Growth of the *Chromolaena odorata* fallow vegetation in semi-permanent food crop production systems in South-West Côte d'Ivoire

J.J.P. SLAATS[1*], W.M. VAN DER HEIDEN [1], C.M. STOCKMANN [1], M. WESSEL[1] AND B.H. JANSSEN [2]

[1] Department of Agronomy, Wageningen Agricultural University, P.O. Box 341, NL-6700 AH Wageningen, The Netherlands
[2] Department of Soil Science and Plant Nutrition, Wageningen Agricultural University, P.O. Box 8005, NL-6700 EC Wageningen, The Netherlands
[*] Corresponding author (fax: +31-317-484575)

Received 23 April 1996; accepted 17 August 1996

Abstract

Growing population pressure pushes farmers to use the young *Chromolaena odorata* fallow vegetation for food crop production. As a first step in defining appropriate management for such a fallow, the growth of this vegetation was studied by following changes in biomass, composition and nutrient content over time. The fallow vegetation rapidly covered the soil after crop harvest. Right from the start *C. odorata* was the dominant species, at an average growth rate of 8.7 t ha^{-1} per year. Standing biomass of the fallow vegetation reached a peak of 22 t ha^{-1} in the third year, while in subsequent years growth stagnated as a result of dieback of *C. odorata*. In the fifth year other woody species tended to succeed *C. odorata* as the main component of the fallow vegetation. In five years the vegetation accumulated 130 kg N, 9 kg P and 160 kg K ha^{-1}. Results suggest that a fallow period of three years is most appropriate when using this type of fallow vegetation in semi-permanent food crop production systems.

Keywords: *Chromolaena odorata*, fallow species, fallow period, shifting cultivation alternatives, Côte d'Ivoire, biomass accumulation, nutrient uptake, weed suppression, succession

Introduction

In humid West Africa traditional shifting cultivation can no longer provide enough food for the increasing population. Moreover, further extension threatens the remaining tropical forests. Farmers extend cropping periods and shorten fallow periods but they keep relying on the natural fallow to maintain the chemical and physical soil properties and to reduce weed growth at the start of the subsequent cropping period. Whether crop production under these practices is stable and efficient depends on the length of the fallow period (Nye & Greenland, 1960) and on characteristics of the fallow vegetation (Jaiyebo & Moore, 1964; Nye & Hutton, 1957). The trend to shorten fallow periods is clearly demonstrated in some parts of Africa and Asia, where farmers no longer allow the forest vegetation to re-establish. They already clear the field after a few years of fallow, when the vegetation mainly consists of the shrub *C. odorata* (Dove, 1986; De Foresta & Schwartz, 1991).

The composite *C. odorata*, native in Central and South America, has spread rapidly through Africa and Asia during the last century following the more intensive land use (Cruttwell-McFadyen, 1991; Gautier, 1993). Because of its enormous seed production and rapid growth (Gautier, 1992; Yadav & Tripathi, 1982) *C. odorata* is a predominant colonizer of open spaces. Hence, it is considered a serious weed in agricultural systems where the spontaneous regrowth of the natural vegetation is hampered by intensive cultural practices (Audru *et al.*, 1988; Holm *et al.*, 1977). Research on the species mainly deals with control measures, whereas studies on its growth and development are scarce and focus on its role in the secondary succession (Gautier, 1992; De Rouw, 1991; Saxena & Ramakrishnan, 1984; Toky & Ramakrishnan, 1983a,b).

As more and more *C. odorata* dominated fallow tends to be used for food crop production, the prospects of this semi-permanent cropping system for the humid tropics needs to be examined with regard to productivity and sustainability. An agronomic assessment of the *C. odorata* fallow system was carried out from 1989 to 1992 in South-West Côte Ivoire, as part of a research programme of Wageningen Agricultural University on analysis and design of land use systems in that region. In this paper dry matter production, nutrient accumulation and suppression of herbaceous species in the *C. odorata* fallow vegetation over time are discussed. The aim was to gain a thorough understanding of the growth of this species, needed to identify the appropriate length of the fallow period for optimum nutrient management and weed suppression. 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). This involved monitoring vegetation development on fallow plots of different ages.

