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BRAZILIAN AMAZONIAN CABOCLO AGRICULTURE: EFFECT OF FALLOW PERIOD ON MAIZE YIELD

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Abstract

Traditional Amazonian farmers (*caboclos*) along the Xingu River near Altamira, Pará, Brazil, practice shifting cultivation using fallow periods (periods during which cultivated areas are temporarily abandoned and invaded by secondary forest) which they consider necessary to restore soil nutrients and control weeds and insect pests. At the end of the growing season, maize production was measured in the farmers' fields in randomly selected 9-m^2 quadrats. Yield was significantly higher in agricultural plots derived from secondary forest (n = 11) than from old growth ("virgin") forest (n = 11). Yield on plots derived from mature secondary forest (11-30 years old; n = 4) was also significantly higher than that on plots derived from young secondary forest (3-10 years old; n = 7) and "virgin" forest. A significant positive relationship was encountered between length of fallow period and maize yield over the range of fallow ages studied (3-30 years).

Keywords: Secondary forest, Successional forest, Amazon; Brazil; *Caboclo*; Fallow period; Maize yield; Slash-and-burn agriculture; Shifting cultivation; Swidden

1. Introduction

Secondary or successional forests are becoming increasingly widespread vegetation forms in the tropics (Brown and Lugo, 1990). These forests are often cleared for agriculture. The agricultural potential of fields cleared from stands of different ages is likely to be an important factor affecting the age to which farmers allow successional stands to regrow, and is also likely to affect their choice of sites for fields in secondary versus old growth or "virgin" forest. Here "virgin" forest refers to forest that has not been cut in recent decades, even though it could have been used for shifting cultivation by indigenous people in past centuries.

Shifting or swidden cultivation is the traditional form of agriculture used by human populations in Amazonia. Indigenous populations have used slash-and-burn agriculture for centuries as a means of subsistence (Carneiro, 1960; Harris, 1971; Meggers, 1971; Wagley, 1976; Gross et al., 1979). Caboclos or ribeirinhos, rural Amazon people of mixed Amerindian, Portuguese and Northeastern Brazilian ancestry (Parker, 1985), have also used this type of cultivation for many years (Moran, 1974; Wagley, 1976; Brabo, 1979).

In the most common form of shifting cultivation, clearings are opened in the original forest during the dry season, the cut vegetation is allowed to dry and is then burned. Partially burned wood is often gathered and burned again. Crops are planted at the beginning of the rainy season. The cultivation period lasts from one to two years. Afterwards, the areas are abandoned during a long fallow period, sufficient for regeneration of site quality prior to cutting the secondary succession in preparation for the next cropping period.

Abandonment of agricultural plots after 1-2 years is generally attributed to a gradual loss of productivity. This decline in yield has been linked to exhaustion of soil fertility and competition with weeds or brush (e.g. Penteado, 1967; Watters, 1971; Sánchez, 1973, 1976; Moran, 1981; Fearnside, 1985, 1986). The need for fallow to obtain good yields is also part of the folk wisdom of traditional Amazonian farmers. The importance of fallow periods in sustaining production in shifting cultivation systems has been suggested by many authors (e.g. Nye and Greenland, 1960; Egler, 1961; Ackermann, 1966; Sioli, 1973, 1980; Moran, 1981; Fearnside, 1986). Short fallow periods result in a reduction of soil fertility, thereby converting a potentially sustainable agricultural system into an unsustainable one (Moran, 1981; Smith, 1981; Fearnside, 1986). At present, little quantitative data exist to assess the benefits of different fallow periods.

In the present study we investigated the influence of fallow periods on maize (corn) yield in plots cultivated by a _caboclo_ population on the Xingu River near Altamira, Pará. Maize yield is more sensitive to the effects of acidic soil than are other crops in the area such as upland rice and manioc (Fearnside, 1986, pp. 200-201). Fallow period, in this system, corresponds to the age of secondary forest before it was cleared, burned and cultivated. Maize yield was also measured in plots derived from "virgin" forest for comparison with yields obtained on fallow land.

