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AGRICULTURAL PRODUCTIVITY ALONG BRAZIL'S TRANSAMAZON HIGHWAY

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ABSTRACT

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The paper reviews agricultural problems associated with Brazil's effort to colonize a 3000 km pioneer rain forest highway. Attention is focused on cash crops since a major objective of the government settlement scheme was to provide opportunities for landless peasants to become entrepreneurial farmers.

INTRODUCTION

The 3000 km Transamazon highway, started in 1970 and completed by 1975, was designed, in part, to provide an avenue for settling the sparsely populated southern interfluves of Amazonia (Fig.1). Originally, plans called for settling 100 000 families, mostly from the drought-plagued Northeast, on 100 ha lots along the highway and associated side-roads (Smith, 1976 a). As of September 1977, however, only 5333 families had been settled by INCRA (Instituto Nacional de Colonização e Reforma Agrária) on the highway, and less than half of these are Northeasterners. Disappointing agricultural production has been a major factor in the slowdown of the colonization rate.

STUDY AREAS

Considering the environmental heterogeneity of the highway transect, general statements on agricultural productivity must be taken with caution. In an effort to provide some basis for extrapolation, and to gain an appreciation of the ecological and cultural diversity of settlement areas, three well-separated study sites were selected.

Three government-built communities (agrovilas), containing 48 to 66 houses, served as field bases. Agrovila Coco Chato, km 42 Marabá-Altamira, is situated in a region of red-yellow podzolic soils (ultisols) underlain by a

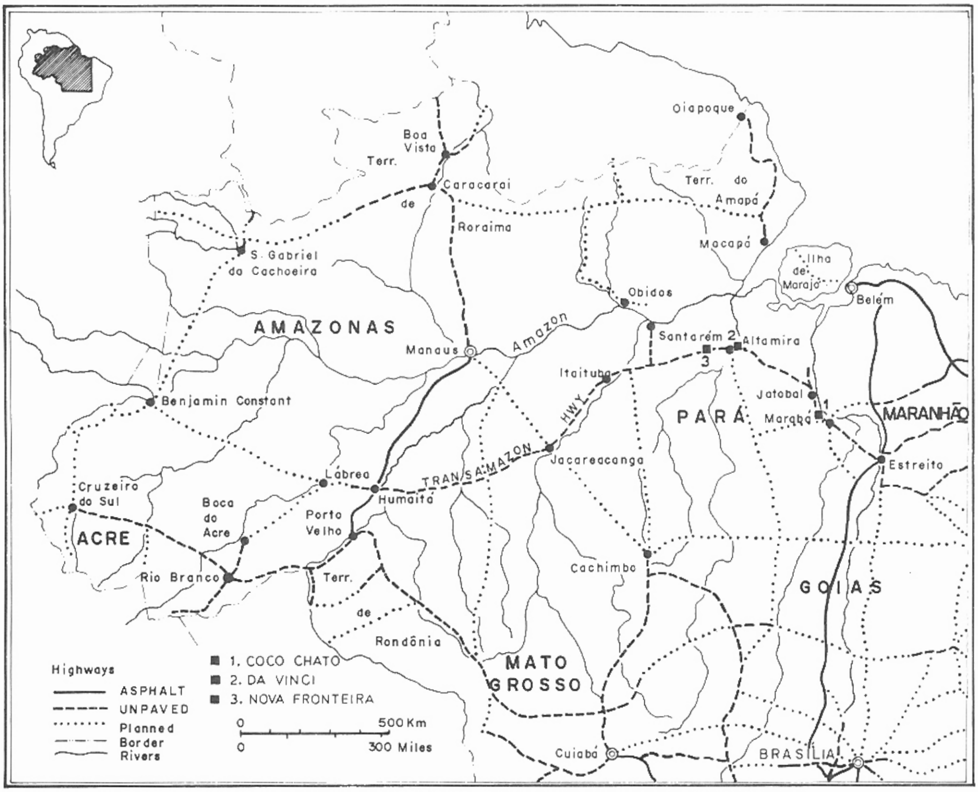

Fig.1. The Brazilian Amazon highway system, 1977.

Pre-Cambrian granitic shield (Falesi, 1972; DNPM, 1974 a). Approximately 30 families have engaged in slash and burn agriculture in the area for 15 years prior to the arrival of the Transamazon, consequently the vegetation is characterized by a mosaic of mature upland forest interspersed with second growth at various stages of succession. Most of the residents of Coco Chato in 1974 came from the northern state of Pará (63%).

