytical data, with exception of pH, per unit of volume of total soil, i.e. the fine earth plus gravel, than per unit of mass of the fine earth (Van Reuler and Janssen,subm. b). For that purpose, the data per unit of mass of fine earth fraction must be multiplied by a factor MF, where

$$MF = [100 - \text{gravel content (mass \%)}] * \text{volumic mass (kg dm}^{-3}).$$

Volumic mass (VM) was calculated on the basis of the following relation established for the Taï region (Van Reuler and Janssen,subm. b)

VM (kg dm^{-3}) = 1.43 + 0.008 * gravel content (%); $R^2 = 0.74$

At harvest, plant samples were collected. The 1987 plant samples were analyzed by ORSTOM (Gouzy,1973b) and the 1988 samples in Wageningen (Houba et al.,1985).

7.2.3 Field trials

Table 7.2 presents some soil analytical data, being the mean values of 12 and 16 composite soil samples (at Sites I - V and VI - VIII, respectively). On the basis of the gravel data, the multiplication factors were established for the conversion of the other data into (m)g dm^{-3}.

The experimental sites were cleared by the respective farmers applying the traditional slash-and-burn practice. After the burn, unburnt wood was removed by hand as much as possible. As a result, the area that could be planted was 5-20% larger than on farmers' fields. In both years, the fields were fenced.

The test crop, upland rice (*Oryza sativa*, cultivar IDSA 6), was grown during the main growing season (March to August). It was sown in the traditional way with a planting stick or a machete. The average density of planting holes was 100,000 ha^{-1} with five to ten seeds per hole. When necessary, the fields were weeded by hand, leaving the weed remains as a surface mulch. During the maturing stage the fields were guarded against bird damage. The rice was harvested after approximately 120 days. The yield data refer to grains with a moisture content of 14%. The dimensions of the experimental units were 4 * 5 m, and of the net, harvested plots 3 * 4 m.

In 1987 (Sites I - VI), the experimental design was a 2^4 factorial in three replicates, with N, P, K and lime as factors. Application rates were 0 and 50 kg N ha^{-1} applied as urea (46% N), 0 and 50 kg P ha^{-1} applied as triple superphosphate (20% P), 0 and 50 kg K ha^{-1} applied as potassium chloride (50% K), and 0 and 400 kg $Ca(OH)_2$ ha^{-1}. Liming was practised before sowing. N and K fertilizers were broadcast, and applied in two equal portions, at 10 and 50 days after sowing. P was placed in holes of 1 cm diameter at a depth of less than 12 cm and at a distance of about 7 cm from the plants, at the time of the first application of N and K.

In 1988 (Sites VII and VIII), the experimental design was a factorial comprising 2 N * 4 P * 2 K levels, in three replicates. Method and time of application, fertilizer types, and sizes of experimental units were the same as in 1987. For N and K the application rates were again 0 and 50 kg ha^{-1}, whereas P was applied at four levels, 0, 12.5, 25 and 50 kg P ha^{-1}.

At harvest, grain samples were collected for chemical analysis, and also a limited number of panicle and straw samples. Plant samples were dried (24 h) at 70 ^{0}C, and grain samples also at 105 ^{0}C. Thereafter samples were ground and analyzed. P contents were calculated for grain, straw and panicles as the product of dry matter and P mass fractions and total P uptake was calculated by adding these contents. Also the relationships between P in grains and total P uptake were established. This relationship was used to calculate total P uptake for the plots of which only grain samples had been analyzed. The recovery fraction of fertilizer-P was calculated as the ratio of fertilizer-P absorbed and fertilizer-P applied. The value for fertilizer-P absorbed was found as the difference in uptake between fertilized and non-fertilized plots. Efficiency of utilization (EU) was calculated as the ratio of grain yield to total uptake.

Table 7.2 Analytical data of the topsoil (0-20 cm) of the experimental sites. Gravel content is expressed as fraction of the total soil, other chemical properties as a fraction of the fine earth (< 2 mm).

	Experimental site							
	VII	IV	I	III	II	VIII	VI	V
Gravel (%)	14	20	32	4	2	1	1	1
Sand	75.6	74.1	70.9	69.2	67.8	81.3	76.9	67.3
Silt	5.9	7.5	7.2	6.6	6.1	6.1	10.3	8.1
Clay	17.9	14.9	18.3	21.2	22.8	11.8	10.5	21.4
pH-H_2O	6.1	4.9	4.0	4.1	4.0	5.6	4.3	4.4
pH-KCl	5.5	4.5	3.8	4.0	3.9	5.0	4.0	4.1
Org. C (g kg^{-1})	12.9	11.5	16.1	8.9	11.4	9.8	8.6	10.2
Org. N	1.3	1.2	1.4	0.9	1.2	0.9	0.8	1.2
Total P (mg kg^{-1})	161	129	72	138	91	113	80	134
P-Dabin	6.0	13.1	16.7	10.1	10.4	6.8	17.1	22.6
CEC (mmol(+) kg^{-1})	54.2	48.9	75.7	46.6	57.0	40.5	34.4	56.5
Exch. cations								
Ca (mmol(+) kg^{-1})	16.7	15.3	8.7	6.4	7.0	10.0	8.1	8.2
Mg	7.1	7.3	5.3	3.3	4.0	4.8	4.4	5.7
K	2.5	2.6	2.2	2.2	1.4	1.3	1.1	2.3

Table 7.3 Grain yield (t ha^{-1}) and coefficient of variation (%) in grain yield of upland rice of some selected fertilizer treatments.

		Experimental site							
Treatment		VII	IV	I	III	II	VIII	VI	V
Control		2.55	2.50	1.48	2.57	1.55	2.56	3.14	3.11
P0	N0	2.82	2.61	1.63	2.35	1.56	2.43	2.99	3.82
	N1	3.04	2.79	1.66	2.09	1.75	2.81	3.19	3.91
	K0	2.64	2.71	1.71	2.32	1.56	2.79	3.25	3.67
	K1	3.25	2.69	1.57	2.15	1.78	2.45	2.93	4.06
	L0		2.79	1.64	2.39	1.84		3.14	3.71
	L1		2.60	1.65	2.10	1.47		3.04	4.03
P1	N0	3.39					2.55		
	N1	3.60					3.56		
	K0	3.32					3.12		
	K1	3.68					2.99		
P2	N0	3.02					2.98		
	N1	3.68					3.60		
	K0	3.29					3.16		
	K1	3.41					3.43		
P3	N0	3.08	3.82	2.67	2.71	1.97	3.12	3.32	3.70
	N1	3.29	3.79	2.63	2.46	2.09	3.86	3.61	4.07
	K0	3.01	3.73	2.48	2.60	2.17	3.55	3.49	3.83
	K1	3.37	3.88	2.83	2.57	1.88	3.44	3.43	3.94
	L0		3.87	2.44	2.57	1.77		3.50	4.04
	L1		3.74	2.88	2.60	2.28		3.42	3.73
C.V.		14.9	16.3	34.9	15.8	25.2	11.9	15.0	18.6

7.3 Results

7.3.1 Yield

Rice yields on individual experimental units varied from 0.7 to 5 t ha^{-1}. Table 7.3 presents the average grain yields of the control and the various P treatments in relation to the application of N, K and lime.

At all sites, except the imperfectly drained site V, a significant, positive response to P was found. At the other 1987 sites, the response to 50 kg P ha^{-1} varied from 0.4 to 1.1 t ha^{-1}. At the 1988 sites (VII and VIII), an application of 12.5 kg P ha^{-1} resulted in a yield increase of 0.5 and 0.4 t ha^{-1}, respectively. Yields increased further when 25 or 50 kg P ha^{-1} was applied at Site VIII, but not at Site VII.

A significant, positive response to N was found only at Site VIII, whereas at Site III the response to N was significantly negative. The other treatments had no significant effects on yields.

The coefficient of variation (C.V.) in yield was high, especially on the sites cleared of primary forest (I and II) (Table 7.3). The harvest index (H.I.), calculated as the ratio of grain mass dried at 70 °C to total above-ground dry mass, varied a little among sites. Site V had the lowest value (0.38), and Site VI the highest (0.46). The average value of all plots was 0.42. H.I. was unaffected by fertilizer treatments.

Table 7.4 P uptake (kg ha^{-1}) by above-ground plant parts and coefficient of variation (%) in P uptake of upland rice of some selected fertilizer treatments.

		Experimental site							
Treatment		VII	IV	I	III	II	VIII	VI	V
Control		4.89	3.93	2.14	4.20	2.53	4.91	5.16	8.51
P0	N0	5.38	4.28	2.44	4.18	2.60	4.00	5.64	10.14
	N1	5.48	4.51	2.54	3.49	2.77	4.84	5.48	8.74
	K0	5.01	4.34	2.63	4.07	2.53	4.80	5.79	8.92
	K1	5.83	4.45	2.14	3.66	2.89	4.04	5.33	9.97
	L0		4.54	2.35	4.02	3.10		5.43	9.11
	L1		4.25	2.43	3.73	2.27		5.69	9.77
P1	N0	6.32					5.45		
	N1	6.20					5.72		
	K0	5.91					6.20		
	K1	6.69					4.97		
P2	N0	6.95					6.05		
	N1	8.17					6.94		
	K0	7.64					5.39		
	K1	7.48					7.49		
P3	N0	7.29	8.10	5.08	5.69	4.11	5.58	8.01	10.31
	N1	8.05	7.95	5.11	5.25	4.43	8.39	7.64	10.84
	K0	6.61	7.85	4.74	5.54	4.71	7.51	7.83	10.35
	K1	8.73	8.20	5.48	5.40	3.83	6.46	7.81	10.85
	L0		8.27	4.77	5.46	3.90		7.87	10.97
	L1		7.78	5.45	5.48	4.65		7.77	10.17
C.V.		21.8	20.7	39.1	16.6	29.5	24.1	15.5	16.1

7.3.2 P uptake

In Table 7.4, the average P uptake of the control and the various P treatments in relation to the application of N, K and lime are presented. P uptake of P0-treatments varied from 1.1 to 13.0 kg P ha^{-1} on individual experimental units. The highest uptake was found at Site V located on the lower part of the catena. At all sites, P application significantly increased P uptake (Table 7.4). N application resulted in a significant increase in P uptake at Site VIII, and in a significant decrease at Site III. The other treatments had no significant effects on P uptake.

The coefficient of variation (C.V.) in P uptake was even higher than that in yield, again with the highest values on the sites cleared of primary forest (Sites I and II) (Table 7.4).

At Sites VII and VIII P uptake was higher at P3 (50 kg P ha^{-1}) than at lower P rates. The recovery fractions of fertilizer-P, as calculated from the data of Table 7.4, were higher at P1 and P2 than at P3. The maximum value was 9.4% for P1 at Site VIII. The recovery fractions for P3 varied from 0.3 % at Site V to 6.9% at Site IV.

7.4 Discussion

The control yields were much higher than the 0.8 to 1.0 t ha^{-1} which are obtained by local farmers (De Rouw,1991a). The main reasons for this difference are the better management at the experimental fields, and the larger net area planted to rice, as a consequence of the removal of unburnt wood (Van Reuler and Janssen,1989). The highest control yields were obtained at Sites V and VI, both located on the lower slope.

The values for the coefficients of variation of both grain yield and P uptake seem to increase with the age of the vegetation that was cleared. One of the reasons may be the heterogeneous ash distribution resulting from poor burning of the slashed big trees of old regrowth and primary forest due to incomplete drying.

On the well drained soils of the crest, upper and middle slope, P obviously was the main limiting nutrient (Table 7.3). Apart from the yield responses to P application, this is reflected in the high values of efficiency of utilization. In Fig. 7.1 the relation between grain yield and P uptake is presented. For uptake, the higher values of the average uptakes of the N1P0 and N0P0 treatments were used. These values were considered the best possible estimates of the potential P supply of the soils. At all sites, except Site V, approximately 600 kg of grain are produced per kg absorbed P. This is the maximum value found by Van Keulen and Van Heemst (1982) and Janssen et al. (1990), and it indicates that P is the main yield limiting factor. At Site V the EU values for N and K are 37 and 42, respectively. Maximum values reported are 70 for N and 100-120 for K (Van Keulen and Van Heemst,1982; Janssen et al.,1990). Therefore it can be concluded that neither N nor K did limit the yield at Site V. The maximum yield obtained at experimental stations for the used rice cultivar is 5.2 t ha^{-1}, and the yields at Site V were rather close to this value (Poisson and Doumbia,1987).

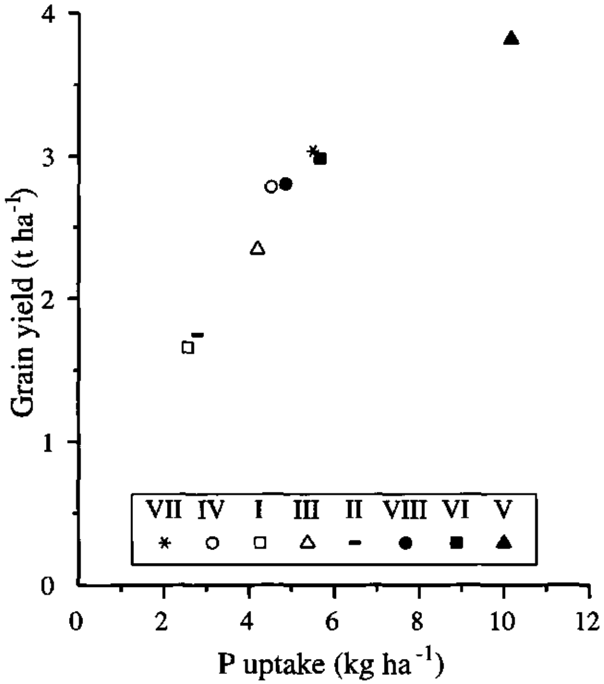


Fig. 7.1 Relation between grain yield (t ha^{-1}) and P uptake (kg ha^{-1}) at the various sites.

In Fig. 7.2, the uptake of P from the soil alone has been plotted against P-Dabin and total P, respectively. For uptake, again the higher values of the average uptakes of the N1P0 and N0P0 treatments were used. Fig. 7.2 shows a fairly good relationship for five sites. Two sites, both with a relatively high pH (Sites VII and VIII) have a relatively high P uptake, and Site I, with a low pH (I and II) has a relatively low P uptake. There is a clear relation between P uptake and total P for six sites. Sites V and VI have a higher P uptake. These sites differ in two aspects from the other sites, namely (i) their values for P-Dabin are above 17 mg kg^{-1}, and (ii) they are situated on the lower slope, and hence they are not perfectly drained (imperfectly for Site V and moderately well for Site VI). From these observations it may be concluded that besides P-Dabin, which is the index for available P, at least total P and pH affect P uptake, and perhaps drainage conditions too. Unfortunately, we had not more than eight experimental sites, and as the mentioned properties are partly correlated (Table 7.5), it is not well possible to establish the influence of each individual factor in a satisfactory way.

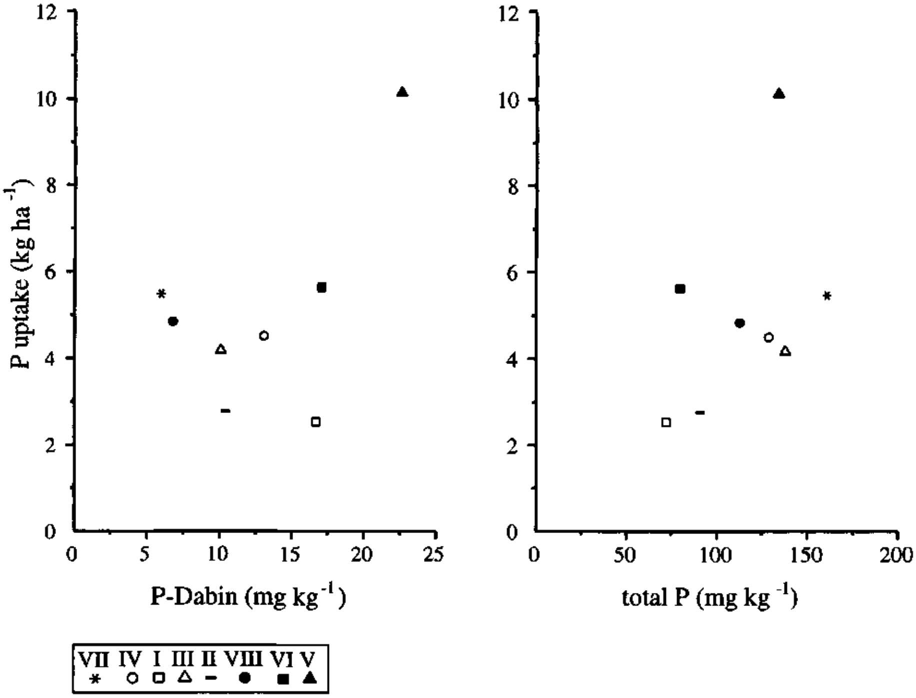


Fig. 7.2 Relation between P uptake (kg ha^{-1}) and P-Dabin content (mg kg^{-1}) and total P content (mg kg^{-1}) at the various sites.

Table 7.5 Correlation matrix for soil properties related to soil P supply and/or recovery of fertilizer-P.

	P-Dabin	Total P	pH	Silt	Clay	Silt + Clay	Drainage class
P-Dabin	1.000						
Total P	-0.344	1.000					
pH	-0.602	0.615	1.000				
Silt	0.722**	-0.407	-0.385	1.000			
Clay	0.107	0.233	-0.394	-0.454	1.000		
Silt + Clay	0.375	0.114	-0.575	-0.149	0.949**	1.000	
Drainage class[a]	0.762**	-0.147	-0.253	0.833**	-0.189	0.086	1.000

[a] Sites VII,IV, I, III, II and VIII class 1; Sites VI and V class 2

** $P < 0.05$; *** $P < 0.001$

Multiple linear regression yielded the equations presented in Table 7.6. The coefficient of determination is higher when soil data are expressed on a volume basis than on the basis of mass of fine earth. The positive effect of the pH on P uptake seems to contradict the fact that liming had no significant effect on P uptake, but several reasons can be put forward to explain why these findings are not conflicting. Soils differing in pH by nature are different in more aspects than pH only, because soil pH is the result of a large number of soil properties and processes. These do not or at least not immediately change upon liming. Other reasons for the lack of a liming effect in the present trials may be that not more than 400 kg $Ca(OH)_2$ ha^{-1} were applied and that the lime was not worked into the soil.

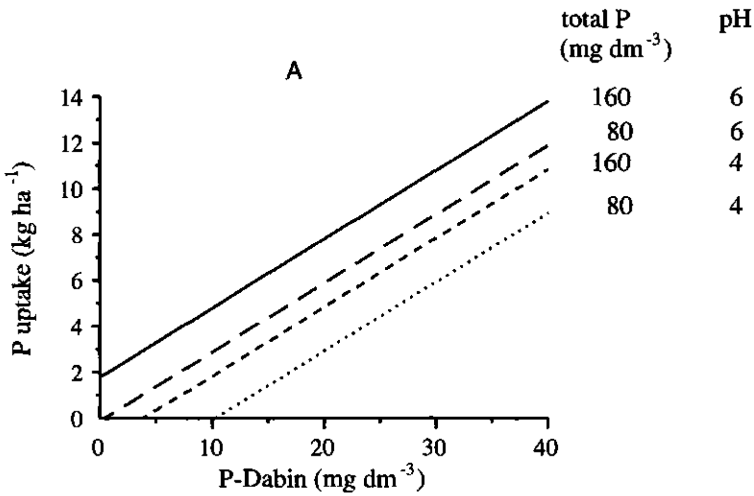
Table 7.6 Regression equations for P uptake and recovery of fertilizer-P.

A. Soil properties expressed per unit of mass of the fine-earth fraction			
UP	= 1.097 + 0.034*TPmfe	R^2 = 0.20	(1)
UP	= -2.236 + 0.216*PDmfe	R^2 = 0.27	(2)
UP	= -5.281 + 0.319*PDmfe + 0.054*TPmfe	R^2 = 0.72	(3)
UP	= -10.893 + 0.403*PDmfe + 0.038*TPmfe + 1.360*pH	R^2 = 0.81	(4)
RFP	= 15.611 - 0.454*SCmfe	R^2 = 0.71	(5)
RFP	= 15.627 - 0.395*SCmfe - 0.113*PDmfe	R^2 = 0.79	(6)
RFP	= 16.835 - 0.368*SCmfe - 0.145*PDmfe - 0.013*TPmfe	R^2 = 0.81	(7)
RFP	= 17.344 - 0.377*SCmfe - 0.147*PDmfe - 0.012*TPmfe - 0.086*pH	R^2 = 0.81	(8)
B. Soil properties expressed per unit of volume of the total soil			
UP	= 0.651 + 0.028*TPvs	R^2 = 0.28	(9)
UP	= 1.755 + 0.188*PDvs	R^2 = 0.40	(10)
UP	= -4.711 + 0.232*PDvs + 0.037*TPvs	R^2 = 0.85	(11)
UP	= -10.941 + 0.301*PDvs + 0.024*TPvs + 1.483*pH	R^2 = 0.97	(12)
RFP	= 14.952 - 0.032*SCvs	R^2 = 0.83	(13)
RFP	= 15.071 - 0.027*SCvs - 0.095*PDvs	R^2 = 0.93	(14)
RFP	= 15.461 - 0.026*SCvs - 0.105*PDvs - 0.004*TPvs	R^2 = 0.94	(15)
RFP	= 17.601 - 0.028*SCvs - 0.112*PDvs - 0.374*pH	R^2 = 0.94	(16)
RFP	= -18.020 - 0.029*SCvs - 0.112*PDvs - 0.456*pH + 0.002*TPvs	R^2 = 0.94	(17)

UP = P uptake in kg ha^{-1}
RFP = recovery of fertilizer-P in %
PDmfe = P-Dabin in mg P kg^{-1} of fine earth
TPmfe = total P in mg P kg^{-1} of fine earth
SCmfe = silt + clay in % of fine earth
PDvs = P-Dabin in mg P dm^{-3} of total soil
TPvs = total P in mg P dm^{-3} of total soil
SCvs = silt + clay in g dm^{-3} of total soil

No clear relation was found between the recovery fraction of applied fertilizer-P and soil P, either P-Dabin or total P. The content of fine soil particles proved of much more importance, in accordance with Juo and Fox (1977). Table 7.6 presents the results of multiple linear regression analysis, including or not including soil P characteristics. Inclusion of pH did not further increase the correlation coefficient. Again the correlation coefficients are higher when soil data are expressed on a volume basis than when expressed on the basis of mass of fine earth.

The found relations are schematically shown in Fig. 7.3. Fig. 7.3A presents the relations between P uptake and P-Dabin for various values of total P and pH, and Fig. 7.3B those between fertilizer-P recovery and silt-plus-clay content for various values of P-Dabin.



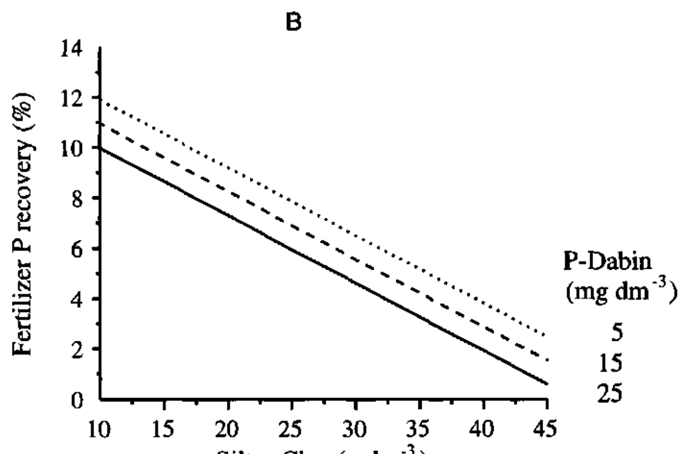


Fig. 7.3 A. Relation between P uptake and P-Dabin content as influenced by total P and pH according to equation 12 (Table 7.6).
B. Relation between the recovery of fertilizer-P and silt-plus-clay content as influenced by the P-Dabin content according to equation 14 (Table 7.6).

7.5 Conclusions

This study confirmed the findings of earlier studies that P is the main limiting nutrient during the first cropping season in the shifting cultivation system of the Taï area.

The supply of P by the soils is dependent on P-Dabin (indicating soil available P), total P, pH, and possibly also on the drainage conditions (position on the slope). The recovery of fertilizer-P is related mainly to silt-plus-clay content, and to some extent also to soil P.

In the Taï region, where gravel makes up a substantial part of the soil material, the values of soil properties should be expressed on a volume basis rather than on a mass basis.

Part IV

Nutrient dynamics in space and time

Chapter 8

The relations between soils, nutrient uptakes and yields of upland rice along a catena during the first season after clearing of the fallow vegetation

Key words: apparent fertilizer recovery, catena, Côte d'Ivoire, chemical soil fertility, efficiency of nutrient utilization, harvest index, physical soil fertility, shifting cultivation, potential soil nutrient supply, soil properties on a volume basis, upland rice

Abstract

The growing population in the Taï region of south-west Côte d'Ivoire requires a higher food production than is attained in the present shifting cultivation system. A higher production can be achieved by increasing crop yields per ha and/or by extending the cultivation period. The success of such practices may depend on soil characteristics and on the position of the site in a representative catena of the undulating and rolling uplands of Taï. Therefore, field trials were established at five sites along such a catena. The trials were conducted over a period of five seasons after clearing. This paper deals with the results of the first season. The soils on the upper and middle slope (Sites A, B and C) were very gravelly and well drained. The non-gravelly soils of the lower slope, Sites D and E, were moderately well drained and imperfectly drained, respectively. Treatments, indicated by control, PK, NK, and NP, were 0-0-0, 0-25-50, 50-0-50 and 50-25-0 (expressed in kg N-P-K ha^{-1}), respectively. The PK, NK and NP treatments were intended to estimate the maximum supplies from the soils of N, P and K, respectively. The experimental crop species was upland rice. Yields and uptakes of P and K increased upon application of P, at all sites except Site E where only the P uptake increased. Yield responses varied from 0.76 to 1.0 t ha^{-1}. N uptake was significantly increased by fertilizer P and, at Sites A, B and E, also by fertilizer N. Application of K had no effects. The apparent recovery fraction of fertilizer P varied from 7.6 to 9.9 %, without significant differences amongst the sites. Soils did not significantly differ in N and K supplies. Imperfectly drained Site E supplied significantly more P than the other, well and moderately drained, sites. When soil properties were expressed on a volume basis rather than on a fine-earth mass basis, relations between soil nutrient supply and soil properties improved substantially. Site E had the highest chemical fertility as indicated by the yields of the '-P' treatments, while Site A had the highest physical fertility as indicated by the yields of the '+P' treatments. Site D was the

lowest in chemical as well as in physical fertility. At this site the efficiency of utilization of absorbed P and the harvest index were significantly lower than at the other four sites. A factor other than N, P or K, probably moisture stress, was considered the cause of the poor growth.

