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Cropping and fallowing sequences of small farms in the “terra firme” landscape of the Brazilian Amazon: a case study from Santarem, Para

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Abstract

This paper analyzes field survey results and develops a conceptual model of the factors that influence cropping and fallowing practices on small farms in the terra firme landscape near Santarem, Brazil. A multi-fallow cultivation system that used rice, corn and bitter manioc in various relay-intercropping combinations was the most common cultivation practice observed. Five different types of fallow vegetation were identified and used by the farmers: (1) mature forest vegetation greater than 20 years old; (2) secondary forest vegetation 8 to 12 years old; (3) young secondary forest vegetation 3 to 6 years old; (4) brushy vegetation 2 to 4 years old; and (5) weed vegetation less than 2 years old. Distinct relay-intercropping sequences were associated with each of these fallows. We suggest that the selection of fallow length and cropping sequence is subject to the following general constraints: (1) the productivity of the landscape as determined by soil, water and climate; (2) ecological requirements and risks associated with particular crops; (3) land availability and the costs of site preparation, and cultural treatments; (4) the availability of hired labor; (5) the age structure of the families, their subsistence requirements and preferences for particular crops, leisure and non-farm-related production activities; and (6) local economic conditions including land values, access to credit and non-farm-related employment, and the conditions of commodity markets. To maximize agricultural production and general household utility given these constraints, the farmers have several options, including: (1) varying the length of fallows; (2) varying the types and sequences of crops that are planted following a given fallow; (3) modifying the clearing and cultivation practices; (4) improving subsequent yields by managing regeneration within a fallow; (5) developing diversified land use systems that contain combinations of pasture, perennials, semi-permanent annuals, areas of extractive reserves and true shifting cultivation; and (6) increasing production through the use of

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external inputs like fertilizer, irrigation and farm machinery. Most farmers in the study area have chosen to modify cropping sequences and vary the lengths of natural fallows rather than using expensive external inputs. Our data suggest that a major factor in selecting a fallow length is the cost of land clearance and preparation. Moreover, since clearing costs are dramatically reduced for young secondary vegetation, the reduction in site preparation costs over several short rotations compensates for the lost production caused by using short fallows instead of long fallows.

Keywords: Amazonia; Cropping/fallowing practices; Land rotation; Shifting agricultural model

1. Introduction

Much of the recent research on land use dynamics in Amazonia has focused on development policies, indigenous groups, inexperienced colonists, cattle ranchers, or logging operations (Moran, 1981; Fearnside, 1985; Redford and Padock, 1992; Fearnside et

al., 1993, and others). While the importance of these groups is widely acknowledged, there is a growing realization that the role of small farmers on resource poor lands has been overlooked (National Research Council, 1993). Nevertheless, 80% of the total food production in the Brazilian Amazon is produced by 400 000 shifting cultivators who live on relatively