2. Study site and methods

The study was carried out between August 1989 and August 1990 in an area located on the left bank of the Xingu River, approximately 30 km north of the town of Altamira, Pará, Brazil. The study area is centered around a settlement called Arroz Cru da Gleba Pakissamba, or more simply as 'Arroz Cru,' in the municipality of Senador José Porfírio (3°16'S, 52°00'W). The climate is characterized by a rainy season (February-April) during which the lowest temperatures occur, and a dry season (August-November). Mean annual precipitation for the 1960-1980 period was 2000 mm at Altamira (Brazil, SUDAM, 1984). Precipitation during the study period was 1607 mm (at Arroz Cru). The temperature varies little during the year, with a difference of only 1.4°C between means for the hottest and coldest months and an annual mean of 26°C at Altamira (Salati and Marques, 1984).

Most soils in the area are Ultisols (latosols), which are deep, clayey and of low fertility. Most of the cations have been leached from these geologically old soils. They are generally low in phosphorus, very acid and high in aluminum (Brazil, Projeto RADAMBRASIL, 1974). This predominant soil type is interspersed with small patches of more fertile types: _terra roxa_ (Alfisol) and _terra preta do índio_ (anthropogenic black soil).

Two types of vegetation are found in the area: ombrophilous ("shade-loving") open submontane forest (As-0) and ombrophilous dense submontane forest (Ds-0) (Brazil, IBGE and IBDF, 1988; see Fearnside and Ferraz, 1995 for explanation of Amazonian vegetation types and codes). The average aboveground dry-weight biomass (live + dead) of these forest types is estimated to be 258 and 356 t ha^{-1}, respectively (Fearnside, unpublished, see Fearnside, 1994).

The human population of Arroz Cru is a traditional one, composed of individuals born in the State of Pará of Portuguese and Amerindian descent. Ninety-eight percent of the parents of the current inhabitants also lived in the study area or nearby. Before the 1970s, the population of Arroz Cru lived on fluvial islands of the Xingu River near the current settlement. While living on the islands the population survived mainly from extracting rubber latex (_Hevea_ *brasiliensis*) and collecting Brazil nuts (*Bertholletia excelsa*), complementing these activities with manioc cultivation, hunting and fishing.

During the 1970s, with the creation of the National Integration Program (PIN), the National Institute of Colonization and Agrarian Reform (INCRA) encouraged these people to move from the fluvial islands to *terra firme* (upland forest not subject to flooding). During this decade, the population moved and each family received a lot averaging 100 ha in area with definitive title of land ownership. Following resettlement, the principal occupation of the population became agriculture. This recent change explains the clear memory that the *caboclos* have of the age of vegetation in the cultivated areas.

Structured interviews were used to collect information from *caboclos* regarding the age of the secondary vegetation cut to make agricultural plots. Information on the history of the local population and agricultural management practices was also collected. Vegetation on fallow plots before clearing was classified into two age classes: young secondary forest (1-10 years) and mature secondary forest (11-30 years).

Maize yield was estimated in the fields of farmers who grew this crop using their normal seeds and methods: no attempt was made to establish controlled conditions, as by distributing identical seed or by instructing farmers to follow a uniform management protocol of planting density, planting dates, effort applied to weeding, etc. Differences among farmers undoubtedly contribute to random variation in our data, but there is no reason to believe that this variation would tend to bias the results in any particular direction.

To estimate maize yield, three 9-m^2 quadrats were chosen randomly in relatively homogeneous areas. In one plot with very variable terrain, three quadrats were chosen in each of two distinct sub-areas and the results averaged. In each quadrat, all ears of maize were collected and shucked, and the dried kernels were weighed on a spring balance accurate to 10 g. Total production for each plot was converted to yield per unit area.

A total of 37 plots were studied, but 9 of these were eliminated from the analysis. In 6 plots it was not possible to estimate maize yield. Five plots were excluded because they had a poor burn. Burning releases nutrients from the vegetation into the soil, and badly burned fields in areas with acidic soils produce stunted crops (Fearnside, 1986, p. 53). One plot was not used in the analysis because it was on *terra preta do índio* and one because it was on *terra roxa* (Alfisol), both of which are chemically fertile soils that could be expected to produce well independent of fallow period. One was discarded because it was in an area of _terra preta do índio_ and was also badly burned.