Materials and methods

Site selection

The study area is situated near the village of Taï, in the lowlands of South-West Côte d'Ivoire (5°N, 7°W). It has as a humid tropical climate. Rainfall is bimodally distributed over the period March–October and amounts to an annual mean of 1885 mm (Collinet *et al.*, 1984). The dry season extends from November to February. Mean monthly temperatures range from 24.7 °C to 27.4 °C. The study sites are located at the higher parts of the rolling to undulating landscape and are representative of 30 to 50% of the area (De Rouw *et al.*, 1990). Soils on these positions have similar characteristics: they are gravelly, strongly weathered and chemically poor. The upper 5 cm of the soil is sandy loam, on top of a 50 to 90 cm deep layer of sandy clay loam with a high gravel content. The soil below this layer is clayey and contains a small amount of gravel only. These soils are classified as Ferric Acrisols (Van Reuler 1996).

The growth of the *C. odorata* fallow vegetation was studied from May till November 1991 on twelve plots left fallow by farmers for different periods. On three of these plots the fallow period started during the observation period and these plots 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 observations (June 1991) by the research team in order to rule out possible differences in farmers' weeding practice. The other nine 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 had been cropped more than once during the ten years prior to the last cropping.

Observations

The dry weights of the above-ground biomass and litter were determined by sampling the vegetation. Details of the sampling procedure are given in Table 1. 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. Samples of the vegetation were cut off at ground level and separated into *C. odorata*, other woody species, forbs and grasses. Subsamples of *C. odorata* and other woody species were separated into leaves and stems. The litter particles of *C. odorata* and other plant species were raked up (2 cm distance between rake teeth) and weighed. On the 0-Y and 1-Y plots, no collection was made as litter was practically absent. All samples were dried at 70 °C for 24 hours to determine the dry weight.

Leaf area index (LAI) of *C. odorata* was estimated by multiplying leaf dry weight by specific leaf area. The latter was determined in separate leaf samples.

The composition of the fallow vegetation was determined simultaneously with its dry weight, by counting plants of *C. odorata*, other woody species, forbs and grasses in all samples. 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

Table 1. Sampling method of dry weight of *C. odorata* fallow vegetation and litter.

	Age of the fallow vegetation (year)				
	0	1	2	3	5
Number of plots	3	3	2	2	2
Sample size (m^2)	3.75	7.5	9.0	9.0	9.0
Number of replicates	4	4	5	5	5
Sampling frequency [a]	2	3	3	3	3

[a] 2: August and October 1991, 3: May/June, August and October/November 1991

standing vegetation, the composition of the regrowth was examined 40 days after sampling for the areas sampled in May and August on the 2-Y, 3-Y and 5-Y plots. This was done by separately estimating the soil cover of *C. odorata*, other woody species, and forbs plus grasses.

The rooting pattern of one or two representative *C. odorata* plants per fallow age was studied. The lateral expansion was measured after exposing the superficial roots, the vertical penetration was determined in a 1.5 meter deep pit dug near the stem. As rooting appeared to be predominantly superficial, the root biomass was determined in the top 20 cm only. In quadrats (1 m^2) 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 visually separated from those of other species by their characteristic white colour and structure. The selected roots were dried and weighed. Rooting pattern and root biomass were measured once during the period March–November 1991. No observations were made on the 0-Y plots, since the methods used were considered impracticable for seedlings given their large numbers and fine root system.

The nutrient mass fractions in *C. odorata* and litter were determined in the samples taken in May-June, and in the root samples of the layer 0–10 cm. 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 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.

Data processing

Assuming a constant rate of biomass accumulation once the ground surface is covered (Van Heemst, 1986) and a constant proportion of the biomass that is lost as litter (Poels, 1987), the growth of *C. odorata* over time can be approximated by the rate of net dry weight increase:

$$dW/dt = C - kW \tag{1}$$

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

$$W = W_{max}(1-e^{-kt}) \tag{2}$$

with W_{max} the maximum dry weight of the above-ground *C. odorata* (kg ha^{-1}), and t the time (months). Dry weights of the above-ground biomass measured in August were used to estimate the growth.

Results

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, when values of 20.8 t ha^{-1} and 22.3 t ha^{-1} respectively were reached (Table 2). 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 2). 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. LAI increased with age of the fallow to a maximum of 5.6 on the 3-Y plots (Table 2). Seasonal changes in LAI were similar to those in the proportion of leaves in the *C. odorata* biomass: an

Table 2. 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 parentheses).

Fallow age (yr)	Observation date	Dry weights (t ha^{-1})						Proportion of leaves in *C. odorata* (%)		Leaf area index of *C. odorata*	
		C. odorata		Total vegetation		Litter					
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, maize was grown till August 1991, last weeding took place in June 1991

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.