The second study site, agrovila Leonardo da Vinci, located at km 18 Altamira-Marabá, is surrounded by red-yellow latosols (oxisols), probably a weathering product of Devonian sandstone (Falesi, 1972; DNPM, 1974 b). Liana forest is the characteristic vegetation in the vicinity of the agrovila. Northeasterners are the predominant (56%) farmers in the area. The third study community, agrovila Nova Fronteira, situated at km 80 Altamira-Itaituba, was built in a relatively fertile terra roxa (eutrophic oxisol) zone, derived from a Silurian diabase dike. Mature upland forest prevails in the vicinity of the latter agrovila. Southerners account for 47% of the colonists in the area, Paraenses for 33%.

Annual rainfall in the region of the three agrovilas averages approximately

1700 mm, with a pronounced dry season extending from June until December. Average monthly temperatures are in the order of 25° C with little seasonal variation. The climate is classified as Aw according to the Köppen system.

SHORT CYCLE CROPS

INCRA envisaged upland rice (*Oryza sativa*) as the principal cash and subsistence crop of Transamazon colonists, consequently most recently cleared fields (*roças*) are planted to the cereal. Settlers are not encouraged to plant root crops since they are considered of little commercial or nutritional value.

Manioc (*Manihot esculenta*), the basic staple of Amazonian peasants, is often criticized for exhausting soils (Normanha and Pereira, 1950; King, 1968; Corrêa, 1970), and for contributing to malnutrition because of the low protein content (less than 2% vs 8% for rice) of the roots (Walcott, 1915; Brock and Autret, 1952; Castro, 1955, p.69; Fonaroff, 1965; Ellis, 1966, p.419; Penteado, 1969; Borgstrom, 1970, p.340; Kellman, 1975). Yet manioc is less demanding of soil nutrients per food calorie than cereals (Jones, 1959, p.25; Harris, 1968, 1972), and excessive consumption of any basic staple, including cereals, can provoke nutritional disorders, as in the case of pellagra and corn (Roe, 1973). Other sources of protein, such as game and domestic animals are available to provide for the amino-acid requirements of settlers (Smith, 1976 b).

Some writers have stressed the important role of manioc in increasing agricultural productivity in the tropics (Pickles, 1942; Albuquerque, 1969; Coursey and Haynes, 1970; Miracle, 1973; Moran, 1973, 1976 a and b; Sternberg, 1973 a and b), and for a number of cultural and ecological reasons, the root crop could become a much more significant and reliable source of subsistence and cash income for Transamazon settlers.

In order to compare manioc and rice productivity, the tuber yield of the former is converted to a 12 month basis. Manioc yields vary along the highway due to variables such as soil and spacing of plants. The estimated yield of *mandioca* on three terra roxa sites ranged from 34 000 to 75 000 kg/ha, comparable to yields obtained on terra roxa without fertilization in southern Brazil (Albuquerque, 1969, p.133). In a less fertile red-yellow podzolic soil in the vicinity of agrovila Coco Chato, a yield of 43 000 kg/ha was obtained, similar to yields reported from areas under traditional cultivation in the Yungas region of Bolivia (Jorgensen, 1972), and the Cauca valley of Colombia (Ramoes, 1970). Since the above examples are based on limited sampling and may be exceptional, a yield of 20 000 kg/ha is selected as more representative of manioc fields cropped at 12 months in recently cleared areas of the highway. In second growth areas in the Bragantina zone of Pará, for example, manioc yields of 20 000 kg tubers/ha in highly leached latosols are not considered unusual (Albuquerque, 1969, p.43).

Since 60—70% of the tuber weight is water, the roots are converted to flour (*farinha*) to compare the carbohydrate yield with rice. To make *farinha seca*, tubers are peeled and grated, the dough is squeezed in a press to remove water