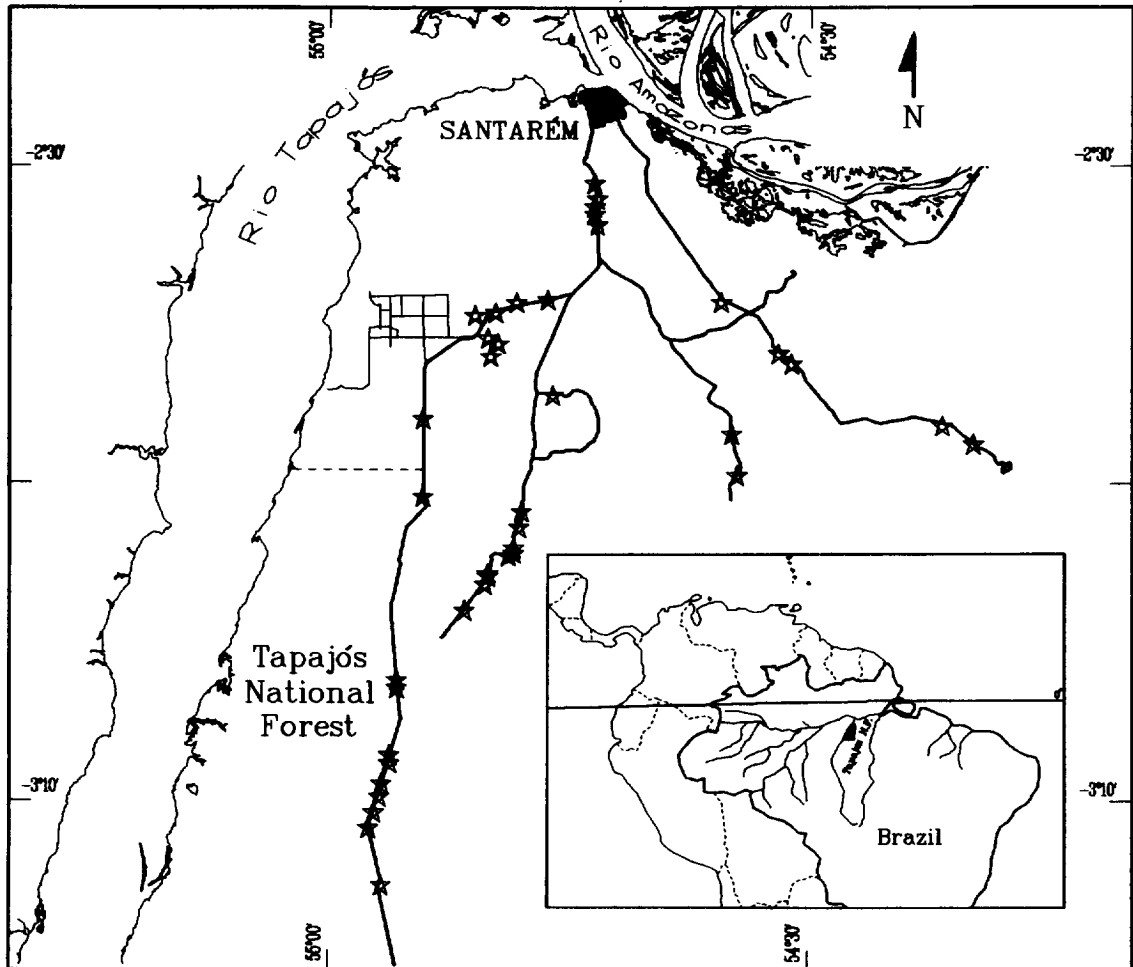


Fig. 1. Location map of study area. Stars indicate location of surveyed farms.

resource-poor upland landscapes (Serrao and Homma, 1993). These cultivators are one of the largest socio-economic group within the Amazon, and have agriculture practices that are distinct from indigenous or large-scale producers (Flohrschiuetz and Kitamura, 1991). The identification of the ecologic and economic factors that influence these farmers—cropping, fallowing and forest clearing practices—is critical to developing sustainable land uses for the region (Staver, 1989; Serrao and Homma, 1993).

This paper analyzes a survey of individual farms that was designed to characterize agricultural practices that are used on small farms in the terra firme landscape south of the city of Santarem, State of Para, Brazil (Longitude 55°00' W, Latitude 2°45' S). The paper has two main objectives. The first is to assess farm infrastructure and identify the cropping and fallowing practices used on these farms. The second objective is to develop a conceptual model that interrelates both the economic and ecologic factors that influence land rotation on small farms in this region. The paper is organized as follows. The following section describes the area and the survey methodology used in the study. Section 3 summarizes those results pertaining to farm structure and operation. Section 4 provides an analysis of cropping practices and links fallow age to cropping systems. The final section discusses the results and presents a conceptual model of the ecologic and environmental factors that influence small-scale agriculture in the area.

2. Study area and farm survey

2.1. Study area

The study farms were all located in the vicinity of the Santarem-Cuiaba highway, along the stretch between Santarem to Rurópolis (Fig. 1). This area is within the Tapajos interfluvial plateau and has a piedmont, rolling uplands topography that is locally referred to as “interfluvial terra firme” or “plano alto.” Soils are classified as Dystrophic yellow latosols, acric ferrasols, or oxisols by Brazilian, FAO and USDA classification systems respectively (da Silva and dos S. Carvalho, 1991).

The area has an AMi Koppen-type climate (Silva, 1989) and is within the “tropical moist rain forest” life zone (*sensu* Holdridge, 1967). This climate type covers approximately 41% of the Brazilian Amazon. Annual rainfall averages 1920 mm and the heaviest rains occur from December to May. A relatively short dry period occurs in September to October. The native vegetation has been classified as “dense rain forest” (Denich, 1991) and “dense terra firme” forest (Silva, 1989). This forest type covers nearly 200 million ha of the Amazon basin.

The oldest pottery found in the Western Hemisphere has been excavated from a prehistoric site near Santarem, and archeological evidence indicates continuous human occupation in the area for the past 7000 to 8000 years (Roosevelt et al., 1991). In the 17th century Europeans encountered large indigenous populations in the area, but by 1850 these large populations no longer existed and Santarem was officially classified as a Brazilian city. Today Santarem is the third largest city in the Amazon and a regional trade and agricultural center. Lumber, fibers, Brazil nuts, cattle, fishing and mining are all major sectors of the region’s economy. The rate of deforestation in the state has decreased since the late 1970s, but is still the highest in the Brazilian Amazon in absolute magnitude (Serrao and Homma, 1993; Serrao et al., 1996).

