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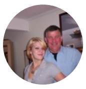

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Agroforestry performance on small farms in Amazonia: Findings from the Rondonia Agroforestry Pilot Project

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Abstract. Experiences from not only 'success stories' but also 'failed' agroforestry projects provide potentially useful lessons for future agroforestry-project designers. Experimental one-hectare agroforestry plots were established on 50 small-scale farms in the western Brazilian Amazon State of Rondonia from 1993 to 1995. Drawing from a menu of 25 different species (10 tropical hardwoods and softwoods and 15 fruits and palms), this species trial shows encouraging survival and growth performance for most species under wide ranging plot management regimes. Tropical hardwood survival rates (after 18 months) ranged from 65% for Cerejeira (Torresea acreana) to 88% for mahogany (Swietenia macrophylla). Survival rates for commercial fruit and palm species were even higher. A comparison of attributes of two sub-groups (successful and unsuccessful planters) suggests that previous experience with perennial monocultural cropping, greater social participation, land use history, and soil chemistry are positively associated with successful agroforestry species performance, while no significant differences exist between successful and unsuccessful planters in household size, area deforested, area in pasture, and land tenure security. A closer analysis of 'failed' agroforestry plots indicates the primary importance of social factors originating at the household-level (e.g. inadequate plot maintenance, improper planting techniques, illness, etc.). Twelve different causes of plot failure were cited, falling into three classes. Of the total number of reasons given for plot failure, household level factors represented 54% of all causes cited. Project design and implementation factors (inappropriate plot design, defective planting material, etc.) were cited 25% of the times and environmental factors (soil fertility constraints and pasture grass invasion) were cited 21% of the times.

1. Introduction

This paper presents the findings of the first phase (1993–98) of the Rondonia Agroforestry Pilot Project (RAPP). This is an on-farm experimental agroforestry project involving 50 small-scale farmers in two tropical forest localities in the Southwestern Brazilian Amazon State of Rondonia. The Project, initiated as a species performance trial, also seeks to clarify the role of 'social factors' in determining success or failure in the adoption and performance of on-farm experimental agroforestry plots. This paper presents the growth performance findings for the first five years of the project for 20 different species planted in RAPP. By the Project's fifth year, 13 of the original 50 farmers had dropped-out of RAPP, their agroforestry plots classified as failures. Another 11 farms, by contrast, exhibited exemplary growth performance well in excess of the sample mean measurements for the experimental group overall and were considered probable ‘success stories’ in agroforestry diffusion. This paper compares key attributes of both sub-groups of farms in the Project, failed and successful agroforesters, and then identifies specific factors that appear to contribute to agroforestry failure in the short term, providing potentially useful benchmarks for future agroforestry project designers.

2. Materials and methods

2.1. *Site description*

Two project sites were selected in recently settled agricultural communities in the municipios of Alto Paraiso and Nova União in the southwestern Brazilian Amazon State of Rondonia.[1] Draining into a principal Amazon tributary, the Madeira River, Rondonia covers an area of 239,000 square kilometers along the Bolivian border, roughly between latitude 7°35′30″ and 13°41′30″ S and longitude 59°50′4″ and 66°15′00″ W. The predominant vegetation class is ‘transition forest’ or ‘tropical-seasonal moist transitional forest’ extending over approximately 75% of the State’s area. ′Dense’ or ‘closed’ tropical forest occurs in large patches in the northern portions of the state bordering on the State of Amazonas. A band of savannah grassland (*cerrado*) is found in the higher elevations of the south-central hill ranges (Paca·s Novos, Uopione and Parecis). Seasonally inundated floodplains follow the major boundary rivers (Guaporé, Mamoré) and their estuaries. The humid, tropical climate falls within the ‘Awi’ classification on the Koppen scale, with a distinct rainy season (usually October to April). Annual rainfall ranges from 1800 to 2200 mm and average monthly temperatures vary from 21 to 27 degrees Centigrade. Approximately 90% of the land area in Rondonia is covered by a relatively infertile dystrophic latosols. Only 10% contains eutrophic podsols, considered suitable for annual or permanent cultivation (World Bank, 1981).

2.2. *Site history*

Despite severe soil constraints for conventional commercial shifting cultivation, exceedingly optimistic estimations of soil suitability for agriculture encouraged Brazilian government planners to open Rondonia to massive pioneer settlement in the 1970s with a road-building program and land give-aways (Browder, 1988, 1994; EMBRAPA, 1975; Falesi, 1974; FJP, 1975; Mahar, 1989). Small farmers, predominantly former tenant farmers displaced by agricultural mechanization in Southeast Brazil, poured into Rondonia at a pace that exceeded 2,000 families per month in the late 1970s and early 1980s in what *The Washington Post* called the ‘greatest land rush since the settling of the American West’ (Bridges, 1988). From 1970 to 1991, the population of Rondonia grew from 111,000 to an estimated 1,132,692 inhabitants (IBGE 1996). The rapid and massive settlement of Rondonia triggered the greatest conflagration of tropical forests in Amazonia, prompting urgent calls from ecologists, conservationists and policy makers to develop alternatives to commercial slash and burn farming systems practiced by Rondonia’s agrarian population. While in 1978 only 2% of the State’s natural vegetation cover was classified as ‘altered’ (i.e. deforested), by 1996 deforestation had claimed 23% of the State’s area (SEDAM 1997).

It is in this historical context of rapid environmental transformation that the widespread adoption of agroforestry is being commonly pursued as an alternative, more sustainable land use in frontier areas like Rondonia (Smith et al., 1995).