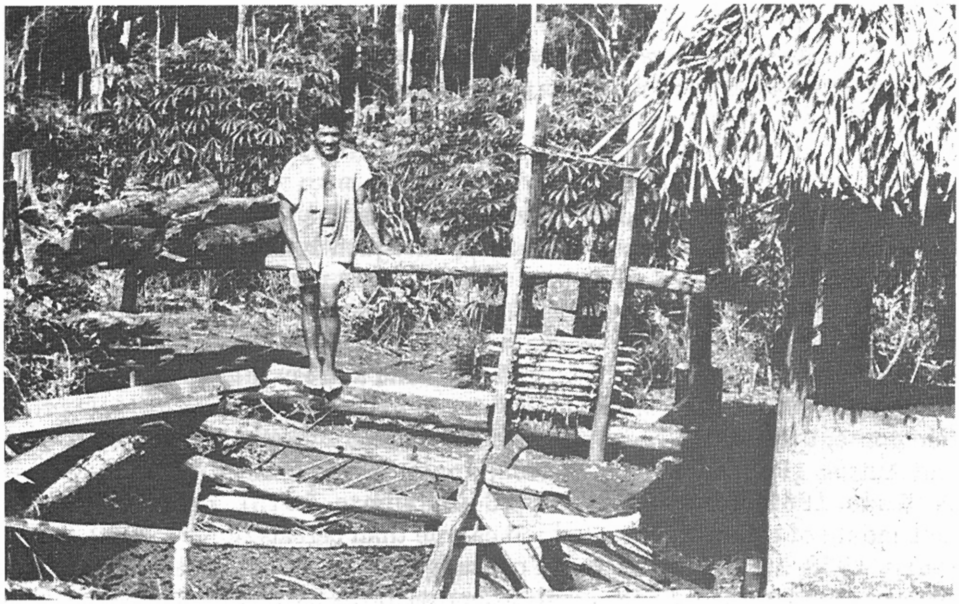

Fig. 2. One of the several kinds of manioc press used along the Transamazon. Note the *casa da farinha* on the right. Km 400 Altamira-Itaituba, October 1973.

(Fig. 2), then the mass is agitated over a heated griddle until dry. Both sweet (*macaxeira*) and bitter (*brava*) varieties are used to make flour; in the case of the latter variety, heating drives off the poisonous prussic acid. To prepare *farinha puba*, tubers are left in water for 2 or 3 days until soft, thus rendering the grating step unnecessary. An average of 3.3. kg ($s = 0.4$, $n = 4$) of peeled roots are required to make 1 kg of flour*, and since there is an estimated 30% wastage due to attached earth, peelings and rotten portions, an average 1 ha of manioc (20 000 kg) would yield 4242 kg of flour.

The generally undulating topography of the highway, combined with the high cost of irrigation, renders paddy rice cultivation impractical. Consequently, only one crop is produced annually. Rice yields depend on the year planted, variety, and soil to mention a few of the variables involved (Tables I—III). In 1973, for example, yields were generally low (445 kg/ha, $s = 503$, $n = 13$) because INCRA distributed *barbalha*, a variety from the north eastern state of Pernambuco, apparently unsuited to the soil and climatic conditions of the highway. To compare rice and manioc productivity, an average rice yield of 1688 kg/ha ($s = 792$, $n = 32$) is used, based on the average of non-*barbalha* varieties on first year plots.

After the rice harvest in June 1977, colonists received US $7.93** per 50

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* If unwashed and unpeeled tubers are considered the ratio is 4.3 : 1. Other ratios reported range from 2.5 : 1 (Le Cointe, 1922), 2.8 : 1 and 3.2 : 1 (BNB, 1971, p.17), 3.6 : 1 (Normanha and Pereira, 1950), to 4 : 1 (Albuquerque, 1969, p.177).

**Monetary values expressed in US $. Exchange rate in July 1977 was US $1 = 14.50 cruzeiros.

TABLE I

Rice yields on terra roxa in vicinity of agrovila Nova Fronteira

Year	Vegetation cleared	Years field cropped	Variety	Ha planted	Harvested yield (kg/ha)
1972	Forest	1	IAC 101	5	2300
1972	Forest	1	IAC 101	4	2625
1972	Forest	1	IAC 101	6	1792
1972	Forest	1	IAC 101	4	2500
1972	Forest	1	IAC 101	3	2333
1973	Forest	1	Barbalha	5	420
1973	2nd growth	2	Barbalha	4	112
1973	Forest	1	Barbalha	5	800
1973	2nd growth	1	IAC 101	2	1300
1973	2nd growth	1	IAC 101	2.5	960
1973	Forest	1	IAC 101	6	2167
1973	2nd growth	2	Barbalha	6	1250
1974	Forest	1	IAC 101	2	575
1974	Forest	1	IAC 1246	3	1700
1974	Forest	1	IAC 101	6	750
1974	Forest	1	IAC 1246	3	292
1974	2nd growth	2	IAC 101	6	1833
1974	2nd growth	2	IAC 101	5	1800
1974	Forest	1	IAC 101	3	850

Note: Yields estimated by interviewing colonists as to number of sacks produced and area planted.