Santarem and its surrounding hinterland have a long tradition of both agriculture and agroforestry activities. Between 1924 and 1945 the Ford Motor Company operated large rubber tree plantations in the area (Moran, 1981). During the 1940s and 1950s the cultivation of fiber for the fabrication of coffee bags was a major agricultural product. However, the substitution of plastic for natural fiber eliminated the demand and production of this agriculture commodity. In 1959 gold was discovered in the upper Tapajos river creating a mining industry that continues today. Although gold is not mined within the study area, several of the larger fazendas were developed with capital derived from the mining industry. In the 1970s the Santarem-Cuiaba road was complete and transportation throughout the study area was greatly improved. Pepper became a major cash crop during the 1980s. However, due to oversupply in world markets, damage from fungal disease and competition from larger producers, the crop is currently not

economical and many farmers have abandoned their plantations.

2.2. Survey methodology

Interviews were conducted on 68 landholdings that were selected in a systematic fashion: i.e., every sixth farm along the road. All of the interviews were conducted by an international team of researchers from EMPRAPA-CAPTU and the USDA Forest Service during October and November of 1992. Of the 68 landholdings, three were large cattle operations. These properties were excluded from the analysis presented here when the focus was on small-scale production.

At each farm, three different types of surveys were made: (1) an interview with the family to assess the social and economic characteristics of the household (Homma et al., 1993; Walker et al., 1993); (2) a visual inspection of the farm buildings, access roads and water supplies; and (3) an interview with the farmer to assess the cropping and fallowing sequences used on the farm. In this assessment the respondents were queried about their standard agricultural practices, the type of vegetation they utilize, and the cropping systems associated with different fallows. The fallow history, the type of vegetation that had been cleared prior to its most recent cultivation and the types and sequence of crops planted were determined for 100 standard fields. Home gardens were not considered in this analysis.

The various cropping and fallowing sequences that were identified by the farmers are illustrated as decision pathways in Fig. 2 through 6 and are explained in Section 4.2. The percentages at each decision point in these figure are conditional probabilities; i.e., the probability that a given outcome occurs given the occurrence of a prior decision. For example, in Fig. 2, 19% of all the fields surveyed had been cleared from mature forest. Of these, 42% ended in pasture and 17% in perennials. The remaining were fallowed and replanted. In Fig. 3, manioc followed the cultivation of rice in 36% of the fields that had been cleared from mature forest (i.e., with a probability of 0.36, conditional on an initial crop of rice). Of those fields, 20% were then turned into pasture after they were planted in manioc.

3. Farm characteristics

3.1. Farm characteristics and infrastructure

The sampled farms were situated in a dispersed settlement pattern and were occupied by relatively immobile owners (Table 1). Most of these farmers had the characteristics that have been attributed to successful farmers in adjacent areas of the Amazon (Moran, 1981). Moreover, they have lived on other farms in the past so they have a range of farming experience, and they have been permanent residents in the study area long enough to have obtained knowledge of the local climate and biological resources. The average farm size, excluding the three large operations and the farmers who did not report their farm's size, was 88 ha ($n = 61$). The length of ownership (14 years), the area cleared and burning per year (3.1 ha per year) and the size of the farm work force (4.3) were relatively constant between the farms. Fifty-one percent of the respondents had acquired their property by the end of the 1970s, the period of highway development in the region. None of the farms was owned or occupied by traditional caboclos or riberinhos (*sensu* Hiraoka, 1992) and over 60% of the owners were born outside the state of Para. Most of these owners were from the North-eastern region of the country and 31% of all respondents were born in the state of Ceara.

All of the small farms produced their own food and had entered into local and regional markets to some extent. Access to bank loans was considered a problem in 25% of the farms. Farm wood was used for structural material and fuel wood in 54 and 48% of the farms, respectively. Only 6% of the respondents claimed to sell wood or other forest products from their land. Hunting was practiced on 43% of the farms. Fishing was rare due to lack of surface water resources in the immediate area. All of the farms had some type of home garden with agroforestry elements adjacent to their home.

