Chromolaena odorata fallow in food cropping systems

An agronomic assessment in South-West Ivory Coast

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Chromolaena odorata fallow in food cropping systems

An agronomic assessment in South-West Ivory Coast

Joep Slaats

Proefschrift

ter verkrijging van de graad van doctor
in de landbouw- en milieuwetenschappen
op het gezag van de rector magnificus,
dr C.M. Karssen
in het openbaar te verdedigen
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Stellingen

1 Om recht te doen aan de inhoud van dit proefschrift dient de naam *Chromolaena odorata* veranderd te worden in *Chromolaena adorata.*
Dit proefschrift

2 De geschiktheid van *Chromolaena odorata* in braaksystemen berust op haar gemakkelijke vestiging als braakvegetatie en de eenvoudige wijze waarop zij als onkruid tijdens de teeltperiode bestreden kan worden.
Dit proefschrift

3 De term "terres fatiguées" ter aanduiding van gronden onder een *Chromolaena odorata* braakvegetatie zegt meer over de duider dan over het geduide.
Dit proefschrift

4 In de beoordeling van de geschiktheid van een plantesoort als braakvegetatie dient de gehele cyclus van braak en teelt, inclusief de teeltmaatregelen, betrokken te worden.
Dit proefschrift

5 In braaksystemen in de humide tropen zijn boeren met recht gebrand op branden.

6 De expansie van de teelt van cacao in Ivoorkust toont duidelijk aan dat onderzoek de landbouwkundige ontwikkeling niet kan sturen.
Bunting, A.H., (1983). Agricultural research and farming practice in the Third World: The role of the International Course for development oriented Research in Agriculture. ICRA Bulletin No. 9.

7 De aandacht in het landbouwkundig onderzoek voor variatie mag niet leiden tot verontachtzaming van kennis van de basisprincipes onder homogene omstandigheden.
Almekinders, C.J.M., Fresco, L.O. & Struik, P.C., (1995). The need to study and manage variation in agro-ecosystems. Netherlands Journal of Agricultural Science, 43:127-142.
Steenhuijsen Piters, C.B., (1995). Diversity in fields and farmers. Explaining yield variations in northern Cameroon. Proefschrift Landbouwuniversiteit Wageningen.

8 Voor onderzoek van de Landbouwuniversiteit in de tropen verdient samenwerking met internationale onderzoeksinstituten de voorkeur boven zelfstandige uitvoering via steunpunten.

9 De trend onder Wageningse studenten om bergschoenen dagelijks te gebruiken plaatst vraagtekens bij de studeerbaarheid van hun opleiding.

10 Met een kunstijsbaan in Wageningen begeven de regionale schaatsverenigingen zich op glad ijs.

Stellingen behorend bij het proefschrift van Joep Slaats:
Chromolaena odorata fallow in food cropping systems.
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Wageningen, 13 november 1995

Abstract

Slaats, J.J.P., 1995. *Chromolaena odorata* fallow in food cropping systems. An agronomic assessment in South-West Ivory Coast. Doctoral thesis, Wageningen Agricultural University, Wageningen, The Netherlands. 177 p. English, French and Dutch summaries. Also published in the series Tropical Resource Management Papers, No. 11, Wageningen Agricultural University, ISSN 0925-9495.

In tropical Africa, traditional shifting cultivation can no longer provide sufficient food for the rapidly increasing population, whereas it threatens the remaining forests. An alternative is a fallow system based on the shrub *Chromolaena odorata*. Food crop cultivation in rotation with this fallow type in Ivory Coast was analysed and options for efficient and sustainable land use were identified. Farmers obtained 1.8 t ha^{-1} maize without external inputs in a three-year fallow-cropping cycle. After crop harvest the *C. odorata* fallow vegetation established rapidly and effectively smothered herbaceous weeds. Experiments showed that the poor nutrient availability in this fallow system limited maize yields. During the cropping period *C. odorata* in maize was controlled by one weeding in the first month, whereas radical weeding practices set back its re-establishment after cropping. Shorter fallow periods and particularly extended cropping periods impaired both maize yield and *C. odorata* re-establishment. The *C. odorata* fallow system will be important for future food production because of the easy establishment and control of the species. To sustain intensive land use, farmers' cultivation practices can be improved by increasing nutrient availability, introducing suitable additional crops and developing practices that hardly check *C. odorata* re-establishment.

Additional keywords: slash-and-burn agriculture, labour requirement, clearing method, fallow period, prolonged cropping, weeding, fertilizer application, nutrient uptake, maize, secondary succession, vegetation dynamics, regeneration.

Aperçu

Slaats, J.J.P., 1995. *Chromolaena odorata* fallow in food cropping systems. An agronomic assessment in South-West Ivory Coast. Thèse de l'Université Agronomique de Wageningen, Wageningen, Pays-Bas. 177 p. Résumés en français, anglais et néerlandais. Cette thèse a également été publiée dans la série Documents de la Gestion des Ressources Tropicales, No. 11, Université Agronomique de Wageningen, ISSN 0925-9495.

En Afrique tropicale, la production vivrière dans la culture itinérante traditionnelle n'est plus suffisante pour nourrir la population croissante. De plus, ce système de culture menace les derniers restes de forêt tropicale. Une alternative est un système de jachère avec l'arbuste *Chromolaena odorata.* La production vivrière sur ce type de jachère a été analysée en Côte d'Ivoire et des possibilités pour une utilisation de terre productive et durable ont été identifiées. Les paysans obtenaient 1.8 t ha^{-1} de mais sans apport d'intrants dans un cycle jachère-culture de trois ans. Après la récolte, la végétation de jachère à *C. odorata* s'installait rapidement, en étouffant la sous-couche herbeuse. Des essais ont montré que la disponibilité restreinte d'éléments minéraux dans ce système de jachère limitait le rendement du maïs. Pendant la période de culture la croissance de *C. odorata* était contrôlée par un désherbage pendant le premier mois, alors que des désherbages radicaux ralentissaient la régénération de cette espèce après la récolte. Des périodes de jachère plus courtes ainsi que des périodes de culture prolongées diminuaient le rendement du maïs et la régénération de *C. odorata.* En raison de la croissance et dominance rapide et du contrôle facile de l'espèce, le système de jachère à *C. odorata* paraît important pour la production vivrière de l'avenir. Afin de soutenir une utilisation de terre intensive, les pratiques culturales paysannes peuvent être améliorées en augmentant la disponibilité d'éléments minéraux, en introduisant des cultures additionnelles appropriées et en développant des pratiques qui ne freinent pas la régénération de *C. odorata.*

Mots-clés supplémentaires: culture sur défriche-brûlis, temps de travail, méthode de défrichage, période de jachère, période de culture, désherbage, fertilisation minérale, absorption d'éléments minéraux, maïs, successions secondaires, dynamique de la végétation, régénération

Preface

In October 1988 I was appointed for two years as an agronomist in the Wageningen Agricultural University research programme "Analysis and design of land use systems in the Taï region, South-West Ivory Coast". My work was to study the transformation of shifting cultivation into more permanent cropping systems. Gradually I focused my research on the use of *Chromolaena odorata* fallow for food crop cultivation which turned out to be a cropping system of increasing importance. As work progressed, writing a thesis came within reach and I decided to seize the opportunity. This resulted in my staying two more years in the Taï region and finally in the book lying before you now. Here, I would like to thank those who have supported me in all kinds of manners during various stages of my research.

First of all, I am obliged to my promotor, Prof. Dr. Marius Wessel, for his support and his always and everywhere being available to give advice. Marius, you made me aware of the importance of *Chromolaena odorata* and had me time and again focus on the practical relevance my research has for day-to-day farming. I highly appreciated the way in which we worked together, your enthusiasm for my research and your warm and sincere interest in people.

I also truly thank Dr. Bert Janssen, my co-promotor. Your understanding of plant nutrition and your help in streamlining the research findings were very important. I set great store by your commitment and interest, and your challenging questions which constantly forced me to look for further explanations.

I owe a great debt to the villagers of Taï and Ponan for their hospitality and to the farmers for their enthusiastic participation in my research. I shall always remember their tolerant and open attitude to outsiders. I felt greatly supported by the Ivorian field staff, in particular by Toubaté Guy Abel Noël, Abou Koné Bacary and Chris Stevens. Without them, carrying out the field work would have been devastating. Their dedication, accuracy and enthusiasm made this period very pleasant and fruitful. I also thank the students participating in this research for their inspiring and helpful contributions. Moreover, Janette Bessembinder, Steven Starmans, Robert-Jan Hijmans, Jeroen Thijssen, Ton Elie, Sander Roes, Cecile Stockmann, Wieneke van der Heide, Fopko Louis, Ferko Bodnár, Lenie Ruygrok and Theo Bakker, you were good company.

I wish to express my acknowledgements to the Ministry of Scientific Research (Ministère de la Recherche Scientifique et de l'Enseignement Supérieur Professionnel et Technique) in Ivory Coast for their permission to carry out this study. I am grateful to The Tropenbos Foundation for granting me financial support during my last year in the field and for the publication of this thesis.

I appreciated the collaboration with my colleagues in the Wageningen Agricultural University research programme in Ivory Coast. Among them I wish to single out Henk van Reuler, Marie-Claire Henry and Anneke de Rouw. The exchange of results and fruitful discussions on research topics with Patrick Autfray (IDESSA), Laurent Gautier (CSRS), Koffi N'Goran (IRCC) and Tie Bi Tra (ENSA) were valuable for me. I thank the staff of the former Centre Néerlandais in Ivory Coast for providing me with facilities and support. My thanks also go to the Centre Suisse de Recherches Scientifiques, in particular the directors Liliane and Enrique Ortega, for their hospitality and excellent lodging facilities.

Credit goes to Prof. Dr. Louise Fresco, to Dr. Jan Wienk and to Dr. Egbert Westphal for their support in drafting the research proposals and for discussing the research findings. I thank Gerrit Gort and Dr. Klaas Scholte for their valuable advice on statistics, and Dr. Patrick Hommel and Dr. Ben Post for their useful criticism on the topics of vegetation science. I am grateful to my colleagues from the Department of Agronomy, in particular Wouter Gerritsma, Conny Almekinders and Janette Bessembinder for the many discussions and for their help.

The Department of Agronomy was very helpful when it provided me with a place to work throughout the period of data analysis and writing. I thank Joy Burrough-Boenisch for correcting my draft and making my legible writing readable.

I sincerely thank my relatives and friends, in particular Josephie Brefeld, Gert Jan Hofstede, Henk and Peggy van Reuler and Hans Bronswijk, for their understanding, encouragement and helping hand. De tout coeur je remercie Barbara Böni, qui, de loin et de près, m'a accompagné et stimulé pendant cette période et qui a partagé des humeurs diverses infligées par une "rivale" si forte.

This thesis
is dedicated
to my parents

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Part I

Background of the study

Chapter 1

General introduction

1.1 Transformation of cropping systems

Studies on agricultural development use systems theory to analyse the existing farming situation. For this, crop production is arranged in cropping systems, which are subsystems of the farming system. A cropping system is defined as a land use unit comprising soil, crop, weed, pathogen and insect subsystems (Fresco 1986, Fresco & Westphal 1988). It transforms solar energy, water, nutrients, labour and other inputs into food, feed, fuel, fibre and raw materials for medicines. There are several ways of classifying cropping systems, but in this thesis Ruthenberg's (1980) approach is followed. He ranks cropping systems according to land use intensity which he describes by the symbol R, indicating the proportion (in %) of area under cultivation in relation to the total area available for farming. He distinguishes shifting cultivation systems (R<33), fallow systems (R between 33 and 66) and permanent cultivation systems (R>66).

In the humid tropics, shifting cultivation is an important land use system. This system is characterized by a high labour productivity which has little scope for improvement (Ruthenberg 1980, Clark & Haswell 1970), and can only be sustained when population pressure is low. As described by Ruthenberg (1980), population increase and growing market demand cause shifting cultivation to gradually develop towards systems of permanent agriculture such as perennial crop cultivation, permanent upland cultivation and irrigation farming. On the generally poor soils in the humid and subhumid tropical lowlands, the transformation towards permanent upland cropping systems is difficult and slow. Farmers usually start to shorten fallow periods and extend cropping periods thus changing shifting cultivation into fallow systems.

1.2 Functions of fallow in cropping systems

The purpose of fallows in shifting cultivation and fallow systems is to maintain the chemical and physical soil properties, to suppress weeds and check the build-up of diseases and pests at the start of the subsequent cropping period (Ahn 1979, Fehlberg 1989, Nye 1958, Sanchez 1976). To meet this goal, fallow vegetation plants should preferably cover the soil rapidly, and accumulate considerable quantities of nutrients by a high biomass production and deep roots, but they should not be hosts to diseases and pests (MacDicken 1991, Prinz 1986, Reijntjes *et al.* 1992).

The efficiency of the fallow depends on the length of the fallow period (Nye & Greenland 1960). Guillemin (1956) illustrated the theoretical relationship between length of the fallow period and soil fertility restoration. Obviously, long fallows are at the expense of efficient land use. Weed suppression is related to the length of the fallow period in much the same way as soil fertility, although the time scale is probably different (de Rouw 1995, Saxena & Ramakrishnan 1984b). But the efficiency of the fallow also depends on plant characteristics, as these determine the time needed to establish a closed canopy for weed suppression and the capacity to store nutrients (Ahn 1979, Jaiyebo & Moore 1964, Nye & Hutton 1957).

In the transformation from shifting cultivation into fallow systems, crop yields and labour productivity tend to decline because fallow generally remains the only means of maintaining soil fertility and of reducing the incidence of weeds. Unless manure or fertilizers are used, this fallow system will ultimately lead to low yields if the soil is not intrinsically fertile.

1.3 Alternatives for shifting cultivation

The common opinion is that shifting cultivation no longer can meet the increasing demand for agricultural products, whereas its extension jeopardizes the remaining tropical forests. The danger of food shortages in the tropics and the awareness that forests are ecologically very valuable have incited scientists to study alternatives to shifting cultivation. Continuously cultivating the same plot without fallow is feasible but requires large amounts of labour and/or capital inputs (Sanchez *et al.* 1982). Intercropping hedgerows of woody species with food crops, i.e. alley cropping, gives stable but rather low crop yields and requires much labour (Kang & VanDenBeldt 1990, Kang *et al.*1990, van der Meersch 1992, Raintree & Warner 1986). A third possible alternative is improved fallows that are aimed at increasing the efficiency of the fallow period by replacing the natural vegetation with plant species of economic interest or accelerated growth. There are various examples of improved fallow systems developed by farmers in the tropics: a system based on oil palm in Benin (Brouwers 1993, Kang *et al.* 1991), one based on *Acioa barteri* in Nigeria (Kang *et al.* 1990, Vine 1968) and one based on *Leucaena leucocephala* in the Philippines (MacDicken 1991). According to Nye (1958) and Sanchez (1976), plant species selected for improved fallows should produce many seeds, establish early, and be easy to clear. Exotic plant species used as improved fallow mostly require extra labour during the establishment phase, so in order to be accepted by farmers they should offer economic advantages (Sanchez 1976). Nitrogen-fixing legumes are used in particular in alley cropping and improved fallows because they improve the N supply to the crop (Gichuru 1991, Kang & VandenBeldt 1990, van der Meersch 1992).

In this thesis another example of the third alternative for shifting cultivation is studied: a farmer-initiated cropping system based on the shrub *Chromolaena odorata* in the Taï region, South-West Ivory Coast. During the last thirty years, the population in the region has increased sharply through immigration and large areas of forest have been converted into cocoa and coffee plots. The resulting diminishing area of forest made it impossible to grow food crops in the traditional shifting cultivation system. The more intensive land use has enabled *C. odorata* to establish in the region and to dominate the vegetation during the early stage of the fallow period. Recently, farmers have started to clear *C. odorata* fallow to grow food crops.

1.4 *Chromolaena odorata*

1.4.1 Origin and distribution

C. odorata (L.) R. King & H. Robinson is native in Central and South America (Cruttwell-McFadyen 1991a). It was brought in Asia in the late nineteenth century, probably as an ornamental (Gautier 1992). However, it escaped and spread rapidly over mainland Asia, and later over the islands of Asia and Oceania. It arrived in West Africa and in South Africa from Asia in the 1940s (Gautier 1993a), and was introduced in South-East Ivory Coast around 1950, where it spread very rapidly over the humid southern part of the country (de la Barre 1977). It did not arrive in the Taï region until the early eighties, probably because the area's isolation and relatively dense forest hindered an earlier invasion (de Rouw 1991b).

Nowadays *C. odorata* has spread all over the Taï region, but is most abundant on roadsides and on frequently cropped fields near villages. On the catena the species is found from crest to the lower slope, without an indication for a preferred position. However, it is rare in valley bottoms. When abundant, as on fallows of frequently cropped sites, the species forms a thicket which dominates the vegetation for the first five years. The spread of *C. odorata* is closely related to human activities, in particular frequent disturbances of the natural vegetation such as agriculture and road maintenance (de la Barre 1977, de Foresta & Schwartz 1991, de Rouw 1991b). Frequent cropping and the implementation of radical cultivation practices causes *C. odorata* to disappear and be replaced by grasses (Gautier 1992, Herren-Gemmill 1991, de Rouw 1991a).

1.4.2 Plant characteristics and use

C. odorata (Fig. 1.1), formerly known as *Eupatorium odoratum* L., belongs to the Asteraceae. The species is called "Siam weed" in anglophone countries, "L'herbe du Laos" in francophone countries, and "Sekou Touré" or "Indépendant" in Ivory Coast (because the species invaded farms at the time the country achieved independence). It is a perennial shrub that forms a three-metre high thicket of tangled soft-wooden branches when in full light. The rooting system is fibrous and limited to the upper thirty centimetres of soil (Cruttwell-McFadyen 1988). Stems are spreading, profusely branched, herbaceous when young, tough and semi-woody when older. Leaves are ovate-deltoid, dotted with glands which emit a distinctive smell when crushed. The inflorescence is a many-flowered terminal corymb arising from the axil of upper leaves, with whitish florets. The fruits (achenes) are narrow, 3 to 5 mm long and have a pappus of the same size.

C. odorata seedlings emerge after four to twelve days, remain small during the first three months, and develop rapidly afterwards (Audru *et al.* 1988). Plants flower once a year, starting in the first year of their growth. Flowering is initiated by a combination of shortening days, decline in rainfall and drop in temperature (Gautier 1993b). *C. odorata* produces 90,000 to 180,000 seeds m^{-2} (Gautier 1992, Yadav & Tripathi 1982). Between 33 and 66% of the seeds are viable, but only 2% germinate immediately in situ, the rest disperse or remain dormant (Erasmus & van Staden 1986, Yadav & Tripathi 1981). Wind dispersal is common, but spreading by animals and man are important as well. The species also reproduces vegetatively as the nodes of branches may form roots (Gautier 1992).

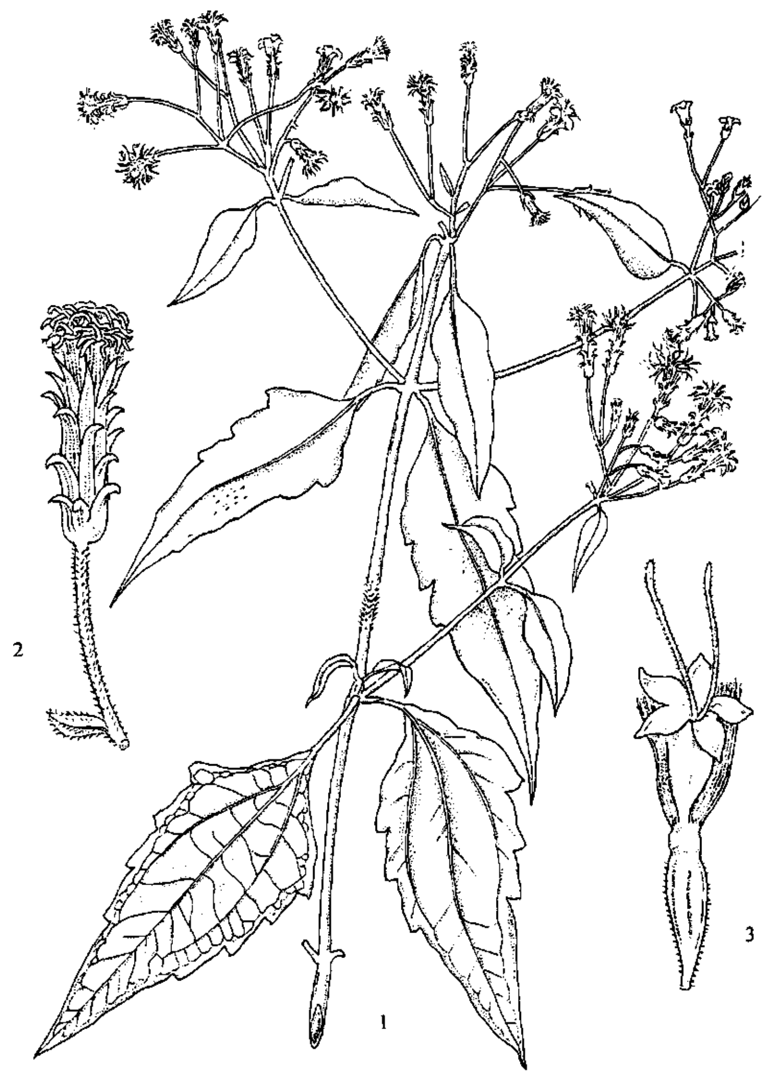


Figure 1.1 *Chromolaena odorata* (L.) R.M. King & H. Robinson. 1, habit of flowering plant; 2, inflorescence; 3, flower. From PROSEA (in prep.)

C. odorata is heliophile, has an optimal temperature range of 20 to 37°C (Muniappan & Marutani 1991) and is found in areas with a minimum annual rainfall of 1100 mm and a dry season of no more than five months (Gautier 1992). It grows on a wide range of soil types, but not on inundated sites. The plant tolerates mechanical injuries of slashing and burning as it is able to form new shoots on the swollen upper part of the primary root. However, frequent injuries will deplete the capacity to regenerate and the plant will perish.

Experiments with *C. odorata* as green manure in permanent crops (Litzenberger & Ho Tong Lip 1961, Obatolu & Agboola 1993) or as mulch in food crops (Hulugalle *et al.* 1987; Opara-Nadi & Lal 1987) gave favourable results. The species is known to control *Imperata cylindrica* (Chevalier 1952, Lucas 1989, Tjitrosoedirdjo *et al.* 1991). In Asia as well as in West and Central Africa, the natural fallow of *C. odorata* is progressively being used in systems of semi-permanent food crop production (Dove 1986, Field 1991, de Foresta & Schwartz 1991). The pH, structure and biological activity of the soil are reported to increase under a *C. odorata* fallow (de Foresta & Schwartz 1991, Gyasi *et al.* 1994). But its use as an auxiliary plant is limited as it hosts parasites and pathogens injurious to crops (Esuruoso 1971, Oritsejafor 1986). *C. odorata* is considered a serious weed in plantations of perennial cash crops and timber, in pastures and natural grasslands, and in nature conservation areas in Asia and in Africa (Audru *et al.* 1988, Holm *et al.* 1977, Kluge 1990). Mechanical, cultural and chemical control are satisfactory but mostly not attractive as they are labour-intensive, short-lasting or expensive (Erasmus 1988, Muniappan & Marutani 1991). As to biological control, the introduction of oligophage insects from the American continent into several African and Asian countries has achieved varying degrees of success (Cruttwell-McFadyen 1991b).

1.5 The study area

1.5.1 Location and climate

The study refers to the Taï region in southwestern Ivory Coast (Fig. 1.2), a region that stretches 70 km in north-south direction and borders the Parc National de Taï (PNT) in the East and the Cavally river in the West (de Rouw *et al.* 1990). All villages within this region lie along the main dirt road Zagné-Tabou. Research activities of the present study were carried out in the northern part of the region, mainly around the villages Taï and Ponan.

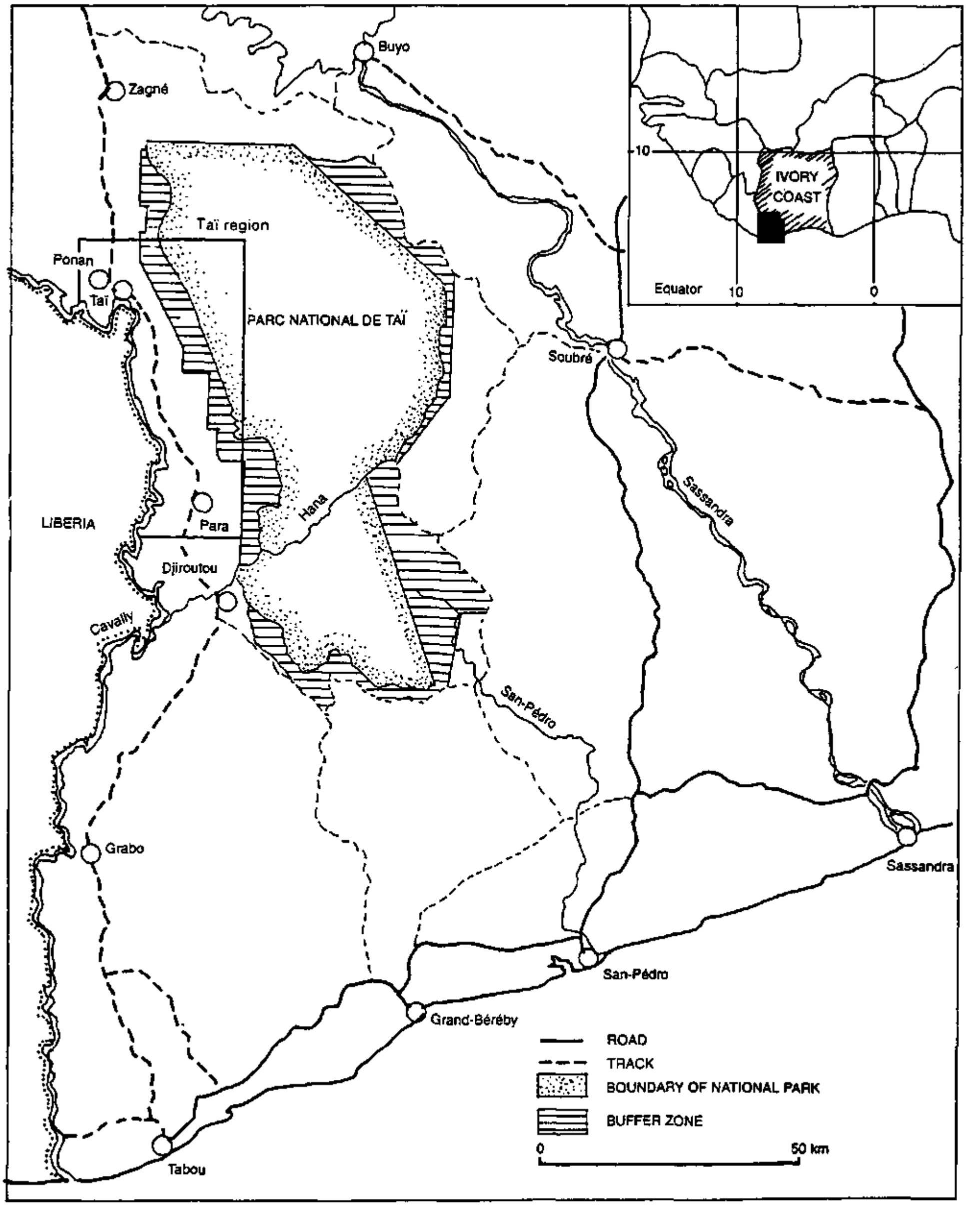


Figure 1.2 Map of South-West Ivory Coast and location of the study area

The area has a tropical monsoon climate with two distinct seasons, classified as Aw-type according to Köppen. The long rainy season from March to October is interrupted by a relatively drier period in July - August. During the dry season, lasting from November to February, relative humidity is low and sometimes wind from the Sahel (Harmattan) blows into the area. Mean annual rainfall in Taï is 1885 mm with a standard error of 338 mm (Collinet *et al.* 1984). The average monthly rainfall are highest in June and September (Fig 1.2). The mean monthly temperatures vary from 24.7°C to 27.4°C. Mean monthly global radiation varies from 1200 $Jcm^{-2}day^{-1}$ in July to 1700 $Jcm^{-2}day^{-1}$ in March (Collinet *et al.* 1984), and the average monthly potential evapotranspiration from 81 mm in July to 136 mm in March (Casenave *et al.* 1980). According to the climatic conditions two cropping seasons can be distinguished: the early season from April to July and the late season from August to November.

1.5.2 Geomorphology and soils

The landscape is undulating to rolling with long, mostly convex slopes, and relatively narrow valleys. The area lies 150 - 200 m above sea level, and differences in altitude are on average 20 to 25 m. The landscape is the result of erosion and dissection of an uplifted peneplain of Precambrian migmatite rocks. These peneplains were covered with extensive ironstone crusts, remnants of which are still found as iron caps on the crests and as lateritic gravel on the upper parts of the slope (de Rouw *et al.* 1990). Five positions can be distinguished on the catena: crest, upper slope, middle slope, lower slope and valley bottom (Fig. 1.3). Soils on the crest and upper slope positions contain large amounts of ironstone gravel, sometimes up to 80 % of the soil volume. The gravel layer begins at the surface or at shallow depth and is mostly more than 50 cm thick. The topsoil is a dark brown sandy loam to sandy clay. The subsoil contains more clay and its colour varies from strong brown to reddish or yellowish brown. Downslope, the soil becomes less gravelly and the gravel layer thins out. Near the valley bottom soils become poorly drained, their colour changes to yellowish and greyish brown and texture is more loamy and sandy.

In general, soils are strongly weathered and chemically poor. Analytical data of the topsoil of the different positions on the catena are given in Appendix I. The pH and the availability of phosphorus decline downslope (Stoorvogel 1993). P deficiency is the main yield-limiting factor (van Reuler & Janssen, 1989). Field trials of this study were laid out on the crest and upper slope positions, which cover 30 to 50% of the area (de Rouw *et al.* 1990). According to the FAO-UNESCO classification the soils here are Ferric Acrisols (Van Reuler & Janssen 1989).

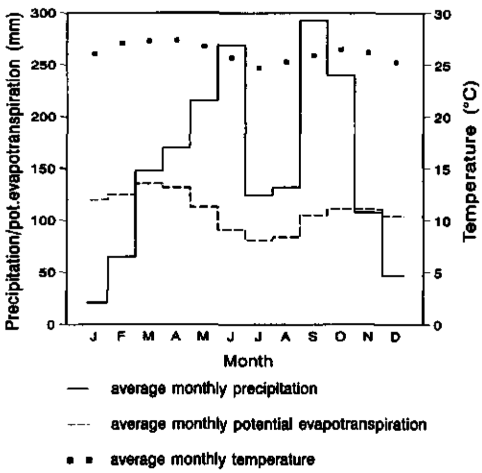


Figure 1.3 Average monthly precipitation, potential evapotranspiration and temperature (MAB station Taï 1978-1982, after Montheny 1983)

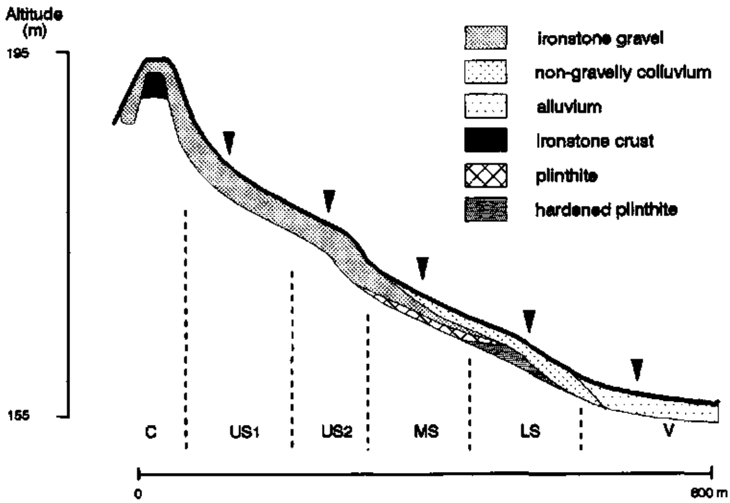


Figure 1.4 Schematic representation of of soil characteristics along the catena in the Taï region. Distinguished positions are: crest (C), upper slope (US1, US2), middle slope (MS), lower slope (LS) and valley bottom (V). Arrows indicate analytical soil data presented in Appendix I (after Nooren *et al.* 1995)

1.5.3 Vegetation

Using the UNESCO (1973) world classification, Vooren (1985) has defined the natural vegetation as a tropical evergreen seasonal forest. The closed canopy is at 25-35 m while prominent trees are even taller. The density of large forest trees and the number of tree species gradually decrease at a regional scale from northeast to southwest and at a local scale along the catena (van Rompaey 1993). The regional change is related to the rainfall gradient while the local change depends on soil moisture availability. The biomass of the forest vegetation ranges from 560 t ha^{-1} near the top of the slope to 350 t ha^{-1} in the valley bottoms (Huttel 1977). No data are available on the amount of nutrients accumulated in the undisturbed forest vegetation in the Taï region. Using figures of a forest vegetation near Abidjan, they can be estimated as 1150 kg ha^{-1} N, 90 kg ha^{-1} P, 520 kg ha^{-1} K, 1000 kg ha^{-1} Ca, and 430 kg ha^{-1} Mg (Bernhard-Reversat 1975).

Considering its land form, soil and vegetation, the study area can almost entirely be classified as rolling, moderately dissected uplands derived from migmatite in the northern rainfall-vegetation zone, land unit Unm2 in the land use survey conducted by De Rouw *et al.* (1990). This land unit covers about one third of the total Taï region.

1.6 Research objectives and approach

1.6.1 Objectives and context of the research

The objective of the research was to analyse the prevailing *C. odorata* fallow system and to explore the feasibility of increasing its productivity in terms of yield per unit land and of making it sustainable. Here, sustainability is defined as the successful management of resources for agriculture to satisfy changing human needs without degrading the natural resource base (TAC 1989). At the same time the research aimed at contributing to the development of appropriate permanent or semi-permanent cropping systems in the humid tropics. As alternatives to shifting cultivation, these systems may meet the increasing demand of food and limit the claims on the remnants of tropical forest. As the research period was restricted to four years, the study envisaged a broad overview of the *C. odorata* fallow system, its limitations and prospects for improvement, rather than an in-depth analysis.

The research was carried out in the period 1989 to 1992 as part of the interdisciplinary research programme of Wageningen Agricultural University (WAU), The Netherlands. The objective of that programme was to establish an analysis of the particular conservation-development interface for the design of appropriate land use systems in the given socio-economic setting in South-West Ivory Coast, with special reference to the Taï region (Wessel 1992). The disciplines integrated in this programme were agronomy, forestry, soil science, weed science and public health science. In 1992, the research on *C. odorata* received financial support from the Tropenbos research programme on the conservation and wise utilization of forest lands in Ivory Coast.

1.6.2 General methodology of the study

The main research activities were descriptive and explorative surveys and vegetation sampling, and field experiments. Surveys were used to characterize the major farming systems as well as cropping systems, to define the relevance of the *C. odorata* fallow system among the other cropping systems and to examine the prevailing *C. odorata* fallow system. The surveys included interviews with farmers, observations of their cultivation practices and field measurements. The *C. odorata* fallow vegetation was sampled to monitor development in terms of dry matter increase, weed suppression and nutrient accumulation. Experiments were used to study the effects of cultivation practices on crop production and on the re-establishment of the fallow vegetation after cropping. The factors concentrated on were length of the fallow period, method of clearing, weeding frequency, fertilizer application and length of the cropping period. The experiments were researcher-managed trials, laid down on six fallow fields rented from farmers. The preset criteria for the selection of these fields were: (1) fallow vegetation dominated by *C. odorata*, (2) maize as crop before fallow, (3) cropped twice or more during the last ten years, (4) located near Taï village where cropping intensity was relatively high, (5) located on the upper part of the catena. The soil characteristics prior to clearing of each field are given in Table 1.1. Information gained from surveys and vegetation sampling was used to design the experiments and to discuss the relevance of the results. A complete overview of the experiments is presented in Appendix II. The *C. odorata* fallow stands that were studied and used after clearing for experiments had all established spontaneously after farmers had cultivated food crops.

Table 1.1 Position on the catena, length of the preceding fallow period and analytical data of topsoil of the experimental fields laid out on land cleared from *C. odorata* fallow

Field	Topographic position	Fallow period (years)	Gravel content (%)	Soil texture			pH H_2O	pH KCl	Extr.P Dabin (mg kg^{-1})	Organic C (g kg^{-1})	Exchangeable cations (mmol(+) kg^{-1})			
				sand (%)	silt (%)	clay (%)					K	Ca	Mg	CEC
I	middle slope	0	6	67	7	23	6.1	5.1	4	14	2	26	6	45
II	upper slope	2	40	70	11	16	6.3	5.4	21	18	1	44	8	67
III	upper slope/ middle slope	3	11	71	7	18	6.1	4.9	4	14	1	22	6	49
IV	upper slope	3	39	68	15	16	6.2	5.2	9	19	2	38	7	57
V	upper slope	4	31	72	7	18	6.3	5.2	11	18	2	45	8	63
VI	upper slope	2	45	nd[a]	nd	nd	nd	5.0	nd	17	nd	nd	nd	nd

Gravel content expressed as a fraction of the whole soil, other chemical data (except pH) expressed as the fine earth (< 2 mm)
[a] nd = not determined

1.6.3 Outline of this thesis

This general introduction is followed by Chapter 2 which covers the transformation of cropping systems and the newly developed farming systems in the Taï region. It links the rise of the *C. odorata* fallow system with the transformation and gives an indication of the importance of this fallow system in present agriculture in the region.

The second part of the thesis reports on the prevailing *C. odorata* fallow system. Chapter 3 describes crop cultivation by farmers in this system, highlighting clearing and cropping practices, labour input and crop yields. In Chapter 4 the development of the *C. odorata* vegetation during the fallow period[a] is analysed. The results of this analysis are compared with the development of other bush- and forest fallows.

The third part of the thesis deals with crop production on the cleared *C. odorata* fallows in relation to cultivation practices. The effects of the length of the fallow period on the subsequent crops are elucidated in Chapter 5. The effects of different methods of clearing on the subsequent crops are compared in Chapter 6 . The effects of extending the cropping period are examined in Chapter 7. All these effects are studied under different regimes of weeding frequency and fertilizer application.

[a] In this thesis the fallow period of the *C. odorata* fallow system refers to the time (rounded in years) since weeding the last crop, which generally takes place one month after clearing and planting.

Part four covers the regrowth of *C. odorata* as influenced by cultivation practices. In Chapter 8 the development of *C. odorata* during cropping is monitored and the effects of clearing methods and cultivation are examined. The effects of cultivation practices on the re-establishment and composition of the fallow vegetation after cropping are compared in Chapter 9.

In the last chapter the main research findings are evaluated in the context of the *complete* fallow-cropping cycle. The *C. odorata* fallow system is compared with the traditional shifting cultivation system and its prospects in future food crop production are discussed.

Chapter 2

Transformation of cropping and farming systems in the Taï region

2.1 Introduction

In the Taï region, the transformation of cropping systems started about thirty years ago. Before then, the region was isolated and sparsely populated, and covered with rain forest. The indigenous people practised shifting cultivation, hunting, fishing and the gathering of forest products. In the shifting cultivation system, one rice crop was alternated with a fallow of at least sixteen years (Moreau & de Namur 1978, de Rouw 1991a). Cash crops like cocoa and coffee were planted on a very small scale. In the early sixties, this situation changed very drastically as the region was opened up, population density increased and large areas of forest were converted into smallholder cocoa and coffee plots. Perennial crop cultivation, semi-permanent food crop production on uplands and wet-rice cultivation in valley-bottoms became the major cropping systems.