TABLE II

Rice yields on latosols in vicinity of agrovila Leonardo da Vinci

Year	Vegetation cleared	Years field cropped	Variety	Ha planted	Harvested yield kg/ha
1973	Forest	1	Longo	3	2383
1973	Forest	1	IAC 101	6.4	2265
1973	Forest	1	IAC 1246	5	3160
1973	Forest	1	Barbalha	42.4	1156
1973	Forest	1	Barbalha	2.7	1204
1973	Forest	1	Barbalha	5	630
1973	Forest	1	IAC 1246	21.2	1429
1974	Forest	1	Preto	3	1333
1974	2nd growth	2	IAC 1246	0.7	1357
1974	Forest	1	IAC 101	3	1667
1974	2nd growth	2	IAC 1246	1.8	667

TABLE III

Rice yields on podzolic soils in vicinity of agrovila Coco Chato

Year	Vegetation cleared	Years field cropped	Variety	Ha planted	Harvested yield kg/ha
1972	Forest	1	IAC 101	2	3000
1972	Forest	1	IAC 101	3	1250
1972	2nd growth	1	IAC 101	1.2	833
1972	2nd growth	1	IAC 101	4.8	1667
1972	Forest	1	IAC 101	2.4	1042
1972	2nd growth	1	IAC 101	3.6	833
1972	Forest	1	IAC 101	2.4	1042
1973	Forest	1	Barbalha	6	0
1973	Forest	1	Barbalha	4.5	44
1973	Forest	1	Barbalha	12	0
1973	Forest	1	Barbalha	2.4	0
1973	2nd growth	1	Barbalha	3.6	0
1973	2nd growth	1	Barbalha	3	167
1973	Forest	1	IAC 101	3	833
1973	Forest	1	IAC 101	1.8	2083
1973	Forest	1	IAC 101	4.8	1146
1973	2nd growth	1	IAC 101	4.8	1250
1973	2nd growth	1	IAC 101	1.2	1250
1974	2nd growth	2	Canela	4.8	1354
1974	2nd growth	1	IAC 101	2.6	2115

kg sack of the unhusked cereal; therefore the expected earnings from 1 ha of the cereal would be US $268. A 50 kg sack of good quality manioc flour sold for an equivalent price, thus a colonist can earn US $673 by processing a 1 ha field of manioc (20 tons) into flour. Since settlers do not usually plant another crop after rice because of the pronounced dry season, manioc flour production seems 2.5 times more profitable per ha than rice cultivation. However, production costs in the two systems must be considered.

An estimated 16 man-days are required to weed, harvest and thresh 1 ha of rice, whereas 137 man-days are needed to process an equivalent area of manioc into flour*. Although time inputs in the manufacture of manioc flour are large, all tasks can be performed by a family without resorting to hired labor. A family of six with older children can process a 3 ha manioc plot within a year, thereby earning US $2019 from the sale of flour. Since colonists plant an average of 5 ha of rice, expected income is US $1340 with a yield of 1688

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* Approximately 115 man-days are required to process 20 tons of harvested tubers into 4242 kg of flour using a gasoline-powered grater. Wagley (1967, p.66) estimates that two adults spend 1 day to make 30 kg of manioc flour with a manually-operated grater, equivalent to 282 man-days to produce 4242 kg of flour.

kg/ha. Although the magnitude of the financial advantage of manioc cultivation varies in response to soil and market conditions, the root crop is more profitable than rice cultivation in most cases.

If the area of rice cultivation could be increased, then theoretically at least, settlers could increase their income. Even if a colonist is able to increase his cropping area beyond 5 ha by employing power saws and workers, problems arise at the harvest.

Birds are particularly avid rice feeders along the highway, as in areas of Central America and Africa (De Grazio and De Haven, 1974). Flocks of up to 150 blue-headed parrots (*Pionus menstruus*) were frequently observed feeding on Transamazon rice from unburnt logs and branches in fields. Whereas the parrots normally inhabit the forest, finches observed feeding on rice directly from the stalks, such as blue-black grassquits (*Volatinia jacarina*) and yellow-bellied seedeaters (*Sporophila nigricollis*), are second growth and grassland species that have colonized the disturbed corridor of the Transamazon. Rice predation by fringillids is likely to increase as ruderal grasses, already established along the highway such as *Panicum maximum*, *P. mertensii*, *Hyparrhenia rufa*, *Andropogon bicornis*, *Digitaria insularis*, *D. sanguinalis*, *Paspalum conspersum*, *P. conjugatum*, *Eleusine indica* and *Leptochloa virgata* proliferate as more forest is cleared.

The most commonly planted rice variety along the highway, IAC 101 from Campinas, São Paulo, is long-stemmed and easily lodges when the panicles are ripe, particularly during storms. A flattened crop not only takes longer to harvest, but the seeds rot on the ground and are eaten by rats and ruddy ground-doves (*Columbina talpacoti*).