The availability of water for domestic uses was considered a major problem in 41% of the farms. Surface water supplies were not common and none of the small farms had irrigation systems (Table 2). Surface water supplies did exist on all farms with cattle and several large farms in the area had well-

Table 1
Characteristics of farms surveyed along Santarem-Cuiaba highway, October and November 1992

	Mean	Standard error
Farm size (ha)	88	
Length of ownership	14.8	2.6
Age of owner	46	13
% of owners born in the State of Para	44	
Number of farms owner had previously lived on	1.9	0.3
Size of farm work force	4.3	0.9
Number of ha burned per farm per year	3.1	0.4

developed irrigation systems. Rainfall catchment systems that collect water from rooftops were the most common type of water supply on the farms. On the average, 62% of the rainwater cisterns were made of manufactured materials that were designed specifically for use as cisterns and 36% of the houses were catching rainfall from at least 50% of the potential catchment area. In comparison with cisterns observed elsewhere, these systems were well maintained and developed (White et al., 1972; Scatena, personal observations). However, due to the lack of rainfall during the 2- to 3-month dry season and the episodic nature of rainfall during the rest of the year, most households considered these cisterns as a supplemental rather than primary supply. During dry periods the farmers had to rely on groundwater, buy water from supply trucks, or travel to the nearest public source.

Groundwater wells were present in 44% of the farms. Because the average depth to groundwater in these wells was 31 m, most wells had to be mechanically drilled rather than using less capital-intensive, but more labor-intensive manual methods. In addition, the majority of the wells were too deep to be

Table 2
Percent of different water supplies on survey farms along the Santarem-Cuiaba highway, October and November 1992

Rain water cisterns	61
Wells, drilled	33
Intermittent streams	26
Permanent streams	22
Ponds or surface water catchments	18
Wells, manual-dug	11

pumped manually; 58% of all wells were equipped with petroleum-powered pumps. Of the farms with wells, 47% also had rainwater collection systems and 41% of the respondents felt that the well water was non-potable.

Only 11% of the surveyed farms indicated that a lack of access to farm equipment (both heavy and light) was an important problem. Access to transportation was considered a significant problem in 41% of the farms surveyed. While 40% of the farms had short entrance roads from the public road to the main house, only 20% of the farms had internal farm roads that could be used to transport produce directly from the fields where it is grown. None of the farm roads was paved, but 71% were constructed by earth-moving equipment and had some type of drainage system to manage road related runoff. In several of the farms, this runoff was diverted to provide additional water for either field crops or animals. Extensive rills, gullies, colluvial deposits, or other physical features that would indicate seriously accelerated soil erosion (Coleman and Scatena, 1986) were not observed in either agriculture fields or along farm roads.

4. Cropping and fallow practices

4.1. Cropping characteristics

The shifting cultivation observed in this study can be classified as "bush fallow agriculture" (*sensu*

Table 3
Characteristics of farming practices and cropping systems at surveyed sites along the Santarem-Cuiaba highway, October and November 1992

Farm type and cropping system	Percent of surveyed sites
Shifting cultivation only, < 200 ha total farm size	19
Annuals and perennials, < 200 ha total farm size	74
Perennials only, < 200 ha total farm size	3
Ranching, > 700 ha total farm size	4
Rice planted with or without other crops	58
Corn planted with or without other crops	50
Manioc planted with or without other crops	43
Beans planted with or without other crops	28

Staver, 1989), “forest area shifting cultivation” (sensu Sanchez, 1976), or “cyclic systems practiced by permanent residents using digging-sticks, hoes and seed planting technologies” (sensu Spencer, 1966). A total of 23 distinct annual cropping patterns were observed in the 100 fields surveyed. A relay-intercropped system that contained a combination of rice, corn and bitter manioc was the most common cultivation practice observed (Table 3). Only 28% of the sites planted legumes in part of their cropping pattern and another 28% were not intercropped for part of their cultivation cycle. The majority (77%) of the fields were cropped for 1 year before they were put into some form of fallow. The remaining fields (23%) were all cropped twice before they were fallowed.

Only 17% (11 of 65) of the respondents used fertilizer. However, in all the fields litter and organic debris were manually accumulated around the base of various plants. The farmers indicated that this practice was used to maintain soil moisture during dry periods rather than to increase soil productivity. Vines and weeds within the fields were occasionally removed by farmers, but were not extensively managed. None of the farmers interviewed claimed to purposely plant woody species in fallow areas to either shorten the fallow period or increase their

Table 4
Perennials observed on sample farms and along the Santarem-Cuiaba highway, October and November 1992

Perennials	Percent of farms
Black pepper (<i>Pimenta dioica</i>)	53
Oranges or tangerines (<i>Citrus</i> sp.)	44
Coffee (<i>Coffea arabica</i>)	19
Bananas (<i>Musa</i> sp.)	19
Rubber trees (<i>Ficus elastica</i>)	12
Cocoa (<i>Theobroma cacao</i>)	10
Avocado (<i>Persea americana</i>)	10
Coconut (<i>Cocos nucifera</i>)	9
Mango (<i>Mangifera indica</i>)	9
Peach palm (<i>Gaussia attenuata</i>)	6
Cupuacu	6
Annatto (<i>Bixa orellana</i>)	6
Pomar	3
Cashew (<i>Anacardium occidentale</i>)	3
Acerola (<i>Malpighia emarginata</i>)	3
Others	7