2.3. *Project participant population and land uses*

The social characteristics of the farming populations in both project sites are similar (Table 1). On whole, the population could be accurately characterized as low-input, small scale commercial farmers with various forms of legal title to their farms that range from 70 to 90 hectares in size. This population has resided on their farms for 15–20 years and live in households of approximately 10 persons (including six to seven working age persons). Few household members are engaged in off-farm work, between 10% and 16% have commercial bank savings accounts, and virtually none received commercial loans or government subsidized rural credits. Most of these farmers report extracting non-timber forest products from the primary forest patches on their farms and half of the population surveyed indicated an interest in adopting agroforestry practices.

Colonist farming strategies and land use patterns in Rondonia are considerably more complex, heterogeneous and dynamic than those often depicted in conventional shifting cultivator models and so defy facile classification (for review see Thrupp, Hecht and Browder, 1996). One commonly observed pattern in Amazonia is the transition from mixed (permanent-annual) crop systems to cattle ranching (*pecuarizão*). Frequently, small farmers practicing mixed cropping experience low yields or successive annual crop failures and are forced to sell their farms to larger landholders who typically plant pasture. In other cases, small farmers plant pasture in degraded crop fields but are too poor to buy cattle. In either case, the lack of farmer resilience to risk reinforces the land use transition to pasture, a prevalent trend throughout the region (Browder, 1994). But other patterns, including ‘spontaneous’ adoption of various agroforestry practices, are also evident. The Rondonia Agroforestry Pilot Project has attempted to build upon the experiences of innovative colonist farmers who have already planted trees, often in association with ground crops, in order to diversify farm production.

Table 1. Characteristics of Project Sites (1992), Rondonia Agroforestry Pilot Project, Southwestern Brazilian Amazon.

Variable	Nova União	Alto Paraiso
Location	62°35′ W x 10°50′ S	63°20′ W x 9°35′ S
Altitude (meters above sea level)[a]	100–225	110–369
Average annual rainfall (mm)	1600–1700	2000–2100
Main soil type[b]	PE 3/Re[c]	Pva 13/Rd 3[d]
Vegetation cover type[e]	TTSMF[f]	TTSMF
Project area (hectares)	7,130	7,273
Number of project area farms	97	82
Average farm size (hectares)	73.5	88.7
Mean year of farm establishment	1981	1982
Percentage of farmers with legal land title or deed	69.0	75.9
Number of persons dwelling per farm (1992)	11.2	9.3
Number of workers per farm (1992)[g]	6.8	6.05
Percentage of workers with off-farm employment	5.7	7.8
Percentage of farms with bank savings accounts	13.8	15.8
Percentage of farms receiving commercial or government loans (1991)	1.0	0
Percentage of farms extracting non-timber forest products	69.1	96.3
Percentage of farmers interested in planting trees together with temporary ground crops	48.9	50.0

Notes:
[a] *Source:* Instituto Brasiliero de Georgrafia e Estatística (IBGE), Elevation maps, 1974.
[b] *Source:* Projeto Radambrasil., Mapa Exploratório de Solos, 1:1,000,000. Folha SC.20 Porto Velho, 1979.
[c] Eutrophic yellow-red podsols with patches of eutrophic litolic soils.
[d] Alic yellow-red podsols with patches of distrophic litolic soils.
[e] *Source:* IBGE, Mapa de Vegetação de Brasil, 1988.
[f] Transitional tropical seasonal moist forest (*Floresta Ombrófila Aberta*).
[g] Worker: persons age 11–65 years.
Source: Survey of 179 farmers (male and female) in Alto Paraiso municipio (linhas 80, 90 and 95) and Nova União municipio (linhas 80/40 and 80/44), July 1991 (except as noted in footnotes, below).

The two project sites display many similar biophysical characteristics, but are distinguished in terms of the predominant soil types (Table 1). Nova União, with its predominantly eutrophic podsols, is somewhat preferable for conventional low-input farming than Alto Paraiso with its largely distrophic soil base. The difference in soil types between the two project sites was an important criterion in determining project site selection (see end-note 1).

2.4. *Project goals and objectives*

The long-term goal of the Rondonia Agroforestry Pilot Project is to identify and evaluate the conditions which influence the successful adoption of agroforestry systems by small-scale farmers in Rondonia. The project entails two phases. In the first phase (1993–98), the survival rates and biological productivity of 20 species in different planting configurations were monitored. The second phase (1999–2004) will evaluate the financial impacts of the trial plots on household income and evaluate the relative importance of different social factors in determining successful agroforestry project outcomes. In both phases of the project, regular site visits to participating farms enable identification of social factors affecting successful integration of agroforestry practices into prevailing farming system. Although it is premature to evaluate these long-term research goals, this paper presents findings from the project's first phase and identifies factors that influence success and failure in the adoption of agroforestry practices in the short term.

2.5. *Planting material and experimental design*

An experimental group of 50 farmers was initially selected on the basis of responses to a baseline survey administered to a total of 242 farmers in three *municipios*.[2] Participating farmers were invited to select from a menu of 20 different species each producing one or more commodities of local market interest (Appendix 1).[3] Seedlings were produced on local project nurseries using regionally available seed stock. Plots were designed to fit on a one-hectare area containing no primary forest vegetation. Each plot consisted of between 800 and 1,000 individuals of various species (the average number of species was 4.4, but ranged from two to 18) that typically included a mix of fruit, palm, latex, and nut-producing species with potential commercial yields beginning within five years. Two species (Theobroma grandiflorum, Bactris gasipaes) and various citrus and hardwood species were especially popular due to their strong local markets. While more detailed information about these leading agroforest species is presented here, Villachica (1996) also presents an excellent review of some 50 Amazon fruit and horticultural species, including many of those planted in the RAPP. Longer-term tropical industrial softwoods and hardwoods with potential harvests beginning in the range of 10–40 years were also planted by most farmers in the experimental group. To enhance household income in the short-term, participating farmers were offered a bee-keeping component (materials and training), an option which 18 (36% of the) experimental farmers elected.