One plot was discarded because of severe attack by pests--a condition that would mask the effect of soil. Although crops are more susceptible to pests and diseases when the plants are weakened by nutritional deficiencies that are the result of poor soil, the tremendous variability in pest and disease attack would make the detection of soil effects impractical without increased sample size were severely attacked fields included in the analysis. On average, one would expect the effect of pests and diseases as augmented by soil exhaustion to magnify the effect on yields in the same direction as what would be detected on the basis of soil effects alone. We therefore do not believe that eliminating the severely attacked plot introduces a bias that would alter the direction of the result detected.

The exclusions, taken together, reduced the usable sample size to 11 plots in fields cut from "virgin" forest and 11 plots in fields cut from secondary forest. Of the secondary forest stands, 7 were young and 4 mature.

3. Results

The measured maize yields and the characteristics of the sites are given in Table 1. The relationship between fallow period and agricultural productivity is given in Equation 1. This indicates that maize yield depends on fallow period. Although the relationship is statistically significant, fallow period explains only 44% of the variance in maize yield.

$$Y = 0.0097\ X + 0.172 \qquad (1)$$
($r^2 = 0.44$, SE = 0.072, $p < 0.05$, n = 11)

where Y = maize yield (kg m^{-2}), and X = fallow period (years).

[Table 1 here]

An analysis of variance of differences in yield in fields cleared from secondary and "virgin" forest indicated a significantly higher yield of maize ($p < 0.05$, F = 6.6, df = 1, 20) in plots derived from secondary forest (X = 0.261 kg m^{-2}, SD = 0.091, n = 11) than in "virgin" forest plots (X = 0.166, SD = 0.082, n = 11). Including the pest-attacked field in the analysis would not alter this result, with higher yields ($p < 0.05$, F = 5.8, df = 1, 21) indicated in plots derived from secondary forest (X = 0.252 kg m^{-2}, SD = 0.091, n = 12) than in "virgin" forest plots (X = 0.166, SD = 0.082, n = 11).

The age category of the secondary forest affects maize yield. When three vegetation categories were considered (young secondary forest, mature secondary forest and "virgin" forest), a significantly higher yield was observed ($p < 0.05$, F = 5.9, df = 2, 20) in plots derived from mature secondary forest (X = 0.324 kg m^{-2}, SD = 0.060, n = 4) than in those derived from young secondary forest (X = 0.225 kg m^{-2}, SD = 0.088, n = 7).

Burn quality had a significant effect on maize yield in secondary forest plots. Yields were higher ($p < 0.05$, F = 15.8, df = 15) in fields with good burns (X = 0.253 kg m^{-2}, SD = 0.091, n = 12) than in fields with poor burns (X = 0.068 kg m^{-2}, SD = 0.009, n = 4).

4. Discussion

Agricultural plots in Amazonia commonly undergo a gradual decline in yield with continued cultivation. This decline is generally attributed to two factors: exhaustion of soil fertility and infestation by invading weeds. The relative importance of these two factors depends on the initial fertility of the soil (Sánchez, 1976). Where the soil is extremely infertile, exhaustion of nutrients is thought to be critical (Herrera et al., 1978). In richer soils, invasion by weeds and nutrient depletion are expected to be of more or less equal importance in diminishing yield (Popenoe, 1964). In the case of the Kuikuru Indians in the upper Xingu River, Carneiro (1960) holds that, rather than declining soil fertility, lack of workers to clear invading weeds forces farmers to abandon a site; these Indians prefer "virgin" to secondary forest for planting manioc because weeds are likely to be fewer, even though soil fertility under secondary forest would be adequate (Carneiro, 1983, p. 105). Other investigators have suggested that movement of indigenous tribes is unrelated to agricultural problems and occurs instead because of local depletion of the game and fish populations upon which these groups depend to meet their protein requirements (Gross, 1975; Roosevelt, 1980).

