ELSEVIER

Catena 22 (1994) 133–152

CATENA

Effect of fire on soil, rice, weeds and forest regrowth in a rain forest zone (Côte d'Ivoire)

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Abstract

In south-western Côte d'Ivoire mature forest is felled and burned and one crop of upland rice is grown. Forest is then allowed to regenerate for 15 or more years before being cropped again. Soils are very gravely, clayey, acid, thoroughly leached and chemically poor. Forest, soil, rice, weeds and regrowth were studied in the fields of local farmers in permanent plots during 2–5 years. The fields (16) covered all currently cultivated soil types and forest types. Burning leads to an instant mineralisation of organic matter and the ashes produce a marked decrease in acidity (before burning pH 4.4–5.2, after burning pH 5.4–6.2). The nutrient availability is further stimulated by the reduction of Al activity in the soil solution. Fire is a decisive factor in cultivation: slightly burnt or unburnt areas are wholly unproductive. The rice thrives on the nutrients contained in the ash of the burnt forest rather than on the nutrients of the mineral soil: the nature of the soil is of relatively little importance, as long as large quantities of biomass are burnt. A fire of normal intensity destroys enough buried seeds and vegetative parts of forest plants to avoid weed stress, yet allows the survival of a sufficient number of forest plants for forest regrowth after the rice crop. Excessive burning kills sprouts and buried seeds. Regeneration comes then from seeds dispersed into the field after the fire, mainly grasses and forbs. Grassy shrub land or thickets are thus formed.

1. Introduction

The agricultural use of a forest soil requires the removal of the forest and substitution by crop plants. In most cases burning is the only device for clearing away the vegetation. With burning there is a loss of nitrogen and sulphur due to volatilisation and an instant mineralization of organic matter. The liberation of large quantities of mineral nutrients to the soil leads to an accumulation of all kinds if minerals but

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SSDI 0341-8162(93)E0023-S

especially phosphorus and potash (Brinkmann and Nascimento, 1973; Andriesse and Schelhaas, 1987). Burning produces a marked decrease in acidity which stimulates further release of cations. Most of the soil flora and fauna is destroyed (Nye and Greenland, 1960, p. 67; Dommergues, 1952; Maggi et al., 1990). Crops are then planted which grow while the decomposition of the forest residues continues. With most of the nutrients accumulated over many years present in the ash, it is not surprising that the first crop after burning is good. In Northern Thailand (Sabhasri, 1978), in Brazil (Salati and Vose, 1984) and in Amazonia (Sanchez et al., 1982) the first harvest was almost entirely dependent on minerals derived from the ash. After the area has been cropped for some time, the release from the organic residues further slows down and crops suffer. Liberated nutrients are used up, removed with the harvest, fixed by colloids or are lost by leaching (Harcombe, 1980). In most rain forest soils the supplying capacity of the soil is not sufficiently large to continue cropping. The field is abandoned to revert to forest. Secondary forest species can apparently absorb nutrients at lower ranges of availability than crops (Ahn, 1979).

In a forest soil, dormant seeds of many plants have accumulated through time. The all importance of this seed bank as a factor in weed infestation after clearing, has been recognised by many authors (Putz and Appanah, 1987; Uhl et al., 1981; Garwood, 1989; Alexandre, 1989). Fire is a well-known means to control this source of weed infestation. After felling many stumps and roots produce coppice shoots. Certain rain forest species may re-sprout after an initial burn, but successive fires eliminate most, if not all (Uhl, 1987; Whitmore, 1983; Smitinand et al., 1978). The unburnt, or slightly burnt areas serve a vital function in forest regrowth. The re-sprouting plants grow out rapidly, protect the soil against erosion and check weed growth (Zinke et al., 1978; Vine, 1954; Rappaport, 1971; Delvaux, 1958).

Many authors have shown how universal are the tropical systems of shifting agriculture, by which forest is slashed and burned for crops to grow in the ashes (Barlett, 1957; Ruthenberg, 1976; Nye and Greenland, 1960; Spencer, 1966). Most often the effect of burning has been studied on one particular aspect of the cycle, either the soil, weeds, crops or regrowth vegetation. This study is concerned with the full shifting cultivation cycle: land preparation, cropping and fallowing.

2. Study area

The Taï rain forest area (5°57′–5°20′; N latitude and 7°30′–7°14′; W longitude, Fig. 1) receives an annual rainfall of about 1900 mm, distributed in two rainy seasons. The farmers in the Taï region use the rainy season, from March to August, following the long dry period to grow crops. They convert forest into arable land by slashing and burning mature forest vegetation with the aim to crop it with rainfed rice for one season, and then let it return to forest. In this shifting cultivation system very short cropping periods alternate with long forest fallow (15–30 years) and a new field is required each year. Under the present population pressure, the cropping period is