This chapter describes the driving forces behind the transformation and the resulting changes in land use, crops, cropping and farming systems. The results of two surveys and informal discussions with farmers are used to compare the resources and strategies of indigenous and immigrant farmers. One survey dealt with farmers' resources and cropping activities. It was conducted in 1989 and included a representative group of 42 indigenous and immigrant cocoa growers in the village of Ponan. The other survey focused on food crop production in 1992 and was conducted among 38 Burkinabé immigrant farmers, also living in Ponan. The surveys highlighted the bottlenecks resulting from this transformation process and also indicated how farmers incorporate *C. odorata*, considered as one such bottleneck, into their food crop production system.

2.2 Forces driving the transformation

2.2.1 Government policy

The agricultural development of the Taï region was strongly stimulated by a master plan made by the government in 1965 to open up and develop the southwestern part of Ivory Coast. This plan envisaged the development of a large-scale plantation industry, the improvement of small-holders agriculture, the creation of production forest and the preservation of forest in defined areas. A detailed land evaluation had been done to allocate land for the different uses (Dosso *et al.* 1981, Léna 1984). To realize this plan, immigration into the largely uninhabited area was stimulated and infrastructure was improved

The development of the agricultural sector envisaged in this master plan was part of a nation-wide policy elaborated since independence (1960) to increase the production of cash crops for export. According to this policy, immigration was promoted by demoting traditional ownership of land and recognizing the user as owner instead (Jakobeit 1988, Ruf 1984b, Sawadogo 1977). The smallholder's production of cocoa and coffee was strengthened by releasing new planting material and introducing improved cropping and processing practices (Colin 1990, Jakobeit 1988, Wiese 1988). Diversification of cash crops was achieved by creating schemes of industrial plantations with outgrowers of rubber, oil palm and coconut (Colin 1990, Sawadogo 1977). The establishment and functioning of these schemes became the responsibility of semi-governmental organizations, which provided outgrowers with credit, plant material and technical advice.

In the master plan forest reserves were created to guarantee the future supply of valuable timber and to preserve a climatic barrier (Wessel 1982). This barrier was to prevent the dry Sahelian wind from blowing into the coastal agricultural area and to protect the hydrological infrastructure of the Cavally and Sassandra rivers.

When the master plan was implemented there was a huge influx of immigrants into southwestern Ivory Coast. Settlements were rather chaotic and only part of the land use plans could be realized. The improved access into the forest, the policies favouring land ownership and cocoa and coffee production, plus farmers' interest in short-term benefits pushed farmers, especially the immigrants, to large-scale deforestation and extensive land use. Forest reserves were threatened, although not invaded by farmers on a large scale. In the seventies, the major reserve in the centre of the area was designated a national park (Parc National de Taï, PNT) and presently preserves 430,000 ha of forest (de Rouw *et al.* 1990).

The agricultural development was also favoured by the government's price policy for cocoa and coffee. The trade in these commodities was entirely controlled by a national marketing board that paid guaranteed minimum prices to farmers. These prices followed the doubling of the world market price of both commodities during the period 1975-1980 and were again brought in line with the world market nine years after prices had dropped (Jakobeit 1988).

2.2.2 Immigration

Immigration into southwestern Ivory Coast was mainly directed towards the search for land or employment. The government policy described in Section 2.2.1 was an important external stimulus. Also, people moved into this area because of the serious drought in the savanna region between 1966 and 1973, and because they were forced to move from the central part of the country by the construction of a hydro-electric dam (Léna 1984, Wiese 1988).

Immigration was mainly spontaneous. The newcomers were Ivorians as well as foreigners. Most Ivorian immigrants belonged to the Baoulé and Dioula ethnic groups, originating in the central and eastern part and the northern part of Ivory Coast respectively. The foreigners came from Burkina Faso and Mali. The various ethnic groups arrived in southwestern Ivory Coast in different periods (Léna 1984). Baoulé and Dioula mainly came during the sixties and seventies, whereas Burkinabé and Malinese arrived from the seventies until the end of the eighties.

Immigrants also differed in their experience in perennial cash crops. One group of immigrants lacked experience in growing perennial cash crops. They were Dioula as well as Burkinabé and Malinese coming directly from their home lands in the northern dry savanna zone. The other group of immigrants consisted of farmers and land labourers, who were already involved in cash crop production in the eastern and central parts of Ivory Coast. They were Baoulé or Burkinabé and Malinese who had immigrated into Ivory Coast in earlier days. Their arrival in the southwestern region formed the last phase of a more extensive movement of people from East to West Ivory Coast (Colin 1990, Léna 1984, Ruf 1984a). They left the more densely populated eastern part of the country where forest had almost completely been converted into smallholder cocoa and coffee plots, and looked for forest in the central and sparsely populated southwestern part, with a view to grow cash crops.

Immigration was an essential element in the agricultural development in the forest zone of Ivory Coast and particularly in the southwestern region. It brought people with ample access to labour together with people who controlled huge areas of land, and this resulted in a booming cash crop production. Immigration and the related extension in the area under cash cropping marked the transition from subsistence to commercial farming.

2.3 Changes in agriculture

2.3.1 Changes in population, land use and crops

The opening up of the region and the influx of immigrants led to changes in population, land use and crops, and consequently in cropping and farming systems. Immigration caused the total population in the Sous-Préfecture Taï to rise from 4,551 in 1968 (Schwartz & Richard 1970) to 30,039 in 1988 (Ministère du Plan 1988), while the proportion of indigenous inhabitants dropped from 80% to 22% (de Rouw 1991a). In 1991 the population had risen by a further 27,214 persons as refugees of the civil war in Liberia had settled down in Taï and the neighbouring villages (Bonnehin 1991). At present, the population density is estimated at 35 persons km^{-2}.

The population increase is clearly reflected in a change in land use. According to de Rouw *et al.* (1990), agricultural land use had expanded over a vast area between 1956 and 1988, mainly as a result of cash cropping by immigrants. The area under undisturbed primary forest outside the PNT had dropped drastically and was mainly confined to the buffer zone adjacent to the PNT where farming was prohibited. The increasing land use intensity in the Taï region can best be indicated by changes in the area in which remnants of the primary forest cover less than 25%, given by de Rouw *et al.* (1990). This area expanded from 39% of the total land outside PNT and bufferzone in 1956 to 56% in 1988.

With the arrival of the immigrants, maize, yam and cassava became major staple foods beside rice. Moreover, the area under cocoa and coffee increased exponentially and other perennial crops were introduced. From 1989 onwards, for instance, farmers in the area north of Taï village planted rubber as an outgrowers' crop, while those living in the area to the south started with oil palm.

2.3.2 Changes in cropping and farming systems

Strictly speaking, the cropping system had already changed before the early sixties, when the first indigenous farmers started to grow cocoa and coffee. But in the last thirty years, both indigenous and immigrant farmers have made perennial crop cultivation their major cropping activity, thus giving momentum to the transformation of shifting cultivation towards permanent cropping systems. In this system of perennial crop cultivation, cocoa and coffee are planted on land cleared from primary, and sometimes secondary forest. During the establishment phase, these crops are associated with a mixture of food crops. The main crops such as rice, maize and yams are harvested during the first year, while secondary food crops like cassava, plantains and tannia (*Xanthosoma sagittifolium*) are harvested in following years. From the third year onward hardly any food crops are grown since the cash crops have formed a closed canopy. Each year, farmers grow food crops on newly cleared forest plots. This change for permanent cropping systems has occurred throughout the entire Taï region, although indigenous farmers have not completely refrained from shifting cultivation. In some years, they do not plant cocoa or coffee on newly cleared land, but simply abandon it after rice harvest.

In the last decade, immigrants have begun to grow food crops in an upland fallow system based on *C. odorata*. In this system, one maize crop is followed by two or three years of fallow during which *C. odorata* dominates the vegetation. A detailed description of the system is given in Chapter 3. Immigrant farmers have also started wet-rice cultivation in valley bottoms as they used to do in their savanna homelands. Some local people with limited access to land have followed this example. Water supply and management are not yet well developed and yields do usually not exceed 3 t ha^{-1}.

With the introduction of cash cropping the traditional farming system that focused on subsistence agriculture changed into market-oriented farming systems. The use of land, labour and capital for agricultural activities shows similar characteristics on all farms. Cash crop cultivation is merely an activity of the male members of the household and of labour from outside the farm. The availability of this external labour is crucial for the success of cash cropping (Ruf 1979, 1984a). Capital input is rather low, as the farm equipment consists solely of simple hand tools (cutlass, short hoe, axe) and the use of agro-chemicals is restricted to some pesticides in cocoa. Farmers hardly practise soil fertility conservation and crop protection. This explains the low yields of food and cash crops reported by de Rouw (1991a) and Budelman & Zander (1990).

2.3.3 Resulting farming systems

A general distinction can be made between indigenous and immigrant farming systems on the basis of access to land and labour and the extent of growing cash crops. The main characteristics of both farming systems are given in Table 2.1.

Table 2.1 Characteristics of farming systems of indigenous and immigrant farmers. Immigrant farmers have been subdivided into the ethnic groups they belong to (results farm survey Ponan 1989)

	Indigenous farms (n=9)	Immigrant farms Baoulé (n=6)	Burkinabé (n=21)	Dioula (n=6)
Household				
age household head (year)	47	36	36	48
time since immigration of household head (year)	na [a]	12	6	11
permanent male family labour (persons household^{-1})	2.0	2.5	2.6	2.7
temporary male family labour (% households using)	0	0	30	50
hired labour (% households using)	100	80	70	80
Cropping system				
farm area (ha)	19	16	10	13
cash crops (% farm area)	36	78	88	50
- cocoa	15	60	69	42
- coffee	16	18	19	8
- rubber	5	0	0	0
forest (% farm area)	64	22	12	50
mean area cleared per year (ha)	0.3	1.2	1.4	0.6

[a] na: not applicable

Indigenous farmers have less permanent family labour at their disposal than do the immigrants. The use of hired labour is similar for both groups of farmers. Immigrants farmers rely on the labour of relatives from their homelands who assist in farm activities for one season up to several years. Many immigrant farmers also rely on mutual assistance from neighbours and relatives for field work, whereas the indigenous farmers do not.

The indigenous people have relatively large farms but grow cash crops on only a small part of their land. As land is not cleared each year, the mean annual rate of clearing for cash crop cultivation is low. They grow as much cocoa as coffee, and three of the nine farmers questioned have started to cultivate rubber. The preference for coffee is even more pronounced than indicated by these results, as farms without cocoa production were excluded from the survey. Indigenous farmers prefer rice as staple food, as they did in the traditional farming system, and the division of labour among men and women has hardly changed. All farmers interviewed still own forest, although some of them have only a small area.

Immigrants have relatively small farms, but a large proportion of this land is under cultivation. Most farmers clear forest for cash crop production each year. The area under cocoa is far bigger than the one under coffee, and rubber is not grown. Immigrant farmers grow rice, maize and cassava as staple foods. Male farmers assist their wives in sowing and harvesting these crops. The immigrant Baoulé farmers clearly prefer growing yam as staple food, which is planted and harvested mainly by men. A quarter of the immigrant farmers, Burkinabé immigrants mostly, have run out of forest.

The shortage of male labour is one important reason why indigenous people are involved in cash crop production to a moderate extent only. This problem also occurs elsewhere in South-West Ivory Coast (Ruf 1979). There are relatively few males on the farms because many of them are attending schools outside the region or have found urban employment. Moreover, indigenous farmers do not have recourse to temporary family labour. Presumably, another reason that indigenous farmers plant only a small area with cash crops is because they are not very interested in economic benefits, as they have to share these with relatives or fellow villagers. The limited availability of male labour and low economic incentives also explain why the indigenous farmers grow coffee instead of cocoa. In the Taï region, coffee seems more appropriate under conditions of extensive management as it copes better with neglect during the establishment phase, hardly suffers from pests and diseases and its post-harvest handling is simple. This suits the indigenous farmers, who have a limited supply of labour and live in the village some distance from the farm. One of the main objectives of indigenous farmers seems to be to generate cash to enable children to go to school. However, the ample use of external labour and the partial reliance on food produced by immigrants suggest that indigenous farmers also use their access to land to lighten the workload of the family members. A similar attitude was reported for farmers in eastern Ivory Coast (Foucher 1983).

Immigrants, on the other hand, were attracted by the opportunity to earn money (Léna 1984). Although cocoa growing demands better management, they prefer this crop over coffee because it gives higher returns to land and labour (Ruf 1984b). Having easy access to labour and living on the farm, they are able to meet the labour requirements of cocoa growing. However, among immigrant farmers crop management is extensive too, because they are unsure about their claims of land ownership. Supposedly, it also is economically more attractive to extend the planted area than to improve cultivation practices. According to Ruf (1982, 1984b), farmers are inclined to intensify crop production once the availability of land is restricted. The farming system characteristics clearly indicate that immigrants use their resources to generate cash which is invested in non-agricultural activities e.g.: house construction and commerce.

Differences within the immigrant farming system are small and are related to the ethnic group farmers belong to. The later immigrants had arrived in the region, the smaller their farm, a common phenomenon among immigrant farmers in South-West Ivory Coast (Budelman & Zander 1990, Léna 1984, Ruf 1979). Dioula immigrants, who were among the first ones to arrive, resemble the indigenous farmers the most by cultivating a relatively small proportion of their land and having settled in the village and not on their farms. They prefer living in the village because household members are involved in crafts and commerce, and being Muslim they can pray in the village mosque.

2.4 Transformation and the rise of *Chromolaena odorata*

2.4.1 Problems resulting from the transformation

As a result of the transformation, bottlenecks arose in food crop production and in perennial crop cultivation. Growing food crops is increasingly hampered by the sharply diminishing area of forest and farmers have developed alternatives (Table 2.2), which are similar to those reported in other parts of southern Ivory Coast (Bonnehin 1988, de Rouw 1991a, Ruf 1984b).

Farmers still having forest use it more intensively. Those who have no forest or only a very limited area, plant food crops on upland plots cleared from *C. odorata* fallow and in open sites in mature cocoa or coffee plots. They may also grow rice in valley bottoms, although Dioula farmers do so even when they still have a considerable area under forest. Growing food crop on land cleared from *C. odorata* fallow is an alternative rapidly gaining importance in the region, and is practised by Burkinabé immigrants. Many of these fallow lands are hired from the indigenous people. The more intensive use of uplands in these alternatives will undoubtedly result in low yields, given the poor soil fertility. Moreover, it will favour the further establishment of *C. odorata,* which is a weed during cropping and delays the forest regeneration. Handing out fallow land to immigrants jeopardizes the traditional shifting cultivation system of the indigenous people as forest regrowth is postponed. The extent to which *C. odorata* is a bottleneck in upland crop production is elucidated in Section 2.4.2.

Table 2.2 Land resources and food crop production of indigenous and immigrant farmers (in % of farmers interviewed). Immigrant farmers have been subdivided into the ethnic groups they belong to (results farm survey Ponan 1989)

	Indigenous farms (n=9)	Immigrant farms Baoulé (n=6)	Burkinabé (n=21)	Dioula (n=6)
Land resources:				
- forest land	100	83	67	100
- valley bottoms	78	67	71	83
Food crop production:				
- in valley bottoms [a]	14	25	27	60
- on own upland plots	nd [b]	100	81	100
- in mature cash crop plots	0	33	19	17

[a] percentage of farmers having valley bottoms on their farm
[b] not determined, but is assumed to be 100%

The transformation has also resulted in the problem of unstable permanent land use under cacao because trees cease production within fifteen years after planting instead of the usual fifty years (Lass 1985). This early die-back is mainly caused by capsid damage and is aggravated because the poor soil properties prevent trees from recovering. Moreover, the prevailing management of the cocoa plots is largely insufficient to control capsids or to stimulate the recovery. When confronted with die-back, farmers replace dead plants with new seedlings in recently established plots, plant preferably coffee on newly cleared land, abandon seriously affected plots, and in extreme cases may sell their farm and leave the region. Coffee, rubber or oil palm seem to be more appropriate crops in this environment, a view also held by extension agents and scientists of the national cocoa and coffee research institute.

2.4.2 The incorporation of *C. odorata* in the food crop production systems

The importance of *C. odorata* fallows in food crop production of Burkinabé immigrants was highlighted in the 1992 survey. Most immigrants grew food crops on upland plots, and a considerable part of them also had food crop plots in the valley bottoms (Table 2.3). Thirteen farmers used *C. odorata* fallow and ten of these had no forest left. A large proportion of the plots cleared from *C. odorata* were hired. As to valley bottom lands, 70% of the farmers having such land used it to grow food crops. Roughly half of the farmers had also planted food crops in open sites in mature cocoa and coffee plots. These data prove that uplands under *C. odorata* fallow and valley bottoms are gradually becoming major land types for food crop production. Around Taï village, food crop production on land cleared from *C. odorata* fallow is even more widespread than in Ponan, because many Burkinabé farmers owned land within the buffer zone of the PNT where farming is now prohibited.

Table 2.3 Where Burkinabé farmers grow their food crops (food cropping survey 1992, n=38)

	Number of users	Number of owners [a]	Main crops
On uplands plots:			
- forest fallow	13	10	rice, yam[b]
- bush fallow	6	6	maize
- *C. odorata* fallow	13	5	maize
On valley bottom plots	21[c]	15	rice
In mature cash crop plots	19	19	cassava

[a] users who own the plot
[b] maize is grown in the second year after clearing
[c] 15 of these farmers also grew food crops on upland plots

Many of the *C. odorata* fallow plots rented by Burkinabé immigrants are old rice plots of the indigenous farmers. In return, Burkinabé immigrants provide them with labour or a part of the yield, or pay a rent in cash. Indigenous farmers let out *C. odorata* fallow for various reasons. Firstly, many of them no longer hand out forest land because they have become aware of its rapid disappearance. Secondly, *C. odorata* fallows do not fit their food crop production system. Rice, the preferred staple food, is very sensitive to competition from the abundant weeds on the plots cleared from this fallow. Moreover, indigenous farmers do not use a short hoe, the tool which is needed to weed these plots effectively. In contrast with this, Burkinabé farmers prefer maize as staple food, a crop which tolerates weeds better, and hoe-weeding was a standard practice in their savanna homelands. However, an increasing number of indigenous farmers are refusing to hand out *C. odorata* fallow because they intend to plant it with rubber under the newly introduced planting scheme for outgrowers, or do not want to further delay the re-establishment of the forest.

2.5 Conclusions

Cultivation of cocoa and coffee, strongly favoured by government policy and immigration, led to the transformation of shifting cultivation into perennial crop cultivation, with temporary intercropping with food crops during the establishment phase. At present, the farming system of the indigenous people where labour to land ratio and land use intensity are low, can be distinguished from the farming system of immigrants where both parameters are high. The transformation towards permanent cropping systems is hampered by the early die-back of cocoa. As a result of the large-scale conversion of forest into cash crop plots, an increasing number of farmers are also running out of forest and have to grow food crops in other ways. The alternative food crop production systems imply a more intensive land use and a greater demand for labour. The commonest alternatives are wet-rice cultivation in the valley bottoms and upland food crop cultivation in alternation with short periods of *C. odorata* fallow. This fallow system is mainly practised by Burkinabé immigrants, who rent the *C. odorata* overgrown plots of indigenous farmers in exchange of labour or money. In the short term, this exchange appears profitable, but in the long term it will undermine the traditional shifting cultivation of the indigenous farmers.

Part II

The prevailing *Chromolaena odorata* fallow system

Chapter 3

The present use of *Chromolaena odorata* fallow for crop production

3.1 Introduction

As indicated in Chapter 2, immigrant farmers in the Taï region who have run out of forest have started to grow crops on young fallows dominated by *C. odorata*. This change in cropping system, implying a considerable shortening of fallow periods, has resulted in weeds being more numerous on plots cleared from a *C. odorata* fallow than on those cleared from a forest fallow. No visible symptoms of nutrient deficiencies in the crops grown on plots cleared from *C. odorata* fallows have yet been observed. Farmers may cope with weeds by changing cultivation practices and by extra weeding. However, labour is not readily available, and is particularly in short supply at the start of the cropping season. Therefore, the labour requirements for clearing and weeding are used in this chapter as a criterion in addition to crop yield to evaluate the *C. odorata* fallow system.

In this chapter, the cultivation practices used in the *C. odorata* fallow system of Burkinabé immigrants are described and key data on labour input and crop yields are given. A comparison is made with the traditional shifting cultivation system on forest fallows in the Taï region.

3.2 Materials and methods

Information and data on crop production in the *C. odorata* fallow system were obtained in surveys, including interviews with farmers, observations of their practices, and measurement of labour input and crop yield on their plots. The measurement of labour input was restricted to clearing and weeding operations which, according to Dvoràk (1992), account for most agricultural labour in almost all farming systems in West Africa.

The clearing practices of farmers interviewed consist of slashing and burning the fallow vegetation. The labour input for slashing during a single day was measured on sixteen plots. The total time workers spent on the field was recorded and the area cleared during the day was measured. On six out of the sixteen plots, the working time, i.e. the total time excluding breaks, was recorded. The clearing performance of workers, i.e. the area an individual worker cleared per time unit, was measured during observation periods of exactly thirty minutes. This was done one to three times during the day, and in total fifty-one observations were made on the sixteen plots. The time spent on burning was not recorded, as this took relatively little time and was not considered a crucial activity in terms of labour requirement.

Records of weeding labour mainly refer to the first weeding operation as this was carried out by all farmers in a well-defined period. Weeding labour was observed during twenty-three days. On some plots, weeding was monitored during a single day, on other plots during several days. In total, weeding records were kept on eleven plots. On each day, the total time workers spent on the field and the working time were recorded, and the area they weeded and their weeding performance (the latter for some workers only) were measured. Time records were made for all workers separately. As workers weed in any direction, it was impossible to measure the area an individual had weeded in one day. That is why only the total weeded area at the end of the day was surveyed. Weeding performance was measured during observation periods of thirty minutes. On the eleven plots eighty-four observations were made in total for male workers and forty for female workers.

With the records mentioned above the labour requirements of the first weeding are defined for men and women separately. For that purpose the measured weeded area per day is compared with the calculated weeded area per day. The area weeded per day (A) is calculated by:

$$A = N_m * W_m * O_m + N_f * W_f * O_f \qquad (3.1)$$

with N the recorded number of workers, W the recorded working time in hours day^{-1} and O the average weeding performance in m^2 h^{-1} person^{-1} based on thirty-minutes measurements, with subscripts for men (m) and women (f).

As the second weeding was of minor importance and was not carried out in a distinct period, the working time and weeded area relating to this weeding were recorded on four plots only. Weeding performance was not measured, because weed growth was not uniform and the tall maize plants made it difficult to measure areas accurately.

Crop yield was measured in ten plots. In each of these plots four quadrats (5 x 5 m) were laid down, in which plant sites, plants and cobs were counted, and cobs and stover were weighed. Per quadrat, ten cobs were separated into grains and spikelet plus husks and weighed. Both fractions and the cut stover of two plants were sampled to determine moisture content.

3.3 Results

3.3.1 Cultivation practices

Cropping and fallow periods

Usually, farmers grow a crop on plots cleared from *C. odorata* fallow during the early cropping season only. They lack time to crop the plot in the late cropping season because they have to weed and harvest their cocoa and coffee. Only on farms where the household comprises more than about six adults, the cleared plot is sometimes cropped in the late season. The following year, farmers abandon the old plot and shift to another fallow. The old plot is cropped again after three years of fallow, starting from the year of the first clearing. However, farmers tend to shorten fallow periods to two years because of the increasing demand for land, particularly near Taï village. Some farmers had even started to grow a crop in the second year after clearing.

Selection and clearing of plots

When selecting a plot, farmers prefer a fallow vegetation without a herbaceous undergrowth, with a high amount of biomass and litter, and few *C. odorata* stumps. In their opinion the best yields are obtained on a three- to four-year-old *C. odorata* fallow, where much ash is produced at burning. In reality, most farmers clear land under younger fallow. Soil qualities are hardly used as criteria to select a plot. Most plots are laid out on the upper slopes where soils contain gravel and are well drained. However, farmers avoid soils that are very gravelly.

The period of clearing a *C. odorata* fallow may extend from February to June. Most farmers, however, clear between March and May. Clearing is not carried out in one go, but distributed over a period of several weeks. In this way a part of the plot is slashed, burnt and planted, sometimes even before slashing is started on another part.

Slashing is a task purely for men, carried out individually or together with another farmer in a reciprocal arrangement. Some farmers also hire labour to carry out this operation. The fallow vegetation is cut off at ground level with a cutlass, but stumps of *C. odorata* and trees are not uprooted. The slashed vegetation is left to dry for about one week before burning As to burning, farmers are in favour of a rapidly advancing fire to be sure that all parts of the plot are touched. So they start burning early in the afternoon when there is some wind. Burning is rather superficial; often the slashed vegetation is not totally burnt. On cleared young fallows, the fire normally does not reach all parts of the plot. In that case, farmers pile up the remaining slash for a second burning.

Crop management and harvest

Maize is the main crop on plots cleared from *C. odorata* fallow. Traditional varieties with flint or dent grains are grown. Plants attain a height of three to four metres and mature in four to five months. Farmers usually save seed for sowing. As soon as the first rains start, men and women make plant holes with a short hoe or cutlass, and put two to four maize seeds in each. Maize is mainly grown in a pure stand, and is mixed with bulrush millet (*Pennisetum typhoides*) and beans in a small part of the plot only.

Weeding is done twice: at 1 to 3 weeks and at 6 to 12 weeks after sowing. All farmers carry out a first weeding which they consider essential for obtaining a reasonable harvest. At that moment, *C. odorata* and *Spigelia anthelmina* are among the most abundant non-crop plant species. In farmers' view, they are not weeds as opposed to some grasses, forbs and the creeping legumes *Centrosema pubescens* and *Pueraria phaseoloides*. The first weeding is carried out by men and women, and may involve children as well. They till the soil superficially and cut back sprouting stumps of *C. odorata* and other woody species with a short hoe. Sometimes, *C. odorata* stumps are uprooted.

Although farmers think that the second weeding favours the development of maize plants and of associated crops, eliminates potential shelter for rodents and gives better access at harvest, not all of them weed a second time. The second weeding is mainly a task for men and consists of cutting back sprouting stumps of *C. odorata* and other woody species as well as high herbs with a cutlass. The most abundant non-crop species at that moment is *C. odorata*.

No external inputs such as herbicides, insecticides or fertilizers are used, when cultivating maize on plots cleared from *C. odorata* fallow. Most of the cobs are picked when fully mature, and the grains are consumed as made into porridge or dough. A minor part of the maize cobs is harvested when grains are in the milky stage. These immature cobs are boiled or roasted for own consumption or for sale. At harvest, only the cobs are removed from the plot. If necessary, maize stalks are cut back to facilitate the development of the associated crops or to clear the plot for a second crop.

3.3.2 Labour input

Data on the labour used for slashing and weeding are presented in Table 3.1. Ranges instead of averages of the observations are given for the second weeding, because data were variable and few in number. The involvement of men and women in these operations is already mentioned above. Women spent less time on the plot as they arrived later and often left earlier. During the first weeding long days were made, whereas the second weeding took relatively little time and was often combined with other activities. The second weeding was the least demanding operation and the first weeding needed most time. The estimated labour input corresponded to 30 person days ha^{-1} for slashing and 57 person days ha^{-1} for the first weeding under the given ratio of male and female workers. The second weeding took 6 to 19 person days ha^{-1}, assuming that the working time of this operation was 4 hours day^{-1} as for slashing.

Table 3.1 Characteristics of labour spent by farmers in field operations of maize cropping in the *C. odorata* fallow system, early season 1991 (average values for slashing and first weeding, value ranges for second weeding)

Operation[a]	Workers		Working time[b] (h)	Work performance[c] (m^2 h^{-1} p^{-1})	Worked area (m^2 d^{-1})	Estimated labour input (h ha^{-1} p^{-1})
	No./field	Sex				
Slashing	1.4	M	4.0	93	463	118
First weeding	1.6	M	5.0	59	594	224
	1.8	F	3.0	43		
Second weeding	1.0	M	1.0-3.0	130-422	300-626	23-77

[a] Numbers of observations: 16 for slashing, 23 for first weeding and 4 for second weeding
[b] working time = total time excluding breaks
[c] measured per individual worker during 30 minutes for slashing and first weeding, calculated as the total weeded area divided by working time for the second weeding; p = person

To estimate the labour requirements of the first weeding for men and women separately, the weeded area calculated by Equation 3.1 was plotted against the area weeded per day measured on each plot (Fig. 3.1). The calculated weeded area was in most cases lower than the measured weeded area and both variables appeared linearly related. Using the linear regression it can be derived that on average a man needs 198 hours (about 41 days) to weed one hectare, while a woman needs 274 hours (89 days).

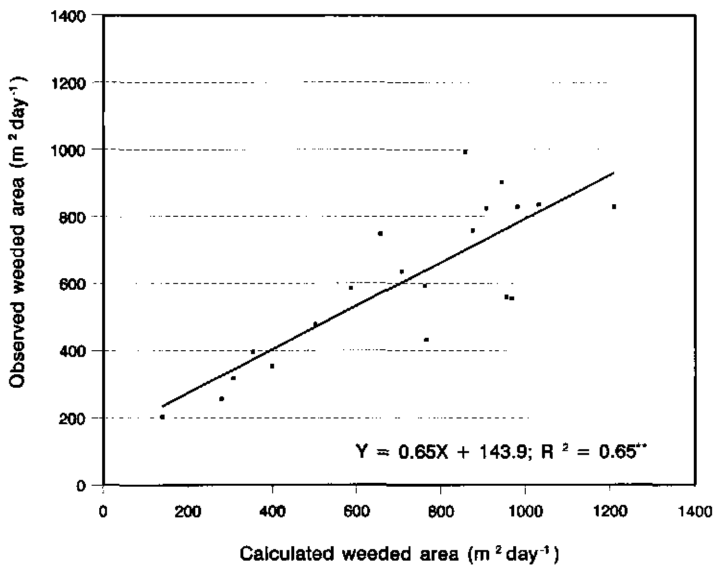


Fig. 3.1 Relationship between the observed and calculated area weeded per day on farmers' maize fields in the *C. odorata* fallow system, early season 1991

3.3.3 Crop yields

Data on crop production that varied most among sample quadrats were grain yield, number of plant sites, number of plants and proportion of empty cobs (Table 3.2). On the other hand, the proportion of plants bearing a cob and grain weight hardly differed. Virtually all plants had produced at least one cob, and in most cases this cob carried grains. On average, plants had more than one cob, but the second cob was often empty.

Table 3.2 Yield characteristics of a farmers' maize crop grown in the *C. odorata* fallow system, early season 1991 (standard error of mean in parentheses)

Characteristic	Average	SE
Grain yield (t ha^{-1})	1.8	(0.1)
Harvest index (%)	33	(1)
Weight of 1000 grains (g)	304	(4)
Density of plant sites (no. m^{-2})	1.0	(0.1)
Density of plants (no. m^{-2})	2.0	(0.1)
Proportion of plants with a cob (%)	98	(1.0)
Number of filled cobs[a] per plant	0.9	(0.0)
Number of empty cobs per plant	0.5	(0.1)

[a] filled cob = cob containing at least one grain

Crop yield appeared most closely related to plant density as shown by the line calculated for the quadrats with density between 1.0 and 2.5 plants m^{-2} (Fig. 3.2). In this interval, grain yield increased by 80 g per plant. Data of one plot were not presented in this figure, because late weeding resulted in outlying low yields.

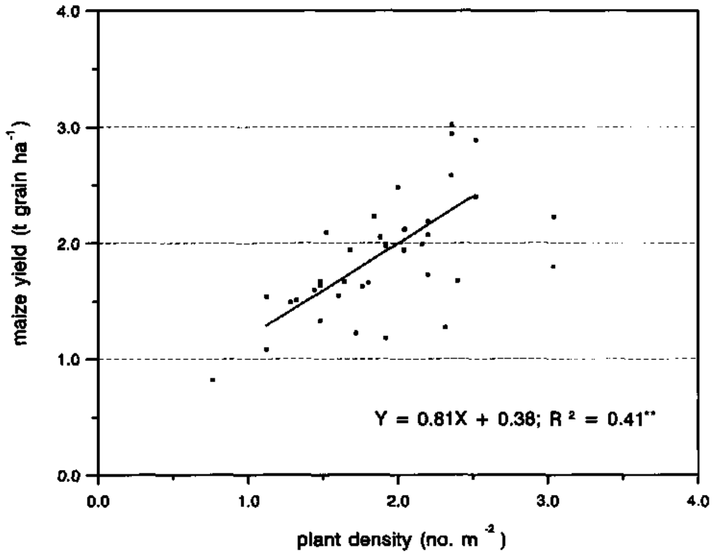


Fig. 3.2 Relationship between maize yield and plant density on nine farmers' plots (36 quadrats) in the *C. odorata* fallow system, early season 1991

3.4 Discussion and conclusions

3.4.1 Cultivation practices

Farmers' criteria for selecting a *C. odorata* fallow for maize cropping are related to weed growth and availability of nutrients. Burning large amounts of biomass and litter kills weed seeds in the top soil and improves nutrient availability. A low density of *C. odorata* stumps and the absence of a herbaceous undergrowth imply that few non-crop plants will develop after clearing. The criteria are met when allowing the fallow vegetation to develop during three to four years.

Weeding has to be carried out within a few weeks after the maize is sown in order to prevent serious yield losses. To meet this requirement farmers phase clearing and planting, thus spreading the high labour demand of weeding. The importance of early weeding for maize grown in a fallow system is stressed in an example from southern Benin, where farmers who weeded once within four weeks after planting obtained 84% of the yield on fields kept free from weeds (Lutzeyer 1991).

Phased clearing of the *C. odorata* vegetation is possible because, in comparison to a forest vegetation, slashing takes little time and the slashed vegetation dries quickly, even when the first rains have started. This is due to the relatively small above-ground biomass and the absence of thick stems in the *C. odorata* vegetation. Another advantage of phased clearing is that the period between slashing and burning is too short for stumps to sprout, so burning is not hampered. Autfray (1992) reported that burning carried out some weeks after slashing a *C. odorata* fallow was very difficult because stumps of this species produced numerous sappy shoots.

As a result of phased sowing, crop plants differ in growth stage, reducing the risk of crop failure due to a sudden dry spell at the beginning of the rainy season. Moreover, the period during which immature cobs are available is extended. The opportunity to harvest immature cobs for consumption or sale is considered important, as it provides farmers with early food or cash in a lean period.

The farmers do not regard *C. odorata* as a serious weed because seedlings develop slowly during the first weeks and shoot growth can be delayed effectively with one weeding. Lutzeyer (1991) found the same among farmers in the savanna of southern Benin. This point of view is confirmed by experiments in southern Ivory Coast showing that the development of *C. odorata* in maize cultivation was easily controlled by one or two herbicide applications (Autfray 1992, Vernier *et al.* 1995).

3.4.2 Labour input

The first weeding was the most labour-intensive practice in maize cultivation in a *C. odorata* fallow system. Long days were made because the crop had to be weeded in time, i.e. within four weeks after planting. Hence, labour availability during this period was most critical. The low labour input required and the large spread in time of the second weeding indicate that weeds are not a serious constraint to crop production after the first month.

Men not only have clearing as their specific task, but they also carry out most of the weeding. The involvement of men in weeding is common among Burkinabé in their home land, but it also indicates that much labour is required for the first weeding. Women make shorter days than men because they also have to manage their household. Normally, they arrive in the field with the food they have already prepared at home. While the men rest, women occupy themselves with the children and sometimes search for fire wood or water. This explains why the weeding performance of women was lower than that of men.

A labour requirement of 30 person days ha^{-1} for slashing *C. odorata* fallow vegetation has also been reported in Indonesia (Field 1991) and Ivory Coast (Vernier & Gbaka Tchetche 1991). In South Africa, labour input in manual slashing of *C. odorata* infestations was calculated at 32.5 man days ha^{-1} (Erasmus 1988). According to Vernier *et al.* (1995), 168 person hours ha^{-1} were needed to weed rice grown after clearing a five-year-old *C. odorata* fallow. This low labour input confirms farmers' statement that weeds are few after some years of fallow.

3.4.3 Crop yields

The average maize yield of 1.8 t ha^{-1} is relatively high for peasant crop production without fertilizer application given the 0.8 t ha^{-1} on land cleared from bush fallow in Belize (Arnason *et al.* 1982) or the 1.2 t ha^{-1} in a fallow system in the savanna zone of southern Benin (Lutzeyer 1991). Thornton (1973) reported a yield of 1.7 t ha^{-1} for maize grown on a bush fallow in southeastern Ghana.

Farmers' yields on plots cleared from *C. odorata* fallow were positively related to plant density. This density was low, but crop yield was high compared to general data on maize cropping in tropical Africa given by Purseglove (1972), Irvine (1969) and Acland (1971). It is possible the farmers chose a wide spacing because they planted tall growing varieties. The low densities were not due to intercropping, as in all quadrats maize was planted as sole crop. In a fallow system in South-West Nigeria, the low maize yield (1.22 t ha^{-1}) was mainly caused by the loss of plants during the cropping season, resulting in a stand of 1.7 plants m^{-2} (Mutsaers & Walker 1990). These authors also reported that yield increased linearly with the plant density, at a rate of 80 g per plant.

In this survey, however, plant density explained only part of the variation in yield. Site specific factors such as age and composition of the preceding fallow vegetation, quality of burning at clearing, soil type, soil fertility and seed quality probably also affected crop yield, but no quantitative data were gathered on these parameters.

The low plant density and low harvest index, which is considered typical for the traditional tall varieties grown, suggest that in farmers' maize cultivation the production potential of the *C. odorata* fallow system is not fully utilized.

3.4.4 Comparison with the traditional cropping system

The traditional cropping system in the region is shifting cultivation on forest fallows with upland rice as main crop and a fallow period of more than sixteen years (Moreau & de Namur 1978, de Rouw 1991a). Compared to this system, the *C. odorata* fallow system showed changes in the choice of the main crop and the tool for weeding, in the timing of clearing, in labour input for clearing and weeding, and in labour division among sexes. These changes are related to the more abundant weed development on plots cleared from *C. odorata* fallow. The choice of maize instead of rice and the need to use a hoe for weeding were already explained in Section 2.4.2. The reasons for phased clearing shortly before and at the start of the rainy season are given in Section 3.4.1.

In the *C. odorata* fallow system, the labour input was low for clearing but was high for weeding compared to the 26-48 person days ha^{-1} needed for clearing and 0-18 person days ha^{-1} for weeding in the traditional cropping system (de Rouw 1991a). This shift in major labour-demanding activity from clearing to weeding is a general feature in the transition towards more intensive cropping systems. The shorter fallow period leads to a vegetation with less biomass and trees without thick trunks, so clearing is easier. But the shorter fallow period implies that many seeds buried in the soil are still viable, while the relatively small biomass of the fallow vegetation results in a rapid superficial burning, which is less effective in killing these seeds. As a consequence, weed development will be more abundant and requires a considerable weeding effort.

Labour division among sexes is less pronounced in the *C. odorata* fallow system than in the traditional cropping system in which men clear the forest and women are responsible for sowing, weeding and harvest (de Rouw 1991a). This division is specific to the ethnic groups the indigenous people belong to. Burkinabé farmers are able to obtain these relatively good maize yields on plots cleared from *C. odorata* fallow because both men and women participate in weeding.

