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LAND USE CHOICES IN THE TROPICAL FOREST FRONTIER: THE POTENTIAL ROLE OF MALARIA

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1. Introduction

> *"As the combination of economic failure and malaria led to the extension of 'latifundia' in the Campagna Romana, the same factors lead, in the Amazon, to the accumulation of land by cattle growers and the final transformation of the tropical forest into pastureland."(Nájera 1994: 28)*

The major role played by malaria throughout history in determining the location of new human settlements, in influencing seasonal migratory flows, and in the accumulation of large portions of land in the hands of few has been documented for ancient Rome (Celli and Celli-Fraentzel 1933; Nájera 1994) and 18th century England (Dobson 1994). Most recently, these findings have been also linked to the patterns of land use and concentration in the Amazon region, as highlighted in the citation presented at the opening of this article. Although it seems appealing to accept the argument, no study has ever shown concrete evidence of the malaria-pasture-cattle link in the Amazon. Additionally, one needs to distinguish the context of human settlements in ancient Rome, 18th century England, and the Amazon. First, in Rome and England settlers did have an option of migrating to healthier areas, and therefore choosing ideal settlement locations; in the Amazon, settlers are assigned a plot of land, and leaving the area means giving up the chance to secure land tenure in the future. Second, part of the cattle growers in the Amazon started their business due to the higher demand for beef in the market and to the incentives provided by the government. Therefore, their decision to turn the forest into pasture was not based on economic failure or malaria incidence. Therefore, Nájera's statement should be investigated considering only the decisions made by small farmers.

Potential links between malaria and cattle production in the Amazon could happen through different mechanisms. First, settlers extremely harmed by successive malaria infections give up their lands for any price, which may end up in the hands of large cattle ranchers. Second, the settler may individually decide to change the use given to the land, in order to minimize the risk of malaria transmission. This could result in adoption of different crops and/or cattle. Third, lands with poor soil and subjected to high malaria risk may experience a very high turnover, with settlers successively clearing new portions of land and leaving it behind. In the long run, the area may also end up in the hands of cattle ranchers. Fourth, settlers that are not severely affected by the disease may secure more financial resources in the long run, and decide to invest in cattle.

The latest agro census conducted in Brazil (1995) revealed that 77% of the deforested areas in the Amazon had been converted into pasture, mostly in the hands of large cattle ranches that were attracted to the area because of a higher demand for beef, and an unfortunate governmental policy that included fiscal incentives. A small fraction of those pasture areas are located in areas owned by small farmers. Understanding their decisions on what use to give to their land is a critical information for the purposes of planning sustainable development in the area. A large body of literature addresses the pattern of land use adopted by small farmers in the Brazilian Amazon using different socio-economic and ecological variables as potential determinants (Moran 1993; McCraken, Brondízio et al. 1999; Wood and Porro 2002; Futemma and Brondízio 2003; Perz and Skole 2003; Browder 2004). Interestingly enough, the possible impact of malaria incidence on the decision of land use has not been thoroughly investigated. The only reference to the potential impact of malaria on land use decision is provided by Browder (2002). The author suggests a list of 44 potential factors that may have an impact on land use decisions of small farmers; one of them relates to the health conditions of the household. Additionally, the author describes three distinct individual cases, chosen among 70 farmers who were interviewed in Rolim de Moura municipality, Rondônia in 1984. In the first case, the farmer struggled with poor soils and recurrent malaria episodes, lost days of work and financial resources to the disease, and eventually left the area. In the second case, the farmer, who contracted no malaria or other diseases, was in area of very fertile soils. He succeeded in producing multiple crops, and managed to generate a surplus of income, which was invested in cattle (considered as a secure asset). Finally, the third case narrates the story of a farmer with extremely limited financial resources who obtained a government loan to improve his production. His success, however, was doomed by malaria, since he was unable to work during the planting season, and therefore had no products to sell and no ways to pay the loan. His fate, however, changed when relatives came to the area with cattle, which in the long run became the most important activity of the farm. No definite relationship between malaria and land use decisions can be inferred from these three narratives, although it is clear that this potential link deserves a careful investigation.