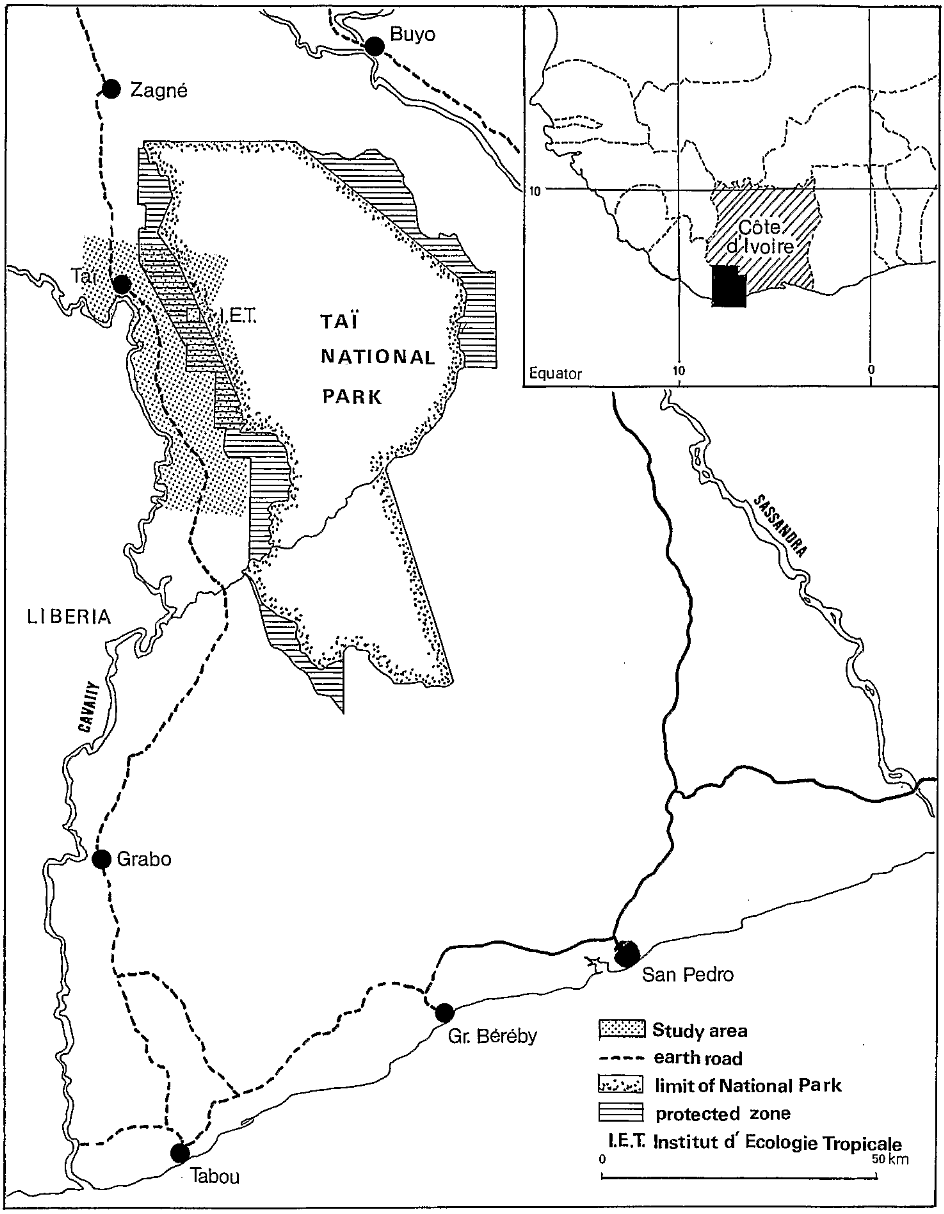

Fig. 1. Location map of the study area.

sometimes extended to two years and fallow periods are shortened to 6–10 years. Cocoa and coffee farming is widespread as a cash crop (De Rouw, 1991).

The primary forest vegetation is a tropical lowland evergreen seasonal forest in the UNESCO (1973) world classification. The standing biomass of primary forest varies from 350 t/ha in the valley bottoms to 500 t/ha on the slopes (Huttel, 1977), and of

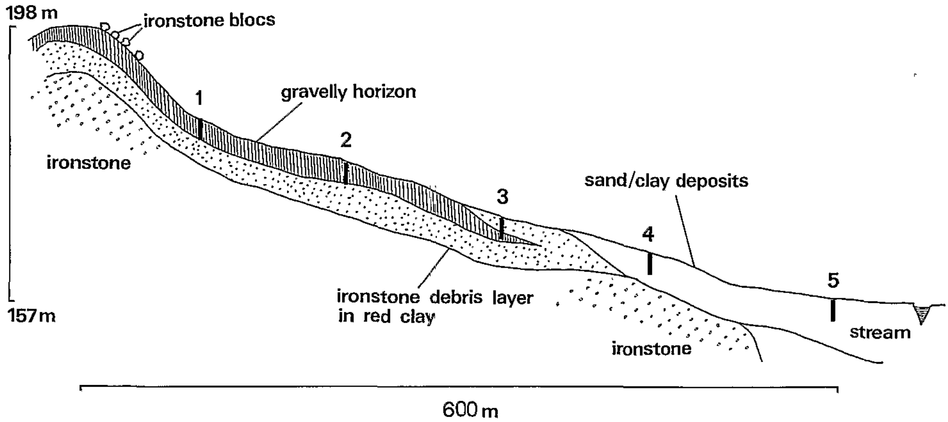

Fig. 2. Typical toposequence in the Taï region, after Fritsch (1980). For details see text.

secondary forest from 75 t/ha, 15 years old, to 230 t/ha, 40 years old (Jaffré and De Namur, 1983).

2.1. Landform and soils

The geology of the Taï region is dominated by granites and associated metamorphic rocks of the Precambium Basement Complex. The land is undulating to sloping. The difference in elevation between crest and the nearest valley bottom is generally between 20 and 40 m over a slope length of 500–700 m (Papon, 1973; Avenard et al., 1971). In the hot, humid climate the ancient rocks have weathered in situ to a depth of 3–20 m. The end products are severely leached, poor acid soils with kaolinite as the main clay mineral, low CEC, low organic matter content and much sesquioxides (Development and Resources Corporation, 1967; Fritsch, 1980; Van Kekum, 1986).