8.1 Introduction

For approximately 250 million people shifting cultivation is the major land-use system (Robison and McKean,1992). It is primarily found in sparsely populated areas where power implements and fertilizers are not available (Sanchez,1976). In the humid tropics the forest vegetation is slashed, dried and burnt. Thereafter crops are planted. The soils in most shifting cultivation areas have a low inherent chemical fertility. Burning the slashed vegetation supplies nutrients to crops to be grown. During successive cropping yields decline, and that is the reason why farmers shift to other fields (Nye and Greenland,1960). Fields are abandoned when farmers expect the yield of a subsequent crop to be less than 50% of the first crop after clearing (Sanchez,1976; De Rouw,1991). In many areas an increased population forces farmers to intensify the extensive shifting cultivation system by growing more than one crop per year and/or extending the cultivation period. For the development of a more intensive farming system, data on soil fertility and its dynamics are essential.

In the Taï region, south-west Côte d'Ivoire, shifting cultivation is the main farming system. Since the mid 1960s the population density has increased enormously through immigration. Moreover, land available for agricultural purposes has decreased because of the establishment in 1972 of the Taï National Park (340,000 ha). The consequence is that more food must be produced on less land, and this can be achieved only by intensification.

In the traditional shifting cultivation system of the Taï region upland rice is the main food crop. One crop per year is grown. Yields amount to 1 t ha^{-1} and after one or two years either fields are abandoned or tree crops (coffee, cacao or rubber) are planted. The reason for abandoning is yield decline caused by the combined effects of ash depletion and weed infestation (Van Reuler and Janssen,1993b). On the well drained soils, P proved the main yield-limiting nutrient in the first season after clearing. However, inherent soil fertility and response to fertilizer differed greatly among soil types (Van Reuler and Janssen,1989; subm. a). The average annual rainfall in the Taï region amounts to 1885 mm with a standard deviation of 338 mm (Collinet et al.,1984). The rainfall distribution enables cultivation of two crops per year.

The landscape consists of uplands with an undulating to rolling relief. The soils are developed on metamorphic rocks, mainly migmatite (Development Resources Corporation,1967; Fritsch,1980; Van Kekem,1986 and De Rouw et al.,1990). They can be characterized by a so-called catena, which is defined as a sequence of soils of about the same age, but having different characteristics due to variations in relief and drainage (Soil Science Society of America,1973). Such a catena offers a continuum of edaphic and hydromorphic conditions (Moormann et al.,1977; Veldkamp,1979). Five sub-elements can be distinguished, viz. crest, upper slope, middle slope, lower slope and valley bottom. The physio-hydrographic position determines the source of water for crops grown: pluvial for the crest, upper and middle slope, phreatic for the lower slope and fluxial for the valley bottom (Moormann and Van Breemen,1978; Andriesse and Fresco,1991).

On a representative catena, an experiment was established with the objective to study soil fertility dynamics of the different soil types along the slope. These trials were continued during five seasons, during which crop yield, nutrient uptake, response to fertilizer application and changes in soil properties were monitored. In this paper the results of the first season after clearing the fallow vegetation are presented.

8.2 Materials and methods

The study area was located about 10 km south of the village of Taï (Fig. 2.1). At 5 locations along a representative catena field trials were established. The fields were cleared of one-year-old secondary vegetation, which was slashed and removed. The experimental design was a half-replicate of a 2^3 factorial in 4 repetitions. The factors investigated were N, P and K. Application rates were 0 and 50 kg N ha^{-1} as urea (46% N), 0 and 25 kg P ha^{-1} as triple superphosphate (20% P), 0 and 50 kg K ha^{-1} as muriate of potash (50% K). The treatments included were 0-0-0 (control), 0-25-50 (PK), 50-0-50 (NK) and 50-25-0 (NP). The N and K applications were split into two equal parts and broadcast at 16 and 50 days after sowing. P was placed in holes of 1 cm diameter at a distance of about 7 cm from the plants and at a depth of less than 12 cm, at 16 days after sowing. The PK, NK and NP treatments were intended to estimate the maximum N, P and K supplies from the soils, respectively.

The size of the experimental units was 5*4 m. Before the start of the trial four composite soil samples (0-20 cm) were collected at each site. In the centre of each site a profile pit was studied and sampled.

Upland rice (*Oryza sativa*, cultivar IDSA 6) was sown in the traditional way with planting stick or machete. Average density of plant holes was 100,000 ha^{-1} with five to ten grains per hole. Fields were fenced and weeded twice by hand, with weeds left in the field as surface mulch. During the maturing stage rice fields were guarded against bird damage. The rice was harvested after approximately 120 days. Harvested plot size was 3*4 m. Yield data refer to grains with a moisture content of 14%. At harvest grain samples of all treatments and, to a limited extent straw- and panicle samples were collected for analysis. All above-ground crop residues were removed from the plots.

8.2.1 Laboratory analysis

Topsoil samples (0-20 cm) were air-dried, next the gravel content (> 2 mm) was determined followed by analysis of the fine earth (< 2 mm), according to Walinga et al. (1989). In (very) gravelly soils, the volume to be exploited by roots for water and nutrients absorption is limited. Hence it is more appropriate to express the analytical data per unit of volume than on the basis of fine-earth mass. For that purpose the analytical data of the fine earth were multiplied by:
[100 - gravel content (%)] * volumic mass
The volumic mass (VM) was calculated according to:

$$VM = 1.43 + 0.008 * \text{gravel (\%)} - R^2 = 0.74.$$

This relation was established with data from this catena.

Plant samples were dried at 70 °C for 24 h, ground and analyzed as described in Van Reuler and Janssen (1993a). Grain samples were also dried at 105 °C, to allow calculation of grain yields at 14% moisture content.

8.2.2 Interpretation of yield and nutrient uptake data

In this study the following concepts are used: harvest index, apparent recovery fraction of applied nutrients and efficiency of utilization of absorbed nutrients.

The harvest index is defined as the ratio of grain mass to total above-ground dry mass. In this paper dry mass means dried at 70 °C. Its value is crop- and cultivar-specific, but depends also on the prevailing growing conditions.

The apparent fertilizer recovery fraction is the fraction of the quantity of a nutrient applied by fertilizer that is absorbed by the crop.

The efficiency of utilization is defined as grain yield per unit of nutrient absorbed in above-ground plant parts. The EU is an indication of the availability of the particular nutrient in relation to other growth factors. According to Van Keulen and Van Heemst (1982), grain yield of small cereals maximally increases by 70 kg per kg N absorbed, by 600 kg per kg P and by 55 to 100 kg per kg K absorbed. Janssen et al. (1990) report for maize maximum values of 70 kg per kg N, 600 per kg P and 120 kg per kg K absorbed. Minimum values, indicating accumulation in the crop are 30, 200 and 30 kg grain per kg N, P and K, respectively.

8.2.3 Statistical analysis

For statistical analysis SAS software was used (SAS Institute Inc.,1989). Due to the experimental design the N, P and K main treatments are confounded with the PK, NK and NP interactions, respectively. Differences between sites were tested at a probability level of 0.01, if not stated otherwise.

8.3 Results

8.3.1 Soils

A brief description of the soils including the classification according to FAO (1988) and Soil Survey Staff (1990) and properties of the topsoil are presented in Figure 8.1, and in Tables 8.1 and 8.2.

The soils of the upper and middle slope are well drained, while soils of the lower slope are moderately well drained. The fringe of the valley bottom is imperfectly drained and the soils of the valley bottom are poorly drained. The landscape was formed by dissection of an old peneplain. The soils of the upper and middle slope (Sites A, B and C) are very gravelly. The gravels are probably the remnants of an ironstone crust belonging to the peneplain. These remnants were partly left in situ and partly transported down the slope. In the subsoil of the profile C plinthite occurs and in the subsoil of Site D hardened plinthite is found. The soils are strongly weathered as indicated by the low CEC of the fine earth fraction. Site D has the lowest pH and lowest content of exchangeable bases. The Sites D and E have the lowest total P content. Site E has the highest available P content. Site C has the highest CEC and the highest organic C content. When data are expressed on a volume basis, the chemical fertility of the gravelly soils is diluted.

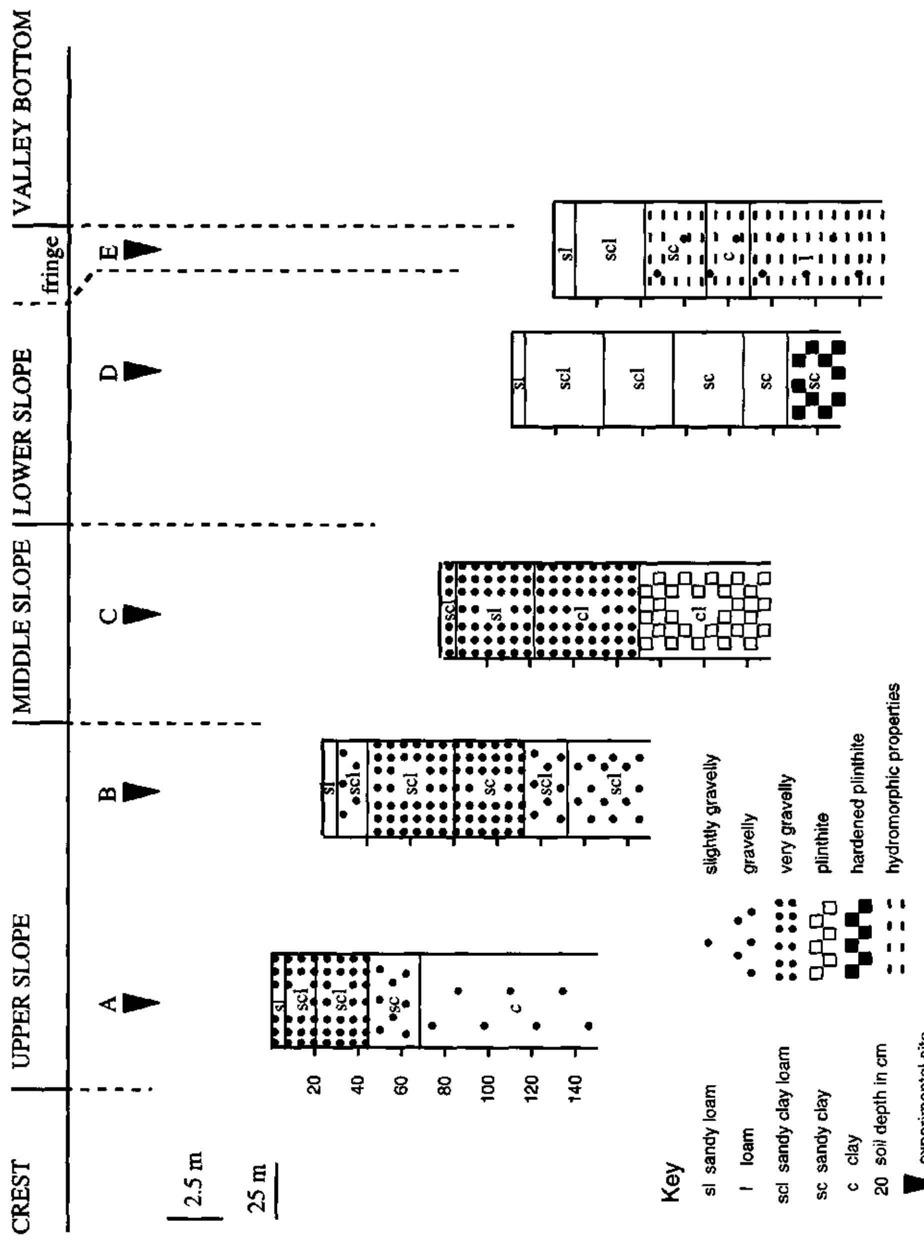


Fig. 8.1 Location of the experimental sites on the catena representative of the Taï region.

Table 8.1 Brief description of the 5 sites along the catena

Profile	Physiographic position	Brief description	Classification FAO (1988)/ Soil Survey Staff (1990)
A	Crest-Upper slope	Upper 75 cm is very gravelly. Brown to dark brown sandy loam topsoil changing into yellowish red clay loam and from 50 cm onwards into red clay.	Ferric Acrisol/ loamy-skeletal Typic Kandiudult
B	Upper slope	Upper 5 cm is non-gravelly brown to dark brown loam loam. Up to 90 cm the subsoil is very gravelly. The colour changes from strong brown to yellowish brown and the texture from clay loam into clay loam.	Ferric Acrisol/ loamy-skeletal Typic Kandiudult
C	Middle slope	Upper 70 cm is very gravelly. Dark brown sandy clay loam topsoil changes into yellowish red sandy clay. Below 70 cm plinthite is found.	Plinthic Ferralsol/ clayey-skeletal Plinthic Kandiudult
D	Lower slope	Brown to dark brown non-gravelly loamy sand topsoil over yellowish red sandy loam changing into a brownish yellow sandy clay loam. Below 70 cm plinthite is found.	Plinthic Ferralsol/ loamy silcious Plinthic Hapludox
E	Lower slope-Valley bottom	Brown non-gravelly sandy clay topsoil changing via very pale brown sandy clay into white sandy clay subsoil. Mottling starts at 30 cm.	Dystric Gleysol/ loamy Aeric Tropaquept

Table 8.2 Gravel content of the topsoils (0-20 cm) of the different sites and physical and chemical data expressed per unit mass of fine earth and per unit of volume of total soil.

	Site				
	A	B	C	D	E
Gravel (%)	64.8	32.7	62.7	0.8	0.3
Fine earth, mass basis					
sand (%)	68.3	71.5	60.5	73.5	72.5
silt	14.8	9.0	10.3	9.0	9.0
clay	12.8	17.3	24.8	16.3	17.3
pH-H_2O	5.9	5.7	5.4	5.0	5.8
pH-KCL	4.6	4.6	4.3	4.1	4.8
Org C (g kg^{-1})	15.8	14.8	22.3	14.0	13.3
Org N	1.2	1.1	1.5	0.9	1.1
Total P (mg kg^{-1})	211	134	185	84	95
P-Dabin (mg kg^{-1})	4.5	7.0	6.3	6.7	6.6
P-Bray	2.4	2.6	2.9	4.6	5.6
P-Olsen	1.4	1.4	2.1	2.2	3.1
P-$CaCl_2$	0.06	0.07	0.06	0.04	0.11
CEC[a] (mmol(+) kg^{-1})	37.8	38.3	61.3	34.8	33.8
Extractable cations[b]					
Mg (mmol(+) kg^{-1})	2.8	2.7	3.8	1.5	2.5
K	1.7	1.6	2.1	0.8	1.5
Total soil volume basis					
Org C (g dm^{-3})	10.7	16.7	16.0	19.9	18.9
Org N	0.8	1.2	1.1	1.3	1.5
Total P (mg dm^{-3})	144	152	133	119	135
P-Dabin (mg dm^{-3})	3.0	7.9	4.5	9.5	9.4
P-Bray	1.6	2.9	2.1	6.5	8.0
P-Olsen	0.9	1.5	1.5	3.1	4.4
P-$CaCl_2$	0.04	0.07	0.04	0.05	0.16
CEC[a] (mmol(+) dm^{-3})	25.6	43.4	44.1	49.5	48.2
Extractable cations[b]					
Mg (mmol(+) dm^{-3})	2.0	3.0	2.7	2.1	4.4
K	1.1	1.8	1.6	1.2	2.2

[a] pH 7
[b] $CaCl_2$ extraction

Micromorphological studies showed features of clay illuviation in the profiles A, B and D (A. Van Der Velden, pers. comm.). The Sites A and B were classified as Ferric Acrisols/Typic Kandiudults according to FAO (1988)/Soil Survey Staff (1990), respectively. The subsoils of the profiles C and D fulfil the requirements of a ferralic horizon and are therefore classified as Plinthic Ferralsols (FAO,1988). Profile D meets the requirements of an oxic horizon in Soil Taxonomy, in contrast to profile C (Soil Survey Staff,1990). Therefore, Site C is classified as a Plinthic Kandiudult and Site D as a Plinthic Hapludox. Due to the mottling within 50 cm depth Site E was classified as Dystric Gleysol/Oxic Dystropept.

8.3.2 Yield and nutrient uptake

Fig. 8.2 shows the yields and the uptakes of N, P and K, averaged per treatment-site combination. Control yields varied from 0.85 t ha^{-1} at Site D to 1.81 t ha^{-1} at Site E. N and K applications did not result in significant yield responses. At Site E, the response to P was 0.21 t ha^{-1}, which was not significant. At the other sites the yield responses to P varied from 0.76 (Site C) to 1.0 t ha^{-1} (Site B) and were significant. At these sites, the uptakes of N, P and K were significantly increased by P application. The uptake of N was significantly increased by fertilizer N at Site A ($P < 0.05$), and at Sites B and E the increase was significant at $P < 0.1$. At the other sites the N uptake did not change significantly upon application of N. Application of K did not affect the uptakes of nutrients, not even K uptake.

The five sites are compared in Table 8.3. Because P was most limiting, the average yields of the treatments with and without fertilizer P are given. The yields of the +P treatments may be considered as the maximum yields obtainable and therefore as indirect indications of the levels of growth factors other than plant nutrients, which may be combined in the term physical soil fertility. The yields of the -P treatments are indicators of the inherent chemical soil fertility. Physical soil fertility decreases in the order: A > E > D, while B and C do not significantly differ from either A or E. For inherent chemical soil fertility, the order is E > A > B > D, while C does not significantly differ from either A or B. The low ranking of Site D finds also expression in the harvest index (HI) which is significantly lower at Site D than at the other sites, for the -P treatments as well as for the +P treatments.

The highest ranking of Site E in inherent chemical soil fertility shows up again in the values of P uptake of treatment NK, considered as the potential soil P supply (Table 8.4). Site D had the highest and Site A the lowest N supply (PK treatment), while the K supply (NP treatment) did not differ among the sites.

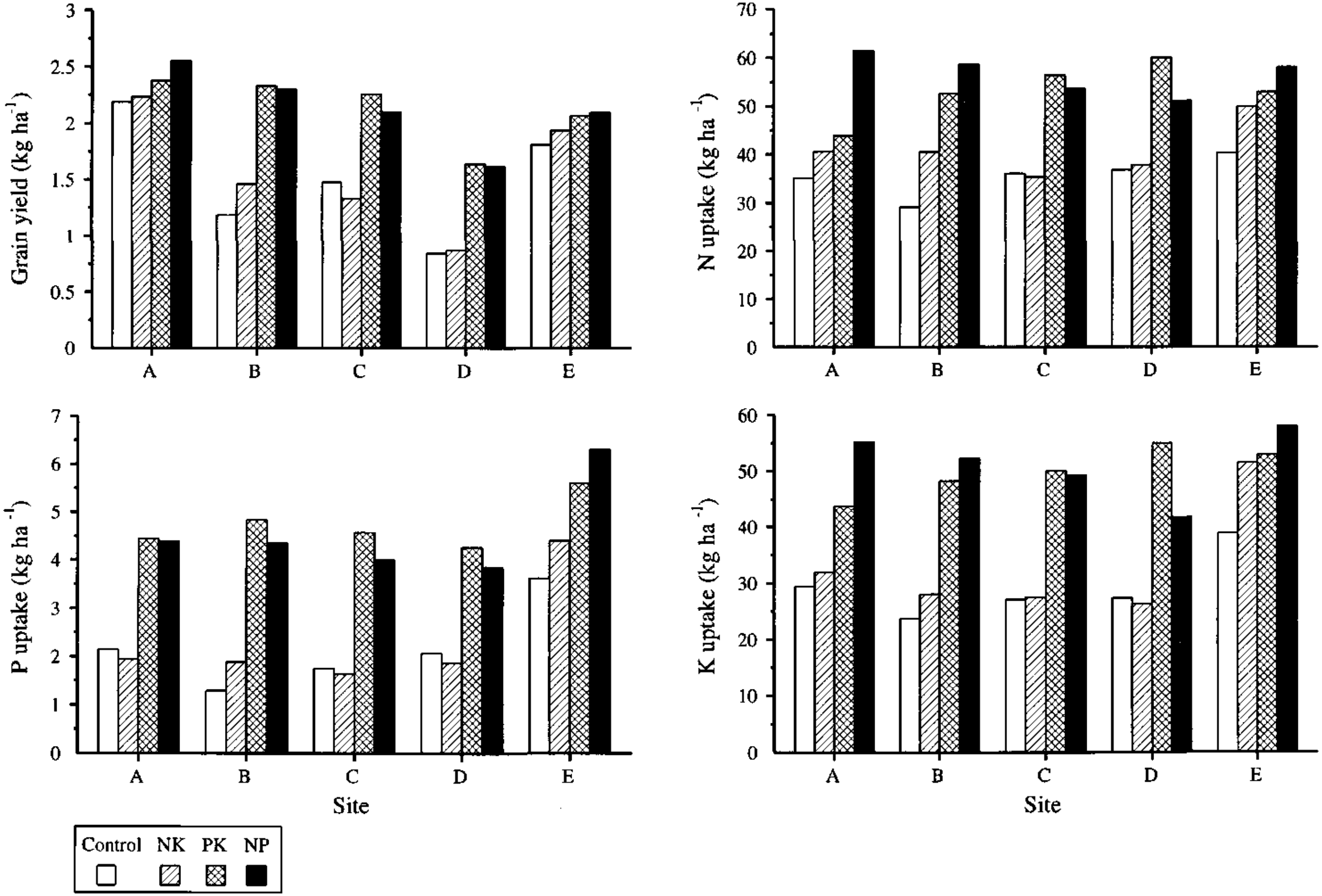


Fig. 8.2 Rice grain yields and uptakes of N, P and K of the different treatments at the five experimental sites.

Table 8.3 Average yield (t ha^{-1}) and harvest index (HI) of the -P and +P treatments. Values in one row followed by the same letter are not significantly different.

	Site				
	A	B	C	D	E
Average yield					
-P	1.66ab	1.32c	1.41bc	0.86d	1.87a
+P	2.47a	2.32ab	2.19ab	1.63	2.07b
HI					
-P	0.45a	0.39b	0.41ab	0.30e	0.43ab
+P	0.43a	0.39a	0.39a	0.32b	0.40a

Table 8.4 Potential soil nutrient supply (kg ha^{-1}). Values in one row followed by the same letter are not significantly different.

	Site				
	A	B	C	D	E
N	43.9b	52.6ab	54.7ab	60.1a	52.9ab
P	1.84b	1.89b	1.65b	1.84b	4.40a
K	55.2a	52.3a	49.2a	41.7a	58.0a

8.3.2.1 Apparent recovery fraction of applied fertilizer nutrients

At the sites where application of N significantly increased N uptake (Sites A, B and E), the apparent recovery fractions ranged from 25% at Site A to 17.5% at Site B. At Sites D and C the apparent recovery fractions did not significantly differ from zero. The apparent recovery fractions of P ranged from 7.6% (Site E) to 9.9% (Site B) and no significant differences among the sites were found. As K application did not result in an increase in K uptake, the recovery fractions for K did not significantly differ from zero.

8.3.2.2 Efficiency of utilization of absorbed nutrients (EU)

EU values were averaged for the treatments with and without the respective nutrients (Table 8.5).

At Sites D and E, EU for P was significantly lower than at Sites A, B and C. At Sites A, B and C, the minus-P treatments had very high EU values for P. They were well above the maximum value of 600 reported for maize. This confirms that P is the yield-limiting nutrient at these sites. The EU values for N were significantly lower at Site D than at the other sites, while EU for P and K was at Site D as low as at Site E. At all sites, except D, P application lowered the EU value for P significantly. N and K application did not change the respective EU values significantly.

Table 8.5 Efficiency of utilization (EU) of absorbed nutrients (kg kg^{-1}) for various fertilizer treatments. Values in a row followed by the same letter are not significantly different.

	Site				
	A	B	C	D	E
EU of N					
- N	51a	44b	42b	27c	44b
+ N	41a	39a	38a	28b	38a
EU of P					
- P	853a	849a	827a	487b	486b
+ P	562a	515a	523a	405b	358b
EU of K					
- K	54a	48ab	50ab	37c	42bc
+ K	54a	51a	47ab	33c	40bc

8.4 Discussion

8.4.1 Relation between chemical soil fertility indices and potential supplies of N and P

In Fig. 8.3, the potential soil N supply (N uptake of the PK treatments) has been plotted against the organic C content, either expressed as mass fraction or as g per dm^3 topsoil. In the latter case the relation is clearly improved.

No clear relations were found between potential soil P supply (P uptake of NK treatments) and a single soil P index. According to Van Reuler and Janssen (subm. a) the P supply of soils in the Taï region can be described by:

$$SP = -10.941 + 0.301*PDvs + 0.024*TPvs + 1.483*pH \quad (R^2=0.97)$$

where SP = potential P supply in kg ha^{-1} per season
PDvs = P-Dabin in mg P dm^{-3}
TPvs = total P in mg P dm^{-3}

In Fig. 8.4 (left-hand side) the relation between the calculated supplies of P and measured uptakes is presented. At the Sites B and D less P is absorbed than could be anticipated on the basis of the values of P-Dabin, total P and pH. The low EU for P and the low HI of Site D indicate that growth was not optimal; hence it is likely that not all available P was absorbed. For the difference between the measured and calculated P uptake at Site B no explanation is available. In this study the slashed vegetation was removed before the experimental fields were planted, whereas in the study in which the above equation for SP was developed, the slashed vegetation had been burnt leaving ash as fertilizer. Van Reuler and Janssen (1993a) found that through ash approximately 10 kg P ha^{-1} is applied. Such a quantity of ash P corresponds with about 3 mg total P per kg of topsoil, and that quantity cannot be recovered in the analyses because it is less than the standard deviation of total P. Nevertheless, burning did increase yields, and that was mainly due to P contained in the ash (Van Reuler and Janssen,1993b). We estimate that in case the one-year-old secondary vegetation of the catena sites of the present study had been burnt, P uptake would have been 0.5 - 1.0 kg ha^{-1} higher than was found now. Addition of such an amount of P to the measured uptake would have given a better agreement with the calculated potential supply of P in Fig. 8.4 for Sites B and D, but not for the other sites.