In this article we offer a preliminary assessment of the potential role of malaria in decisions of land use adopted by farmers in the Machadinho settlement project, located in the eastern portion of Rondônia state, Brazilian Amazon. Using data collected in the area in 1985, 1986, 1987, and 1987, we test if malaria had any effect on the pasture area observed in 1995. Two approaches are used to account for the impact of malaria. First, we identify the plots that had a significant clustering pattern of high and low malaria rates in each year. Second, we use spatially estimated malaria rates as an indication of most severely affected areas. All the analysis presented in this article is based on self-reported measures, and an appraisal of the implications of this approach is provided. In summary, results show that those plots exposed to higher malaria transmission over time resulted in less pasture area in 1995. Although a comprehensive explanation for this relationship demands a much more detailed analysis, we suggest that in plots exposed to higher malaria transmission settlers do not succeed in generating income surplus, and therefore cannot afford cattle. In those cases, settlers can abandon the plot, which will eventually be occupied by another settler, or illegally sell it. The buyer can be another settler, or a cattle rancher. The extent to which the latter alternative happens also needs further investigation.

The potential effects of malaria on the patterns of land use adopted by small farmers not only sheds further light on the discussion about settlers' choices in the forest frontier, but has also major implications for future policies oriented to establish sustainable agriculture production in the Amazon.

2. Background on the Amazon frontier expansion

The Amazon Basin covers 7% of the Earth's surface, and roughly half of the South American continent. It comprises an area of more than 6.4 million km^2. Brazil holds the largest fraction of the forest, approximately 70% (IDB 1992), which occupies 60% of the Brazilian territory.

According to the last Brazilian Census 21.1 million people lived in the Amazon in the year 2000, or 12.4% of the population. In 1872, the population of the Amazon was approximately 752 thousand, and in 1980 it had reached 11 million. This increase in the Amazonian population was not uniformly distributed over time, but mostly driven by economic boom-and-bust cycles. Most recently, a government geopolitical strategy to promote settlement of the Amazon, and ultimately occupation, changed this demographic scenario. Rivers, which were the traditional routes of transportation, gave way to highways, opening a new frontier in Brazil.

2.1. Opening of the Amazon frontier

A Program of National Integration – PIN, as part of a National Development Plan – PND, was created by the Brazilian military government (1964-1985) in 1970. The major goal was to link the Amazon with the rest of the country. To achieve this goal, the Transamazon highway was projected, designed to link Recife (in the Northeast region of Brazil) to the Peruvian border, in more than five thousand kilometers cut through an unknown territory. The highway was publicized as a chance to populate the almost uninhabited area and to alleviate the suffering of the northeasterners who suffered the effects of a severe drought in 1970[1]. However, plans for its construction were finished before 1970 and had a military, instead of a social, purpose (Sawyer 1984).

The government revised its development policy, and a second PND for the Amazon, called POLAMAZONIA, was formulated in 1974. It focused on corporate investment (with the promotion of fiscal incentives)[2], extraction activities, energy production, and cattle ranching (Mahar 1979). As Mahar (1979) pointed out, the goal was to build the necessary infrastructure to create "*a more favorable 'investment climate' for private enterprise*". Companies (many of them foreign-owned) bought huge tracts of land, pushing indigenous communities and small farmers off their lands. Violent conflicts started and were often resolved in favor of the companies.

In 1976, just two years after the focus of development plans for the Amazon had changed to large-scale private enterprises, many projects had been approved for launching in the area. This included 335 projects in the agricultural sector (a large number of them for cattle activities), 171 in the industrial

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[1] Military president E. G. Médici, after visiting the Northeast in 1970, tried to attach a social goal for the PIN, and his most popular words at that time were "*to give men without land a land without men*" (Moran 1981; Moran 1985).

[2] Failure in achieving economic success in the settlement areas linked to the Transamazon Highway led the government to assume that development of the Amazon could not be carried out by small farmers (Jordan 1987).

sector, and 22 for infrastructure (Moran 1981). This shift in strategy left settlement areas promoted during the first PND abandoned. In 1980, the third PND made another shift in its strategy for integration, highlighting the need to respect indigenous people and the environment (Neto 1990).