The growth of the above-ground parts of *C. odorata* was well approximated by Equations 1 and 2 when the observed dry weights of this species in the fallow vegetation up to three years old were used (Figure 1). The maximum dry weight, W_{max}, calculated by extrapolation, was 36 t ha^{-1}. The relative mortality rate, k, was estimated at 2% $month^{-1}$ or 24% y^{-1}, and the growth rate of the biomass, C, at 727 kg ha^{-1} $month^{-1}$ or 8.7 t ha^{-1} y^{-1} during the first three years. 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 an increase in k, implying that Equation 2 was not appropriate to approximate the real growth of *C. odorata* older than three years.

Structure and 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

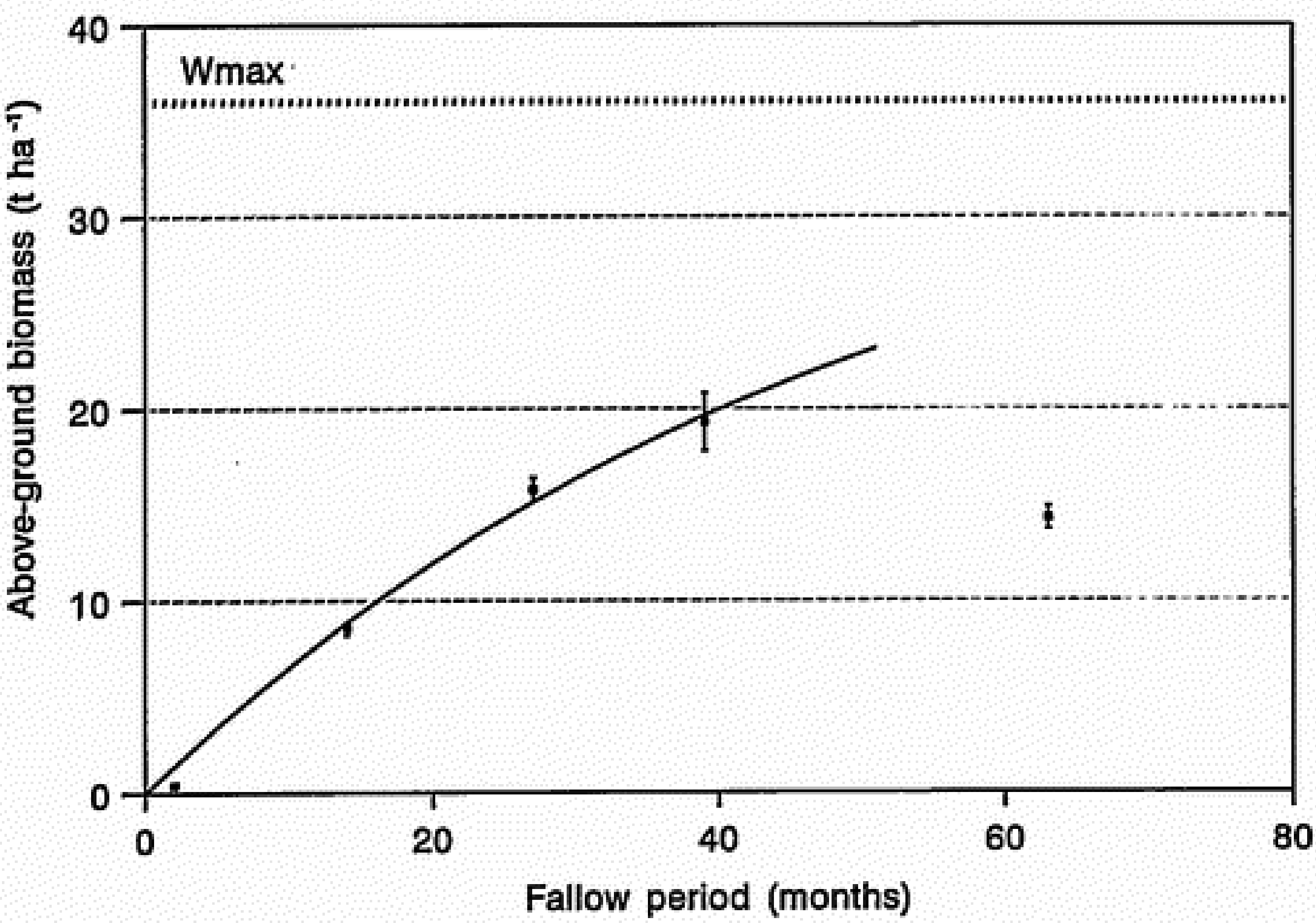

Figure 1. Dry weight increase of the above-ground biomass of *C. odorata* in relation to the length of the fallow period. (■ measured, —— fitted, ······ maximum biomass: the model $W=W_{max}(1-e^{-kt})$ was used to fit the curve).