All rice harvesting is performed by hand, usually with a sickle or machete. Some 9 man-days are required to harvest 1 ha of rice, thus a family of six spends 10—14 days harvesting 5 ha. If a farmer plants more rice than he can harvest within 2 weeks, losses increase so there is little profit in planting more of the crop. Even if a settler can afford to hire labor at the daily wage of US $2.75 including food, he encounters difficulty contracting help since most of the rice fields mature within a 3—4-week period and workers are in heavy demand. Furthermore, the incidence of malaria, a major health problem along the highway, increases at the beginning of the dry season when rice harvesting is underway (Smith, 1976 c).

As soon as the crop is cut, kernels must be separated from the stalks before they rot in the humid climate, or are eaten by pests. Unfortunately, INCRA distributed very few rice threshing machines, these often break down, and few colonists can afford to buy one at US $4345. Some wealthier settlers rent their machines for US $0.35 a sack, but access is difficult, and often impossible, because of the gutted and muddy condition of the roads.

The poor surface of the Transamazon and side-roads, exacerbated by the 6-month rainy season, impedes the removal of harvested rice (Fig.3). The quality of the harvest is further reduced when trucks must wait up to 10 days to unload at government-operated warehouses. Similar rice transportation and

Fig.3. Colonists carrying rice crop to Transamazon from side-road at km 90, Altamira-Itaituba in June 1974.

storage difficulties are reported in other areas of the Transamazon (Moran, 1975), and in pioneer zones of the Alto Beni in Bolivia (Nelson, 1973, p. 205). In the case of manioc, harvesting can be staggered from 8 months to 3 years after planting, although the fibre content of the roots increases after 18 months.

Neither pests nor diseases significantly affect manioc yields along the highway. Leaf cutter ants (*Atta* sp.) and brocket deer (*Mazama americana*) destroy recently planted manioc in a few cases, but their overall impact on manioc production is currently negligible. In the event that leaf cutter ants proliferate in the future, as has occurred in other cultivated areas of the Neotropics (Weber, 1947; Butt, 1970), yields of manioc and other crops are likely to decline.

Another advantage of manioc for Transamazon settlers is that the technology required for processing flour is relatively simple and easy to acquire. Iron griddles are the only items commonly purchased to make good quality flour. In 1977, the thick pans of approximately 2 m diameter could be purchased for US $80. Some colonists have bought 7 h.p. gasoline-powered graters for US $240, though manually-operated ones are also used successfully. Other materials used in the *casa da farinha*, such as bricks for the oven and wood for the press, can be fashioned from clay and trees in the colonist's lot.

Manioc cultivation fosters co-operation and social cohesion. Families assist each other in processing flour during the protracted harvest. The *casa da farinha* serves as an important center for the exchange of information, and helps lay the foundation for the future development of co-ops, particularly relevant in view of the failure of such efforts along the highway (Smith, 1977).

Problems with the cultivation of upland rice along the Transamazon do not preclude the great potential for paddy rice on the floodplains of silt-laden rivers. In the Amazon estuary, peasants regularly harvest yields of 3000 kg/ha without resorting to fertilizers (Camargo, 1948; Lima, 1956). By employing fertilizers, herbicides, insecticides and dikes on the Amazon floodplain near Jari, two crops with a total yield of 10 tons are obtained a year.

Maize (*Zea mays*), sometimes intercropped with rice, is grown mainly to feed chickens and pigs. The cereal does not provide a reliable cash income because yields on the better soils average only 956 kg/ha ($s = 420$, $n = 11$, Smith, 1976 c), and maize sells for only half the price of manioc flour. Low yields are due, in part, to colonists who frequently save some seed grown from hybrid varieties for planting the following year. Rats and chickens consume recently planted seed and leaf cutter ants damage growing plants. While the crop is ripening, rats climb the stalks and gnaw the kernels. In a sample of 600 plants in six maize fields, an average of 5% of the plants were found damaged in this manner. No destruction was noted on maize plants where fire ants (*Solenopsis* sp.) were milking aphids (*Rhopalosiphum maidis*), since the stinging attacks of the ants discourage predation. Cobs on collapsed stalks are eaten by diurnal agoutis (*Dasyprocta* sp.) and nocturnal pacas (*Agouti paca*).

The greatest damage occurs in stored maize when it is attacked by beetles. The most common pest in harvested maize along the highway is a cosmopolitan snout beetle (Curculionidae: *Sitophilus zeamais*), which by boring into kernels, usually renders the crop commercially worthless within 3 to 4 months. The harvest is generally stored on or near the ground where it becomes mouldy and is invaded by beetles that feed on fungi and whose larvae tunnel into the kernels. From one site alone, a total of seven species of Coleoptera representing four families were collected (Nitidulidae: *Carpophilus pilosellus, C. dimidiatus, C. freemani, C. mutilatus;* Cryptophagidae: *Hapalips* sp.; Cucujidae: *Ahasverus advena;* Curculionidae: *Sitophilus zeamais*), an indication of the rich diversity of crop pests. The Arara Indians who formerly inhabited the region around agrovila Nova Fronteira, suspended their three varieties of maize from the ceiling of their communal house. In this manner, the cereal would keep dry and the smoke from interior fires might discourage insect predation.