A major development project for the Amazon was approved in 1981, and named Northwest Region Integrated Development Program – POLONOROESTE. Partly financed by the World Bank, it was a complex and ambitious project that emphasized two States in the Amazon: Rondônia (RO) and Mato Grosso (MT). The majority of the financial resources for this project were put into road construction. In numbers 41.6% of the total estimated costs were allocated to the pavement of BR-364 highway (Cuiabá/MT-Porto Velho/RO highway).

In 1990, another development project was created in order to correct some of the problems generated by POLONOROESTE in the State of Rondônia. Named Rondônia Natural Resources Management – PLANAFORO, its main goal was to promote a rational utilization of natural resources in order to preserve biodiversity. Further expansion of the frontier in the State of Rondônia was not encouraged. As opposed to POLONOROESTE, PLANAFORO was planned to allocate 21% of its financial resources to environment protection, 25.0% to rural credit, and only 17.6% on transportation. However, like previous development projects, execution was dramatically different from initial plans. By the end of 1993, only 6.9% of the resources were invested in environmental protection, while 51.6% were used in infrastructure. Later revaluations of the project partially corrected this distortion, and by 1997, 20.8% of the resources were invested in environment protection (Pedlowski 1998).

The most recent national development program implemented by the Brazilian government started in 2000, and is called ‘Advance Brazil’. Regarding the Amazon, the program plans for the pavement of 4,600 Km of roads (1,800 Km of these cutting through undisturbed forest), and the construction of railways and hydroelectric dams. The roads are likely to affect 8.4% of the total indigenous areas located in the Amazon, and 50.7% of areas designed for conservation (Nepstad, Capobianco et al. 2000). Simulations show that the increase in deforestation resulting from this project may vary between 269,000 ha and 506,000 ha annually (Fearnside and Laurance 2002). If history repeats itself, the pavement of these roads is likely to attract new migrants to the area, who would probably settle along them. Without a very organized and controlled plan of frontier expansion, including investment in education and health, the same problems that occurred in the past will be observed: rapid deforestation, conflicts with indigenous populations, land disputes, low agricultural production, and malaria outbreaks.

In summary, over a period of more than 40 years political and military factors drove the ideals of national security and integration. These factors led successive governments in Brazil to cut the tropical forest with roads. The selection of sites for road construction and settlement was not based on agricultural potential, but as a result of a geopolitical strategy (Fearnside 1990). Despite the accumulated experience, recent projects adopt strategies similar to those that failed in the past. The expansion of the Amazon frontier will likely continue to echo some of the major problems linked traditionally to the area: conflicts with indigenous population, increasing rates of deforestation, and high incidence of malaria.

2.3. Malaria in the Amazon frontier

After more than a decade of successful malaria eradication campaigns, malaria reached its lowest level in Brazil in 1970 when slightly more than 52,000 cases were registered in the country. At that time, the Amazon contained 60.6% of the national cases. In that same year, the first colonization projects were initiated in Rondônia State. Following the opening of roads, an intensive migratory process was responsible for dramatic demographic growth, resulting in a population much larger than the effective carrying capacity of the area. A disorganized occupation, associated with disturbance of the natural environment and with a lack of infrastructure, resulted in severe malaria epidemics. Moreover, the discovery of new mining camps and the construction of dams also contributed to an increase in the number of malaria sites. Malaria cases embarked on a rising path during the 1970s, experiencing a dramatic increase during the 1980s.

At present, malaria risk in Brazil is restricted to the Amazon region. In 2000, the area contained 99.7% of all malaria cases registered in the nation. However, malaria cannot be considered a disease of the Amazon. Instead, it is a disease of parts of the Amazon. Its spatial distribution is very irregular, with most high risk locations concentrated in settlement projects and gold mining areas. Malaria incidence in all other States outside the Amazon region is considered residual, and mostly driven by imported cases.