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 on the 5-Y plots 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*, *Macaranga barterii* and *Xylopia aethiopica* had already reached 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 3). 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

Table 3. 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 parentheses).

Fallow age (yr)	Observation date	*C. odorata*		Other woody spp.		Herbs		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	

on the 5-Y plots where its density was similar to that of other woody species.

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 3). 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 composition and age of the fallow was also found in the regrowth of the fallow vegetation 40 days after sampling. The soil cover of *C. odorata* shoots dropped from 25% on the 2-Y plots 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 plots to 22% on the 5-Y plots. Other woody species covered less than 1% and 2% respectively. The soil cover was patchy, partly because *C. odorata* seedlings were most numerous and vigorous around the stumps of the same species.

Rooting pattern and root biomass of C. odorata

The rooting system of *C. odorata* was superficial. On all plots, about 90% of the roots was found in the upper 10 cm (Table 4). 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 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.

Nutrient content

The amount of nutrients accumulated in the various plant parts of *C. odorata* increased with the age of the fallow vegetation (Table 5). On the 3-Y plots, the nutrient content of the above-ground parts plus litter was much higher than that on the 1-Y plots, but differed only slightly from that on the 5-Y plots. The nutrient contents of litter and roots were lower than those of leaves and stem and branches. The impor-

Table 4. Root dry weight in 0–20 cm soil, its distribution over the soil layers and root:shoot ratio of *C. odorata* in fallow vegetations of increasing ages (standard error of mean in parentheses).

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)

Table 5. Nutrient content (in kg ha^{-1}) in various parts of *C. odorata* and in litter of fallow vegetations of increasing ages (standard error of mean in parentheses).

Fraction	Fallow age (yr)	N		P		K		Ca		Mg	
C. odorata leaves	1	30.0	(1.9)	2.0	(0.1)	22.8	(1.5)	22.5	(1.5)	9.6	(0.6)
	2	23.9	(2.4)	1.8	(0.2)	16.1	(1.6)	21.8	(2.2)	8.8	(0.9)
	3	41.8	(5.2)	2.7	(0.3)	26.2	(3.3)	27.7	(3.4)	11.5	(1.4)
	5	42.4	(1.2)	2.6	(0.1)	30.2	(0.8)	22.2	(0.6)	10.5	(0.3)
C. odorata stem and branches	1	33.0	(2.5)	2.3	(0.2)	84.2	(6.4)	19.1	(1.5)	11.6	(0.9)
	2	28.6	(3.5)	3.1	(0.4)	90.5	(11.1)	30.5	(3.7)	23.1	(2.8)
	3	52.2	(7.3)	4.7	(0.7)	135.0	(18.8)	47.9	(6.7)	24.2	(3.4)
	5	51.3	(2.3)	4.3	(0.2)	98.7	(4.4)	34.1	(1.5)	23.0	(1.0)
C. odorata roots (0–10 cm)	1	23.2	(6.2)	1.3	(0.3)	20.3	(5.4)	14.8	(4.0)	5.8	(1.6)
	2	11.5	(0.6)	0.8	(0.0)	14.0	(0.8)	4.7	(0.3)	8.7	(0.5)
	3	40.5	(9.8)	2.2	(0.5)	30.2	(7.3)	18.6	(4.5)	28.6	(6.9)
	5	25.8	(19.0)	1.4	(1.0)	20.7	(15.3)	9.6	(7.1)	15.2	(11.2)
Litter of the total vegetation	2	23.0	(15.1)	1.2	(0.8)	4.2	(2.8)	24.3	(15.9)	6.8	(4.5)
	3	16.3	(1.9)	0.8	(0.1)	3.6	(0.4)	18.8	(2.2)	4.7	(0.6)
	5	39.6	(0.5)	1.7	(0.0)	5.9	(0.1)	31.1	(0.4)	11.1	(0.1)
Above-ground parts of *C. odorata* plus litter	1	63.0	(3.4)	4.3	(0.2)	107.0	(6.8)	41.7	(2.2)	21.2	(1.1)
	2	75.5	(20.9)	6.1	(1.3)	110.9	(15.4)	76.6	(21.8)	38.7	(8.2)
	3	110.3	(10.5)	8.2	(0.9)	164.9	(21.6)	94.4	(7.9)	40.4	(4.2)
	5	133.3	(3.0)	8.6	(0.2)	134.8	(5.2)	87.5	(1.8)	44.6	(1.2)

tance of the leaves in the accumulation of N, P, Ca and Mg changed with the fallow age. On the 1-Y plots, 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.