Beans (*Phaseolus vulgaris*), planted after rice by some colonists for domestic consumption, do not provide a significant source of cash income for the majority of settlers. In 1972, yields on relatively fertile terra roxa averaged only 443 kg/ha (s = 177, n = 5, Smith, 1976 c), and by 1973, a widespread fungus (*Thanatephorus cucumeris*) had seriously affected productivity (IPEAN, 1973). Rabbits (*Sylvilagus brasiliensis*) crop bean sprouts, and yields are reduced after harvest by at least two species of bruchid beetles, *Callosobruchus maculatus* and *Zabrotes subfasciatus*, which bore into most of the beans within 4 months of storage, a problem noted in other tropical areas (Sefer, 1959; Jurion and Henry, 1969, p.247). Planting seed is preserved by sealing them, liberally dusted with insecticide and fungicide, in steel drums or bottles, but no effective measures are taken to protect beans for human consumption. Bruchid beetles were observed in packaged beans in stores, and planting seed may have been another mode of dispersal.

PERENNIAL CROPS

Although bananas (*Musa* spp.) produce abundantly along the highway, much of the crop spoils on the ground because local markets in Marabá, Altamira and Itaituba are saturated. Bananas do not transport well over large distances on the hot and bumpy Transamazon, and larger urban centers such as Belém are more cheaply supplied by river from nearby growers.

Pepper (*Piper nigrum*) is grown profitably by JapaneseBrazilians in Amazonia, particularly at Tomé-Açu in Pará, but *pimenta* plantations along the Transamazon will not ensure settlers a reliable income. Pepper cultivation requires careful treatment with mulches, fertilizers, insecticides and sometimes herbicides (Egler, 1961). Whereas the Japanese are traditionally skillful at intensively managing small farms, most Transamazon settlers lack the knowledge and capital to grow pepper commercially. Even at Tomé-Açu, fungal diseases such as *Fusarium solani piperi* have caused serious damage, forcing diversification of the crop base with cacau (*Theobroma cacao*), papaya (*Carica papaya*) and passion fruit (*Passiflora* sp.).

Wild relatives of the domesticated cacau are native to the Amazon forest where they are primarily understorey trees. In commercial plantations in Latin America, cacau is usually planted under shade trees such as *Gliricidia* spp. or *Erythrina* spp. that also fix atmospheric nitrogen at root nodules. Along the Transamazon, little provision is made for the permanent shading of the crop and mortality rates are therefore high, especially in podzolic soils. The pronounced dry season and generally poor soils also retard development of the crop. In terra roxa areas, cacau is growing well, but fungal diseases, especially *Phytophtora palmivora*, could reduce the economic viability of the crop.

Coffee (*Coffea arabica*) was initially envisaged as a promising cash crop for the highway and IPEAN (Instituto de Pesquisa Agropecuária do Norte, now

EMBRAPA) imported a southern variety, *Mundo Novo*, apparently resistant to coffee rust (*Hemileia vastatrix*). However, expensive weekly applications of insecticide are required in some cases to control lepidopteran larvae (*Perileucoptera coffeella*) (IPEAN, 1973). Furthermore, coffee fruits all year long on the highway, as well as other areas of Amazonia, which is useful for domestic consumption but it reduces the commercial potential of the crop.

Although a US $6 million sugar mill has been built at km 92 Altamira-Itaituba with an annual capacity of 70 000 tons, as of July 1977, less than 1000 ha of cane had been planted in the Altamira region. The mill is in a relatively fertile terra roxa zone, but the topography is sharply undulating and transportation of the crop to the mill is difficult.

Some farmers sow guinea grass (*Panicum maximum*) with rice so that pasture may form after the rice is harvested. Colonists regard the process of substituting second growth with pasture as a potential solution to their cash crop problem. The idea of cattle raising is attractive to peasants because of the prestige associated with ranching in Luso-Brazilian culture and because of the apparently leisurally life of the *fazenda.*

Sowing grass is a relatively easy task, but maintaining pastures open from weed invasion and stump sprouting is burdensome. Fencing is costly and time consuming. Even if a colonist is able to convert up to 80% of his 50 ha cropping area* to good pasture, beef production on such a small area would not be economically viable. The year-round carrying capacity of artificial pastures in upland Amazonia generally averages 1 head/ha/year, and cattle require 4 years to reach a slaughter weight of 350 kg (IDESP, 1970; FAO, 1973), thus the productivity of such pastures is only 44 kg/ha/year, allowing for calves and reproducers. Under optimal conditions, therefore, a colonist might be able to produce 1760 kg of undressed beef a year on 40 ha, and would earn US $739 from the sale of cattle (based on July 1977 live-weight rate of US $0.42/kg). Flour produced from a 3 ha manioc field can provide US $2,019, clearly more lucrative than cattle raising, and less environmentally destructive.