3. Study area

In order to evaluate the potential impact of malaria on the amount of land turned into pasture, the ideal study area should have available data from the inception of the project until the community is consolidated. To the best of our knowledge, the only such field survey for a settlement area was conducted in the Machadinho settlement project. Machadinho is located in the western part of the Brazilian Amazon, in the northeast portion of Rondônia State.

Machadinho is one of the settlement areas promoted by the Northwest Region Integrated Development Program – POLONOROESTE, a project co-sponsored by the Brazilian federal government and the World Bank. The area of the project was primarily jungle before the settlement started, sparsely populated by rubber tappers. There were no disturbances to the environment; no malaria was officially registered in the area, although rubber tappers most likely had malaria at low symptomatic levels. The interaction between the incoming population (some of whom were already infected), the local environment, and the rubber tappers should solely determine malaria transmission in the area.

Machadinho is physically divided by a river into two tracts: tract 1 located to the south of the river, and tract 2 to the north. These two tracts comprise a total of 1,742 plots, which are the section of land assigned to a settler. An urban center, located at the northeastern portion of the project, concentrates most of the available infrastructure (hospital, government agencies, drugstores, etc.). Plots have an average size of 40 ha, and are the spatial unit of analysis here considered.

Due to a multitude of factors, detailed in Castro (2002), and Singer and Castro (2001), the area soon became high risk for malaria. In 1985, 65.7% of the population had malaria at least once, and this number jumped to 90.1% in the next year. Also in 1986, 55.9% of people had malaria episodes in more than five months of the year (Sydenstricker 1992), and almost 40% of cases registered in Rondônia were observed in Machadinho (Sawyer and Sawyer 1987). Transmission, however, was very focal, and in certain areas some people reportedly suffered considerably more severely than others. In 1995, ten years after the onset of occupation, malaria became endemic, with lower rates and seasonal outbreaks in certain areas.

4. Data

Field surveys in Machadinho were organized and coordinated by a faculty team at the Center for Regional Development and Planning – CEDEPLAR, of the Federal University of Minas Gerais – UFMG. Field data collection started as soon as settlers moved to Machadinho in 1985, with follow up surveys carried out in 1986, 1987, and 1995, allowing for a dynamic analysis of how a colonization area evolves through time. A core set of questions remained the same throughout all four years, and some were included/excluded each year based on the experience of previous surveys. Overall, questions included data on migratory history, malaria episodes, knowledge about malaria transmission, socio-demographic characteristics, protective behavior against malaria, use of health services, land use, ecological transformations, agricultural production, and housing conditions. Data sets based on the questionnaires vary from 136 variables in 1985 to 292 variables in 1995.

All settlers who were effectively occupying their plots were interviewed. That means that those plots whose owners did not clear any forest area or did not live at least part-time in Machadinho were not included in the survey (Sawyer 1985). Therefore, the number of observations for each year is not the same, as shown in Table 1.

Table 1 – Number of plots and people surveyed, person-months exposed to the disease, malaria cases, and exposure weighted malaria illness rate – Machadinho, 1985/95

Year	Total number of plots surveyed	Total number of people surveyed	Number of person-months	Malaria cases	Malaria rate (%)
1985	267	1,366	4,587	1,041	22.69
1986	545	2,736	24,938	8,006	32.10
1987	740	3,982	38,121	9,012	23.64
1995	954	5,278	59,437	3,939	6.63

Malaria risk is measured by the exposure weighted malaria illness rate (referred to simply as malaria rate). Its numerator records the number of months each settler had malaria during a year, and the denominator records the exposure time - number of person-months exposed to the disease (Sawyer 1988), as shown in Table 1. The source of information to compute the rates is self-reported malaria episodes collected in the field surveys. Settlers are asked to report if they had malaria and where they were in each month among the twelve prior to the survey. Self-reported malaria is considered as the most appropriate kind of measure in areas where prevalence is very high and immunity is low[3]. The advantage of self-reported information is that it provides data on a highly mobile population, where blood samples would be difficult to obtain (Castilla and Sawyer 1993). The reliance primarily on self reported data is further supported by a study of perceived malaria illness reports, collected in a field survey in southern Pará in 1984 (Singer and Sawyer 1992). This study compared reported malaria episodes with serological tests showing that such data are reliable for studying malaria in the Amazon.