Soil maps (1 : 500,000 to 1 : 200,000) have been prepared by Leneuf (1956), Development and Resources Corporation (1967), Van Kekum (1986). More detailed studies were carried out by Fritsch (1980), who gave a good illustration of the way soils change along a toposequence from crest to valley bottom. Fig. 2 shows a cross-section of a typical toposequence of the small hills around Taï. The profile pits (Nos. 1–5) were described by Van Kekum (1986) and monoliths were made (National Soil and Reference Collection, ISRIC, Wageningen, Netherlands). The analytical data from these pits (topsoil under primary forest) are presented in Table 1

- From the hilltop to the mid slope (slope gradient 0–20%) the topsoil is built up by gravely layers to a depth of 70 cm: 50% of the volume consists of coarse fragments. The gravel is embedded into a red clay. These soils are classified as "sols ferrallitiques fortement désaturés, remaniés modaux" (CPCS, 1967) or as "Ferric Acrisols" (FAO/UNESCO, 1974). The soils are well drained.
- From mid slope to one third lower slope, extending over 100 to 150 m, the slope gradient is decreasing from 20 to 5%. The gravel layers become less thick, 20–

Table 1
Analytical data of topsoil under primary forest. Profile pits 1–5 refer to the typical toposequece of the Taï region, Fig. 2. Gravel content as% of whole soil, other analysis of fine earth only (after Fritsch, 1980 and Guillaumet et al., 1984)

Profile pit		1	2	3	4	5
Gravel	0–7 cm	76	75	3	0	0
(%)	7–20 cm	75	71	56	0	0
pH H_2O	0–10 cm	5.9	5.6	4.5	4.3	4.2
	10–20 cm	4.9	4.7	4.7	4.4	4.4
pH KCl	0–10 cm	4.8	4.2	3.6	3.8	3.7
	10–20 cm	3.8	3.8	3.8	3.8	3.9
CEC	0–10 cm	8.9	9.6	6.2	2.3	4.7
(m-equiv./100 gr)	10–20 cm	5.1	5.4	4.7	3.0	3.2
Organic C	0–10 cm	3.11	3.45	1.78	0.93	1.57
(%)	10–20 cm	1.32	1.08	0.89	0.65	1.18

30 cm, and they are generally covered by 10 to 20 cm of yellowish sandy loam. These soils are classified as "sols ferrallitiques fortement désaturés, remaniés à recouvrement apprauvris", or as "Plinthic Acrisols" or "Plinthic Ferralsols". The soils are moderately well drained.

- The lower one third slope, extending over 100 to 120 m, has yellow, sandy topsoil layers and more clayey layers below. In the first 100 cm no gravel occurs. The structure is massive but faunal activity has introduced large pores. In the lower part, about 120 cm deep, a mottled layer may be hardened to a petroplinthic layer (carapace). These soils are classified as "sols ferrallitiques fortement désaturés apprauvris indurés", or as "Xanthic Ferralsols", or "Plinthic Ferralsols". The soils are moderately well drained.
- In the valley bottoms the soils are hydromorphic with gley. They show much variation in texture both vertically and laterally, ranging from coarse, white sand to greyish clay loam. They are classified as "sols hydromorphes minéraux à gley d'ensemble", or as "Dystric Gleysols". The soils are poorly drained (Fritsch, 1980).

3. General methods

The effect of fire on soil, rice crop, weeds and forest regrowth was studied through trials in 16 fields of local farmers spread over different forest types and topographic positions (Table 2). The main differences between fields were related to topographic position and type of forest cleared: primary forest or secondary forest, either old (30–15 years) or young (7–6 years). The slash and burn technique of farmers was studied through direct observation and interviews. All fields were felled, burned and cul-

Table 2
Topographic position of experimental fields and type of forest cleared. Fields 6, 7, 8, 9, 10, 12, 13, 14 one rice crop, fields 1, 2, 3, 4, 5, 11 two successive rice crops

Forest type cleared	upper slope	mid slope	lower slope	valley bottom
Primary forest	6		4, 5, 16	5, 10
Secondary forest (14–30 yrs)	12	1, 11, 14	7, 13, 3	
Secondary forest (6–7 yrs)		2	8	9

tivated with rice following local practice. The commonest local rice variety was used, a long cycle (150 days) land race "Demandé".

Sites (1 ha) were surveyed before clearing: the soil by augering down to 120 cm and the vegetation by making relevés. Rice trials were conducted during four growing seasons: 1983, 1984, 1985 and 1986. Studies of the forest regrowth on these fields continued up to 1988. Fields were abandoned after the rice harvest, 5–6 months after burning. The experimental fields 1, 2, 3, 4, 5 and 11 (Table 2) were re-cropped with rice at the onset of the following long rainy season. Slashing and burning the weedy regrowth preceded this second rice crop. During cultivation and fallowing, observations were made in the same permanent plots: for the rice, yield and yield components: for the weeds, floristic composition and biomass: and for the soil, a chemical analysis of topsoil (0–10 cm) each year in each permanent plot. There were 12 permanent plots in field 1 and 2 and 6 permanent plots in the other fields. Plot size was 9 m^2.

After the cultivation of food crops the field is either left to revert to forest or planted with cocoa (or coffee). Soil data from rice fields were supplemented with data from the soil under cocoa plantations (39), 5 years after the initial burning.

In two fields, 1 and 3, covering the same slope, trials were designed for more detailed studies (see below).

3.1. Experiment on burning intensity and rice growth

Although the result of the first burning in field 1 was considered satisfying by the farmer, still about 5% of the surface had received only a mild fire. Normally burnt areas had charred trunks, branches and stumps and showed other visible traces of fire like black coal and white ashes on the soil surface. Slightly burnt areas were characterised by the absence of the above mentioned features and by the presence of twigs and an occasional living leaf.

In the experiment two factors were investigated: intensity of burning, normal or slight, and weeding, clean weeding or no weeding. Plots were units of 9 m^2 and there was one repetition. Rice was sown (dibbled) a few days after the burn. Observations on the rice (stand density, height, number of panicles, dry paddy yield) and on the weeds (number of individuals, species, growth form, height, cover, biomass) were made 41, 60, 90 and 150 days after sowing. Special attention was paid to coppice growth of stumps and roots which had been part of the secondary forest and had survived the fire. At the same time recordings on sprouts were made: number of resprouting plants/m^2, number of shoots/plant, and biomass produced.