Discussion

Vegetation growth, weed suppression and succession

C. odorata showed a fast and uniform natural establishment. The species rapidly dominated the fallow vegetation because the seedling population is high. At the same time, some of the plants developed from sprouting stumps, giving them a better initial start than the forbs and grasses that develop from seeds only. Moreover, *C. odorata* seedlings showed an early stem growth, indicated by the decreasing proportion of leaves in the *C. odorata* biomass after two months. For this reason they are considered strong competitors as reported by Gautier (1992) and Saxena & Ramakrishnan (1983).

The dominant position of *C. odorata* led to the suppression of the undergrowth of forbs and grasses during the first two years of the fallow period. Extending this period reduced the development of herbs in the regrowth after clearing, indicating the exhaustion of the seed bank. Probably seeds in the soil gradually lost viability because the shade of the dense and leafy *C. odorata* canopy prevented them to germinate. The horizontal layer of tangled *C. odorata* shoots in older fallows is thought to have enhanced this effect of shading. Hence, a fallow period of at least three years is desirable to facilitate weed control in crop production on land cleared from *C. odorata*.

Leaf fall which occurs during the dry season (Slaats, 1995) explains why the *C. odorata* dry matter increased mainly from May to November and why the leaf dry matter and LAI peaked between May and August. The high rainfall between August and November probably stimulated decomposition causing the sharp decline in the amount of litter accumulated on the vegetation floor. The decreasing number of *C. odorata* plants over time implies that little labour is needed for clearing when the vegetation gets older. Although stems become more lignified over time, the wood is soft, so felling hardly requires an effort. The falling density of *C. odorata* plants also implies a gradual reduction for weed control efforts during the cropping period, when the regrowing *C. odorata* stumps are the main non-crop plants. A similar decrease in the number of *C. odorata* plants was reported in studies in northeastern India. It was explained by a diminishing seed production after the third year and an increased mortality of seedlings and shoots as a result of strong inter- and intraspecific competition for resources (Kushwaha *et al.*, 1981; Yadav & Tripathi, 1981). In the older plots of the present study, the plant density of other woody species declined more gradually with the fallow age than the plant density of *C. odorata*, whereas the proportion of the former species in the total dry matter increased. 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. It is in line with the fallow vegetation development in northeastern India, where *C. odorata* and *Imperata cylindrica* are succeeded by other shrubs, trees and bamboos after five years (Toky & Ramakrishnan, 1983a). The mathematical expression for the dry weight increase of the above-ground biomass over time also indicated that there must have been a die-back after the third year. Competition from other woody species certainly played a role in this. But other factors seemed to be involved as well, given that *C. odorata* declined even on places where there were no tall tree shoots or shrubs. Possible reasons for the decline are the low soil fertility or the plant's inability to maintain its large, semi-woody support structure.

Nutrient accumulation

The rate of nutrient accumulation was highest during the first year; this may be the result of the well developed lateral rooting system. As in forest fallows

(Bartholomew *et al.*, 1953; Brubacher *et al.*, 1989), the content of leaves contributed considerably to the nutrient accumulation in the early stage of development, while in subsequent years it increased less than that of other plant parts, notably the stem and branches. The amount of accumulated nutrients increased up to the third year of fallow. Probably most nutrients are extracted from the topsoil because roots hardly penetrate into deeper layers.

Figure 2 shows that the pattern of nutrient accumulation in the *C. odorata* fallow in Taï is similar to those of the forest fallow in Taï during the first three years (Jaffré, 1985; Jaffré & De Namur, 1983) and the bush fallow in Belize (Brubacher *et al.*, 1989). Nutrient accumulation was somewhat lower in the fallow vegetation in northeastern India that during the first five years was dominated by *C. odorata* and *Imperata cylindrica* (Toky & Ramakrishnan, 1983a,b). On the other hand, it was much higher in the *Acioa barterii* fallow in Nigeria (Nye & Hutton, 1957) and in the forest fallow in Zaïre (Bartholomew *et al.*, 1953). During the first 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. 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 reported by Van Reuler & Janssen (1989, 1993).

C. odorata as fallow species

Qualities that make *C. odorata* a suitable fallow species are the rapid establishment and soil cover, and the ability to suppress herbaceous species and to accumulate as much nutrients as other fallow species during the initial fallow period.