Malaria risk was incorporated in this analysis in two distinct forms. First, we used spatially estimated malaria rates, obtained by applying kriging models to the observed rates (Singer and Castro 2001; Castro 2002). These calculations were done for all four years of data, and estimated rates were classified into high, median, and low. Second, we used local indicators of spatial association to detect the presence of clusters in the area. For each year we identified the plots that had a significant clustering pattern for high or for low rates (Castro 2002). In the one hand, while the former approach provides information for all plots, the latter is limited to those plots that were occupied during the field survey. On the other hand, the former approach does not carry as much emphasis on risk as the latter, since a plot with a high rate has a different interpretation than a plot with a significant clustering pattern for high rates.

The extent to which pasture has been adopted as the land use choice by settlers is measured by the amount of area used as pasture, as declared by the settler. At the time of data collection, interviewers had no information of the total area of each plot, so this variable may not be highly accurate, depending on the previous agricultural experience of the settler.

Ownership of the plot by only one person between 1985 and 2001 is used as a proxy for the success of the settler in the area. The impact of this variable on the amount of pasture area can be negative or positive. If the settler succeeds, he/she may decide to expand the agriculture production, and concentrate the land use of the plot on farming, and the effect on pasture area would be negative. However, if the extra income is invested on cattle (perceived a more secure asset than a savings bank account), then the effect would be positive.

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[3] It is important to note that self-reported information was the most appropriate for studies in Machadinho given the basic characteristics observed in the area. In other places where malaria prevalence is low and immunity is high this probably would not be the best approach to analyze malaria episodes (Sawyer and Sawyer 1987).

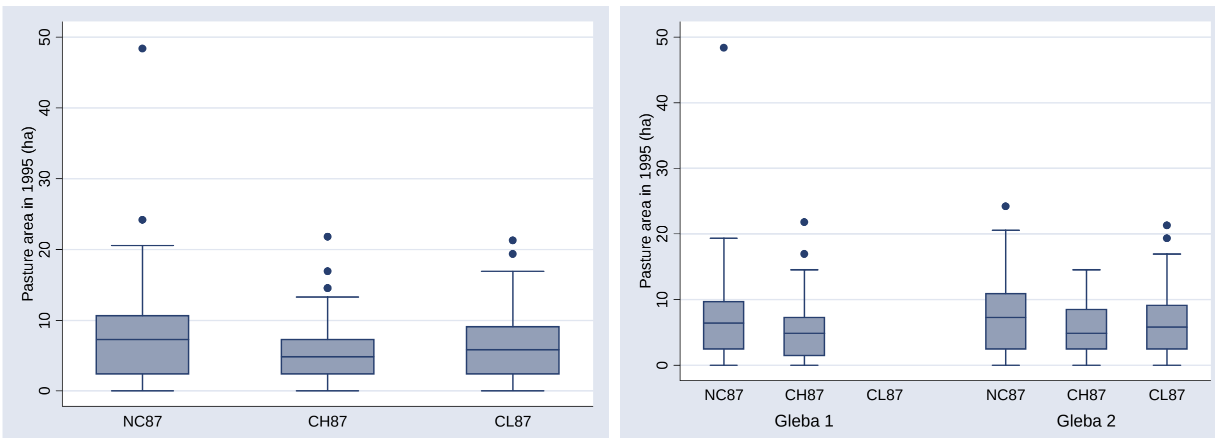
Seniority is captured by the time of arrival in Machadinho, and previous experience evaluated by the region where the settler used to live in the 12 months prior to their arrival. Therefore, settlers who used to live in the Center-East region of Brazil, where cattle production is very intensive, are expected to adopt this type of land than those coming from the South region of Brazil, where agriculture was an important activity.