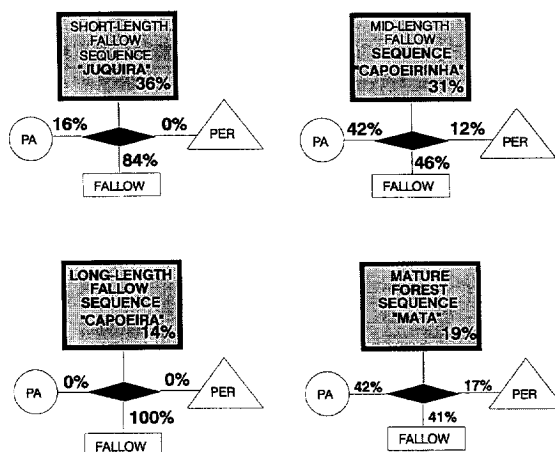


Fig. 2. Percent of fields using a given fallow type observed in farms near the Santarem-Cuiaba highway. October and November 1992. Cropping sequences associated with each fallow type are discussed in text and diagramed in Figs. 3 to 6. PA = pasture; PER = perennials.

subsequent yields. Multipurpose trees, typically Brazil nut and babassu palm, were scattered across fields and fallow areas. Babassu palm was the dominant emergent in 66% of the fallowed fields surveyed and appeared to be a reliable indicator of prior agricultural use, as has been suggested elsewhere (May, 1992). Black pepper and citrus were the dominant perennial crops (Table 4). However, many of the black pepper plantations were abandoned because of fungal disease and/or low prices. The planting of citrus crops for commercial markets rather than domestic uses was generally limited to operations with reliable methods of transporting their perishable goods to markets.

4.2. Fallow types and cropping sequences

Field inspections and interviews indicated that farmers in this region use five different types of fallow vegetation: (1) mature forest vegetation greater than 20 years old, which is locally referred to as “Mata”; (2) or secondary forest vegetation 8 to 12 years old known as “Capoeirao”; (3) secondary forest vegetation 3 to 6 years known as “Capoeira”; (4) brushy vegetation 2 to 4 years old known as “Capoeirinha”; and (5) weed vegetation less than 2 years old, known as “Juquira.” Distinct cropping

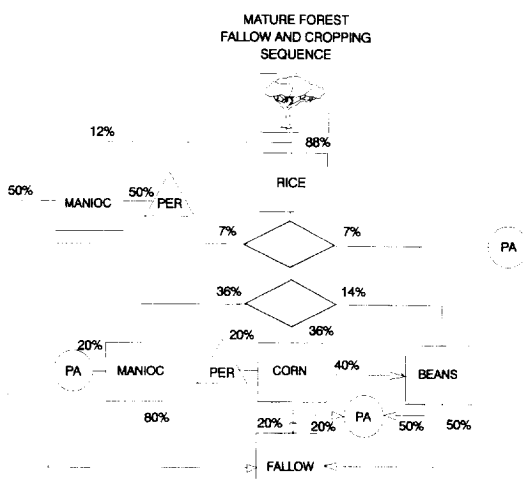


Fig. 3. Flow diagram of cropping sequence following the clearing and burning of mature (> 20 years old) forest. Percentages are the conditional probabilities associated with each decision level. PA = pasture; PER = perennials.

sequences were associated with each of these fallows (Figs. 2–6).

Our interviews indicate that the farmers first burn and clear a plot of mature forest (“mata”) or mature secondary forest (“capoeirao”) after they have removed valuable wood products that can be sold or used for domestic purposes. This land is then planted in rice and various crops for a period of 1 or 2 years (Fig. 3). The plot is then fallowed for 1 or 2 years, given a light burn to remove the weedy “juquira” vegetation, and re-planted with a short fallow cropping sequence (Fig. 4). Following this cropping, the fields are fallowed for 3 to 6 years, cleared of their “capoeirinha” vegetation and re-planted with a mid-length cropping sequence (Fig. 5). If the productivity of the site is considered high, this mid-length fallow is repeated and followed by a short fallow cropping sequence. If site productivity is considered low, the field is fallowed for 8 to 12 years before its “capoeira” vegetation is cleared and the plot is returned to cultivation (Fig. 6). Depending on the decisions made by the farmer, it can take between 12 to 22 years to complete this entire cultivation cycle on any individual field.