During the first half of the rainy season, seedlings were distributed to each farm according to the plot plans collaboratively developed by project designers and participating farmers. Farmers were not charged any fee for the seedling stock, but were expected to use their own labor to plant the seedlings according to the plans during the rainy season.[4] Within six months of planting each farm was visited, seedling growth was measured, and problems with plot maintenance were described. After the first year, annual farm visits were conducted to monitor seedling growth rates, mortality, changes in household demographics and economic activity that might influence farmer agroforestry plot management and performance. By the end of the fourth year (1997), 37 (74%) of the plots continued to be maintained by participating farmers. The remaining 13 (26%) were declared 'failures.'

3. Results

3.1. *Biological Performance*

The growth and survival rates were measured after 18 months based on periodic project monitoring surveys of a systematically selected sample of plants in each experimental plot undertaken between 1993 and 1997.

3.1.1. *Timber species*

The growth and survival rates of eight industrial wood species are presented on Table 2. Survival rates after 18 months were found to be 80% or higher, except for Andiroba and Brazilian Cherry (Cerejeira). After 42 months most species had more than doubled their girth. The mean diameter at breast height (DBH) of mahogany increased from 3.03 cm (six months after planting) to 7.43 cm (after 42 months).

Two species (mahogany and freijo) warrant further discussion in this study.

Mahogany (Swietenia macrophylla). A prime tropical hardwood, mahogany potentially reaches a minimum harvest size (35–40 cm DBH) in 40 years (W. Abdala, pers. comm. 7/11/93), providing a long-term investment option for farmers seeking to upgrade property resell values, a secure retirement, or a 'trust fund in the ground' for their children. Wild mahogany is virtually depleted in Rondonia due to unregulated logging on open access public forest-lands during the 1980s. Current mill-gate prices range between US$150 and US$200 per cubic meter (Browder et al., 1996). The regenerative capacity of mahogany under experimental planting conditions is unclear. However, environments subject to shifting cultivation or periodic natural disturbance (e.g. hurricanes, fires) are believed to offer ideal regenerative niches for mahogany (Snook, 1993). One persistent problem is mahogany's susceptibility to the shoot-borer (*Hypsipila grandella*), which infests the apical stems of young saplings. Unless the sapling's crown is reduced to a single leader stem by corrective manual pruning, the infestation typically results in a deformed bole structure. Recent research on the financial feasibility of mahogany silviculture in Rondonia in distinctive types of regimes including agroforestry suggests that the shoot borer is a widespread and serious problem for farmers

Table 2. Mean Stem Height and Diameter at Breast Height (DBH) in centimeters (standard deviations) by months after planting and survival rates after 18 months of selected industrial woods species in Rondonia Agroforestry Pilot Project, Southwestern Brazilian Amazon.

Species	Height at 6 months	Height at 18 months	DBH at 6 months	DBH at 18 months	DBH at 42 months	Survival rate (%)
Andiroba (*Carapa guianensis*)	144 (55.5)	231 (61.6)	1.17 (0.25)	n.a.	3.07 (1.62)	75.0
Bandarra (*Parkia paraensis*)	850 (70.7)	1,040 (188.4)	10.8 (1.75)	n.a.	14.1 (5.79)	80.0
Cedro (*Cedrela odorata*)	235.9 (163.2)	318.5 (118.7)	4.25 (1.31)	n.a.	9.34 (1.67)	88.5
Cerejeira (*Torresea acreana*)	85.8 (55.4)	175.2 (68.9)	0.75 (0.35)	n.a.	6.49 (1.77)	64.5
Cumaru (*Coumarouma odorata* Aublet)	100.5 (19.1)	215.5 (0.71)	n.a.	2.75 (1.06)	4.81 (2.87)	n.a.
Freijo (*Cordia alliodora*)	169.3 (103.4)	290.1 (160.1)	2.21 (1.37)	n.a.	7.95 (2.83)	87.1
Mahogany (*Swietenia macrophylla*)	123.6 (78.2)	259.6 (87.9)	3.03 (1.70)	n.a.	7.43 (2.65)	87.8
Teak (*Tectona grandis*)	488.3 (129.9)	631.2 (176.4)	4.77 (1.45)	6.4 (3.49)	8.5 (8.65)	87.7

Source: Annual Project Monitoring Reports, 1993–1997.

interested in planting mahogany. In a survey of six different planting regimes, Matricardi and Abdala (1993) reported that all or most of mahogany plantings were infected by the *Hypsipila larvae* usually within the first two years of planting.

Freijo (Cordia alliodora). This industrial hardwood has a wide range of end uses in civil construction and furniture and reaches a minimum harvest size after 10 years. Recent producer prices for 80 cm pieces (used in banisters) is about US$5.00 (W. Abdala, pers. comm. 7/11/93). Freijo, best planted in open clearings, is a suitable companion to other agroforestry species, providing shade, wind-blocks and living fence. Its flower is a source of nectar favored by several varieties of honey bees, complementing bee-keeping activities pursued by 18 project participants as part of their agroforestry plot experiments.

3.1.2. *Key agroforest crops*

The growth and survival rates after 18 months of five key agroforestry plant species were calculated. These cash crops demonstrated reasonable survival and growth performance during the 18 month period following planting, although performance differed for some crops between the two study sites

(Table 3). Three agroforestry cash crops (cupuaçu, pupunha or peach palm, and various citrus) stand-out in this category:

Cupuaçu (Theobroma grandiflorum). The 18 month mean survival rate for cupuaçu plantings, the single most popular species in the experimental group chosen by 48 out of 50 participating farmers (96%), exceeded 91% in Alto Paraiso, and 81% in Nova União project farmers. Cupuaçu begins to fruit in 2.5 to four years and reaches mature production in five to ten years. The fruit pulp is used in ice creams, desserts, juice, liquors, and other confections, and enjoys a well-established regional market (Ribeiro, 1992). A relative of cacau, cupuaçu kernels can be processed into a fine quality of chocolate (*cupulate*). A native Amazonian shade-favoring species, cupuaçu can be planted in association with various other fast-growing, sun-loving, shade-providing species (e.g. banana, palms). Like other fruit species planted in agroforestry configurations, cupuaçu requires relatively substantial labor inputs (mainly weeding, mulching and trimming, adding up to 40–50 work-days per hectare per year) during the first two to three years (Ribeiro, 1992; Calzavara, 1984).