As for soil fertility maintenance, nutrient and carbon contents in vegetation and topsoil under *C. odorata* fallow are likely to be lower than those under a mature forest fallow because the fallow period is shorter. Consequently, a smaller quantity of nutrients will be released after clearing and the initial nutrient status will be regained earlier during the fallow period. These characteristics may explain the relatively large yield decline in prolonged cropping on land cleared from a *C. odorata* fallow after a initial maize yield of about 3 t ha^{-1} (Slaats, 1995). They also imply that losses of nutrients due to run off and leaching after clearing are relatively small as a larger proportion of the nutrients is taken up by the crop. Thus the *C. odorata* fallow system has a more intensive land use than the traditional forest fallow system, an adequate control of weeds, a satisfactory yield when cropping periods are short, and probably an efficient use of the nutrients present in the vegetation-soil system.

With regard to the length of the fallow period, the present study showed that the presence of the herbaceous species in the *C. odorata* fallow vegetation was effectively reduced and the density of *C. odorata* stumps had considerably decreased after three years. At the same moment, the biomass accumulation and the uptake of most nutrients in the fallow vegetation had reached their maximum values. Therefore, a fallow period of three years is considered optimal for both reducing the weed pressure and contributing to soil fertility maintenance in a semi-permanent crop production system.

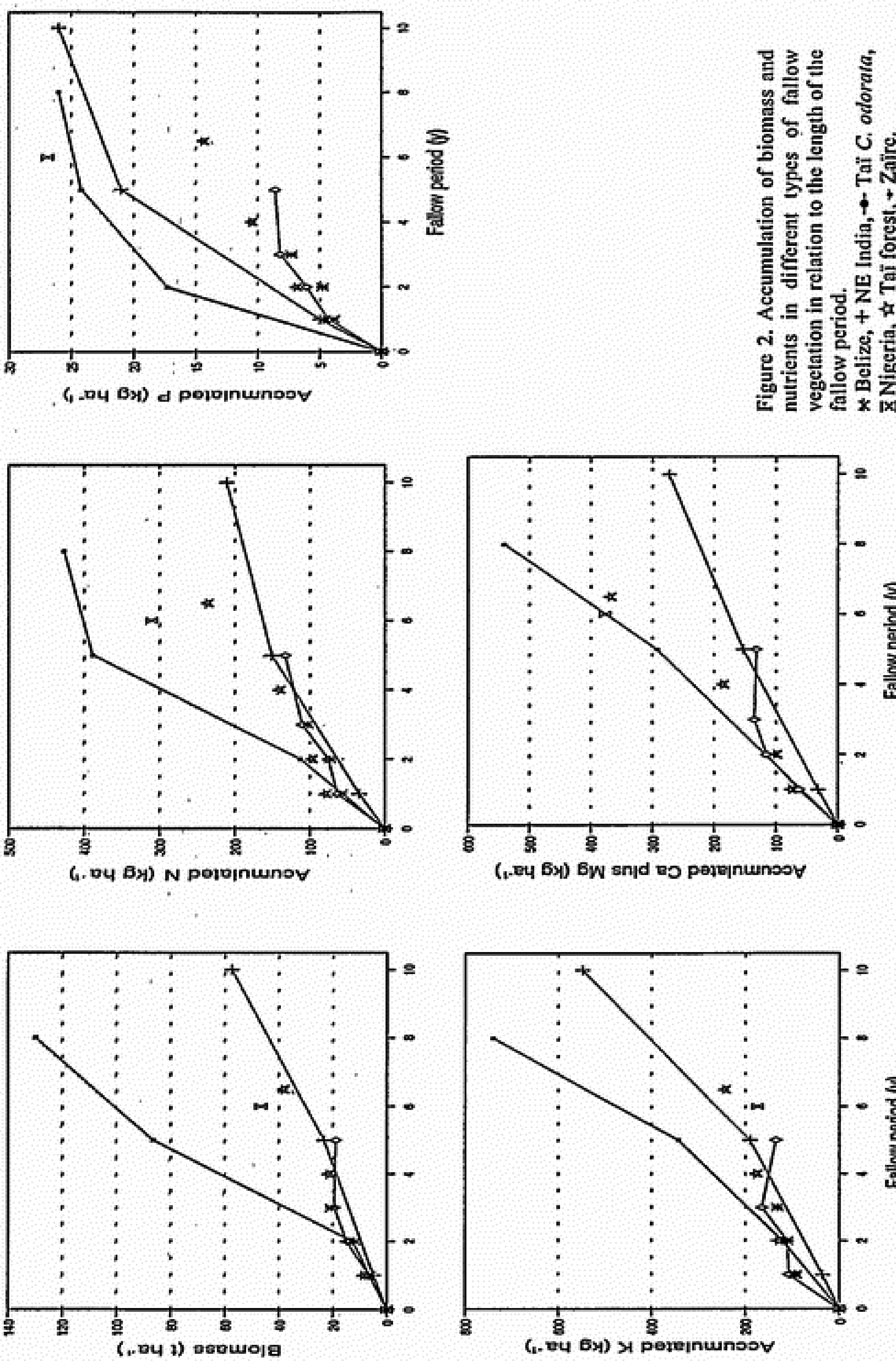

Figure 2. Accumulation of biomass and nutrients in different types of fallow vegetation in relation to the length of the fallow period.
✱ Belize, + NE India, -•- Taï *C. odorata*, ⌧ Nigeria, ☆ Taï forest, ◆ Zaïre.

Acknowledgement

We thank the Ministry of Scientific Research in Côte d'Ivoire for the permission to carry out this study. We acknowledge the field staff for their assistance in data collection. We thank Dr. J.F. Wienk and Dr. H. Van Reuler for critical reading of the manuscript.

References

Audru, J., M. Berekoutou, M. Deat, G. De Wispelaere, F. Dufour, D. Kintz, A. Le Mason & P. Menozzi, 1988. L'herbe du Laos. Synthèse des connaissances actuelles sur la plante et sur les moyens de lutte. Etudes et Synthèses de l'IEMVT 28. IEMVT-CIRAD, Maisons-Alfort, 186 pp.