3.2. Experiment on fire and the destruction of buried weed seeds

The day before felling started of the field 3 (1 ha), the forest area was divided into nine compartments, each 33 × 33 m. From each compartment 20 cores of soil were taken with an auger to a depth of 10 cm at regular intervals. After mixing the cores from a particular compartment, two wooden boxes (50 × 50 × 3 cm) were filled with a six kg soil sample each. The boxes were protected against seed contamination by mosquito netting and were regularly watered. The whole operation was repeated two months later, the day after burning. Thus a total of 36 boxes of topsoil were prepared, 18 with the pre-burn soil samples, 18 with post-burn soil. Emerging seedlings in the boxes were counted every two weeks. The day after the burning, sowing with rice started. Presence and abundance of weeds and crop performance was monitored in 45 quadrates, covering a total of 400 m^2.

3.3. Observations on forest regrowth following burning

This experiment was conducted with Dr. R. Moreau (soil scientist, ORSTOM) in order to study the effects of a normal burn on early succession. Soil and vegetation were sampled one year after the burning, implying that the regrowth that had sprung up after the rice harvest was about seven months old. A small area (28 × 35 m) of field 1 was used, outside the other observation plots. Burning had been normal to good and the place had received no weeding of importance. The topsoil was sampled ($n = 30$, 0–5 cm depth), at 7 m interval, in a grid pattern so as to make a map. From these samples the pH-H_2O was determined. In the same area common plant species were mapped as well as maximum height growth of the vegetation. The development of the vegetation was mapped using three categories:

1. Well developed. Secondary forest trees constituted a closed canopy 3–4 m above the ground, absence of grasses and weedy dicots (Composites);
2. Intermediately developed. Secondary forest trees formed a broken canopy 1–3 m above the ground, absence of grasses and presence of some weedy dicots (Composites);
3. Poorly developed. Secondary forest trees formed a broken canopy 1–2 m above the ground, presence of grasses and weedy dicots.

4. Results and discussion

4.1. Local burning technique

Farmers in Taï discriminate at least four beneficial effects from burning:
- it cleans the field, making it thus accessible to planting crops,
- it makes the topsoil soft and friable so dibble planting is easy and no tillage is needed,

Fig. 3. Soil surface of a field a few days after burning. Note the white ashes and the abundance of unburnt wood littering the soil. Burning followed the local practice and was considered successful.

– the ashes fertilize the soil,
– it eliminates many weed seeds and limits coppice growth.

Burning is a delicate work. Success depends on the correct timing of cutting activities, a proper use of the weather conditions and adequate firing techniques. If the clearing period is well planned in relation to the dry season, the felled vegetation dries rapidly and rots but slowly. If the clearing period is less well planned, with the rainy season starting, the debris dries slowly and rot becomes a problem. Primary forest and secondary forest are handled in different ways. There is no limit to the period a slashed primary forest is allowed to dry out. The leaves are generally hard and contain many chemical substances protecting them from rapid attack by micro-organisms. The main inconvenience is the enormous mass of material which dries but slowly. The debris of a secondary forest on the other hand, less resistant, is thus more quickly attacked by insects and micro-organisms. Here the main danger putting the whole burning operation at risk are layers of moist trash starting to rot. Care is taken to let the first layer of felled vegetation dry out sufficiently before it is covered with fresh material.

Burning is done at the end of the dry season, on windy afternoons. If the cut vegetation is very dry, burning can be delayed into the rainy season without serious consequences. There is no danger of flames escaping into the forest bordering the field because of constantly moist conditions there. The midribs (rachis) of the dry leaves of the Raphia palm are split and tied together with lianas, to form torches about 2 or 3 m long. The burning end of the torch is trusted into the dry vegetation every three or four metres. The farmer works against the wind, covering all the field by walking in a zig-zag. Burning is never complete (Fig. 3). Places with too thick a layer of trash and patches covered by moist material, especially field margins, will only be slightly burnt. Unburnt logs and stumps are left as such. The only reason for which a burning may be repeated — but this is rare — are large unburnt trees, felled but not cut to pieces, which prevent with their branches access to part of the field. This wood is cut, piled and burnt in small heaps, while the sowing of another part of the field has already started. The deposit of the ashes forms an irregular pattern, but ash is not re-distributed over the field. An incomplete, spotty burning is quite common, a poor overall burning is less frequent. The chief reason for burning to fail is that the felled vegetation is still moist. The field is then considered lost.

Shifting cultivators in the wet tropical forest region either subsist on cereals (rice or maize) or tubers (cassava, yams etc.). One, careful burning in order to get as much ash as possible is done by rice (or maize) cropping people (Zinke et al., 1978; Sevin, 1983; Andriesse and Schelhaas, 1987; Swaine and Hall, 1986). Piling up and re-burning the smaller logs and branches not consumed by the first fire in order to clean the field is often practised by shifting cultivators planting mainly root crops (Grenand and Haxaire, 1977; Hames and Vickers, 1983; Budelman and Zander, 1990). A soil surface littered with unburnt material greatly hinders the work of planting and digging up tubers. The unburnt surface of the field, whether after one or two burnings, is often not even planted because the soil is utterly unproductive (Grenand, 1979; Buschbacher et al., 1988).

4.2. Fire and changes in the topsoil

Ash input after burning a primary forest in Taï; was measured at 242 and 208 gram ash per m^2 (Guillaumet et al., 1984, p. 163). Burning was far from complete but the field was suitable for rice planting. The same field had an important fine litter adding, estimated at 0.5 kg/m^2 which disappeared completely within four months after burning. A quite complete burn of a Costa Rican rain forest brought 670 gram ash per m^2 (Ewel et al., 1981), and a normal burn in Amazonia, left about 400 gram ash per m^2 (Seubert et al., 1977). A rapid decomposition of unhumified material was also reported from Ghana (Nye and Greenland, 1964). To see better the effect of fire on a number of chemical soil characteristics, data from soils similar in gravel and clay content and in topographic position are shown in Table 3. The analytical data do not differ greatly as to measured N, C, P_2O_5 and CEC. All values are very low. The C/N is hardly affected by burning and values of total P are low in all soils. Changes in available P_2O_5 (Olson, 0–10 cm) measured before and after burning a primary forest in Taï, were not significant at the 1% level. However, values were so low that the limits of detection might have been reached (0.01–0.02%, Guillaumet et al., 1984, p. 169). It has been observed that measures of total P in 1 : 1 lattice clayey soils do not give much information on quantities available to the plant. In addition, these acid soils tend to fix phosphate (Ahn, 1970, pp. 166 and 229).