Current export prices for frozen cupuaçu pulp of highest quality range from US$3.50 to 4.50 per kilogram. The producer price ranges from US$0.75 to 0.90 per unpulped fruit under current market conditions. Farmers planting 220 bushes (a relatively sparse 7 × 6 m planting on one hectare) can expect to produce upwards of 3,300 fruits after five years, representing a total gross income of US$2,970, a substantial income supplement.

Table 3. Mean height in centimeters (standard deviation) by months following planting and survival rates after 18 months of key crops, Rondonia Agroforestry Pilot Project, Southwestern Brazilian Amazon.

Species		Alto Paraiso			Nova União		
	At planting	6 month	18 months	Survival rate (%)	6 months	18 months	Survival rate (%)
Cupuaçu (*Theobroma grandiflorum*)	57.6 (7.8)	88.6 (14.8)	141.0 (29.8)	91.5	94.0 (33.3)	139.0 (46.1)	81.2
Pupunha (*Guilielma gasipaes*)	22.6 (6.9)	71.7 (27.7)	181.1 (86.5)	79.4	126.8 (62.6)	256.4 (115.1)	93.5
Açai (*Euterpe olercea*)	38.9 (14.1)	55.7 (16.1)	97.7 (30.9)	78.5	70.3 (21.7)	139.0 (50.6)	79.3
Araça boi (*Eugenia stipitata*)	27.4 (14.4)	46.7 (26.9)	80.9 (46.7)	90.0	75.7 (26.2)	152.2 (35.8)	96.5
Caju (*Anacardium occidentale*)	26.1 (7.0)	74.5 (23.6)	184.2 (125.3)	75.0	–	–	–

Source: Annual Project Monitoring Reports, 1993–1997.

Pupunha Palm (Bactris gasipaes). Pupunha palm (or peach palm) is a widely planted *terra firme* substitute for açai (*Euterpe oleraceas* Mart), extracted from the wild on the Amazon floodplains. Both produce palm hearts (palmito), enjoying a large international market, and palm fruit, the mesocarp of which is used to prepare flour and cakes for regional markets. The growth of pupunha and açai palms was somewhat disappointing in Alto Paraiso with a mean height of less than two meters after 18 months. Generally, the rate of plant growth was higher in Nova União due in large part, we hypothesize, to somewhat better soil quality. Pupunha propagates by seed and stem harvesting typically begins after 18 months following transplanting. If managed carefully, two to three stems can be harvested annually, each ranging from 1.5 to 8.0 kg per stem. At 18–24 months, each apical bud contains between 100 and 300 grams of soft palmito heart. Producers cut these to size after harvest. They are jarred in 500 gram quantities and sold to wholesalers for about US$3.50 each in June 1996 (D. McGrath, pers. comm. 6/4/96).

Citrus. Presently about 95% of all citrus fruits consumed in Rondonia's urban markets are imported from the Southeast of Brazil (Sao Paulo, Minas Gerais). Porto Velho alone, with about one-third of Rondonia's urban population, consumes approximately 1,200 metric tons of oranges each year. At current (July 1998) market prices (US$0.30 per kg), which are low due to excess supply in Sao Paulo, this consumption represents US$360,000 per year of imported oranges that could be captured by local producers, although the quality (i.e. sugar content) of local citrus is lower than oranges produced in the south of Brazil.

The growth and survival rates of several other agroforestry tree species were also measured (Table 4). On the whole, the growth performance and market potential of these agroforestry plots is reasonably promising, suggesting that a variety of commercial perennial species can be cultivated in agroforestry formations with minimal inputs and that natural environmental factors do not pose insurmountable barriers to agroforestry development even on badly degraded tropical forest lands. However, in several cases, the establishment of agroforest plots was unsuccessful in the short-term and farmers abandoned or destroyed their plots. We turn to those factors that might explain initial growth performance next.

3.2. *Factors affecting growth performance of agroforestry species*

The experimental group of participating farms was divided into two subgroups: Sub-group 1 farms had abandoned their agroforestry plots during the five-year Phase I period (13 farms), i.e. clear failures over the short term. Sub-group 2 farms were those in which agroforestry plots contained key species demonstrating biological growth and survival performance at least 5% greater than mean growth for the experimental group overall, i.e. clearly successful plots over the short term (11 farms). The analysis focuses on these

Table 4. Mean stem height in centimeters (standard deviation) by months after planting and survival rates after 18 months of selected tree-crops in Rondonia Agroforestry Pilot Project, Southwestern Brazilian Amazon.

Species	At planting	6 months	18 months	Est. survival rates (%)
Acerola (*Malphighia punicifolia*)	36.7 (11.0)	n.a.	132.0 (31.0)	100.0
Bacuri (*Platonia insignis*)	27.0 (15.8)	44.7 (23.9)	n.a.	100.0
Condessa (*Annona reticulata*, Linn.)	67.8 (12.9)	91.1 (20.6)	201.7 (55.2)	85.0
Lemon (*Citrus* spp.)	n.a.	174.0 (31.0)	240.0 (21.9)	75.0
Orange (*Citrus sinensis*)	n.a.	73.6 (32.0)	164.7 (33.7)	82.8
Pomelo (*Citrus maxima* Merrill)	n.a.	94.4 (26.1)	137.6 (28.4)	100.0
Ponkan (*Citrus reticulata*)	n.a.	118.9 (31.8)	202.8 (61.4)	72

Source: Annual Project Monitoring Reports, 1993–1997.

two sub-groups, identifying those factors that most likely affect plot failure and success (Table 5).