Leaving land fallow is one of the principal management techniques in this form of agriculture. The secondary vegetation that invades the abandoned plots accumulates nutrients, returning them together with organic material to the soil. Secondary forest growth also controls noxious weeds and helps improve porosity and other physical characteristics of the soil (Nicholaides et al., 1983; Fearnside, 1985; Moran, 1990). That secondary vegetation improves soil quality is accepted by many investigators, but the mechanisms responsible for this improvement remain poorly understood. One factor that would act in the opposite direction is the effect of burning on soil pH: because soil acidity can limit maize yields and burning raises soil pH, more frequent burning (i.e. shorter fallows) could result in higher pH and, consequently, higher yields (Fearnside, 1986, p. 139). This applies to the extremely acid soils of Brazilian Amazonia, where the positive effects of burning (especially raising pH and thereby increasing available phosphorus and reducing aluminum toxicity) outweigh negative effects in burning off nitrogen and sulfur.

While the changes associated with increased fallow length can have a variety of effects on crop productivity, some positive and some negative, our results from the Xingu region suggest that the net effect is positive, at least in the case of maize in the range of fallow ages studied (maximum 30 years). As fallow lengths increase beyond this age range and the vegetation comes to resemble "virgin" forest the relationship would become negative, as we found higher maize yields in soils originating from secondary forest than from "virgin" forest.

The apparently counterintuitive result of higher yields in secondary forest sites could have various explanations. We regard the possibility as unlikely that the result is an artifact of farmers having chosen the more fertile soil for clearing first, such that the native fertility of the secondary forest sites is higher than the "virgin" forest sites. The sites are nearby and the soils apparently identical, the plots with different (better) soil types having been eliminated from the yield analysis in the data selection.

According to Buol et al. (1975), the restrictions imposed by Amazonian soils on agricultural development are more chemical than physical. A higher chemical fertility is expected on plots derived from secondary forest due to greater burn efficiency. Secondary vegetation, with a larger quantity of branches and thin trunks, can be expected to burn better than "virgin" forest, where many thick trunks remain practically intact after burning. Although the relation of diameter to completeness of burning is very strong (Fearnside et al., 1993), poor burns can be significantly more frequent in secondary than in "virgin" forest clearings. For example, in 247 "virgin" forest burns studied among Transamazon Highway colonists, 76 (30.8%) were "bad" burns, whereas in 54 secondary forest burns, 31 (57.4%) were classified as "bad" ($p < 0.05$)(Fearnside, 1989). The current study of caboclos is suggestive of the same pattern: of 12 "virgin" forest burns, 1 (8.3%) was poor, while of 19 secondary forest burns, 5 (26.3%) were poor, but the frequency of poor burns is not significantly different between the two forest types ($p = 0.21$).

While burning brings a temporary increase in the availability of nutrients to the soil (Brinkmann and do Nascimento, 1973), rapid leaching of nutrients following burns may significantly reduce these benefits; up to 70% of the potassium may be rapidly lost and nearly all the phosphorus fixed in forms unavailable to crop plants (Moran, 1990). Burning may also have detrimental effects on the physical properties of the soil, increasing bulk density (compaction) and diminishing porosity. These changes tend to occur in recently exposed soils but appear to be reversible when the land is fallowed (Martins et al., 1991). Soil nitrogen may either increase or decrease on clearing depending on burn intensity (Fearnside, 1986), and is increased under fallow (Greenland and Nye, 1959).

The effect of burn quality differences between secondary and "virgin" forest could be obscured by the removal of cases with very poor burns in the selection of data for the analysis. However, including all of the fields in the study for which yield results are complete also suggests higher mean yield in fields cut from secondary forest ($\bar{X}$ = 0.214 kg m^{-2}, SD = 0.106, n = 19) than in "virgin" forest fields ($\bar{X}$ = 0.162 kg m^{-2}, SD = 0.079, n = 12), but the difference is not significant at the 5% level.