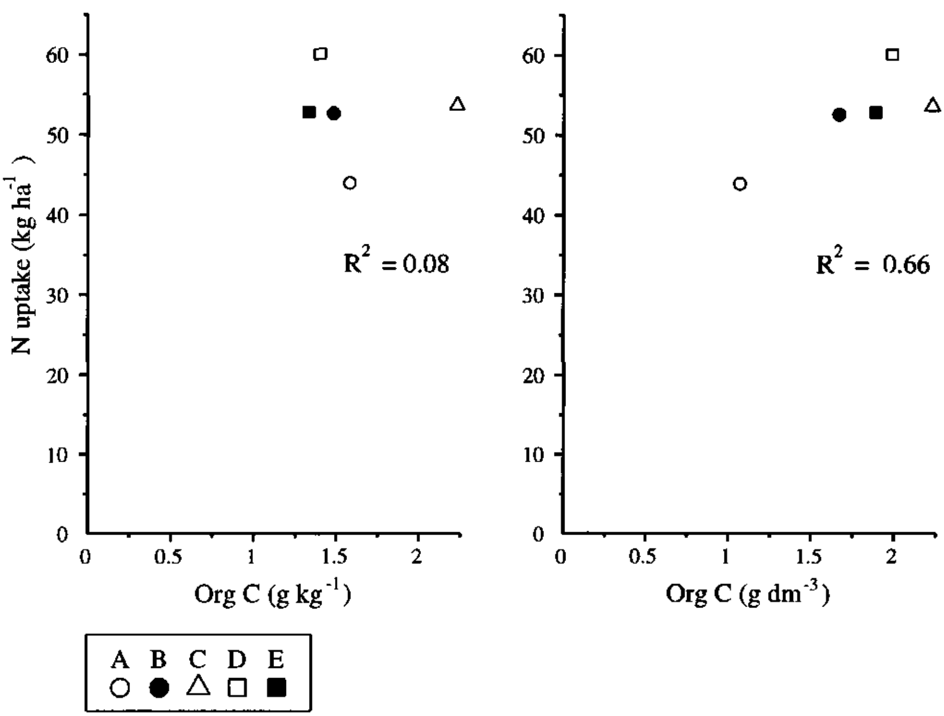


Fig. 8.3 Relation between potential soil N supply (PK treatment) and soil organic matter content, expressed on a mass basis and on a volume basis.

8.4.2 Recovery of fertilizer-P

In the same paper by Van Reuler and Janssen (subm. a), it was found that the apparent recovery fraction of fertilizer-P (RFP) could be described by:

RFP = 15.071 - 0.027*SCvs - 0.095*PDvs (R^2 = 0.93)

where RFP = apparent recovery fraction of fertilizer-P in %
SCvs = silt + clay in g dm^{-3} of total soil
PDvs = P-Dabin in mg dm^{-3} of total soil

In Fig. 8.4 (right-hand side) the relation between the calculated and measured recoveries of fertilizer-P is presented. The measured recovery is higher than the calculated recovery, for which two reasons can be given. The first reason is that the equation was based on experimental recovery data obtained at application rates of 50 kg P ha^{-1}, while in the present study the rate was 25 kg P ha^{-1}. It was shown by Van Reuler and Janssen (subm. a) that the increase in P uptake and hence the recovery of fertilizer-P by rice is much higher between application rates of 0 and 25

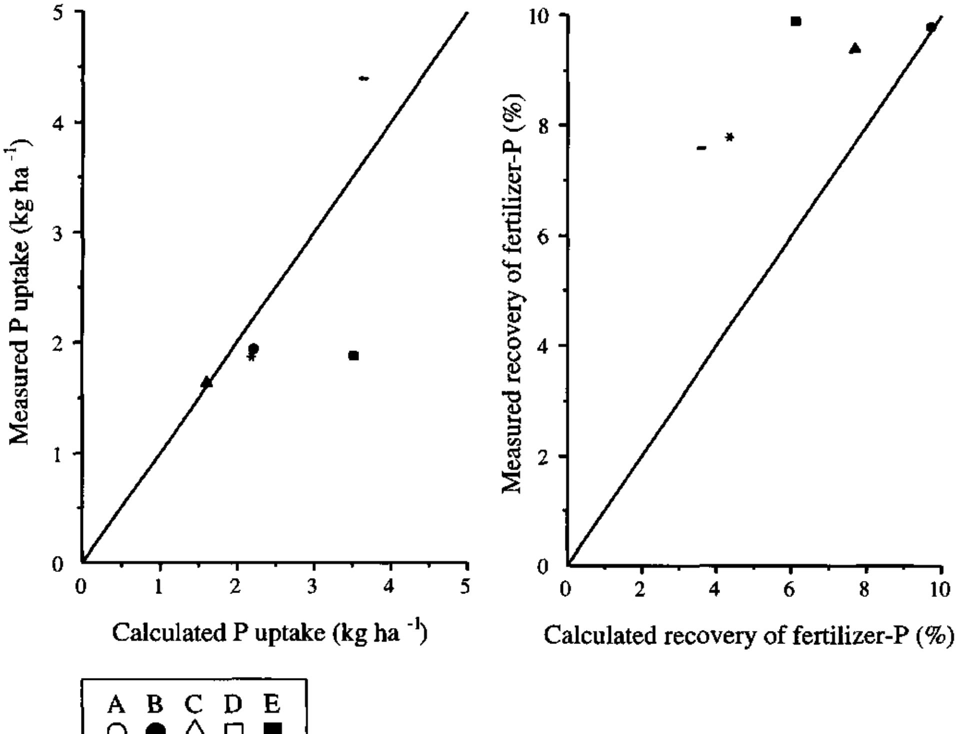


Fig. 8.4 Measured potential soil P supply and recovery of fertilizer-P in relation to the values calculated with equations from Van Reuler and Janssen (subm. a).

than between rates of 25 and 50 kg P ha^{-1}. The second reason is that in the former experiment, P uptakes were higher because of ash, and hence the demands for fertilizer-P were lower than in the present experiment.

8.4.3 Efficiency of utilization of absorbed nutrients

The relation between grain yield and P uptake of the '-P' and '+P' treatments is presented in Fig. 8.5. For a given amount of absorbed P, grain yields decrease in the order A > B = C > E > D, and so does of course the EU for P calculated for the case of 4 kg P ha^{-1} absorbed (Table 8.6).

The decrease in EU for P cannot be explained by insufficient availability of N and K, as the estimated amounts of N and K absorbed do not differ significantly among the sites. The EU's for N and K follow the same pattern as the EU for P. The amounts of N and K absorbed at the Sites D and E as well as their respective EU values indicate that these nutrients have not limited growth. The poorer performance of the crops on these sites must be due to other factors, as discussed below.

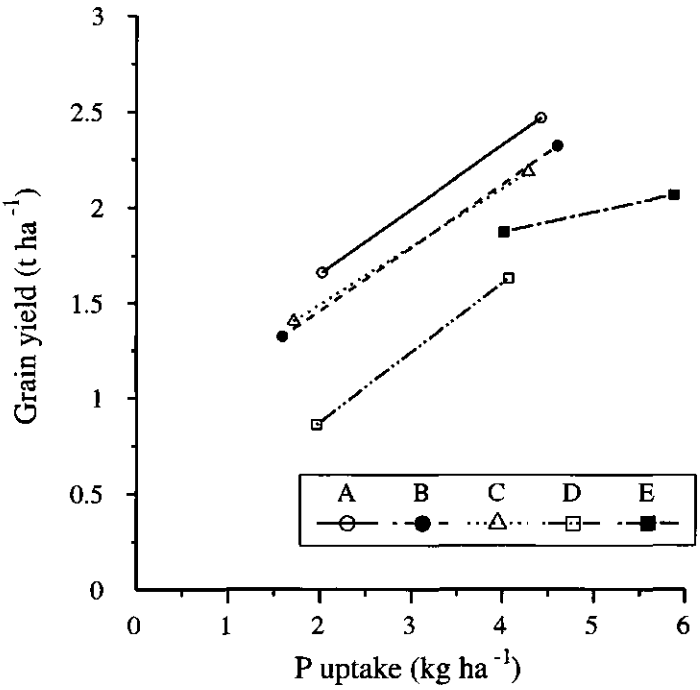


Fig. 8.5 Relation between rice grain yield and P uptake for the five sites. Symbols at the left and right-hand ends of the lines stand for the '-P' and '+P' treatments.

8.4.4 Evaluation of soil productivity of the catena

Site E has the highest inherent chemical and Site A the highest physical soil fertility. Site D was clearly the poorest one, in chemical as well as in physical soil fertility. As the relative differences among the sites are larger for EU than for HI, the low EU values at Site D cannot entirely be ascribed to the low harvest index (HI). Both low EU and low HI point to the presence of other growth-limiting factors than N, P and

Table 8.6 Comparison of estimated grain yield (t ha^{-1}), nutrient uptake (kg ha^{-1}), efficiency of utilization (EU) of absorbed nutrients (kg kg^{-1}), harvest index (HI) at a standardized P uptake of 4 kg ha^{-1} and pH of the different sites.

	Site				
	A	B	C	D	E
Grain yield	2.30	2.10	2.06	1.58	1.86
N uptake	49.8	51.3	52.5	54.8	45.0
EU of N	46	41	39	29	41
K uptake	46.0	45.0	47.3	47.8	45.0
EU of K	50	47	44	33	41
HI	0.43	0.40	0.39	0.32	0.43
pH	5.9	5.7	5.4	5.0	5.8

K. The HI and the EU of N seem to be related to soil pH (Table 8.6), and Site D has the lowest pH. Site D differs further from Sites A, B and C, in that it has a gravel-free topsoil. Because upland rice is tolerant of acid soil conditions, it is questionable whether low pH is the cause of the low yields at Site D. In first instance, the difference in gravel content seems an even less likely reason, because the larger water-holding capacity of gravel-free soils suggests that yields could be higher than on gravelly soils. In case of lasting drought, the small water-holding capacity makes the gravelly soils indeed more vulnerable. A low water-holding capacity is, however, not necessarily and under all circumstances a drawback. Given a certain quantity of infiltrating rainwater, moisture tension is less negative and hence moisture will be more easily available in gravelly than in non-gravelly soils. When rainfall is well distributed over the growing season and not extremely low, gravelly soils may yield better than non-gravelly soils. Another positive aspect of gravelly soils is the higher root density per unit of fine earth compared to non-gravelly soils, which may result in a better exploitation of the soil. This might explain the good yields obtained on gravelly soils in this study.

8.5 Conclusions

The imperfectly drained soils at the lowest positions of the catenas in the Taï region have the highest chemical fertility and the soils at the crest-upper slope position have the highest physical fertility. The sandy soils at the lower slope have the lowest chemical as well as the lowest physical fertility.

The low values for HI and EU for P obtained at the lower slope point to growth-limiting factors other than N, P or K. A possible reason is moisture stress.

In the Taï region, where gravel constitutes a substantial part of the soil material, the values of soil properties should be expressed on a volume basis rather than on a mass basis.

Chapter 9

Yields and nutrient uptakes in subsequent seasons

Keywords: apparent fertilizer recovery, catena, Côte d'Ivoire, chemical soil fertility, efficiency of nutrient utilization, physical soil fertility, potential nutrient supply, maize, soil chemical properties, upland rice

Abstract

Over a period of five seasons at five sites along a catena in the Taï region, south-west Côte d'Ivoire field trials were conducted. The aim of these trials was to study soil fertility dynamics. In this paper the results of the second up to the fifth growing season after clearing are discussed. In this period one upland rice and three maize crops were grown. The rice suffered from drought and the results are not discussed in detail. At all sites in all three seasons with maize P application significantly increased the grain yield. The responses to N and K application were erratic. The yields of the -P and +P treatments were used as indicators for chemical and physical soil fertility, respectively. At all sites, the chemical and physical fertility decreased with time. Exceptions were the Sites B and D where the -P yields did not change with time. The decrease in fertility was more pronounced for the sites at the upper/middle slope (Sites A, B and C) than for the sites at the lower slope (Sites D and E). The gravelly soils of the upper/middle slope had a higher physical fertility than the non-gravelly soils of the lower slope. The N and P supplies of the lower slope sites were initially higher than the supplies at the upper/middle slope sites. In subsequent seasons, however, the decrease was much more pronounced at the lower slope than at the upper/middle slope. In these experiments yield levels could not be maintained. Interpretation of the yield-P uptake relation showed a decrease in efficiency of utilization of absorbed P with time. The most probable reason for this decrease was a deterioration of the physical soil conditions. Comparison of soil chemical properties of samples collected before the start of the experiments and after five seasons showed slightly lower pH values and no differences in organic carbon and total P values. The variability of the data was high.

9.1 Introduction

Attempts to intensify crop production in shifting cultivation systems by extending the cultivation period are often fruitless because of yield decline. The rate of yield decline depends on, among others, the nature of the vegetation before clearing, soil properties, cropping systems and crop management (Sanchez,1976). In non-volcanic regions of the humid tropics, soils with a low nutrient status dominate. Nutrients supplied through ash produced by burning the slashed forest vegetation form a major part of the total nutrient supply for crops to be grown. This source of nutrients, however, is rapidly exhausted by crop uptake and leaching. Another important source of nutrients, especially of N, P and S, is soil organic matter (SOM). SOM content also decreases sharply during the cultivation period. Sanchez et al.(1983) found in Peru an organic carbon decrease of 30% in the first year after clearing; this was followed by stabilization. It indicates that mineralization is rapid initially but soon slows down to very low rates. Also in West Africa this phenomenon was observed. In Nigeria, the rate of N mineralization in the second year was only one-third of the mineralization rate in the first year (Mueller-Harvey et al.,1985;1989). Therefore N deficiency is to be expected when the cultivation period is extended. In Peru, N deficiency was found from the second crop onwards in a system with three crops per year (Sanchez,1982). Application of N may stimulate the uptake of other nutrients, and thus enhance the development of deficiencies of these nutrients.

The objectives of the present study were to look into the soil fertility dynamics of the different soil types along a representative catena in the Taï region, south-west Côte d'Ivoire. Yardsticks are crop yield, nutrient uptake, response to fertilizer application and changes in soil properties.

Two crops per year were grown, in contrast to the practice of the indigenous farmers who grow only one crop, mainly upland rice. Because soil pathogens and/or accumulation of toxic substances may have a yield-reducing effect when upland rice is grown continuously (Gupta and O'Toole,1986), it was decided to alternately plant rice and maize.

In Part I of this series, the results of the first season after clearing were presented. In the present paper the results of the next four seasons are discussed.

9.2 Materials and methods

Rates and methods of fertilizer application, chemical analyses and procedures for data interpretation were described in Part I of this series. Fertilizer applications were repeated every season. The cropping sequence was: rice (Season 89-1, the first season), maize (Season 89-2), rice (Season 90-1), maize (Season 90-2) and again maize (Season 91-1). In Season 90-1, upland rice (*Oryza sativa*, cultivar IDSA 6) was sown in the same way as in 89-1. The rice was harvested after 126 days. Maize (*Zea mays*, Pioneer 3274) was sown in rows with a density of 55,555 plants ha^{-1} (60

* 30 cm). In Seasons 89-2, 90-2 and 91-1, maize was harvested after 100, 103 and 105 days, respectively.

During each cropping season, fields were weeded twice by hand, leaving weeds in the field as surface mulch. Maize was sprayed regularly with insecticide (Decis) against stalk borers. A detergent was added to increase the efficiency. During maturing, rice fields were guarded against bird damage and maize fields against monkey damage. At each harvest grain samples were collected of each experimental unit, and straw samples of a limited number of units. All above-ground crop residues were removed from the fields.

For statistical analysis the SAS programme was used (SAS Institute Inc.,1989). Treatment averages were calculated by least squared means.

After the last harvest (Season 91-1), composite soil samples (0-20 cm) were collected of each experimental unit.

9.3 Results and discussion

9.3.1 Yields

Grain yields are presented in Table 9.1. Because in Season 90-1 the rice crop was strongly affected by drought and termite damage, these results are discussed separately.

9.3.1.1 Maize (Seasons 89-2, 90-2 and 91-1)

At all sites and in all three seasons, P application significantly increased maize grain yield. The response to N was rather irregular: a positive significant response was found at Site E in 89-2 and 90-2, at Site B in 89-2 and at Site A in 91-1. The response to K application was even more erratic: significantly negative at Site B in 89-2, at Site C in 90-2 and at Site A in 91-1, and significantly positive at Site D in 90-2.

Fig. 9.1 shows the development of maize yields of the -P and +P treatments during the three seasons. It was explained in the first paper of this series that these yields can be considered as indicators for the inherent chemical and physical soil fertility, respectively.
Seasons 90-2 and 91-1 yielded less than Season 89-2 for the +P treatments at all five sites, and for the -P treatments at Sites A, C, and E. In some cases, yields were

Table 9.1 Grain yields (t ha^{-1}) along the catena of maize in 89-2, rice in 90-1, and maize in 90-2 and 91-1. Treatment effects per season and per site are indicated by * ($P < 0.05$) and ** ($P < 0.01$).

	A				B				C				D				E			
	89-2	90-1	90-2	91-1	89-2	90-1	90-2	91-1	89-2	90-1	90-2	91-1	89-2	90-1	90-2	91-1	89-2	90-1	90-2	91-1
Control	2.50	0.64	1.04	1.34	0.59	0.83	0.62	0.64	1.31	0.75	0.78	0.80	0.53	1.38	0.25	0.41	1.62	0.87	0.83	1.09
-N	3.03	0.85	1.78	1.98	1.85	1.45	1.44	1.40	2.12	0.95	1.32	1.24	1.20	1.36	0.71	0.54	1.69	1.03	0.97	1.29
+N	3.66	0.78	1.88	2.36*	2.28**	1.57	1.62	1.56	2.58	0.76	1.65	1.63	1.00	1.38	0.43	0.38	2.27**	0.98	1.48**	1.60
-P	2.75	0.69	1.13	1.34	0.64	1.06	0.72	0.71	1.45	0.72	0.74	0.86	0.53	1.33	0.29	0.31	1.73	0.90	0.99	1.16
+P	3.94**	0.94	2.53**	3.00**	3.48**	1.96**	2.34**	2.25**	3.24**	0.98	2.23**	2.01**	1.67**	1.41	0.86**	0.61**	2.23*	1.10**	1.46*	1.74*
-K	3.41	0.72	1.79	2.36	2.22	1.34	1.52	1.48	2.50	0.78	1.70	1.57	1.03	1.43	0.40	0.49	2.16	0.94	1.32	1.54
+K	3.28	0.91	1.87	1.98*	1.89**	1.68**	1.53	1.48	2.20	0.92	1.28*	1.30	1.17	1.32	0.74*	0.44	1.80	1.06*	1.13	1.36

Table 9.2 N uptake (kg ha^{-1}) along the catena by maize in 89-2, rice in 90-1 and maize in 90-2 and 91-1. Treatment effects per season and per site are indicated by * ($P < 0.05$) and ** ($P < 0.01$).

	A				B				C				D				E			
	89-2	90-1	90-2	91-1	89-2	90-1	90-2	91-1	89-2	90-1	90-2	91-1	89-2	90-1	90-2	91-1	89-2	90-1	90-2	91-1
Control	37.5	19.8	23.7	25.5	15.9	23.2	17.8	14.8	26.0	22.2	20.0	15.8	12.2	36.1	7.4	9.6	24.5	22.9	17.3	19.3
-N	41.2	22.6	36.3	33.4	31.0	35.1	30.2	25.4	35.4	24.8	31.2	21.6	20.9	34.1	16.5	11.0	25.3	24.4	20.4	23.5
+N	52.9*	23.2	42.4	44.7**	39.9*	40.1	36.4	28.4	43.6	23.0	40.9	29.5	18.7	36.0	11.5	8.9	33.3**	27.1	28.3*	25.7
-P	44.0	20.9	29.0	27.4	16.6	28.2	21.3	16.6	29.3	21.9	22.3	18.4	11.7	34.6	8.7	8.1	27.0	24.4	20.7	20.7
+P	50.1	24.8	49.3**	50.8**	54.4**	47.1**	45.3**	37.2**	49.7**	26.0	49.9**	32.7**	27.9**	35.5	19.3**	11.8**	31.6	27.1	28.0*	28.4*
-K	46.4	22.1	35.7	42.8	39.3	35.1	32.9	26.6	41.5	23.4	38.7	26.9	19.6	37.5	10.2	10.4	30.8	25.5	24.9	24.3
+K	47.7	23.7	41.6	35.3*	31.7	40.2	33.7	27.2	37.6	24.5	33.4*	24.2	20.0	32.6	17.8*	9.5	17.7	25.9	23.8	24.9

Table 9.3 P uptake (kg ha^{-1}) along the catena by maize in 89-2, rice in 90-1 and maize in 90-2 and 91-1. Treatment effects per season and per site are indicated by * ($P < 0.05$) and ** ($P < 0.01$).

	A				B				C				D				E			
	89-2	90-1	90-2	91-1	89-2	90-1	90-2	91-1	89-2	90-1	90-2	91-1	89-2	90-1	90-2	91-1	89-2	90-1	90-2	91-1
Control	3.64	0.79	1.86	2.33	1.18	1.01	2.62	1.22	2.42	0.94	1.71	1.51	1.02	1.80	0.86	0.96	3.10	1.54	2.24	2.46
-N	5.29	1.87	3.82	4.04	4.00	3.24	4.14	3.32	4.34	1.88	2.78	2.62	2.37	2.60	1.56	1.41	4.50	2.73	3.39	2.88
+N	5.58	1.55	3.81	4.79	3.89	3.17	3.16	3.54	4.98	1.40	4.89*	3.50	2.72	2.98	1.13	0.95*	4.97	2.51	3.55	4.04
-P	3.89	0.89	2.33	2.23	1.19	1.42	2.09	1.32	2.46	0.81	1.94	1.59	1.05	1.92	0.83	0.71	3.14	1.64	2.37	2.52
+P	6.98**	2.53**	5.30**	6.59**	6.70**	4.99**	5.21**	5.53**	6.86**	2.46**	5.73**	4.53**	4.04**	3.66**	1.86**	1.64**	6.33**	3.61**	4.58**	4.40*
-K	5.33	1.45	3.34	4.88	3.88	2.76	3.69	3.44	5.04	1.52	4.66	3.46	2.41	2.86	1.16	1.20	4.94	2.41	3.42	3.98
+K	5.53	1.97	4.29	3.94**	4.01	3.64	3.60	3.42	4.27	1.76	3.01	2.66	2.68	2.73	1.52	1.16	4.53	2.83	3.53	2.95

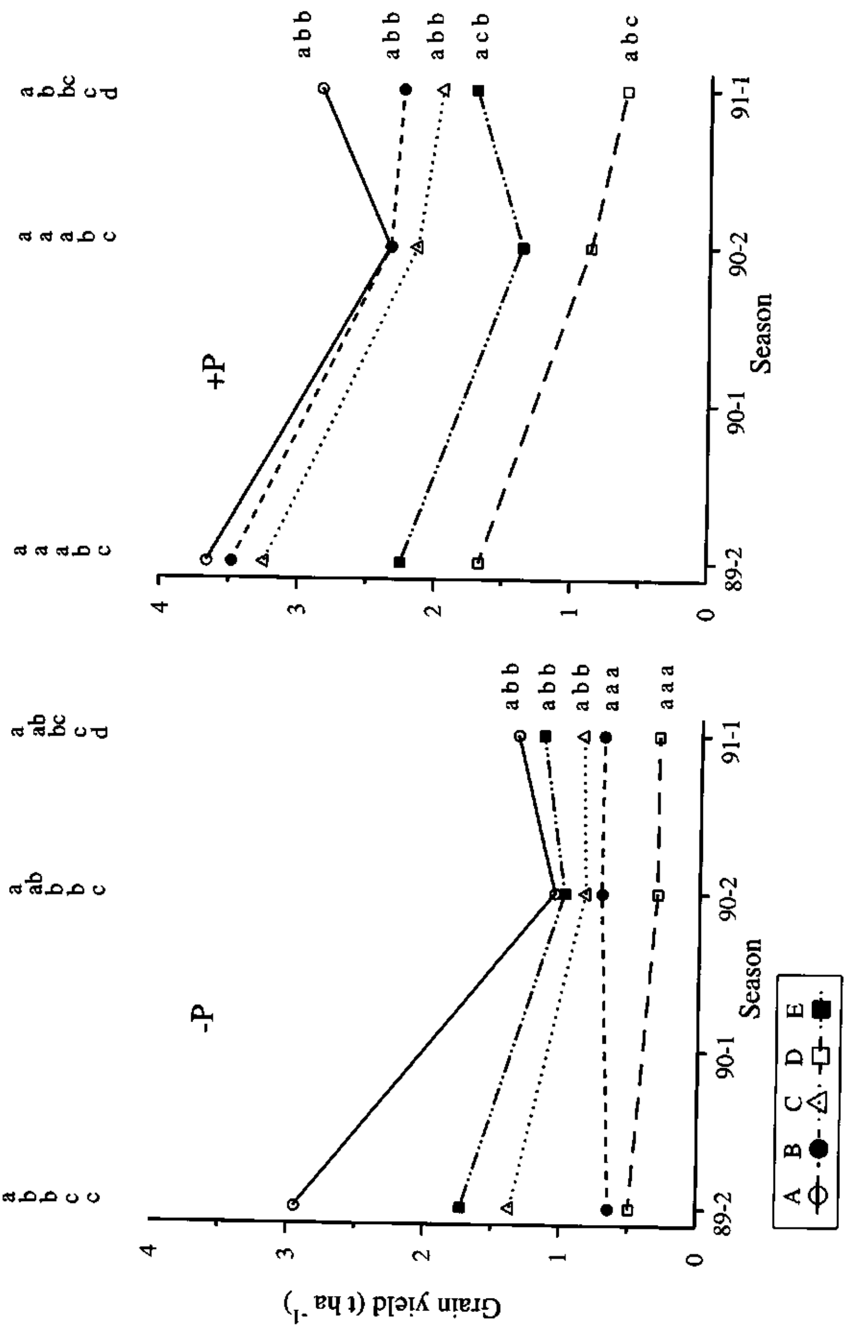


Fig. 9.1 Maize yield of the -P and +P treatments obtained at the different sites in the seasons 89-2, 90-2 and 91-1. Significant differences between the sites in one season are indicated by different letters in the column. Significant differences between the seasons at each site are indicated by different letters in the row.

higher in Season 91-1 than in Season 90-2. The yield difference suggests that better growth conditions in Season 91-1 (April-August) compared to Season 90-2 (August-November) could more than compensate for the decrease in soil fertility. The better growth conditions may be attributed to higher radiation (Collinet et al.,1984).