Bartholomew, W.V., J. Meyer, & H. Landelout, 1953. Mineral nutrient immobilization under forest and grass fallow in the Yangambi (Belgian Congo) region – with some preliminary results on the decomposition of plant material on the forest floor –. *INEAC Série scientifique* 57. INEAC, Brussels, 27 pp.

Brubacher, D., J.T. Arnason, & J.D.H. Lambert, 1989. Woody species and nutrient accumulation during the fallow period of milpa farming in Belize, Central America. *Plant and Soil* 114: 165–172.

Collinet, J., B. Monteny, & B. Pouyaud, 1984. Le milieu physique. In: Guillaumet, J.L., G. Couturier, & H. Dosso, (Eds). Recherche et aménagement en milieu forestier tropical humide: le Projet Taï. UNESCO, Notes techniques du MAB 15. UNESCO, Paris, pp. 35–59.

Cruttwell-McFadyen, R.E., 1991. The ecology of *Chromolaena odorata* in the Neotropics. In: R. Muniappan & P. Ferrar, (Eds). Ecology and management of *Chromolaena odorata*. Biotrop Special Publication 44, ORSTOM and SEAMEO BIOTROP, Bogor, pp. 1–9.

De Foresta, H. & D. Schwartz, 1991. *Chromolaena odorata* and disturbance of natural succession after shifting cultivation: an example from Maycombe, Congo, Central Africa. In: R. Muniappan & P. Ferrar, (Eds). Ecology and management of *Chromolaena odorata*. *Biotrop Special Publication* 44, ORSTOM and SEAMEO BIOTROP, Bogor, pp. 23–41.

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

De Rouw, A., H.C. Vellema & W.A. Blokhuis, 1990. A land unit survey of the Taï region, South-West Côte d'Ivoire. Tropenbos Technical Series No.7. *The Tropenbos Foundation*, Ede, 222 pp.

Dove, M.R., 1986. The practical reason of weeds in Indonesia: peasant versus state views of Imperata and Chromolaena. *Human Ecology* 14:163–190.

Gautier, L., 1992. Contact forêt-savane en Côte d'Ivoire Centrale: Rôle de *Chromolaena odorata* (L.) R. King & H. Robinson dans la dynamique de la végétation. PhD-thesis University of Geneva, Geneva, 260 p.

Gautier L., 1993. Taxonomy and distribution of a tropical weed: *Chromolaena odorata* (L.) R. King & H. Robinson. *Candollea* 47:645–662.

Hase, H. & H. Fölster, 1982. Bio-element inventory of a tropical (semi)-evergreen seasonal forest on eutrophic alluvial soils, Western Llanos, Venezuela. *Oecologia Plantarum* 17:331–346.