A limited area of grassland for dairy cattle is warranted, but converting most of the 50 ha cropping area into cattle pasture is risky. Productivity is likely to decline as the pasture is impoverished through soil compaction and nutrient loss, due to fires, removal of cattle and leaching. Intercropping with legumes may replenish nitrogen, but other nutrients, particularly phosphorus, may require fertilization, which considering the high cost of commercial fertilizers along the highway**, is unlikely to prove economically feasible.

INCRA and SUDAM (Agency for Amazonian Development) are opening up 3.7 million ha of forest, mostly destined for cattle raising, in lots ranging from 3000 to 66 000 ha, along the Marabá-Itaituba stretch of the highway. Whereas

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*In accordance with article 44 of law 4.771 (1965), colonists are not supposed to clear more than 50% of their lots.

**Fertilizer prices in Altamira in July 1977: N (urea) = US $0.41/kg, P (superphosphate) = US $0.41/kg, K (potash) = US $0.20/kg.

large companies may abandon degraded pastures with little or no financial loss, since they only invest between 5 and 25% of their own funds due to SUDAM fiscal incentives (Brasil, 1973; Foucher, 1974; Katzman, 1976), colonists would encounter difficulties trying to cultivate compacted soils, exhausted of nutrients, on their 100 ha lots.

ENVIRONMENTAL IMPACT OF AGRICULTURE

Concern has been expressed at the prospects for agricultural colonization in Amazonia, particularly along the Transamazon, in view of the apparent dangers of soil erosion, compaction, laterization, as well as the creation of scrub savannas and deserts (Le Cointe, 1918; Camargo, 1948; Guerra, 1952; Lima, 1958; McNeil, 1964, 1972; Richards, 1967; Anderson, 1972; Paula, 1972; Denevan, 1973; Sioli, 1973 a and b, 1974; Tricart, 1974; Wesche, 1974; Dasmann, 1975, p.122; Goodland and Irwin, 1975; Siskind, 1975, p.41; Tricart, 1975; Schubart et al., 1976). In order to increase agricultural productivity, the importance of modernizing swidden farming has been emphasized (Chang, 1968; Watters, 1971; Kellman, 1974). In spite of the paucity of data, the impact of machinery, fertilizers, herbicides and pesticides on Transamazon agroecosystems warrants examination.

To accelerate the planting of sugar cane, INCRA is clearing forest with Caterpillar D 8 bulldozers in the vicinity of the mill. Such machinery, while useful for preparing building sites, mixes the relatively fertile topsoil with less fertile lower horizons and compacts the soil. A D 8, without a protective cabin cover, weighs 24 450 kg (Caterpillar, 1975), and exerts a pressure of 0.7 kg/cm^2 through the two treads which have 3.5 m^2 in contact with the soil surface. In contrast, a 60 kg man creates 0.1 kg/cm^2 of pressure on the ground through the 600 cm^2 soles of his feet. In experimental plots on a podzolic soil in the Peruvian Amazon, bulldozers reduced the infiltration rate by 95% compared to areas cleared manually (Anonymous, 1973).

The application of lime to the generally acid Transamazon soils may provoke trace element deficiencies, humus decomposition and structural deterioration, particularly in latosols (Richardson, 1951; Popenoe, 1960, 1966). Erosion and run-off may introduce calcium to streams and ponds enabling planorbid snails, intermediate hosts for schistosomiasis already established in Altamira (Moraes, 1972; Pinheiro et al., 1974), to proliferate. Fertilization can increase pest damage (Eden, 1952), and insecticides can produce the same effect by destroying pest predators (Tidman, 1951). Herbicides control some weeds, such as species of *Solanum*, *Eupatorium* and *Cecropia*, but as in the case of upland rice fields in the Peruvian Amazon, grasses resistant to toxic chemicals can reduce agricultural productivity (Sanchez and Nureña, 1972).