The action of secondary vegetation on the soil before slashing and burning secondary forest plots can have beneficial physical effects that result in an improvement in fertility as compared to soils under annual crops (e.g. Kleinman et al., 1996). Secondary forest trees have a larger proportion of biomass in the form of roots, some of which reach deep soil layers (Moran, 1990; Nepstad et al., 1994). The effect of secondary forest roots may be similar to those of tropical kudzu (_Pueraria phaeseoloides_), a leguminous vine used to maintain and improve soil quality in many agroforestry systems. _Pueraria_ roots have been shown to improve the matric structure and increase the porosity of clayey Ultisols compacted by heavy machinery (Chauvel et al., 1991). Soils planted with _Pueraria_ have a larger volume of macropores than do soils under primary forest, increasing the availability of water to plants and micro-organisms.

Higher maize yield in secondary forest areas may also be partly explained by the greater percentage of soil surface that remains covered with unburned wood in agricultural plots derived from "virgin" forest (Fred Rumawas, personal communication). In addition, allelopathic compounds tend to be more abundant in mature forest soils and may also contribute to the difference in yield (David Arkcoll, personal communication). Higher yields in fields cleared from secondary succession have been found in some other shifting cultivation systems, such as upland rice cultivation in northern Kalimantan, Indonesia (Jessup, 1981). Higher second-year rice yields have also been reported from central Kalimantan (Driessen et al. 1976 cited by Jessup, 1981). The more common view, however, is that fields cleared from "virgin" forest produce greater yields and sustain a longer cropping period. Freeman (1955, p. 115) found this in his classic study of upland rice cultivation among the Iban of Sarawak; cultivation of maize under the _milpa_ system in Central America shows the same pattern (Bernsten and Herdt, 1977, p. 376).

The relative importance of the various ways in which fallow age might affect yields could differ by crop, and maize may not always respond in the same way as rice and other crops. Transamazon Highway colonists near Altamira believe that maize yield is better in the second year than in the first (Fearnside, 1985). In a study in the Zona Bragantina (500 km NE of Altamira), maize was the only crop (in contrast to rice and manioc) for which yields were higher in fields derived from secondary succession (800-1000 t ha^{-1}) than from "virgin" forest (600-800 t ha^{-1}), and was also the only crop for which yields were higher in the second year than in the first (Vieira et al., 1967, p. 14). Higher maize yields in the second year than in the first have also been noted in clearings from "virgin" forest in _milpa_ agriculture in Central America, but the reverse applies if the clearing is from secondary succession less than 20 years old (Bernsten and Herdt, 1977, pp. 376-378). Sensitivity to allelopathic agents in "virgin" forest soil might explain such a crop-specific response.

For a farmer deciding between a "virgin" and a secondary forest site, the effects of burn quality and pest attack are inseparable from the direct effects of fallow age. Farmers correctly perceive the superiority of the better soils. Taking the non-soil factors (pest attack and burn quality) together, the data are suggestive that the mean yield on secondary forest plots was higher ($X = 0.207$ kg m^{-2}, $SD = 0.113$, $n = 16$) than on "virgin" forest plots ($X = 0.162$ kg m^{-2}, $SD = 0.079$, $n = 12$), but the difference is not significant ($p = 0.26$).

Altamira is located on Brazil's Transamazon Highway and is the principal town serving the largest of the settlements established along the Highway in the early 1970s. Despite its proximity to Altamira, Arroz Cru does not have a road connection to the Transamazon Highway and its associated settlements. Colonists settled along the Transamazon Highway, most of whom came from other parts of Brazil, do not have the tradition of shifting cultivation that _caboclos_ like the residents of Arroz Cru have. Long before population density could increase to the point where farmers would be obliged to shorten their fallow periods, the recently arrived colonists on the Transamazon Highway cleared secondary succession with such frequency that the benefits of fallow were largely foregone and sustainability of the system as practiced in the 1970s was unlikely (Fearnside, 1984). Fallows of 2 years or less were frequent, some land in this age group being cleared in over 70% of cases where such vegetation was available for clearing. Over the succeeding two decades, behavior patterns shifted to longer fallows. Moran et al. (1994) used LANDSAT-TM imagery to measure land-use patterns in the Transamazon Highway colonization project in 1985 and 1991 in areas centered at km 23 and km 46 west of Altamira. These data can be used to derive a Markov matrix of transition probabilities, indicating that secondary succession in abandoned farmland was cleared at a mean age of 6.7 years (Fearnside, 1996). The traditional _caboclo_ farmers of Arroz Cru appear to use a somewhat longer fallow period, although variability is too high for firm conclusions: fields derived from secondary forest had been cleared from stands with a mean age of 8.6 years (SD = 6.6, n = 17).