In Season 89-2 the yields of the -P treatments ranged from 0.5 to 3.0 t ha^{-1}. In subsequent seasons the differences between the sites became much smaller. The ranking of sites for inherent chemical soil fertility, as expressed in the -P yields, was in season 89-2: A > E = C > B = D and changed to A ≥ E ≥ C ≥ B > D in Season 91-1. Compared to Season 89-1 Site A and E have switched places and Site E now equals C. The ranking for physical fertility of the sites, as expressed in the +P yields, was the same in the Seasons 89-2 and 90-2: A = B = C > E > D. and changed in Season 91-1 to A > B ≥ C ≥ E > D. Compared to Season 89-1 Site A differs now from B. Hence, it is obvious that growth conditions on the non-gravelly soils at the lower slope are poorer than on the gravelly soils at the middle and upper slopes.

Setting the yields obtained in Season 89-2 at 100%, relative values for inherent chemical and physical soil fertility in the other seasons were calculated. The left-hand side of Fig. 9.2A shows the average values for the soils of the upper/middle slope (Sites A, B, and C), and the right-hand side those for the soils of the lower slope (Sites D and E). The inherent soil fertility decreased with time at the same relative rate as the physical soil fertility, while for both, inherent as well as physical soil fertility, the decrease in fertility was somewhat more outspoken for the soils at the lower slopes than for those at the upper/middle slopes.

9.3.1.2 Upland rice (season 90-1)

Yield was depressed by severe drought and termite damage (Table 9.1). Termites ate the roots of the rice plants, and consequently further growth was reduced. Drought and termite damage were severe especially on the most gravelly soils at Sites A and C. At these sites the average harvest index (HI) was 0.31, while it was 0.42 in Season 89-1 (Van Reuler and Janssen, subm. b). At the other sites, average HI values were 0.40 which is about the same as in Season 89-1. At Site D, HI was even higher in Season 90-1 than in Season 89-1. It is obvious that the results of Season 90-1 were exceptional. Striking differences with the other seasons are that (a) only at Site B a significant yield response to P was found, (b) Site D ranked first for the -P yields and second for the +P yields, while in the other seasons yields at this site were by far the lowest, and (c) only in this season a significant positive yield response to K was found.

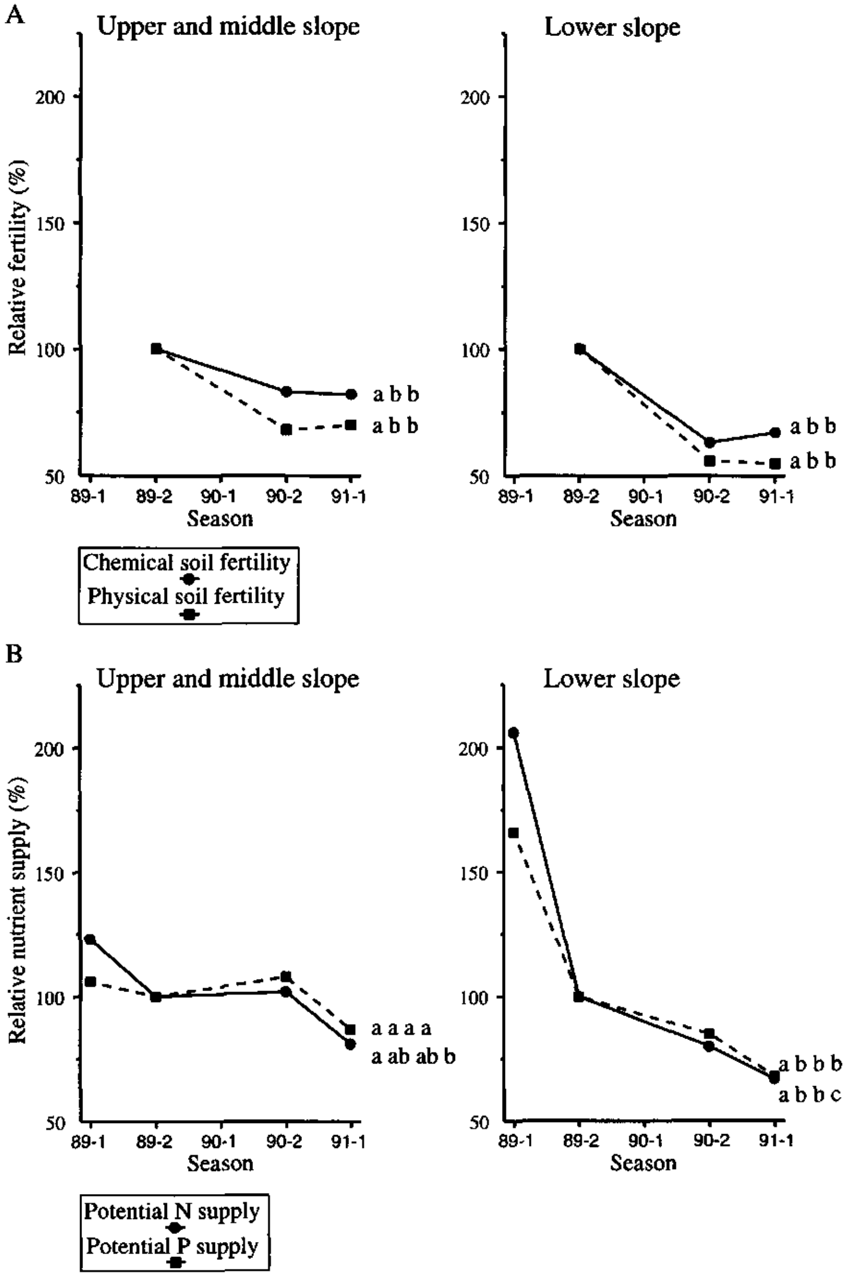


Fig. 9.2 Change with time of (A) relative chemical and physical soil fertility of the Upper/Middle and Lower slope sites, and of (B) relative potential N and P supply of the Upper/Middle and Lower slope sites. Significant differences between the seasons are indicated by different letters on the right-hand side of each figure.

9.3.2 Nutrient uptake and apparent recovery fraction of applied fertilizer N and P

9.3.2.1 Nitrogen

Total N uptakes (sums of N in grain and straw) are presented in Table 9.2. The drought in Season 90-1 had a smaller effect on N uptake than on yield. Only on the gravelly soils of Sites A and C, there was an obvious dip in uptake. P application increased the N uptake significantly in 13 out of the 15 site-season combinations (Season 90-1 excluded) and N application did so in 5 cases. For these cases, apparent recovery fractions of fertilizer N were calculated. They varied between 15 and 37% which is rather low (Table 9.4). K application significantly decreased N uptake in two cases (at Site C in Season 90-2 and at Site A in Season 91-1), while at Site D in Season 90-2 a significant increase was found.

9.3.2.2 Phosphorus

Total P uptakes (sums of P in grain and straw) are presented in Table 9.3. At all sites and in all seasons, P application significantly increased P uptake. The recovery of fertilizer P varied among sites and seasons; values for the apparent recovery fraction ran from 3.9 to 24% (Table 9.4). Because the application of P was repeated in each season, the apparent recovery fractions encompass the residual effects as well, and hence it could be expected that the values of the recovery fractions would increase with time. This was, however, not observed indicating that other factors than P may have been yield-limiting. The ranking of the sites for recovery fraction averaged for the three seasons is: B > C > A > E > D. It is again Site D that shows the poorest results.

Table 9.4 Apparent recovery fractions (%) of the +P treatments for N and of the +N treatments for P along the catena in the seasons 89-2, 90-2 and 91-1.

	Site				
	A	B	C	D	E
N					
89-2	14.6	33.0	-.[a]	-	18.2
90-2	-	-	-	-	21.7
91-1	36.6	-	-	-	-
P					
89-2	9.2	21.5	20.7	10.8	14.0
90-2	13.9	12.6	23.6	4.5	8.4
91-1	21.1	16.9	15.5	3.9	11.6

[a] not calculated as the effect of fertilizer-N was not significant

9.3.2.3 Potential N and P supply

The potential soil supplies of N (total N uptake of PK-treatments) and of P (total P uptake of NK-treatments) are presented in Tables 9.5 and 9.6. The data of Season 89-1 are also included, although the crop was rice instead of maize. Apparently these crops differ less in nutrient uptake than in yield.

In Season 89-1 there were no large differences in soil N supply among the sites, only the supply at Site A was significantly lower. In the subsequent seasons, the N supplies at the sites were higher at the upper and middle slopes than at the lower part of the catena. In Season 91-1, also at the middle slope (Site C) less N was supplied than at the upper slope. Site A was the only field where N supply did not change with time. At Sites B and C, the N supply became significantly lower in the last season, whereas at Sites D and E this lowering already occurred in the second season.

Table 9.5 Potential soil N supply (kg ha^{-1}) along the catena. In a row, values followed by a lowercase letter are not significantly different ($P < 0.05$). In a column, values followed by a uppercase letter are not significantly different ($P < 0.05$).

	Site				
	A	B	C	D	E
89-1	43.9b A	52.6ab A	56.4ab A	60.1a A	52.9ab A
89-2	44.9a A	46.1a A	43.6a AB	29.2b B	28.0b B
90-2	48.9a A	42.7a AB	42.3a B	27.5b B	21.7a B
91-1	41.3a A	36.0a B	27.5b C	12.4c C	29.6b B
Total[a]	204.3	224.5	195.6	158.4	158.1

[a] inclusive amount absorbed in 90-1

In Season 89-1, soil P supply at Site E was about twice as high as at the other sites. In the subsequent seasons, P supply was highest at Sites A and E, and lowest at Site D. At Sites B, D and E, more P was supplied in Season 89-1 than in subsequent seasons. At Sites A and C, maize in Season 89-2 absorbed more P than rice in the preceding season.

Setting the supplies found in Season 89-2 at 100%, relative supplies were calculated for the other seasons in a similar way as the relative values for yields. These results are also shown in Fig. 9.2, again averaged for the upper/middle slope (Sites A, B, and C), and the lower slope (Sites D and E). In the course of time, the relative N supplies decreased at a little higher rate than the relative P supplies. Again the decreases were sharper at the lower slope than at the upper/middle slopes, especially between seasons 89-1 and 89-2. The supplies of N and P decreased, however, at a lower rate than the yields of the -P and +P treatments which were used to indicate inherent and physical soil fertility. Hence, efficiency of nutrient utilization by the crop must have decreased during the subsequent seasons.

Table 9.6 Potential soil P supply (kg ha^{-1}) along the catena. In a row, values followed by a lowercase letter are not significantly different ($P < 0.05$). In a column, values followed by a uppercase letter are not significantly different ($P < 0.05$).

	Site				
	A	B	C	D	E
89-1	1.94b B	1.89b A	1.65b B	1.87b A	4.40a A
89-2	4.38a A	1.21c B	2.40b A	1.03c B	3.17b B
90-2	2.14a B	1.55b AB	2.02ab AB	0.83c B	2.50a B
91-1	2.14ab B	1.43b AB	1.63b B	0.46c B	2.59a B
Total[a]	12.18	7.90	8.48	6.24	14.40

[a] inclusive amount absorbed in 90-1

9.3.2.4 Efficiency of utilization of absorbed P

In Fig. 9.3 the relations between maize grain yield and total P uptake are presented per site and per season. The figure also shows the lines indicating maximum dilution (YPD) and accumulation (YPA), as established by Janssen et al. (1990).

Comparison of the EUP among sites at a P uptake of 3 kg P ha^{-1} resulted in the following ranking:

A > C > B > D > E. At all sites the EUP values were highest in Season 89-2 and decreased with time indicating that P absorbed was used less efficiently. Because EUP also decreased when N or K had been applied, the decrease cannot be attributed to a decrease in N or K availability. Deficiencies of other nutrients, e.g. Mg and S, may have caused the decrease. However, in other experiments in the Taï region, no effects of Mg or S were found (Van Reuler and Janssen, subm. d). Micronutrient deficiency cannot be excluded as a possible cause, but it is not a probable one as the cropping history of the fields was still relatively short. Another explanation might be deterioration of the physical soil conditions.

At all sites the EUP in Season 91-1 was equal to or higher than in Season 90-2, which is another indication that the growth conditions in the first season were better than in the second season.

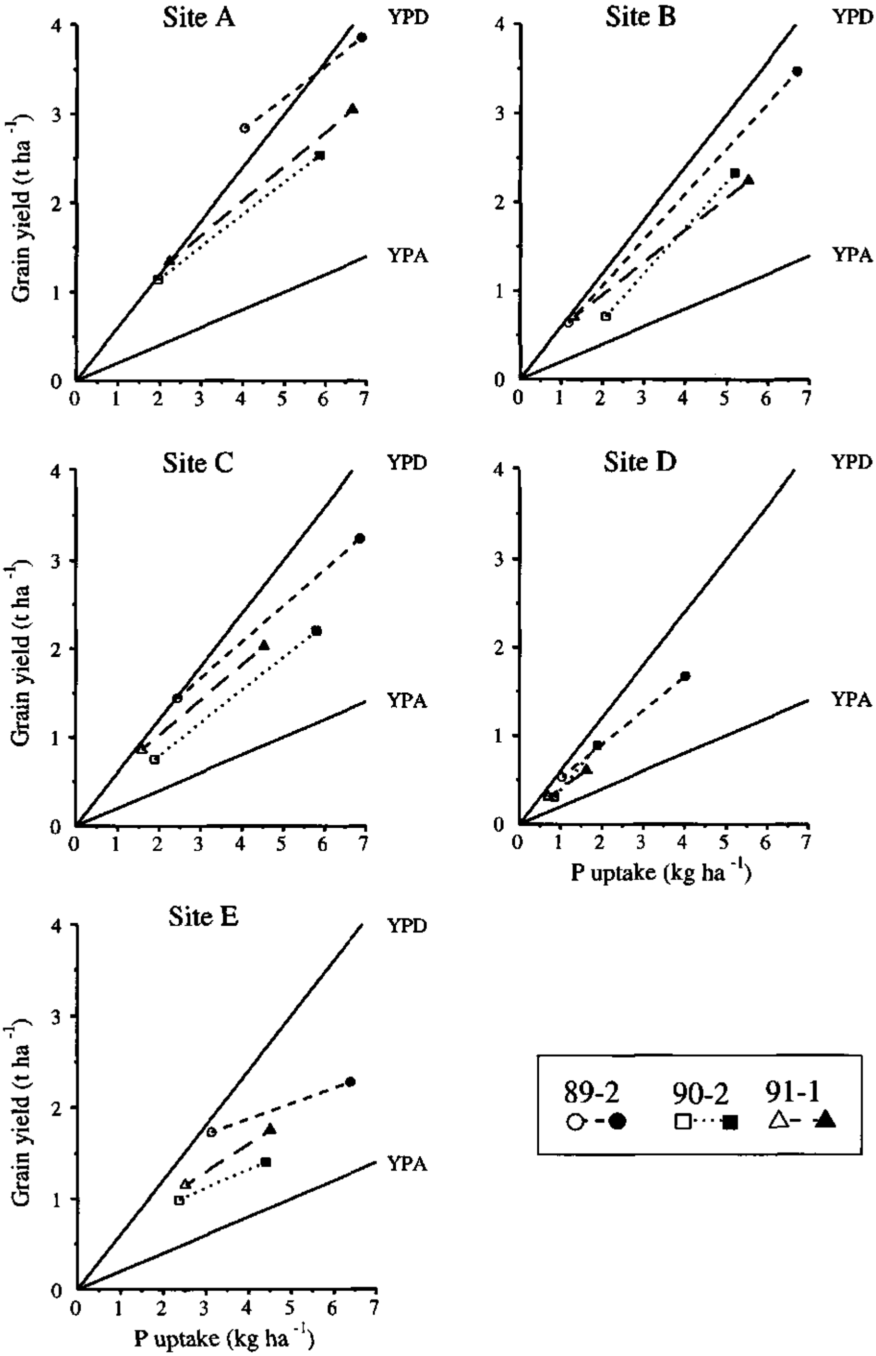


Fig. 9.3 Change with time of the relation between maize yield and P uptake at the five sites in the seasons 89-2, 90-2 and 91-1. Open and close symbols stand for -P and +P treatments, respectively. YPD and YPA indicate the maximum dilution and maximum accumulation of absorbed P, respectively.

9.3.3 Soil chemical properties

Table 9.7 presents the values of some soil chemical properties as found before the first season and after the fifth season. After five seasons, pH was slightly lower than at the start of the experiment, the decrease being positively related to the starting value. Such a decrease is due to a loss of basic cations from the exchange complex (Juo and Manu,1994).

In contrast to many other studies (Brams,1971; Mueller-Harvey et al.,1985,1989; Sanchez et al.,1983; Kang,1993), no decrease in organic carbon was found. The first sampling probably took place after the period of drastic decrease in organic matter, which according to Sanchez et al. (1983) is found immediately after forest clearing.

Table 9.7 Changes in soil properties of the sites along the catena during the cropping period.

	Site					
	A	B	C	D	E	Average
pH						
89-1	5.9	5.7	5.4	5.0	5.8	5.6
91-1	5.5	5.4	5.3	5.0	5.6	5.4
Org. C (g kg^{-1})						
89-1	15.8	14.8	22.3	14.0	13.3	14.0
91-1 - P	19.1	16.0	26.6	15.3	14.1	18.2
91-1 + P	19.3	16.3	27.0	14.3	15.0	18.4
total N (g kg^{-1})						
89-1	1.3	1.1	1.5	0.9	0.7	1.1
91-1 - P	1.4	1.0	1.8	0.8	0.9	1.2
91-1 + P	1.1	0.9	1.6	1.0	0.8	1.1
total P (mg kg^{-1})						
89-1	227	130	162	69	72	132
91-1 - P	240	137	220	81	77	151
91-1 + P	241	137	251	114	87	166

Total P data are given for the -P and +P treatments separately. Total P contents of the -P treatments were not lower in 1991 than at the beginning in 1989. The amounts of P absorbed by plants on the NK plots during five seasons varied from 6 (Site D) to 12 kg P ha^{-1} (Site A), corresponding with approximately 2 and 4 mg kg^{-1} soil. Such amounts are too low to cause a noticeable decrease in total P content. The cumulative P application was 125 kg P ha^{-1} and the cumulative amounts absorbed on the +P plots were 15 kg at Sites D and 25 kg P ha^{-1} at the other sites. Thus, the expected differences in total P between 1989 and 1991 are about 100 kg P ha^{-1} or 35 mg P kg^{-1} soil. This corresponds with the average difference found between the

Season 89-1 and 91-1. However, the variability is very high.

9.4 Concluding remarks

Maximum grain yields in Côte d'Ivoire of the used rice cultivar (IDSA 6, 125 days) and of the used maize hybrid (Pioneer 3274, 105 days) are 5.2 t ha^{-1} (Poisson and Doumbia,1986) and 7.0 t ha^{-1}, respectively. In this experiment, however, the highest rice yield was 2.5 t ha^{-1}, and it was obtained in the first season after clearing (89-1). The highest maize yield was 4.0 t ha^{-1}, obtained in the second season after clearing, which was the first season with maize (89-2). In 89-1 the highest EUP for rice of the -P treatment was about 900, while the corresponding value for maize did not exceed 700. Apparently rice can produce more grain per kg of absorbed P than maize, but it absorbs less P than maize. A possible reason for the latter is that the root system of rice is less extensive than that of maize. Yao et al. (1990) report that the major part of the roots of this rice cultivar is found in the upper 40 cm of the soil, which is shallow compared to other cultivars. No data on rooting of the used maize variety are known.

It was not possible to maintain yields at the initial level when the cropping period was extended. Applications of NP, NK, or PK, which were the treatments in this experiment, could not prevent the decline in yield.

The relation between yield and P uptake made clear that the decline in yield must be ascribed to a decrease in the efficiency of utilization of absorbed nutrients rather than to a decrease in nutrient uptake. The most probable cause of the yield decline is a deterioration of physical soil conditions. Such a change in physical conditions cannot be derived from the available soil analytical data of Table 9.7. The only property that may give some information on the physical soil conditions, organic carbon content, did not change. The crop residues were removed from the fields after each harvest and this may have caused lack of food for the soil fauna. A decrease in the number of soil animals may have resulted in poorer soil aeration and drainage and, through that, in poorer crop growth.

Generally a high gravel content is thought to influence the suitability of soils negatively. In this study, however, it was shown that the gravelly soils on the upper and middle slope of a catena representative of the Taï region have a higher chemical and physical soil fertility than the soils on the lower slope. A negative property of gravelly soils is the low water-holding capacity. When rainfall is well distributed, a low water-holding capacity has no strong effects on yields, as was found in all seasons except 1990-1. Only in the latter season this disadvantage of gravelly soils became evident.

The soils of the upper/middle and lower slope differed in their N and P supplies to crops. At the lower slope the N and P supplies were high in the first season after clearing but decreased rapidly in subsequent seasons. At the upper/middle slopes, the N and P supplies decreased as well but much less pronounced.
Differences in the decrease of inherent chemical and physical fertility and their dynamics among the soils of the upper/middle and lower slope may have been caused by differences in biological activity. Nooren et al. (1995) found that on the upper/middle slope of a comparable catena under undisturbed forest earthworm activity, as expressed by the number of worms and worm casts on the soil surface, was significantly lower than on the lower slope. The worm casts had a higher clay and organic matter content than the surrounding soil. Casts were easily disintegrated by rain splash and surface runoff. As the infiltration rate on the lower slope is lower than on the upper/middle slope (Wierda et al.,1989), erosion through surface runoff is most severe for soils on the lower slope. Consequently, the soils on the lower slope may impoverish more rapidly than the soils on the upper/middle slope.

Chapter 10

Optimum P management over extended cropping periods

Key words: apparent fertilizer recovery, Côte d'Ivoire, efficiency of nutrient utilization, potential P supply, optimum P fertilizer rate, maize, upland rice, soil chemical properties

Abstract

In the Taï region of south-west Côte d'Ivoire P is the yield-limiting nutrient on (moderately) well drained soils. In order to find the optimum P application rate, a factorial experiment (2N*4P*2K) in three replicates was conducted at two sites during six seasons. The factors investigated were N (0 and 50 kg N ha^{-1}), P (0, 12.5, 25 and 50 kg P ha^{-1}) and K (0 and 50 kg K ha^{-1}). N (urea) and K (muriate of potash) applications were split into two equal parts and broadcast. From the third season onwards the N application was raised to 100 kg N ha^{-1}. P (triple superphosphate) was placed near the young plants. Upland rice and maize were used as test crops. The experimental sites were located at the crest (Site VII) and lower slope (Site VIII) of a catena. At Site VII, applications of more than 12.5 kg P ha^{-1} did not result in significantly higher yields. At Site VIII, an aplication of 25 kg P ha^{-1} was sufficient. At this site also N application resulted in a positive response. In all seasons, except in the relatively dry season 90-1, yields were higher at Site VII than at Site VIII. The rice yield level could not be maintained. The efficiency of utilization of absorbed P (EUP) of rice was high in the first season after clearing but decreased in subsequent seasons. This is in contrast to EUP for maize which remained constant with time. Hence, it is concluded that the rice yield decline is caused by other factors than nutrient deficiencies. A probable factor is deterioration of physical soil conditions. The residual effect of fertilizer-P could reasonably well be described by a simple formula: $RFP_t = (0.9 - RFP_1)^{t-1} * RFP_1$, where RFP and RFP_1 are the apparent recovery fractions of fertilizer-P in year t and year 1, respectively. In all seasons, except in the first season after clearing, the potential P supply was higher at the crest (Site VII) than at the lower slope (Site VIII). Extending the cropping period proved possible when fertilizers were applied and maize was grown. For both sites fertilizer recommendations could be formulated. For the crest-upper slope a cropping period of four years and for the lower slope a three year-period is proposed. Comparison of soil chemical data (pH, organic C, total N and total P) before the start of the experiment and after six seasons did not show changes. At the +P plots the balance of P applied with fertilization and exported P with harvested products

was only partly recovered in the total P analysis.

10.1 Introduction

In the shifting cultivation system of the Taï region, south-west Côte d'Ivoire, phosphorus was found to be the yield-limiting nutrient on (moderately) well drained soils. Localized application of 50 kg P ha^{-1} resulted in a yield increase of upland rice of 0.4 to 1.1 t ha^{-1}, while the apparent recovery fraction of fertilizer-P varied from 3.3 to 6.9% (Van Reuler and Janssen, 1989; subm. a). When 50 kg P ha^{-1} was applied, grain production per kg absorbed P varied between 450 and 520. These efficiency of utilization values are well below 600, which is considered the maximum value for small grains (Van Keulen and Van Heemst, 1982). It was assumed therefore that the same yield increase could be established with lower P application rates.

This paper describes the results of two field trials carried out during six seasons. The objectives were to find the optimum rate of fertilizer-P, and to study the dynamics of soil and fertilizer-P. It was expected that gradually also other nutrients could become limiting. This hypothesis was based among others on the results of an experiment comparing the fertilizing effects of ash from burnt vegetation with the effects of mineral fertilizers (Van Reuler and Janssen,1996). It was found that per kg P absorbed from ash more grain was produced than per kg P absorbed from triple superphosphate (TSP). The difference suggests that other nutrients contained in the ash but not in TSP had improved the efficiency of utilization of absorbed P. Hence, it was decided to study the effects of other nutrients on yield and on the relationships between P uptake and yield as well.

The trials had a factorial design with four application rates for P and two for N and K. In the last season, the response to sulphur, magnesium and a mixture of trace elements was studied too.