3.4.5 Conclusions

In the *C. odorata* fallow system farmers grow one maize crop followed by a fallow period of two to three years. They prefer to use older fallows, knowing from experience that weed growth is reduced and more nutrients are available. They contend that weeding should be carried out within one month after planting, and know that weeds developing afterwards do not clearly reduce crop yield any more. Farmers reduce weeding labour by planting a rapidly growing crop. They meet peak demands in labour by phased clearing and planting, and by a flexible sharing of labour among the sexes. The labour requirements for slashing the fallow vegetation and the first weeding are estimated at 30 and 57 person days ha^{-1} respectively. In comparison with the traditional shifting cultivation, the major labour-demanding operation has shifted from clearing to weeding. The yield of the traditional maize varieties differs greatly among plots, but is 1.8 t grains ha^{-1} on average. Within the range of 1.0 to 2.5 plants m^{-2} the yield increases with higher plant densities

Chapter 4

Growth of the *Chromolaena odorata* fallow vegetation

4.1 Introduction

In semi-permanent agriculture the fallow period is essential for maintaining soil fertility and controlling weed growth. During the fallow, nutrients accumulate in the vegetation and are subsequently released by litter decomposition and burning. Herbs gradually die out under the shade of the canopy. These processes depend on the composition of the fallow vegetation and the length of the fallow period. Plant species in the fallow vegetation may differ in biomass and litter production, nutrient concentration, habitus and rooting system. If the fallow period is extended, usually more nutrients are saved and the ground is shaded for a longer period. On the other hand, long fallow periods imply inefficient land use. Indications of the appropriate length of the fallow period are obtained by studying the development of the fallow vegetation.

The average annual increase in the above-ground biomass of forest fallow vegetations varies from 5 to 10 t ha^{-1} during the first ten years (Uhl 1987). At the start of the fallow period, grasses and forbs are abundant, but within three years they disappear under the canopy of pioneer trees that dominate the regrowth (Brubacher *et al.* 1989, Jaffré & de Namur 1983, Uhl 1987). In the first years of the development of a vegetation, leaves contain a large proportion of the total amount of accumulated nutrients; in later stages, stems and branches are more important (Bartholomew *et al.* 1953, Brubacher *et al.* 1989). During a fallow period of four years the forest regrowth in the Taï region accumulated 140 kg N, 10 kg P and 175 kg K ha^{-1} (Jaffré 1985). The nutrient contents in five-year-old forest fallows in Zaïre and Colombia were much higher (Bartholomew *et al.* 1953, Fölster *et al.* 1976). In humid West Africa, the natural forest regrowth appeared to be at least as effective as alternative fallow species in accumulating nutrients (Jaiyebo & Moore 1964, Nye 1958, Nye & Hutton 1957).

Although *C. odorata* is widespread in Asia and Africa, there are few studies on its development. In slash-and-burn agriculture in northeastern India, *C. odorata* and *Imperata cylindrica* dominated the fallow vegetation during the first five years after cropping (Saxena & Ramakrishnan 1984a, Toky & Ramakrishnan 1983a). Seed production peaked in the third year, but dropped thereafter and mortality of seedlings and shoots increased as a result of strong inter- and intra-specific competition for available resources (Kushwaha *et al.* 1981, Yadav & Tripathi 1981). The density of *C. odorata* decreased over time. In the fifth year the total standing biomass had a dry weight of 23 t ha^{-1} and contained 140 kg N, 20 kg P and 190 kg K ha^{-1} (Toky & Ramakrishnan 1983b). After five years *C. odorata* was succeeded by other shrubs, trees and bamboos. Annual litter fall in five-year-old vegetations was estimated at 5 t ha^{-1} (Olaoye 1986, Toky & Ramakrishnan 1983a). In the transition zone between forest and savanna in Central Ivory Coast, *C. odorata* is succeeded by forest species if there is little disturbance of the vegetation (Gautier 1992). Fifteen-year-old vegetations dominated by *C. odorata* with a standing biomass of 9 t ha^{-1} also occur. In both countries *C. odorata* can outcompete other species in the vegetation because of its high number of seedlings, higher relative growth rate and the allocation of more dry matter and nutrients to the stem during early stages of development (Gautier 1992, Saxena & Ramakrishnan 1983b). *C. odorata* seedlings are not considered strong competitors for nutrients (Saxena & Ramakrishnan 1984c).

The study described in this chapter was aimed to follow dry matter production, nutrient accumulation and suppression of herbs over time in order to be able to define the appropriate length of the fallow period. As it was not feasible to study the *C. odorata* vegetation over a long fallow period, the 'false time series' approach was used (Hase & Fölster 1982, Waterloo 1994). This involved monitoring vegetation development on fallow plots of different ages during a seven-month period.

4.2 Materials and methods

4.2.1 Site selection

The development of the *C. odorata* fallow vegetation was studied from May till November 1991 on fifteen plots left fallow by farmers for different periods. Three plots were at the start of the fallow and are further referred to as 0-Y plots. From March to August 1991 they were used by immigrant farmers for growing maize; weeds growing on these plots were considered to be the initial stage of the fallow vegetation. The plots had been weeded at the start of the study in order to rule out possible differences in farmers' weeding practice. The other twelve plots included three plots with one-year-old fallow (1-Y plots), two plots with two-year-old fallow (2-Y plots), two plots with three-year-old fallow (3-Y plots) and two plots with five-year-old fallow (5-Y plots). All plots were situated on crest and upper slope positions, and had been cropped more than once during the ten years prior to the last cropping.

4.2.2 Observations

This section describes the observation methods in detail. The number of plots monitored, the number of observations per plot and the frequency of observations are summarized in Appendix III.

Dry weight of above-ground biomass and litter, and leaf area index

The dry weight of the above-ground biomass and litter was determined by sampling the vegetation. The areas sampled on the 0-Y and 1-Y plots were smaller than those on the older plots, because the fallow vegetation on former plots was denser and more homogeneous. On the 2-Y, 3-Y and 5-Y plots, each sample covered 9 m^2, and five samples were taken per plot at each sampling. On the 1-Y plots, each sample covered 7.5 m^2 and four of them were taken per plot at each sampling. On the 0-Y plots, each sample measured 3.75 m^2 and at each sampling four samples were taken.

Samples of the vegetation were cut off at ground level and separated into *C. odorata*, other woody species, forbs and grasses. Each category was weighed. Subsamples of *C. odorata* and other woody species were separated into leaves and stems, which were weighed. The litter was raked up and weighed as well, except on the 0-Y and 1-Y plots, where this was not done because there was very little litter. All samples were dried at 70°C for 24 hours to determine the dry weight.

The vegetation sampling was carried out in May, August and November 1991 on the 2-Y, 3-Y and 5-Y plots, and in June, August and October 1991 on the 1-Y plot. Because the 0-Y plots had been weeded at the start of the observation period, the vegetation was sampled in August and October only.

Leaf area index (LAI) of *C. odorata* was estimated by multiplying leaf dry weight by specific leaf area. The latter was determined from leaf samples. On the 1-Y plots, these samples comprised all leaves of *C. odorata* in two quadrats of 1 m^2. On the older fallow plots, the leaves from four random branches of *C. odorata* were used. The leaf area was estimated by counting the number of points on a transparent one-centimetre point screen covered by each leaf. Afterwards, the leaves were dried and weighed.

Life form composition of the vegetation

The life form composition was determined simultaneously with the vegetation dry weight, by counting plants of *C. odorata* and other woody species in all samples. On the 0-Y and 1-Y plots, forbs and grasses were counted as well. On the 2-Y, 3-Y and 5-Y plots, the numbers of forbs and grasses were not recorded, as they were few and highly variable.

Besides the composition of the standing vegetation, the composition of the regrowth was examined after samples had been taken. This was done on the 2-Y, 3-Y and 5-Y plots by separately estimating the soil cover of *C. odorata*, other woody species, and forbs plus grasses. In the areas where the vegetation had been sampled in May, the composition of the regrowth was examined 40 and 120 days later. In the areas sampled in August, the regrowth was examined only once, 40 days later.

Litter fall

Litter fall was measured by collecting litter in traps placed in the plots. These traps covered a total surface of 3 m^2 on each plot. In the 5-Y plots, twelve traps consisting of 0.5 m x 0.5 m trays covered with a perforated plastic sheet were placed. Because of the high plant densities, such trays could not be used on the 2-Y plots and 3-Y plots, so instead, three traps of another type were placed on these plots. They consisted of a perforated black plastic sheet (2.0 m x 0.5 m) covering the soil surface and enclosed by 10 cm high wooden boards. On the 0-Y and 1-Y plots, litter fall was not measured because it seemed very low.

The collected litter was dried the same day (70° C, 24 h) and weighed. The amount of litter produced was recorded fourteen times between June 1991 and July 1992. In December 1991 all traps in one of the 5-Y plots had disappeared, and only nine traps were left on the other plot. In February 1992 only four traps could be found on the latter plot. Therefore, litter fall on the 5-Y plots was no longer monitored after February 1992. The litter composition of the samples collected in August and in October 1991 was examined.

Rooting pattern and root biomass of C. odorata

The rooting pattern of *C. odorata* was studied on one or two representative plants per fallow age. First, the superficial roots were exposed and the longest lateral root was measured. Subsequently, a pit was dug (1.0 m x 2.0 m, 1.5 m deep) at 20 cm from the stem. In order to study and measure the vertical penetration of the roots, the soil of the pit wall facing the plant was carefully removed. The rooting pattern was observed in August on the 1-Y plots and in October on the older plots.

As rooting appeared to be predominantly superficial, the root biomass was determined in the top 20 cm only. In quadrats of 1.0 m x 1.0 m, laid out in the area where the vegetation had been sampled, the soil layers 0-10 cm and 10-20 cm were collected and sieved (1 mm mesh diameter) separately. Roots of *C. odorata* were selected, dried and weighed. The root biomass was examined in June 1991 on the 1-Y plots and in November on the older plots. No observations of rooting pattern and root biomass were made on the 0-Y plots, since the methods used were considered impracticable for seedlings given their large numbers and fine root system.

Nutrient content of C. odorata and litter

The nutrient mass fractions in *C. odorata* and litter were determined in the samples taken for the first dry weight measurement of above-ground biomass and litter, and in those for root dry weight measurement (see above). These samples were chemically analysed according to the standard procedures described by Walinga *et al.* (1989). Two vegetation samples per plot were analysed for the one-year-old vegetation. Two samples taken on the same plot were used for the older fallow vegetations. The numbers of root samples per plot and fallow age were the same as those of the above-ground vegetation. The nutrient contents of the various parts of *C. odorata* and of the litter were calculated by multiplying the average dry weight by the average nutrient mass fractions, per fallow age.

4.2.3 Data processing

Assuming a constant biomass accumulation once the ground surface is covered (van Heemst 1986) and a constant proportion of the biomass that is lost as litter, the growth of *C. odorata* over time can be approximated by the rate of net dry weight increase:

$$dW/dt = C - Kw \qquad (4.1)$$

with C the growth rate of the biomass (kg ha^{-1} month^{-1}), k the relative mortality rate of biomass ($month^{-1}$), and W the dry weight of *C. odorata* (kg ha^{-1}). Integration of Equation 4.1 gives the change in dry weight in time:

$$W = W_{max}(1-e^{-kt}) \qquad (4.2)$$

with W_{max} the maximum dry weight of the above-ground *C. odorata* (kg ha^{-1}), and t the time (months). Litter fall is estimated as biomass increase (C x time) minus net dry weight increase (Equation 4.2) over a given period. Dry weight of the above-ground biomass measured in August were used to estimate the growth, as most leaves were present at that time.

4.3 Results

4.3.1 Dry weight of above-ground biomass and litter, and leaf area index

Dry weights of *C. odorata* and the total vegetation increased with the age of the fallow until the third year (in November), when values of respectively 20.8 t ha^{-1} and 22.3 t ha^{-1} were reached (Table 4.1). The yearly net increase in *C. odorata* dry weight, calculated as the difference in dry weight on plots at corresponding sampling times, was 7 to 8 t ha^{-1} during the first year, 6 to 7 t ha^{-1} during the second, and 4 to 5 t ha^{-1} during the third year. The *C. odorata* dry weight on the 5-Y plots was 2 to 3 t ha^{-1} lower than that on the 3-Y plots. From May to November the *C. odorata* dry weight increased by 3 to 4 t ha^{-1} on all plots. On the 0-Y plot, the dry weight increased by 2.6 t ha^{-1} in two months (August to October), which corresponds with 46 kg ha^{-1} day^{-1}.

The amount of litter accumulated on the ground was rather similar on the 2-Y and 3-Y plots, but it was half as much as on the 5-Y plots. In the period August-November, the amount decreased on all plots.

On the 0-Y and 1-Y plots, the proportion of leaves in the *C. odorata* dry weight declined over time (Table 4.1). On the 2-Y, 3-Y and 5-Y plots this proportion was rather similar and fluctuated between 9 and 14%. On each of these plots, it increased in the period May-August and fell during August-November.

Table 4.1 Dry weight of the above-ground biomass of *C. odorata* and the total vegetation, and of litter, proportion of leaves in the dry weight of the above-ground biomass of *C. odorata* and leaf area index of this species in fallow vegetations of increasing ages on three times during 1991 (standard error of mean in small font)

Fallow age (yr)	Observation date	Dry weights *C. odorata*		Dry weights Total vegetation		Dry weights Litter		Proportion of leaves in *C. odorata* (%)		Leaf area index of *C. odorata*	
0 [a]	August	0.4	0.2	0.9	0.1	nd		69.3	2.8	nd	
	October	3.0	0.9	4.3	0.5	nd		42.5	0.7	nd	
1	June	6.6	0.4	9.2	0.7	nd		19.7	0.8	3.2	0.2
	August	8.6	0.4	11.8	0.9	nd		18.3	0.8	3.9	0.4
	October	9.8	0.5	13.0	0.6	nd		13.0	0.8	4.3	0.4
2	May	12.3	1.0	14.3	1.0	2.7	1.3	9.2	0.0	2.5	0.4
	August	15.8	0.6	16.8	0.5	1.7	0.6	13.0	1.2	4.4	0.5
	November	15.2	0.7	17.5	0.0	0.7	0.2	12.5	0.5	4.3	0.6
3	May	16.9	1.6	18.1	1.8	2.7	0.2	10.6	0.5	3.8	0.4
	August	19.3	1.5	20.1	1.4	2.2	0.8	13.6	0.4	5.6	0.4
	November	20.8	0.5	22.3	0.1	0.8	0.1	11.8	0.3	5.5	0.6
5	May	13.2	0.4	17.4	0.5	5.8	0.1	13.0	0.4	3.6	0.5
	August	14.3	0.6	16.3	1.6	6.5	1.4	13.8	0.4	4.1	0.5
	November	16.5	0.7	20.4	1.6	3.1	0.3	9.9	0.8	3.5	0.4

[a] cleared in March 1991, grown with maize till August 1991

LAI increased with age of the fallow to a maximum of 5.6 on the 3-Y plots (Table 4.1). Seasonal changes in LAI were similar to those in the proportion of leaves in the *C. odorata* biomass: an increase in the first half of the observation period and a drop in the second half. On the 5-Y plots the LAI dropped considerably. On the 1-Y plot, the proportion of leaves decreased between August and October, whereas the LAI increased.

The growth of the above-ground parts of *C. odorata* was well approximated by Equations 4.1 and 4.2 when the observed dry weights of this species in the fallow vegetation up to three years old were used (Fig. 4.1). The maximum dry weight, W_{max}, was estimated at 36 t ha^{-1}, the relative mortality rate, k, at 2% $month^{-1}$ or 24% y^{-1}, and the growth rate of the biomass, C, at 727 kg ha^{-1} $month^{-1}$ or 8.72 t ha^{-1} y^{-1}. Dry weight of the five-year-old fallow was not included, as it was lower than that of the three-year-old fallow, indicating some die-back. This had led to k increasing and meant that Equation 4.2 was no longer appropriate for approximating the real growth of *C. odorata*.

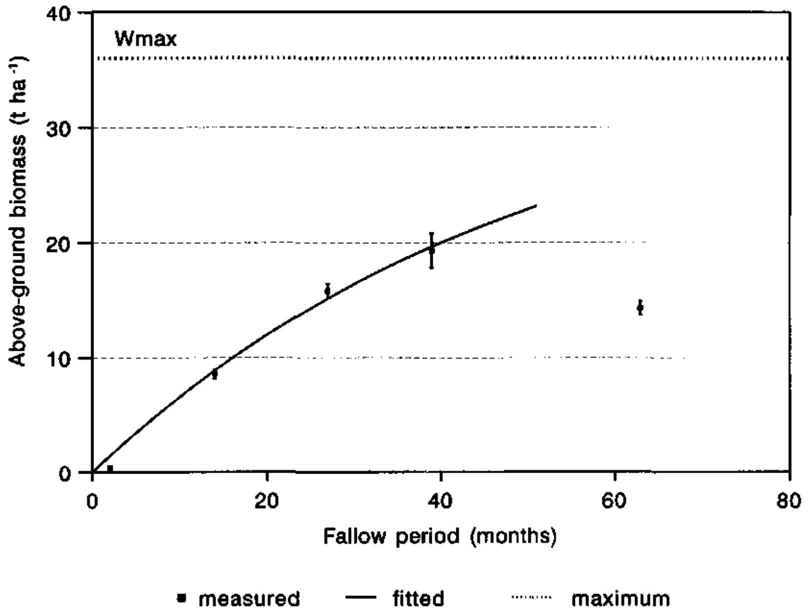


Figure 4.1 Dry weight increase of the above-ground biomass of *C. odorata* in relation to the length of the fallow period (the model $W = W_{max}(1-e^{-kt})$ was used to fit the curve)

4.3.2 Structure and life form composition of the fallow vegetation

The structure of the vegetation changed over time. On the 0-Y plots, the vegetation was made up by a lower stratum of seedlings of grasses, forbs and *C. odorata*, and a higher stratum consisting of erect shoots grown from the stumps of *C. odorata* and certain other woody species. Seedlings made up 98% of the total number of *C. odorata* plants. In August, two months after weeding, soil cover was estimated at 61%. In October it attained 93%. The vegetation on the 1-Y plots consisted mainly of a dense stand of erect *C. odorata* plants and of grasses and forbs that covered the ground almost completely. In contrast to the situation on the 0-Y plots, seedlings of *C. odorata* could not be distinguished from shoots. On the 2-Y and 3-Y plots, there was a closed canopy mainly consisting of *C. odorata*. Shoots of this species that had bent over under their own weight, tangled and formed a horizontal layer half way up the height of the fallow vegetation. On the 5-Y plots, this layer had started to sag and the canopy was no longer completely closed.

The fallow age also affected the composition of the vegetation, in terms of both dry weight and plant density. The proportion of *C. odorata* in the dry weight of the total above-ground biomass increased with the length of the fallow period and reached a maximum value of 94% on the 3-Y plots. On the 0-Y plots, forbs and grasses made up 33% of the total dry weight, but their contribution dropped to 5% on the 1-Y plots. On the 2-Y and 3-Y plots these life forms made up barely 0.3% of the total dry weight, whereas in the 5-Y plot they were absent. The proportion of other woody species varied between 6 and 21% and did not show a clear relationship with the age of the fallow. Most plants in this category were small and were growing in the shade of *C. odorata*. Only a few fast-growing species like *Alchornea cordifolia* (K.Schum. and Thonn.) Müll.Arg., *Macaranga barterii* Müll.Arg., and *Xylopia aethiopica* (Dunal) A.Rich. had reached already the *C. odorata* canopy after two years.

As regards plant density, *C. odorata* outnumbered all other components right from the start of the fallow (Table 4.2). On the 0-Y plots, *C. odorata* comprised 56% to 71% of the total seedling population which consisted further of forbs and grasses. The dominance of *C. odorata* in plant density was also found on the other plots, except on the 5-Y plots where its density was similar to that of other woody species.

Table 4.2 Densities (no. of plants m^{-2}) of *C. odorata*, other woody species, forbs and grasses in fallow vegetations of increasing ages on three times during 1991 (standard error of mean in small font)

Fallow age (yr)	Observation time	*C. odorata*		Other woody spp.		Forbs		Grasses	
0	August	181.1	71.8	6.0	1.3	120.6	41.3	19.3	12.6
	October	157.1	31.0	7.0	2.8	49.0	23.4	6.5	3.8
1	June	49.1	23.4	13.2	4.9	10.4	1.1	14.7	9.4
	August	46.6	29.4	10.2	4.8	2.7	1.8	7.3	3.4
	October	22.2	9.2	8.7	3.8	3.8	2.0	5.4	3.4
2	May	45.6	17.0	4.7	0.2	nd		nd	
	August	22.6	5.8	3.5	0.3	nd		nd	
	November	22.0	6.7	4.6	1.6	nd		nd	
3	May	21.3	5.5	8.3	3.1	nd		nd	
	August	15.9	5.6	4.0	1.3	nd		nd	
	November	9.1	0.9	3.8	0.9	nd		nd	
5	May	2.2	0.9	2.6	0.5	nd		nd	
	August	2.5	0.9	1.1	0.2	nd		nd	
	November	1.0	0.1	1.5	0.5	nd		nd	

In general, standard errors of plant numbers were high, indicating a patchy distribution over the plot. Plant densities of *C. odorata*, forbs and grasses decreased with the fallow age (Table 4.2). Changes in the density of other woody species were not clearly related to fallow age, but density was lowest on the 5-Y plots.

A relation between life form composition and age of the fallow was also found in the regrowth of the fallow vegetation 40 and 120 days after sampling. The soil cover of *C. odorata* shoots dropped from 25% on the 2-Y to 2% on the 5-Y plots, and the cover of grasses and forbs decreased from 5% to zero. On the other hand, the soil cover of *C. odorata* seedlings increased from 5% on the 2-Y plot to 22% on the 5-Y plots. Other woody species covered less than 1% and 2% respectively. The soil cover was patchy and nowhere reached 100%. The patchy pattern was partly due to *C. odorata* seedlings being most numerous and vigorous around the stumps of the same species.

4.3.3 Litter fall

Litter production on the 2-Y and 3-Y plots increased steadily during the period August-November and peaked between December and March (Figure 4.2). On the 5-Y plots, litter production peaked in September-October. In November-December it dropped, but upturned in January-February, suggesting a second peak afterwards. Similar to the litter on the ground gathered during vegetation sampling, the amount of fallen litter on the 5-Y plots was about twice those on the 2-Y and 3-Y plots. From June-November, it reached 2.4 t ha^{-1} on the 5-Y plots and 1.1 t ha^{-1} on the 2-Y and 3-Y plots. Between 7 June 1991 and 7 July 1992, 4.2 t ha^{-1} litter was produced on the 2-Y plots and 4.7 t ha^{-1} on the 3-Y plots. The litter produced in exactly one year amounted to respectively 3.9 and 4.3 t ha^{-1}. Using Equation 4.2 and the estimated total biomass increase rate given in Section 4.2.3, the annual litter fall was estimated to be 4.3 t ha^{-1} on the 2-Y plots and 5.3 t ha^{-1} on the 3-Y plots.

As regards the composition of the litter, the average proportion of *C. odorata* material in the litter was estimated to be 70% in August, and 80% in October. The proportion of other woody species in the litter was highest on the 5-Y plots. The leaf to wood ratio of the *C. odorata* material in the litter differed with the fallow age. On the 2-Y and 3-Y plots the *C. odorata* litter largely consisted of leaves, though towards November 1991 more twigs were found. On the 5-Y plots, however, the *C. odorata* material was largely made up of woody material. The material of other woody species in the litter usually consisted solely of leaves.

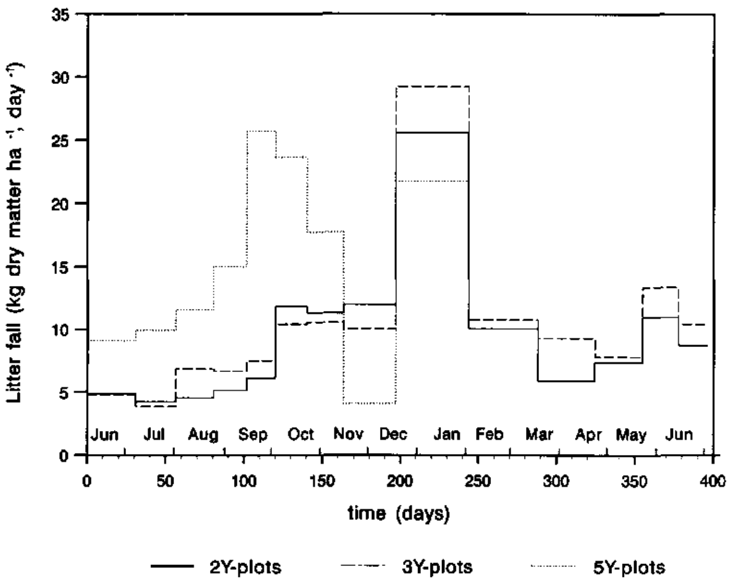


Figure 4.2 Litter production over time for three *C. odorata* fallow vegetations differing in age (standard errors are presented in Appendix III)

4.3.4 Rooting pattern and root biomass of *C. odorata*

The rooting system of *C. odorata* was superficial. On all plots, about 90% of the roots in the 0-20 cm soil layer was found in the upper 10 cm (Table 4.3). Most roots spread laterally and only a few roots penetrated into deeper soil. The biggest horizontal spread was 445 cm on the 3-Y plot. The roots penetrated up to 80 cm deep in the 1-Y plot, and even deeper in older plots. The root biomass was highest

Table 4.3 Root biomass in 0-20 cm soil layer, its distribution and root:shoot ratio of *C. odorata* in fallow vegetations of increasing ages (standard error of mean in small font)

Fallow age (yr)	Root biomass 0-20 cm soil (t ha^{-1})		Fraction of root biomass in 0-10 cm soil(%)		Ratio root:shoot	
1	2.4	0.7	89	2	0.37	0.13
2	2.2	0.1	94	0	0.14	0.02
3	6.6	1.7	96	1	0.29	0.05
5	3.4	2.5	92	3	0.20	0.15

on the 3-Y plot and lowest on the 1-Y and 2-Y plots, where the amounts hardly differed. Both primary and secondary roots appeared to penetrate into deeper soil and some of them did so after having developed horizontally first. The root to shoot ratio differed per plot and was lowest on the 2-Y plot. This ratio did not show a trend in relation to fallow age. Variation was relatively low on the 2-Y and 3-Y plots and high on the 1-Y and 5-Y plots.

4.3.5 Nutrient content

Nutrient mass fractions in stem and branches, and in roots of *C. odorata*, and those in litter were highest on the 1-Y plots (Table 4.4). The decrease in nutrient mass fractions with the age of the fallow was most evident in litter. On the older fallow plots, the mass fractions of N in stem and branches and in roots increased slightly

Table 4.4 Nutrient mass fractions (g kg^{-1}) in various parts of *C. odorata* and in litter in fallow vegetations of increasing ages (standard error of mean in small font)

Vegetation fraction	Fallow age (yr)	N		P		K		Ca		Mg	
C. odorata leaves	1	23.2	0.6	1.5	0.0	17.7	0.4	17.5	0.2	7.4	0.1
	2	20.6	0.1	1.6	0.0	14.0	1.0	18.8	0.1	7.6	0.3
	3	24.2	0.2	1.5	0.0	15.2	0.8	16.1	0.5	6.7	0.8
	5	25.6	1.0	1.6	0.0	18.2	1.6	13.4	0.6	6.3	0.5
C. odorata stem and branches	1	6.2	1.4	0.4	0.0	15.8	1.1	3.6	0.6	2.2	0.2
	2	2.6	0.4	0.3	0.1	8.1	0.4	2.7	1.1	2.1	0.5
	3	3.4	0.6	0.3	0.1	8.9	0.6	3.2	2.5	1.6	0.3
	5	4.4	1.7	0.4	0.0	8.6	2.0	3.0	1.8	2.0	0.3
C. odorata roots	1	10.7	1.3	0.6	0.1	9.4	0.8	6.9	1.7	2.7	0.4
	2	5.5	0.4	0.4	0.0	6.7	1.4	2.2	0.6	4.2	0.4
	3	6.4	0.6	0.3	0.0	4.8	1.7	2.9	0.2	4.5	0.7
	5	7.9	0.8	0.4	0.0	6.3	0.7	2.9	0.5	4.6	0.7
C. odorata above-ground[a]	1	9.5		0.6		16.2		6.3		3.2	
	2	4.3		0.4		8.7		4.3		2.6	
	3	5.6		0.4		9.6		4.5		2.1	
	5	7.1		0.5		9.8		4.3		2.5	
Litter of the total vegetation	2	8.5	1.7	0.4	0.1	1.6	0.0	9.0	2.6	2.5	0.5
	3	6.1	1.1	0.3	0.0	1.4	0.2	7.1	0.2	1.8	0.3
	5	6.8	0.8	0.3	0.0	1.0	0.1	5.4	0.6	1.9	0.1

[a] weighted average of leaves, stem and branches of *C. odorata*

again. Nutrient mass fractions in leaves were higher than those in other plant parts and did not change clearly with the age of the fallow. The mass fractions of N, P and Ca in leaves were four to eight times higher than those in stem and branches. The average mass fractions of N, K and Ca in the total plant dropped after the first year of fallow, while those of P and Mg remained fairly constant. On the 5-Y plot, the average mass fraction of N had increased again.

The amount of nutrients accumulated in the various plant parts of *C. odorata* increased with the age of the fallow vegetation (Table 4.5). On the 3-Y plot, the nutrient content of the above-ground parts plus litter was much higher than that on the 1-Y plot, but differed only slightly from that on the 5-Y plot. The nutrient contents of litter and roots were lower than those of leaves and stem and branches. The importance of the leaves in the accumulation of N, P, Ca and Mg changed with the fallow age. On the 1-Y plot, the leaves contained as much of these elements as the stem and branches. On the older plots, the leaves contained about 30% of the total amounts of each of these elements in above-ground parts and litter, whereas stem and branches contained 40 to 60%. Leaves were not important for the storage of K, as on all plots 70 to 80 % of the total amount of K had accumulated in the stems and branches.

4.4 Discussion and conclusions

4.4.1 Vegetation growth, weed suppression and succession

Several factors may explain how *C. odorata* became the dominant species in the fallow vegetation within a relatively short period. Firstly, some of the plants developed from sprouting stumps, giving them a better initial start than the forbs and grasses which had to start from seed. Secondly, the seedling population of *C. odorata* is numerous. Thirdly, seedlings are strong competitors because of their early stem growth (Gautier 1992, Saxena & Ramakrishnan 1983b). The decreasing proportion of leaves in the *C. odorata* biomass indicated that stem growth started after 2 months.

The dominant position of *C. odorata* led to the undergrowth of forbs and grasses being suppressed during the first two years of the fallow period. Prolonging this period reduced the development of herbs in the regrowth after clearing, probably because seeds in the soil under the dense and shady *C. odorata* canopy gradually lost viability. Shading provided by the horizontal layer of tangled *C. odorata* shoots in

Table 4.5 Nutrient content (kg ha^{-1}) of various parts of *C. odorata* and of litter in fallow vegetations of increasing ages

Fraction	Fallow age (yr)	N	P	K	Ca	Mg
C. odorata leaves	1	30.0	2.0	22.8	22.5	9.6
	2	23.9	1.8	16.1	21.8	8.8
	3	41.8	2.7	26.2	27.7	11.5
	5	42.4	2.6	30.2	22.2	10.5
C. odorata stem and branches	1	33.0	2.3	84.2	19.1	11.6
	2	28.6	3.1	90.5	30.5	23.1
	3	52.2	4.7	135.0	47.9	24.2
	5	51.3	4.3	98.7	34.1	23.0
C. odorata roots	1	23.2	1.3	20.3	14.8	5.8
	2	11.5	0.8	14.0	4.7	8.7
	3	40.5	2.2	30.2	18.6	28.6
	5	25.8	1.4	20.7	9.6	15.2
Litter of the total vegetation	2	23.0	1.2	4.2	24.3	6.8
	3	16.3	0.8	3.6	18.8	4.7
	5	39.6	1.7	5.9	31.1	11.1
Above-ground parts of *C. odorata* plus litter	1	63.0	4.3	107.0	41.7	21.2
	2	75.5	6.1	110.9	76.6	38.7
	3	110.3	8.2	164.9	94.4	40.4
	5	133.3	8.6	134.8	87.5	44.6

older fallows probably also played a role. A similar effect of fallow age on the development of weeds after clearing had been reported for bush fallows in northeastern India (Saxena & Ramakrishnan 1984b) and Peru (Staver 1991), and for forest fallow in the Taï region (de Rouw 1991a, van Reuler & Janssen 1993b).

Leaf fall during the dry season (November-February) is an important characteristic of the *C. odorata* vegetation. It explains why the major part of the net annual increase in *C. odorata* dry matter was produced from May to November and why leaf dry matter and LAI peaked between May and August on all plots. In the sub-humid zone of Nigeria, a similar seasonal fluctuation of the LAI was found in a vegetation dominated by *C. odorata* (Adedeji 1985).

The decreasing number of *C. odorata* plants since the onset of the fallow period was presumably due to inter- and intraspecific competition (Kushwaha *et al.* 1981, Yadav & Tripathi 1981). On older plots, other woody species became more important because their plant densities declined more gradually with the fallow age. This change in composition is reflected in the higher proportion of other woody species in the total dry matter. Moreover, their shoots were able to penetrate the disintegrating *C. odorata* canopy. By providing shade these species hamper the further development of *C. odorata* and so gradually become dominant.

The above- and below-ground *C. odorata* biomass peaked in the third year. This confirms the findings on the development of this species in northeastern India, mentioned in Section 4.1. Approximating the dry weight increase of the above-ground biomass over time by a mathematical formula indicated a die-back after the third year. Competition from other woody species presumably played a role in this. But other factors seem to be involved as well, given that *C. odorata* declined even on sites where there were no tall tree shoots or shrubs. Possible reasons for the decline in vegetation after three years are the low soil fertility or the plant's inability to maintain its large, semi-woody support structure. The occurrence of fifteen-year-old *C. odorata* vegetations (Gautier 1992), albeit under other ecological conditions, suggests that the life-span of the species largely exceeds five years. It also implies that the die-back found in this study is not solely the result of natural senescence.

4.4.2 Litter production

The data on litter fall (Figure 4.2) probably underestimate the actual litter production because of decomposition during the intervals between the collections. The data presented in Tables 4.1 and 4.5 underestimate the actual amount of dry matter and nutrient content of litter, because during sampling, the rake did not collect the finest particles.

Litter production of *C. odorata* showed a clear seasonal pattern. The increased litter fall during the period December-January is attributed to leaf shedding and mortality of stems and branches. This is probably caused by moisture stress during the dry season which starts in November. A similar seasonal pattern in litter fall was reported in Nigeria (Olaoye 1986, Agbim 1987). The relatively small amount of litter collected during the vegetation sampling of November is caused by an accelerated decomposition during the rains in September and October. The relatively high proportion of twigs in the litter on the 5-Y plots also indicates the decline in *C. odorata*.

The annual litter fall measured is in line with that reported for *C. odorata* vegetations in Nigeria (Olaoye 1986) and in northeastern India (Toky & Ramakrishnan 1983a). It is less than the 9 to 10 t ha^{-1} reported for the seven-year-old vegetation of the bush species *Acioa barterii* in Nigeria (Okeke & Omaliko 1991) or the litter fall of forest fallow in eastern Guatemala which increased from 5 t ha^{-1} in the second year to 7 t ha^{-1} in the fifth year of development (Ewel 1976).

4.4.3 Nutrient accumulation

The nutrient mass fractions in *C. odorata* and in litter fell after the first year of fallow, and were probably even higher at the onset of the fallow. The nutrient mass fractions in *C. odorata* of the present study were lower than those reported for *C. odorata* in other studies (Saxena & Ramakrishnan 1983b, 1984a, Agbim 1987, Daryono & Hamzad 1979, Litzenberger & Ho Ton Lip 1961, Hulugalle *et al.* 1986, Herren-Gemmill 1992, De *et al.* 1988), whereas the dry weight was similar or higher. This indicates that *C. odorata* uses nutrients more efficiently in the Taï region, suggesting that the nutrient availability was more limiting there than elsewhere, and more than other growth factors. The mass fractions of P were particularly low, whereas the N:P ratios were relatively high, pointing at the poor availability of P in the well drained soils of the Taï region, previously reported by van Reuler & Janssen (1989). The K:N ratios were also relatively high, indicating that the availability of N was limited too.

The amount of accumulated nutrients increased up to the third year of fallow. The rate of nutrient accumulation was highest during the first year; this may be the result of the well developed superficial rooting system. As in forest fallows, leaves contributed considerably to nutrient accumulation in the early stage of development, while in subsequent years their nutrient content increased less than that of other plant parts, notably the stem and branches.

In Figure 4.3 the accumulation of dry matter and nutrients in above-ground biomass plus litter of the *C. odorata* fallow vegetation is compared with that of other fallow vegetations. No litter data were available for the forest fallow in the Taï region and the bush fallow in Belize. It is assumed that in these studies litter was not a very important component. The accumulation of dry matter and nutrients in the *C. odorata* fallow in Taï is underestimated because it was measured in *C. odorata* plants and litter only. From the figure it can be seen that the patterns and amounts of nutrient accumulation in the *C. odorata* fallow in Taï are similar to those of the forest fallow in Taï (Jaffré 1985, Jaffré & de Namur 1983) and the bush fallow in Belize (Brubacher *et al.* 1989). Nutrient accumulation was somewhat lower in the bush fallow in northeastern India (Toky & Ramakrishnan 1983a,b). On the other hand, it was much higher in the *Acioa barteri* fallow in Nigeria (Nye & Hutton 1957) and in the forest fallow in Zaïre (Bartholomew *et al.* 1953). During the first

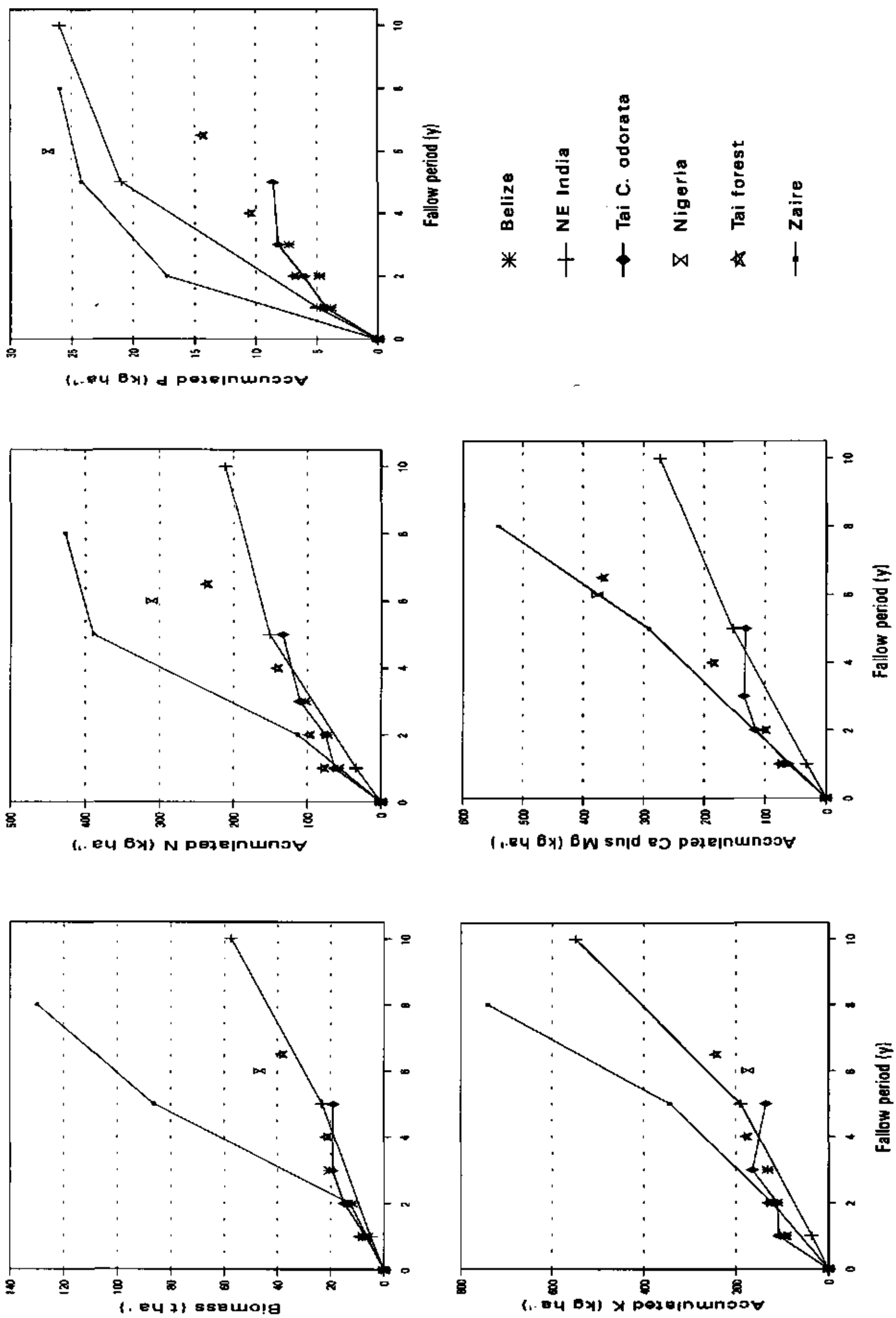


Figure 4.3 Accumulation of biomass and nutrients in different types of fallow vegetation in relation to the length of the fallow period

two years of fallow, however, neither the uptake rates nor the amounts of N, K and Ca+Mg accumulated in the *C. odorata* fallow in Taï differed from those in the forest fallow in Zaïre. In the fallow vegetation of the present study, the accumulation of dry matter and nutrients levelled off after three years. This did not change drastically after correction for the nutrient uptake in other woody species, assuming that these species contributed as much to nutrient uptake as to dry weight (25% of the total accumulation on the 5-Y plots). It indicates that after the third year the nutrient content of the *C. odorata* fallow increases only slowly. The accumulation of P was low both in the *C. odorata* fallow and the forest fallow in the Taï region, indicating the limited supply of the element in this area, as already mentioned in Section 4.4.3.