Holm, L.G., D.L. Plucknett, J.V. Pancho & P.D. Herberger, 1977. The world's worst weeds – distribution and biology. University Press of Hawaii, Honolulu, pp. 212–216.

Jaffré, T. 1985. Composition minérale et stocks des bioéléments dans la biomasse épigée de recrûs forestiers en Côte d'Ivoire. *Acta Oecologica/Oecologia Plantarum* 6:233–246.

Jaffré, T. & Ch De Namur, 1983. Evolution de la biomasse végétale épigée au cours de la succession secondaire dans le Sud-Ouest de la Côte d'Ivoire. *Acta Oecologica/ Oecologia Plantarum* 4:259–272.

Jaiyebo, E.O. & A.W. Moore, 1964. Soil fertility and nutrient storage in different soil-vegetation systems in a tropical rain forest environment. *Tropical Agriculture (Trinidad)* 41:129–139.

Kushwaha, S.P.S., P.S. Ramakrishnan & R.S. Tripathi, 1981. Population dynamics of *Eupatorium odoratum* in successional environments following slash and burn agriculture. *Journal of Applied Ecology* 18:529–535.

Nye, P.H. & D.J. Greenland, 1960. The soil under shifting cultivation. Technical Communication No. 51. Commonwealth Bureau of Soils, Farnham Royal, 156 pp.
Nye, P.H. & R.G. Hutton, 1957. Some preliminary analyses of fallows and cover crops at the West African Institute for Oil Palm Research, Benin. *Journal of West African Institute of Oil Palm Research* 2:237–243.
Poels, R.L.H., 1987. Soils, water and nutrients in a forest ecosystem in Suriname. PhD-thesis Wageningen Agricultural University, Wageningen, 253 pp.
Saxena, K.G. & P.S. Ramakrishnan, 1983. Growth and allocation strategies of some perennial weeds of slash and burn agriculture (Jhum) in northeastern India. *Canadian Journal of Botany* 61:1300–1306.
Saxena, K.G. & P.S. Ramakrishnan, 1984. Herbaceous vegetation development and weed potential in slash and burn agriculture (Jhum) in northeastern India. *Weed Research* 24:135–142.
Slaats, J.J.P. 1995. *Chromolaena odorata* in food cropping systems. An agronomic assessment in South-West Ivory Coast. PhD thesis Wageningen Agricultural University, Wageningen, 177 pp.
Toky, O.P. & P.S. Ramakrishnan, 1983a. Secondary succession following slash and burn agriculture in north-eastern India. I. Biomass, litterfall and productivity. *Journal of Ecology* 71:735–745.
Toky, O.P. & P.S. Ramakrishnan, 1983b. Secondary succession following slash and burn agriculture in north-eastern India. II. Nutrient cycling. *Journal of Ecology* 71:747–757.
Van Heemst, H.D.J. 1986. Physiological processes. In: H. Van Keulen & J. Wolf, (Eds). Modelling of agricultural production: weather, soils and crops. Pudoc, Wageningen, pp. 13–26.
Van Reuler, H. & B.H. Janssen, 1989. Nutritional constraints in secondary vegetation and upland rice in South-West Ivory Coast. In: J. Proctor, (Ed). Mineral nutrients in tropical forest and savanna ecosystems. Special Publication 9 of the British Ecological Society, Blackwell Scientific Publications, Oxford, pp. 371–382.
Van Reuler, H. & B.H. Janssen, 1993. Nutrient fluxes in the shifting cultivation system of the Taï region, South-West Côte d'Ivoire II.Short-term and long-term effects of burning the slashed vegetation on the yield and nutrient uptake of food crops. *Plant and Soil* 154:179–188.
Van Reuler, H. 1996. Nutrient management over extended cropping periods in the shifting cultivation system of South-West Côte d'Ivoire. *Tropical Resource Management Papers* 12, Wageningen Agricultural University, Wageningen, 189 pp.
Walinga, I., W. Van Vark, V.J.G. Houba, & J.J. Van der Lee, 1989. Soil and plant analysis. Part 7: Plant analysis procedures. Department of Soil Science and Plant Nutrition, Wageningen Agricultural University, Wageningen, 263 pp.
Yadav, A.S. & R.S. Tripathi, 1981. Population dynamics of the ruderal weed *Eupatorium odoratum* and its natural regulation. *Oikos* 36:355–361.
Yadav, A.S. & R.S. Tripathi, 1982. A study of seed population dynamics of three weedy species of Eupatorium. *Weed Research* 22:69–76.