In the first season after application of fertilizer-P, the apparent recovery fraction by the crop is usually about 10%. In case the application is repeated, the apparent recovery fraction of the latest P application may be overestimated due to the residual effect of previously applied P. The P which is not absorbed remains in the soil. The recovery fractions in subsequent seasons of residual P are lower than those during the season of application. An obvious cause of this is removal of P by the harvested crop. Another cause is the "aging" of P, ascribed to processes like diffusion into internal pores of soil particles and subsequent sorption onto internal sorption sites. The process of decreasing availability of residual fertilizer-P with time may be described as a transfer of P from the labile to the stable pool. On the basis of long-term field trials and modelling, it was concluded that each year a fraction of 0.2 of the labile pool is transferred to the stable pool (Janssen et al., 1987; Wolf et al., 1987). Janssen and Wolf (1988) showed that for easily soluble fertilizers, the residual effect during four or five years after a single dosis of P can be calculated by a simple equation: $RFP_t = (0.8\text{-}RFP_1)^{t-1} * RFP_1$, where RFP_t and RFP_1 are the apparent recovery fractions in year t and year 1, respectively. When fertilizer-P is applied every year the total effect after n years is the sum of RFP_1, RFP_2, RFP_3, ... and RFP_n.

10.2 Materials and methods

10.2.1 Study area

The environmental conditions of the experimental area and of the soil properties of the two sites were described elsewhere (Van Reuler and Janssen,subm. a). The trials were conducted at Sites VII and VIII of that study. The sites were cleared of 20-year-old (Site VII) and one-year-old (Site VIII) secondary vegetation, respectively. The vegetation was slashed, dried and burnt in the traditional way. The experiment was carried out in three replications. The experimental units had a size of 4 * 5 m. Fields were fenced against damage by rodents and, at maturing stage, guarded against bird (rice) and monkey (maize) damage.

10.2.2 Field trials

Two crops per year were grown, in the sequences shown in Table 10.1. Upland rice (*Oryza sativa*) was planted by means of a planting stick or machete. The average density was 100,000 plant holes ha^{-1} with 6 to 10 grains in each hole. The cultivar was IDSA 6 with a growth period of 125 days, except in Season 88-2 at Site VIII when cultivar IDSA 10 with a growth period of 100 days was planted. Maize (*Zea mays*, Pioneer 3274) with a growth period of 105 days was planted in rows (60 * 30 cm) resulting in 55,555 plants ha^{-1}. Maize was sprayed with an insecticide (Decis) against stalk borers. A detergent was added to increase the efficiency. In all seasons fields were weeded twice leaving the weeds as surface mulch. At harvest all crop residues were removed from the fields.

The factors investigated in the factorial experiment (2N * 4P * 2K) were N (0 and 50 kg N ha^{-1}), P (0, 12.5, 25 and 50 kg P ha^{-1}) and K (0 and 50 kg K ha^{-1}). N (urea) and K (muriate of potash) applications were split into two equal parts and broadcast at one week and at about seven weeks after planting. P (triple superphosphate) was placed one week after planting at approximately 8 cm from the plants at a depth of maximally 10 cm. From 89-1 onwards, the N rate was increased to 100 kg N ha^{-1} at both sites.

Table 10.1 Crop sequences at the two sites.

	Season						
Site	88-1	88-2	89-1	89-2	90-1	90-2	91-1
VII	rice	maize	rice	maize	rice	-	maize
VIII	rice	rice	rice	maize	rice	-	maize

In Season 91-1 sulphur, magnesium and a mixture of trace elements were included in the trial. The trials at both sites were combined into one experiment with a partially balanced incomplete block design (4P * 2^5 (N, K, S, Mg, trace elements) in three replications divided over two locations. S was applied as phosphogypsum at a rate of 30 kg S ha^{-1}, and Mg as $MgCl_2$ at a rate of 30 kg Mg ha^{-1}. The mixture of trace elements contained Cu (1.8 kg Cu ha^{-1} as $CuSO_4.5H_2O$), Mn (4.0 kg Mn ha^{-1} as $MnSO_4.H_2O$), Zn (8.0 kg Zn ha^{-1} as $ZnCl_2$), Mo (0.46 kg Mo ha^{-1} as $(NH_4)_6Mo_7O_{24}.4H_2O$ and B (1.1 kg B ha^{-1} as H_3BO_3. The mixture was sprayed about 54 days after sowing.

10.2.3 Soil and plant analysis

Composite soil samples (0-20 cm) were collected before the start of the trials. After six seasons each experimental unit was sampled. The samples were air-dried, thereafter the gravel content (> 2 mm) was determined and, next, the fine earth (< 2 mm) analyzed, according to Walinga et al. (1989).

At harvest grain samples of all treatments and, to a limited extent, straw- and panicle samples were collected for analysis. Plant samples were dried at 70 °C for 24 h, ground and analyzed as described in Van Reuler and Janssen (1993a). Separate grain samples were also dried at 105 °C, to allow calculation of grain yields at 14% moisture content.

10.2.4 Statistical analysis

Statistical analysis was carried out with the General Linear Model (GLM) procedure of the SAS statistical programme (SAS Institute Inc.,1989). In 91-1, all experimental units having received the trace element mixture had to be excluded (see below). Consequently, the number of experimental units per site was reduced from 48 to 24.

This would have resulted in a confounding of some treatments, but that could be avoided by combining the three P application rates into one (henceforth indicated as +P). This procedure was justified by the fact that there were no significant differences among P rates. Yields and nutrient uptakes were estimated by adjusted means (LSMEANS), when necessary.

10.3 Results

Grain yields and P uptakes of the main treatments obtained at the two sites are presented in Tables 10.2 and 10.3.

10.3.1 Rice

In Season 90-1, drought and termite damage reduced yields and nutrient uptakes. The reduction was severe at the well drained gravelly Site VII, but far less at the moderately well drained non-gravelly Site VIII. The gravelly soils of the Taï region have a low water-holding capacity which makes them susceptible to drought. The results of this season are reported for the sake of completeness, but they will not be discussed.

In Seasons 88-1 and 89-1, yields were significantly higher at Site VII than at Site VIII, reflecting differences in inherent soil fertility. Rice yields were mainly limited by P at Site VII, and by N as well as by P at Site VIII. Highest yields were obtained with an application of 12.5 kg P ha^{-1} at Site VII, and with a combination of N and 25 or 50 kg P ha^{-1} at Site VIII.

At both sites the P uptake increased with increasing P application rates. At Site VIII a positive response to N application was found as well.

10.3.2 Maize

At Site VII during three and at Site VIII during two seasons maize was grown. Yields of maize too were higher at Site VII than at Site VIII. Maize responded more strongly to nutrient application, in terms of both yield and P uptake, than upland rice. At both sites the optimum P was 12.5 kg P ha^{-1}. In contrast to yields the P uptake increased at higher application rates. At both sites the highest uptakes were found when 50 kg P ha^{-1} was applied.

At Site VII in all three seasons a significant N effect was found. At Site VIII the response to N aplication was significant in season 89-2 only.

Table 10.2. Grain yield (t ha^{-1}) and P uptake (kg ha^{-1}) of upland rice and maize at Site VII. Values within a column, for each of the nutrients, followed by the same letter are not significantly different ($P < 0.05$).

	Rice			Maize		
	88-1	89-1	90-1	88-2	89-2	91-1
Grain yield						
Control	2.55	1.57	0.80	1.85	1.46	2.64
N0	3.08 a	2.14 a	0.90	2.51 b	2.14 b	3.33 b
N1	3.33 a	2.27 a	0.80	3.69 a	3.97 a	4.13 a
P0	2.86 b	1.60 b	0.76	2.17 b	2.07 c	2.91 b
P1	3.42 a	2.40 a	0.82	3.33 a	3.06 b	
P2	3.35 a	2.50 a	0.94	3.46 a	3.58 a	4.55* a
P3	3.19 ab	2.33 a	0.85	3.45 a	3.52 ab	
K0	3.06 a	2.19 a	0.89	2.95 a	2.81 b	3.55 a
K1	3.34 a	2.22 a	0.82	3.25 a	3.30 a	3.91 a
- S						3.82 a
+ S						3.64 a
- Mg						3.67 a
+ Mg						3.80 a
P uptake						
Control	4.89	3.50	1.81	3.73	3.26	6.34
N0	6.48 a	6.46 a	3.00	7.24 b	5.49 b	9.37 a
N1	6.70 a	6.78 a	2.54	8.85 a	8.96 a	10.51 a
P0	5.01 b	3.95 c	1.73	5.03 c	4.15 c	6.66 b
P1	6.13 b	6.80 b	2.67	8.17 b	6.66 b	
P2	7.56 a	7.52 ab	3.46	8.82 b	8.50 a	13.22* a
P3	7.67 a	8.22 a	3.33	10.15 a	9.59 a	
K0	6.18 a	6.66 a	2.58	7.27 b	6.51 b	8.92 a
K1	7.00 a	6.59 a	2.96	8.81 a	7.94 a	10.96 a
- S						10.54 a
+ S						9.35 a
- Mg						9.58 a
+ Mg						10.30 a

* average of +P treatment combinations

In Season 91-1 no differences among different P application rates were found and the P treatments were combined into one +P rate in order to avoid confounding with other treatments. Statistical analysis of the combined results of the Sites VII and VIII showed significant Location, N, P effects and N*P interaction ($P<0.01$) and the K treatment was significant at $P<0.10$. No interaction between location and treatments was significant.

Table 10.3. Grain yield (t ha^{-1}) and P uptake (kg ha^{-1})of upland rice and maize at Site VIII. Values within a column, for each of the nutrients, followed by the same letter are not significantly different ($P < 0.05$).

	Rice				Maize	
	88-1	88-2	89-1	90-1	89-2	91-1
Grain yield						
Control	2.56	0.76	1.70	1.39	1.55	1.62
N0	2.77 b	0.98 b	1.94 b	1.57 a	1.94 b	1.97 a
N1	3.46 a	1.40 a	2.25 a	2.00 a	3.30 a	2.48 a
P0	2.62 c	0.85 b	1.68 c	1.60 a	1.83 b	1.73 b
P1	3.05 b	1.21 a	2.05 b	1.81 a	2.85 a	
P2	3.29 ab	1.25 a	2.22 ab	1.81 a	2.66 a	2.75* a
P3	3.49 a	1.46 a	2.42 a	1.89 a	3.13 a	
K0	3.15 a	1.15 a	2.26 a	1.74 a	2.30 b	2.01 a
K1	3.08 a	1.24 a	1.92 b	1.83 a	2.93 a	2.44 a
- S						2.40 a
+ S						2.06 a
- Mg						2.25 a
+ Mg						2.20 a
P uptake						
Control	4.91	1.59	4.17	4.48	2.57	2.82
N0	5.17 b	3.66 b	6.18 b	5.90 b	4.81 b	3.96 a
N1	6.47 a	4.61 a	7.82 a	7.21 a	7.28 a	5.49 a
P0	4.42 b	1.99 c	4.51 c	5.17 c	3.17 c	2.41 b
P1	5.59 b	3.84 b	6.75 b	6.39 b	5.89 b	
P2	6.30 ab	4.48 b	7.57 ab	6.90 ab	6.65 b	7.03* a
P3	6.99 a	6.22 a	9.18 a	7.75 a	8.47 a	
K0	5.91 a	3.93 a	7.61 b	6.50 a	5.56 a	4.56 a
K1	5.74 a	4.34 a	6.39 a	6.61 a	6.53 a	4.88 a
- S						4.80 a
+ S						4.64 a
- Mg						5.30 a
+ Mg						4.15 a

* average of +P treatment combinations

In 91-1 the response to trace elements was studied as well. After spraying the mixture of trace elements, however, leaves died within 48 h, and all experimental units having been sprayed had to be excluded. A greenhouse experiment where maize was sprayed with each of the compounds of the trace element mixture separately, revealed that leaves died only when sprayed with $ZnCl_2$. Leaves also died when sprayed with $ZnSO_4$, thus indicating that Zn was responsible.

10.3.3 Apparent recovery fraction of applied N and P

The apparent recovery fractions of applied N (RFN) and P (RFP) are presented in Table 10.4. The RFN is calculated for the P+ and the RFP for the N+ treatments. At Site VII the RFN of maize is higher than of rice, while at Site VIII values are similar for both crops. The highest RFP values are found for the P1 treatments, except at Site VII in 88-1. The RFP values increase for both crops with time. P application was repeated each season and the RFP encompasses the residual effect. The low RFP values of rice at Site VIII in 90-1 suggest that also at this site rice suffered from drought.

Table 10.4 Recovery (%) of applied N (+P treatments) and P (+N treatments) at the two sites in the different seasons.

	Site VII						Site VIII					
	rice			maize			rice				maize	
	88-1	89-1	90-1	88-2	89-2	91-1[a]	88-1	88-2	89-1	90-1	89-2	91-1[a]
N[b]	23.2	15.9	-	62.3	35.6	45.0	34.6	40.6	30.5	25.3	23.6	36.2
P1	10.4	21.8	-	29.3	27.1	59.2	7.0	16.6	19.3	6.8	25.0	36.9
P2	14.2	15.4	-	14.2	21.3	34.8	8.4	10.1	9.8	6.4	16.7	20.3
P3	6.8	8.0	-	11.1	15.7	12.0	7.1	10.1	9.3	4.4	12.3	11.7

[a] P recovery data biased due to confounding
[b] from Season 89-1 onwards the N application rate was increased from 50 to 100 kg N ha^{-1}

10.4 Discussion

10.4.1 Efficiency of utilization of absorbed nutrients

In Fig. 10.1 the efficiencies of utilization of absorbed P (EUP) for rice and maize of N+ treatments are presented. These figures also show the maximum dilution (YPD) and accumulation (YPA) of absorbed P, as established for maize by Janssen et al. (1990). The EUP of rice was near its maximum value of 600 at both sites in Season 89-1 but decreased substantially afterwards, most prominent at Site VIII. Because P uptake did not decrease, it is concluded that P was still available, but could not efficiently be used.
The EUP for maize did not decrease with time, in contrast to that of rice.

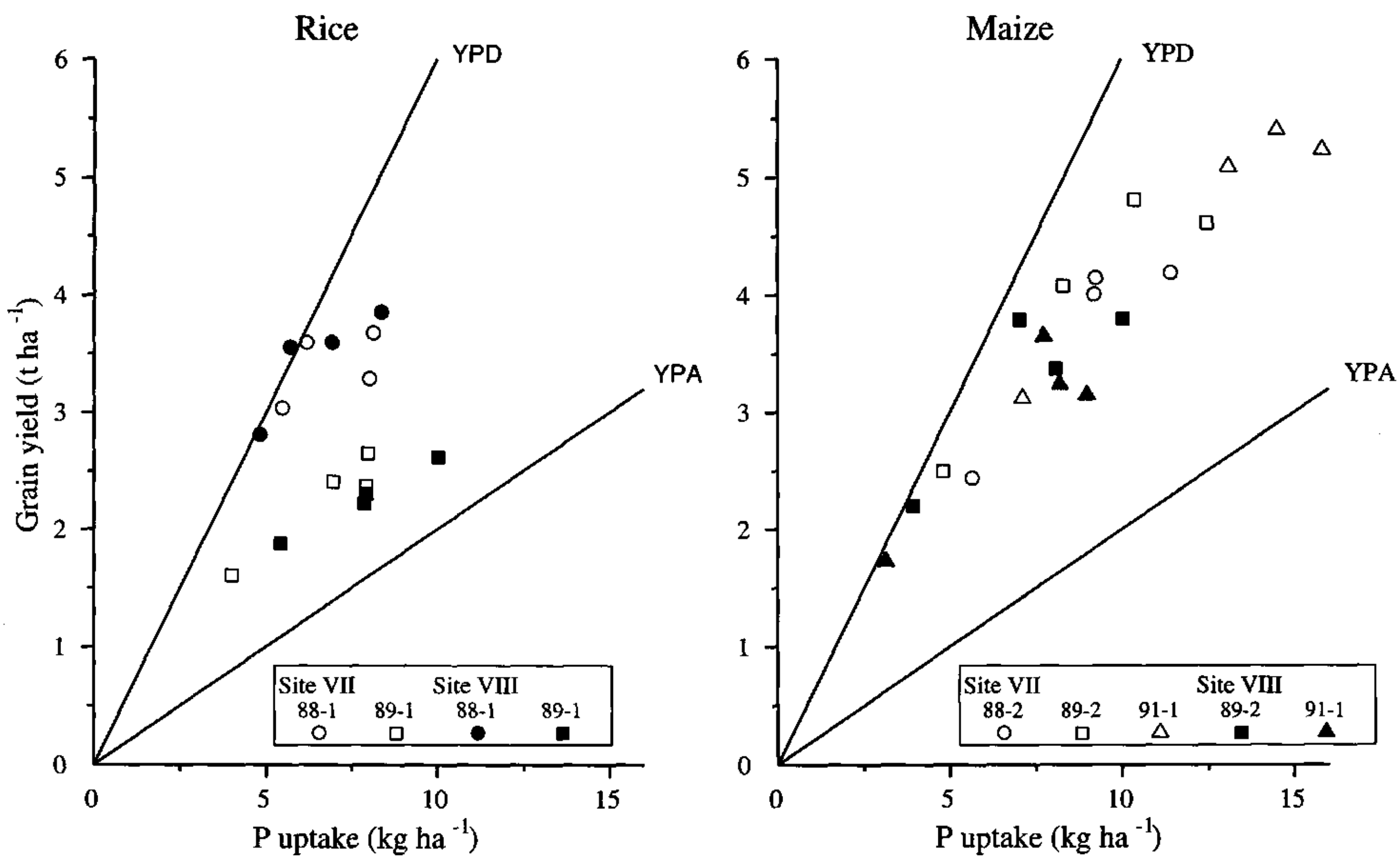


Fig. 10.1 The efficiencies of utilization of absorbed P for rice and maize in different seasons at the Sites VII and VIII. YPD and YPA indicate the maximum dilution and maximum accumulation of absorbed P, respectively

The EUP's were equal for rice and maize at comparable amounts of absorbed P. However, maize could absorb more P than rice and at higher amounts absorbed the EUP of maize decreased.

In another experiment in the Taï region (Van Reuler and Janssen,subm. c), it was found that the EUP for maize decreased with time as well. The two studies differ in the way the fields were cleared. In the present study the slashed vegetation was burnt, while in the other experiment the slashed vegetation was removed from the fields. Another difference is that in the present experiment NPK treatment combinations were included, while in the former only NP treatment combinations occurred.

It is often found that yields decline when rice is grown continuously. The decline is thought to be caused by soil pathogens, nutrient depletion, soil structure deterioration or accumulation of toxic substances (Gupta and O'Toole,1986). From the fact that maize can maintain its EUP and rice not, it is concluded that the decline in EUP is caused by factors to which rice is susceptible and maize not.

10.4.2 Residual effect of fertilizer-P

The apparent recovery fraction (RFP) was calculated by the equation of Janssen and De Wolf (1988):
$RFP_t = (0.8\text{-}RFP_1)^{t-1} * RFP_1$, where RFP_t and RFP_1 are the apparent recovery fractions in year t and year 1, respectively. In this study two crops per year were grown and therefore the factor 0.8 was changed into 0.9, and t expressed in seasons. Because upland rice and maize differ in their capacity to absorb fertilizer-P, RFP_1 obtained for rice could not be used for maize. The first time that maize was grown was Season 1988-2, on Site VII. The recovery in this season consisted of a first season recovery and a residual response to P that was applied to rice in 1988-1. Hence, the measured recovery of maize in 1988-2 (RFP_{1+2}) can be described by:

$$RFP_{1+2} = RFP_{1\ maize} + RFP_{1\ maize} * (0.9\text{-}RFP_{1\ rice})$$

$RFP_{1\ maize}$ was derived from this equation, and turned out to be 16.3%. This value was also used for Site VIII.

In Fig. 10.2 the calculated and measured recovery fractions are compared for the N1P1 treatments at both sites. In three out of eight comparisons the calculated RFP values are much higher than the measured ones. In Season 90-1 for Site VIII it is clear that drought has influenced maize growth negatively. The growth conditions were apparently low at both sites. For the other two seasons no explanation for the difference is available.

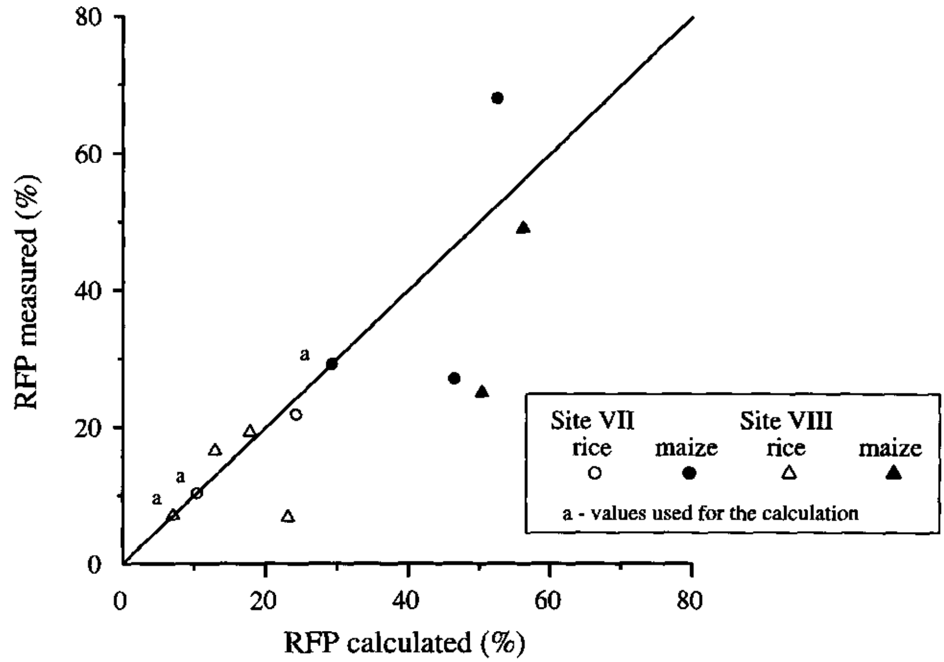


Fig. 10.2 Comparison of the calculated and measured apparent recovery fractions of fertilizer-P (RFP).

10.4.3 Potential soil P supply

P uptake in the N1P0 treatments is used as indicator of the potential soil P supply. Based on the EUP it can be assumed that only in the first season after clearing rice growth was limited by P only, and hence only that rice season could be used for the estimation of the maximum amounts of P absorbed. Because for maize EUP did not decrease with time, all maize seasons could be used. Thus in Fig. 10.3, the first season supply is from rice and those in subsequent seasons from maize. In all seasons, except 88-1, the potential P supply at Site VII was higher than at Site VIII. At Site VIII in Season 89-2 the potential P supply was lower than in Season 88-1. There is a continued decrease at Site VIII while at Site VII in Season 91-1 higher amounts were absorbed than in the preceding seasons. Two factors may have contributed to the increase of the potential P supply at Site VII in Season 91-1. Firstly, the growth conditions in the first season were better than in the second season due to higher radiation (Collinet et al.,1984). Secondly, the fallow Season 90-2 may have had a positive effect on the potential P supply in the following growing season. At Site VIII these effects could not avoid a further decrease in potential P supply.

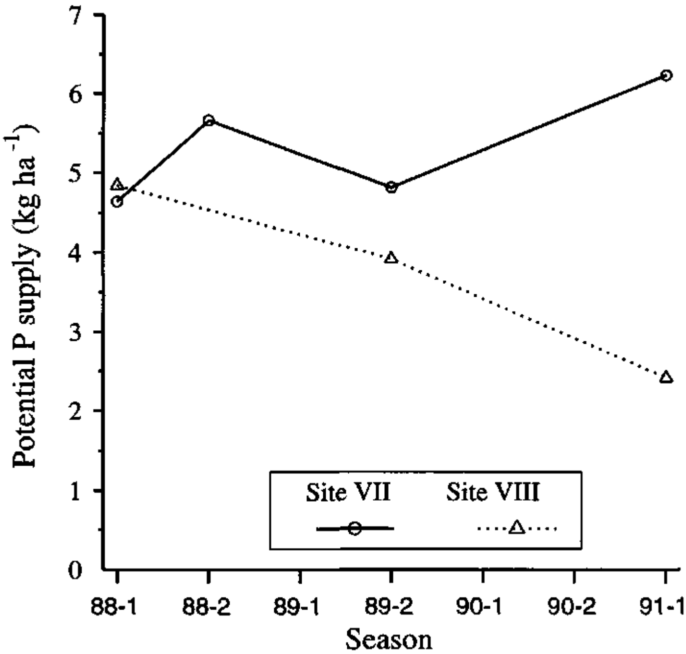


Fig. 10.3 Potential soil P supply of the Sites VII and VIII.

10.4.4 Soil chemical properties

In Table 10.5 the soil chemical properties before the start of the experiment in 88-1 and after the last harvest in 91-1 are presented. No differences between the two sampling dates in pH, organic C, total N and total P (-P plots) were found. In many studies (Brams,1971; Sanchez et al. 1983; Mueller-Harvey et al.,1985,1989) a decrease in organic matter content during extended cultivation was found. In this study the organic C content shows an increase instead of a decrease. The same trend was found in another study in the Taï region (Van Reuler and Janssen,subm. c).

In the plots sampled in 91-1 the cumulative application was 150 kg P ha^{-1}, and about 50 kg P ha^{-1} was exported. The expected differences in total P between Season 89-1 and 91-1 are 100 kg P ha^{-1} or 35 mg P kg^{-1} soil. At Site VII this balance was almost completely recovered in the topsoil and at Site VIII only partly.

Table 10.5 Soil chemical properties before the start of the experiments (88-1) and after the last harvest (91-1).

	Site VII			Site VIII		
	88-1	91-1		88-1	91-1	
		-P	+P		-P	+P
pH	6.2	6.7	6.3	5.6	5.4	5.2
Org C (g kg^{-1})	11.7	17.3	16.0	9.8	13.7	13.0
total (N g kg^{-1})	0.12	0.11	0.10	0.08	0.08	0.08
total P (mg kg^{-1})	152	150	179	110	101	115

10.5 Conclusions

The crop performance on the gravelly well drained soils (Site VII) of the crest-upper slope of a catena was in each season better than the performance on the non-gravelly moderately well drained soils on the lower slope (Site VIII). A drawback of the gravelly soils is the low water-holding capacity, but this can be overcome by a well distributed rainfall.