The incremental benefits of waiting for fallows to further improve site quality can be expected to diminish with increasing fallow age, making the optimal fallow less than the very long periods (> 30 years) observed in many indigenous societies (Ahn, 1979). The long fallows among indigenous tribes are the result of population densities being limited to low levels by factors other than soil and other aspects of site quality that are regenerated by fallows. Tribal peoples have been observed to cut and plant in old secondary forest stands with the objective of preventing the trees from growing too large to be easily felled using the primitive tools available (Robert L. Carneiro, personal communication for the Yanomami of Venezuela; Roy Rappaport, personal communication for the Tsembaga of Papua New Guinea). Shifting cultivators are likely to base their decisions concerning fallow length and "virgin" versus secondary forest use on returns per day of labor rather than per hectare of land. Labor requirements for felling increase sharply with tree diameter, especially when tools are primitive (Carneiro, 1979). The rational choice may therefore be to clear fallows prior to full recovery of soil quality. The lower labor requirement for clearing secondary forest causes Hanunóo shifting cultivators in the Philippines to prefer secondary to primary forest (Conklin, 1954, p. 137); the same phenomenon is common in west Africa (Greenland and Nye, 1959, p. 294). On the other hand, shifting cultivators in Zaïre have been seen as allowing land to remain fallow longer than necessary to regenerate soil fertility (Guillemin, 1956). Identification of optimal fallows for Amazonian farmers would require further work, but the relation between maize yield and fallow age found at Arroz Cru indicates that the short fallows sometimes adopted by pioneer farmers have an agronomic cost in the form of reduced yields.

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TABLE 1: MAIZE YIELD AND SITE CHARACTERISTICS

Category		Fallow age (yr)	Soil type[a]	Burn quality[b]	Pest attack	Maize yield (kg/m^2)
Young secondary forest (0-10 yr)						
		3	LAV	medium	no	0.174
		3	LA	medium	no	0.194
		4	LA	medium	no	0.283
		5	LA	medium	no	0.262
		5	LAV	medium	no	0.230
		6	LAV	medium	no	0.076
		8	LAV	medium	no	0.353
	Mean					0.225
	SD					0.088
	n					7
Mature secondary forest (11-30 yr)						
		14	LA	good	no	0.287
		15	LA	medium	no	0.280
		17	LAV	good	no	0.316
		20	LAV	medium	no	0.411
	Mean					0.324
	SD					0.060
	n					4
"Virgin" forest						
		"virgin"	LA	good	no	0.122
		"virgin"	LAV	good	no	0.074
		"virgin"	LA	good	no	0.216
		"virgin"	LA	medium	no	0.177
		"virgin"	LA	good	no	0.079
		"virgin"	LA	medium	no	0.223
		"virgin"	LAV	good	no	0.203
		"virgin"	LAV	good	no	0.150
		"virgin"	LA	good	no	0.081
		"virgin"	LAV	medium	no	0.144
		"virgin"	LV	good	no	0.352

Mean				0.166
SD				0.082
n				11
Fields excluded from the analysis				
3	TR	good	no	0.193
3	LAV	poor	no	0.065
4	LA/TP	good	no	0.307
5	TR	poor	no	0.255
6	LAV	poor	no	0.057
11	LAV	poor	no	0.077
20	LA	poor	no	0.074
25	LAV	good	yes	0.168
"virgin"	LAV	poor	no	0.124

(a)Soil types: LAV=latossolo amarelo-vermelho, or yellow-red latosol (Ultisol), LA=latossolo amarelo, or yellow latosol (Ultisol), TP=terra preta do indio, or anthropogenic black soil (Anthroposol), TR=terra roxa, or "purple earth" (Alfisol).
(b)"Good" and "medium" burn qualities are considered equal in the analysis.