Fritsch (1982) found that the cation exchange complex in these kaolin clay soils is related to the quantity of organic matter present. For primary forest he concluded that the increase in non-biological mineralization during the first year after felling releases approximately 5 ton of carbon/ha and 2 ton of nitrogen/ha, resulting in a

Table 3
Analytical data from pre-cultivation sites and rice fields (6–12 months after burning, topsoil 0–10 cm). All soils mid slope, correction have been made for the gravel content (0.4–29%) of each sample

	Organic N (%)	Organic C (%)	Total P_2O_5 (%)	CEC (m-equiv./100 gr)	pH H_2O	pH KCl
Pre-cultivation soils						
Primary forest						
(Fritsch, 1980)	0.107	1.378	0.025	5.30	4.5	4.0
(variance)	(0.005)	(0.024)	(0.003)	(0.041)	(0.4)	(0.3)
Secondary forest (14–30 yrs)						
Fritsch (1980)	0.98	1.185	0.024	4.70	4.7	4.0
(variance)	(0.011)	(0.187)	(0.001)	(0.420)	(0.2)	(0.1)
This study	0.124	1.435	0.018	6.70	4.2	3.9
(variance)	(0.007)	(0.253)	(0.003)	(0.630)	(0.1)	(0.1)
Rice fields						
In primary forest						
Fritsch (1982)	0.090	1.223	0.023	4.59	5.7	4.8
(variance)	(0.011)	(0.138)	(0.002)	(0.400)	(0.1)	(0.1)
Van Reuler and Janssen (1989)	0.095	0.894	0.026	4.19	4.5	N.D.
(variance)	(0.009)	(0.034)	(0.003)	(0.275	(0.4)	
In secondary forest (14–30 yrs)						
This study	0.113	1.541	0.022	6.92	6.5	5.8
(variance)	(0.033)	(0.324)	(0.008)	(1.830)	(0.7)	(0.7)

slight decrease in soil organic matter. This seems less clear where a secondary forest is burnt (Table 3).

Nye and Greenland (1960, p. 70) state that on very acid soil the rise in pH is one of the most important effects of burning as it indicates a substantial increase in the availability of many cations. It also reduces aluminium activity in the soil solution. At low pH levels aluminium hydroxy ions block negative sites on the kaolin clays. As the pH is raised, insoluble $Al(OH)_3$ is formed, thereby freeing the negative charged sites. The relationship between pH and Al saturation has been studied by Blokhuis (De Rouw et al., 1990). In Fig. 4 values from topsoil (0–10 cm) of soils resembling the

Table 4
pH-H_2O and pH-KCl of soils (0–10 cm) in rice fields one year after burning at different positions on the slope

	upper slope ($n = 15$)	mid slope ($n = 15$)	lower slope ($n = 6$)	valley bottom ($n = 3$)
pH H_2O	6.2	6.0	5.7	5.4
pH KCl	5.5	5.3	4.8	4.7

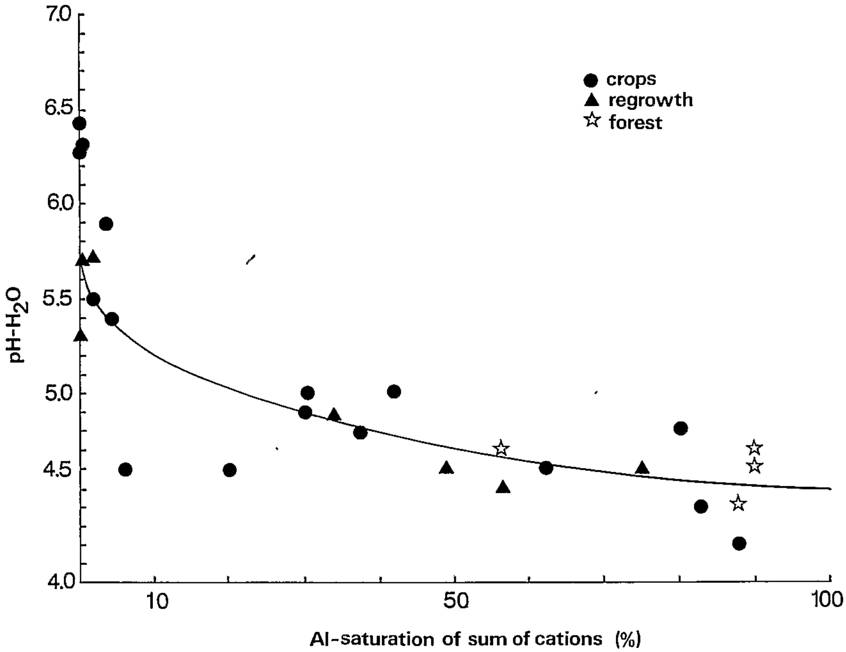

Fig. 4. pH and aluminium saturation relationships in topsoil (0–10 cm) of soils resembling the typical toposequence (Fig. 2). Analysis from pits in the Taï region, Appendix 9, De Rouw et al. (1990).

typical transect described in Fig. 2 are shown. A saturation of 50% is considered critical for crop growth. This is reached when pH-H_2O drops below 4.8, as is the case in primary and secondary forest soil before burning (Table 3). After burning average levels of pH in the topsoil are such that almost all Al is precipitated.