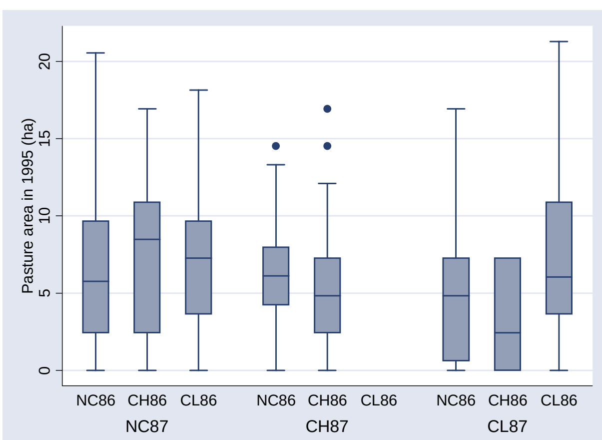
Soil quality is assessed by the common knowledge disseminated by personnel employed by the Technical Assistance and Rural Extension Company – EMATER (a governmental agency). It is unknown the extent to which this information conforms to an official soil reconnaissance data (this is part of our future research) although this is the information that settlers seeking technical assistance in local government offices are likely to receive.

The number of goods owned by the settler is used as a proxy for economic conditions. Goods include, among others, radio, TV, bicycle, stove, fridge, chainsaw, and car. The potential impact of this variable on the amount of pasture area is analogous to that described regarding the ownership of the plot. It all depends on how the settler decides to invest his/her extra income, based on individual perceptions of asset's security.

5. Results and discussion

To investigate the potential impact of malaria on the total area tuned into pasture in Machadinho, we selected the reported pasture area in 1995 as the main outcome. Since data is available for 1985, 1986, 1987, and 1995, if an impact does exist, it is most likely to be perceived in 1995. At that time, settlers have had time to succeed or failure in their attempt to promote sustainable agricultural production, and most decisions regarding land use have already been made. Initially, the pasture area was analyzed by different assessments of malaria (clusters and spatial estimation) ignoring other variables. Figure 1 shows box plots of pasture area in 1995 by clusters of malaria in 1986 and 1987, and by tracts (*gleba*). The distribution of pasture area by clustering pattern in 1987 reveals that, on average, plots that were not significant clusters of malaria and those that were significant clusters of low malaria showed larger pasture area than those that were significant clusters of high malaria rates. Moreover, clusters of high malaria rates did not show a large variation in the reported area of land used for pasture, which might indicate that the decision to turn the land into pasture in a scenario of high malaria rates seems to be similarly unlikely. Detailing the clustering pattern observed in 1987 by tract indicates the same behavior. Finally, comparing the clustering pattern of malaria rates observed in 1986 and 1987 with pasture area in 1995 suggests that those plots that were not significant for clustering in 1987, despite the clustering pattern that they had in the previous year, show larger averages and maximum values of pasture area in 1995.





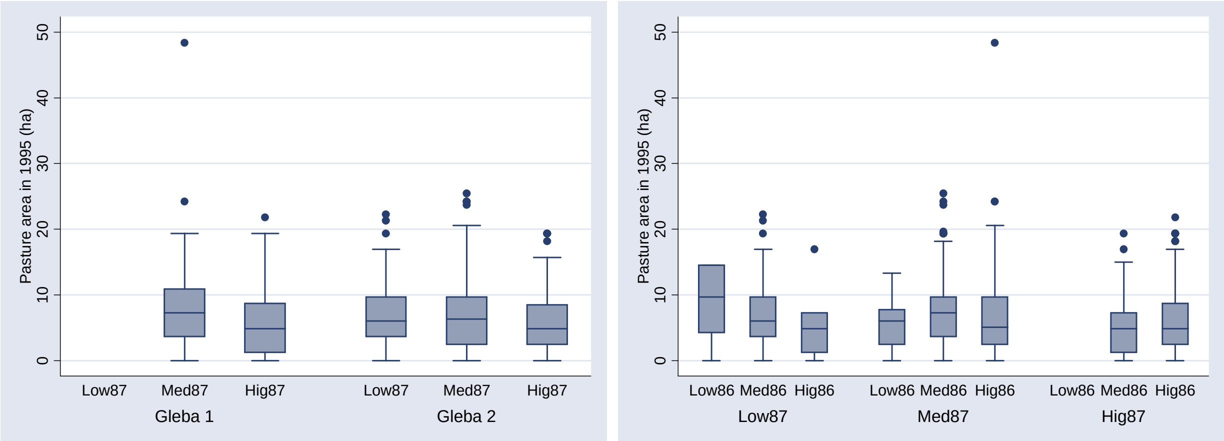
NC – Plots that were not significant for a clustering pattern