If crops with poor ground cover are cultivated continuously at the same site, the topsoil is likely to harden, due partly to the impact of rain. The top 5 cm of soil in fields examined along the highway became more compact within 3 years of cultivation ($P = 0.001$, $n = 15$, Smith, 1976 c), a tendency noted in other tropical areas (Popenoe, 1957; Cunningham, 1963; Scott, 1974; Schubart et al., 1976). Field soils in study areas of the highway became sandier under cultivation ($P = 0.001$). Although neither compaction (< 1.35 g/cc), nor the loss of clay in the topsoil, were great within the first few years of cultivation, eventually the loss of colloids and the increased moisture stress in the soil could reduce crop yields. Ploughing, practiced by a few colonists from the South, alleviates compaction, but the mixing of the soil horizons dilutes fertility.

The high cost of fertilizers, herbicides, insecticides and machinery prevents most colonists from employing these potentially destructive techniques. Instead, second growth fallow plays an important role in restoring soil fertility and structure, as well as suppressing pest populations, as in many other tropical regions (Popenoe, 1957; Greenland and Nye, 1959; Nye and Greenland, 1960; Kellman, 1969; Janzen, 1970). In order to extend fallow periods, deemed essential for sustained-yield agriculture along the highway, cropping systems are needed that enable farmers to cultivate plots for several years without triggering adverse ecological changes.

ABORIGINAL AGRO-ECOSYSTEMS

The Arara, a Carib group of approximately 200 Indians who lived in the vicinity of agrovila Nova Fronteira when the first highway colonists arrived, provide a valuable store of information on agricultural practices adapted to the ecological conditions of the region. The most striking aspect of the six abandoned Arara fields examined is the diversity of intercropped plants, a feature often noted in gardens of other Amerind groups (Frikel, 1959; Harris, 1971; Dickinson, 1972; Harner, 1973, p.50). The Arara cultivate at least 19 varieties of plants belonging to 13 species. All the fields were in the order of 2 to 3 ha in area, yet none were identical in crop composition.

In one field, squash (*Cucurbita* sp.) and sweet potato (*Ipomoea batatas*) provide ground cover, with manioc, the basic staple, forming the middle storey. Three varieties of banana (*roxo, comprida, ouro*), planted in clumps, as well as dispersed papaya and araticum (*Anona nitida*), form the top layer. Isolated clumps of canna (*Canna paniculata*), were possibly grown for the hard black seeds used in ceremonial wear and for the edible roots. Patches of ginger (*Renealmia occidentalis*), two varieties of pineapple (*Ananas cosmosus*), and a bunch grass (*Andropogon paniculatis*), the latter possibly cultivated for ceremonial use, were also found in the field. Other plots contained various combinations of crops including cotton (*Gossypium hirsutum* var. Marie-Galante), and urucu (*Bixa orellana*). The Arara also cultivate black, red, and yellow varieties of maize.

By simultaneously cultivating at least six polycultural plots, ranging from 2 to 5 years old, the Arara were supplied with a variety of foods on a year-round basis. Within each field there is a sequence of crop maturation until the *roça* is abandoned after about 6 years. In this manner, the impact of disease and inclement weather on agricultural productivity is reduced. The multi-storied cropping system of the Arara simulates the forest structure, albeit on a simplified scale, and provides good ground cover, thereby minimizing weed problems, soil compaction and erosion. All of the Arara fields were cleared on relatively flat surfaces, a further safeguard against erosion.

The Arara space their *roças* at least 2 km apart, and between 1 and 4 km from the village, thus reducing the danger of a pest or disease epidemic among crops. According to Fautereau (1955), for example, nuptial flights of leaf cutter ants rarely extend beyond 1 km. The arara, as in the case of some other aborigianl groups in Amazonia (Murphy and Quain, 1955; Salisbury, 1968), may have separated their fields so that enemies find it more difficult to locate their village. Transamazon fields lack a protective forest buffer zone since most colonists are clearing from the roadside into their lots. Consequently, the highway provides an avenue for the dispersal of crop pathogens and pests.

CONCLUSION

A diversified crop base, with manioc serving as a major source of cash and subsistence during the first few years of settlement, not only reduces pest and disease damage, but provides security against oscillating prices of agricultural products. Manioc alone will not provide a panacea for all the agricultural problems of the highway, but it can help build a foundation of trust, mutual assistance and financial solvency which can foster co-operative efforts and provide a catalyst for agricultural development.

Agricultural planners in Amazonia might consult the considerable cultural and ecological experience of peasants and aboriginal groups when devising colonization schemes. Future projects might be located near rivers with fertile floodplains where there is an abundance of relatively flat terrain, fish, and cheap water transportation. Whether on floodplains or uplands, attempts to introduce more advanced farming systems, which rely heavily on large inputs of capital and machinery, are inherently unstable in areas settled by relatively unskilled and illiterate colonists.

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