In this experiment it was shown that cropping can be extended successfully when N and P fertilizers are applied, and maize is grown. The rice yield level, however, could not be maintained at the first-season level. The efficiency of utilization (EUP) of absorbed P for rice decreased with time, while the EUP for maize remained constant. It was concluded that rice yield decline was caused by extraneous factors to which rice is susceptible and maize not. Therefore in an extended cropping system upland rice can be grown only once or twice.

Fertilizer recommendations for soils at the crest/upper slope during such an extended cropping system are given in Table 10.6.

In the first season after clearing the soil supplies enough N for crops grown. In subsequent seasons the N application is based on an average efficiency of N utilization of 50, indicating that per 4 t grain 80 kg N ha^{-1} is absorbed. In order to compensate for this removal by the crop and for losses out of the soil-plant system 100 kg fertilizer-N ha^{-1} is recommended.

Table 10.6 Fertilizer recommendation (kg nutrient ha^{-1}) for a rice target yield of 3.5 t ha^{-1} and a maize target yield of 4 t ha^{-1}. N and K applications are split into equal parts and broadcast. P application is placed.

	Season							
	1 rice	2 maize	3 maize	4 maize	5 maize	6 maize	7 maize	8 maize
All crop residues are removed from the field								
N	-	100	100	100	100	100	100	100
P	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
K	-	-	-	-	-	-	-	-
All crop residues are left on the field								
N	-	75	75	75	75	75	75	75
P	10	10	10	10	10	10	10	10
K	-	-	-	-	-	-	-	-

Burning the slashed vegetation supplies about 10 kg P ha^{-1} (Van Reuler and Janssen,1993a). P application rate is based on an average efficiency of P utilization of 400, indicating that per 4 t grain 10 kg P ha^{-1} is absorbed. An application of 12.5 kg P ha^{-1} will compensate for removal by the crop and P sorption processes. In subsequent seasons the residual effect of repeated fertilizer-P applications will compensate for depletion of ash-P.

The response to K application was erratic. In the first two seasons after clearing the soil K supply is sufficient. In subsequent seasons an application of 50 kg K ha^{-1} is recommended.

These recommendations are based on experiments in which all crop residues were removed from the field. In case all residues are left behind on the field the application rates can be reduced substantially.

About 70% of the absorbed N is exported from the fields with grain, i.e. 56 kg N ha^{-1} and the N application rate can thus be reduced to 75 kg N ha^{-1}. Also about 70% of absorbed P is exported with grain, i.e. 7 kg P ha^{-1}, and the P application rate can be reduced to 10 kg P ha^{-1}. The export of K with grain is less than 10 kg K ha^{-1}. This amount can easily be supplied by the soil.

The recommendation differs slightly for soils at the lower slope. The target grain yield for the moderately well drained soils is 3 t ha^{-1} and the proposed cropping period three years. Due to the lower target yield the N application can be reduced to 80 kg N ha^{-1}, but it is recommended from the first season after clearing onwards. At these sites, 25 kg P ha^{-1} is recommended in the first and second season after clearing, which can be reduced from the third season onwards to 12.5 kg P ha^{-1}. The K application remains the same as for the well drained soils. In case all crop residues are left behind on the fields the N application rate can be reduced to 60 kg N ha^{-1}, the P application rate to 10 kg P ha^{-1} and no K needs to be applied.

Part V

Synthesis

Chapter 11

Major conclusions and outlook

11.1 Introduction

Intensification of food crop production in shifting cultivation systems can take place by extending the cropping period, by shortening the fallow period, by improving crop management and thus increasing yields per ha per season, or by combinations of these measures. In this thesis, attention was focussed on intensification through extending the cropping period and increasing the yields per ha per season. Extension of cropping periods usually results in yield decline being the reason for abandoning fields. Hence, the research was concentrated on measures for maintaining the yield level with emphasis on nutrient management. Therefore, on-farm field trials with controlled management were conducted. In these trials upland rice and maize were grown as test crops. In all experiments crop residues were removed to allow maximum nutrient supply of the soils to be studied.

In south-west Côte d'Ivoire, the Taï National Park is threatened by a structural increase in population density in the region. For instance, in the sous-préfecture Taï the population density rose from 4.1 persons per km^2 in 1965 to 34 in 1988. Consequently, more land is needed for food crop production. Increasing the agricultural production is considered to be the most realistic and most feasible way to reduce the pressure on the Park.

In this Chapter the main results of this study will be discussed. Thereafter, based on these results, some practical implications will be formulated. Finally, some questions still remaining in relation to the intensification of food crop production in the Taï region are examined.

11.2 Main results of the present study

11.2.1 Yields and major nutrient fluxes in the traditional shifting cultivation system

On traditionally cleared fields, upland rice yields varied in the first season after clearing from 1.5 to 3.8 t ha^{-1}. These yields were obtained without use of inputs but with controlled management (timeliness of clearing, appropriate planting material, weeding, fencing and guarding at maturing stage). The range reflects differences in inherent fertility among sites. The average farmer's yield is 1 t ha^{-1}. The differences between farmer's yields and those at the experimental sites indicate the effect of improved crop management. For a grain yield of one ton rice 20-35 kg N, 1.5-2.7 kg P and 19-37 kg K were absorbed by the above-ground plant parts. In case all crop residues were left on the field, per ton grain 12-15 kg N, 1.1-1.8 kg P and 1.6-2.3 kg K were exported from the fields.

11.2.2 Relation between soil fertility and the position of the soils on the slope of the characteristic catenas in the Taï region

The soils of the Taï region form typical catenas (toposequences), which are representative of an area of about 350,000 ha. The gravelly soils of the crest, upper and middle slope are well drained. The non-gravelly soils of the lower slope are moderately well to imperfectly drained, while those of the valley bottom are poorly drained. The inherent fertility of the soils is low. Field trials were executed at locations ranging from the crest to the fringe of the valley bottom.

In the first season after clearing, P was the main limiting nutrient for crop growth on the well and moderately well drained soils. On the imperfectly drained soils no response to P application was found which is partly explained by the higher available-P content of these soils compared to the better drained soils. The soils of the upper part of the catena with up to 80% gravel proved much better than gravelly soils are generally assumed to be. The drawback of their low water-holding capacity is not prohibitive for a good crop performance when rainfall is well distributed.

11.2.3 Effect of burning

Burning the slashed vegetation supplies nutrients to crops grown. Moreover, burning reduces the degree of weed infestation during the cropping period. At two sites cleared from 4- and 20-year-old secondary vegetation, burning produced about 2.5 t ash per ha. With this quantity of ash 26 kg N, 8-11 kg P, 70-124 kg K, 118-125 kg Ca, 42-47 Kg Mg, 5-6 kg Mn and 0.3 kg Zn were supplied. In the first season after clearing, burning almost doubled the rice yield compared to non-burnt fields. The residual effect of burning the slashed vegetation lasted at least two seasons. Thereafter the difference in yields between burnt and non-burnt plots disappeared.

11.2.4 Fertilizing value of ash

A 20-year-old secondary vegetation was slashed, dried, piled and burnt. The fertilizing value of the ash produced was compared with that of N, P, K fertilizers and lime. The response to ash application was mainly a P effect. The relative effectiveness, defined as the ratio of the crop recovery of ash-P to the crop recovery of fertilizer-P, was 0.67. This implies that for the uptake of a unit P, 1.5 times as much ash-P as fertilizer-P should be applied. The effectiveness of ash as liming material was 0.59 compared to that of $Ca(OH)_2$, hence 1.7 times as much ash as burnt lime is needed to bring about a same increase in pH.

The efficiency of utilization of absorbed ash-P was higher than the efficiency of absorbed triple superphosphate-P. No conclusive explanation for this difference could be given.

11.2.5 Optimum application rate of phosphorus, the most limiting nutrient

On well drained soils application of 12.5 kg fertilizer P ha^{-1} increased the yield of upland rice with at least 0.5 t ha^{-1} and of maize with at least 1 t ha^{-1}. On the moderately well drained soils application of 25 kg P ha^{-1} was necessary for establishing the same yield responses. Higher P application rates resulted in higher P uptakes but not in higher yields.

11.2.6 Soil characteristics for the evaluation of soil fertility

As P is the main limiting nutrient for crop growth, an attempt was made to establish a relationship between the availability of this nutrient and other soil properties of traditionally cleared fields. The same was done for the apparent recovery fraction of fertilizer-P. The parameters used to estimate the soil P supply were P-Dabin, total P and pH. The apparent recovery fraction of fertilizer-P was best described by an equation including silt-plus-clay content, P-Dabin and/or total P. Both relations improved substantially by expressing the values of soil properties on the basis of total soil volume rather than on that of the fine-earth mass.

11.2.7 Yields during extended cropping periods

Fig.11.1 presents four different fertilizer treatments (+N means only N was applied, etc.) the yield development on a site located at the upper slope (Site IV). In the period 1987-1991, four rice (A) and four maize crops (B) were grown. In 87-2 the maize yield was severely reduced by insect damage, and the results are therefore not included.

It is evident that application of N, P and K is not sufficient to maintain the yield level of upland rice. The yield - P uptake relations show that the efficiency of utilization of absorbed P by rice decreased with time. This decrease indicates that other factors than P deficiency caused the yield decline. Probable causes are deterioration of the physical soil fertility, allelopathy, nematodes or a combination of these factors.

Also maize yield decreased with time. However, the decrease was much less pronounced than for rice. P application increased the maize yield significantly, while the N*P interaction was significant as well. In 91-1 application of N, P and K resulted in yields of over 4 t ha^{-1}. The efficiency of utilization of absorbed P for maize did not decrease, or only slightly so with time.

11.2.8 Change in soil fertility during subsequent growing seasons

The change in soil N and P supplies with time was different for the soils at the various positions along the catena. In the first season after clearing, all sites supplied about the same amount of N. In subsequent seasons, however, the N supply of sites located at the lower slope decreased sharply and was significantly lower than the supply at the upper slope. At the upper/middle slope the supply also decreased, but less pronounced.

In the first season after clearing the imperfectly drained site supplied the highest amount of P. In subsequent seasons P supply at the upper/middle slope remained stable, whereas at the lower slope a significant decrease was found.

In this study, chemical soil properties could not explain why crop yields declined. Only pH decreased with time, but other soil parameters, like total P and organic C content, did not change.

11.3 Practical implications of the research outcomes

11.3.1 Prerequisites for extending the cropping period

Prerequisites for growing two crops per year and/or for extending the cropping period to more than one year are that fields are timely cleared, and that appropriate planting material, fertilizers and insecticides are available. Moreover, at least one round of weeding is necessary and fields need to be protected against animal damage

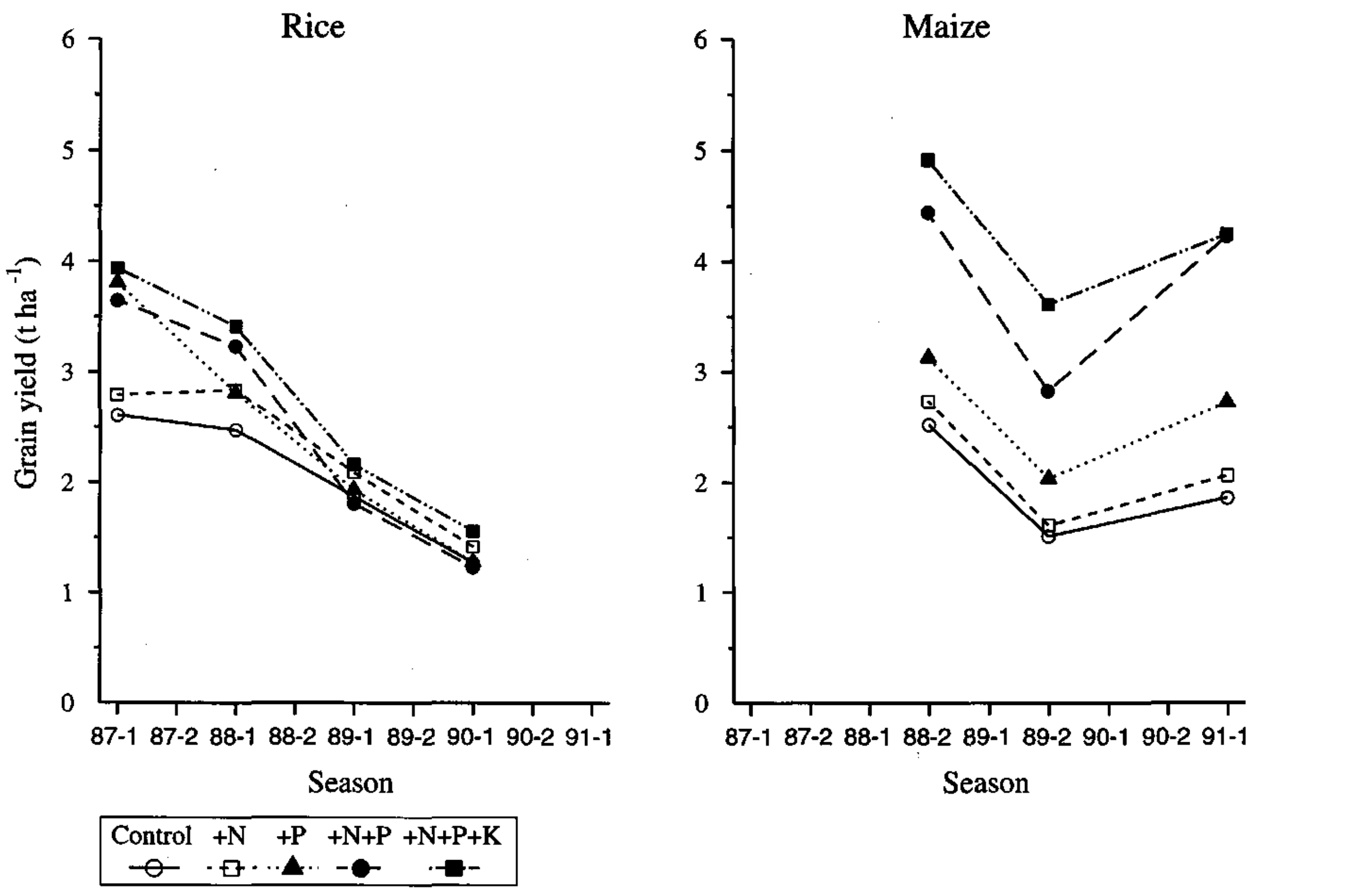


Fig. 11.1 Yields of upland rice and maize for different fertilizer treatments in the period 1987-1991. +N means only N was applied etc.

(birds, monkeys and rodents). Farmers need training for an efficient use of the inputs. Therefore, assistance by extension workers will be necessary.

11.3.2 Rice and maize during the long and short rainy seasons

In our experiments upland rice and maize were grown as test crops. In an extended cropping period rice yield declined due to other reasons than deficiencies of N, P or K. Consequently in an extended cropping period upland rice can be grown only once or twice. The first growing season lasts from April to August (120 days) and the second from August to November (105 days). In this study usually upland rice was grown in the first season and maize in the second. Due to higher radiation the growing conditions in the first season are usually better than in the second.

11.3.3 Fertilizer recommendations

It was shown that the cropping period can be extended when fertilizers are applied (see 11.2.7). For the well drained soils of the crest, upper and middle slopes over a period of at least eight seasons crops can be grown. In Table 1 the fertilizer recommendations for such a cropping system are presented. Two cases are distinguished, with and without removal of all crop residues. In case crop residues are left on the field the N and P application rates can be reduced and no K application is necessary.

Table 11.1 Fertilizer recommendation (kg nutrient ha^{-1}) for a rice target yield of 3.5 t ha^{-1} and a maize target yield of 4 t ha^{-1}. N and K applications are split into equal parts and broadcast. P application is placed.

	Season							
	1 rice	2 maize	3 maize	4 maize	5 maize	6 maize	7 maize	8 maize
All crop residues are removed from the field								
N	-	100	100	100	100	100	100	100
P	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
K	-	-	50	50	50	50	50	50
All crop residues are left on the field								
N	-	75	75	75	75	75	75	75
P	10	10	10	10	10	10	10	10
K	-	-	-	-	-	-	-	-

For the moderately well drained soils of the lower slope a three-year cropping period is proposed. For the same target yields from the first season onwards 100 kg N ha^{-1} should be applied. The first two season after clearing 25 kg P ha^{-1} is required, from the third season onwards the P application rate can be reduced to 12.5 kg P ha^{-1}.

At most locations the imperfectly drained soils of the narrow fringe of the valley bottom are only suitable for rice cultivation. These sites can be used for two seasons without fertilizer application.

11.3.4 Economical profitability of fertilizer use

Fertilizers and other inputs are expensive and their use needs to be profitable. At this moment no fertilizers are available in the Taï region. Therefore, the 1995 prices in the capital Abidjan at 600 km from Taï are used: 391 FCFA[1] per kg N (urea), 912 FCFA per kg P (triple superphosphate) and 227 FCFA per kg K (KCl). In case all crop residues are left on the fields the maximum fertilizer input would cost per season FCFA 38,445 ha^{-1}.

It is often stated that the value cost ratio (VCR), defined as the incremental value of production divided by the incremental costs of fertilizer use, should be at least 2 in order to induce farmers to use fertilizers. The average maize yield response to these fertilizer inputs is about 2 t ha^{-1}. In order to obtain a VCR of at least 2, the price of one kg maize needs to be higher than FCFA 39.

11.4 Remaining questions and suggestions for further research

11.4.1 Increasing the efficiency of fertilizer use

In our experiments the apparent recovery fraction of fertilizer N was low. The main processes through which N may become lost are: runoff, immobilization, leaching, volatilization and denitrification. Runoff losses may occur, although high hydraulic conductivity and rough soil surface as found in the Taï region are likely to prevent runoff over long distances. In shifting cultivation systems fields are never totally cleared, and micro-organisms responsible for the decomposition of the remaining woody materials and roots may immobilize part of applied N and P, as suggested by Braakhekke et al. (1993). Part of the N will be lost by leaching, because there is a rainfall surplus during the growing season. Leaching is probably the main process

[1]FCFA = Franc Communauté Financière Africaine
100 FCFA = 1 FF (French Franc)

by which N is lost. N loss through volatilization is prominent in areas with high pH. Despite generally low pH levels of the soils in the Taï region, through ash addition locally higher pH levels may occur and then ammonia may volatilize. The drainage classes of the experimental sites varied from well drained to poorly drained. With respect to denitrification heavier losses are to be expected on the poorly drained soils.

The main processes through which K may become lost are runoff and leaching. For loss through runoff the same applies as for N. Losses of K through leaching are probably more important than through runoff. The ECEC values of the soils in the Taï region are low, and calculations show that applied K can therefore not be retained by the existing exchange complex. Therefore, a large part of applied K will be lost due to leaching.

Attempts to increase the efficiency of fertilizers should aim at preventing losses by increasing the recovery by plants. Possible measures are: placing the fertilizers near the plants instead of broadcasting, working the fertilizers into the soil instead of broadcasting and, three split applications instead of two.

11.4.2 Other soil fertility problems

11.4.2.1 Trace elements

Application of N, P and K could not prevent yield decline of maize when the cropping period was extended (see 11.2.7). The question arises whether nutrient deficiencies or other factors cause the decline. In this study no responses to S and Mg application were found. Unfortunately, the experiments in which the responses to trace elements were studied failed. At an experimental site located near Taï the efficiency of utilization of ash-P was found to be higher than that of fertilizer-P (see 11.2.7). A possible explanation for this difference is that on this field one or more micronutrients may have turned deficient as a result of the probably frequent cultivations due to its location at a short distance of the village. With the ash these micronutrients may have been applied. If true, such deficiencies may also develop at other sites. In comparable areas Zn deficiency was found (Kang and Juo,1984).

11.4.2.2 Physical soil fertility

In an extended cropping system with applications of N, P and K, the yield level of upland rice and maize could not be maintained. The yield decline of upland rice, however, was much more pronounced than the yield decline of maize. As main causes for the rice yield decline are reported allelopathy and nematodes. For both crops the yield-P uptake relation showed a decrease in efficiency of utilization of absorbed P. A probable reason for the decrease for maize might be deterioration of soil physical conditions. The activity of the soil fauna may have decreased by removal of crop residues being an important food source. It needs to be studied whether by leaving behind all crop residues maize yield level can be maintained. If so, further extension of the cropping period is possible.

11.4.3 Length of fallow period in intensified systems

Intensification of food crop production by extending the cropping period will increase the degree of weed infestation. The predominant types of weed species also change. Weed control will ask a great effort of farmers. The type of regrowth that will develop on abandoned sites depends on the length of the cropping period. After a short cropping period the regrowth will be dominated by *Chromolaena odorata*, which use as a fallow vegetation was extensively studied by Slaats (1995). In case of a longer cropping period grasses will dominate the regrowth. The question arises how to stimulate vegetations that are efficient in suppressing weeds and accumulating nutrients.

11.5 Alternatives to shifting cultivation

In the Taï region of south-west Côte d'Ivoire intensification of food crop production is directly related to the protection of the Taï National Park. The need for intensification of shifting cultivation is, however, a universal problem. Intensification can also contribute to the limitation of emission of greenhouse gasses. It is estimated that 15 to 25% of the global warming is due to clearing of tropical rainforests, which is occurring now at an annual rate of 7 million hectares (Sanchez,1993). The same author states that people do not cut rainforest because they like to, but because they need to grow more food. Sustainable management practices can therefore contribute to the reduction of deforestation.

For every ha put in these sustainable soil management technologies by farmers, 5 to 10 ha year^{-1} of tropical rainforests may be saved from the shifting cultivators' ax, because of higher soil productivity.

Table 11.2. Estimates of the amount of land saved through using alternative management systems in Yurimaguas, Peru (Sanchez,1993).

1 ha managed under sustainable option	ha saved from deforestation annually
Flooded rice	11.0
Low-input cropping (transitional)	4.6
High-input cropping	8.8
Legume-based pastures	10.5
Agroforestry systems	to be determined

Which option is most suitable for a certain region depends on the local conditions. Agboola (1994) states that combining agronomic technology with local environmental knowledge will probably help to develop a sustainable system that can replace shifting cultivation. Any attempt to increase food production should start with optimizing crop management.

11.5.1 Flooded rice

Flooded rice is an alternative in regions where water, labour and technology are available. A consortium of national and international research institutes (West African Rice Development Association, International Institute for Tropical Agriculture, Agricultural University at Wageningen, The Netherlands) is executing a programme on the sustainable use of valley bottoms for rice cultivation (Anonymous,1993). The first results of this programme have been published by Andriesse et al. (1994). This research may yield options which are also useful for the Taï region.

11.5.2 Low- and high-input cropping

The low external input option is regarded as a transition technology to other options. According to Sanchez and Salinas (1981) low-input technologies should be used on soils with a low chemical fertility where, because of soil properties, landscape position and market accessibility, low-input technology has a comparitive advantage over high-input technology. The best land in terms of soil productivity, access to markets and other advantages can be managed more efficiently with higher external input technologies. Sometimes low external input agriculture is equated with sustainable agriculture. This is, however, not necessarily true. Application rates of nutrients should be high enough to compensate for the nutrients exported with harvested products, which implies that high doses are needed when yields are high. The nutrient budget is a useful tool to check sustainability (Smaling et al.,1993).

11.5.3 Legume-based pastures

On land cleared by slash-and-burn practices the nutrients supplied with the ash enable a rapid pasture development. Another possibility is to interplant crops with pasture species so that when the crop is harvested, the pasture is established. Management of the established pasture, including soil fertility maintenance, is necessary to maintain its initial productivity and botanical composition (Sanchez and Salinas,1981). The pasture option may work well in Latin America, but is not a suitable option for the Taï region due to tsetse fly infestation.

11.5.4 Agroforestry systems

In some regions of the humid tropics agroforestry techniques have been successfully introduced as alternatives to shifting cultivation. However, most research has been conducted on chemically rather rich non-acid soils, while the dominant soils in the humid tropics are chemically poor and acid (Kang et al.,1990). Szott et al. (1991) summarized the results of six years of agroforestry research on the acid soils of the Yurimaguas region in Peru. The aim of this project was to study whether the three main functions of agroforestry, viz. nutrient recycling, soil organic matter maintenance, and protecting soils from erosion, can be attained in acid soils. Three agroforestry systems were tested for their abilities to overcome the specific problems of the Yurimaguas region: alley cropping, managed leguminous fallows to accelerate the restoration of soil fertility and reduce the length of the fallow period, and fruit tree-annual crop sequential cropping systems.

11.5.4.1 Alley cropping

The main benefit of alley cropping is the recyling of nutrients through prunings. However, on soils with a low inherent chemical fertility the benefits of alley cropping were strongly reduced due to competition of the food crops with the hedges. At these soils P proved to be the most limiting nutrient. Szott et al. (1991) concluded that alley cropping should not be recommended for continuous cropping on acid soils. Recently Sanchez (1995) expressed in a keynote address to the World Forestry Congress his disappointment in the possibilities of alley cropping.

11.5.4.2 Managed fallows

Several leguminous species were identified as growing well on acid soils. It was found that leguminous fallows may decrease the length of the fallow period for shifting cultivation. Several species suppressed weeds and restored soil fertility more rapidly than natural secondary vegetation. In case the fallow includes trees or other vegetation that produces economically important products its adaptation by farmers is more likely.

11.5.4.3 Fruit tree option

The Yurimaguas region proved to have a high potential for fruit tree production systems. Fruit trees were interplanted with food crops, upland rice and cowpea, for one or two years. Thereafter a leguminous cover crop was planted for soil protection, weed control and source of nitrogen and organic matter. Szott et al. (1991) did not report on the marketing of fruits and other products. Generally shifting cultivation areas are quite remote and marketing of products may be a constraint.

11.5.5 Which option is suitable for the Taï region?

Several options for intensification of food crop production on (moderately) well drained soils are available for farmers in the Taï region. Any option should take into account that the yield on these soils is limited by P and that P application will be necessary.

11.5.5.1 Natural fallow vegetation

In the traditional shifting cultivation system fields were abandoned after one or two seasons and the fallow period lasted at least 15 years. In case the cropping period is extended, the re-establishment of the forest will be hampered. On fields abandoned after a short cropping period a vegetation dominated by *Chromolaena odorata* will develop. Slaats (1995) studied the use of *C. odorata* as fallow vegetation. A system of one maize crop followed by three years *C. odorata*-dominated fallow proved to work well in terms of yield and re-establishment of the regrowth. Further intensification by extending the cropping period or by shortening the fallow period resulted in lower yields and a fallow vegetation dominated by grasses and some hardy shrubs.