3.2.1. *Soil chemistry*

Although several features of the natural environment would likely affect the biological performance of agriculture (including topography, relief, drainage, local water supply, unusual climatic characteristics), due to project budget constraints we confined our analysis to but one important natural limiting factor: soil chemistry. Soil samples were systematically collected at three strata (0–20 cm, 21–40 cm, and 41–60 cm) from each agroforestry plot site just prior to planting using a standard collection methodology. Soil chemistry analysis was undertaken at the soils laboratory of the Empresa Brasiliera de Pesquisa Agropecuaria (EMBRAPA) in Porto Velho. The results of the soil chemistry analysis for the first stratum were evaluated based on a nominal rating scale of 0.0 to 3.0, where a rating of 3.0 indicates the minimum theoretical threshold concentration for Phosphorus and Potassium and soil pH levels necessary for sustaining desired plant growth. Ratings less than 3.0 indicate relative deficiencies in these nutrient concentrations and soil alkalinity. Not surprisingly the two groups displayed significant differences in soil chemistry. Experimental farms with successful agroforestry plots (Sub-group 2) had a mean soil quality rating of 2.44, while farms with failed plots (Sub-group 1) rated only 0.83 on the soil quality scale. It should be noted that while soil chemistry is considered an ‘environmental factor,’ soil quality

Table 5. Identification of selected factors influencing species growth performance, Rondonia Agroforestry Pilot Project, Southwestern Brazilian Amazon.

Factor	Successes (*n* = 11)[a] (Sub-sample 2)	Failures (*n* = 13)[b] (Sub-sample 1)
Environmental factors		
Soil rating[c]	2.375	0.83
Household factors and land use differences		
Household size (persons)		
1991	3.2	6.0
1995	4.2	4.0
Area deforested (hectares)		
1991	11.4	11.8
1995	12.9	15.7
Area in temporary crops (hectares)		
1991	2.3	1.3
1995	1.6	1.4
Area in perennial crops (hectares)		
1991	3.0	3.9
1995	6.1	3.7
Area in pasture (hectares)		
1991	5.2	4.4
1995	8.5	9.1
Years in prior use	5.75	9.0
Definitive land title (%)	57.1	66.7
Years of continuous cropping	18.4	17.8
Average output of annual crops (60 kg sacks), 1991	138.0	157.5
Percent of annual crop output sold , 1991	27.6	43.9
Average output of perennial crops (40 kg sacks), 1991	560.0	184.0
Percent of perennial crop output sold, 1991	96.9	97.2
Social participation rates[d]	80.0	44.4
Percentage of farmers receiving bank financing	0	0
Percentage of farmers having commercial bank savings account	20.0	0

Notes:

[a] Sub-sample of project farms where experimental agroforest plot performance in project's fifth year was equal to or greater than 5.0% higher than the average growth performance for the experimental group overall.

[b] Sub-sample of project farms that failed to sustain experimental agroforest plots for five years.

[c] Index of soil quality is the combined minimum theoretical thresholds for agricultural suitability for P (4 ppm = 0, 4–13 ppm = 1.0, > 13 ppm = 2.0); K (< 45 ppm = 0, 45–150 ppm = 1.0, 151–250 ppm = 2.0, > 250 ppm = 3.0); and pH (< 5.5 = 0, 5.5–7.5 = 1.0) where the minimum threshold for each P and K and pH is 1.0 or combined rating of 3.0.

[d] Percentage of the sub-sample that actively participated in at least one of three different social organizations during preceding 12 months (rural workers union, labor exchange group, or marketing cooperative).

Source: Baseline household survey (1992) and 1995 Annual Project monitoring report.

is also influenced by human use and social factors (e.g. prior land use history, plot management, etc.) and these must be considered in explaining soil characteristics.

3.2.2. *Household size*

Household size has multiple impacts on farm productivity. For large households with high (child-adult) dependency ratios, household size is likely to be a factor limiting productivity. For large households with a lower dependency ratios, larger household sizes theoretically favor increased farm productivity. Not surprisingly, demographic factors were significantly different between the two groups. Recognizing that children typically begin productive activities at an early age, we adopted a definition of household labor force as any physically functional household member between the ages of 11 and 65 years. Given this definition, we found, curiously, that Sub-group 1 experimental farms began the project with an average household labor force level nearly twice as large as Sub-group two farms with successful plots (6.0 and 3.2 workers, respectively), but that after four years the former had experienced a one-third reduction in household labor (to 4.0 workers) while the average labor force of Sub-group 2 farms increased by one-third (to 4.2 workers). We speculate that the short-term decline in Sub-group 1 farm labor is due to the lower productivity of labor in agriculture overall in this subsample of farms which is also reflected by their failed attempts to expand into agroforestry. We cannot attribute the cause of the plot failure entirely to household labor force reduction since by 1995 both groups had roughly equal numbers of household workers.

3.2.3. *Land use factors*

There are several important differences in land use between the two groups. In terms of total farm area deforested there were no significant differences between the successful agroforestry adopters and failed ones (27.4 and 28.3 hectares, respectively). By year five some separability in forest clearing emerges with Sub-group 1 farmers clearing more primary forest than Sub-group 2 farmers (37.7 and 31.0 hectares, respectively). These findings take-on added meaning when considered in relation to the permanent cropping practices of the two groups. In the project's first year, there were no significant differences between Sub-groups 1 and 2 in the area planted in permanent crops such as coffee (9.4 and 7.2 hectares, respectively). By the Project's fifth year, significant differences emerged between the two groups in this land use, where Sub-group 1 (failures) had planted 8.9 hectares while Sub-group 2 (successes) had planted 14.6 hectares. These findings suggest that farmers who register early successes in planting perennial crops are also likely to do better with agroforestry than farmers who are less successful planting perennials. Interestingly, while an image emerges of tree-planters being better conservationists, there were no significant differences between the two groups in relative farm area devoted to pasture over time. For both sub-groups, the trend toward pasture expansion is significant although the rate of expansion is slightly greater among farmers who failed at agroforestry.