Although Andriesse and Schelhaas (1987), Brinkmann and Nascimento (1973) and Tomkins et al. (1991) observed many changes in the topsoil as a result of slashing and burning of a tropical forest (increase in total and exchangeable phosphorous and other cations, a rise in pH, a decrease of the aluminium content level, as well as a rise in CEC and base saturation); no such dramatic changes except for pH were measured in the topsoils of the Taï region (Fritsch, 1982, Guillaumet et al., 1984, pp. 163–170). We will use the surface pH as main indicator for the likely release of cations and other topsoil changes.

Table 5
pH-H_2O and pH-KCl of soils (0–10 cm) under young secondary forest, 1, 2, 3, 4, and 5 years after burning

Years after burning	1 ($n = 18$)	2 ($n = 19$)	3 ($n = 20$)	4 ($n = 25$)	5 ($n = 4$)
pH H_2O	6.1	5.8	5.0	5.4	4.7
pH KCl	5.4	5.0	4.5	4.4	3.8

Table 6
pH-H_2O of soils under cocoa plantations after felling different types of forest, five years after burning

Forest cleared		Primary ($n = 30$)	Secondary ($n = 9$)		
Age			3–6 years	8–15 years	> 30 years
pH H_2O	0–10 cm	4.7	6.0	7.2	5.4
	40 cm	4.7	5.8	6.8	5.1

pH changes in the topsoil

Generally rice fields situated uphill are less acid than those occupying lower positions on the slope (Table 4). This difference exists already in soils under primary forest (Guillaumet, 1967; Fritsch, 1980; Moreau, 1983).

After the cultivation period, while a forest regrowth develops, acidity increases slowly with time (Table 5). If the farmers plants cocoa after the rice harvest instead of leaving the land to fallow, pH values are still high five years later (Table 6) especially if the plantation was established in secondary forest. The difference in acidity between soils under forest regrowth and under cocoa five years after burning the forest, is probably due to a decision of the farmer. He slashes and burns a patch of forest for rice every year but chooses the most promising soil to plant cocoa.

The data in Tables 3, 4 and 5 express the general knowledge among Taï farmers, namely, that the beneficial effects of burning are easiest exploited if one prepares a field mid-slope, felling a secondary forest about 18–25 years old.

On places where an excessive quantity of biomass has been consumed the upper few centimetres of the soil are blackened with charcoal. Further down to about 5–7 cm the soil is coloured red. The pH-H_2O on these spots (0–5 cm) is always over 7.5 to a maximum of 8.4, six months after burning. A normally burnt field always has a few per cent of its surface occupied by such black spots.

4.3. Burning intensity and rice

Normally burnt and slightly burnt areas

A farmer drops five to ten rice seeds in a hole bored in the topsoil with a pointed stick. Densities of the rice plants thus depend on the number of rice seeds buried together in a hole and the number of such holes per unit area. Table 7 shows differences in rice performance between plots where burning had been normal and plots where burning had been slight. Plots were kept weed-free. In the normally burnt plots all emerging hills carried fertile panicles, this in contrast with the slightly burnt plots where 28% of emerging hills remained vegetative. All plots were sown by the same farmer in the same manner so we suppose that densities of sowing had roughly been the same for all plots. Bad rice condition in the slightly burnt plots was visible through many aspects of crop development: poor seedling establishment, stunted height growth, few panicles formed of which 35% was infertile, and low grain weight.

Acid soils, lack of fertilizing ashes and the absence of the other beneficial effects of

Table 7
Intensity of burning and rice yield components. Plots were clean weeded. Values within a column followed by the same letter are not significantly different at a 1% level

	Normally burnt		Slightly burnt	
pH H_2O (0–10 cm, 5 months after burning)	6.8	7.3	5.6	5.2
Number of hills/m^2 emerged	7.44	6.44	6	6
Number of hills/m^2 present at harvest	7.44	6.44	5.89	5.78
Number of hills/m^2 with fertile panicles	7.44	6.44	3.89	4.78
Number of rice plants/hill 41 days after sowing	6.52a	5.69a	3.17b	3.5b
(variance)	(3.48)	(2.87)	(2.10)	(1.87)
Height of rice plants/hill 41 days after sowing (cm)	34a	38a	21b	29b
(variance)	(6.28)	(9.37)	(5.41)	(7.32)
Height of rice at harvest (cm)	160	160	100	120
Number of fertile panicles/m^2	48.9	43.2	5.8	10.2
Dry paddy yield (t/ha)	1.97	1.72	0.06	0.12

burning, resulted in almost total yield loss on slightly burnt places. In most of our experimental fields this was about 5% of the field surface. Fields prepared in primary forest have almost always high rates of unburnt or slightly burnt areas (10–30%). On-farm experiments in Taï by Van Reuler and Janssen (1989) showed that rice yields were extremely low where the topsoil remained acid after burning. Liming (broadcasted) had no effect, leading to the conclusion that rapid availability of minerals from ash plays a role in rice growth.

Soil type and paddy yield

Where rice was planted immediately after the slashing and burning of a primary or an old secondary forest, dry paddy yield was between 1.83 and 0.67 t/ha (mean of 6 plots of 9 m^2/field). Prominent soil features as gravel content in the topsoil, texture, topographic position, organic matter content and CEC, did not appear to have an effect on yield. In Sarawak, position on the slope appeared to be unimportant to crop yield al well (Andriesse and Schelhaas, 1987). The type of forest cleared, primary or secondary, and the length of the previous fallow period (15–30 years), did not have a significant effect on yield either. Thus it seems that the rice crop thrives on the nutrients contained in the ash rather than the nutrients of the mineral soil: the nature of the soil is of relatively little importance as long as large quantities of biomass are burnt.