Rice was planted more frequently in fields that had previously been in mature forest or had been under a long fallow. Manioc was planted after all

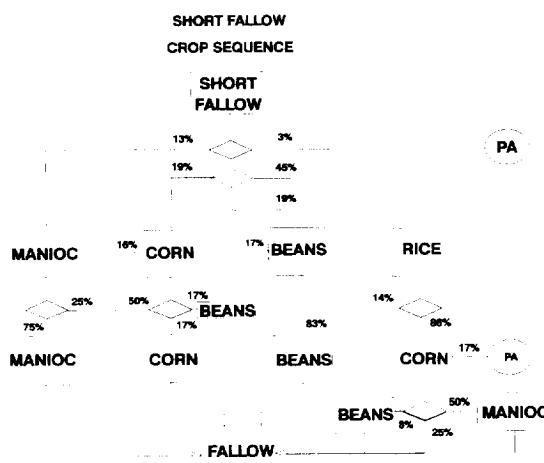


Fig. 4. Flow diagram of cropping sequence following the clearing and burning of a short-fallowed (1–2 years old) field. Percentages are the conditional probabilities associated with each decision level. PA = pasture; PER = perennials; MA = manioc.

fallow periods and was typically intercropped with beans or corn. The manioc fields that were not intercropped were cultivated by market-oriented producers of manioc flour or by smaller operations without the labor required to cultivate more labor-intensive crops. Beans were typically planted in fields that had been cropped once and then allowed to be overgrown with a light cover of herbaceous vegetation. These fields were given a light burn to remove

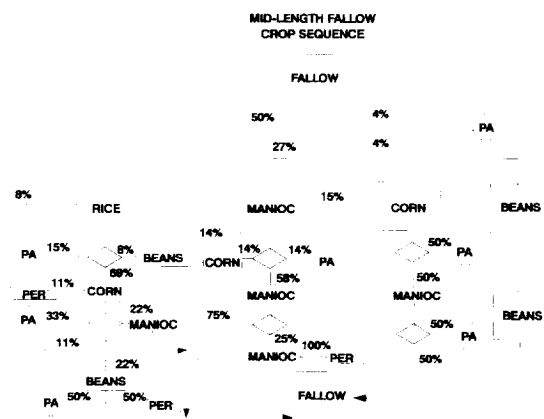


Fig. 5. Flow diagram of cropping sequence following the clearing and burning of a medium-length fallow (3–6 years). Percentages are the conditional probabilities associated with each decision level. PA = pasture; PER = perennials.

the herbaceous cover before they were planted with beans. For the entire set of cultivated fields, 23% were turned into pasture and 6% were turned into perennial production. Of those planted with perennials, 50% originated from areas that had previously been in mature forest and 50% from areas of mid-length fallow. The transition to pasture was also more common in the early part of the cultivation cycle and in fields that had mature or mid-length fallow vegetation prior to cultivation.

The average fallow length/cropping length observed in this area ($x = 4.3$, $stderr = 0.35$, $n = 62$) was greater than the average of 55 other tropical locations ($x = 3.6$, $stderr = 0.43$, $n = 55$) reported in the literature (Watters, 1971; MAB, 1983; ICRAF, 1985). Decades of research in the tropics suggest that if fields are fallowed for less than 2 to 3 years for every year they are in production, they will have a steady decline in soil fertility (Sanchez, 1976; MAB, 1983; Norman et al., 1984; Trenbath, 1984). If these ratios apply to this region, then at least 1/2 of the fields were being used, at least temporarily, to an extent that could result in long-term decline in soil productivity. However, when these farms are considered in their entirety, such that the average rate of clearing and cultivation (3.5 ha per farm per year in Table 1) is uniformly rotated over the potential

producing area of the farm (48 ha or one-half of the average farm area as is required by law), then 14 years of fallow could be allowed for every year of cultivation. This discrepancy between maximum potential fallow length and the fallow periods that were observed suggests that land availability is not a sole constraint on shifting cultivation in this region, and that these farmers are basing their production systems and land use rotations on factors other than the availability of land.