CH – Plots that were significant clusters of high malaria rates

CL – Plots that were significant clusters of low malaria rates

Figure 1 – Pasture area (ha) reported by settlers in Machadinho in 1995, by gleba and clustering patterns of malaria rates in 1987 and 1986

One shortcoming of the box-plots shown in Figure 1 is the fact only plots that were included in the surveys in each year can be classified as clusters. Therefore, some of the plots occupied in 1995 have no data for the previous year (we'll detail this issue in section 6). Therefore, we conducted the same analysis using spatial estimates of malaria rates, which were classified into high, medium and low rates, as shown in Figure 2. Plots with an estimated low or medium malaria rate show a higher average of pasture area in 1995 regardless of the tract where they are located. Considering the estimated malaria rates in 1986 and 1987, Figure 2 shows that plots that had low malaria rates for both years are those that presented the larger average of pasture area in 1995. The transition from high rates in 1986 to low or medium rates in 1987 did not result in very different average areas of pastures when compared to plots that were estimated to have high rates in both years. One possible explanation may lie on the decision the settler took in 1986 regarding his permanence on the plot. Very high rates in 1986 could have motivated the settler to abandon his/her plot, and then the decision of using the land for pasture would depend on the socio-economic characteristics and expectations of the newcomer.



Low – Plots where the estimated malaria rate was considered to be low; Med – Plots where the estimated malaria rate was considered to be medium; Hig – Plots where the estimated malaria rate was considered to be high

Figure 2 – Pasture area (ha) reported by settlers in Machadinho in 1995, by gleba and kriged malaria rates in 1987 and 1986

Table 2 presents the correlation (with its level of significance) between pasture area in 1995 and some selected variables. Significant positive correlation was observed for those settlers whose region of residence before coming to Machadinho was the Center-East region of Brazil. Interestingly enough, this is a region that witnessed a significant cattle expansion during the 1960s, in response to an increase in the national demand for beef. Therefore, migrants from the Center-East region are more likely to have previous experience with cattle, and may have higher chances to use the land for pasture.

Plots with poor soils also show a positive correlation with the amount of pasture area in 1995. In those cases, pasture may be the only way to provide some financial security to the settler, since agricultural production is not likely to succeed. The decision to use the land for pasture may be taken by the settler, considering that he/she has some capital to invest in cattle, or it may be a result of the abandonment of the plot, which eventually will end up in the hands of large cattle ranchers.

Early arrival in Machadinho also shows a positive correlation with the amount of pasture area in 1995, suggesting that pasture may be a later use given to the land, and not the primary option of settlers. Finally, the amount of pasture area declared in 1987 is also positively correlated with the pasture area in 1995.

Table 2 – Correlation between pasture area in Machadinho in 1995 and selected variables, and OLS coefficients of pasture area in 1995 obtained by a piecewise model

Variables	Correlation	OLS coefficients[1]
Success in settlement		
One single owner until 2001	0.042	-0.60
Previous experience (declared in 1987)		
Came from South region	-0.002	
Came from Center-East region	0.104†	
Soil quality for agriculture		
Poor soils	0.135†	2.31†
Medium soils	-0.071*	0.89
Clustering pattern for malaria in 1987		
High rates	-0.063‡	-1.58*
Malaria rates in 1987		
Estimated high rates	-0.113†	
Seniority in 1995		
Arrived in Machadinho between 1985/7	0.073*	1.05*
Economic conditions in 1987		
Owns 5 or more goods	-0.010	
Pasture area declared in 1987	0.282†	0.55†
Plot located in Tract 2	0.053	-0.95

[1] The intercept was 5.43, and $R^2 = 0.13$

* $p < 0.05$

† $p < 0.01$

‡ $p < 0.10$

Significant negative correlations are observed for malaria rates and plots with medium quality soil. The latter suggests that those plots can still offer conditions for agriculture production (maybe through the application of soil improvements) and therefore the chance of turning them into pasture is not so high as those plots with poor soil. Regarding malaria rates, plots that had a pattern of high malaria rates in 1987, regardless if this pattern was captured by spatially estimated rates or by clustering assessment, are likely to have a lower area used for pasture in 1995, as was previously suggested by the exploratory data analysis shown in Figures 1 and 2.