Finally, an important land use variable influencing soil productivity concerned planting site history (e.g. number of years planting site had been in continuous cultivation, years of fallow, frequency of burns, etc.). Generally we found the expected negative relationship between years of continuous use and successful plot recovery into an agroforest environment. Failed experimental plots had significantly longer prior use periods (9.0 years) than successful agroforestry plots (5.75 years). 'Tired soils' is an important factor limiting biological growth performance. It is notable that no farmers cleared primary forest to plant the experimental agroforestry plots, consistent with Project requirements.

While these land use indicators provide only a partial picture of the farming systems of these colonist farmers, they support the observation that farmers who are successful in adopting agroforestry practices tend to be successful farmers overall as evidenced by increasing intensification (enlarged permanent cropping area over time), stable temporary cropping patterns, and a gradually growing pasture area.

3.2.4. *Land tenure*

World-wide secure land tenure is considered to be an important prerequisite to farmer innovation and risk-taking behavior (Raintree, 1987). In Brazil, several different forms of official property ownership status exist, the most secure of which is possession of a certified definitive land title. While no farmer was accepted into the experimental group of RAPP without some official document conferring land ownership status, it is interesting that a higher percentage (67%) of Sub-group 1 farmers (with failed agroforestry plots) owned definitive land titles than Sub-group 2 farmers (57%), suggesting that the most secure land tenure is not necessarily a precondition for successful integration of agroforestry practices. We speculate that since most of the farmers in the experimental group had resided on their farms for 10–11 years, any potential disputes over land tenure would have arisen years ago. Hence, land tenure may not be as important a determinant of agroforestry outcomes as initially expected.

3.2.5. *Years of continuous cropping*

Over time successful farmers learn how to manage their local environments to maintain productivity. Intuitively, the longer a farmer is able to maintain cultivation, the more knowledge the farmer acquires of the local environment that should enhance prospects for successful adoption of innovative production practices. Interestingly there was no significant difference in years of continuous cropping between successful and unsuccessful agroforestry adopters (18.4 and 17.8 years, respectively).

3.2.6. *Agricultural productivity and commercialization*

We hypothesized that farmers who were more productive in their agricultural practices, especially perennial tree cropping, would be more successful agroforesters. In terms of annual crops (beans, upland rice, and maize), Sub-group 1 farmers (with failed agroforestry plots) actually enjoyed slightly higher annual yields (157.5 sacks per farm) and marketed a greater proportion of that output (44%) than did Sub-group 2 farmers (138 sacks, 28% marketed). However, as predicted, there was a significant difference in productivity of perennial crops (mainly coffee and cocoa) between the two groups decidedly favoring Group 2 farmers (successful agroforesters). Both groups tended to sell nearly 100% of perennial crop output.

3.2.7. *Social participation*

We hypothesized that farmer participation in production-oriented non-governmental organizations also would be influential in determining agroforestry performance. Our surveys determined whether farmers participated in one or more of three types of production-oriented organizations: rural workers union, marketing cooperatives, and labor exchange groups. Although the specific impacts of participation in such organizations remain to be examined, there is a significant difference between the two sub-groups of experimental farmers in terms of social participation. The average participation rate (80%) of Sub-group 2 farmers (successful agroforesters) was nearly twice as high than that for Sub-group 1 (unsuccessful agroforester) farmers.

4. Discussion: why agroforestry fails

For each of the 13 farms belonging to the project's experimental group whose agroforest plots were declared abandoned or destroyed by 1997, an exhaustive enumeration of factors contributing to plot failure was undertaken (Table 6). Each farm attaining the distinction of Group 1 status (failed plots) was visited at least twice by project field staff to document the nature of the failure and re-interview the farmer, gaining detailed information about the reasons for failure. In several instances of failed plots, problems were detected early in Phase I and so ultimate failures came as no great surprise. We found a total of 12 specific factors that are grouped into three categories (environmental, project design and household factors). Our analysis suggests that while environmental factors are often considered to be the most important limiting factors in agroforestry, rarely is deficient soil quality a singularly decisive cause of failure. Only when nutrient-poor or compacted soils are combined with other social factors does a more comprehensive explanation of failure emerge.

Table 6. Specific factors contributing to agroforestry plot failure, Rondonia Agroforestry Pilot Project, Southwestern Brazilian Amazon.

Factor	# of mentions[a]
Environmental factors	12 (21.4%)
Renegade pasture grass invasion	6 (10.7%)
Soil nutrient deficiency	6 (10.7%)
Project design and implementation factors	14 (25.0%)
Inappropriate farmer selection	5 (8.9%)
Inappropriate plot design	4 (7.1%)
Deficient planting material	2 (3.6%)
Untimely delivery of plant material	3 (5.3%)
Household-level Factors	30 (53.6%)
Inadequate or poor plot maintenance	13 (23.2%)
Inappropriate plot site location	5 (8.9%)
Improper planting	5 (8.9%)
Movimento Sem Terra	4 (7.1%)
Farmer illness	2 (3.6%)
Farmer family disputes	1 (1.8%)

[a] A total of 56 factors were cited or mentioned as contributing to agroforest plot failure on the 13 farms classified as Group 1 farms in the Project's experimental group by 1997. The number of mentions associated with each factor gives some indication of their relative importance (percentage of total mentions).