In the experimental fields where rice cultivation continued a second year, all fields suffered severely from weeds, while pests (rodents) and diseases were frequent. Dry paddy yields were below 0.20 t/ha in the fields with thick gravely layers in the topsoil (1, 2). One middle slope field (11) yielded 0.72 t/ha. Here, soil conditions were somewhat better than average: a loamy, gravel free layer down to 30 cm and a slightly gravely soil down to 50 cm. Weed infestation was also less. The lower slope fields (3, 4) yielded 0.40 and 0.41 t/ha. The clayey valley bottom field (5) yielded 0.67 t/ha.

Fig. 5. Example of a well burnt rice field being weeded with a machete. Weeding was delayed to three months after burning as few weeds were present. The field was prepared in a valley bottom. (r = charred Raphia palm, t = Tarrietia utilis, primary forest tree left standing).

Though the occurrence of weeds and pests made interpretation of the soil data difficult, we may conclude that soils somewhat less poor (field 11, 5) have more possibilities to sustain a second rice crop. In the period between two successive crops little biomass is produced, so very few new nutrients are liberated by burning this regrowth. Much of the nutrients liberated by the first burning have been subject to leaching especially in well drained soils. Subsequently, the second rice crop puts higher demands on the soil and some of the intrinsic differences of soils show up in the condition of the crop. The fields prepared in young secondary forest (2, 8, 9) though thoroughly burned, suffered from weed stress. Yields were between 0.3–0.6 t/ha dry paddy.

4.4. Fire and weeds

Destruction of buried seeds

The number of seedlings emerging from 108 kg of topsoil sampled in field 3 before burning was 1652, and 970 plants emerged from the 108 kg topsoil sampled the day after burning. This implies a reduction from about 2000 viable seeds/m^2 in the pre-burn soil, to about 1100 seeds/m^2 in the burnt soil: almost half of the number of seeds had lost its ability to germinate. Actual weed densities during the cropping period in the field 3 never exceeded 70 weed plants/m^2, being only 6% of the stock buried in the soil. Little or no weeding was required. Most of the weeds in the boxes, either from the pre-burn or post-burn samples, and in the field belonged to woody species, mainly secondary forest trees. Fig. 5 shows a rather well burnt field and a farmer weeding

Table 8
Effect of burning intensity on rice yield components and weeds. Plots were not weeded

	Normally burnt		Slightly burnt	
pH H_2O (0–10 cm, 5 months after burning)	6.8	7.3	5.6	5.2
Rice				
Height of rice at harvest (cm)	180	180	100	110
Number of fertile panicles/m^2	34.4	27.2	3.0	6.9
Dry paddy yield (t/ha)	1.29	1.81	0.03	0.13
Weeds established from seed				
Height of weeds at harvest (cm)	150	150	50	100
Number of weeds/m^2 at harvest	89	25	75	81
Total biomass produced in 5 months (gr. dry weight/m^2)	164	73	93	110
Re-sprouting stumps of forest plants				
Height of re-sprouting plants at harvest (cm)	150	50	50	50
Number of re-sprouting plants/m^2 at harvest	1.33	0.80	5.67	3.56
Number of shoots/m^2 at harvest	5.56	3.56	21.89	17.44
Total biomass produced in 5 months (gr. dry weight/m2)	25.6	26.9	38.5	36.3

with a machete. Weeding in this case was delayed to three months after burning, as few weeds were present.

A similar experiment in Costa Rica demonstrated the disappearance through burning of 52% of the seed stock which was initially valued at 8000 seeds/m^2 (Ewel et al., 1981). Saxena and Ramakrishnan (1984) in India found equally significant weed seed reduction after burning of a 20 year old forest. Seeds to a depth of 5 cm could be killed by fire (Brinkmann and Vieira, 1971).

Weeds in normally burnt and slightly burnt areas

The number of weed plants established from seed was counted in the normally burnt plots and in the slightly burnt plots (field 1). Densities of plants/m2 were rather similar between 75 and 90, except for the somewhat excessively burnt plot (pH 7.3) where only 25 weeds/m^2 appeared during the growing season (Table 8). As rice suffered from the poor soil conditions in the slightly burnt plots, so did weeds. Average dry weight/plant and height was inferior to weeds in the normally burnt plots.

The number of plants regenerating by sprouting was strongly affected by the intensity of the fire: 5.9 re-sprouting plants/m^2 in the slightly burnt plots against 1.5 plants/m^2 in the normally burnt plots (Table 8). The number of shoots produced depended on the size of the plant and on the intensity of the fire the plant had suffered from. The same species coppiced with a double amount of shoots in the slightly burnt plots, resulting in an average of 5.5 shoots/m^2 in the normally burnt plots and 25.1 shoots/m^2 in the slightly burnt areas. Although more seeds and vegetative parts of

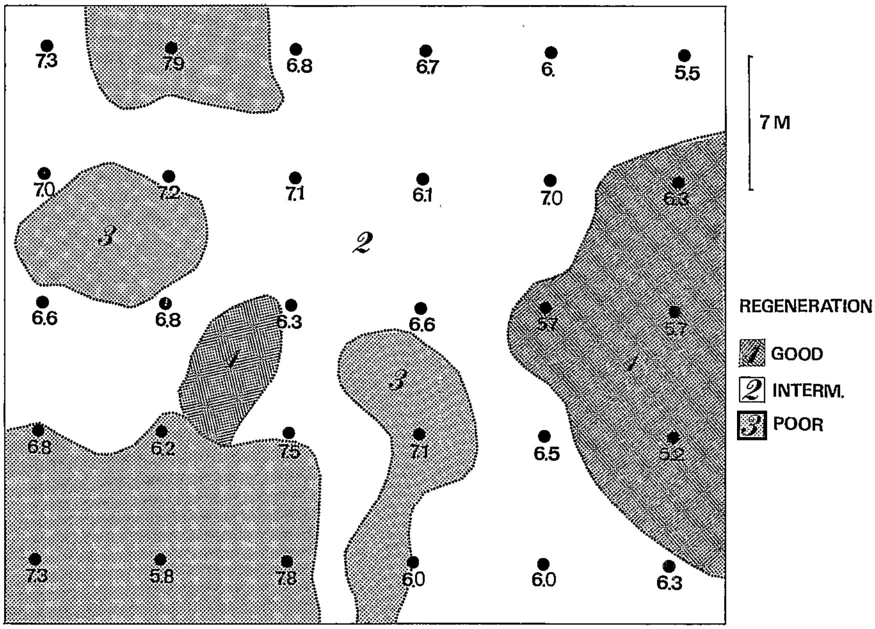

Fig. 6. Relation between pH-H_2O of topsoil (0–5 cm) one year after burning, 7 months after the rice harvest and quality of regeneration of the vegetation: 1 well developed, 2 intermediately developed, 3 poorly developed. Total area mapped 28 × 35 m.