5. Discussion

5.1. Conceptual model of shifting agriculture

The observations presented here indicate that small-scale producers in Amazonia are faced with many factors that influence their selection of agricultural production systems. Previous studies of shifting cultivation have also identified many factors that influence the selection of a cropping sequence and the decision to fallow fields. These include soil fertility, weed pressure, pest build-up, household dietary needs and preferences, the availability of land and labor, and the conditions of commodity markets (Boserup, 1965; Spencer, 1966; Sanchez, 1976; Uhl,

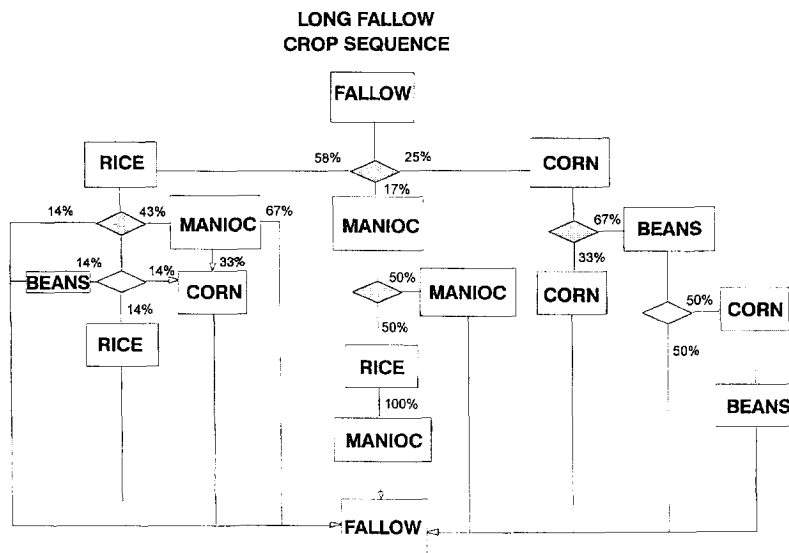


Fig. 6. Flow diagram of cropping sequence following the clearing and burning of long-length (8–12 year) fallows. Percentages are the conditional probabilities associated with each decision level. PA = pasture; PER = perennials.

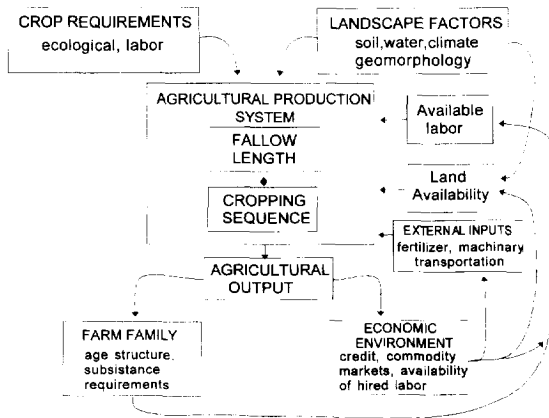


Fig. 7. Schematic diagram of the inter-relationships between the various economic and ecological factors that influence the selection of fallow lengths and cropping sequences on small farms along the Santarem-Cuiaba highway in October and November 1992.

1987; Staver, 1989; Jones and O'Neill, 1993; and others). In addition to these factors, our observations suggest that the wide variety of annuals, perennials and animals that can be raised, the risk of crop failures due to market, climatic or ecological disturbances, and the continual need to meet basic subsistence requirements should also be considered.

One implication of this complexity is that there is no sole determinant that influences fallow length and crop selection on individual farms or individual fields. Instead, we hypothesize that the agricultural production on these small farms is influenced by several interrelated economic and ecologic factors (Fig. 7). These general factors are: (1) the productiv-

ity of the landscape as determined by soil, water and climate; (2) the ecological requirements, costs of site preparation and cultural treatments, and risks associated with particular crops; (3) land availability; (4) the availability of hired labor; (5) the age structure of the families, their subsistence requirements and preferences for particular crops, leisure and non-farm-related production activities; and (6) local economic conditions including land values, access to credit and non-farm-related employment and the conditions of commodity markets.

To maximize their agricultural production given these constraints, the farmers have several options. These include: (1) varying the length of natural fallows; (2) varying the types and sequences of crops that are planted after a given fallow; (3) modifying the clearing and cultivation phases of the planting cycle; (4) improving subsequent yields by managing regeneration within a fallow; (5) developing diversified land-use systems that use combinations of pasture, perennials, annuals, extractive reserves and true shifting cultivation; and (6) increasing production through the use of external inputs like fertilizer, irrigation and farm machinery.