4.4.4 Conclusions

C. odorata has certain qualities that make it a suitable fallow species. Its natural establishment is very easy and uniform, and the species rapidly covers the ground. Within two years it suppresses the herbaceous undergrowth due to its competitive ability, and during the following years the seedbank of herbs under the closed vegetation canopy is almost exhausted. As the vegetation develops, the number of *C. odorata* stumps decreases, which may reduce the labour required for clearing. During the first three years of fallow, dry matter and nutrient accumulation in *C. odorata* are as high as those in other fallow types. However, some qualities make *C. odorata* less suitable as a fallow species. Firstly, because of its superficial root system it will hardly take up nutrients from deeper in the soil, and therefore *C. odorata* has no "nutrient-pumping" capacity. Secondly, the nutrient content of *C. odorata* is limited because the vegetation biomass hardly increases after three years.

Given the pattern of nutrient accumulation in the *C odorata* fallow vegetation and also the pressure on land, it is preferable to have short fallow periods. But longer fallow periods may be desirable from the point of view of weed control. After all, *C. odorata* is the main non-crop species during cultivation and may compete with the crop, particularly because of its fast-growing shoots. A fallow period of three years seems optimal to balance both functions of fallowing. To assess the impact of the length of the fallow period on the subsequent crop yields a field experiment was conducted, described in the next chapter.

Part III

Crop production in relation to cultivation practices in the *Chromolaena odorata* fallow system

Chapter 5

The effect of the length of the fallow period on subsequent crop yields

5.1 Introduction

As indicated in Chapter 4, reduction of weed growth and improvement of nutrient availability at the start of the cropping period depend on the length of the preceding fallow period in shifting cultivation and fallow systems. Crop production can be optimized by choosing a fallow period that reconciles improvement of the conditions for crop growth mentioned above with efficient land use.

The optimum length of the fallow period is usually scientifically defined by examining the development of the fallow vegetation and changes in soil characteristics under this vegetation. A number of authors in humid West Africa have investigated the optimum length by studying the effects of the fallow age on the subsequent crop growth. For example, de Rouw (1991a) found that fallow periods varying between fourteen and thirty years had a similar effect on the subsequent rice yield in the traditional shifting cultivation system on forest fallows in the Taï region, but a six-year-old fallow gave a poor yield because of abundant weed growth. In the same region, van Reuler & Janssen (1993b) found that crop yields after four years of forest fallow were similar to those after twenty years, although in the latter case there were considerably fewer weed seedlings during the cropping period. In a fallow system in East Nigeria, crop yields depended largely on the length of the fallow period, which varied between one and six years (Lagemann 1977). In southern Cameroon, extending the fallow period from one to two years increased the yield of the subsequent crop yield (ICRAF 1993). Kang & Moormann (1977) reported that the maize yield following a four-year-old fallow was intermediate between the yields on a plot cleared from a nine-year-old fallow and on a cassava plot.

In this chapter, a study of the effects of the length of the fallow period on subsequent crop production in the *C. odorata* fallow system is presented. The 'false time series' approach was used (Hase & Fölster 1982, Waterloo 1994), comparing crop yields obtained on fields differing in the duration of the preceding fallow. To examine the effects of the length of the fallow period on weed competition and nutrient availability, various weeding frequencies and fertilizers were applied.

5.2 Materials and methods

5.2.1 Experimental design

The experiments were conducted on Fields II, IV and V during the early season (April-July) and late season (August-November) of 1991, further referred to as (1991-E and 1991-L) and the early season of 1992 (1992-E). These fields had last been cropped respectively two, three and four years previously. They represented two-, three- and four-year-old *C. odorata* fallows. The experimental design was factorial, combining two weeding frequencies (one versus two weedings in the cropping season) with three fertilizer treatments (no fertilizer, P, P plus N). On Field II, the trial was laid out in five replicates, on Fields IV and V in four replicates.

5.2.2 Sampling of the fallow vegetation

Prior to clearing, the fallow vegetation of the experimental fields was sampled. On Field II, fourteen sample plots (5m x 5m) were laid out, while Fields IV and V had nine plots each. In these plots, the vegetation was cut off at ground level, plants were separated into *C. odorata*, other woody species, forbs and grasses, and each category was weighed. Samples of *C. odorata* and other woody species were separated into leaves and stems, which were weighed. The litter was raked up and weighed as well. Each component of the vegetation was sampled for dry weight determination and chemical analysis. The numbers of stumps of *C. odorata* and other woody species in the sample plots were recorded.

5.2.3 Field preparation, crop management and observations

After sampling, the fallow vegetation on each field was slashed, left on the field to dry for about one week and burnt. Before sowing the 1991-E crop, only large unburnt branches were removed from the field. After the harvest, the weed vegetation was slashed and left in situ. Burning did not take place and a second maize crop was sown directly. After the second crop had been harvested, the fields were fallowed during the dry season. At the start of the subsequent cropping season

(1992-E), the plots were cleared according to the method of the first season (1991-E) and maize was sown. In all the three seasons the hybrid variety "Pioneer 3274 yellow", maturing in 105 days, was used. It was sown 0.30 m apart in rows 0.60 m apart. Weeding was done at 3 and 6 weeks after sowing (WAS) using a short hoe. Phosphorus was applied as triple super phosphate at a rate of 25 kg P ha^{-1} at 3 WAS. Nitrogen was applied as urea at a rate of 100 kg N ha^{-1} and was split into equal parts given at 3 and 6 WAS. The crop was sprayed with insecticides at regular intervals. At harvest, maize plants and ears were counted, and ears and stover were weighed. Ten ears were taken from each plot and subdivided into grains and spike plus husks and weighed. These two fractions as well as the cut stover of two plants were sampled. After the harvest, all above-ground parts of the crop were removed from the field.

5.2.4 Laboratory analysis and data processing

The fallow vegetation and crop samples were dried at 70°C for 24 h and weighed. Grain samples were also dried at 105°C to calculate the grain weight at 14% moisture. Samples of the fallow vegetation and of the twice weeded crop of the first season were chemically analysed according to the standard procedures described by Walinga *et al.* (1989).

The concept of efficiency of utilization (EU) of the absorbed nutrients was used to interpret nutrient availability relative to other growth factors. EU is defined as grain yield (14% moisture) per unit nutrient absorbed by the crop. According to Janssen *et al.* (1990), maize grain yields increase maximally by 70 kg per kg N, 600 kg per kg P and 120 kg per kg K absorbed, and minimum values, indicating nutrient accumulation in the crop, are 30, 200 and 30 kg grain per kg N, P and K, respectively.

Differences in crop characteristics between fields and the effects of weeding frequency and fertilizer application were statistically tested by analysis of variance. Data of the third crop yield and of the Ca uptake by the first crop were transformed to logarithmic values as their variance differed greatly between fields.

5.3 Results

5.3.1 Dry weight, composition and nutrient content of the fallow vegetation

The dry weight of the total fallow vegetation was lower on Field II than on Fields IV and V (Table 5.1). The biomass of *C. odorata* was similar on all fields, whereas the biomass of other woody species was highest on the Field IV. The amount of litter clearly increased with the age of the fallow vegetation. On Fields II and IV the average dry weight of herbaceous plants was about 10 kg ha^{-1}, whereas on Field V herbs had disappeared. Forbs were most abundant on Field IV, grasses occurred mainly on Field II. The stump density of *C. odorata* was considerably lower on Fields IV and V than on Field II. Stumps of other woody species were particularly numerous on Field IV and was reflected in the large dry weight on this field.

Table 5.1 Dry weight of above-ground biomass and stump density of woody species in the *C. odorata* fallow vegetation on three fields differing in the length of the fallow period

Field	Fallow age (yr)	Dry weight (t ha^{-1}) *C. odorata*	Other woody spp.	Litter	Stump density (no. m^{-2}) *C. odorata*	Other woody spp.
II	2	9.6 ±0.5	3.3 ±0.6	1.5 ±0.1	17.1 ±3.2	5.8 ±0.7
IV	3	10.3 ±0.9	6.6 ±1.2	3.2 ±0.4	4.8 ±1.3	14.8 ±4.6
V	4	11.5 ±0.7	3.8 ±1.0	6.4 ±0.3	7.7 ±0.9	2.0 ±0.2

The nutrient content of the fallow vegetation increased following the sequence Field II - Field IV - Field V (Table 5.2). The only nutrient present in greater amounts on Field IV than on Field V was K. On Field II, about 10% of the total N, P, Ca and Mg accumulated in the fallow vegetation was found in the litter, on Field V this proportion was greater: about 30%. The proportion of K in the litter did not exceed 16%.

After the initial burning there were black patches on the soil on Field II, but the blackening was more uniform on the other two fields. The unburnt woody material removed from the field after burning made up 6% of the total dry weight on Field II and 10% on both other fields. The amount of nutrients removed in this material amounted to 5% of the total nutrient accumulation on Field II and to 10% on both other fields.

Table 5.2 Nutrient content (kg ha^{-1}) of the total above-ground biomass plus litter in the *C. odorata* fallow vegetation on three fields differing in the length of the preceding fallow period

Field	Fallow age (yr)	N	P	K	Ca	Mg
II	2	70.7	5.0	109.3	69.6	27.6
IV	3	84.7	6.8	130.2	102.6	35.2
V	4	144.6	8.2	127.8	136.6	42.7

5.3.2 Crop yields

In the first season, overall average crop yield increased significantly from 3.9 t ha^{-1} on Field II to 5.3 t ha^{-1} on Field V (Table 5.3). In the second and third seasons, the overall average yield dropped to about 3 t ha^{-1} on all fields.

Table 5.3 Effects of weeding frequency and fertilizer application on maize yield (t grain ha^{-1}, 14% moisture) during three cropping seasons after clearing the *C. odorata* fallow vegetation on three fields differing in the length of the preceding fallow period

Cropping season	Field	Fallow period (year)	Weeding frequency[a]			Fertilizer application[b]				Overall average
			1	2	LSD(5%)	0	P	NP	LSD(5%)	
1991-E	II	2	3.69	4.11	0.37	2.63	3.22	5.84	0.45	3.90
	IV	3	4.89	4.86	0.41	3.59	4.67	6.37	0.50	4.88
	V	4	5.19	5.46	0.41	3.82	5.17	6.99	0.50	5.33
	average		4.59	4.81	0.23	3.35	4.35	6.40	0.28	
1991-L	II	2	2.84	3.20	0.29	1.59	2.69	4.78	0.35	3.02
	IV	3	3.13	3.48	0.32	1.61	3.04	5.26	0.39	3.30
	V	4	2.89	3.28	0.32	1.61	2.68	4.96	0.39	3.09
	average		2.95	3.32	0.18	1.60	2.80	5.00	0.22	
1992-E	II	2	2.73	3.73	0.36	1.71	2.85	5.12	0.45	3.23
	IV	3	3.42	3.52	0.41	1.88	2.84	5.69	0.50	3.47
	V	4	3.16	3.73	0.41	1.45	3.26	5.34	0.50	3.43
	average		3.10	3.66	0.23	1.68	2.98	5.38	0.28	

[a] averages over all fertilizer applications
[b] averages over all weeding frequencies
Statistically significant differences between overall averages per field in 1991-E ($P<0.05$, LSD 0.37)
Interaction fertilizer application and field statistically significant in 1991-E ($P<0.05$)
Interaction weeding frequency and field statistically significant in 1992-E ($P<0.05$)

During the three seasons, weeding twice instead of once raised the average yields. The interaction between weeding frequency and field was significant in the third season only. In that season, yield increase as a result of a second weeding was higher on Field II than on Field IV. During the first and third season, however, the second weeding gave higher increments on Field II than on Field V (Table 5.3). On Field IV crop yield hardly increased as result of a second weeding. Testing of the yield data of the third crop after logarithmic transformation showed that the effect of a second weeding was significantly ($P<0.05$) higher on Field II than on Field V (not shown in Table). When the results were analysed for each field separately, weeding twice instead of once gave a significantly ($P<0.05$) higher yield on Field II in all three seasons and on Field V in the second season (not shown in Table).

Application of P and P plus N gave significant yield increases on all fields (Table 5.3). The interaction between fertilizer application and field was significant during the first season. The yield increase upon application of P was significantly higher on Field V than on Field II, while the increment attributable to the application of N was significantly higher on Field II than on Field IV and Field V. In the following two seasons yield increments as result of fertilizer application were similar on the three fields. Interactions between weeding and fertilizer treatments were not significant ($P=0.05$).

5.3.3 Nutrient uptake and utilization

Both the uptake and utilization efficiency of nutrients in the crop differed among fields. On Fields IV and V, the average uptake of N, K and Mg was significantly higher than on Field II (Table 5.4). The average uptake of P significantly increased following the sequence Field II - Field IV - Field V. Testing the data after logarithmic transformation showed that the uptake of Ca was also higher on Fields IV and V than on Field II ($P<0.05$). Application of P almost doubled the P content of maize plants. Moreover, it enhanced the K uptake on Fields II and V. N application substantially increased the N content of the crop and also enhanced the uptake of K, Ca and Mg. Interactions between fertilizer application and field were not significant ($P=0.05$).

Table 5.4 Effect of fertilizer application on the total uptake (kg ha^{-1}) of nutrients by maize on plots weeded twice during the first season after clearing the *C. odorata* fallow vegetation on three fields differing in the length of the preceding fallow period

Nutrient	Field	Fallow period (year)	Fertilizer application 0	P	NP	LSD(5%)	Average uptake [a]
N	II	2	45.7	48.3	97.2	19.6	76.3
	IV	3	73.7	79.0	125.2	22.7	92.6
	V	4	71.0	86.8	135.5	22.7	97.7
	average		63.5	71.4	119.3	12.4	
P	II	2	5.5	8.9	11.7	2.7	8.7
	IV	3	6.4	11.4	13.4	3.2	10.4
	V	4	7.8	15.7	16.9	3.2	13.5
	average		6.6	12.0	14.0	1.7	
K	II	2	44.6	64.7	88.3	26.4	66.2
	IV	3	106.2	93.1	103.7	30.5	101.0
	V	4	64.7	107.5	115.4	30.5	95.9
	average		71.8	88.4	102.5	16.7	
Ca	II	2	8.3	11.0	23.4	12.7	14.3
	IV	3	17.8	19.0	35.2	14.6	24.0
	V	4	16.4	20.3	26.1	14.6	20.9
	average		14.2	16.8	28.2	8.0	
Mg	II	2	8.7	9.5	13.2	3.2	10.5
	IV	3	12.6	12.9	17.0	3.6	14.1
	V	4	13.8	14.0	17.4	3.6	15.1
	average		11.7	12.1	15.9	2.0	

[a] LSD(5%) for comparison of average uptake between fields is 17.4 for N, 1.4 for P, 24.4 for K and 2.1 for Mg. The uptake of Ca differed significantly after logarithmic transformation of data

The average efficiency of utilization (EU) of N was significantly higher on Field II than on Field V, and the EU of P was significantly higher on Field IV than on Field V (Table 5.5). Changes in the EU of N and P as reaction to fertilizer application were similar on the three fields. The EU of N increased when P fertilizer was applied and dropped when N was given too; this response was particularly marked on Field II. Application of P reduced the EU of this element. After application of N in addition to P, the EU of P increased, particularly on Field II. Application of P increased the EU of K on Field IV in particular. The EU values indicate that N was diluted maximally in the crop when P was applied on Field II, while maximum dilution of P occurred in the unfertilized crop on Field IV.

Table 5.5 Effect of fertilizer application on the efficiency of nutrient utilization (kg grain per kg total nutrient uptake) in maize on plots weeded twice during the first season after clearing the *C. odorata* fallow vegetation on three fields differing in the length of the previous fallow period

Nutrient	Field	Fallow period (year)	Fertilizer application 0	P	NP	LSD(5%)	Average EU [a]
N	II	2	63	76	61	12	69
	IV	3	52	62	54	13	56
	V	4	56	67	56	13	60
	average		57	68	57	7	
P	II	2	544	384	551	135	493
	IV	3	640	421	494	156	518
	V	4	513	335	439	156	436
	average		566	380	495	86	
K	II	2	63	52	72	14	62
	IV	3	33	51	66	17	50
	V	4	58	54	65	17	59
	average		51	52	68	9	

[a] LSD (5%) for comparison of average EU between fields is 12 for N and 57 for P; the EU of K did not differ significantly among fields

5.4 Discussion and conclusions

5.4.1 Length of the fallow period and fallow vegetation development

The development of the fallow vegetation was similar to that described in Chapter 4, although the three-year-old vegetation contained less *C. odorata* and more other woody species than the vegetation of other ages and than the three-year-old fallow vegetation presented in the previous chapter. The amount of above-ground biomass increased up to the third year. In the fourth year, the amount of litter had increased considerably, indicating the decline of *C. odorata*. Extending the fallow period from two to four years caused the undergrowth of grasses and forbs to disappear, the number of *C. odorata* stumps to fall, and more nutrients to accumulate in the vegetation. The relatively small increase in the accumulation of N in the three-year-old vegetation can partly be explained by the rather small proportion of leaves in the biomass of *C. odorata* and other woody species on Field IV. Moreover, mass fractions of N in leaves, branches and stems of other woody species were small.

The vegetation dry weight of the experimental fields was substantially smaller than that of the sampled fallow plots of the same age presented in Chapter 4. This is probably because the vegetation of the experimental fields was sampled in March, when *C odorata* had shed most of its leaves, some of which might have already decomposed and thus are not found as litter. For the same reason, nutrient accumulation in the fallow vegetation on the experimental fields was less than on the sampled fallow plots presented in Chapter 4.

The patchy blackened soil surface after burning on Field II suggests that burning had been incomplete on this field. There was probably too little fallow vegetation biomass for a good spread of the fire.

5.4.2 Length of the fallow period and weed competition

The crop on Field IV seemed to respond to weeding somewhat differently than on the other two fields. This may have something to do with the composition of the fallow vegetation on this field, which contained relatively few *C. odorata* plants but many other woody species. On Field II, a second weeding was more effective than on either of the other two fields, indicating that weed competition with the crop was reduced by prolonging the fallow period. However, the differences in reaction to weeding frequency among fields were too small to be statistically significant. The more pronounced weed competition on Field II might be related to the high number of *C. odorata* stumps, the presence of grasses in the fallow vegetation and incomplete burning. The importance of *C. odorata* stumps and grasses as weeds in maize was confirmed in discussions with local farmers. As the stumps sprout easily after clearing and grow rapidly, they probably compete with the crop. Grasses in the undergrowth of the fallow vegetation indicate the presence of soilborne seeds which will emerge after clearing (Saxena & Ramakrishnan, 1984b). Staver (1991) reported that the seed bank of grasses declined with the length of the fallow period in a bush fallow in Peru. The incomplete burning on Field II may have resulted in fewer seeds and *C. odorata* stumps being eliminated. Saxena & Ramakrishnan (1984b) reported that the low intensity of burning on young fallows is an important factor that may account for the high weed population under short cropping cycles in a bush fallow system in northeastern India.

5.4.3 Length of the fallow period and nutrient availability

The older the fallows, the higher the maize yields during the first season. This effect of the length of the fallow period can be explained by an increase in nutrient availability. The low crop yield on Field II is presumably due to a low N supply, as this element was more diluted than on other fields. The shortage of N was confirmed by the weak response to P application and the large response to N application. Gichuru (1991) also reported a positive relationship between N availability and crop yield on young fallows in South-East Nigeria. The high EU of P on Field IV, particularly in the unfertilized crop, suggests that P is deficient. It again indicates that this field was unlike the two other fields.

When the fallow period is extended more P accumulates in the vegetation and becomes available for crop growth after clearing and burning. The increased N uptake in the crop on older fallow clearings could not be explained satisfactorily. The accumulation of N in the fallow vegetation increased in time, but most of it probably volatilized at burning, as reported in other slash-and-burn studies (Ewel *et al.* 1981, van Reuler & Janssen 1993a). Moreover, the uptake of N in the crop did not correspond to the content of this element in the fallow vegetation. It is also tempting to attribute the increased N uptake in the crop to the content of organic N in the soil increasing when the fallow period is prolonged. Lagemann (1977) reported that in his research the soil organic matter content was positively related to crop yield and to length of the fallow period. Jaiyebo and Moore (1964) found that maize yields were closely related to the soil organic matter content, and the uptake of N was related to the amount of organic N in the soil. In the present study, however, the soil organic matter content in the three experimental fields was similar at the moment of clearing (Table 1.1); this implies that the amount of soil organic N did not change when the fallow period was prolonged from two to four years. In a bush fallow system in Belize, the N content of the soil did not differ significantly between one-, two- and three-year-old fallows either (Brubacher *et al.* 1989). In other studies, it increased when the fallow lasted more then five years (Ramakrishnan & Toky 1981, Tiessen *et al.* 1992, Wadsworth *et al.* 1990). It is more likely that on the two-year-old cleared fallow the N supply was limited because of immobilization of soil N during the decomposition of the unburnt remnants of the fallow vegetation, as will be discussed further in Chapter 6.

Yields were not clearly related to the uptake of K, Ca and Mg, suggesting that these elements did not limit crop growth during the first season. Differences in the uptake of K, Ca and Mg upon fertilizer application reflected differences in crop biomass. The content of cations in the fallow vegetation largely exceeded the uptake by the first crop. Only the uptake of K on fertilized plots, particularly when both P and N were applied, approached the amount of K stored in the vegetation. The higher demand for this element is reflected in a higher value of the EU for K in the NP-fertilized crop. Nye & Greenland (1960) presented several examples of K becoming deficient when N and P were applied.

The short-lasting effect of fallow age on crop yields suggests that the extra amounts of accumulated N and P have disappeared after the first season. The amount of P in the fallow vegetation is equivalent to the amount which was taken up by the first season's crop. A large part of the released N must have been taken up as well, since this element was limiting crop yield. Any dissolved inorganic N that remained in the soil at the end of the first season had probably been leached. Yield decline in prolonged cropping on plots cleared from *C. odorata* fallows will be discussed further in Chapter 7.

The significant yield increase with fertilizer application throughout the duration of the experiments clearly indicates that P restricts crop production on *C. odorata* fallows, and that N becomes limiting when P fertilizer is given. This is furthermore shown in the high utilization efficiencies of both elements in the crop. Deficiencies of N and P in crop production on forest soils are common, particularly when fallow periods are short and soils are poor in organic matter or in P, as in the Taï region (Kang *et al.* 1977, Mueller-Harvey *et al.* 1985, Nye & Greenland 1960).

5.4.4 Conclusions

On fields cleared from three- and four-year-old *C. odorata* fallows the yield of the first crop was higher than on a field cleared from a two-year old fallow, irrespective of fertilizers had been applied whether or not. Weed competition tended to be less after a longer fallow period. In the second and third season after clearing, the yield of the unfertilized crop fell to the same low level of 1.5 t ha^{-1} on all fields, irrespective the length of the preceding fallow period. Fertilizer application boosted crop yield greatly and enabled it to be maintained at 5 t ha^{-1}. Phosphorus seriously limited crop production on *C. odorata* fallows, and when P was applied N also became limiting. Yield responses and nutrient utilization by the crop indicated that the availability of nitrogen was particularly low after a short fallow period of two years.

Chapter 6

The effect of clearing methods on subsequent crop yields

6.1 Introduction

Clearing land by slash and burn is an important cultivation practice in shifting cultivation and fallow systems. When the slashed fallow vegetation is burnt , weed seeds in the topsoil and stumps are killed and consequently weed development is reduced (Ewel *et al.* 1981, Kellman 1986, de Rouw & van Oers 1988, Uhl *et al.* 1981). Nutrients stored in the fallow vegetation are released by burning (Adedeji 1984, Nye & Greenland 1960, Seubert *et al.* 1977, Strømgaard 1992). According to van Reuler & Janssen (1993a) burning intensity depends on the amount of leaves and litter, as these smaller sized fractions burn easily. In forest fallow systems in the humid tropics, nutrient release by burning is essential, as the vegetation contains an important part of the nutrients, particularly of the cations, in the ecosystem (Bartholomew *et al.* 1953, Zinke *et al.* 1978). On the other hand, part of the carbon, nitrogen and sulphur incorporated in the fallow vegetation volatilizes as a result of burning (Ewel *et al.* 1981, van Reuler & Janssen 1993a). The ash of the burnt vegetation increases the pH of the topsoil and this affects the availability of soil nutrients. Furthermore, burning partially sterilizes the topsoil (Sanchez 1976), which may reduce the incidence of plant pathogens. Burning is considered as a labour-extensive way of getting rid of the biomass of the fallow vegetation.

In the cropping system based on *C. odorata* fallow, farmers also practise slash and burn. This study was carried out to ascertain whether these practices are appropriate, given that the accumulation of biomass and nutrients is limited by the short fallow period and the combustion of the slash is often incomplete. Two field experiments were conducted to compare the effects of the prevailing clearing method on the yield and nutrient uptake of the subsequent crops with those of alternative methods. In addition, one of the experiments involved various weeding frequencies and fertilizer applications, so that the effects of the clearing methods on weed competition and nutrient availability could be studied. One alternative clearing method was to increase the amount of fuel with the underlying idea that this may lead to more intensive burning and a larger amount of available nutrients. A similar method of concentrating fuel on a reduced area to increase nutrient availability, known as the chitemene system, is practised by farmers in the savanna woodlands of northern

Zambia (Araki 1993, Strømgaard 1992). As a second alternative, the slashed fallow vegetation was left as a mulch on the field during the cropping period. It was assumed that this would suppress weed growth and prevent N and organic matter being lost by burning. According to Obatolu & Agboola (1993), up to 48% of the N in *C. odorata* may be lost by burning.

6.2 Materials and methods

6.2.1 Experimental design

The first experiment (A) was conducted during the early and late cropping seasons of 1991 (1991-E and 1991-L) and the early season of 1992 (1992-E). It had a split-plot design and was laid out in five replicates. The main factor was three intensities of clearing: (1) removing the slashed fallow vegetation plus litter, further referred to as **Removing,** (2) burning the slashed fallow vegetation (**Burning**), the prevailing farmers' practice, and (3) burning the slashed vegetation plus the vegetation and litter from treatment (1) (**Intensive Burning**). The sub-plot factors were weeding frequency (one versus two weedings in the cropping season) and fertilizer application (no fertilizers, P, P plus N). A split-plot design was chosen because the extra space required for firebreaks made it impossible to burn small plots.

The second experiment (B) was part of a larger trial and was carried out during the early season of 1992 (see Chapter 8). This trial had a split-plot design with six replicates, having clearing methods as main factor and cultivation treatments as sub-plot factor. One cultivation treatment is maize growing. In this chapter, these subplots are dealt with as a separate experiment, having a randomized complete block design with four treatments and six replicates. The treatments were the three clearing methods used in experiment A, and a fourth method: leaving the slashed fallow vegetation in situ as a mulch (**Mulching**).

In both experiments, the Removing treatment was included to separate the dual effect of burning on seedling development: damaging seeds in the topsoil and removing the soil cover. The treatment was also included because other experimental fields had been cleared in this way (see Appendix II). In this treatment, the slashed vegetation was raked up, but the smallest litter parts, further referred to as fine litter, remained on the plots.

Experiments A and B were conducted on Fields II and VI respectively, which had both been under fallow for two years prior to clearing.

6.2.2 Sampling of the fallow vegetation

Prior to clearing, the fallow vegetation was sampled according to the method described in Section 5.2. Fourteen sample plots were laid out on Field II, and twelve on Field VI. After sampling, all the fallow vegetation of both fields was cut. On Field VI the fine litter was also sampled in two quadrats of 25 cm x 25 cm per plot. The material of both samples was weighed, subsequently pooled and subsampled.

6.2.3 Field preparation, crop management and observations

In Experiment A, the slashed fallow vegetation of both burning treatments was burnt after ten days of drying. Before the 1991-E crop was sown any large unburnt branches were removed from the field. On plots from which the slashed vegetation had been removed, the soil was tilled superficially with a short hoe just before sowing, as had been done in trials conducted on Fields III and I in previous years (see Chapter 7). After the harvest, the weed vegetation was slashed and left in situ. Burning did not take place, and a second maize crop was sown directly. After the second crop had been harvested, the field was fallowed during the dry season. At the start of the subsequent cropping season (1992-E) the same clearing methods were applied as in the first season (1991-E).

The clearing methods in Experiment B were the same as in Experiment A. However, on the plots where the slashed fallow vegetation had been removed, the soil was not tilled prior to sowing. The interval between slashing and burning was seven days. Residues of the burnt vegetation were sampled in three 25 cm x 25 cm quadrats per main plot of 60 m^2 immediately after burning, and the three samples were pooled. Maize was sown with the first rains, seven days after burning.

In both experiments, the maize variety, crop protection measures, observations, harvesting and sampling of the crop were the same as those described in Section 5.2. In Experiment A, weeding was carried out at 3 and 6 weeks after sowing (WAS). Phosphorus was applied at a rate of 25 kg P ha^{-1}, given as triple super phosphate at 3 WAS, and nitrogen was applied at a rate of 100 kg N ha^{-1}, in the form of urea, split into equal gifts at 3 and 6 WAS. In Experiment B, all plots were weeded once, at 3 WAS, and no fertilizers were applied.

6.2.4 Laboratory analysis and data processing

The fallow vegetation and crop samples of both experiments were handled as described in Section 5.2. Samples of the burnt plant residues were dried at 70°C for 24 hours and then weighed. They were sieved (2 mm mesh diameter) to separate and remove the incompletely burnt remainders, and the fine fraction was weighed. The samples were chemically analysed as plant material, according to the standard procedures described by Walinga *et al.* (1989). In a separate analysis, the organic matter content of the samples was determined by loss-on-ignition.

As in Chapter 5, the concept of efficiency of utilization (EU) of the absorbed nutrients was used to interpret nutrient availability relative to other growth factors. In Experiment A, the effects of clearing methods, weeding frequency and fertilizer application on crop characteristics were tested statistically. The same was done for the effects of clearing methods in Experiment B. To compare the effects of clearing methods on crop yield in Experiment A with those in Experiment B, crop yields obtained on the unfertilized once-weeded plots of Experiment A were analysed separately.

6.3 Results

6.3.1 Dry weight and nutrient content of the fallow vegetation, litter and burnt residues

The dry weights of *C. odorata* and those of coarse litter were similar on both experimental fields (Table 6.1). On Field II other woody species reached a larger dry weight than on Field VI, whereas forbs and grasses had smaller weights. *Centrosema pubescens* was the main forb species on Field VI. The fine litter component made up 19% of the total dry weight on Field VI. The amounts of accumulated nutrients in the fallow vegetation were similar on both fields. Results obtained on Field VI showed that the fine litter fraction contains a large proportion of the total amount of nutrients, except for potassium.

At the start of Experiment A in 1991-E, the soil surface on the burnt plots was a mosaic of black patches and patches that had hardly been touched by the fire. The soil surface on the intensively burnt plots was more uniformly blackened. In 1992-E, burning in Experiment A was again rather incomplete, but burning in Experiment B was better.

Table 6.1 Dry weight (t ha^{-1}) and nutrient content (kg ha^{-1}) of the above-ground biomass of the two-year-old *C. odorata* fallow vegetation on Field II (Experiment A) and Field VI (Experiment B)

	Chromolaena odorata	Other woody spp.	Forbs	Grasses	Coarse litter	Fine litter	Total (excl. fine litter)
Field II							
Dry weight	9.6±0.5	3.3±0.6	<0.1	<0.1	1.5±0.1	nd	14.3±0.5
N	29.8	32.2	nd	nd	8.7	nd	70.7
P	3.1	1.3	nd	nd	0.6	nd	5.0
K	75.7	26.1	nd	nd	7.5	nd	109.3
Ca	34.0	25.5	nd	nd	10.1	nd	69.6
Mg	19.2	5.1	nd	nd	3.3	nd	27.6
Field VI							
Dry weight	10.0±0.6	1.3±0.4	0.2±0.1	<0.1	1.5±0.2	3.0±0.2	13.0±0.7
N	49.4	12.2	3.3	nd	12.2	47.7	77.1
P	3.0	0.7	0.1	nd	0.6	2.6	4.4
K	98.1	11.7	2.5	nd	5.9	3.3	118.2
Ca	34.8	11.3	1.7	nd	9.7	31.1	57.4
Mg	21.1	2.6	0.3	nd	3.5	10.6	27.5

Table 6.2 Mass fractions, dry weight, nutrient and organic matter content of the burnt plant residues of a two-year-old *C. odorata* fallow vegetation for two clearing methods in experiment B

Clearing treatment	Dry weight	N	P	K	Ca	Mg	Organic matter
Mass fraction (g kg^{-1})							
Burning	na	3.7±0.6	3.1±0.5	43.3±6.8	29.0±6.0	15.9±1.9	218±15
Intensive burning	na	3.6±0.3	4.7±0.6	62.0±9.8	46.8±6.2	24.6±3.4	206±15
Dry weight (t ha^{-1}) and nutrient content (kg ha^{-1})							
Burning	1.1±0.1	4.0	3.2	44.6	30.3	16.7	231
Intensive burning	1.6±0.2	6.0	7.4	97.7	73.7	38.6	330
LSD (5%)	ns[a]	ns	2.9	44.5	38.3	17.0	ns

[a] not significant

In Experiment B, the quantity and nutrient content of burnt plant residues were larger in the Intensive Burning treatment than in the Burning treatment (Table 6.2). The content of P, K, Ca and Mg increased by more than 100% and differences between both burning treatments were statistically significant. The increases in dry weight, content of organic matter and of N were about 50% and were not significant.

6.3.2 Crop yields

In both experiments, burning instead of removing the slashed vegetation significantly increased the yield of the once-weeded unfertilized crop in the first season after clearing (Table 6.3). In Experiment A this increase was statistically significant. In both experiments, Intensive Burning tended to give higher yields than Burning. Mulching gave a lower crop yield than both burning treatments, but the differences were not statistically significant. Yields obtained on the mulched plots varied between 0.48 and 3.47 t grains ha^{-1}. Excluding the Mulching treatment reduced the coefficient of variation in Experiment B from 37% to 27%. In that case, crop yield in the Intensive Burning treatment appeared significantly higher than in the Removing treatment ($P<0.05$). The yield in the Burning treatment did not differ significantly from those in the other two treatments.

Table 6.3 Effect of clearing methods on yield (t ha^{-1}) of the first maize crop after clearing a two-year-old *C. odorata* fallow in two experiments

Clearing method	Experiment[a] A	Experiment[a] B
Mulching	na	1.68
Removing	1.68	1.68
Burning	2.49	2.22
Intensive burning	2.92	2.79
LSD(5%)	0.60	ns

[a] in both experiments the data were taken from plots which were weeded once and did not receive fertilizer

Crop yields in Experiment A showed significant interactions between clearing method and fertilizer application (Table 6.4). During the first and third seasons, the yields of the unfertilized crop were higher after burning and intensively burning the fallow vegetation than after removing it. During the second season, crop yield was higher in the Intensive Burning treatment than in the Removing treatment. When P was applied, however, Burning and Intensive Burning reduced the crop yield of the first season. After N and P had both been applied, Burning and Intensive Burning increased the yield in the third season. Interactions between weeding frequency and clearing method were not significant ($P=0.05$). Weeding twice instead of once gave a significantly higher yield in the three seasons. This increase was more pronounced in the third season than in the first and second seasons. Interactions between weeding frequency and fertilizer application were not significant either ($P=0.05$). The overall average yield dropped from about 4 t ha^{-1} in the first season to 3 t ha^{-1} during the following two seasons.

Table 6.4 Effect of clearing methods on maize yield (t grain ha^{-1}, 14% moisture) at different weeding frequencies and fertilizer applications during three consecutive cropping seasons after clearing a two-year-old *C. odorata* fallow (Experiment A)

Cropping season	Clearing method	Weeding frequency[a]		Fertilizer application[b]			Overall average
		1	2	0	P	NP	
1991-E	Removing	3.77	4.19	1.83	4.24	5.86	3.98
	Burning	3.69	4.11	2.63	3.22	5.84	3.90
	Intensive burning	4.10	4.50	3.08	3.57	6.25	4.30
	Average	3.85	4.26**	2.52	3.68	5.99	4.06
1991-L	Removing	2.85	3.29	1.11	3.09	4.79	3.06
	Burning	2.84	3.20	1.59	2.69	4.78	3.02
	Intensive burning	3.17	3.36	1.89	2.77	5.14	3.27
	Average	2.95	3.24**	1.54	2.85	4.90	3.10
1992-E	Removing	2.09	2.94	0.87	2.65	4.04	2.52
	Burning	2.73	3.73	1.71	2.85	5.12	3.23
	Intensive burning	3.47	4.09	2.87	2.98	5.49	3.78
	Average	2.76	3.59**	1.82	2.83	4.88	3.18

[a] averages over all fertilizer applications
[b] averages over all weeding frequencies
** significant difference between averages ($P<0.01$)
Interactions between clearing methods and fertilizer application were significant during three seasons ($P<1\%$). LSD(1%) are 0.62, 0.66 and 0.75 in seasons 1991-E, 1991-L and 1992-E respectively for comparison between clearing treatments with the same fertilizer application, and 0.56, 0.46 and 0.71 for comparison between fertilizer applications with the same clearing treatment

6.3.3 Nutrient uptake and utilization

Intensive Burning significantly increased the P uptake by the first crop in both experiments, as well as the uptake of Mg in Experiment B (Table 6.5). In Experiment B, nutrient uptake in the Mulching and Removing treatments was low, although not significantly different from that in both burning treatments. Uptake figures in Experiment A exceeded those in Experiment B.