4.1. *Environmental factors*

While our analysis focuses on social factors, two important 'environmental' factors warrant brief discussion. Representing only 21% of the 'mentions' given for plot failure, environmental factors (in this case, low soil nutrient concentrations and acidity) were significant, but not necessarily insurmountable barriers to successful agroforestry performance. Future projects can compensate for soil nutrient deficiency with artificial fertilizers and natural mulches to retain soil moisture and intensify release of nutrients from decomposing forest litter at the time of planting. More pernicious and less manageable is the increasingly chronic problem of restraining invasive pasture grasses, a problem encountered on 46% of Group 1 farms and credited with 11% of the total mentions. Grasses (especially *Brachiaria* spp.) quickly migrate from established pastures and crowd-out agroforestry species in the first months following planting. There is relatively little that farmers can do to control pasture grass invasion short of large scale applications of herbicides (an expensive and ecologically risky intervention), successive burning (also risky), or stocking cattle in agroforestry plots (which, depending upon the degree of plot development, usually results in some destruction of seedlings from trampling). One lesson from this experience points to the importance of the location of the agroforestry plot within the farm. By insisting that farmers select their plot sites from already degraded clearings on their farms, the Project design practically ensured that abandoned pastures and adjoining areas would be prominent among those locations selected as sites for agroforestry plots.

4.2. *Project design and implementation factors*

The second most frequently cited set of factors contributing to plot failure concern deficiencies in the design and implementation of the project itself. In five cases, an inappropriate farmer selection was made and this decision was considered decisive in affecting agroforestry failure. During the initial project design period, 242 farmers were screened in 1992 on the basis of their responses to several agroforestry propensity indicator questions. These questions were intended to reveal a farmer's aptitude and capacity for, knowledge of, and interest in planting trees on farm. For the most part these questions proved to be reliable indicators. However, we learned after the experimental group had been identified and constituted that the project implementing organization, a non-governmental research and development organization (NGO) based in Porto Velho called the Instituto de Prehistoria, Antropologia e Ecologia (the Institute), had added several farms to the list of participating households for apparently political reasons. In one instance, the Institute felt it a necessary gesture of good will to add the chief of the federal agrarian reform and colonization office (INCRA) to the list of beneficiaries. This individual proved to be more interested in gold-mining than either agroforestry or traditional farming and not surprisingly his plot was one of the first to be declared a failure. For similar reasons and with similar results, the former president of the local rural workers syndicate was included in the experimental group.

Inappropriate plot design was considered to be a major factor contributing to agroforestry plot failure on four Sub-group 1 farms. The failure of the Institute to recruit experienced and trained project agronomists and foresters early in Phase I led to several plot designs involving ecologically inappropriate plant associations (e.g. all shade-requiring species on an open plot site, two species of the same genera planted together, planting of over a dozen tree species on miniscule area, etc.). Fortunately these deficiencies were confined to only a few farms and in several cases fresh plantings based on corrected plot designs were initiated in the second and third years of the project.

Deficient planting material was a serious problem for numerous experimental farms. While the Institute had contracted local nurseries to produce seedlings for the project, nursery management was often deficient and numerous seedlings left the nursery for the field blighted with fungus and insect infestations. In the third year of the project, scarcely any seedlings were produced for the project, although the nursery was working full-time producing cupuaçu seedlings for a large-scale plantation producer. When forced to catch-up the next year, the Institute sent truck-loads of tiny premature seedlings to the field for farmer planting, making the planting material more susceptible to various problems once planted on site. In other cases, the implementing NGO delivered seedlings too late in the rainy season for root systems to sufficiently develop for the long five month dry season. These types of deficiencies by the implementing organization clearly had a negative impact on the Project's performance and were decisive factors in plot failure on at least five farms in the experimental group. The obvious lesson for project designers and directors is to be fully knowledgeable about prospective local partner organizations. Many have multiple, often conflicting, programmatic interests and political affiliations.

4.3. *Household level factors*

The single most important set of factors contributing to agroforest plot failure arose from the farmer households themselves. This is understandable given the considerable flexibility that the Project afforded to the participating farmers. The Project adopted the view that one of its strategic pedagogical objectives was to see how farmers experiment and improvise within the project and informally teach themselves about methods for overcoming plot management problems. So, when we indicate that 54% of the mentions were classified as household in nature, we do not intend to 'blame the victim' for the failure of the agroforestry plots.

Clearly several of the failed plots might have been saved with better plot management practices, the single most frequently cited cause of plot failure. Farmer negligence and carelessness proved to be a regular issue among Group 1 farms for which plot management practices were deemed either inadequate or poor. On two farms, the agroforestry plots were destroyed when loose cattle were inadvertently permitted to graze on the plot trampling the young seedlings. On two other plots, excessive doses of a toxic herbicide used to protect coffee bushes destroyed agroforestry species with which they were interplanted. On another farm, day workers hired to clear secondary growth on a site containing the agroforestry plot, pulled-up most of the agroforest plants in the process. These simple unfortunate experiences might have been avoided by more careful management of the agroforestry plots by the farmers themselves or with better guidance from Project extensionists.

On five farms, these management factors were compounded by the farmer's decision to locate the agroforestry plot on an inappropriate site. For example, one farmer selected an abandoned crop field as the agroforestry plot site that had been previously used for several years as the local football field by young boys. The plot was not totally depleted of nutrients but was severely compacted. Although the farmer made an effort to enhance soil quality by spreading sawdust from his small lumber mill, the plot became susceptible to invasive vines and pioneer weed species that quickly adapted to the improved site conditions and strangled the planted seedlings. Although a sizeable proportion of the desired agroforestry plantings survived the first two years, lack of farmer commitment to fertilizing, weeding and irrigating the plot subsequently led to its demise. In another instance, the farmer elected to situate the experimental plot vertically along the slope of an abandoned clearing. Without contour planting, the area once cleared of underlying vegetation eventually eroded during the subsequent rainy season destroying most of the desired plantings.