A stepwise linear regression was performed among pasture area in 1995 and the variables described in the previous section of this article. The results of the final model are also presented in Table

2. Poor soils, early arrival and the amount of pasture in 1987 have a positive effect in the total area dedicated for pasture in 1995, while a clustering pattern for high malaria rates have a negative effect.

These preliminary results suggest that Nájera's statement (Nájera 1994) presented in the opening of this article may not apply to small farmers living in settlements areas opened by the government in the Amazon. For those settlers, high malaria rates are likely to impact their capacity to accumulate income, which is necessary to allow the initial investment in cattle. However, abandonment of plots with high rates may facilitate the acquisition of the land by large cattle ranchers, which will ultimately turn the plot into pasture. The narratives provided by Browder (2002), and highlighted in the introduction of this article, suggest that there is a myriad of factors that can play a critical role in the process of using the land for pasture. Therefore, a more systematic analysis is crucial for evaluating Nájera's statement, as detailed in the next section.

6. Shortcomings and future research

The results presented in this article represent a preliminary assessment of the potential impact of malaria on the small farmers' decisions regarding land use in settlement areas in the Brazilian Amazon, and are intriguing enough to encourage us in pursuing further research.

Despite the fact that this study used the best available database for the purposes of investigating the role of malaria transmission on land use choices, some shortcomings must be highlighted. First, given the definition of occupied plots described before, only 93 plots have information for all four years (5.3% of the total 1,742 plots, and 9.8% of the total plots occupied in 1995). Moreover, only 52% of plots interviewed in 1987 also had information for 1987. Therefore, although we have information on pasture area for 940 plots in 1995, we cannot fully assess the impact that factors observed in previous years had on that outcome. In the case of malaria transmission, this problem was minimized through the use of spatially estimated malaria rates.

Second, we used only self reported measures, which can introduce errors especially in the declared pasture area in the plot. Settlers with previous experience in farming may provide more accurate information on used area in the plot, while those who used to work on non-agricultural activities may offer biased information (either under or over reported). This problem can be dramatically reduced by the use of remote sensing techniques. Ground validated information on pasture area could be obtained for all plots, which would also minimize the previous highlighted problem. We do have satellite images for 1985, 1986, and 1995, all taken at approximately the same moment in time when field work was conducted. Due to cloud coverage limitations, no image for 1987 has been obtained.

Third, the information on land tenure was obtained at a local government agency in Machadinho that keeps all the records of every plot in the settlement project. Although an official regular inspection of plots' occupation has not been perfect since the project started, these records give very good information about land tenure and turnover. There is no summarized report or routine statistics that follow up on this data, but in a site visit in 2001 one of the authors was able to analyze the information of each one of the 1,742 plots of Tracts 1 and 2 (Castro 2002). Since one person cannot legally receive land tenure on more than one plot, it might be the case that the governmental agency has one name as the owner, but in practice the plot is owned by another.

Fourth, the soil quality used in this analysis, as described before, is based on the local perception of soil potential for agriculture. Currently we are processing maps generated by a detailed reconnaissance soil survey done in 1982 on a scale of 1:50,000 (EMBRAPA/SNLCS 1982). This information will allow us to use more accurate information on soil quality, but also to assess the main limiting factors for soil quality (erosion, water, fertility, barriers to mechanization).

Our next step in this research is to incorporate both remote sensing data and accurate soil quality information. In the long run, we expect to conduct a new round of interviews in Machadinho, with a careful attention to the issue discussed in this article. Historical trajectories of settlers who, at present, made the decision to have only crops, only cattle, or a combination of both types of land use might shed further light in this important discussion.

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