In Experiment A, interaction between clearing method and fertilizer application was not significant ($P=0.05$). However, the nutrient uptake of the fertilized crop seemed lower in the Burning treatment than in the Removing and Intensive Burning treatments. The average nutrient uptake over all clearing methods was significantly higher when fertilizers were applied. The amounts of P and K taken up increased most when P was given, while the uptake of N, Ca and Mg was markedly higher when N was added to P fertilizer.

Table 6.5 Effects of clearing methods and fertilizer application on the total uptake (kg ha^{-1}) of nutrients by maize during the first season after clearing a two-year-old *C. odorata* fallow in two experiments

Nutrient	Clearing method	Experiment A[a] Fertilizer application 0	P	NP	Mean	Experiment B[a] No fertilizers applied
N	Mulching	na	na	na	na	25.4
	Removing	49.1	71.2	113.1	77.8	29.1
	Burning	48.7	48.2	105.0	67.3	36.1
	Intensive burning	48.3	61.2	118.6	76.0	43.5
	Average	48.7	60.2	112.2		
	LSD(0.05)		8.4[b]		ns[c]	ns[c]
P	Mulching	na	na	na	na	3.0
	Removing	4.0	12.0	13.5	9.8	2.9
	Burning	5.5	8.9	11.7	8.7	5.0
	Intensive burning	6.6	12.1	15.9	11.5	7.2
	Average	5.4	11.0	13.7		
	LSD(0.05)		1.2		1.7	2.2
K	Mulching	na	na	na	na	31.1
	Removing	40.1	80.8	91.0	70.6	34.4
	Burning	45.7	65.3	87.7	66.2	41.3
	Intensive burning	52.6	81.6	106.1	80.1	50.0
	Average	46.1	75.9	94.9		
	LSD(0.05)		9.7		ns	ns
Ca	Mulching	na	na	na	na	5.1
	Removing	10.2	16.6	25.3	17.4	5.2
	Burning	8.4	11.1	23.4	14.3	7.9
	Intensive burning	8.8	14.5	18.7	14.0	7.4
	Average	9.1	14.1	22.5		
	LSD(0.05)		4.3		ns	ns
Mg	Mulching	na	na	na	na	4.4
	Removing	9.1	10.8	16.9	12.3	5.1
	Burning	8.8	9.6	13.2	10.5	7.1
	Intensive burning	8.4	11.3	14.8	11.5	8.7
	Average	8.8	10.6	15.0		
	LSD(0.05)		1.2		ns	2.4

[a] the crop was weeded twice in Experiment A and once in Experiment B
[b] LSD for differences between averages per fertilizer treatment (same line Exp. A)
[c] LSD for differences between averages per clearing treatment (same column Exp. A and Exp. B)

In Experiment A, Burning and Intensive Burning increased the EU of N in the first crop (Table 6.6). On the other hand, Intensive Burning gave a lower EU of P than Burning. In Experiment B, clearing methods did not significantly affect the EU of N, whereas Burning and Intensive Burning reduced the EU of P. In general, the EU of N in the unfertilized crop was higher in Experiment B than in Experiment A. The opposite was true for the EU of K.

Table 6.6 Effects of clearing methods and fertilizer application on the efficiency of nutrient utilization (kg grain per kg total nutrient uptake) in maize during the first season after clearing a two-year-old *C. odorata* fallow in two experiments

Nutrient	Clearing method	Experiment A[a] Fertilizer application 0	P	NP	Mean	Experiment B[a] No fertilizers applied
N	Mulching	na	na	na	na	89
	Removing	46	67	56	56	71
	Burning	63	76	61	67	79
	Intensive burning	72	66	58	66	73
	Average	60	70	59		
	LSD(0.05)		8[b]		8[c]	ns[c]
P	Mulching	na	na	na	na	691
	Removing	570	386	463	473	713
	Burning	544	384	551	493	522
	Intensive burning	523	320	429	424	424
	Average	546	364	481		
	LSD(0.05)		74		52	153
K	Mulching	na	na	na	na	58
	Removing	53	58	69	60	52
	Burning	63	51	72	62	57
	Intensive burning	61	46	65	58	58
	Average	59	52	69		
	LSD(0.05)		5		ns	ns

[a] the crop was weeded twice in Experiment A and once in Experiment B
[b] LSD for differences between averages per fertilizer treatment (same line Exp. A)
[c] LSD for differences between averages per clearing treatment (same column Exp. A and Exp. B)

In Experiment A, the effect of fertilizer application on the EU was not the same for all clearing methods, but the interaction was not significant (P=0.05). Fertilizer application had a pronounced effect on the averaged EU of all three elements. The average EU of N was similar in the unfertilized crop and in the crop that had received N and P. The same was true for the EU of P. When only P was applied, the average EU of N increased whereas the average EU of P dropped significantly. The average EU of K was reduced by giving P, but increased substantially when both N and P were applied.

6.4 Discussion and conclusions

6.4.1 Comparison of the experimental fields

On both experimental fields, the *C. odorata* fallow vegetation established uniformly. The similarities in nutrient content of the total vegetation suggest that soil fertility on these sites was the same. The relatively low biomass of other woody species on Field VI was compensated by a high biomass of *C. odorata* and forbs.

On both fields, crop yield was increased by burning instead of removing the slashed fallow vegetation. On field VI, however, the effect of burning was not very obvious as yields obtained with the same clearing treatment varied considerably. The variability was presumably due to heterogeneous soil conditions, e.g. microrelief, and rather large distances between replicates of the trial.

6.4.2 Clearing method and ash production

Adding vegetation plus litter, as done for the Intensive Burning treatment, gave a better combustion, as indicated by the higher mass fractions of P, K, Ca and Mg in the burnt plant residues. However, the plant material was not completely burnt; this could be deduced from the fact that the residues after intensive burning still contained carbon and that the mass fraction of N was not much lower than after normal burning. Burning a two-year-old *C. odorata* fallow vegetation provided a small amount of nutrients compared to the amount released by burning a forest fallow. In the Taï region, the ash of a twenty-year-old forest contained 27 kg N ha^{-1}, 8 kg ha^{-1} P, 70 kg K ha^{-1}, 118 kg Ca ha^{-1} and 47 kg Mg ha^{-1} (van Reuler & Janssen 1993a).

6.4.3 Clearing method and weed competition

The yield increase upon an extra weeding indicates that weed growth was not effectively reduced by any of the clearing methods. Visual observations during the first weeding, however, gave the impression that weed development on intensively burnt plots was reduced compared to that on burnt plots. If this is true, it implies that after intensive burning the first weeding can be postponed and that a second weeding is not necessary.

Clearing methods did not result in significantly different crop responses to an extra weeding. This finding suggests that burning was as effective in reducing early weed competition as the removal of the slashed vegetation followed by a soil tillage with a short hoe. It can be said that the farmers' practice of burning after slashing the fallow vegetation is adequate and labour-saving.

In all the clearing treatments, the gain in yield obtained by a second weeding was highest in the third season. This indicates that competition between the weeds and the crop was more severe when the cropping period was extended. In the dry season after the second crop the field was fallowed and weeds were able to develop and probably produced seeds. This enrichment of the seed supply, in combination with a poor burning due to the small amount of fallow vegetation, probably resulted in a more severe weed competition in the third season. Staver (1991) reported that under short fallow periods the amount of viable seeds in the soil remains large. De Rouw (1991a) and Kang *et al.* (1977) also mentioned an increased weed competition when the cropping period was prolonged.

6.4.4 Clearing method and nutrient availability

Burning the slashed fallow vegetation is an effective method of increasing the availability of P. This was clearly indicated in the unfertilized crop, where yield increase due to burning was accompanied by an increase in P uptake and a drop in the EU of P. Increasing the amount of vegetation burnt (treatment Intensive Burning) raised the uptake of P more effectively. The slight increase in the EU of K and N indicates that the soil, and for K also the ash, could not easy supply the extra amounts of these nutrients needed to support the higher yield induced by burning. In Experiment A, the uptake of N by the unfertilized crop was not affected by burning, but the considerable increase in EU suggests that all available N was taken up. The effect of burning on yield was most pronounced in the next cropping season. On a cleared forest fallow in the Taï region, burning instead of retaining the slashed vegetation also raised crop yield and nutrient uptake (van Reuler & Janssen 1993b). On a forest fallow in Belize, however, burning instead of removing the slashed vegetation resulted in a higher yield in the second year of cropping but not in the first year (Lambert & Arnason 1989).

In the third season, the response of the unfertilized crop to burning was larger than in the first season. The yield increase was more pronounced if a larger amount of vegetation was burnt. Probably P had become more deficient because the uptake of this element by the first crop was equal to the content in fallow vegetation and the availability of P in the soil was poor (van Reuler & Janssen 1989). Presumably, burning also slightly raised the pH of the soil, which according to van Reuler & Janssen (1993b) improves the utilization of absorbed P. Increased weed competition in the third season is an unlikely explanation for the greater response to burning, because the interaction between weeding frequency and clearing treatment was not statistically significant in the third season.

Crop response to burning was entirely different if fertilizers were applied. During the first season, the yield of the P-fertilized crop on the burnt plots was low. The low yields were accompanied by a low N uptake by the crop and a high EU of this element, indicating that N was limiting crop production. These indicators of N deficiency were less explicit on plots which had been burnt intensively or from which the fallow vegetation had been removed. Hence, the deficiency of N is apparently not caused by volatilization or removal of N stored in the vegetation. On the contrary, the results indicate that intensive burning or removal of the fallow vegetation improves N availability. It is more likely that N deficiency on the burnt plots is due to immobilization of soil N because these plots were not burnt completely and the unburnt remnants of the fallow vegetation supposedly have a high C:N ratio. Given the limited growth of the P-fertilized crop on the burnt plots, the uptake of cations was also reduced. When both P and N were applied, crop yields were similar for all clearing methods. This suggests that differences in the availability of N due to clearing treatments were nullified when a large amount of N was applied. Immobilization is likely to be particularly important after clearing a young fallow, as the limited amount of fallow vegetation biomass resulted in incomplete burning. This explains why in Chapter 5 the availability of N on the field cleared from the young fallow was low compared to that on the fields cleared from older fallows where burning was more complete.

During the second and third seasons, the availability of N was apparently no longer affected by the clearing method, as the yield of the P-fertilized crop was similar in all clearing treatments. This is feasible, because the fallow vegetation was not burnt at the start of the second season. In the third season, the slashed vegetation mainly consisted of young leafy material which, if it had not been burnt completely, probably decomposed readily without immobilizing N. In the second and third seasons, yields dropped relative to the first season, even when P and N were applied. The lower yields of the fertilized crop is probably related to a deterioration in the conditions for crop growth e.g.: availability of cations, the amount of soil organic matter, pH or increased incidence of plant parasites such as nematodes. A similar decline in soil properties in prolonged cropping under humid tropical conditions was reported by Juo & Kang (1989) and by Kang (1993). As regards the first two aspects mentioned above, it must be stressed that crop residues had been removed after each harvest. Repeated burning may have affected crop yield during the third season, as it raises the pH of the topsoil and leads to cations incorporated in the fallow vegetation being released. Yield decline in prolonged cropping on cleared *C. odorata* fallows will be dealt with in further detail in Chapter 7.

The effects of the Mulching treatment are difficult to interpret as the crop responses were very variable. Leaving the slashed fallow vegetation as a mulch instead of removing did not affect yield levels or nutrient uptake. Apparently, nutrient release by decomposition of the slashed fallow vegetation was too slow to stimulate crop production during the subsequent cropping season. Other studies mention the high decomposition rate of leaves and leaf litter of *C. odorata* compared to other plant species (Agbim 1987, Obatolu & Agboola 1992). As the mass fractions of N and P in woody parts of the slashed vegetation were rather low, less than 5 g kg^{-1} and 0.3 g kg^{-1} respectively, it seems probable that nutrients released by decomposition of the leaves were immobilized immediately during decomposition of the woody parts. This strengthens the argument that incompletely burnt remainders of the fallow vegetation may have immobilized nutrients. In a laboratory analysis, litter gathered under a forest cover in the Taï region proved to immobilize both P and N (Braakhekke *et al.* 1993). Sanginga & Swift (1992) presumed that nutrient immobilization caused the reduced maize growth following application of Eucalyptus leaf litter. Lambert & Arnason (1989) reported that crop yield on a cleared forest fallow was lower when the vegetation was retained instead of burnt.

The pronounced effects of fertilizer application on crop yield indicated that P seriously limits crop growth on young *C. odorata* fallows in the Taï region, and N becomes deficient as soon as the availability of P was improved. This explains the high recovery of these fertilizers: 32% for P on the unburnt plots and 58% for N on the intensively burnt plots where P was applied.

6.4.5 Conclusions

As expected, burning instead of removing the slashed vegetation when clearing a two-year-old *C. odorata* fallow, has a positive effect on yields of unfertilized crops. This effect is most pronounced in the next cropping season. The higher yield is due to the increased availability of nutrients, in particular of P. Burning, however, may cause N to become deficient, probably as a result of immobilization in the incompletely burnt residues. When the cropping period is extended, burning also reduces the decline in yields of the unfertilized as well as the fertilized crop. Burning is an adequate and labour-saving clearing method. It does not reduce weed competition throughout the cropping season and weeding is required. When the amount of vegetation is doubled burning is more intensive, a higher proportion of nutrients is released and crop yield is increased even more. However, this alternative is not recommended as the additional crop yield does not offset the higher land and labour requirements. Leaving the slashed fallow vegetation as a mulch is not an appropriate alternative for burning either, because the nutrients incorporated in the vegetation are apparently not released during the next cropping season.

Chapter 7

The effect of extending cropping periods on yield

7.1 Introduction

7.1.1 Research objectives

In the Taï region more intensive land use has resulted in traditional shifting cultivation being transformed into a *C. odorata* fallow system. Given the increasing population, it is very likely that this trend will continue. Therefore, the prospects for the *C. odorata* fallow system will largely depend on the options available for using land more efficiently. As in other fallow systems, the two options for intensifying land use are shortening the fallow periods and prolonging the cropping periods. The option of shortening the fallow period was dealt with in Chapter 5. In this chapter, the option of prolonged cropping is studied. A literature study (see 7.1.2 for details) identified two main constraints to prolonged cropping: decreasing chemical soil fertility and accelerated weed growth. Other growth factors may also play a role, but are difficult to identify. Therefore, external inputs such as fertilizers or other measures such as extra weeding are needed to prevent yield decline.

The objectives of the experiments described in this chapter were to study the decline in yields under prolonged cropping, and the potential of extra weeding and fertilizer application to mitigate this decline. As an option of land use intensification crops were grown during the early season (April-July) and late season (August-November), thus enabling the possible influences of weather conditions to be studied. Two experiments aimed at monitoring yield decline for several years were conducted on fields specially created for this purpose. The experiments used to study the effects of varying fallow periods and clearing methods (Chapter 5 and 6), provided an estimate of yield decline in two consecutive early seasons and of the difference between early and late seasons, both in relation to length of the preceding fallow period and to method of clearing. In this chapter, these two groups of experiments are referred to as "Long-term experiments" and "1991-1992 Seasons experiments" respectively.

7.1.2 Literature review

In this literature review information on maize production in prolonged cropping in the humid tropics is presented. Declining maize yields in long-term studies had been reported in Ghana (Nye & Greenland 1960), Nigeria (Juo & Kang 1989, Kang 1993, Kang *et al.* 1977), Zambia (ICRAF 1993) and Peru (Alegre & Sanchez 1988). Sanchez (1976) found that yield decreases in shifting cultivation were generally more pronounced on soils low in base-status and pH than on soils with a high base-status and pH. Juo & Kang (1989) and Kang (1993) reported that yields as well as values of chemical soil properties such as soil organic matter, pH, exchangeable Ca and Mg, dropped under continuous cropping on alfisols in West Africa. The application of fertilizer and leaving crop residues in the field after harvest kept yields and soil fertility at higher levels, but did not prevent them declining in time. Experiments on continuous cropping carried out in Yurimaguas, Peru, showed that maize yields could be maintained at about 3 t ha^{-1} over 13 years if fertilizers and lime were applied (Alegre & Sanchez 1988). However, these inputs were applied at rather high rates and the soil dynamics had to be monitored constantly, so that the necessary adjustments could be made (Sanchez *et al.* 1982). In Zambia, yields in prolonged cropping were better maintained when fertilizers were applied (ICRAF 1993). On the same site, the first crop on older fallows produced better than those on young fallows but the high yield was not maintained when cropping was prolonged to three years. Autfray (1993) studied yields in prolonged cropping after a five-year-old *C. odorata* fallow in southern Ivory Coast. Maize was grown in the early seasons (April-August) followed by leguminous cover crops in the late seasons (August-December) in farmer-managed plots. Maize yields did not decline when both herbicides and fertilizers were applied, but fell from 2.2 t ha^{-1} in the first year to 1.7 t ha^{-1} in the third year, when only herbicides were used.

All the above-mentioned studies show that decreasing chemical soil fertility is a major cause of the decline in yields. It is, however, not the only factor involved. Often, declining yields are considered to be also the result of competition from weeds (Kang *et al.* 1977, de Rouw 1991a). Yields in a low-input cropping system in Peru, based on crop rotation, residue return and minimum fertilizer application, decreased moderately during the first three years, but considerably afterwards (Sanchez & Benites 1987). One year of *Pueraria phaseoloides* fallow drastically reduced weed incidence and increased the yield of the subsequent crop. However, this cropping system was only viable when initial conditions were favourable in terms of nutrient availability and weed pressure.

The appropriate timing of weed control measures appears to be very important when reducing weed competition. Autfray (1992) found one timely weeding to be sufficient for an adequate control of weeds in maize grown on plots cleared from *C. odorata* fallow in southern Ivory Coast, and Lutzeyer (1991) obtained similar results on a bush fallow in southern Benin. The optimum timing of weeding operations is related to the critical period of the crop, i.e. the period during which competition from weeds should be absent. The critical period varies with season, soil, weeds and location (Zimdahl 1993). Introducing this concept, Nieto *et al.* (1968) reported a critical period from 12 to 30 days after planting for maize grown on an experimental station in Mexico. On land cleared from bush fallow in southern Benin, Lutzeyer (1991) defined the critical period of maize as being between 2 and 5 WAS. Rice grown after clearing *C. odorata* fallow in the Taï region, produced significantly more when weeded at 3 and 6 WAS instead of 3 WAS only (Slaats 1992). Presumably, this crop is more susceptible to weeds than maize, as it stays smaller and takes more time to cover the ground. This is certainly borne out by the farmers, who stated that rice was not a suitable crop to be grown on cleared *C. odorata* fallows because of weeds.

The low yields obtained by Autfray (1993) suggest that apart from chemical fertility and weeds, other, not-identified, growth factors were suboptimal in his study. The fact that under continuous cultivation, yield decreased more severely in sole cropping of maize than in a rotation of maize and cover crops (Juo & Kang 1989), also implies that other growth factors are decisive too. Juo & Lal (1977) stressed that management of organic matter is important. They found that removal of crop residues led to a decline in soil chemical properties such as pH, soil organic matter, CEC and the amount of exchangeable K, and to a degradation of physical soil properties such as bulk density and infiltration.

In West Africa, maize yields are lower in the late season than in the early season. In the subhumid zone, this is mainly attributable to the lower rainfall later in the year (Saragoni *et al.* 1992, Ahn 1974). In the humid zone, maize yields have been found low because of the high incidence of maize streak virus and stem borers (Remison 1979), or possibly because N is lost by leaching, given that at the start of the late season precipitation largely exceeds evapotranspiration (Nguyen 1987).

7.2 Materials and methods

7.2.1 Long-term experiments

Location and experimental design

Long-term experiments were laid out on Fields I and III. Field III was cleared from a three-year-old *C. odorata* vegetation in 1989, and experiments were conducted during six seasons in the period 1989-1992. Immediately prior to the experiments, Field I was covered by a young vegetation composed of *C. odorata*, forbs and grasses. Experiments on this field started in the early season of 1990 (1990-E), directly following its abandonment by the farmer, and lasted until the early season of 1992 (1992-E).

The trials had a factorial design with weeding frequency and fertilizer application as experimental factors. On Field III, two weeding frequencies (once versus twice per season) were combined with two fertilizer treatments (P versus P plus N), carried out in six replicates. On Field I, the same weeding frequencies were combined with three fertilizer treatments (no fertilizer, P and P plus N), laid out in eight replicates.

Field preparation, crop management and observations

In general, the materials and methods used on both fields were as described in Sections 5.2 and 6.2. Below, only departures from the standard procedure will be mentioned.

The slashed vegetation had been removed after clearing and the soil was superficially tilled with a short hoe prior to sowing. This method of land preparation was repeated in each cropping season. Field III was weeded once (at 6 WAS) and thrice (at 3, 6, and 9 WAS) instead of once (at 3 WAS) and twice (at 3 and 6 WAS) during 1989-E, and received 50 instead of 100 kg N ha^{-1} in both seasons of 1989.

Crop development in 1990-E was poor on both fields and many plants did not produce any cob. The poor growth was not related to experimental treatments. In this particular season, the maize yield was estimated by harvesting the twelve best developed plants of each plot and converting the data obtained from them to production per hectare using the plant density at the moment of tasselling (about 7 WAS). On Field I, only the plants of two replicates had developed well enough to be harvested. Crop development on Field III was also very poor in 1992-I, the last cropping season. Plant density was low and most plants did not produce any cob containing grains.

Laboratory analysis and data processing

Chemical analysis was restricted to the 1992-E crop of Field III. This crop was sampled to study the yield decline more in detail. Grain and stover samples of the plants with a filled cob were dried at 70°C for 24 hours, and chemically analysed according to the standard procedures described by Walinga *et al.* (1989).

The effects of weeding frequency and fertilizer application on crop yield of each season were tested statistically by the analysis of variance. Differences in crop yield over time and the effect of weeding frequency and fertilizer application on these differences were tested separately for early seasons and late seasons, by making combined analyses of all yields. In this analysis, the experiment was considered a split-plot trial with weeding frequency and fertilizer application as main factors and season as sub-plot factor. The 1990-E yields were not included in this analysis as they were poorly estimated. Therefore, for Field III, the yields of 1991-E and 1991-L were compared with those obtained in 1989-E and 1989-L respectively, whereas only the yields from 1990-L onwards were used for Field I. The 1990-E yields were considered good enough for the weeding and fertilizer effects to be analysed within the same field.

7.2.2 1991-1992 Seasons experiments

In these experiments, crops were grown during three consecutive seasons in 1991 and 1992. Details are given in Chapters 5 and 6. Yields of 1992-E were calculated relative to the 1991-E yields, to indicate the effect of prolonged cropping. Yields of 1991-L were calculated relative to the average value of the yields obtained in 1991-E and 1992-E, to indicate the effect of the cropping season. A value close to unity would mean that conditions for crop growth hardly changed by prolongation or were similar in the early and late seasons.

7.3 Results

7.3.1 Long-term experiments

Effect of crop management

Two weedings instead of one did not significantly increase crop yields, except on Field I in 1990-L (Fig. 7.1). Three weedings at 3, 6 and 9 WAS, as carried out on Field III during the first season after clearing, gave a significantly higher yield than one weeding at 6 WAS. When P was applied, yields approximately doubled (Field I). Application of N increased crop yields on both fields, but responses were generally higher on Field I than on Field III. In 1990-E, the crop did not react to an application of N. In 1991-L and 1992-E crop response to N was zero on Field III, and small on Field I.

Effect of extending the cropping period

Extending the cropping period reduced the yields of the early and late seasons (Fig. 7.1). This reduction was significant ($P<0.01$, not shown in Figure 7.1) and became more pronounced with each further extension. Yields could not be maintained by weeding twice instead of once per season. On Field I, two weedings even resulted in a significantly ($P<0.05$) larger yield decrease during the late seasons of 1990-1991. In general, crop yields could not be maintained by applying P or NP (Table 7.1). This was particularly true for the high yields of the NP treatment on Field I. On Field III, the yields obtained after applying P or NP remained high during five seasons, from 1989-E to 1991-E, but declined to very low values afterwards.

The poor crop development during the last two seasons on Field III merits special attention. In 1991-L, many plants lodged and turned dry before the grains had fully formed. Weeding and fertilizer treatments did not significantly affect crop yields ($P<0.05$). However, two weedings instead of one increased the numbers of plants and cobs, whereas application of N reduced both. In 1992-E, crop yield was merely 0.3 t ha^{-1} and seedling emergence was poor. Plant height was very heterogeneous in individual plots, and the overall average of 97 cm was low compared to the 196 cm measured in 1991-E. The average number of productive plants (plants with a filled cob) amounted to 15,200 ha^{-1}, instead of the usual 50,000 ha^{-1}. The number of productive plants was significantly related to crop yield (Pearson correlation coefficient $(r)=0.84$, $P<0.01$). The mass fraction of K in the stalk was small, but was not significantly related to crop yield ($r=0.37$, $P>0.05$).

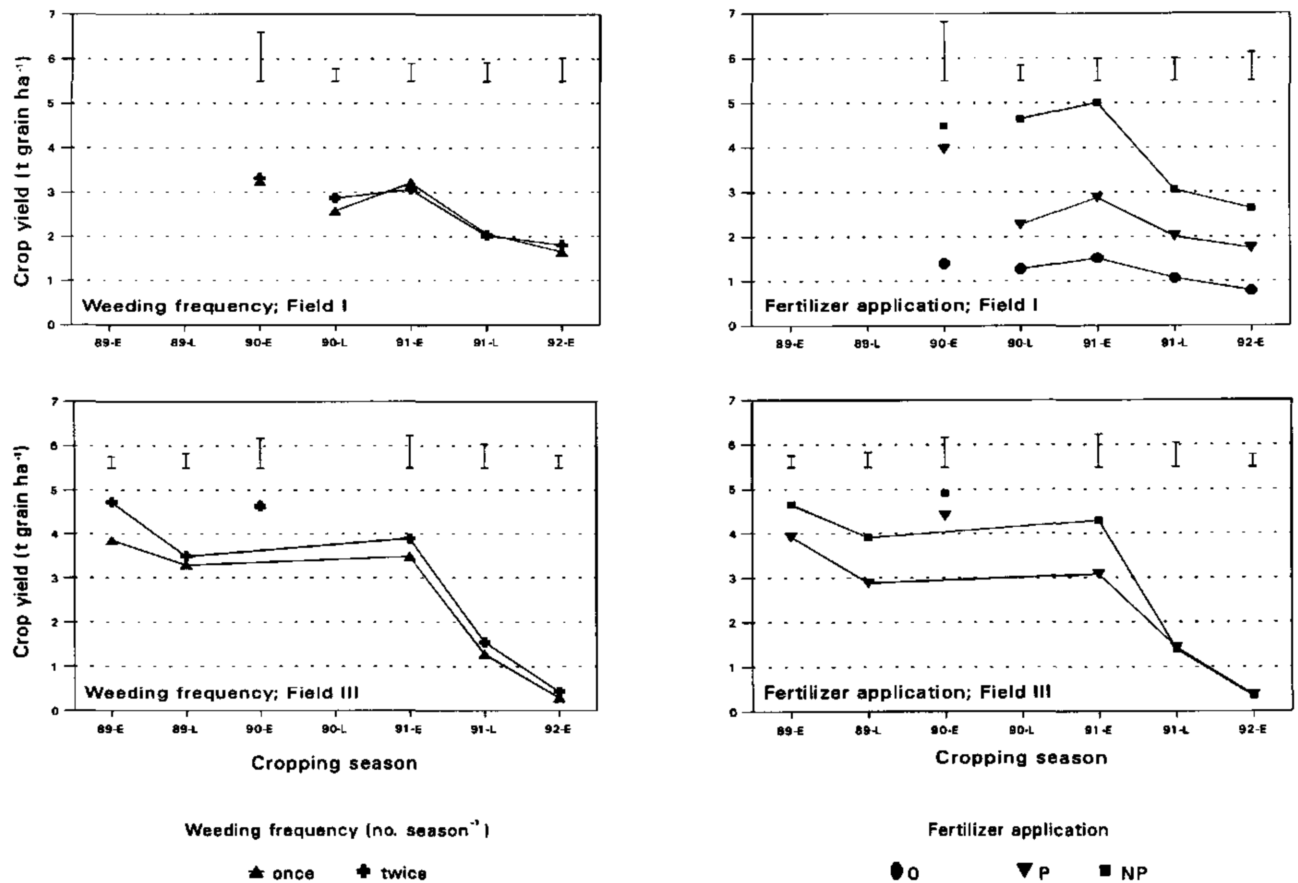


Fig. 7.1 Effect of prolonged cropping on yields of maize grown under different weeding frequency and fertilizer application regimes on two fields cleared from *C. odorata* fallow (Long term experiments; vertical bars indicate LSD (5%))

Table 7.1 Yield decrease (t ha^{-1}) of early and late season maize crops under different fertilizer regimes as a result of extending the cropping period on two fields cleared from *C. odorata* fallow (Long-term experiments)

Field	Season	Cropping period	Fertilizer application[a] 0	P	NP	LSD(5%)[b]
III	Early	1989-1991	na	0.8	<u>0.4</u>	0.8
	Late	1989-1991	na	1.5	2.5	0.6
	Early	1991-1992	na	2.7	3.9	0.8
I	Late	1990-1991	<u>0.2</u>	0.3	1.5	0.4
	Early	1991-1992	0.7	1.2	2.4	0.5

Underlined yield decreases are not significant
[a] averages over all weeding frequencies
[b] LSD for comparing yield decreases between treatments for the same season

Crop characteristics varied with the weeding and fertilizer treatments, but remained at very low values (Table 7.2). Two weedings instead of one significantly increased the number and proportion of productive plants, but did not affect crop yield, seedling emergence, plant height or mass fractions of N, P and K in grains and stalk (P=0.05). Application of N hampered crop development, since it reduced yield, seedling emergence and the number of productive plants significantly. It also reduced the mass fraction of K in the stalk, but increased the mass fractions of N, P and K

Table 7.2 Effects of weeding frequency and fertilizer application on various crop characteristics of early season's maize in 1992-E, the sixth crop grown on Field III cleared from a three-year-old *C. odorata* fallow (Long-term experiments)

Crop characteristic		Weeding frequency[a] 1	2		Fertilizer application[b] P	NP		Overall average
Grain yield (t ha^{-1})		0.22	0.30	ns	0.32	0.19	*	0.26
Seedling emergence (%)		72	75	ns	80	67	**	73
No. of productive plants ($x10^3$ ha^{-1})		11.5	18.9	**	20.0	10.4	**	15.2
Proportion of productive plants		35	52	*	52	34	**	43
Nutrient mass fractions (g kg^{-1})								
grains	N	14.5	13.7	ns	11.6	16.6	***	14.1
	P	3.3	3.2	ns	2.9	3.6	***	3.2
	K	3.8	3.7	ns	3.5	4.0	***	3.8
stalk	N	7.6	7.6	ns	5.8	9.4	***	7.6
	P	1.1	0.9	ns	0.9	1.1	ns	1.0
	K	3.0	3.4	ns	4.2	2.3	**	3.2

Values of characteristics are averages after removal of three outliers
[a] averages over all fertilizer treatments
[b] averages over all weeding frequencies
*, **, *** significant at P<5%, 1% and 0.1% respectively, ns = not significant

in the grains and that of N in the stalk ($P<0.05$). In the early season of 1992, plants in some plots of Field I also turned dry prematurely, pointing to the onset of a degradation similar the one that occurred on Field III during the last two seasons.

7.3.2 1991-1992 Seasons experiments

Effect of extending the cropping period

On all the experimental fields, crop yields were significantly ($P<0.01$) lower in 1992-E than in 1991-E (see Tables 5.3, 6.3 and Fig. 7.1). In Table 7.3 the relative yields of 1992-E of all fields are presented as averages per fertilizer treatment. Average yields per weeding treatment are not given because weeding frequency did not significantly affect the relative yield ($P=0.05$) except on Field II. On this field, weeding twice instead of once gave a higher relative yield. Applying fertilizers led to the relative yield of 1992-E increasing on all fields except on Fields I and III. Clearing methods significantly affected the relative yield of 1992-E as well. Averaged over all weeding and fertilizer application treatments of Field II, the relative yield was lower if the slashed fallow vegetation had been removed prior to cropping instead of burnt or intensively burnt ($P<0.01$). Moreover, the interaction between clearing method and fertilizer application was significant ($P<0.05$). Fertilizer application increased the relative yields when the slashed fallow vegetation was

Table 7.3 Comparison of maize yields obtained on fields cleared from *C. odorata* fallow in the early seasons of 1991 and 1992 (Figures represent 1992 yield expressed as a percentage of the 1991 yield; 1991-1992 Seasons experiments)

Field	Length of prior fallow period (years)	Cropped before 1991 (seasons)	Clearing method	Fertilizer application[a] 0	P	NP	LSD(1%)	Overall average
III	3	3	Removing	na	12	7	ns	10
I	0	2	Removing	52	60	52	ns	55
II	2	0	Removing	49	62	68	17[b]	60
			Burning	64	90	88		80[c]
			Int. burning[d]	95	84	89		89
IV	3	0	Burning	54	62	89	17	68[c]
V	4	0	Burning	39	62	77	15	60[c]

[a] averages over all weeding frequencies
[b] LSD at 5% for comparisons between fertilizer treatments within a clearing treatment on Field II. LSD(5%) is 18 for comparisons between clearing treatments within a one fertilizer treatment
[c] LSD(5%) for comparison between the average values of the burnt plots of Fields II, IV and V is 8
[d] intensive burning

removed or burnt, but not on the plots on which a double amount of slashed vegetation was burnt. Interaction between clearing method and weeding frequency was not significant (P=0.05).

Differences in the relative yields between fields may be related to the length of the preceding fallow period or to the length of the cropping period, although other factors than these, such as soil properties and quality of clearing may have played a role. The effect of the length of the preceding fallow period was studied by comparing the relative yields of Fields II, IV and V. On the burnt plots of Field II, the relative yield of 1992-E was higher than on Field IV, which in turn was higher than on Field V ($P<0.05$). This indicates that the relative yield was inversely related to the length of the preceding fallow period. The effect of the length of the cropping period was examined by comparing the relative yields of Fields III, I and II, which differed in the number of crops grown prior to 1991. On Field III, which had been cropped three times before 1991, the relative yield of 1992-E was substantially lower than on the other two fields, which had been cropped less often. This finding suggests that crop yield drops considerably when cropping is prolonged to more than four seasons.

Effect of the late season

The relative yield of the late season varied between 68% on Field V and 92% on Field II (Table 7.4). Thus the yields obtained in the late season were less than predicted after taking into account the decrease in yields caused by prolonging the cropping period. Weeding twice instead of once reduced the relative yield of the late season significantly on Field II, but not on the other fields (not shown in Table 7.4). This response was not affected by the method plots were cleared (P=0.05). Fertilizer application significantly mitigated the negative effect of the late season on Fields II, IV and V where crop yields of the late season attained about 3 t ha^{-1} when P was given and about 5 t ha^{-1} when both P and N were applied. On Field III, however, the relative yield of the late season dropped when N was given in addition to P. On Field I, fertilizer application did not significantly affect the relative yield of the late season. Yields on this field remained 2 t ha^{-1} for the P treatment and 3 t ha^{-1} for the P plus N treatment. The relative yield of the late season was not significantly affected by clearing methods (Field II) nor by the number of crops already grown, nor by the length of the preceding fallow period.

Table 7.4 Comparison of maize yields obtained on fields cleared from *C. odorata* fallow in the early and late seasons of 1991 and 1992 (Figures represent late season's yield of 1991 expressed as a percentage of the average of the early season's yield of 1991 and 1992; 1991-1992 Seasons experiments)

Field	Length of prior fallow period (years)	Cropped before 1991 (seasons)	Clearing method	Fertilizer application[a] 0	P	NP	LSD(1%)	Overall average
III	3	3	Removing	na	83	56	26	70
I	0	2	Removing	93	84	79	ns	85
II	2	0	Removing					92
			Burning	74	89	92	10 [b]	84
			Int.burning					79
IV	3	0	Burning	59	81	88	16	76
V	4	0	Burning	60	64	81	17	68

[a] averages over all weeding frequencies
[b] average values of the three clearing methods are given because there was no significant interaction with fertilizer treatments

7.4 Discussion and conclusions

7.4.1 Extending the cropping period

Extending the cropping period reduced yields on all experimental fields and this decrease was hardly affected by weeding frequency. During the first three seasons after clearing, application of P and N slowed down the yield decrease. This finding confirms the generally reported importance of nutrient availability on yield maintenance (Section 7.1.2). When the cropping period was prolonged further, however, application of N tended to enhance the drop in yield. The important role of nutrient availability in yield maintenance was also indicated by a smaller yield decrease if the slashed fallow vegetation had been burned prior to cropping. On fields cleared from older fallows, prolonged cropping resulted in a more pronounced yield decline. As indicated in Chapter 5, the first crop yield was higher on fields where the preceding fallow period was longer whereas the second and third crops gave similar yields on all fields irrespective of the fallow age. When more than four crops were grown consecutively on land cleared from *C. odorata* fallow, crop production seemed to collapse as indicated by a disordered development and by yields that dropped to very low values and could no longer be maintained by fertilizer application. This suggests that factors other than weed competition or deficiency of N or P are important. Likely causes of yield decline are nematodes, deficiency of other nutrients and degradation of soil properties. Examination of plants and soil indicated that large numbers of nematodes of the genus Pratylenchus were present. Their density was considered below that to be detrimental, but under poor conditions it was probably high enough to reduce crop growth. The K content in the maize plants is low compared to the range given by Nijhof (1987); this suggests that the availability of this element limited crop yield too. However, it cannot explain the reduction in seedling emergence and the low proportion of productive plants. As indicated in Section 7.1.2, changes in physical soil properties also affect yields in prolonged cropping. The recurrent tillage at clearing and weeding may have caused the soil structure to deteriorate. This hypothesis is supported by the occurrence of sites with a sealed soil surface in some of the experimental fields. Frequently walking in the field and the removal of fallow vegetation and crop residues probably increased the soil compaction. The gradual disappearance of worm casts when fields were cropped for a longer period indicates that soil fauna activity was strongly reduced. The probable explanation for this is that the removal of fallow vegetation and crop residues deprived soil organisms of an important food source.

7.4.2 Cropping in the late season

The yields obtained during the late season were lower than those from the early season, even when the yield decrease caused by prolonged cropping was taken into account. This demonstrates that conditions for growing maize were less adequate in the late season of 1991, probably because of the dry spell that occurred in the second half of September. In general, the late season is considered to be less appropriate for maize cultivation than the early season because of the lower radiation (Collinet *et al.* 1984), the shorter period of rainfall (Chapter 1), and the great variability in rainfall at the start and the end of this season (Casenave *et al.* 1980). Although stalk borers and locusts were more predominant in the late season than in the early season, this does not explain the seasonal effect on crop yield because in the experiments crop damage was prevented by adequate protection measures. The seasonal effect on crop yield was not clearly related to the number of crops grown before the present ones, the length of the preceding fallow period or competition from weeds. Application of N and P reduced the negative seasonal effect, indicating that despite the less favourable climatic conditions, nutrient availability still limited crop production. On the fields in which crops were grown for more than one year and where the slashed fallow vegetation had been removed prior to cropping, fertilizer application enhanced the seasonal effect on crop yields. This again indicates that factors other than the deficiency of P or N provoke the collapse of continuous maize production on land cleared from *C. odorata* fallow.