11.5.5.2 Managed fallow vegetations

Managed fallows are useful when weed suppression is more successful and nutrient accumulation proceeds faster than in the case of a natural secondary vegetation. In case leguminous species are planted, N-fixation is an additional benefit. Such a fallow requires labour for becoming established. Moreover, due to the usually slow development of such fallows the weed suppression capacity during the early stage of the fallow period is not high. Therefore, leguminous shrubs are not considered as an appropriate alternative to *C. odorata* (Slaats,1995).

In case the fallow period is reduced to one year or less, cover crops like Pueraria or Centrosema become an alternative. Slaats (1995) observed spontaneous growth of these species on abandoned fields in the Taï region. This occurrence may indicate their capacity to compete with *C. odorata*.
In this study it was shown that with application of N, P and K the cropping period can be extended to four years. When the fields are abandoned, a regrowth dominated by grasses will develop at such sites. Planting a fallow can prevent such a development.

11.5.5.3 Tree crop option

In the Taï region Bonnéhin (in prep.) studies domestication of two indigenous fruit trees (*Tieghemelia heckelii* and *Coula edulis*). Aspects studied are vegetative propagation and monitoring seedlings in plantations of smallholders. Farmers are interested in planting these species for their fruits. Interplanting of these trees with food crops during the first years of their establishement might be an option. Such a system would resemble the system as practised in the Yurimaguas region. In case these trees are planted at a large scale a marketing problem may develop.
Tree crop plantations are an important component of the farming systems in the Taï region. Therefore, intercropping of these crops with food crops seems a promising option. The main tree crops are coffee, cacao and recently rubber. In the present farming systems food crops are often interplanted with tree crops. In the case of coffee such an intercropping can be repeated when this crop is pruned. For Côte d'Ivoire pruning is recommended after a four- to five-year cycle (Wrigley, 1988). After pruning at least two seasons food crops can be grown. At present, management of tree crops, including coffee, is very poor. Introduction of such a system requires improved management. To avoid competition between coffee and food crops, support by extension workers will be necessary, especially regarding use of external inputs and plant densities.

Of the options discussed, the latter is thought to be most promising because existing components of the present farming systems are combined. Moreover, there is an existing marketing system for coffee. Therefore the chance of acceptance by farmers is thought to be higher than when completely new practices and/or plant species are introduced.

References

Agboola A A 1994 A recipe for continuous crop production in the forest zone of western Nigeria. *In* Alternatives to Slash-and-Burn Agriculture. Symposium ID-6. Supplement to Transactions. 15th World Congress of Soil Science, Acapulco, Mexico, July 1994. Eds. P A Sanchez and H Van Houten. pp 107-120. International Society of Soil Science.

Akobundu I O and Agyakwa C W 1987 A Handbook of West African Weeds. International Institute of Tropical Agriculture, Ibadan, Nigeria. 521 p.

Allport G, Boesch C, Couturier G, Esser J, Merz G and Piart J 1994 La faune. *Dans* Le Parc National de Taï, Côte d'Ivoire. I. Synthèse des Connaissances. Eds. E P Riezebos, A P Vooren et J I Guillaumet. pp 72-93. La Fondation Tropenbos, Wageningen, Pays-Bas.

Andriesse J P and Koopmans T Th 1984 A monitoring study on nutrient cycles in soils used for shifting cultivation under various climatic conditions in tropical Asia. I. The influence of simulated burning on form and availability of plant nutrients. Agriculture, Ecosystems and Environment 12, 1-16.

Andriesse J P and Schelhaas R M 1987 A monitoring study on nutrient cycles in soils used for shifting cultivation under various climatic conditions in tropical Asia. III. The effects of land clearing through burning on fertility level. Agriculture, Ecosystems and Environment 19, 311-332.

Andriesse W A and Fresco L O 1991 A characterization of rice-growing environments in West Africa. Agriculture, Ecosystems and Environment 33, 377-395.

Andriesse W A, Fresco L O, Van Duivenboden N and Windmeijer P N 1994 Multi-scale characterization of inland valley agro-ecosystems in West Africa. Neth. J. of Agric. 42, 159-179.

Anonymous 1993 Sustainable use of inland valley agro-ecosystems in Sub-Saharan Africa. A proposal for a consortium programme. 79 p.

Backer C A and Van Slooten D F 1924 Geïllustreerd Handboek der Javaanse Theeonkruiden en hunne Beteekenis voor de Cultuur. Algemeen Proefstation voor Thee, Batavia. 308 p.

Barrow N J 1985 Comparing the effectiveness of fertilizers. Fertilizer Research 8, 85-90.

Bartholomew W V, Meyer J and Laudelout H 1953 Mineral nutrient immobilization under forest and grass fallow in the Yangambi (Belgian Congo). I.N.E.A.C. Ser. Sci. no.57. Brussels, 27 p.

Boesch C and Boesch H 1989 Hunting behaviour of wild chimpanzees in the Taï National Park. American Journal of Phys. Anthropology 18, 547-573.

Bonnéhin L 1988 La pression démographique et agricole autour du Parc National de Taï. Rapport de fin d'études, ENGREF, Montpellier, France. 60 p.

Bonnéhin L 1992 Les potentialités des produits forestiers non ligneux. *Dans* Compte rendu Séminaire sur l'Aménagement intégré des Forêts denses humides et des Zones agricoles périphériques. 25-28 Février 1991, Abidjan, Côte d'Ivoire. Eds. A P Vooren, W Schork, W A Blokhuis et A J C Spijkerman. pp 133-139. Tropenbos Series 1. La Fondation Tropenbos Wageningen, Pays-Bas.

Bonnéhin L in prep. Domestication of indigenous fruit trees (*Tieghemelia heckelii* and *Coula edulis*).

Borst A P 1987 Study on the availability of some nutrients in soils of the Tai region, Côte d'Ivoire. M.Sc. thesis, Agricultural University, Wageningen, The Netherlands. 73 p. + annexes.

Boxman O 1990 Chemical soil characteristics. *In* Mechanized annual Cropping on low fertility acid Soils in the humid Tropics. A Case Study of the Zanderij Soils in Suriname. Eds. B H Janssen and J F Wienk. pp 30-35. Wageningen Agricultural University papers 90-5, Wageningen, The Netherlands.

Boxman O and Janssen B H 1990 Availabilty of nutrients and fertilizer use. *In* Mechanized annual Cropping on low fertility acid Soils in the humid Tropics. A Case Study of the Zanderij Soils in Suriname. Eds. B H Janssen and J F Wienk. pp 73-99. Wageningen Agricultural University papers 90-5, Wageningen, The Netherlands.

Braakhekke W G, Stuurman H A, Van Reuler H and Janssen B H 1993 Relations between nitrogen and phosphorus immobilization during decomposition of forest litter. *In* Optimization of Plant Nutrition. Eds. M A C Fragoso and M L Van Beusichem. pp 117-123. Kluwer Academic Publishers, The Netherlands.

Brams E A 1971 Continuous cultivation of West African soils: organic matter diminution and effects of applied lime and phosphorus. Plant and Soil 35, 401-414.

Brinkmann W L F and Vieira A N 1971 The effect of burning on germination of seeds at different soil depths of various tropical tree species. Turrialba 21, 77-82.

Budelman A 1990 Woody legumes as live support systems in yam cultivation. 1. The tree-crop interface. Agroforestry Systems 10, 47-59.

Budelman A and Zander P M 1990 Land use by Baoulé farmers in the Taï region, South-west Côte d'Ivoire (Ivory Coast). Agroforestry Systems 11, 101-123.

Casenave A, Flory J, Guiguen N, Ranc N, Simon J M, Toilliez J and Tourne M 1980 Etude hydrologique des bassins de Taï. Campagnes 1978-1979. Office de la Recherche Scientifique et Technique Outre-Mer, Centre d'Adiopodoumé, Côte d'Ivoire. 77 p.

Catinot R 1984 Propositions opérationelles en sylviculture et aménagement, République de Côte d'Ivoire. FAO, Rome, Italy. 69 p.

Cochran W G and Cox G M 1957 Experimental Designs. Second edition, John Wiley & Sons, New York. 611 p.

Collinet J, Monteny B et Pouyaud B 1984 Le milieu physique. *Dans* Recherche et Aménagement en Milieu forestier tropical humide: Le Projet Taï de Côte d'Ivoire. Eds. J L Guillaumet, G Couturier et H Dosso. pp 35-59. Notes techniques du MAB 15, UNESCO, Paris, France.

Collinet J, Couturier G, Guillaumet J L, Kahn F, Moreau R et Sangaré Y 1984 Le système cultural et ses contraintes. *Dans* Recherche et Aménagement en Milieu forestier tropical humide: Le Projet Taï de Côte d'Ivoire. Eds. J L Guillaumet, G Couturier et H Dosso. pp 113-185. Notes techniques du MAB 15. UNESCO, Paris, France.

Commission de Pédologie et de Cartographie des Sols 1967 Classification des Sols. Laboratoire Pédologie-Géologie, Ecole Nationale Supérieure d'Agriculture, Grignon, France. 87 p.

Dabin B 1967 Analyse du phosphore assimilable dans les sols tropicaux. Cah. ORSTOM, série Pédologie 5, 278-286.

De Geus J G 1973 Fertilizer Guide for the Tropics and Subtropics. Centre d'Etude de l'Azote, Zurich. 727 p.

De Namur Ch 1978 Quelques caractéristiques du développement d'un peuplement ligneux au cours d'une succession secondaire. Cah. ORSTOM, série Biologique 13, 211-213.

De Rouw A 1979 La Culture traditionelle dans le sud-ouest de la Côte d'Ivoire (région de Taï) : le système Oubi confronté aux pratiques agricoles Baoulés immigrés. Office de la Recherche Scientifique et Technique Outre-Mer, Centre d'Adiopodoumé, Côte d'Ivoire. 34 p. + annexes.

De Rouw A 1987 Tree management as part of two farming systems in the wet forest zone (Ivory Coast). Acta Oecologica Applicata 8, 39-51.

De Rouw A 1991a Rice, Weeds and Shifting Cultivation. A Study of Vegetation Dynamics. Ph.D. thesis, Agricultural University Wageningen, The Netherlands. 263 p.

De Rouw A 1991b The invasion of Chromolaena odorata (L.) King & Robinson (ex-Eupatorium odoratum) and competition with the native flora, in a rain forest zone, south-west Côte d'Ivoire. Journal of Biogeography 18, 13-23.

De Rouw A 1992 Les mauvaises herbes dans la culture itinérante sur brûlis. *Dans* Compte rendu Séminaire sur l'Aménagement intégré des Forêts denses humides et des Zones agricoles périphériques. 25-28 Février 1991, Abidjan, Côte d'Ivoire. Eds. A P Vooren, W Schork, W A Blokhuis et A J C Spijkerman. pp 111-123. Tropenbos Series 1. La Fondation Tropenbos Wageningen, Pays-Bas.

De Rouw A and Van Oers C 1988 Seeds in a rain forest soil and their relation to shifting cultivation in the Ivory Coast. Weed Research 28, 373-381.

De Rouw A, Vellema H C and Blokhuis W A 1990 Land Unit Survey of the Taï Region, south-west Côte d'Ivoire. Tropenbos Technical Series 7. Tropenbos Foundation, Ede, The Netherlands. 222 p. + 2 maps.

Development and Resources Corporation 1967 Soil Survey of the South-West Region. Report prepared for the Government of Ivory Coast. New York. 103 p. + technical appendix.

De Wit C T 1953 A physical Theory on Placement of Fertilizers. Verslagen van Landbouwkundige Onderzoekingen. No. 59.4. Ministerie van Landbouw, Visserij en Voedselvoorziening, Directie van de Landbouw, 's-Gravenhage. 71 p.

Dosso H, Guillaumet J L and Hadley M 1981 The Taï project: land use problems in a tropical rain forest. Ambio 10, 120-125.

Dunn P H, De Bano L F and Eberlein G E 1979 Effects of burning on chaparral soils. II. Soil microbes and nitrogen mineralization. Soil Sci. Soc. Am. J. 43, 509-514.

Elie T 1991 Uitgeputte gronden in Taï. Permanente rijstteelt in Djiroutou, Ivoorkust. Stage verslag Tropische Plantenteelt, Landbouwuniversiteit, Wageningen. 37 p. + bijlagen.

Ewel J, Berish C, Brown B, Price N and Raich J 1981 Slash and burn impacts on a Costa Rican wet forest site. Ecology 62, 816-829.

FAO - UNESCO 1974 Soil Map of the World (1:5.000.000). Volume 1 Legend. UNESCO, Paris, France. p.

FAO 1984 Changes in shifting cultivation in Africa. FAO Forestry paper no. 50. FAO, Rome, Italy. 59 p.

FAO 1988 FAO-UNESCO Soil Map of the World. Revised Legend. World Soil Resources Report 60. FAO, Rome, Italy. 119 p.

Fraters D 1986 A Study of a catena in the Tai forest, Ivory Coast. M.Sc. thesis, Agricultural University, Wageningen, The Netherlands. 64 p. + annexes.

Fritsch E 1980 Etude pédologique et représentation cartographique à 1:50.000 d'une zone de 1600 ha. Représentative de la région forestière du sud-ouest Ivoirien. Office de la Recherche Scientifique et Technique Outre-Mer, Centre d'Adiopodoumé, Côte d'Ivoire. 130 p. + annexes + 3 cartes.

Fritsch E 1982 Evolution des sols sous recrû forestier après mise en culture traditionelle dans le sud-ouest de la Côte d'Ivoire. Office de la Recherche Scientifique et Technique Outre-Mer, Centre d'Adiopodoumé, Côte d'Ivoire. 82 p. + annexes

Gouzy M 1973a L'Analyse minerale des produits naturels. Tome III. Sols-roches-mineraux (dosage des éléments majeurs). Office de la Recherche Scientifique et Technique Outre-Mer, Centre d'Adiopodoumé, Côte d'Ivoire. 337 p.

Gouzy M 1973b L'Analyse minerale des produits naturels. Tome IV. Eaux-vegetaux (éléments traces, solutions titrées). Office de la Recherche Scientifique et Technique Outre-Mer, Centre d'Adiopodoumé, Côte d'Ivoire. 348 p.

Greenland D J 1974 Evolution of different types of shifting cultivation. *In* Shifting Cultivation and Soil Conservation in Africa. pp 5-13. FAO-SIDA Soils Bull. 24, Rome, Italy.

Greenland D J 1975 Bringing the green revolution to the shifting cultivator. Science 190, 841-844.

Greenland D J and Kowal J M L 1960 Nutrient content of moist tropical forest of Ghana. Plant and Soil 12, 154-174.

Guillaumet J L 1994 La flore. *Dans* Le Parc National de Taï, Côte d'Ivoire. I. Synthèse des Connaissances. Eds. E P Riezebos, A P Vooren et J l Guillaumet. pp 66-72. La Fondation Tropenbos, Wageningen, Pays-Bas. Guillaumet J L, Couturier G et Dosso H 1984 Recherche et Aménagement en Milieu forestier tropical humide: Le Projet Taï de Côte d'Ivoire. Notes Techniques du MAB 15. UNESCO, Paris. 245 p.

Gupta P C and O'Toole J C O 1986 Upland Rice. A global Perspective. International Rice Research Institute, Los Banos, Philippines. 360 p.

Harwood R R 1994 Agronomic alternatives to slash-and-burn in the humid tropics. *In* Alternatives to Slash-and-Burn Agriculture. Symposium ID-6. Supplement to Transactions. 15th World Congress of Soil Science, Acapulco, Mexico, July 1994. Eds. P A Sanchez and H Van Houten. pp 93-106. International Society of Soil Science.

Hill M O 1979 Decorana - a Fortran Programme for detrended Correspondence Analysis and reciprocal Averaging. Ecology and Systematics, Cornell University, Ithaca, New York. 52 p.

Houba V J G, Novozamsky I, Van Der Lee J J, Van Vark W and Nab E 1985 Chemische analyse van gewassen. Agricultural University, Dept. of Soil Science and Plant Nutrition, Wageningen, The

Netherlands. 62 p.

Huttel Ch 1977 Etude de quelques characteristiques structurales de la végétation du bassin versant de l'Audrénisrou. Office de la Recherche Scientifique et Technique Outre-Mer, Centre d'Adipodoumé, Côte d'Ivoire. 33 p.

Institut de Recherches sur le Café et le Cacao et autres Stimulantes 1987-1990 Rapports annuels d'activités de l'IRCC. Abidjan, République de Côte d'Ivoire.

Jacquot M and Courtois B 1983 Le Riz Pluvial. G.-P. Maisonneuve et Larose, Paris. 134 p.

Jaffré T 1985 Composition minérale et stocks de bioéléments dans la biomasse épigée de recrûs forestiers en Côte d'Ivoire. Acta Oecologica Oecol. Plant. 6, 233-246.

Jaffré T et de Namur Ch 1983 Evolution de la biomassa végétale épigée au cours de la succession secondaire dans le sud-Ouest de la Côte d'Ivoire. Acta Oecologica Oecol. Plant. 4, 259-272.

Janssen B H 1974 A double pot technique for rapid soil testing. Tropical Agriculture (Trinidad) 51, 233-246.

Janssen B H, Lathwell D J and Wolf J 1987 Modelling long-term crop response to fertilizer phosphorus. II. Comparison with field results. Agron. J. 79, 452-458.

Janssen B H and Wolf J 1988 A simple equation for calculating the residual effect of phosphorus fertilizers. Fertilizer Research 26, 145-156.

Janssen B H and Wienk J Eds. 1990 Mechanized annual Cropping on low fertility acid Soils in the Humid Tropics. A Case Study of the Zanderij Soils in Suriname. Wageningen Agricultural University papers 90-5, Wageningen, The Netherlands. 230 p.

Janssen B H, Guiking F C T, Van der Eijk D, Smaling E M A, Wolf J and Van Reuler H 1990 A system for the quantitative evaluation of the fertility of tropical soils (QUEFTS). Geoderma 46, 299-318.

Jordan C F 1985 Nutrient Cycling in tropical Forest Ecosystems. John Wiley & Sons. 190 p.

Juo A S R and Fox R L 1977 Phosphate sorption characteristics of some bench-mark soils of West Africa. Soil Science 124, 370-376.

Juo A S R and Kang B T 1989 Nutrient effects of modification of shifting cultivation in West Africa. *In* Mineral Nutrients in tropical Forest and Savanna Ecosystems. Ed. J Proctor. pp 289-300. Special publication number 9 of The British Ecological Society. Blackwell Scientific Publications.

Juo A S R and Manu A 1994 Chemical dynamics in slash-and-burn agriculture. *In* Alternatives to Slash-and-Burn Agriculture. Symposium ID-6. Supplement to Transactions. 15th World Congress of Soil Science, Acapulco, Mexico, July 1994. Eds. P A Sanchez and H Van Houten. pp 63-77. International Society of Soil Science.

Jurion F and Henry J 1969 Can primitive farming be modernized? Institut National pour l'Etude Agronomique du Congo, hors serie. 457 p.

Kang B T 1993 Changes in soil chemical properties and crop performance with continuous cropping on an Entisol in the humid tropics. *In* Soil organic Matter and Sustainability of Tropical Agriculture. Eds. K Mulongoy and R Merckx. pp 297-305. IITA/K.U. Leuven. A Wiley-Sayce Co-Publication.

Kang B T, Reynolds L and Atta-Krah A N 1990 Alley farming. Advances in Agronomy 43, 315-359.

Kientz A 1992 Protection du Parc National de Taï et gestion des terroirs par la population riveraine. Ministère de l'Agriculture et des Ressources Animales, République de Côte d'Ivoire. Deutsche Gesellschaft für Technische Zusammenarbeit. 79 p. + annexes.

Koch V 1994 Peuplement et ethnies. *Dans* Le Parc National de Taï, Côte d'Ivoire. I. Synthèse des Connaissances. Eds. E P Riezebos, A P Vooren et J I Guillaumet. pp 94-101. La Fondation Tropenbos, Wageningen, Pays-Bas.

Lal R and Cummings D J 1979 Clearing a tropical forest. I. Effects on soil and micro-climate. Field Crops Research 2, 91-107.

Lachenaud Ph 1987 L'association cacaoyer-bananier plantain. Etude de dispositifs. Café, Cacao, Thé 31, 195-202.

Leduc B 1984 Liaison recherche-développement. Recherche des systèmes stables de cultures vivrières en Côte d'Ivoire. Primier bilan 1971-1982, IRCC, Abidjan, République de Côte d'Ivoire.

Lena Ph 1984 Le développement des activités humaines. *Dans* Recherche et Aménagement en Milieu forestier tropical humide: Le Projet Taï de Côte d'Ivoire. Notes Techniques du MAB 15. Eds. J L Guillaumet, G Couturier et H Dosso. pp 59-113. UNESCO, Paris.

Lundgren B O and Raintree J B 1982 Sustained agroforestry. *In* Agricultural Research for Development: Potentials and Challenges in Asia. Ed. B Nestel. pp 37-49. ISNAR, The Hague.

Ministère de l'Economie et des Finances 1988 La Côte d'Ivoire en Chiffres. Edition 86-87. Inter Afrique Presse, Abidjan. 220 p.

Moormann F R, Veldkamp W J and Ballaux J C 1977 The growth of rice on a toposequence - a methodology. Plant and Soil 48, 565-580.

Moormann F R and Van Breemen N 1978 Rice: Soil, Water, Land. International Rice Research Institute, Los Banos, Philippines. 185 p.

Moreau R 1983 Evolution des sols sous différents modes de mise en culture en Côte d'Ivoire forestière. Cahiers ORSTOM, Sér. Pédologie, 20, 311-325.

Moreau R 1986 Effects of methods of deforestation and soil management on properties of some soils in Ivory Coast. *In* Land Clearing and Development in the Tropics. Eds. R Lal, P A Sanchez and R W Cummings Jr. pp 247-264. Balkema, Rotterdam, Boston.

Moreau R et De Namur Ch 1978 Le système cultural traditionnel des Oubis de la région de Taï. Cahier ORSTOM série Biologique, 12, 191-197.

Mueller-Harvey I, Juo A S R and Wild A 1985 Soil organic C, N, S and P after forest clearance in Nigeria: mineralization rates and spatial variability. Journal of Soil Science 36, 585-591.

Mueller-Harvey I, Juo A S R and Wild A 1989 Mineralization of nutrients after forest clearance and their uptake during cropping. *In* Mineral Nutrients in tropical Forest and Savanna Ecosystems. Ed. J Proctor. pp 315-325. Special publication number 9 of The British Ecological Society. Blackwell Scientific Publications.

Noij I G A M, Janssen B H and Van Reuler H 1988 Modelling nutrient cycling in tropical forest areas. A case study of Taï, Côte d'Ivoire. *In* Proceedings Second International Tropenbos Seminar. pp 122-128. The Tropenbos Programme, Ede The Netherlands.

Nooren C A M, Van Breemen N, Stoorvogel J J and Jongmans A G 1995 The role of earthworms in the formation of sandy surface soils in a tropical forest in Ivory Coast. Geoderma 65, 135-148.

Nye P H and Greenland D 1960 The Soil under Shifting Cultivation. Technical Communication No. 51. Commonwealth Bureau of Soils, Harpenden. 156 p.

Ohler F M J 1980 Phytomass and mineral content in untouched forest. Centrum voor Landbouwkundig Onderzoek in Suriname. Rapport 132. 43 p.

Papon A 1973 Géologie et minéralisations du sud-ouest de la Côte d'Ivoire: Synthèse des travaux de l'opération SASCA 1962-1968, SODEMI, Abidjan et MEFP (Secrétariat d'Etat chargé des Mines) Côte d'Ivoire. 286 p. + cartes.

Pinstrup-Andersen P and Pandya-Lorch R 1994 Alleviating poverty, intensifying agriculture and effectively managing natural resources. Food, Agriculture, and the Environment. Discussion Paper 1. International Food Policy Research Institute, Washington. 21 p.

Poisson C et Doumbia S 1987 Côte d'Ivoire Variétés nouvelles de Riz. Conseils pratiques pour une Riziculture moderne. Les Nouvelles Editions Africaine, Abidjan, Côte d'Ivoire. 64 p.

Robison D M and MacKean S J 1992 Shifting Cultivation and Alternatives: an annotated Bibliography, 1972-1989. Wallingford, CAB International. 282 p.

Ruthenberg H 1980 Farming Systems in the Tropics. Clarendon Press, Oxford. 424 p.

Sanchez P A 1976 Properties and Management of Soils in the Tropics. John Wiley & Sons, New York. 618 p.

Sanchez P A 1982 Nitrogen in shifting cultivation systems of Latin America Plant and Soil 67, 91-103.

Sanchez P A 1993 Alternatives to slash and burn agriculture. *In* Technologies for sustainable Agriculture in the Tropics. Eds. J Ragland and R Lal. pp 33-41. ASA Special Publication Number 56. Madison, Wisconsin, USA

Sanchez P A 1995 Science in agroforestry. Agroforestry Systems 30, 5-55.

Sanchez P A and G Uehara 1980 Management considerations for acid soils with high phosphorus fixation capacity. *In* The Role of Phosphorus in Agriculture. Eds. F E Khasawneh, E C Sample and E J Kamprath. pp 471-514. ASA/CSSA/SSSA, Madison, Wisconsin.

Sanchez P A and Salinas J G 1981 Low-input technology for managing Oxisols and Ultisols in tropical America. Advances in Agronomy 34, 279-406.

Sanchez P A, Bandy D A, Villachia J H and Nicholaides J J 1982 Amazon Basin soil: management for continuous crop production. Science 216, 821-827.

Sanchez P A, Villachia J H and Bandy D E 1983 Soil fertility dynamics after clearing a tropical rainforest in Peru. Soil Sci. Soc. Am. J. 47, 1171-1178.

Sanchez P A and Benites 1987 Low-input cropping for acid soils of the humid tropics. Science 238, 1521-1527.

Sanchez P A and Logan T J 1992 Myths and science about the chemistry and fertility of soils in the tropics. *In* Myths and Science of Soils in the Tropics. Eds. R Lal and P A Sanchez. pp 35-47. Soil Science Society of America Special Publication number 29. Madison, Wisconsin, U.S.A.