A curious development leading to reduced farmer commitment to agroforestry plots within RAPP concerned the successful activities of a popular social movement called the Landless Rural Workers Movement (Movimento Sem Terra – MST). Although the Movement sought to represent the rural landless in their efforts to obtain land, usually by invasion or lobbying local authorities to appropriate vacant land on large estates, on four experimental group farms project participants either moved-off or sold their farms, leaving their agroforestry plots standing, or experienced the loss of key household members (usually young adult males) to MST. Although this development has not resulted in the failure of any plots to date, the abandonment of farms or the departure of farm household members to join MST puts the future of these experimental plots in jeopardy and is a curious contradiction within the Movement that suggests another external factor working to destabilize long-term property ownership and resource management in the Amazon.

Finally, three cases of agroforestry plot abandonment were attributed to chronic farmer illness necessitating frequent lengthy absences from the farm to seek medical care, or family disputes involving land on which project agroforestry plot was located. Such problems are unavoidable in any experimental sample.

5. Conclusions

During the first five-year phase of the Rondonia Agroforestry Pilot Project, experimental agroforestry plots involving, on average, four to five species were planted on 50 systematically selected farms in this tropical transition forest environment of Brazil's western Amazon. These farmers, typical of those who settled in Rondonia since the mid-1970s, operate low-input, small-scale family farms that produce cattle, traditional food crops (maize, beans, rice) for subsistence consumption and sale and perennial cash crops (cacao and coffee). The results of the Project are intended to assist policy makers and agroforestry project designers alike in better understanding the social factors that influence agroforest species performance, as well as provide growth performance indicators of selected agroforestry species that might enable comparative studies of agroforestry systems in the neo-tropics.

The initial growth performance results of the Project were encouraging. Over 65% of the initial farmers in the experimental group continued to maintain their plots after five years of the Project's first phase period. This is especially remarkable given that in most cases the location of the experimental plots in the Project were typically degraded crop fields with low regenerative potential that had been abandoned or fallowed and that virtually no fertilizer inputs were applied to plot sites immediately before planting.

The Project's findings tend to affirm the importance of several widely-accepted determinants of successful agroforestry adoption and performance, but raise questions about others. For instance, the study affirms the probable importance of existing soil conditions (fertility), but suggests that other social factors, combined with poor soils, provide a more comprehensive explanation for agroforestry crop failure.

We hypothesized that larger households would have more available labor to maintain agroforestry plots and therefore would be more likely to have successful plots. Household labor force size, however, had ambiguous impacts on performance and was not significantly different between the two groups (failed and successful adopters). In contrast, the land uses strategies of the two groups were different, with successful adopters also being more extensive perennial cash crop planters as well. The analysis suggests that farmers who are less successful in adopting agroforestry are more likely to clear greater areas of primary forest, although the reasons for this are unclear. While both successful and unsuccessful agroforestry adopters tended to plant roughly the same area in annual crops, the more successful agroforesters generally planted greater areas in perennial crops (e.g. coffee, cocoa, etc.), and we would offer this as a potentially strong predictor of success. Definitive land tenure does not appear to be a decisive factor affecting plot performance. Although all farmers in the experimental group had some legal claim to their land there was no significant difference between farmers with definitive land titles (the most secure form of land tenure) and other 'official documents' of property ownership. The management history of the plot, not surprisingly, also emerges as an important land use factor that project designers should consider in experimental plot siting. While bank financing and rural credits were unheard of in this population, successful agrofresters tended to be more active in production-oriented social organizations.

Major reasons why experimental plots failed in the Project were enumerated into three categories, the most important of which were factors emanating from the micro-level of the farmer household and included inadequate plot maintenance, improper planting, inappropriate plot site location, family illness and the popular appeal of the Landless Rural Workers Movement in convincing already established farmers to leave their farms in hope of obtaining new land elsewhere. Project design and implementation defects also played a key role in several plot failures. Environmental factors, we speculate, are overemphasized in the research literature and while pervasive and contextual, often have an accompanying social history that influences the rate and even direction of agroforestry performance.

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Notes

1. The study sites were selected for comparative purposes on the basis of three criteria: (1) Each site would be characterized by a distinct soil type (hypothesized to be an important experimental variable affecting biological performance). (2) The two sites would be distinguished by the degree of local social organization e.g. farmer cooperatives, rural workers unions, labor exchanges, church groups (hypothesized to be an important experimental variable affecting economic performance). (3) All other key characteristics of the two sites would be similar as control variables (e.g. population size, geographic area, age of settlement, mean property size, etc.).
2. The base-line survey included 10 questions that were designed to elicit the respondent's past experience with and present attitude toward risk-taking in general and tree-planting in particular. Respondents who answered five or more of the questions in a manner predetermined to indicate favorable experience and attitudes were selected into a preliminary pool. From this pool of about 90 respondents, 50 randomly selected farmers were screened to verify that they held some legally recognized title to their land and those passing this test were invited to participate in the project's experimental group. Farmers not passing the land title test or declining the invitation were replaced by others randomly selected from the preliminary pool who did meet these criteria until an experimental group of 50 was achieved. This sample selection procedure was biased to eliminate from the experimental group farmers who had no experience and had no interest in integrating trees into their farming systems which is an intuitively sensible approach to experimental group selection.
3. The 20 species included in the menu were selected on the basis of the following three criteria: (1) All species must be native to Amazon (one exception, Teak, was allowed because, although not native, it has been widely planted in the region for the last 30 years with positive results). (2) Seed stock must come from locally available suppliers. (3) All species must have local to state-wide markets. In selecting from the menu, farmers were given ample discretion subject to the constraint that they had to chose both timber and fruit crops, and were encouraged to chose more than one species in each category.
4. Seedlings were typically planted in rows of alternating species with spacing ranging from 4×3 m to 6×10 m.

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