7.4.3 Remarks on crop responses to weeding and fertilizer application

Crop responses in the Long-term experiments confirm the general effects of weeding frequency and fertilizer application found on the fields of the 1991-1992 Seasons experiments (Chapters 5 and 6). In general, one weeding at 3 WAS was sufficient to control weeds, even after several cropping seasons. It must be remembered that these results were obtained on fields in which the slashed *C. odorata* fallow vegetation has been removed and the soil had been superficially tilled prior to each cropping. However, weeding frequency affected crop yields when the first weeding was carried out at 6 WAS instead of 3 WAS. This finding suggests that the critical period of maize grown on land cleared from *C. odorata* fallow corresponds with that found in other studies (2-5 WAS) and is an important criterion for timing the weeding operation. The yield increases following the application of P and N indicate a poor availability of these elements on land cleared from *C. odorata* fallow. On plots where the slashed fallow vegetation had been removed prior to cropping (Field I), the response to application of P during the first season was higher than on plots which had been burnt (Fields II, IV and V). This indicates that the supply of P by the *C. odorata* fallow vegetation was important for crop yield.

7.4.4 Conclusions

Extending the cropping period on land cleared from *C. odorata* fallow results in declining yields. The decline was more severe on fields cleared from older fallows than on fields cleared from younger fallows, because yields dropped to the same low level after the first season, but were higher during the first season on the former fields. When the cropping period is extended by one or two seasons, increasing the availability of N and P by applying fertilizer slows down the yield decline. Burning instead of removing the slashed fallow vegetation prior to cropping has a similar effect, probably because more P is available. Extending the cropping period further than three seasons gives an enhanced yield decline upon N application. If more than four maize crops are grown in succession, yields fall to 0.3 t ha^{-1} and no longer respond to cultivation practices, probably because other growth conditions have degraded. Maize cultivation in the late season, in the context of prolonged cropping, is not very appropriate. Yields are lower than in the early season and are only moderately improved by fertilizer application. Weed competition does not seem decisive for the yield decline in prolonged cropping on land cleared from *C. odorata* fallow, if weeding is carried out at the appropriate moment, i.e. within the first month after planting.

Part IV

Regrowth of *C. odorata* in relation to cultivation practices

Chapter 8

Effects of clearing methods and cultivation on the regrowth of *Chromolaena odorata* during the cropping period

8.1 Introduction

8.1.1 Research objectives

Ideally, a fallow crop should quickly cover the soil and form a sizeable biomass without being a serious weed during the cropping period. As shown in Chapter 4, *C. odorata* fulfils the first requirement but is considered to be an obnoxious weed in Africa and Asia (Castillo *et al.* 1981, Holm *et al.* 1977, Lucas 1989). Rapid re-growth and minimum competition in the *C. odorata* fallow system should be balanced by choosing appropriate clearing and crop management practices.

In this chapter it is investigated whether clearing methods and cultivation treatments can sufficiently control *C. odorata* growth during cropping. As the species re-establishes by sprouting of stumps and by emergence of seedlings (Gautier 1992, Ivens 1974, Olaoye 1986), both mechanisms of regrowth were studied in a field experiment. To obtain additional information, the emergence of seedlings was investigated in soil samples taken from the experimental field. The clearing methods were burning, intensive burning, and retaining the slashed fallow vegetation in the field as a mulch. Burning delays sprouting of stumps and kills seeds in the soil (Ewel *et al.* 1981, Kellman 1986, de Rouw & van Oers 1988, Uhl *et al.* 1981). Intensive burning is thought to enhance these effects, whereas mulching impedes the emergence of seedlings without affecting sprouting. The effects of two cultivation treatments - weeding and cropping - were studied. Weeding with a hoe sets back the regrowth of *C. odorata* stumps and destroys seedlings. On the other hand, by bringing subsoil to the soil surface it may stimulate seedling emergence. In that case it will counteract the negative effect of burning on seedling emergence. Cropping will stop the development of *C. odorata*, as the crop canopy shades out the regrowing shoots and seedlings.

8.1.2 Literature review

Various studies on slash-and-burn agriculture on forest fallows report that burning reduces sprouting and kills seeds in the soil. In Venezuela, Uhl *et al.* (1981) found only a few sprouting stumps (0.6 m^{-2}) four months after burning. During the first cropping season after clearing a forest fallow in the Taï region, de Rouw (1993) found 1.5 sprouting plants m^{-2} on a normally burnt field and about 6.0 m^{-2} on a slightly burnt field. According to Mallik & Gimingham (1985) and Kellman (1986) the sprouting potential of plant species is determined by its carbohydrate reserves and morphology. Older plants can better withstand burning as they have more reserves and a thicker bark to protect the cambium layer. Burning also reduces the number of emerged seedlings on forest fallows, sometimes by over 50% (Ewel *et al.* 1981, Keeley 1977, van Reuler & Janssen 1993b, de Rouw & van Oers 1988, Uhl *et al.* 1981). However, it may accelerate the emergence of seedlings, as reported by Ignacio & Bozan (1988) for herbaceous weeds and by de Rouw & van Oers (1988) for forest species.

On crop fields cleared from forest and bush fallows, weeding reduces the density of tree stumps. Kellman (1980) stated that increased tillage reduced the number of sprouting plants and favoured the regrowth of herbaceous species. In the first cropping season after clearing a two-year-old bush fallow in Peru, one weeding reduced the number of woody sprouting plants from 12.4 m^{-2} to 4.6 m^{-2} and three weedings reduced this further to 3.2 m^{-2} (Staver 1991). In slash-and-burn agriculture in Venezuela, five weedings with a cutlass during two and a half years of cropping reduced the density of sprouting stumps of forest trees from 0.65 m^{-2} to 0.11 m^{-2} (Uhl *et al.* 1982a). On a slightly burnt field cleared from a nineteen-year-old forest vegetation in the Taï region, two weedings with a cutlass during the first season reduced the density of sprouting plants from 5.8 m^{-2} to 3.2 m^{-2} (De Rouw 1993). On a normally burnt field in the same study, weeding hardly affected the density, which was about 1.3 plants m^{-2}.

The effect of weeding on seedlings was to reduce the seedling density of woody species from 17.3 m^{-2} to 5.4 m^{-2} at the harvest of the first crop on cleared forest fallows in the Taï region (de Rouw 1993). On plots cleared from bush fallow in Peru, however, weeding reduced the seedling density of woody species, but not that of herbs (Staver 1991).

8.2 Materials and methods

8.2.1 Growth of *C. odorata* shoots and seedlings

Experimental design and data processing

The experiment was carried out on Field VI, cleared from a two-year-old *C. odorata* fallow. Information on the fallow vegetation and the soil characteristics of this field are given in Table 6.1 and Table 1.1 respectively. The experiment had a split-plot design, laid out in six replicates. The main factor was four intensities of clearing: (1) removing the slashed vegetation, further referred to as **Removing**, (2) burning the slashed fallow vegetation (**Burning**), (3) burning the slashed fallow vegetation plus the vegetation and litter of treatment (1) (**Intensive Burning**) and (4) leaving the slashed vegetation in situ as a mulch (**Mulching**). The subplot factor refers to cultivation treatments subsequent to clearing. There were three of these: (1) no weeding and no cropping after clearing, further referred to as **Fallow**, (2) weeding but no cropping (**Weeded**) and (3) weeding and cropping (**Cropped**).

A split-plot design was chosen because the extra space required for firebreaks made it impossible to burn small plots. Burning has a dual effect on seedling development: it damages seeds in the topsoil and removes the soil cover. In the comparison of seedling development for Mulching and Burning, both effects are confounded. To separate them Removing was added. Removal of the slashed vegetation prior to cropping was also included because other experimental fields had been cleared in this way (see Appendix II). The effect of weeding on the regrowth of *C. odorata* was studied by comparing the Fallow and Weeded plots. The effect of crop development was examined by comparing Cropped and Weeded plots. The yields obtained on Cropped plots are presented in Chapter 6.

The effects of clearing methods and cultivation treatments were tested by analysis of variance. When analysing data on *C. odorata* shoots, the number of stumps was used as a covariate.

Management of the experiment and observations

The slashed fallow vegetation was burnt after seven days of drying. With the first rains, one week later, maize was sown 0.30 m apart in rows 0.60 m apart. It was a hybrid variety "Pioneer 3274 yellow", maturing in 105 days and reaching a maximum height of about two metres 9 weeks after sowing (WAS). Weeding was done 26 days after burning, 3 WAS, using a short hoe to till the soil superficially and to sever shoots emerging from the stumps of *C. odorata* and other woody species. In the Mulching treatment weeding was done with a cutlass, to avoid disturbing the mulch layer.

Observations were made on the development of *C. odorata* shoots and seedlings, recording their numbers, estimating their ground cover and measuring the five tallest individuals of the first developing shoots and seedlings. The living and dead *C. odorata* stumps were counted as well. A 70 cm x 30 cm frame was used for these observations. It was put over the weed vegetation at two permanent sites in each plot. Data on the shoots and stumps were recorded within the entire frame, while those on seedlings were recorded in three 10 cm x 10 cm sections of the frame. The observation period started at the moment of clearing and lasted 82 days. Before weeding, observations were carried out four times for all treatments. After weeding, six observations were made on Weeded and on Cropped plots, and three observations were made on Fallow plots.

8.2.2 Emergence of *C. odorata* seedlings

Experimental design and data processing

This experiment in germination boxes also had a split-plot design with six replicates. The main factor was the clearing method, as in the field experiment (Mulching, Removing, Burning and Intensive Burning). The split factor was soil depth (0-0.5 cm, 0.5-2.0 cm).

The effect of clearing methods on the emergence of seedlings at two soil depths was tested by analysis of variance, after data had been transformed to logarithmic values.

Management of the experiment and observations

Soil samples for filling the germination boxes were taken in the period between one to three weeks after burning. Prior to sampling, the number of seedlings already present was recorded, to correct the observations on emergence in the boxes. Seedling counts were made at exactly the same spots at which soil samples had been taken. The maximum sampling depth was set at 2 cm, as a preliminary emergence test confirmed the conclusion of Yadav & Tripathi (1982) that the seed bank of *C. odorata* was restricted to the upper 2 cm. In each main plot (60 m^2), six samples (each 0.42 m^2 in area) were taken from the top 0.5 cm of soil, and six samples (each 0.19 m^2 in area) were taken from the 0.5-2 cm soil layer. The six samples per layer were subsequently pooled to form two samples. They were air dried and sieved (2 mm mesh diameter).

Wooden boxes with gauze bottoms covered by absorbent paper were divided into four compartments of 20 cm x 30 cm, each containing a 2-cm-thick layer of seed--free subsoil. The soil of the entire pooled sample (1 to 2 kg) was spread over this layer and covered with a thin layer (0.5 cm) of seed-free subsoil. The boxes were arranged in three rows under a roof covered by transparent plastic to protect against rain. They were put on racks to allow free drainage and were watered regularly.

The emerged seedlings in the boxes were counted and then gently removed. The unknown species awaiting identification were left to grow for a maximum of one month. Observations were made at intervals of three to four days, in total nine times in a 45-day-period starting after the first seedlings emerged.

8.3 Results

In presenting the results of regrowth in the field experiment, the effects of clearing methods are given for each cultivation treatment separately. A major distinction is made between Fallow plots versus Weeded plots and Cropped plots because weeding overruled the effects of clearing methods on the regrowth. The results obtained on Weeded plots and on Cropped plots were pooled because they were very similar; this pooling enabled the effects of clearing methods after weeding to be studied more precisely. No data on shoot and seedling number are given, because they show the same trend as data on shoot and seedling cover.

8.3.1 Growth of *C. odorata*

Shoots

On Fallow plots, the shoot cover of the two burning treatments was in general lower than that of the two non-burning treatments (Fig. 8.1). In the first month after clearing, the difference between burning and non-burning treatments was significant ($P<0.05$). In the following two months, the difference in shoot cover between the Removing and Burning treatments became smaller and was no longer significant.

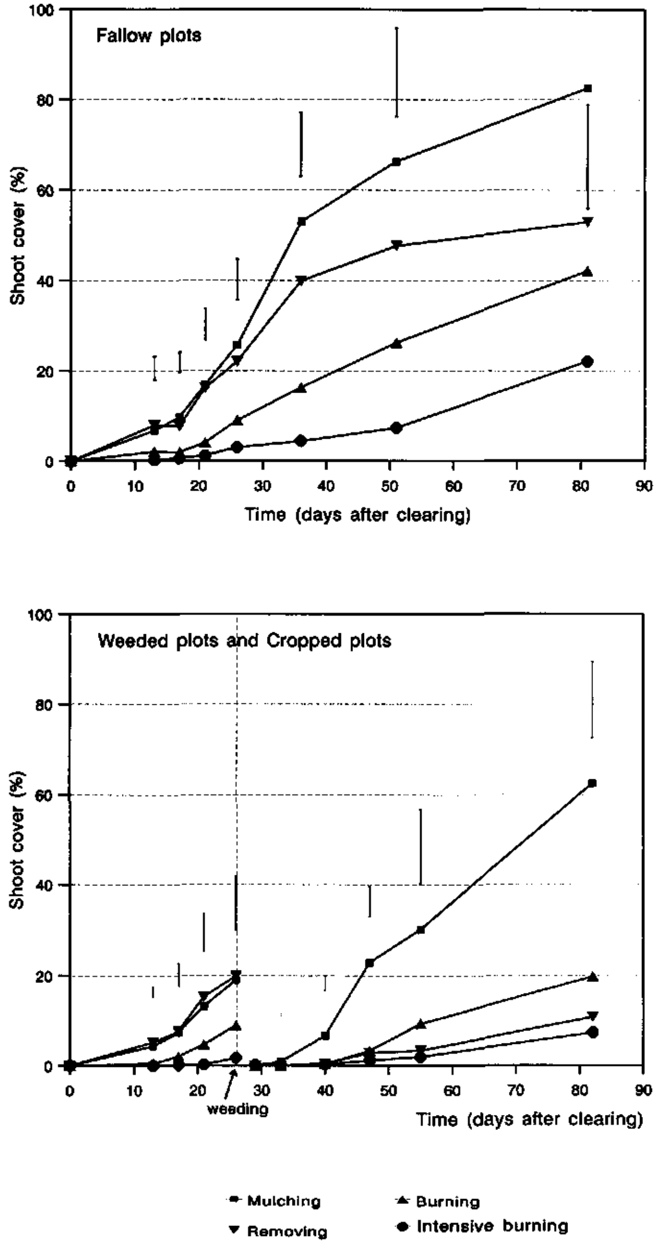


Fig. 8.1 Development of *C. odorata* shoot cover over time for four clearing methods on Fallow plots and on Weeded plots plus Cropped plots (Vertical bars represent LSD at P=5%)

The cover in the Intensive Burning treatment lagged behind, whereas that in the Mulching treatment remained significantly higher than in the Burning treatment.

Until the moment of weeding, 26 days after clearing, shoot cover on Weeded and on Cropped plots developed in the same way as on Fallow plots (Fig. 8.1). After weeding, the shoot cover in the Mulching treatment re-established rapidly. In the other three clearing methods, however, the cover developed very slowly and in the same way. The shoot cover was similar on Weeded and Cropped plots.

In all cultivation treatments alike, the proportion of living stumps on 26 days after clearing was lower if the fallow vegetation had been burnt or intensively burnt than if it had been removed (Table 8.1). The decrease in the proportion of living stumps was largest in the Intensive Burning treatment. Some burnt stumps did not sprout until the moment of weeding; they were recorded as being dead. Moreover, the living stumps on burnt and intensively burnt plots tended to produce fewer shoots per stump than those on the plots where the slashed vegetation had been removed. These results correspond with the lower cover of *C. odorata* shoots in the burning treatments during the first 26 days after clearing (Fig. 8.1).

Table 8.1 Density of stumps, proportion of living stumps and number of shoots per living stump of *C. odorata*, for four clearing methods on Fallow plots and on Weeded plots plus Cropped plots at two times during the cropping season

Cultivation treatment	Clearing method	26 days after clearing			81/82 days after clearing		
		Density stumps (no. m^{-2})	Fraction living stumps (%)	Shoots per living stump (no.)	Density stumps (no. m^{-2})	Fraction living stumps (%)	Shoots per living stump (no.)
Fallow plots	Mulching	nd	nd	nd	18.2	100	2.80
	Removing	15.2	100	5.32	18.0	100	4.10
	Burning	13.5	73	2.98	11.2	90	3.68
	Intensive burning	12.3	20	2.43	7.7	68	2.47
	LSD (5%)[a]	ns	35	ns	ns	ns	ns
Weeded plots plus Cropped plots	Mulching	nd	nd	nd	22.0	100	3.15
	Removing	17.6	93	3.88	4.4	88	3.09
	Burning	21.0	48	2.60	8.7	72	3.02
	Intensive burning	13.3	18	3.33	3.6	41	3.33
	LSD (5%)[a]	ns	25	ns	ns	ns	ns

[a] LSD for comparison between treatments Removing, Burning and Intensive Burning

At the end of the observation period, 81 days after clearing, the effects of clearing methods on the viability of stumps and number of shoots per stump were less evident, as the proportion of stumps with shoots in the Burning and Intensive Burning treatments had increased between 26 and 81 days after clearing. On Fallow plots, the differences in stump density, proportion of living stumps and number of shoots per stump did not differ significantly between the Mulching treatment and the other clearing treatments ($P=0.05$, not shown in Table 81). On Weeded plots and on Cropped plots, the total number of stumps dropped drastically between 26 and 81 days after clearing. The proportion of living stumps was higher in the Mulching treatments than in the other treatments; the difference between Mulching and Intensive Burning was statistically significant ($P<0.05$, not shown in Table 8.1). These results correspond with the low cover of shoots in the Removing, Burning and Intensive Burning treatments after weeding (Figure 8.1). There were no systematic differences in number of stumps or number of shoots per stump between Weeded plots and Cropped plots.

The length of the first developing shoots was not affected by the clearing method. The shoots reached an average length of 120 cm after 81 days on Fallow plots and 50 cm on Weeded plots and on Cropped plots; at that time the maize plants were 172 cm tall. The growth rate of the shoots after weeding was similar to that before weeding and was not clearly affected by maize cropping.

Seedlings

On Fallow plots, burning or intensively burning the slashed fallow vegetation reduced the seedling cover significantly in comparison with retaining it as mulch (Fig. 8.2). Removing the vegetation gave a similar cover than burning or intensively burning it. The decrease in cover at day 26 was probably caused by a dry spell during the preceding days.

On Weeded and on Cropped plots, seedling cover prior to weeding developed in the same way as that on Fallow plots (Fig. 8.2). After weeding, the cover developed very rapidly in the Removing treatment, but it increased slowly in both burning treatments. The very rapid cover development in the Mulching treatment can be attributed to the use of a cutlass for weeding in that treatment. Seedling cover on Cropped plots was similar to that on Weeded plots. However, seedling density at the end of the observation period, 82 days after clearing, was significantly lower when crops were grown ($P<0.05$, not shown).

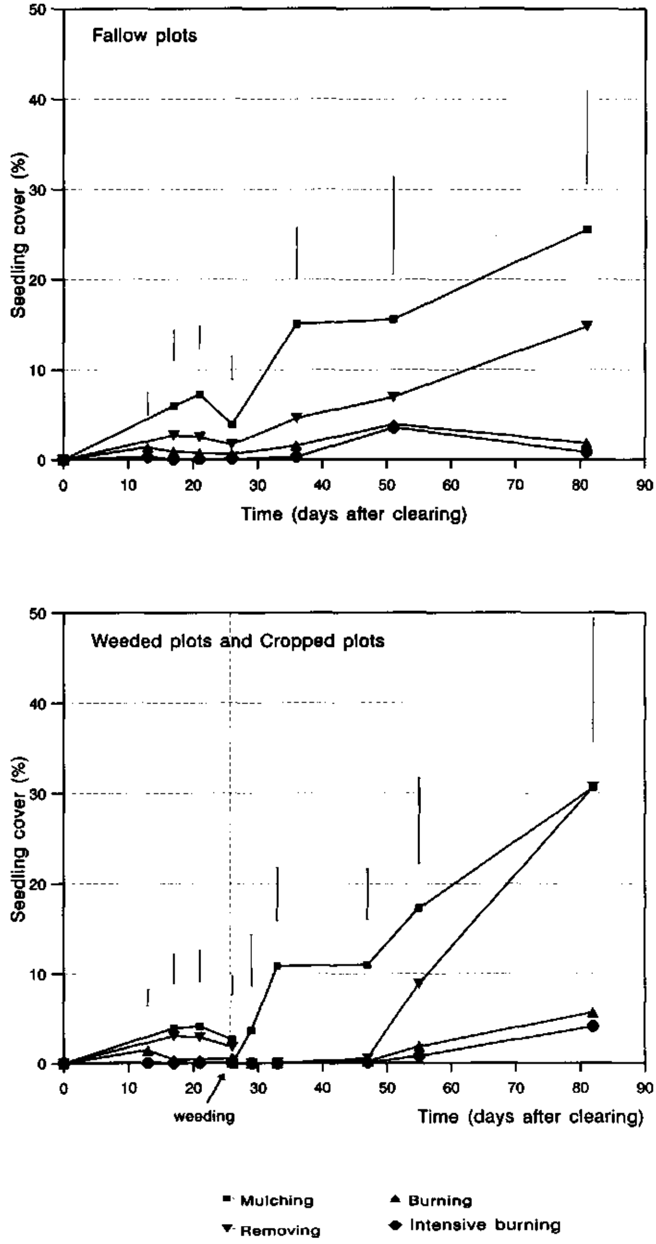


Fig. 8.1 Development of *C. odorata* seedling cover over time for four clearing methods on Fallow plots and on Weeded plots plus Cropped plots (Vertical bars represent LSD at P=5%)

On Fallow plots, seedling height up to 50 days after clearing was not clearly affected by clearing methods. At the end of the observation period, 81 days after clearing, the seedling height ranged from 5 cm in the Intensive Burning treatment to 19 cm in the Mulching treatment, but the differences were not significant (P=0.05).

On Weeded and on Cropped plots, seedling height at 82 days after clearing did not exceed 6 cm in the Removing, Burning and Intensive Burning treatments. In the Mulching treatment, seedlings reached 21 cm at the same time and were significantly taller than those of the other clearing treatments ($P<0.05$). Averaged over all clearing methods, seedlings on Weeded plots reached 12 cm and were significantly ($P<0.05$) taller than those on Cropped plots, attaining 6 cm.

8.3.2 Emergence of *C. odorata* seedlings

About 85% of the *C. odorata* seeds in the 0-2 cm soil layer were found in the top 0.5 cm, as shown by seedling numbers in the non-burning treatments in the germination boxes (Table 8.2). Burning and intensively burning the slashed fallow vegetation reduced the number of seedlings in the 0.5 cm topsoil by about 95% and 80% in comparison with respectively retaining it as a mulch and removing the vegetation ($P<0.05$). The number of seedlings in the field prior to soil sampling was significantly higher in the Mulching treatment than in the other clearing methods. Clearing methods hardly affected the emergence of seedlings in the 0.5-2.0 soil layer.

Table 8.2 Effect of clearing methods on subsequent seedling emergence (no. m^{-2}) of *C. odorata* in germination boxes (subdivided according to the soil layers sampled) and in the field before sampling

	Clearing method			
	Mulching	Removing	Burning	Intensive burning
Box with soil layer <0.5 cm	1354 a	696 a	92 b	82 b
Box with soil layer 0.5-2.0 cm	190 a	101 a	51 b	79 ab
Subtotal	1544	797	143	161
Field before sampling	1773 a	225 b	20 c	49 bc
Total	3317 a	1023 b	162 c	210 c

Results followed by the same letter are not significantly different (LSD(5%))

The rate of emergence in the germination boxes was not affected by the clearing methods and was similar for the seedlings in both soil layers. Half of the final number of seedlings counted after 45 days had emerged within 20 to 25 days after starting the experiment, and by 36 days, 90% were present.

8.4 Discussion and conclusions

8.4.1 Growth of *C. odorata* shoots

Burning the slashed fallow vegetation destroyed a number of stumps, and the surviving stumps tended to form fewer shoots, resulting in a decreased number and soil cover of the shoots. Burning also delayed sprouting, as indicated by the increase in the proportion of sprouting *C. odorata* stumps at the end of the observation period. Burning affected the shoot development of *C. odorata* in the same way as that of woody species in forest fallows. Once stumps started to sprout, the increase in shoot length was similar in all the clearing methods and was not affected by crop development. Given that only the first shoots that developed were measured, little can be said about the effect of clearing methods on length of the shoots that developed later.

The effects of cultivation treatments on shoot development of *C. odorata* were also obvious. Hoe-weeding, carried out on plots where the fallow vegetation had been removed, burnt or intensively burnt, drastically reduced stump density and gave a similar number of shoots per stump afterwards. This effect was brought about by unintentional uprooting which overruled the effect of burning and resulted in a slow and similar shoot development in all the clearing treatments. Weeding with a cutlass had a relatively small effect on shoot cover or stump density. Weeding seemed to reduce the stump density of *C. odorata* more sharply than that of woody species in plots cleared from forest fallow, probably because in the latter case a cutlass was used instead of a hoe and because tree stumps mostly are bigger.

8.4.2 The emergence and subsequent growth of *C. odorata* seedlings

The results of the field trial and the emergence study show that burning reduced both the cover and the number of *C. odorata* seedlings. Burning probably destroyed a large part of the seeds buried in the soil, as suggested in the studies cited in Section 8.1.2. The large effect of burning on seedling emergence can be explained by the concentration of the seed stock in the top soil. The results of the present study confirm Epp's (1987) statement that fire has the potential to eliminate the majority of the *C. odorata* seeds in the soil. Burning did not result in an accelerated emergence, as reported by Ignacio & Bozan (1988) and de Rouw & van Oers (1988). In agreement with observations of Uhl *et al.* (1981), the number of emerged seedlings was not further reduced by intensive burning. These findings suggest that the minimum temperature beyond which *C. odorata* seeds are killed was attained by burning the two-year-old fallow vegetation, which was composed of about 16 t ha^{-1} of dry matter.

The slashed *C. odorata* vegetation is an important source of seeds, as indicated by the larger numbers of seedlings when the vegetation was retained instead of removed. An explanation for this finding is that at the moment of clearing the plants had not yet shed all seeds set during preceding fruiting period. When the slashed vegetation was retained as a mulch, a greater emergence was found even in the deeper soil layer (0.5-2 cm). Seeds had probably been buried by enhanced animal activity and by rains during the period (1-3 weeks) between clearing and soil sampling. The rapid emergence of *C. odorata* prior to soil sampling on plots in which the slashed vegetation was retained might be due to higher soil moisture content and to competing heliophile species such as *Spigelia anthelmia* being suppressed by the mulch layer. This finding is counter to the general belief that mulching suppresses the emergence of seedlings, but has also been reported in other studies on vegetation re-establishment after clearing. On plots cleared from forest fallow in Venezuela, seedling establishment on microhabitats covered by slashed vegetation was significantly higher than on those without a cover (Uhl *et al.* 1981). This microhabitat preference was related to the reduced evaporation on the surface covered by the slash. Lambert and Arnason (1989) reported that on land cleared from forest fallow in Belize, the biomass of herbaceous weeds was greater if the slashed vegetation had been retained than if it had been removed.

The emergence of about 3300 seedlings m^{-2} on the mulched plots gives an estimate of the seedbank in the 2 cm top soil under a two-year-old *C. odorata* fallow vegetation. This figure is rather high compared with the density of less than 1000 seedlings m^{-2} under an one-year-old fallow (Epp 1987) or with 1358 seedlings m^{-2} under a five-year-old fallow (Yadav & Tripathi 1981). This is explained by the seed production of *C. odorata*, increasing up to the third year after emergence and rapidly decreasing when growing older (Kushwaha *et al.* 1981). Moreover, the longer fallow period of the present study compared with Epp's example implies a supplementary seed crop, which accumulated in the soil and did not germinate under the vegetation canopy. The low seedling density in the example of Yadav & Tripathi is partly attributable to the few *C. odorata* plants in the sampled vegetation.

In contrast with their number and cover, the height of the emerged seedlings was not affected by removing, burning and intensively burning the slashed vegetation at clearing. When the vegetation was left in the field, seedlings were taller, probably because weeding had been carried out with a cutlass instead of a hoe. In general, seedlings of *C. odorata* appeared to develop rather slowly.

Cultivation treatments had no lasting effect on seedling cover. Weeding by a superficial soil tillage with a hoe did not change the effect of the preceding burning on the growth of *C. odorata* seedlings. Hence, contrary to expectations, hoe-weeding did not counteract the impact of burning. Moreover, the similar seedling cover at the end of the observation period in all the cultivation treatments suggests that one weeding did not exhaust the seed bank of *C. odorata*. The huge amount of seeds in the soil explains why this species appeared to be far less affected by weeding than woody species in forest and bush fallows.

At the end of the observation period, seedlings were more numerous but remained smaller when a crop was grown, indicating that the presence of the crop favoured seedling emergence or survival after emergence, but impaired subsequent growth. Presumably the shade provided by the maize plants kept the top centimetre of soil moist but reduced radiation. According to Yadav & Tripathi (1981), seedling mortality during the growing season is the result of keen competition for resources They stress its importance in the population dynamics of *C. odorata*, reporting that six months after emergence only 11% of the seedlings were still present on a five-year-old fallow vegetation in northeastern India. In the final analysis, *C. odorata* seedlings cannot be considered as a weed problem in maize, as they remained small irrespective of the cultivation treatment. This finding was confirmed in discussions with local farmers. In a bush fallow system in Benin, farmers did not consider *C. odorata* as a serious weed either, because it developed slowly during the period maize was sensitive to weed growth (Lutzeyer 1991).

8.4.3 Conclusions

Burning the slashed *C. odorata* fallow vegetation at clearing reduced the number of *C. odorata* seedlings that emerge and thus the seedling cover during cropping. Burning also killed some of the stumps and delayed the development of shoots on living stumps of this species. Intensive burning had the same effect on seedling growth but was more effective in suppressing sprouting. Retaining the slashed vegetation as a mulch favoured seedling growth instead of controlling it. Hoe-weeding drastically reduced the growth of shoots, while the impact of weeding with a cutlass was far less pronounced. In the presence of maize plants, *C. odorata* seedlings developed slowly and stayed small, whereas the growth of shoots was not affected. These findings indicate that only *C. odorata* stumps are likely to compete with the maize plants. Burning seems an appropriate clearing method to restrict the weed potential of stumps adequately during the early stages of the cropping season. It is unlikely that shoots will become a threat to a quick-growing crop like maize at a later stage. Because of its serious impact on shoot growth, hoe-weeding hampers the regrowth of the fallow vegetation after cropping. For this reason. it is worth considering the use of a cutlass instead of a hoe to slash back *C. odorata* shoots.

Chapter 9

The effect of cultivation practices on the re-establishment of the *Chromolaena odorata* fallow vegetation subsequent to cropping

9.1 Introduction

9.1.1 Research objectives

The re-establishment of the fallow vegetation is an important phase in the fallow-cropping cycle. There are three main reasons why a quick re-establishment is desirable. Firstly, when the vegetation rapidly covers the soil, losses due to erosion and leaching are reduced. Secondly, the quick re-establishment implies a rapid increase in biomass and thus in accumulated nutrients. Thirdly, it reduces the development of undesirable plant species like grasses. In short, when the re-establishment is quick, the fallow period can be short.

In this chapter the effects of cultivation practices on the re-establishment of the *C. odorata* fallow vegetation are analysed. In combination with information on the development of this vegetation (Chapter 4) and on the effect of cultivation practices on the regrowth of *C. odorata* during cropping (Chapter 8), these results provide a broad understanding of the way *C. odorata* grows and how its growth can be manipulated. The re-establishment was studied during the first four months after the previous crop had been harvested.

9.1.2 Literature review

The re-establishment of forest and bush fallows, and in particular the successional patterns governing this process, has been studied widely. According to Kellman (1980) the re-establishment is disturbed or delayed by intensive cultivation. Herbaceous seeds which arrive from outside are able to establish because the regrowth covers the ground more slowly. They may dominate under conditions of more intensive agriculture because of their short life cycle and high seed production.

In the regrowth of bush fallows in Peru (Staver 1991) and northeastern India (Saxena & Ramakrishnan 1984b) the biomass and density of herbaceous species increased when the previous fallow period was reduced from over ten to six years or less. In the Taï region, the regrowth of a cleared six-year-old forest fallow contained very few trees during the initial stage of re-establishment (de Rouw 1991a, 1995). Studies of the re-establishment of forest fallows in Taï (de Rouw 1991a, 1993) and Venezuela (Uhl *et al.* 1982b) confirm that burning reduces the development of woody plants in the regrowth, as postulated by Kellman (1980). Weeding during cropping reduced the biomass and numbers of woody plants in the regenerating bush fallow in Peru (Staver 1991) as well as in forest fallows in Taï (de Rouw 1991a, 1993) and Venezuela (Uhl *et al.* 1982a). Application of P or NPK fertilizer enhanced the regrowth of herbaceous plants when the fallow vegetation was re-establishing in forest clearings (Harcombe 1977, Nicholson 1981, Uhl 1987). Harcombe reported that stimulating the regrowth of forbs suppressed the development of shrubs and trees, thus retarding the succession. Prolonged cropping generally reduces the development of woody species while favouring that of herbaceous species. In the regrowth of a bush fallow in Peru, the biomass of herbs increased whereas that of woody species dropped when the cropping period was extended from one to two years (Staver 1991). On land cleared from forest fallow in Venezuela, cropping for six years instead of for three resulted in a drop in the number of species and in the density of trees, and to a lesser degree, in a drop in biomass (Uhl 1987). In the forest fallow system in the Taï region, the regrowth was increasingly delayed by prolonging the cropping period from one to three years (de Rouw 1991a).

9.2 Materials and methods

9.2.1 Site selection and experimental design

The effects of various cultivation practices on the re-establishment of the fallow vegetation subsequent to cropping were studied on Fields I, II, V and VI previously used for crop experiments (Chapters 5 to 8). The practices studied were the length of the fallow period prior to cropping, clearing method, weeding frequency, fertilizer application and the length of the cropping period. The experimental design and the number of replicates on the fields were as for the crop experiments (see Appendix II), except for Field II where four replicates were used instead of five.

9.2.2 Sampling of the fallow vegetation and data processing

The re-establishment of the fallow vegetation was studied by sampling the vegetation in November 1992, about four months after the most recent crop had been harvested. Five categories of plants were distinguished: shoots of *C. odorata*, shoots of other woody species, *C. odorata* seedlings, forbs and grasses. Samples were taken from the upper and lower strata of the fallow vegetation. The upper stratum consisted of shoots of *C. odorata* and other woody species, and they were sampled in each of the 20 m^2 plots of the crop experiments. They were cut off just above the ground and weighed. In a subsample, shoots were subsequently separated into leaves and branches. Both fractions were weighed and re-sampled. Simultaneously with cutting, the numbers of sprouting stumps of *C. odorata* and other woody species were recorded. Seedlings of *C. odorata*, forbs and grasses, forming the lower stratum in the fallow vegetation, were sampled in quadrats of 2 m^2 which were laid out in the centre of each plot. The seedlings were cut off at ground level, weighed and sampled. To determine the dry weight, all vegetation samples were dried at 70°C for 24 hours.

The effects of clearing methods, weeding frequency and fertilizer application were studied on various fields differing in the intensity of other cultivation practices implemented. The influence of the length of the preceding fallow period was examined by comparing the re-establishment of Fields II and V, laid fallow for respectively two and four years. The effect of extending the cropping period was analysed by separately comparing the re-establishment after one and three seasons, and that after three and five seasons. This distinction into two stages of prolonged cropping was made to compare plots in which the same clearing and crop management treatments had been implemented. An overview of the vegetation samples used to examine the effects of the cultivation practices on the re-establishment of the fallow vegetation is presented in Appendix IV. The effects of cultivation practices were tested by analysis of variance. Similar results were obtained when data transformed to logarithmic values were tested, so those results will not be presented.

9.3 Results

9.3.1 Length of the previous fallow period

The length of the preceding fallow period had no significant (P=0.05) influence on the total dry weight of the re-establishing fallow vegetation (Table 9.1). The dry weight of the various components of the vegetation seemed to be affected, although differences were not significant (P=0.05) either. Shortening the previous fallow period from four to two years reduced the dry weights of *C. odorata* and forbs, whereas the dry weights of grasses and other woody species increased. The densities of *C. odorata* stumps and seedlings also dropped. The decrease of the latter density was statistically significant. The effects of length of the fallow period and weeding frequency on the density of *C. odorata* stumps showed a significant interaction (P<0.05). After four years of fallow significantly more stumps were eliminated by an extra weeding than after two years. As a result, stump densities on plots weeded twice per season were the same in both fields.

Table 9.1 Regrowth of the *C. odorata* fallow vegetation four months after the harvest of the third successive crop in relation to the length of the preceding fallow period

Field Preceding fallow period (yr)	II 2	V 4	LSD(5%)
Dry weight (t ha^{-1})			
Total vegetation	4.17	4.09	ns
C. odorata shoots	0.59	0.81	ns
Other woody spp.	0.92	0.77	ns
Forbs	1.31	1.80	ns
Grasses	1.24	0.38	ns
C. odorata seedlings	0.12	0.32	ns
Plant density (no. m^{-2})			
C. odorata stumps	1.0	1.7	ns
Other woody spp.	2.9	1.6	ns
C. odorata seedlings	17.6	41.8	18.8

Averages of all weeding frequencies and fertilizer treatments of plots burnt at clearing

9.3.2 Clearing method

Burning reduced the dry weight of *C. odorata* shoots on the fallow plots of Field VI significantly, but it raised the dry weight of other woody species (Table 9.2). On the cropped plots of Field VI and on Field II, however, clearing methods had no significant (P=0.05) effect on the dry weight of the re-establishing fallow vegetation. Burning significantly reduced the density of *C. odorata* stumps on the fallow plots and on the cropped plots of Field VI. On the latter plots, removal of the slashed fallow vegetation also reduced the density of *C. odorata* stumps but increased seedling density of that species.