SAS Institute Inc. 1989 SAS/STAT User's Guide. Version 6, fourth edition, volume 2. Cary, N.C. 846 p.

Seubert C E, Sanchez P A and Valverde C 1977 Effects of land clearing methods on soil properties and crop performances in an Ultisol of the Amazon jungle of Peru. Trop. Agric. Trinidad 54, 307-321.

Slaats J J P 1992 Transformation de système de culture itënérant en systèmes de culture permanents *Dans* Compte rendu Séminaire sur l'Aménagement intégré des Forêts denses humides et des Zones agricoles périphériques. 25-28 Février 1991, Abidjan, Côte d'Ivoire. Eds. A P Vooren, W Schork, W A Blokhuis et A J C Spijkerman. pp 123-133. Tropenbos Series 1. La Fondation Tropenbos Wageningen, Pays-Bas.

Slaats J J P 1995 *Chromolaena odorata* fallow in food cropping systems. An agronomic assessment in South-West Ivory Coast. Ph.D. thesis Agricultural University, Wageningen, The Netherlands. 178 p.

Smaling E M A 1993 The soil nutrient balance: an indicator of sustainable agriculture in sub-Saharan Africa. The Fertiliser Society Proceedings no. 340, 1-18.

Soil Science Society of America 1973 Glossary of Soil Science Terms. Madison, Wisconsin, USA. 33 p.

Soil Survey Staff 1990 Keys to Soil Taxonomy. Soil Management Support Services Technical Monograph 19. Blacksburg, Virginia, USA. 422 p.

Stoorvogel J J 1993 Gross Inputs and Outputs of Nutrients in undisturbed Forest, Taï Area, Côte d'Ivoire. Tropenbos Series 5. The Tropenbos Foundation, Wageningen, The Netherlands. 148 p.

Szott L T, Palm C A and Sanchez P A 1991 Agroforestry in acid soils of the humid tropics. Advances in Agronomy 45, 275-301.

UNESCO 1973 International Classification and Mapping of Vegetation. Ecological Conservation no.6. UNESCO, Paris. 93 p.

Van Der Gaag J 1989 De 'bas-fonds' in de Taï regio. Verslag van een doctoraal onderzoek naar de kleine valleien in zuidwest Ivoorkust. M.Sc. thesis, Vakgroep Bodemkunde en Geologie, Landbouwuniversiteit, Wageningen. 53 p.

Van Der Put I 1990 A marketing plan for Coula nuts, a minor product of Taï National Park, Côte d'Ivoire. M.Sc. thesis, Université Agronomique de Wageningen, Pays-Bas. p.

Van Kekem A J 1984 Légende pour la carte des sols du sud-ouest de la Côte d'Ivoire. Application de la méthode utilisée dans la programme pédologique du MAB. Projet Taï, MAB-UNESCO. 34 p. + 1 carte.

Van Kekem A J 1986 Tai Biosphere Reserve, Ivory Coast. *In* Guidelines for Soil Survey and Land Evaluation in ecological Research. Eds. R F Breimer, A J Van Kekem and H Van Reuler. pp 105-108. MAB Technical Note 17, UNESCO, Paris.

Van Keulen H and Van Heemst H D J 1982 Crop Response to the Supply of Macronutrients. Agric. Res. Report 916, Pudoc, Wageningen, 46 p.

Van Reuler H and Janssen B H 1989 Nutritional constraints in secondary vegetation and upland rice in south-west Ivory Coast. *In* Mineral Nutrients in tropical Forest and Savanna Ecosystems. Ed. J Proctor. pp 371-382. Special publication number 9 of The British Ecological Society. Blackwell Scientific

Publications.

Van Reuler H et Janssen B H 1992 Le rôle des éléments nutritifs dans l'intensification des cultures vivrières dans la région de Taï. *Dans* Compte rendu Séminaire sur l'Aménagement intégré des Forêts denses humides et des Zones agricoles périphériques. 25-28 Février 1991, Abidjan, Côte d'Ivoire. Eds. A P Vooren, W Schork, W A Blokhuis et A J C Spijkerman. pp 72-82. Tropenbos Series 1. La Fondation Tropenbos Wageningen, Pays-Bas.

Van Reuler H and Janssen B H 1993a Nutrient fluxes in the shifting cultivation system of south-west Côte d'Ivoire I. Dry matter production, nutrient content and nutrient release after slash and burn for two fallow vegetations. Plant and Soil 154, 169-177.

Van Reuler H and Janssen B H 1993b Nutrient fluxes in the shifting cultivation system of south-west Côte d'Ivoire II. Short-term and long-term effects of burning on yield and nutrient uptake of food crops. Plant and Soil 154, 179-188.

Van Reuler H and Prins W H 1993 Eds. The Role of Plant Nutrients for sustainable Food Crop production in Sub-Saharan Africa. Dutch Association of Fertilizers Producers, Leidschendam, The Netherlands. 232 p.

Van Reuler H, N'Goran K et Wessel M 1994 L'Agriculture. *Dans* Le Parc National de Taï, Côte d'Ivoire. I. Synthèse des Connaissances. Eds. E P Riezebos, A P Vooren et J L Guillaumet. pp 133-142. Tropenbos Series 8. Fondation Tropenbos, Wageningen, Pays-Bas.

Van Reuler and Janssen B H 1996 Comparison of the fertilizing effects of ash from burnt secondary vegetation and of mineral fertilizers on upland rice in south-west Côte d'Ivoire. Accepted for publication in Fertilizer Research.

Van Reuler H and Janssen B H subm. a The influence of soil P, pH and texture on the uptake of P from soil and fertilizer by upland rice in the shifting cultivation system of south-west Côte d'Ivoire.

Van Reuler H and Janssen B H subm. b Soil fertility dynamics along a catena in south-west Côte d'Ivoire I. The relations between soils, nutrient uptakes and yields of upland rice during the first season after clearing.

Van Reuler H and Janssen B H subm. c Soil fertility dynamics along a catena in south-west Côte d'Ivoire II. Yields and nutrient uptakes in subsequent seasons.

Van Reuler H and Janssen B H subm. d Optimum P management over extended cropping periods in the shifting cultivation system of south-west Côte d'Ivoire.

Van Rompaey R S A R 1993 Forest Gradients in West Africa. A special Gradient Analysis. Ph.D. thesis, Agricultural University, Wageningen, The Netherlands. 142 p.

Veldkamp W J 1979 Land Evaluation of Valleys in a Tropical Rain Area - A case Study. Ph.D. thesis, Agricultural University Wageningen, The Netherlands. 266 p.

Vooren A P 1985 Patterns in tree and branch-fall in a West African Rain Forest. Report D 85-05. Department of Silviculture, Wageningen Agricultural University, The Netherlands. 34 p.

Walinga I, Van Vark W, Houba V J G and Van Der Lee J J 1989 Soil and plant analysis, Part 7: Plant analysis procedures. Department of Soil Science and Plant Nutrition, Wageningen Agricultural University, The Netherlands. 263 p.

Wierda A, Veen A W L and Hutjes R W A 1989 Infiltration at the Taï rain forest (Ivory Coast): measurements and modelling. Hydrological Processes 3, 371-382.

Wolf J, De Wit C T, Janssen B H and Lathwell D J 1987 Modelling long-term crop response to fertilizer phosphorus. I. The model. Agron. J. 79, 445-451.

Wood G A R and Lass R A 1987 Cocoa. Tropical agriculture series. Longman Scientific & Technical. 620 p.

World Bank 1989 Sub-Saharan Africa: from Crisis to sustainable Growth: along-term perspective Study. Washington D.C., U.S.A. 300 p.

World Bank 1992 World Development Report 1992. Development and the Environment.Washington D.C., U.S.A. 308 p.

Wrigley G 1988 Coffee. Tropical agriculture series. Longman Scientific & Technical. 637 p.

Yao N R, Goué B, Kouadio K J et Hainnaux G 1990 Effects of plant density and soil moisture on growth indices of two upland rice varieties. Agron. Afr. 2, 7-14.

Zeeman M 1989 Some aspects of soils and landscape development in the Taï region (Côte d'Ivoire). M.Sc. thesis, Dept. of Soil Science and Geology, Agricultural University, Wageningen, the Netherlands. 42 p. + annexes.

Zinke P J, Sabhasri S and Kunstadter P 1978 Soil fertility aspects of the Lau forest fallow system of shifting cultivation. *In* Farmers in the Forest. Eds. P Kunstadter, E C Chapman and S Sabhasri. pp 134-159. The University Press of Hawaii, Honolulu, Hawaii, USA.

Summary

About 250 million people produce their daily food in shifting cultivation agriculture. In such systems food crops are grown over short periods, and thereafter fields are abandoned. Due to increasing population densities, in many regions this system is under pressure to change. The Taï region in south-west Côte d'Ivoire is an example of such an area. In the sous-préfecture Taï the population density has increased from 4 persons per km^2 in 1965 to 34 in 1988. In this region the Taï National Park is situated. Forest to be cleared for agricultural practices outside the Park boundaries has almost been exhausted and the Park itself is threatened. Intensification of the agriculture may contribute to the protection of the Park.

Intensification can take place by extending the cultivation period, by shortening the fallow period, by improvement of crop management resulting in higher yields per ha, or by a combination of these measures. Extending the cultivation period usually results in lower yields. Such decreases are the main reason for abandoning fields. In the present research, maintenance of the first-year yield level is the main objective, with emphasis on nutrient management. For this purpose, on-farm field trials with controlled management were conducted. The test crops were upland rice and maize. The average farmer's yield is 1 ton per ha. In field trials the yield varied from 1.5 to 3.8 ton ha. The difference with the yield obtained by farmers indicates the effect of improved crop management (timeliness of clearing activities, use of improved planting material, protection of sites against animal damage). The variation in yield is an indication of inherent fertility differences among sites.

The soils of the Taï region can be characterized by so-called catenas. The soils of the upper slope are gravelly and well drained. On the lower slope moderately well drained and imperfectly drained non-gravelly soils are found. The soils are chemically poor.

Burning the slashed vegetation supplies nutrients to crops grown. In the first season after clearing burning almost doubled the rice yield compared to non-burnt fields. The effect of burning lasted at least two seasons. Burning also affects weed growth. The effect is reflected in variations in quantity and composition of weed population.

In the first season after clearing P limited growth on the well and moderately well drained soils. Application of 12.5 kg P per ha resulted in yield increases of 0.5 t rice and 1.0 ton maize per ha. On the moderately well drained soils the optimum P rate

proved to be 25 kg P per ha. On these soils a response to N application was found as well. The imperfectly drained soils showed no response to N, P, K or lime.

P uptake from soil and fertilizer-P can be described by an equation including the available P content (P-Dabin), total P and pH. The recovery fraction of fertilizer-P was described by an equation including the silt + clay content, available P (P-Dabin) and/or total P. Both relations improved substantially by expressing the values of soil properties on the basis of total soil volume rather than on the basis on that of the fine-earth mass.

In extended cropping systems with alternately rice and maize, applications of N, P and K were not sufficient to maintain the yield level obtained in the first season after clearing. Yield decline was much less pronounced for maize than for rice. In the eighth season after clearing yields of 4 ton of maize per ha were still obtained.

The yield - P uptake relation showed that the efficiency of utilization of absorbed P for rice decreased with time. The efficiency for maize did not decrease, or only slightly so with time. Consequently, in an extended cropping system upland rice can be grown only once or twice.

Changes in soil N and P supplies with time were different for different soils along the catena. In the first season after clearing, all sites supplied about the same amount of N. In subsequent seasons the N supply at the lower slope was significantly lower than that at the upper slope. In the first season after clearing the imperfectly drained soils supplied the highest amount of P. In subsequent seasons P supply at the upper/middle slope did not change, whereas at the lower slope a significant decrease was found. In this study, chemical soil properties did not explain why crop yields declined. Only pH decreased with time, but other soil parameters, like total P and organic C content, did not change.

Based on the results of the field trials fertilizer recommendations were formulated for the different soils. For the well drained soils a four-year cropping period with eight crops is proposed and for the moderately well drained soils a three-year period with six crops.

In most long-term experiments yields declined with time. The reason for such declines is not clear. A possible cause is lack of trace elements. Another possibility is a deterioration of soil physical conditions. In the trials, after each harvest crop residues were removed from the fields. These residues are an important food source for soil fauna and residue removal may have negatively influenced soil fauna activities.

There are different options for intensification of shifting cultivation. It is clear that every option should take into account the fact that on well and moderately well drained soils of the Taï region P is the main growth-limiting nutrient.

Résumé

L'agriculture itinérante répond au besoin en nourriture de près de 250 millions de personnes. Le système traditionnel consiste en une ou deux années de cultures vivrières suivies d'une période de jachère de plusieurs années. Dans de nombreuses régions ce système agricole se trouve entravé par une densité de la population accrue. La région de Taï dans le Sud-Ouest de la Côte d'Ivoire est un bon exemple.

Dans la sous-préfecture de Taï la densité de la population s'est accrue de 4 personnes au km^2 en 1965 à 34 personnes en 1988. Dans cette même région se trouve également le Parc National de Taï. Il n'existe presque plus de forêt pouvant être défrichée pour l'utilisation agricole en dehors des frontières du Parc. Ceci ayant pour conséquence une menace pour le Parc lui-même. Une intensification de l'agriculture pourrait contribuer à la protection du Parc.

L'intensification pourrait se faire en prolongeant la période de culture, en raccourcissant la durée de jachère, en améliorant les soins aux cultures grâce auxquels les rendements par ha augmentent ou par une combinaison de ces mesures. Habituellement une prolongation de la période de culture mène à des rendements diminués. Cette diminution forme la cause principale de l'abandon d'un champ. Dans cette recherche il a été étudié de quelle manière on pourrait maintenir le niveau de rendement en insistant sur la gestion des éléments nutritifs. Dans ce but des essais "on-farm" avec du riz pluvial et avec du maïs ont été conduits. La gestion des essais fût exécutée en régie propre. La moyenne des rendements en riz des paysans est à peu près de l'ordre de 1 tonne par ha. Les rendements de nos essais se situent à 1.5 - 3.8 tonnes par ha. La différence avec le résultat des paysans montre l'effet des soins améliorés aux cultures (défricher et brûler à temps, utiliser des semences appropriées, sarcler, protection des champs contre le rongement des animaux). La variation en rendements est une indication pour les différences dans la fertilité du sol parmi les champs divers.

Les sols dans la région de Taï peuvent être caractérisés au moyen de "catenas". Les sols haut-de-versant contiennent beaucoup de gravillons et ils ont un drainage normal. Au bas-de-versant on trouve des sols ayant un drainage modéré et un drainage imparfait sans gravillons. Les sols du bas-fonds ont un drainage pauvre. Tous les sols sont d'une composition chimique pauvre.

Le brûlis de la végétation coupée ajoute des éléments nutritifs au sol. Dans la première saison de culture les rendements du riz sur les champs brûlés étaient deux

fois supérieurs à ceux sur les champs non-brûlés. L'effet du brûlis était perceptible pendant au moins deux saisons. A côté d'un effet sur les éléments nutritifs, le brûlis a également un effet sur la croissance des mauvaises herbes, en quantité comme en composition d'espèces.

Dans la première saison après défrichement il apparût que le P limitait la croissance des cultures sur les sols bien drainés. L'application de 12.5 kg de P par ha donna une augmentation du rendement de 0.5 tonne par ha de riz et de 1 tonne par ha de maïs. Sur les sols avec un drainage modéré, une application de 25 kg de P par ha était nécessaire pour obtenir les mêmes augmentations de rendement. Une application de N donna également parfois une croissance du rendement sur ces sols. Les sols ayant un drainage modéré ne donnèrent aucune croissance du rendement après application de N, P, K ou de calcaire.

La quantité de P pouvant être délivrée par les différents sols peut être décrite au moyen d'une équation contenant le P disponible (P-Dabin), le P-total et le pH. Le rendement en éléments des engrais phosphatés peut être décrit au moyen d'une autre équation contenant le taux de limon + argile, le P disponible (P-Dabin) et/ou le P-total. Une amélioration considérable des relations peut être obtenue en exprimant les caractéristiques du sol en unités de volume du sol incluant les gravillons, au lieu d'unités de "terre fine".

Pendant plusieurs saisons, différents champs furent cultivés. Des applications de N, P et K ne pûrent empêcher une diminution du rendement en riz. Le rendement en maïs diminua également après prolongation de la période de culture, mais beaucoup moins fortement que dans le cas du riz. Dans la huitième saison après défrichement des rendements de 4 tonnes par ha furent encore obtenus.

La relation absorption du P - rendement montra que dans le cas du riz l'efficacité d'utilisation du P diminue avec le temps. Cette diminution démontre que la baisse du rendement est causée par d'autres facteurs que le manque de P. L'efficacité d'utilisation du P pour le maïs ne changea pas ou pratiquement pas avec le temps. Ceci signifie que lors d'une période de culture prolongée il n'est possible de cultiver du riz qu'une ou deux fois.

Lors d'une prolongation de la période de culture, il apparût une nette différence entre les quantités de N et de P pouvant être délivrées par les sols du haut-de-versant et par ceux du bas-de-versant du "catena". Lors de la prolongation la livraison de N et de P du bas-de-versant diminua beaucoup plus fortement que celle du haut-de-versant. Les caractéristiques du sol (P-total, C-organique) ne donnèrent aucune explication pour la baisse des rendements dans un système de culture prolongée. Des conseils pour l'application d'engrais pour les différents sols ont été dressés, basés sur les résultats d'essais pluriannuels. Une période de culture de 4 ans avec 8 cultures est proposée pour les sols avec un drainage normal et pour les sols avec un drainage imparfait, une période de culture de 3 ans avec 6 cultures.

Dans la plupart des essais pluriannuels une diminution du rendement avec le temps fut observée. La cause de cette diminution n'est pas évidente. Il est possible que les micro-éléments nutritifs jouent un rôle. Une autre possibilité est une dégradation de la fertilité physique du sol. Lors des essais les résidus de culture étaient exportés après chaque récolte. Ces résidus sont une source importante d'éléments nutritifs pour la faune du sol et il est possible qu'à cause de cela son activité soit négativement influencée.

Il existe différentes possibilités pour intensifier l'agriculture itinérante. Il est clair que pour chaque mesure prise sur les sols avec un drainage moderé ou normal, il faut tenir compte du fait que le P est l'élément nutritif le plus important pouvant limiter le rendement.

Samenvatting

Ongeveer 250 miljoen mensen voorzien door middel van zwerflandbouw in hun behoefte aan voedsel. In zwerflandbouw worden op velden gedurende een korte tijd gewassen verbouwd en daarna worden de velden verlaten. In vele gebieden staat dit landbouwsysteem onder druk door een toegenomen bevolkingsdichtheid. De Taï regio in zuidwest Côte d'Ivoire is zo'n gebied. In de sous-préfecture Taï is de bevolkingsdichtheid gestegen van 4.1 personen km^{-2} in 1965 tot 34 in 1988. In deze regio bevindt zich ook het Nationale Park Taï. Bos dat ontgonnen kan worden voor landbouwkundig gebruik buiten de grenzen van het Park is er vrijwel niet meer. Het gevolg is dat het Park zelf wordt bedreigd. Intensivering van de landbouw kan een bijdrage aan de bescherming van het Park leveren.

Intensivering kan plaatsvinden door verlenging van de teeltperiode, verkorten van de braak, verbetering van de gewasverzorging waardoor de opbrengsten per ha stijgen, of door een combinatie van deze maatregelen. Verlenging van de teeltperiode leidt gewoonlijk tot lagere opbrengsten. Deze verlaging is de belangrijkste reden om een veld te verlaten. In dit onderzoek is bestudeerd hoe het opbrengstniveau kan worden gehandhaafd met nadruk op het beheer van de nutriënten. Hiervoor zijn veldproeven met regenafhankelijke rijst en maïs bij boeren aangelegd. De verzorging van de proeven werd in eigen beheer uitgevoerd. De gemiddelde rijstopbrengst van boeren is ongeveer 1 ton per ha. In de veldproeven varieerde de opbrengst van 1.5 tot 3.8 ton per ha. Het verschil met de boeren geeft het effect van verbeterde gewasverzorging aan (op tijd ontginnen en branden, geschikt zaaizaad gebruiken, wieden, bescherming van velden tegen vraat van dieren). De variatie in opbrengst is een indicatie voor de verschillen in bodemvruchtbaarheid tussen de verschillende velden.

De bodems in de Taï regio kunnen worden gekarakteriseerd door middel van catena's. De bodems op het hogere deel van de helling bevatten veel grind en zijn goed gedraineerd. Op het lagere deel worden redelijk gedraineerde en matig gedraineerde bodems zonder grind gevonden. De bodems in de vallei zijn slecht gedraineerd. Alle bodems zijn chemisch arm.

Het branden van de gekapte vegetatie voegt nutriënten aan de bodem toe. In het eerste groeiseizoen was de rijstopbrengst op gebrande velden twee keer zo hoog als op niet gebrande velden. Het brandeffect was in ieder geval twee seizoenen merkbaar. Naast een effect op de nutriëntenvoorziening heeft branden ook een effect op de onkruidgroei, zowel qua hoeveelheid als qua soortensamenstelling.

In het eerste seizoen na ontginning bleek op de goed gedraineerde bodems P de gewasgroei te beperken. Toediening van 12.5 kg P per ha gaf een opbrengstverhoging van 0.5 ton rijst en 1.0 ton maïs per ha. Op de redelijk gedraineerde bodems was toediening van 25 kg P per ha nodig om dezelfde opbrengstverhogingen te verkrijgen. Op deze bodems gaf ook N toediening soms een opbrengststijging. De matig gedraineerde bodems gaven geen opbrengstverhoging na toediening van N, P, K of kalk.

De hoeveelheid P die door de verschillende bodems kan worden geleverd kan worden beschreven met eefi vergelijking waarin zijn opgenomen beschikbaar P (P-Dabin), P-totaal en de pH. Het elementrendement van meststoffosfaat kan worden beschreven door een vergelijking met daarin het stof + lutum gehalte, beschikbaar P (P-Dabin) en/of totaal P. Een aanzienlijke verbetering van de relaties kan worden verkregen door de bodemeigenschappen uit te drukken per volume eenheid van de bodem inclusief grind in plaats van per eenheid 'fijne aarde' (< 2 mm).

Op verschillende velden werden gedurende meerdere seizoenen gewassen verbouwd. Toedieningen van N, P en K konden een opbrengstdaling van rijst niet voorkomen. Ook de maïsopbrengst daalde bij verlenging van de teeltperiode, maar de daling was veel minder sterk dan bij rijst. In het achtste seizoen na ontginning werden nog opbrengsten van 4 ton per ha behaald.

De P opname - opbrengst relatie liet zien dat bij rijst de gebruiksefficiëntie van P afnam met de tijd. Deze afname geeft aan dat de opbrengstdaling wordt veroorzaakt door andere factoren dan gebrek aan P. Bij maïs veranderde de P-gebruiksefficiëntie niet of nauwelijks in de tijd. Dit betekent dat in een verlengde teeltperiode slechts één of tweemaal rijst kan worden geteeld.

Bij verlenging van de teeltperiode bleek er een duidelijk verschil te zijn tussen de hoeveelheden N en P die door de bodems op het hogere deel en lagere deel van de catena geleverd kunnen worden. Bij verlenging van de teeltperiode nam de N en P levering op het lagere deel van de helling veel sterker af dan op het hogere deel. Bodemeigenschappen (totaal P, organisch C) gaven geen verklaring voor de lagere opbrengsten in een verlengd teeltsysteem.

Gebaseerd op de resultaten van de meerjarige proeven zijn bemestingsadviezen voor de verschillende bodems opgesteld. Voor de goed gedraineerde bodems wordt een 4-jarige teeltperiode met 8 gewassen voorgesteld en voor de redelijk gedraineerde bodems een 3-jarige teeltperiode met 6 gewassen.

In de meeste meerjarige proeven werd een opbrengstdaling met de tijd gevonden. De reden van deze daling is onduidelijk. Mogelijk spelen micronutriënten een rol. Een andere mogelijkheid is een achteruitgang van de fysische bodemvruchtbaarheid. In de proeven werden bij iedere oogst de gewasresten afgevoerd. Deze resten zijn een belangrijke voedingsbron voor de bodemfauna en mogelijk is hierdoor hun activiteit negatief beïnvloed.

Er bestaan verschillende mogelijkheden om zwerflandbouw te intensiveren. Het is duidelijk dat bij elke maatregel die op de (redelijk) goed gedraineerde bodems genomen wordt, rekening moet worden gehouden met het feit dat P het belangrijkste opbrengst-limiterende nutriënt is.

Curriculum vitae

Hendrik Van Reuler was born on 30 November 1953 in Driebergen, the Netherlands. After obtaining the H.B.S.-B diploma he started his study at the Wageningen Agricultural University in 1971. In the framework of the curriculum "Soil Science and Fertilizer Use" fieldwork was executed in western Kenya in the period June 1975 - April 1976. In the period 1976 to 1980 he combined his studies with several assistantships. In January 1980 he graduated with specializations in tropical soil science, soil fertility and aerial photo interpretation. From August 1980 to August 1984 he worked as an associate-expert in Ecological Sciences (Soil Science) in the framework of the 'Man and the Biosphere' project with UNESCO in S.E Asia. He was stationed at the Soil Research Institute in Bogor, Indonesia. Fieldwork was executed in Thailand, Malaysia and on several islands in Indonesia. This assignment was carried out in close cooperation with the International Soil Reference and Information Centre (ISRIC) at Wageningen, The Netherlands.

After having returned to the Netherlands he started working for the Department of Soil Science and Plant Nutrition of the Agricultural University at Wageningen (AUW), the Netherlands in January 1985. During 1986 he became involved in the AUW training and research project 'Analysis and design of land-use systems in the Taï region, south-west Côte d'Ivoire'. In December 1986 he moved to Côte d'Ivoire as coordinator of the Soil Science programme. This assignment included a study of nutrient cycling in different land-use systems. He returned to the Netherlands in April 1991 for reporting on the results obtained.

In the period 1991 to 1993 he acted as a co-editor of the monograph 'The role of plant nutrients for sustainable food crop production in Sub-Saharan Africa'. This joint project of the Agricultural University and the Nutrient Management Institute (NMI) was financed by the Dutch Association of Fertilizer Producers.