In this study area, the farmers appear to have addressed these constraints by modifying their fallows, crops and cultivation practices rather than using expensive external inputs. Moreover, these farmers have diversified their production portfolios by adopting a long-term land use strategy that uses a variety of fallow lengths and cropping sequences. Namely, several short and mid-length fallows are practiced until the cost of repeated clearing is greater

Table 5

Average clearing costs, in work days per ha, for secondary vegetation of different ages for farms along the Santarem-Cuiaba highway in October and November 1992

Forest type		<i>n</i>	Mean (days/ha)	Standard deviation
Dense forest (Mata)	With chain-saw	13	7.9	2.4
	Without chain-saw	15	13.0	4.4
Secondary forest > 10 years old (Capoeirao)	With chain-saw	9	9.4	4.1
	Without chain-saw	15	11.5	5.6
Secondary forest, 4–10 years old (Capoeirao)		11	6.0	3.0
Secondary forest, 2–4 years old (Capoeirinha)		2	5.5	2.1

Adapted from Homma et al. (1993) and does not include the labor required for burning, soil preparation, or planting.

than the benefits obtained from cultivation. At that point a long-term fallow is invoked. In this region, labor and clearing costs appear to exert a dominant influence on the selection of fallow length and cropping sequence. Moreover, our data suggest that a major factor in selecting a fallow length is the relationship between land clearance costs and the age of vegetation (Table 5). In particular, since clearing costs are dramatically reduced for young secondary vegetation, the reduction in site preparation costs over several short rotations compensates for the lost production caused by using short fallows instead of long fallows. Likewise, the cost/benefit ratio associated with planting and managing regeneration within fallows or using external inputs is presumably greater than the cost/benefit ratio associated with allowing natural succession to occur for a longer period of time. The effectiveness of natural versus managed fallow is in turn influenced by the ecology of the landscape, land availability and labor constraints (Fig. 7).

In addition to the costs associated with clearing and maintaining the landscape, farmers must also balance labor costs with the ecological and labor requirements of different crops (constraints 3 and 4). Cattle require a permanent supply of water. Rice requires intensive periods of seasonal labor (Fearnside, 1984) and cannot tolerate desiccation (Young, 1980). Manioc has a relatively low field labor requirement that is uniformly distributed across the year. Nevertheless, the production of manioc flour for markets can be extremely labor-intensive (Moran, 1981) and was typically observed in farms that had adequate labor forces. The availability of labor is related to the dynamics of the family life cycle (Walker et al., 1993) and local economic conditions (Fig. 7). In particular, labor costs can increase dramatically if outside labor must be hired because adult children have migrated off the farm or the heads of households have aged. Labor, establishment and production costs associated with perennials, tree crop agriculture and extractive reserves have also been noted as constraints elsewhere in Amazonia (Hecht, 1992).

Ecological and environmental factors also influence the types of crops that are planted, the sequence in which they are planted and the recovery time of fallows (Fig. 7). For example, manioc grows well in

soils with low fertility and can remain in the ground for extended periods before it is harvested (Norman et al., 1984). Therefore, it is typically grown in the last cropping a field has before it is fallowed (Figs. 3–6). Other crops, like rice and corn, require relatively fertile soils and are therefore grown in the early part of a cropping cycle in fields that have had a longer fallow period. Likewise, the development of pasture depends, in part, on the availability of surface water supplies for cattle. The rate of secondary forest development and the restoration of soil fertility during fallow periods also depends on soil, climatic and other ecological conditions (Brown and Lugo, 1990).

Finally, it is recognized that geomorphic complexity and the spatial variation in soil properties and climate also influence the land-use options available to individual farmers (Moran, 1981; Fearnside, 1984). In this study a close relationship was observed between the presence of surface water supplies and the presence of pasture and cattle. Another study in a physically heterogeneous region of the Amazon that contained varzea, ancient river terraces and piedmont landscapes revealed 39 distinct forms of agriculture in the 46 households surveyed (Padoch and De Jong, 1992). This complexity was due in part to the relatively heterogeneous nature of that particular study site and indicates the need for further, geographically based studies of cropping systems in Amazonia.

5.2. *Implications and future research*

The long-term multi-fallow sequence described here can only operate in areas where land is sufficiently abundant that farmers have access to older vegetation once overworked land is abandoned. Where different quantities of land, labor, or economic resources exist, differences in the relative importance of various pathways in Fig. 7 will occur. In the Santarem area, the interactions of these various factors has resulted in the use of multiple short- and long-term fallows. The net result is a landscape mosaic of differently aged fields and fallows. Each of the fallow types within this mosaic has different ecological characteristics and requires different silvicultural and restoration techniques when managed. They may also have different impacts on biogeochemical cycles by contributing different amounts of

atmosphere gasses when burned, and may act as either sources or sinks of atmospheric carbon depending on their age and structure (Brown and Lugo, 1990). We suggest that defining these long-term land use sequences and determining the ecological roles of differently aged secondary forests is a necessary prerequisite for understanding present and future land use changes in Amazonia. The approach and conceptual models developed here are useful in unraveling these complexities and should be tested elsewhere.

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