Table 9.2 Effect of clearing methods used prior to cropping on the re-establishment of the *C. odorata* fallow vegetation four months after the last harvest on two fields with different length of the cropping period and cultivation treatments

Field	VI					VI					II			
Cultivation treatment	fallow					cropped					cropped			
Cropping period	0 season					1 season					3 seasons			
Clearing method[a]	M	R	B	I	LSD(5%)	M	R	B	I	LSD(5%)	R	B	I	LSD(5%)
Dry weight (t ha^{-1})														
Total vegetation	9.86	8.71	7.73	7.30	ns	4.83	3.90	3.81	3.72	ns	4.65	4.17	3.88	ns
C. odorata shoots	9.44	7.71	5.43	4.72	2.18	2.86	1.17	2.27	2.03	ns	0.92	0.59	0.32	ns
Other woody spp.	0.16	0.05	0.56	0.62	0.47	0.26	0.34	0.15	0.25	ns	1.19	0.92	1.09	ns
Forbs	0.17	0.33	0.22	0.54	ns	0.40	0.80	0.36	0.60	ns	1.05	1.09	1.08	ns
Grasses	0.05	0.54	1.44	1.38	ns	0.67	0.93	0.66	0.42	ns	1.27	1.24	1.34	ns
C. odorata seedlings	0.06	0.08	0.08	0.03	ns	0.64	0.67	0.32	0.41	ns	0.21	0.12	0.17	ns
Plant density (no. m^{-2})														
C. odorata stumps	18.2	16.0	6.2	4.3	7.7	9.6	2.8	3.6	1.7	2.9	2.0	1.0	0.6	ns
Other woody spp.	1.5	1.2	1.5	3.1	ns	0.9	0.8	1.1	2.6	ns	3.0	2.9	3.8	ns
C. odorata seedlings	151.3	88.7	62.2	10.9	ns	305.4	767.8	244.1	136.8	392.0	41.8	17.6	20.6	ns

On both fields the preceding fallow period was two years

Underlined LSD values at P<1%

[a] Mulching, Removing, Burning and Intensive Burning the slashed fallow vegetation

The large dry weight of grasses on the burnt fallow plots of Field VI was mainly due to the presence of some big tussocks of *Rottboelia exaltata* in the samples. This coarse grass was not evenly distributed in the field, so its presence disturbed the real effects of clearing methods on grass development. When data from the plots containing this species were excluded, average grass dry weight was 494 kg/ha on the burnt plots and 437 kg/ha on the intensively burnt plots.

9.3.3 Weeding frequency

Weeding twice instead of once per season significantly reduced dry weights of the total vegetation, *C. odorata* shoots, and forbs, as well as the number of *C. odorata* stumps (Table 9.3). The dry weight of *C. odorata* seedlings increased when weeding was carried out more frequently, whereas their density did not show a clear change. The dry weight of grasses was not affected by weeding frequency.

Table 9.3 Effect of weeding frequency during cropping on the re-establishment of the *C. odorata* fallow vegetation four months after the last harvest on three fields with different length of the preceding fallow period, length of the cropping period and clearing method

Field	II			V			I		
Preceding fallow period	2 years			4 years			0 years		
Cropping period	3 seasons			3 seasons			5 seasons		
Clearing method	Removing, Burning, Intensive burning			Burning			Removing		
Weeding frequency	1	2	LSD(5%)	1	2	LSD(5%)	1	2	LSD(5%)
Dry weight (t ha^{-1})									
Total vegetation	4.73	3.73	<u>0.53</u>	4.98	3.21	<u>1.40</u>	4.59	3.69	<u>0.56</u>
C. odorata shoots	1.00	0.22	<u>0.36</u>	1.38	0.24	<u>0.66</u>	0.06	0.01	<u>0.04</u>
Other woody spp.	1.09	1.04	ns	0.82	0.73	ns	1.01	0.62	0.37
Forbs	1.23	0.99	ns	2.11	1.49	ns	2.60	1.86	0.59
Grasses	1.28	1.28	ns	0.36	0.40	ns	0.90	1.11	ns
C. odorata seedlings	0.12	0.21	0.06	0.30	0.35	ns	0.01	0.10	<u>0.06</u>
Plant density (no. m^{-2})									
C. odorata stumps	1.8	0.6	<u>0.7</u>	2.8	0.6	<u>1.2</u>	0.1	0.0	<u>0.1</u>
Other woody spp.	3.0	3.5	ns	1.6	1.6	ns	1.0	1.5	ns
C. odorata seedlings	25.5	27.8	ns	47.5	36.1	ns	13.3	18.9	ns

Underlined LSD values at P<1%

9.3.4 Fertilizer application

Application of N and P stimulated the re-establishment of the fallow vegetation (Table 9.4). Dry weights of *C. odorata* shoots and forbs increased when P was given, although the changes were not significant in all cases. Dry weights of *C. odorata* seedlings and grasses were not significantly affected by fertilizer application. The composition of the vegetation changed as a result of differences in reaction to fertilizer application. On land cleared from a two-year-old fallow (Field II) for example, application of P raised the proportion of *C. odorata* shoots in the total dry weight from 11% to 17% and the proportion of forbs from 21% to 34%. Meanwhile the proportions of other woody species dropped from 29% to 22% and that of grasses fell from 34% to 24%. When both N and P were applied, the proportions returned to values similar to those on the unfertilized plots.

On Field II cleared from a two-year-old fallow, fertilizer application and weeding frequency showed a significant interaction ($P<0.05$) on dry weights of *C. odorata* shoots and grasses (not presented in Table). Application of P raised *C. odorata* dry weight and reduced grass dry weight on plots weeded once per cropping season, but not on plots weeded twice.

9.3.5 Length of the cropping period

Extending the cropping period from one to three seasons and from three to five seasons did not significantly affect the total dry weight of the re-establishing fallow vegetation (Table 9.5). The dry weights of *C. odorata* shoots and seedlings as well as the densities of *C. odorata* stumps and seedlings dropped with prolonged cropping. The dry weights of forbs and grasses increased when the cropping period was extended, although this increase was only significant for forbs in the second stage of prolonged cropping. The dry weight and density of other woody species were higher on the field cropped during three seasons than on those cropped during one or five seasons. The interaction between extending the cropping period from three to five seasons and weeding frequency was significant ($P<0.05$). On the field cropped during three seasons, a second weeding reduced shoot dry weight and stump density of *C. odorata* more drastically than on a field cropped during five seasons ($P<0.05$). On the other hand, it gave a more pronounced increase in seedling dry weight of the same species on the field cropped during three seasons than on the field cropped during five seasons. The interaction between extending the cropping period from one to three seasons and clearing methods was not significant ($P=0.05$). The data selected to study the effect of prolonged cropping did not allow interactions

Table 9.4 Effect of fertilizer application during cropping on the re-establishment of the *C. odorata* fallow vegetation four months after the last harvest on three fields with different length of the preceding fallow period, length of the cropping period and clearing method

Field	II				V				I			
Preceding fallow period	2 years				4 years				0 years			
Cropping period	3 seasons				3 seasons				5 seasons			
Clearing method	removing, burning, intensive burning				burning				removing			
Fertilizer application	0	P	NP	LSD(5%)	0	P	NP	LSD(5%)	0	P	NP	LSD(5%)
Dry weight (kg ha^{-1})												
Total vegetation	3.86	4.59	4.24	0.48	3.42	4.40	4.45	ns	3.22	4.80	4.40	0.68
C. odorata shoots	0.48	0.86	0.50	0.33	0.45	0.84	1.15	ns	0.04	0.03	0.05	ns
Other woody spp.	1.12	0.99	1.08	ns	0.87	0.60	0.86	ns	0.70	0.89	0.85	ns
Forbs	0.77	1.47	1.09	0.53	1.26	2.28	1.86	ns	1.49	2.92	2.27	0.98
Grasses	1.31	1.12	1.42	ns	0.51	0.36	0.27	ns	0.95	0.92	1.16	ns
C. odorata seedlings	0.19	0.15	0.16	ns	0.33	0.32	0.32	ns	0.06	0.04	0.07	ns
Plant density (no. m^{-2})												
C. odorata stumps	1.0	1.6	1.0	ns	1.1	1.9	2.1	ns	0.1	0.0	0.0	ns
Other woody spp.	3.3	3.2	3.2	ns	1.7	1.6	1.7	ns	1.2	1.3	1.3	ns
C. odorata seedlings	33.3	28.5	18.3	12.0	46.7	39.9	38.8	ns	19.3	21.2	7.9	10.9

Underlined LSD values at P<1%

between length of the cropping period and weeding frequency or fertilizer application to be identified during the first stage of prolonged cropping (see Appendix IV). The same is true for the interaction between length of the cropping period and clearing method during the second stage.

Table 9.5 Re-establishment of the *C. odorata* fallow vegetation four months after the last harvest in relation to the length of the cropping period for two stages of prolonged cropping

	Stage A			Stage B		
Field	VI	II		II	I	
Cropping period (seasons)	1	3	LSD(5%)	3	5	LSD(5%)
Dry weight (t ha^{-1})						
Total vegetation	3.81	4.24	ns	4.65	4.14	ns
C. odorata shoots	1.85	0.71	0.87	0.92	0.04	0.44
Other woody spp.	0.26	1.14	0.46	1.19	0.81	0.35
Forbs	0.59	0.83	ns	0.55	2.23	0.80
Grasses	0.63	1.41	ns	1.27	1.01	ns
C. odorata seedlings	0.48	0.14	0.28	0.21	0.06	0.10
Plant density (no. m^{-2})						
C. odorata stumps	2.6	1.4	1.0	2.0	0.1	1.1
Other woody spp.	1.5	3.0	ns	3.0	1.3	1.2
C. odorata seedlings	391.1	34.0	220.6	41.8	16.1	21.9

Underlined LSD values at P<1%

Stage A weeding frequency: one weeding per season
fertilizer application: zero
clearing method: removing, burning and intensively burning the slashed fallow vegetation
preceding fallow period: two years

Stage B weeding frequency: one and two weedings per season
fertilizer application: zero, P, NP
clearing method: removing the slashed fallow vegetation
preceding fallow period: two years (Field II) and zero years (Field I)

When comparing both stages of prolonged cropping, it should be remembered that the data refer to different clearing methods and to different weeding frequencies and fertilizer applications (see Appendix IV). Changes in dry weight and densities in both stages suggest that in an early stage of prolonged cropping the seedling density of *C. odorata* dropped, followed by a decrease in stump density in a later stage. After five cropping seasons, the dry weight of *C. odorata* seedlings was higher than that of the shoots, whereas the dry weight of *C. odorata* shoots was no longer increased by the fertilizer application (Table 9.4).

9.4 Discussion and conclusions

Shortening the fallow period in the *C. odorata* fallow system from four to two years led to the density of this species decreasing and to grasses becoming more important. At the start of the last cropping season there were already fewer sprouting stumps on the field cleared from a younger fallow, presumably because fewer seeds had accumulated, given that the seed output of *C. odorata* peaks in the third year of its development (Kushwaha *et al.* 1981). This finding indicates that the effect of shortening fallow periods on the re-establishment of the vegetation depends on the juvenile period of the dominant species in the vegetation.

Clearing methods hardly affected the regrowth of the fallow vegetation after cropping. Only on plots laid fallow immediately after clearing did burning have a negative effect on the development of *C. odorata* shoots. This shows that the effects of clearing on the re-establishment of the fallow vegetation are overruled by the effects of cropping. Retaining the slashed fallow vegetation instead of removing or burning it at clearing resulted in a higher density of *C. odorata* stumps after cropping. This effect, also observed during the cropping period (see Table 8.3), is presumably attributable to the weeding equipment, and not to the clearing method. On the mulched plots, weeding was carried out with a cutlass, whereas the other plots had been weeded with a hoe (Chapter 8). Recurrent clearing followed by growing crops on a plot cleared from a two-year-old fallow had a negative impact of the development on *C. odorata* shoots and seedlings, whereas it stimulated the development of grasses and forbs.

In the present study, the effect of burning was small compared to that obtained on forest clearings. Probably burning of the slashed *C. odorata* vegetation lasted shorter and was less intensive because of the limited mass involved. Another hypothesis is that prior to clearing the *C. odorata* fallow vegetation was already composed of more resistant woody species, because the fields had been frequently cropped before the experiments started. Lutzeyer (1991) also reported that frequent burning had led to the bush fallow vegetation in southern Benin shifting towards fire-resistant woody species.

Weeding twice per cropping season instead of once checked the development of *C. odorata* shoots not only during the cropping period (Chapter 8), but also in the subsequent period of re-establishment. Uprooting of stumps when hoe-weeding is probably the main cause of this check, as both shoot dry weight and stump density were affected. On the other hand, *C. odorata* seedlings tended to develop into bigger plants in the frequent weeding regimes; the dry weight of seedlings increased whereas their density hardly changed. Possibly, weeding also reduced competition from plants other than *C. odorata* stumps. Presumably, the huge amount of *C. odorata* seeds in the soil enables this species to emerge in large numbers even after frequent weeding. Two weedings instead of one reduced the proportion of trees and shrubs in the dry weight of the total vegetation. A study on the mechanical control of *C. odorata* in natural grasslands in the Philippines showed that two slashings in one year reduced the biomass of the species by 50% (Castillo *et al.* 1980).

Fertilizer application increased the total dry weight of the re-establishing fallow vegetation. The composition of the vegetation changed when P was applied, as this element mainly enhanced the development of forbs and *C. odorata* shoots. A similar effect on the developments of forbs has reported in the literature (see Section 9.1.2). Giving N plus P did not have an uniform effect on the composition of the vegetation in the fields of this study.

Extension of the cropping period made grasses and forbs more important in the re-establishing vegetation, probably because it restricted the development of *C. odorata.* The vegetation also contained more hardy species like the forbs *Synedrella nodiflora, Erigeron multiflora* and *Borreria intricans*, and the woody species *Combretum* spp., *Clerodendrum* spp., *Milletia zechiana* and *Griffonia simplicifolia*. The results suggest that prolonged cropping first depletes the stock of seeds, and then exhausts stumps. It is unlikely that soil fertility plays a predominant role in the re-establishment of *C. odorata* as on frequently cropped plots this species no longer responded to fertilizer application.

Large differences in dry weight and density of vegetation components were not always significant, in particular when comparing the re-establishment between fields. This is particularly true for grasses and to a lesser extent for forbs and other woody species. The occurrence of these components was heterogeneous; probably there were too few replicates per field to be able to examine the effect of cultivation practices on their regrowth accurately.

In general, the effects of cultivation practices on the re-establishment of the *C. odorata* fallow vegetation were similar to those reported on other bush fallows and on the forest fallows.

Summarizing: shortening the fallow period, more intensive clearing, weeding twice instead of once and extending the cropping period all have a negative effect on the initial re-establishment of the *C. odorata* fallow vegetation. These practices restrict the stump development and reduce seedling numbers of *C. odorata*, while favouring the growth of grasses and forbs. The re-establishment of the fallow vegetation is hampered more by frequent weeding than by a more intensive method of clearing, as the effects of clearing are overruled by those of cropping. Prolonged cropping is more detrimental to the regrowth of *C. odorata* than shortening the fallow period. Fertilizer application, on the other hand, stimulates the regrowth of *C. odorata* and forbs. For these reasons, cropping periods in a fallow system based on *C. odorata* should not exceed three seasons and weeding should be carried out only once or with a tool which causes little damage to the *C. odorata* stumps.

Chapter 10

The *Chromolaena odorata* fallow system in perspective

10.1 Introduction

In this final chapter, the role of the *C. odorata* fallow in the present and future cropping systems is discussed in the context of increasing intensity in land use. On the chemically poor soils in the lowlands of the humid tropics, intensive land use is generally accompanied by declining nutrient availability and serious weed competition, resulting in poor yields and the degradation of the ecosystem. For these reasons, the research results presented in this thesis are evaluated in terms of productivity and sustainability. Sustainability is considered the successful management of natural resources for agriculture to satisfy present and future human needs without degrading the environment or the natural resource base on which agriculture depends (TAC 1989). Here, only the ecological aspects of sustainability are taken into account. First, the prevailing *C. odorata* fallow system is compared with the traditional shifting cultivation. Secondly, the effects of more intensive land use and improved management practices are discussed. Finally, the prospects of the *C. odorata* fallow system are considered and recommendations for its technological improvement are presented.

10.2 The *Chromolaena odorata* fallow system: an indicator of land use intensity

In the traditional shifting cultivation of the Taï region, one rice crop is followed by more than sixteen years of fallow. This cropping system is under increasing pressure because of a rapid deforestation. Immigrant farmers, who were the first to run out of forest, started to clear land from *C. odorata* fallow instead of forest fallow to grow food crops. They often rent young fallows overgrown with *C. odorata* from the indigenous farmers on which they grow one maize crop and on which they return after three years of fallow, thus developing a cropping system with a short-duration fallow. This change in cropping system illustrates how farmers attempt to intensify crop production by shortening the fallow period. Generally, weed competition is enhanced and nutrient availability decreases when the fallow period in shifting cultivation is reduced. In the *C. odorata* fallow system, non-crop plants occur abundantly during the cropping period. So far there have been no reports of obvious symptoms of nutrient deficiency. Farmers obtain about 1.8 t of maize grain ha^{-1}, which is considered a reasonable yield under these conditions (Chapter 3). This fallow system requires more labour for weeding than the traditional shifting cultivation, but clearing takes less effort. To reduce the need for weeding labour, farmers carefully select the site, phase clearing and planting, and plant a fast-growing crop like maize instead of rice. Peaks in labour requirements are met by a flexible labour division between men and women.

The fallow periods in the *C. odorata* fallow system are considerably shorter than those in shifting cultivation but crop yields change little, suggesting that weed control measures and the availability of nutrients are adequate for crop production. This study proved that the development of *C. odorata*, i.e. the main non-crop species during the cropping period, was adequately controlled by the current farmers' practices. Burning the slashed fallow vegetation prior to cropping killed a large number of *C. odorata* seeds and a considerable number of its stumps, and delayed the sprouting of stumps (Chapter 8). One hoe-weeding in the first month after burning set back shoot development seriously and was generally enough to reduce weed competition in maize such that yields were not affected (Chapters 5 and 7). The relatively low incidence of other weed species can be attributed to the specific characteristics of *C. odorata* (Chapter 4). Its enormous seed bank, the competitive ability of seedlings and the ability of stumps to sprout result in the rapid and uniform soil cover and in a rapid development of the fallow vegetation, thereby preventing other weed species entering from elsewhere to establish and quickly smothering any weeds already present in the vegetation.

Burning released a considerable part of the nutrients stored in the *C. odorata* fallow vegetation (Chapter 6). Results suggest that a larger proportion of the accumulated P was released than in shifting cultivation, because the *C. odorata* vegetation is almost completely burnt, whereas in a forest vegetation many stems and branches are hardly touched by the fire (Lambert & Arnason 1986, van Reuler & Janssen 1993a). The role of burning for releasing P is important, given that it is the element most limiting crop production on the well-drained soils in the Taï region (van Reuler & Janssen 1989).

To illustrate changes in productivity and sustainability in the transition from shifting cultivation to the *C. odorata* fallow system, data from an experiment laid out on a four-year-old *C odorata* fallow are compared with those on a twenty-year-old forest fallow reported in a study by van Reuler & Janssen (1993a,b) (Table 10.1). The data of the traditional shifting cultivation with rice of the Taï region are used, because there are few detailed data sets of shifting cultivation with maize as main crop, and they often refer to very different ecological conditions. Obviously, the productivity of land use, expressed as mean yield per year of the entire fallow-cropping cycle, is higher in the *C. odorata* fallow system than in the shifting cultivation system, because the fallow period is considerably shortened.

Table 10.1 Comparison of crop production in shifting cultivation and the *C. odorata* fallow system in the Taï region

Parameter		Shifting cultivation[a]		*C.odorata* fallow system	
Main crop		rice		maize	
Fallow period (yr)		20		4	
Fallow vegetation					
dry weight ($t\ ha^{-1}$)		117		22	
nutrient content ($kg\ ha^{-1}$)	N	542		145	
	P	13		8	
	K	201		128	
Soil (0-20 cm)					
nutrient content ($kg\ ha^{-1}$)	N_{total}	2282		2320[b]	
	$P_{extr.}$	nd[c]		25	
	$K_{exch.}$	94		180	
Crop yields ($t\ ha^{-1}$)					
first crop (first year, early season)		1.72		3.82	
second crop (first year, late season)		1.42[d]		1.61	
third crop (second year, early season)		1.24		1.45	
Productivity in system with one crop ($t\ ha^{-1}y^{-1}$)[e]		0.09		0.96	
Nutrient uptake in grains of first crop (in $kg\ ha^{-1}$, and in % of total uptake)	N	20.3	(36)	43.9	(62)
	P	1.9	(58)	6.1	(78)
	K	3.3	(51)	11.3	(17)

[a] source: van Reuler & Janssen (1993a,b)

[b] calculated on basis of organic matter content, assuming a C:N ratio of 18, as found in the soil under the shifting cultivation system (van Reuler & Janssen 1993a,b)

[c] available P not determined; in other plots under forest fallow it varied between 6 and 16 kg ha^{-1} (van Reuler & Janssen, in prep. a)

[d] second crop was maize

[e] the calculated productivity is based on a total fallow-cropping cycle of 20 years for shifting cultivation and of 4 years for the *C. odorata* system, because the crops occupy the land for a few months only and are just weeded once

The indicators of sustainability considered in this comparison between both cropping systems are the nutrient content of the vegetation-soil system, the species diversity of the fallow vegetation, and the changes in crop yields over time. The forest fallow vegetation contained more nutrients than the *C. odorata* vegetation, but the reverse was true for the amounts of available nutrients in the topsoil (Table 10.1). More nutrients were exported with crop harvest in the *C. odorata* fallow system than in the shifting cultivation system, implying increased losses of nutrients and hence a decline in soil fertility in the long term. However, the nutrient content of the vegetation-soil system of both cropping systems hardly differs, suggesting that losses of nutrients are similar so far. Although not studied, it is assumed that species diversity in the *C. odorata* fallow vegetation was less than that in the forest vegetation, as indicated by de Rouw (1991a,b). The reason is that many tree species have disappeared in the strongly *C. odorata*-dominated fallow vegetation and relatively few herbs were able to invade. Consequently, it will take many years for a forest vegetation to re-establish on a *C. odorata* fallow. The change in crop yields over seasons is greatest in the *C. odorata* fallow system, suggesting that four years of fallow improve conditions for crop production for a short period only. Summarizing: changing from shifting cultivation to the *C. odorata* fallow system enhances productivity while the effect on sustainability were limited up to now. However, it is probable that conditions for crop production will degrade in the long term. It should be remembered that this study lasted four years only, which is too short to assess the sustainability of land use in the *C. odorata* fallow system properly.

The results presented in Chapters 5 and 9 indicate that one cropping followed by three years of fallow is an adequate land-use intensity for a reasonable crop yield and rapid re-establishment of the fallow vegetation. The increasing population pressure, however, encourages a further intensification of land use in the *C. odorata* fallow system. Experiments showed that more intensive land use by changing fallow and cropping periods, and other practices aimed at improving productivity, such as intensive burning, extra weeding and fertilizer application, affected both crop yield and the re-establishment of the *C. odorata* fallow vegetation (Table 10.2.).

Shortening the fallow period reduced the yield of the first crop after clearing because weed competition increased slightly and fewer nutrients were available for the crop (Chapter 5). These effects are attributed to the incomplete suppression of herbaceous species and poor elimination of their seed stock in this short period, and to the slight and incomplete burning as result of the small biomass of the fallow vegetation. Shortening the fallow period also slowed down the re-establishment of the fallow vegetation (Chapter 9). Intensified burning by addition of extra slashed vegetation

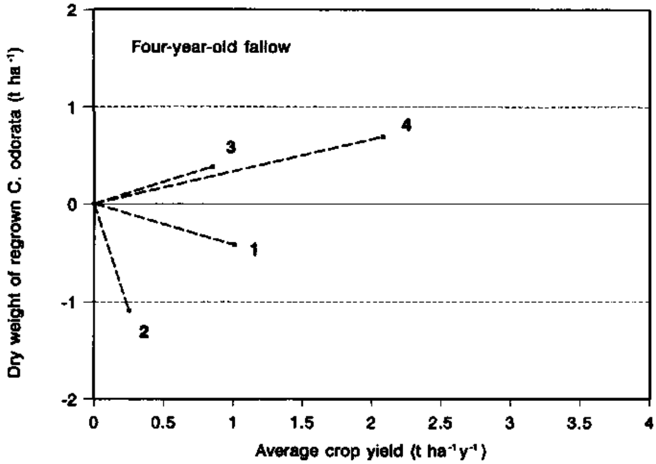
Table 10.2 Qualitative overview of the effects of more intensive cultivation practices on factors affecting crop yield and re-establishment of the fallow vegetation in the *C. odorata* fallow system

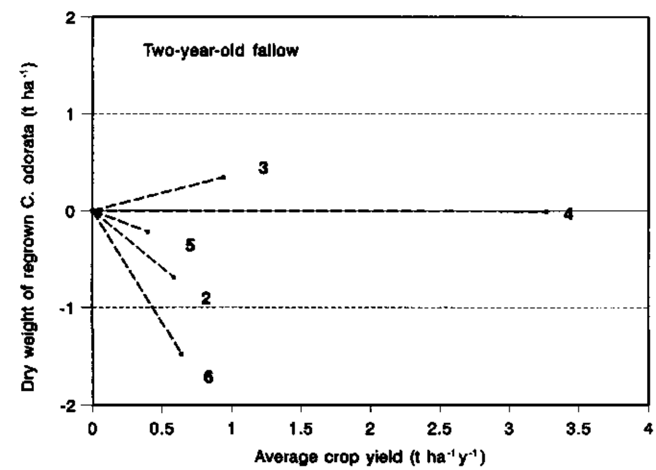
	Crop yield		Re-establishment of *C. odorata*	
Cultivation practice	Weed competition	Nutrient availability	Seedling growth	Shoot growth
Shorter fallow period	+	-	-	-
Intensive burning	±	+	-	-
Extra weeding	-	±	±	-
Fertilizer application	±	+	±	+
Extended cropping period	±	-	-	-

positive (+), negative (-) and no clear (±) effects

on the land cleared from a two-year-old *C. odorata* fallow, slightly increased the availability of nutrients and the crop yield, but hampered the re-establishment more severely than normal burning (Chapter 6,8,9). Leaving the slashed fallow vegetation as a mulch on the field slightly reduced crop yield but resulted in a better re-establishment. An extra hoe-weeding increased crop yield on a cleared young fallow only (Chapters 5,6,7). On the other hand, it seriously restricted the re-establishment of the fallow vegetation on all fields (Chapter 9). Application of fertilizers (P or N and P) strongly increased crop yields and also favoured the re-establishment of the fallow vegetation (Chapters 5,6,7,9). This clearly demonstrates the considerable scope for improvement by raising the availability of P and N, notwithstanding the reasonable yield farmers obtain without applying fertilizers. Extending the cropping period from one to three seasons reduced crop yields. This yield decline was partly attributable to lower nutrient availability, but not to increased weed competition. After four successive crops, yields had fallen to a level that made further cropping not worthwhile. Growing a second maize crop during the late season, also a form of extending the cropping period, was not very suitable given that radiation is lower and the rainfall is more irregular than in the early season. In general, extending the cropping period beyond one year sharply curtailed the re-establishment of the fallow vegetation, as stumps and seedlings of *C. odorata* were eliminated.

The effects of the various practices for more intensive cultivation on the complete fallow-cropping cycle are evaluated by considering the differences in productivity and sustainability of land use (Figure 10.1). The dry weights of *C. odorata* seedlings and shoots in the re-establishing fallow vegetation are used as indicators of sustainability. They serve as a qualitative measure for the development of the fallow vegetation. In Figure 10.1, the origin represents the productivity and *C. odorata*





1: shorter fallow period; averages over weeding and fertilizer treatments
2: extra weeding; averages over fertilizer treatments
3: P application; averages over weeding treatments
4: NP application; averages over weeding treatments
5: intensive burning; averages over weeding and fertilizer treatments
6: extending the cropping period: on plots which were weeded once and did not receive fertilizers

Fig. 10.1 Relationship between changes in average maize yield per year of the complete fallow-crop cycles and changes in the dry weight of *C. odorata* regrowth resulting from more intensive cultivation practices on experimental fields cleared from a four-year-old and a two-year-old fallow respectively regrowth in the farmers' version of the practice considered, averaged over all versions of the other practices. An increase in dry weight of the *C. odorata* implies that the intensive practice favours sustainability, whereas a decrease in dry weight indicates that it makes the cropping system less sustainable. Most practices of intensive cultivation raised the productivity at the expense of the re-establishment and thus of the sustainability.

Only the strategy of increasing the availability of nutrients by fertilizer application improved both parameters. On a four-year-old fallow, shortening the fallow period was more favourable than extra weeding because an unit increase in mean yearly crop yield per hectare resulted in a relatively small decrease in the dry weight of the *C. odorata* regrowth. Moreover, it is relatively easy to shorten the fallow period and this does not require extra external inputs or important modifications in technology. This explains why farmers operating under conditions of low external input begin by shortening the fallow periods to intensify crop production. On the two-year-old fallow, extending the cropping period from one to three seasons resulted in a poor trade-off between productivity and re-establishment of the fallow vegetation. Intensively burning by adding vegetation biomass was not beneficial either, not even when the required extra land and labour are ignored. Clearly, the present trend to intensify crop cultivation in the *C. odorata* fallow system will inevitably endanger the sustainability of that system.

10.3 Role of the *Chromolaena odorata* fallow system in further agricultural development

The main reason farmers started to grow food crops on *C. odorata* fallow in the Taï region was the increasing shortage of forest resulting from the large-scale deforestation for growing cocoa and coffee. The cultivation of these perennial crops has to be taken into consideration when describing the prospects of the *C. odorata* fallow system for further increasing food production in the Taï region. A radical improvement in the present extensive cultivation practices of cocoa, coffee and food crops may reduce farmers' need for more land. However, no such an improvement is likely, because external support for farmers or potential markets for food crops - factors that triggered improved cultivation in eastern Ivory Coast (Chaléard 1988, Colin 1990) - are absent in the Taï region. For these reasons, deforestation for growing food crops, cocoa and coffee will continue, and so will the deterioration of cocoa plantations. Consequently, the area covered by *C. odorata* will expand. At the same time, more farmers will grow crops on cleared *C. odorata* fallows because they are running out of forest and because they will aim for food crop cultivation given the low present cash crop prices and the deterioration of cocoa. Therefore, the present trend of a more intensive use of the *C. odorata* fallow system is likely to continue.

In general, farmers respond to an increased demand for land by shortening the fallow period in upland cultivation. According to Ruthenberg (1980), farmers intend to keep fallow periods at least as long as cropping periods, because up to that point crop yields are considerably higher than those from permanent cultivation. Examples from central Zaïre (Fresco 1986) and southern Benin (Brouwers 1993) show that before changing to permanent upland cultivation, farmers are likely (1) to emigrate to sparsely populated areas, (2) to take up off-farm employment, (3) to intensify crop cultivation in the valley bottoms and (4) to develop permanent compound gardens in addition to upland crop cultivation in a fallow system. In the Taï region, farmers are generally still in the stage of intensifying upland cultivation. At the same time, however, they have already started wet-rice cultivation in valley bottoms and fish farming in village ponds. Emigration is not very likely in the near future, as farmers still have cash crops. Moreover, there are no attractive places to go to because most forests in Ivory Coast have been felled or designated as protected.

More intensive use of land in the *C. odorata* fallow system will result in the disappearance of *C. odorata* and the development of poor fallow vegetations dominated by grasses and some hardy shrubs (Chapter 9). These grasses cause a serious weed problem during cropping. The combination of a shorter fallow period, a limited capacity of these grasses to store nutrients and the more frequent cropping, means that soil fertility is likely to drop and as a consequence crop production will decrease in the long term. Interventions are needed to stop this trend.

Any intervention should require only small amounts of external inputs so that they can be readily adopted by the farmers, who generally have limited financial resources. Before considering such interventions, two questions need to be answered: What is the function of a short-duration fallow and how appropriate is *C. odorata* in that respect? In general, short fallow periods are inadequate to maintain the soil fertility given the limited time available for substantial addition of nutrients by asymbiotic N-fixation and the uptake of nutrients from the subsoil. The main contribution of a short-duration fallow is probably the rapid establishment of a vegetation cover after crop harvest, which prevents excessive weed growth and nutrient losses by erosion. Moreover, the fallow vegetation accumulates nutrients, thereby protecting them against leaching and concentrating them in topsoil at the start of the subsequent cropping period. Apart from that, short-duration fallows are useful compared with continuous cropping because they may interrupt the build-up of pests and diseases. The beneficial nature of short-duration fallows has been demonstrated in continuous cropping, using *Pueraria phaseoloides* (Sanchez & Benites 1987) or *Mucuna pruriens* (Koudokpon *et al.* 1994, Versteeg & Koudokpon 1993), and even in alley cropping (Kang *et al.* unpubl.).

C. odorata appears to be a suitable species for a short-duration fallow in cropping systems, provided that the fallow period is at least two years. It establishes spontaneously, it provides a rapid and uniform soil cover, it suppresses herbs within two years and it accumulates biomass and nutrients at a satisfactory rate (Chapter 4). Although not studied in this research, the symbiosis with mycorrhizae may have enhanced the establishment and growth of *C. odorata*, as found in greenhouse experiments (Boutros-Mikhail 1976, Diederichs 1983, Saif 1983). Plant components that have a nematicidal action (Litzenberger & Ho Ton Lip 1961, M'boob 1991) may also have contributed to the reasonable crop production obtained after clearing the *C. odorata* fallow. When fallow periods are reduced to one year or less, *C. odorata* gradually disappears and is replaced by less favourable grasses.

When identifying alternative fallow species, the length of the fallow period and plant characteristics should be taken into consideration. Leguminous shrubs have the great advantage of fixing N, which explains the higher yield of the subsequent crop compared with that after a natural vegetation in fallows up to three years (Clarke 1962, Gichuru 1991, ICRAF 1993). They may also surpass a natural fallow vegetation in improving the chemical properties of the topsoil (Juo & Lal 1977, Prinz 1986). On the other hand, they only thrive on soils which are not too acid or poor in P and N. Their establishment often requires sowing or planting, weeding, and sometimes inoculation with the appropriate Rhizobium strain (van der Meersch 1992, Ngiumbo & Balasubramanian 1992, Szott *et al.* 1994). Because of their slow initial development, leguminous shrubs are not capable of suppressing weeds during the early stage of fallowing. Given the extra labour needed for establishment, farmers are only likely to plant these species if they offer additional products like poles, fire wood or animal feed. In the Taï region, however, there has so far been no demand for these products. For all these reasons, leguminous shrubs are not considered appropriate alternatives for *C. odorata*.

If the fallow is reduced to one year or less, leguminous cover crops may become alternatives for the *C. odorata* fallow. Besides rapidly establishing a soil cover, they fix N, although this is not necessarily reflected in yield increases of the subsequent crop (Balasubramanian & Ngiumbo 1993, Balasubramanian & Sekayange 1992). On the other hand, they generally require weeding to establish a full soil cover.

Moreover, their spontaneous regrowth after clearing, in particular that of climbing types, hampers the crop. For these reasons, farmers are only likely to use these crops if they provide evident advantages in the short-term. Probably, a leguminous plant species is more attractive to them as second crop.

10.4 Merits of the *Chromolaena odorata* fallow system and recommendations for improvement

The *C. odorata* fallow system is a temporary intermediate stage in the transformation from shifting cultivation into permanent upland cultivation in the Taï region and plays an important role in food production. In this system a fast-growing crop like maize produces a reasonable yield without very high labour requirements. Contrary to the general opinion about the species, *C. odorata* is not a serious weed in a fallow system if appropriate cultivation practices are used. In this respect, the prevailing farmers' practices appear to be well adapted. On the other hand, this research has identified five constraints to a productive and sustainable cropping system on *C. odorata* fallow. First, farmers do not fully exploit the potential in the *C. odorata* fallow system, as they use traditional maize varieties with a low grain-stover ratio and low plant densities. Second, the prevailing weed control by hoe-weeding uproots *C. odorata* stumps thus seriously hampering the re-establishment of the fallow vegetation after cropping. Third, the restricted availability of phosphorus is a major growth limiting factor in the *C. odorata* fallow system. Fourth, nitrogen is also in short supply, in particular when phosphorus is more readily available through fertilizer application, and fifth, more intensive land use and more radical cultivation practices for increasing crop production result in the disappearance of *C. odorata* and the domination of grasses and sturdy forbs. Moreover, the present *C. odorata* fallow system speeds up the breakdown of the traditional shifting cultivation, because a major part of land with this fallow type is rented from the indigenous people.

To exploit the full potential of the *C. odorata* fallow system, a survey among farmers might reveal the criteria they use to select maize varieties and to decide on plant densities. This would enable potentially high-yielding varieties to be screened on these criteria, so that the most promising can be proposed to farmers. To reduce the negative effect of weeding on the re-establishment of the *C. odorata* fallow vegetation, an alternative weeding tool should be used. As regards soil fertility maintenance, application of P through fertilizers should be considered, given the general deficiency in the region and the substantial yield increase after small amounts of this nutrient are applied (van Reuler & Janssen 1989; in prep. b).

Leguminous species may be intercropped to improve the supply of nitrogen. Important criteria for selecting appropriate species are planting time and densities relative to the main crop. In anticipation of a further intensification of the *C. odorata* fallow system, research should be done to identify appropriate crops to be grown during the late season. The growth characteristics of these crops have to be such that the need for weeding is minimal to prevent the disappearance of *C. odorata* and to avoid interfering with the labour profile for cocoa and coffee cultivation. An early-maturing cassava variety might be appropriate, being planted as an intercrop or relay crop in the early season and occupying the plot in the late season. As *C. odorata* is becoming an important fallow species in the humid forest and the subhumid savanna zone of large parts of West Africa, the suitability of other staple crops for integration in the *C. odorata* fallow system should also be tested. The more productive and sustainable use of *C. odorata* fallows may confine the increasing demand for land, thus delaying the breakdown of the traditional shifting cultivation system and contributing to the preservation of the remaining tropical forests.