plants survived burning in the slightly burnt plots, the amount of biomass produced was the same.

Densities of re-sprouting plants in other tropical forests remain inferior to our countings in Taï (Uhl, 1987; Stocker, 1981; Adedeji, 1984). In all rain forest areas most re-sprouting plants are woody. The danger of eliminating the re-sprouting plants by recurrent fires and provoking the establishment of a thicket vegetation or a grass land instead of a forested fallow has been demonstrated for many regions (Hopkins, 1962; Whitmore, 1982; Richards, 1964; Ramakrishnan and Toky, 1981).

4.5. Burning intensity and regrowth

The pH-H_2O of the topsoil (0–5 cm) of field 1 was sampled one year after burning the forest (7 months after the rice harvest). Values were mapped and a vegetation map representing three classes of regrowth was superimposed (Fig. 6). Acidity changed over small distances. Regeneration was best where the soil was rather acid (pH< 6.2). The floristic composition of the regrowth, reflected that of the plants emerged from the soil samples. In both cases secondary forest trees dominated the population. Where regeneration was poor, the soil was generally less acid. The floristic composition had little in common with the forest seed bank. Grasses, weedy dicots and forbs, prominent in this part of the field, were not encountered in the soil samples. We conclude that where the regrowth resembles closely the floristic composition of the forest seed bank, these plants have arisen from a seed bank present before opening up of the forest. The low pH attests to the small impact the fire had, leaving many seeds. Places with a vegetation cover not like the species composition of the forest seed bank, which places also had a high pH, had had most of the superficially buried seeds killed by an intense fire. The present cover on these places has probably arisen from seeds that were dispersed into the site after the fire. If regeneration occurs by propagules from outside the burnt area, plant species with very effective means of dissemination, like grasses and plumed Composites, colonise the area. The few trees present in the vegetation will take longer to suppress and shade out these arable weeds. The present experiment shows the possible consequences of destruction by burning of a local seed bank. The actual consequences in the small area studied were nil because of the vigorous growth of those trees present. The result would be a continuous cover of trees everywhere within a few months. In Taï, Kahn and De Namur (1978) observed no seedlings during six months in soil sterilised by burning. The population that eventually invaded those sites, mainly plumed Composites and grasses, was floristically different from the usual weed population in rice fields, but was similar to the one that swarmed into places where the topsoil had been removed by heavy machinery. This confirms our findings that sites lacking a soil seed bank are colonised by seeds from the "seed rain" and that herbaceous plants instead of woody plants are involved. In other parts of the wet tropics, over-cultivation and over-burning destroyed and impoverished the natural forest vegetation and this was found to be responsible for the encroachment of the savannah into the forest area (Hopkins, 1962). Moderate burning rather promoted the installation of woody colonisers surviving in the soil (Uhl et al., 1981; Garwood, 1989; Boerboom, 1974).

5. Conclusions

In the shifting cultivation system practised in the wet forest of Côte d'Ivoire, fire is a decisive factor in cultivation. Only the fertilizing input of the ashes and the corresponding decrease in acidity make cultivation of rice possible. The rice crop thrives on the nutrients contained in the ash of the burned forest rather than on the nutrients of the mineral soil, and so the nature of the soil is of relatively little importance, as long as large quantities of biomass are converted to ash. Because of demographic pressure, forest farmers tend to re-cultivate a field for a second rice crop, and fallow periods tend to shorten to 6–8 years. As a result less biomass is produced, so less nutrients are liberated by burning. Subsequently, the rice puts higher demands on the soil and the intrinsic differences in soil fertility will show up in the condition of the crop.

Successful burning both results in a small number of weeds and a great quantity of nutrients liberated. After a fire of normal intensity rice grows well. Weed stress is avoided because many buried seeds as well as vegetative parts of forest plants have perished in the fire. Nevertheless seeds and vegetative parts of forest plants have survived in sufficient numbers to allow a rapid forest cover once the field is abandoned. The development of these plants already present at the onset of regeneration prevents the invasion of grasses, weeds, and thicket-forming Composites.

A mild fire does not permit rice cultivation because of the poor availability of nutrients in these acid soils. Most of the buried seed stock survives the fire. Both re-sprouting plants and secondary forest trees established from seed produce rapid forest cover. Though excellent competitors against the invasion of grasses and weeds, less biomass is formed because less nutrients have been liberated by burning.

An intense fire sterilises the soil kills sprouts and buried seeds but allows rice to grow. Regeneration comes from seeds dispersed into the site after the fire. Widely disseminated species as grasses and weeds colonise the place, forming shrubby grassland or thickets. These low, closed vegetations are resistant to the process of reforestation.

Acknowledgement

I wish to thank the Ivorian Ministry of Research for its hospitality, and especially all Ivorian people of the M.A.B. field station in Taï for their enthusiastic co-operation in the field. I am much in debt to Mr. E. Fritsch, R. Moreau, and H. van Reuler for comments and suggestions during fieldwork and to Mr. J.-M. Meynard for comments on an earlier version of the paper.

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