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Appendices

Appendix I: Soil analytic data catena

Table I.1 Analytical data of the topsoil under forest on different positions on a typical catena in the Tai region

Position	Upper slope 1		Upper slope 2		Mid slope		Lower slope		Valley bottom	
Depth	0-7cm	7-20cm	0-10cm	10-30cm	0-10cm	10-20cm	0-8cm	8-20cm	0-7cm	7-20cm
Gravel(>2mm;%)	76	75	75	71	35	6	0	0	0	0
Sand %	67	50	69	58	79	71	77	60	77	73
Silt %	14	16	14	14	12	13	13	16	13	12
Clay %	19	33	17	29	9	16	11	23	10	15
pH-H_2O	5.9	4.9	5.6	4.7	4.5	4.7	4.3	4.4	4.2	4.4
pH-KCl	4.8	3.8	4.2	3.8	3.6	3.8	3.8	3.8	3.7	3.9
Org.Matter (%C)	3.11	1.32	3.45	1.08	1.78	0.89	0.93	0.65	1.57	1.18
CEC (mmol(+) kg^{-1})	89	51	96	54	62	47	23	30	47	32
Base saturation (%)	73	28	53	15	16	11	23	6	37	55

Source: Fraters 1986

Appendix II: Overview of experiments on fields cleared from *C. odorata* fallows

Table II.1 Crop production experiments (Chapters 5 to 7)

Field	Fallow period (years)	A[a] B C	Removing 1 0	Removing 1 P	Removing 1 NP	Removing 2 0	Removing 2 P	Removing 2 NP	Burning 1 0	Burning 1 P	Burning 1 NP	Burning 2 0	Burning 2 P	Burning 2 NP	Intensive burning 1 0	Intensive burning 1 P	Intensive burning 1 NP	Intensive burning 2 0	Intensive burning 2 P	Intensive burning 2 NP	Exp.[b] design	Repl.[c]
I	0		x	x	x	x	x	x													f	8
II	2		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	sp	5
III	3			x	x		x	x													f	6
IV	3					x	x	x	x	x	x										f	4
V	4					x	x	x	x	x	x										f	4

[a] A: clearing method: removing, burning or intensively burning the slashed fallow vegetation
B: weeding frequency in number of weedings per cropping season
C: fertilizer application, 0: no fertilizers applied, P: 25 kg P/ha per season, N: 100 kg N/ha per season

[b] experimental design: f: factorial, sp: split-plot

[c] number of replicates

Table II.2 Experiment on the regrowth of *C. odorata* directly after clearing (Chapter 8)

Field	Fallow period (years)	Cultivation treatment[a]	Clearing method: Mulching[b]	Clearing method: Removing	Clearing method: Burning	Clearing method: Intensive burning	Exp.[c] design	Repl.[c]
VI	2	Fallow	x	x	x	x		
		Weeded	x	x	x	x	sp	6
		Cropped	x	x	x	x		

[a] fallow: abandonned after clearing, weeded:no crop grown, regrowth weeded once after clearing, cropped: crop grown which is weeded once, no fertilizer application

[b] mulching: retaining the slashed vegetation on the field, other treatments as explained in Table II.1

[c] as in Table II.1

Table II.3 Duration of the experiments

Field	Year season[a]	1989 E	1989 L	1990 E	1990 L	1991 E	1991 L	1992 E	1992 L
I				x	x	x	x	x	
II						x	x	x	
III		x	x	x		x	x	x	
IV						x	x	x	
V						x	x	x	
IV								x	

[a] E: early season, L: late season

Appendix III: Observations on the growth of the *C. odorata* fallow vegetation (Chapter 4)

Table III.1 Overview of observations on the growth of *C. odorata* fallow vegetations of increasing ages

Fallow age (years)	Number and frequency of observation	Type of observation Dry weight and composition of above-ground biomass and litter	Specific leaf area	Nutrient content of biomass and litter	Root biomass	Rooting pattern	Litter fall
0-1[a]	Observation frequency	3	3	1	1	1	nd
	Number of plots	3	3	3	3	1	nd
	Number of replicates per plot	4	3	2	2	1	nd
2-3	Observation frequency	3	2	1	1	1	14
	Number of plots	2	1	1	1	1	2
	Number of replicates per plot	5	4	2	3	2	3
5	Observation frequency	3	2	1	1	1	7
	Number of plots	2	1	1	1	1	2
	Number of replicates per plot	5	4	2	3	2	12

[a] the above-ground biomass and composition of the 0-Y fallow vegetation were determined two times only, on three plots having four replicates each

Table III.2 Standard errors of the litter fall per fallow age (additional information to Figure 4.2)

Time[a] (d)	Fallow age (years) 2	3	5
34	2.12	0.75	4.59
55	0.73	0.27	3.89
82	0.53	0.51	4.40
103	1.26	1.43	0.35
119	1.73	1.21	5.07
139	4.14	0.87	5.53
164	4.52	1.27	1.75
187	3.25	1.00	na
250	0.15	0.39	na
288	3.87	2.65	na
326	0.76	4.20	na
358	3.06	1.30	na
378	0.10	7.49	na
396	1.30	4.30	na

[a] since start of observation on 7 June 1991

Annexe IV: Sampling the re-establishing *C. odorata* fallow vegetation (Chapter 9)

Table IV.1 Overview of vegetation sampling on the experimental fields for analyzing the effects of cultivation practices on the re-establishment of the *C. odorata* fallow vegetation

Cultivation practice	Field	Fallow period (years)	Cropping period (seasons)	Treatments in the cropping period: A[a] Mulching		Removing						Burning						Intensive burning					
				B 1	2	1			2			1			2			1			2		
				C 0	0	0	P	NP	0	P	NP	0	P	NP	0	P	NP	0	P	NP	0	P	NP
Length fallow period																							
	II	2	3									x	x	x	x	x	x						
	V	4	3									x	x	x	x	x	x						
Clearing method																							
	VI	2	1	x		x						x			x								
	II	2	3			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Weeding frequency/Fertilizer application																							
	II	2	3			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	V	4	3									x	x	x	x	x	x						
	I	0	5			x	x	x	x	x	x												
Length of the cropping period																							
Stage A	VI	2	1			x						x						x					
	II	2	3			x						x						x					
Stage B	II	2	3			x	x	x	x	x	x												
	I	0	5			x	x	x	x	x	x												

[a] A: clearing method: retaining, removing, burning or intensively burning the slashed fallow vegetation
B: weeding frequency in number of weedings per cropping season
C: fertilizer application: 0: no fertilizers applied, P: 25 kg P $ha^{-1}season^{-1}$, N: 100 kg N $ha^{-1}season^{-1}$

Summary

Shifting cultivation is an important cropping system in traditional subsistence agriculture in tropical Africa. The fallow is a prerequisite to maintain the soil fertility and to check the build-up of weeds, pests and diseases in this system, implying extensive land use. Population increase and better access to markets have resulted in a more intensive land use causing the transformation from shifting cultivation into more permanent cropping systems. This transformation is difficult and proceeds slowly on the generally poor soils in the lowlands of the humid tropics, where conditions for crop growth degrade when cropping after a fallow period is prolonged beyond one or two seasons. Inexpensive and adequate technologies to maintain these conditions are lacking. As a result, crop yields are low in relation to the labour requirements. There is a great need to formulate alternatives for shifting cultivation in order to produce enough food and to preserve the remaining tropical forests. One such alternative is an intermediate stage between shifting cultivation and permanent agriculture, achieved by developing and improving fallow systems, in which an effective short-duration fallow enables a more intensive land use. The cultivation of food crops in a fallow system based on the natural stands of *C. odorata*, as developed by farmers in South-West Ivory Coast, is an example of such a system. The shrub *C. odorata* originates from Central and South America and has spread rapidly through Africa during the last fifty years, mainly as a result of more intensive land use. The plant is known for its enormous seed production and rapid growth. In Africa and Asia it is considered a serious weed in perennial crop cultivation and in grasslands. In both continents, however, young fallow vegetations dominated by this species are increasingly used in food crop cultivation.

The fieldwork for this thesis was conducted from 1989 to 1992 around the villages of Taï and Ponan in South-West Ivory Coast. It involved analysing the prevailing *C. odorata* fallow system and identifying opportunities for improvement, with the aim of developing an efficient and sustainable cropping system for food production as an alternative for shifting cultivation. Surveys and observations on farms were carried out to describe the transformation of shifting cultivation into farming and cropping systems for more permanent agriculture and to characterize the cropping system with *C. odorata* fallow practised by farmers at present. The growth and development of the *C. odorata* fallow vegetation were measured on fallow plots. The effects of land use intensity, clearing methods and crop management on crop yields and on the re-establishment of the fallow vegetation after cropping were quantified in field experiments.

The study illustrates how cocoa and coffee cultivation, stimulated by government policy and immigration, has triggered the change from shifting cultivation to permanent land use under perennial crops in the Taï region. The large-scale deforestation and the long-term "locking up" of land under these perennial crops is forcing an increasing number of farmers to adopt new methods for food crop cultivation. This need is most urgent for immigrant farmers who generally have the smallest farms. They have started to grow food crops on land cleared from a fallow vegetation dominated by *C. odorata*. Often they rent the fallow land overgrown with this species from the indigenous people, thus endangering the continuity of shifting cultivation with long-duration forest fallow.

In the present *C. odorata* fallow system, immigrant farmers grow one maize crop followed by two to three years of fallow. Weed growth is an important constraint to crop yield, forcing farmers to spend considerable time weeding. Farmers reduce the labour required for weeding by careful site selection, by phased clearing and planting and by planting a fast-growing crop like maize. They are able to meet the labour requirement by flexibly sharing tasks between men and women. A survey of some fifteen farmers showed that clearing and weeding took respectively 30 and 57 person days ha^{-1} and that maize yields were about 1.8 t ha^{-1}, which is considered satisfactory under the prevailing conditions of farming. The results of the survey suggest that in the present *C. odorata* fallow system the biophysical potential for crop production is not fully exploited.

A study on the growth and development of the fallow vegetation over five years showed that *C. odorata* dominated this vegetation already shortly after crop harvest, because it provided a rapid and uniform soil cover. Within two years the herbaceous undergrowth in the vegetation was smothered. The density of *C. odorata* plants decreased continuously during the fallow period by intraspecific competition. The biomass and nutrient content of the fallow vegetation increased until the third year, when 22 t dry matter ha^{-1} was produced, in which 110 kg N, 8 kg P and 165 kg K were accumulated. After the third year, biomass increase stagnated and litter production increased.

To explore the options for intensifying crop production in the *C. odorata* fallow system, the effects of a shorter fallow period, clearing methods, weeding frequency, fertilizer application and prolonged cropping were studied in field experiments.

Shortening the fallow period from four to two years reduced the yield of the first maize crop after clearing from 3.8 to 2.6 t ha^{-1} if no fertilizers were applied and from 7.0 to 5.8 t ha^{-1} when fertilizers were used. This reduction was related to the limited availability of nutrients, especially that of phosphorus and nitrogen, and to a more pronounced competition from weeds. The yields of the subsequent crops fell to 1.5 t ha^{-1} without fertilizer application and to 5.4 t ha^{-1} if fertilizers were applied, irrespective of the age of the preceding fallow. Shortening the fallow period also slowed down the re-establishment of the *C. odorata* fallow vegetation after crop harvest.

Burning the slashed *C. odorata* fallow vegetation at clearing increased the subsequent maize yield because nutrients, particularly phosphorus, became more readily available. On land cleared from a two-year-old fallow, burning was incomplete because of the limited amount of vegetation biomass. Therefore, it seems probable that soil nitrogen is immobilized by micro-organisms during the decomposition of the unburnt remnants of the vegetation. Burning reduced the seedbank and the sprouting of *C. odorata* stumps, but weeding was still needed to obtain a good crop. Alternative clearing methods proved to be unattractive. Concentrating the slashed fallow vegetation on a smaller area in order to increase the beneficial effects of burning and to make more nutrients available, resulted in poor gains in relation to the extra land and labour needed. Retaining the slashed fallow vegetation as a mulch gave a relatively low subsequent crop yield because nutrients in the vegetation were not released quickly enough. Moreover, neither of these alternative clearing methods clearly reduced the weed competition. Burning slowed down the re-establishment of the *C. odorata* fallow vegetation after crop harvest, but this effect was far less than the negative impact of weeding and crop cultivation.

One hoe-weeding within the first month after planting proved enough to reduce competition from weeds in a fast-growing crop like maize on fields cleared from a *C. odorata* fallow. However, on one field cleared from a two-year-old fallow, an extra weeding improved yields. The rapidly growing *C. odorata* shoots were potential competitors for the crop. Although very numerous, *C. odorata* seedlings had a slow initial development and were not a threat to crop growth. Hoe-weeding severely reduced the re-establishment of *C. odorata* after crop harvest because it uprooted stumps. This was not the case if a cutlass was used for weeding.

Application of nitrogen and phosphorus fertilizers strongly stimulated maize yields in the *C. odorata* fallow system. This illustrates the importance of the availability of both nutrients for crop production in this system. The availability of phosphorus was particularly low, whereas the availability of nitrogen limited crop production if phosphorus was applied. Fertilizer application, particularly of phosphorus, also stimulated the re-establishment of the *C. odorata* fallow vegetation after crop harvest.

Extending the cropping period to more than one season resulted in decreasing maize yields. The yield decline was smaller on burnt plots than on unburnt plots because burning released nutrients, and it was slowed down but not completely counterbalanced by fertilizer application. Presumably, it was also brought about by the deterioration of other conditions for crop growth, such as degrading physical soil properties and the presence of nematodes. Increased competition from weeds did not play a role. Extending the cropping period by cultivating maize in the late season proved to be not very suitable as yields were below those obtained in the early season. The crop yield fell to 0.3 t ha^{-1} after four consecutive crops, making further cropping not worthwhile. Extending the cropping period also resulted in a pronounced delay in the re-establishment of the *C. odorata* fallow vegetation after crop harvest, because the recurrent clearing and weeding operations sharply reduced the numbers of stumps and seedlings of this species.

The characteristics of *C. odorata* explain why a sizeable crop yield is obtained on cleared fallows of this species, even though the fallow period is shorter than that in the traditional shifting cultivation. During the cropping period, *C. odorata* can easily be controlled in a fast-growing crop like maize. After crop harvest, *C. odorata* readily smothers the herbaceous species and produces a fair amount of biomass making slash and burn feasible and releasing considerable amounts of nutrients. Comparing the data of both systems in the Taï region illustrates that the transformation of shifting cultivation into the *C. odorata* fallow system increased the productivity of land use, but reduced the species diversity. The nutrient content of the ecosystem did not clearly change, but is likely to decrease in the long term. More intensive land use, intensive burning, extra weeding and fertilizer application all resulted in a further increase in the productivity of land use in the *C. odorata* fallow system. Except for fertilizer application, however, these practices slowed down the re-establishment of the *C. odorata* fallow vegetation after crop harvest.

The results presented in this thesis demonstrate that the *C. odorata* fallow system can be an important cropping system in areas of the humid tropics where shifting cultivation with a forest fallow is no longer feasible. Contrary to its widespread reputation, *C. odorata* is not an obnoxious weed in this context. There is a good balance between labour input and crop yield in the fallow system practised at present in the Taï region. Improved cultivation practices are needed to anticipate the trend in intensifying land use. These practices should aim at fully exploiting the biophysical potential for crop production in the *C. odorata* fallow system, increasing the availability of phosphorus and nitrogen, and reducing the negative impact of cultivation on the re-establishment of the fallow vegetation.

Résumé

En Afrique tropicale, la culture itinérante sur défriche-brûlis est un système de culture important pour la production vivrière traditionnelle d'autoconsommation. La jachère dans ce système maintient la fertilité du sol et réduit l'apparition de mauvaises herbes, de parasites et de maladies. Mais elle implique aussi une utilisation de terre extensive. Une pression démographique croissante et un meilleur accès aux marchés ont incité les paysans à utiliser plus intensivement leurs terres, menant à une transformation du système de culture itinérante en systèmes de culture plus permanents. Cette transformation est difficile et se produit très lentement dans les régions tropicales humides où les terres sont en général peu fertiles. Dans ces régions, les conditions du sol se détériorent vite si la période de culture dépasse une ou deux saisons. Des technologies appropriées à prix abordable pour maintenir des conditions favorables font défaut. Il en résulte un faible productivité de travail si la terre est cultivée intensivement. Des alternatives à la culture itinérante traditionnelle sont nécessaires afin de pouvoir produire à long terme suffisamment d'aliments sans pour autant menacer les derniers restes de forêt tropicale. Une alternative intéressante est le développement et l'amélioration des systèmes de jachère. Ces systèmes représentent un stage intermédiaire entre le système de culture itinérante et les systèmes de culture permanents. Dans les systèmes de jachère, une jachère effective de courte durée permet une utilisation de terre plus intensive. La production vivrière sur des jachères à *Chromolaena odorata* pratiquée par les paysans dans le Sud-Ouest de la Côte d'Ivoire peut être citée comme exemple d'un tel système. L'arbuste *C. odorata* a son origine en Amérique centrale et Amérique du Sud, et s'est répandue dans toute Afrique pendant les cinquante dernières années à cause de l'utilisation de terre plus intensive. Une production de graines très élevée et une croissance importante sont les caractéristiques principales de cette plante. En Afrique et en Asie, *C. odorata* est considérée comme une mauvaise herbe dans les cultures pérennes et les prairies. Par contre, les jeunes végétations de jachère dominées par *C. odorata* sont de plus en plus utilisées pour la production vivrière dans ces deux continents.

Les essais et les enquêtes pour ce travail de recherche ont été effectués entre 1989 et 1992 dans les villages de Taï et de Ponan au Sud-Ouest de la Côte d'Ivoire. Ce travail de recherche avait pour but de développer un système de production vivrière efficient et durable en analysant l'utilisation actuelle de jachères à *C. odorata* pour la production vivrière par les paysans et en identifiant des possibilités d'améliorer ce système de jachère. Des enquêtes ont été effectuées auprès de paysans et des observations ont été faites dans leurs champs afin de décrire la transformation des systèmes de culture dans la région de Taï et de caractériser le système de jachère à *C. odorata* développé par les paysans. La croissance et le développement de la végétation à *C. odorata* ont été mesurés dans des parcelles en jachère. Dans le cadre d'expérimentations sur le terrain, les effets des pratiques culturales sur le rendement et sur la régénération de la végétation de jachère ont été quantifiés.

Ces recherches montrent comment la culture de cacao et café, stimulée par la politique gouvernementale et par une immigration massive dans la région de Taï, a provoqué le passage de la culture itinérante sur brûlis en une utilisation de terre permanente. La déforestation à grande échelle et l'occupation des terres à long terme par ces cultures ont forcé de nombreux paysans à développer de nouvelles méthodes pour la production vivrière. Ceci touche en particulier les immigrés qui disposent habituellement de peu de terres cultivables. Ce sont eux qui ont commencé à mettre en culture les jachères à *C. odorata*. Dans ce but, ils louent des parcelles en jachère de la population autochtone et mettent ainsi en danger le système de culture itinérante traditionnel de cette dernière.

Dans le système de jachère à *C. odorata* actuel, les immigrés cultivent du maïs pendant une saison, suivi d'une jachère de deux à trois ans. L'envahissement de mauvaises herbes réduit le rendement et force les paysans à dédier un temps considérable au désherbage. Afin de réduire le travail de désherbage, ils choisissent des parcelles où ils pensent que peu de mauvaises herbes vont pousser, ils défrichent et sèment en phases et ils donnent la préférence à une culture à croissance vigoureuse comme le maïs. La demande de force de travail est couverte par une division flexible des travaux champêtres entre hommes et femmes. Une enquête auprès d'une quinzaine de paysans a montré que le défrichage et le désherbage demandent 30 et 57 personne-jours ha^{-1} respectivement, alors que le rendement moyen s'élève à 1,8 t ha^{-1}, ce qui représente un bon résultat dans les conditions prévalentes. Les résultats de cette enquête indiquent également que dans le système de jachère à *C. odorata* le potentiel biophysique de la production végétale n'est pas entièrement exploité.

Une étude a été effectuée sur les premiers cinq ans de la croissance des végétations de jachère à *C. odorata*. Cette étude montre que très peu après la mise en jachère d'une parcelle, *C. odorata* dominait déjà la végétation à cause de sa couverture de sol rapide et uniforme. En moins de deux ans, elle étouffait les plantes d'espèces herbeuses formant une sous-couche dans la végétation. En raison d'une concurrence intraspecifique, le nombre de plantes de *C. odorata* diminuait continuellement. La biomasse et la teneur en éléments minéraux de la végétation de jachère augmentaient pendant les trois premières années du développement pour atteindre 22 t de matière sèche ha^{-1} et 110 kg N, 8 kg P et 165 kg K ha^{-1}. Après la troisième année, la croissance de la végétation stagnait tandis que la production de litière augmentait rapidement.

Afin d'identifier des options pour améliorer la productivité du système de jachère à *C. odorata*, des champs d'essais ont été établis sur des parcelles paysannes. Les effets sur le rendement et sur la régénération de la végétation de jachère d'un raccourcissement de la période de jachère, de variations dans la méthode de défrichage, dans la fréquence de désherbage et dans l'apport des fertilisants ainsi que les effets de la prolongation de la période de culture ont été étudiés.

Une période de jachère raccourcie de quatre à deux ans réduisait le rendement de la première culture de maïs de 3,8 à 2,6 t ha^{-1} sans apport des fertilisants et de 7,0 à 5,8 t ha^{-1} avec fertilisants. Cette baisse de rendement était liée à une disponibilité limitée d'éléments minéraux, notamment de phosphore et d'azote, et à une compétition plus importante de mauvaises herbes. Le rendement de la deuxième culture de maïs ne dépassait pas 1,5 t ha^{-1} sans apport de fertilisants et 5,4 t ha^{-1} avec fertilisants, indépendamment de la durée de la période de jachère précédente. Une durée de jachère réduite de quatre à deux ans ralentissait également la régénération de la végétation de jachère après la récolte.

Le fait de brûler la végétation de jachère coupée pendant le défrichage augmentait le rendement de la première culture de maïs par une disponibilité accrue d'éléments minéraux, notamment celle de phosphore. Sur la parcelle mise en culture après deux ans de jachère, le brûlis était incomplet à cause de la quantité limitée de biomasse. Par conséquent, il est très probable que l'azote présent dans la terre ait été immobilisé par des micro-organismes qui décomposaient les restes non-brûlés de la végétation. Le fait de brûler la végétation de jachère réduisait le stock semencier et la reprise des souches de *C. odorata*. Cependant, le désherbage était nécessaire afin d'obtenir un bon rendement lors de la récolte. Les deux méthodes alternatives de défrichage présentées ci-dessous ne présentaient que peu d'intérêt. La concentration de la végétation coupée sur une petite surface afin d'augmenter les effets bénéfiques du brûlis et la disponibilité des éléments minéraux ne résultait qu'en une amélioration trop faible par rapport aux investissements additionnels de terre et de travail. La rétention de la végétation coupée comme "mulch" résultait en un rendement relativement faible parce que les éléments minéraux dans cette biomasse n'étaient pas libérés assez vite pour que les plantes de maïs puissent en profiter. De plus, aucune de ces deux méthodes ne réduisait la compétition des mauvaises herbes.

Le fait de brûler la végétation de jachère ralentissait sa régénération après la récolte. Cet effet était cependant largement masqué par l'impact négatif du désherbage et de la mise en culture sur la régénération.

Un désherbage à l'aide d'une houe dans le premier mois suffisait pour limiter la compétition de mauvaises herbes dans une culture à croissance rapide comme le maïs sur des parcelles défrichées à végétation *C. odorata.* Dans une seule parcelle, mise en culture après une période de jachère relativement courte, il a été constaté qu'un deuxième désherbage augmentait le rendement. Ce sont surtout les repousses des souches de *C. odorata* qui paraissaient agir négativement sur la croissance de la culture. Bien que très nombreuses, les plantules se développaient si lentement qu'elles pouvaient être contrôlées facilement par un seul désherbage. Le désherbage à la houe nuisait à la régénération de *C. odorata* après la récolte parce qu'un nombre de souches important a été déraciné. Si la machette au lieu de la houe était utilisée, cet effet se ne produisait pas.

Dans le système de jachère à *C. odorata,* le rendement est largement augmenté en apportant des fertilisants contenant du phosphore et de l'azote. Ceci démontre l'importance de la disponibilité de ces deux éléments minéraux pour la production vivrière dans ce système. Le phosphore en particulier semblait insuffisant, alors qu'une augmentation de sa disponibilité entraînait un déficit en azote. L'apport de fertilisants, notamment de phosphore, stimulait également la régénération de *C. odorata* après la récolte.

La prolongation de la période de culture de plus d'une saison résultait en une baisse du rendement. Cette baisse était moins importante dans les parcelles brûlées pendant le défrichage que dans celles qui n'avaient pas été brûlées, ce qui peut être attribué à une meilleure disponibilité des éléments minéraux. La baisse du rendement résultant de la prolongation de la période de culture pouvait être diminuée par un apport de fertilisants. Une détérioration des conditions de culture telle qu'une dégradation des qualités physiques de sol ou une incidence accrue de nématodes ont probablement aussi contribué à la baisse du rendement. Un enherbement progressivement plus grand des parcelles ne jouait cependant aucun rôle. Il paraissait peu intéressant de prolonger la période de culture en cultivant du maïs pendant la saison des pluies tardives vu que le rendement était plus bas que celui obtenu pendant la saison des pluies précoces. Après quatre cultures de maïs successives, le rendement de la culture fertilisée ainsi que celui de la culture non-fertilisée était tombé à 0,3 t ha^{-1}, rendant une période de culture supplémentaire peu intéressante. La prolongation de la période de culture résultait aussi en une réduction importante du nombre de souches et de plantules de *C. odorata* en raison des préparations de

la terre et des désherbages multiples. Ceci impliquait une ralentissement sérieux de la régénération de *C. odorata* après la récolte.

Les caractéristiques de *C. odorata* expliquent pourquoi un bon rendement peut être obtenu en mettant en culture une jachère dominée par cette espèce, bien que la période de jachère soit plus courte que dans le système traditionnel de culture itinérante. Dans une culture à croissance vigoureuse il est facile de contrôler *C. odorata*. Après la récolte, l'espèce étouffe rapidement les herbes et produit une quantité de biomasse relativement grande permettant le brûlis et libérant ainsi une quantité d'éléments minéraux considérable. La comparaison des données des deux système de culture dans la région de Taï montre que la transformation de culture itinérante en système de jachère à *C. odorata* augmentait la productivité de l'utilisation de la terre, mais réduisait en même temps la diversité des espèces végétales. Les quantités d'éléments minéraux dans l'écosystème entier ne changeaient pas significativement dans le cas présenté, mais à long terme, elles sont supposées de diminuer. L'utilisation de terre plus intensive, le brûlis intensif, un deuxième désherbage et l'apport des fertilisants résultaient tous en une augmentation de la productivité par unité de surface dans le système de jachère à *C. odorata*. Mis à part l'apport des fertilisants, ces pratiques ralentissaient également la régénération de la végétation de jachère à *C. odorata* après la récolte.

Les résultats présentés dans cette thèse montrent que le système de jachère à *C. odorata* peut être un système de culture important dans les régions tropicales humides où la culture itinérante sur défriche-brûlis basée sur une jachère forestière n'est plus faisable. Dans ce contexte *C. odorata* ne semble pas être une mauvaise herbe, comme elle est souvent décrite dans la littéraire. Dans le système de jachère à *C. odorata* pratiqué actuellement dans la région de Taï, un équilibre entre la demande de travail et son rendement peut être constaté. Des pratiques améliorées sont cependant indispensables afin d'anticiper la tendance d'une utilisation de terre encore plus intensive. Ces pratiques améliorées doivent exploiter au maximum le potentiel biophysique de la production végétale dans le système de jachère à *C. odorata*, augmenter la disponibilité du phosphore et de l'azote, et réduire l'impact négatif de la culture sur le régénération de la végétation de jachère.

Samenvatting

Zwerfbouw is een belangrijk teeltsysteem in de traditionele zelfvoorzieningslandbouw in tropisch Afrika. De braak in dit systeem is noodzakelijk voor het instandhouden van de nutriëntenvoorziening en voor het verminderen van onkruiden, ziekten en plagen, en houdt een extensief landgebruik in. Een toenemende bevolkingsdruk en verbeterde toegang tot de markt leiden echter tot een intensiever landgebruik, waardoor zwerfbouw overgaat in meer permanente teeltsystemen. Deze overgang verloopt moeizaam en langzaam bij de teelt van niet-bevloeide voedselgewassen op de veelal arme bodems in het laagland van de humide tropen. In dat milieu nemen na een braakperiode de omstandigheden voor gewasgroei snel af in kwaliteit, terwijl goedkope en adequate technologieën om deze omstandigheden op peil te houden ontbreken. Als gevolg daarvan is de gewasopbrengst bij permanent landgebruik zeer gering ten opzichte van de benodigde arbeidsinspanningen. Er is een grote behoefte aan alternatieven voor de zwerfbouw om voldoende voedsel te produceren en de overgebleven regenwouden te behouden. Een tussenstap naar permanente landbouw is het ontwikkelen en verbeteren van braaksystemen waarin intensiever landgebruik mogelijk is door een effektieve kortdurende braak. Een voorbeeld van een dergelijk teeltsysteem is de door boeren in zuidwest Ivoorkust geïnitieerde voedselteelt met de natuurlijke bestanden van *Chromolaena odorata* als struikvormig braakgewas. De uit Centraal- en Zuid-Amerika afkomstige plantesoort heeft zich de laatste vijftig jaar sterk verspreid over het Afrikaanse kontinent, voornamelijk ten gevolge van intensiever landgebruik. De plant kenmerkt zich door een grote zaadproduktie en een hoge groeisnelheid, en wordt in Afrika en Azië aangemerkt als een belangrijk onkruid in overblijvende gewassen en graslanden. Daarentegen worden in beide kontinenten jonge braakvegetaties van *C. odorata* in toenemende mate gebruikt voor voedselteelt.

Het onderzoek in dit proefschrift werd in de periode 1989-1992 uitgevoerd in zuidwest Ivoorkust rondom de dorpen Taï en Ponan. Het was gericht op het analyseren van het huidige *C. odorata* braaksysteem en op het identificeren van verbeteringen met het doel een efficiënt en duurzaam teeltsysteem voor voedselproduktie te ontwikkelen als een alternatief voor zwerfbouw. Aan de hand van enquêtes en veldwaarnemingen werd de transformatie van zwerfbouw naar bedrijfs- en teeltsytemen met meer permanent landgebruik beschreven, en werd het door boeren ontwikkelde teeltsysteem met *C. odorata* braak gekarakteriseerd. Op braakvelden werden de groei en ontwikkeling van *C. odorata* gemeten. In

veldproeven werden de effekten van landgebruiksintensiteit, ontginningsmethoden en gewasverzorging op de gewasopbrengst en op de hergroei van *C. odorata* na afloop van de teeltperiode gekwantificeerd.

In het onderzoek wordt geïllustreerd hoe de verbouw van cacao en koffie, gestimuleerd door overheidsbeleid en massale immigratie, in de Taï regio heeft geleid tot de overgang van de traditionele zwerfbouw in een permanent landgebruik onder overblijvende gewassen. De grootschalige ontbossing en het langdurig vastleggen van grond onder overblijvende gewassen noopt een toenemend aantal boeren om nieuwe manieren van voedselteelt te ontwikkelen. Deze noodzaak is het grootst voor de immigranten, die veelal over een beperkt areaal land beschikken. Zij hebben de aanzet gegeven tot verbouw van voedselgewassen in een braaksysteem met *C. odorata*. Daarbij huren ze vaak de door *C. odorata* overgroeide braakpercelen van de autochtone boeren, waardoor de nog bestaande zwerfbouw met lange bosbraak in gevaar komt.

In het huidige *C. odorata* braaksysteem wisselen immigranten één teelt van maïs af met een braak van twee of drie jaar. Onkruidgroei is een belangrijke opbrengstreducerende faktor en dwingt boeren tot aanzienlijke arbeidsinzet. Ze weten de benodigde wiedarbeid te beperken door een weloverwogen keuze van het braakperceel, een gefaseerd ontginnen en aanplanten, en de verbouw van een snelgroeiend gewas als maïs. Pieken in arbeidsbehoefte worden opgevangen door een flexibele arbeidsverdeling tussen mannen en vrouwen. In een survey onder een vijftiental boeren bleken ontginning en wieden respektievelijk 30 en 57 mensdagen ha^{-1} te vergen en de behaalde opbrengsten te schommelen rond 1,8 ton ha^{-1}, hetgeen onder de gegeven produktie-omstandigheden als goed beschouwd kan worden. De waarnemingen suggereren echter dat in het huidige *C. odorata* braaksysteem de biofysische mogelijkheden voor gewasproduktie niet volledig benut worden.

Bestudering van de groei van braakvegetaties over een periode van vijf jaar maakte duidelijk dat *C. odorata* al snel na afloop van de teelt de vegetatie overheerste als gevolg van een snelle en uniforme bodembedekking. In minder dan twee jaar verdwenen kruidachtige planten in de ondergroei van de braakvegetatie. Tijdens de braakperiode nam het aantal *C. odorata* planten voortdurend af als gevolg van onderlinge konkurrentie. De biomassa en nutriënteninhoud van de braakvegetatie namen gestaag toe tot in het derde jaar waarbij 22 ton droge stof ha^{-1} werd geproduceerd waarin 110 kg N, 8 kg P en 165 kg K ha^{-1} werden vastgelegd. Daarna stagneerde de groei en nam de strooiselproduktie sterk toe.

Om na te gaan of de gewasteelt in het *C. odorata* braaksysteem kan worden geïntensiveerd, werden de effekten van een verkorting van de braakperiode, de ontginningswijze, de wiedfrequentie, de bemesting en de verlenging van de teeltduur op gewasopbrengst en herstel van de *C. odorata* braakvegetatie na afloop van de teelt in veldproeven bestudeerd.

Door verkorting van de braakperiode van vier naar twee jaar nam de opbrengst van het eerste maisgewas na ontginning af van 3,8 naar 2,6 t ha^{-1} zonder bemesting, en van 7,0 naar 5,8 t ha^{-1} met bemesting. Deze afname bleek gekoppeld te zijn aan een beperkte beschikbaarheid van nutriënten, met name fosfaat en stikstof, en een hogere onkruiddruk. De opbrengst van daaropvolgende gewassen daalde naar een lager nivo, 1,5 en 5,4 t ha^{-1} voor onbemeste respektievelijk bemeste maïs, en werd niet meer bepaald door de duur van de voorafgaande braakperiode. De hergoei van *C. odorata* na de teeltperiode bleek vertraagd te worden door het verkorten van de voorafgaande braakperiode.

Het branden van de gekapte *C. odorata* braakvegetatie tijdens de ontginning stimuleerde de gewasopbrengst omdat nutriënten uit deze vegetatie, met name fosfaat, voor het gewas beschikbaar kwamen. Branden op jonge braakpercelen was onvolledig door de beperkte omvang van de gekapte vegetatie. Als gevolg daarvan kon stikstof uit de bodem geïmmobiliseerd worden door micro-organismen bij de afbraak van de onverbrande vegetatie-resten. Branden reduceerde de zaadbank en de uitloop van stronken van *C. odorata*, maar wieden bleef noodzakelijk voor het behalen van een goede gewasopbrengst. Alternatieve ontginningsmethoden bleken weinig aantrekkelijk te zijn. Het concentreren van de gekapte braakvegetatie op een kleiner oppervlak teneinde het positief effekt van branden te vergroten en een grotere hoeveelheid nutriënten beschikbaar te maken, gaf weinig meeropbrengst in vergelijking met de extra behoefte aan land en arbeid. Het achterlaten van de gekapte braakvegetatie als mulch gaf een relatief lage opbrengst omdat de nutriënten uit de vegetatie te langzaam voor het gewas beschikbaar kwamen. Bovendien verminderden beide alternatieven de onkruidkonkurrentie niet. Branden benadeelde de hergroei van *C. odorata* na de teelt, maar dit negatieve effekt kwam niet duidelijk tot uiting omdat de daaropvolgende teeltmaatregelen een grotere negatieve uitwerking op de hergroei hadden.

Op velden ontgonnen uit een *C. odorata* braakvegetatie was één keer wieden met een hak binnen één maand na zaaien voldoende om onkruidkonkurrentie in een snelgroeiend gewas als maïs te beteugelen. Alleen na een korte braakperiode kon een extra wiedronde de opbrengst verhogen. Vooral de snelgroeiende uitlopers van *C. odorata* stronken leken de gewasgroei te hinderen. Hoewel zeer talrijk, groeiden zaailingen dermate langzaam dat ze bij één keer wieden geen belemmering vormden voor maïs. Wieden met een hak benadeelde in hoge mate de hergroei van *C. odorata* na de teeltperiode omdat een groot aantal stronken werd ontworteld. Bij gebruik van een kapmes trad dit effekt niet op.

In het *C. odorata* braaksysteem werd de gewasopbrengst sterk verhoogd door toedienen van fosfaat- en stikstofmeststoffen. Dit illustreert het belang van een goede voorziening van beide nutriënten voor gewasproduktie in dit systeem. Met name fosfaat bleek in het minimum te zijn, terwijl bij verruiming van het aanbod van fosfaat de beschikbaarheid van stikstof beperkend werd. Bemesting, in het bijzonder met fosfaat, bevorderde de hergroei van *C. odorata* na afloop van de teelt.

Het verlengen van de teeltperiode tot meer dan één seizoen leidde tot een daling in gewasopbrengsten. Op gebrande percelen nam de opbrengst minder sterk af dan op niet-gebrande percelen, wat toegeschreven kan worden aan een betere nutriëntenvoorziening. De terugval in opbrengst werd afgezwakt doch niet volledig teniet gedaan indien het aanbod aan nutriënten verhoogd werd door bemesten. Dalende opbrengsten bij verlenging van de teeltperiode bleken niet te wijten aan toenemende onkruidkonkurrentie, maar wellicht wel aan een verslechtering van andere produktie-omstandigheden, zoals een achteruitgang in de fysische bodemeigenschappen en een toename van het aantal nematoden. Verlenging van de teeltperiode door benutting van het late teeltseizoen bleek niet erg geschikt omdat de maïsopbrengsten geringer waren dan die behaald in het vroege teeltseizoen. Na vier opeenvolgende teelten van maïs was de opbrengst van het bemeste en onbemeste gewas teruggelopen tot 0,3 t ha^{-1}, waardoor verdere gewasproduktie niet meer aantrekkelijk is. Verlenging van de teeltperiode leidde tevens tot een sterke vertraging in de hergroei van *C. odorata*, omdat het aantal stronken en zaailingen sterk gereduceerd werd door het herhaald zaaiklaar maken van het land en door het wieden.

De eigenschappen van *C. odorata* verklaren dat na een korte braakperiode relatief goede gewasopbrengsten behaald kunnen worden in vergelijking met de traditionele zwerfbouw. In de teelt van een snelgroeiend gewas als maïs is de plant gemakkelijk te beheersen. Na afloop van de teeltperiode schakelt *C odorata* kruidachtige planten snel uit en vormt in korte tijd een zodanige hoeveelheid biomassa dat ontginning door kappen en branden mogelijk is en er een behoorlijke hoeveelheid nutriënten beschikbaar komt. Vergelijking van experimentele gegevens van beide teeltsystemen in de Taï regio maakt duidelijk dat de overgang van zwerfbouw naar het *C. odorata* braaksysteem de produktiviteit van het landgebruik verhoogt, maar de diversiteit van de vegetatie vermindert. De nutriënteninhoud in het ecosysteem is nog niet duidelijk veranderd, maar zal op de lange termijn waarschijnlijk afnemen. Intensiever landgebruik, intensiever branden, extra wieden en bemesten in het *C. odorata* braaksysteem leiden tot een verdere stijging in de produktiviteit van landgebruik, maar met uitzondering van bemesting gaat dit ten koste van het herstel van de braakvegetatie.

Resultaten van dit onderzoek tonen aan dat het *C. odorata* braaksysteem een belangrijk teeltsysteem kan zijn in die gebieden waar zwerfbouw met bosbraak niet meer houdbaar is. In tegenstelling tot zijn algemeen wijdverbreide reputatie, bleek *C. odorata* in het onderzoek in Taï geen lastig onkruid te zijn. In het braaksysteem zoals momenteel bedreven in de Taï regio, bestaat er een gunstige verhouding tussen gewasopbrengsten en geleverde arbeidsinspanning. Verbeterde teeltmaatregelen zijn echter nodig om in te spelen op de trend van intensiever landgebruik. Deze maatregelen moeten gericht zijn op een betere benutting van de biofysische mogelijkheden voor gewasproduktie in het *C. odorata* braaksysteem, een betere beschikbaarheid van fosfaat en stikstof en een minder negatieve uitwerking op het herstel van de braakvegetatie na de teeltperiode.

Curriculum Vitae

Josephus Johannes Petronella Slaats was born on 25 January 1958 in Leende, The Netherlands. He obtained his Gymnasium-ß certificate from the St. Willibrord Gymnasium at Deurne in 1976. In the same year he entered Wageningen Agricultural University to study Tropical Crop Science. As part of his university course, he spent a practical training period in southern Ivory Coast to study food crop cultivation of small farmers. He did his MSc research on nutrient management in maize cultivation on low fertility acid soils at the Centre for Agricultural Research (CELOS) in Surinam. In 1984 he graduated with specializations in Tropical Crop Science, Soil Science and Plant Nutrition, Development Economics and Extension Education. Subsequently, he joined the fifth International Course for development oriented Research in Agriculture. During the field training period of this course, he was a member of an interdisciplinary team conducting farming systems research in Mexico. From November 1986 to October 1988, the Netherlands Development Organization (SNV) employed him as an advisor of the agricultural extension service in Central Rwanda. In October 1988, he was appointed as a researcher in the Wageningen Agricultural University research programme "Analysis and design of land use systems in the Taï region, South-West Côte d'Ivoire". Under this programme he conducted fieldwork in the Taï region from 1989 to 1992. The results of the study are presented in this thesis.