Burn Quality Prediction for Simulation of the Agricultural System of Brazil's Transamazon Highway Colonists[1]

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ABSTRACT

High variability in burn quality of agricultural fields is critical for crop yields among pioneer settlers occupying 100 ha lots in Brazil's Transamazon Highway Colonization area near Altamira, Pará. Prediction of burn qualities, using clearing and burning dates and weather information, is part of a larger simulation of the colonists' agroecosystem for estimating human carrying capacity. Colonist pioneer agriculture has been largely based on annual crops such as upland rice, maize, beans, cowpeas, and manioc; perennial crops and pasture are now increasing. Burn qualities of both second growth (at least eight months uncultivated) and "virgin" forest (uncleared by recent Luso-Brazilian colonists) are predicted using discriminant analysis from precipitation, evaporation, and insolation between cutting and burning, and from precipitation in the 15 days prior to burning. Simulations use two burn categories: good and bad, condensed from a more complete 4-level taxonomy. Virgin burn prediction discriminant function correctly classifies 74% of 247 cases; second growth discriminant function correctly classifies 65% of 54 cases. Weather patterns, also modeled on carrying capacity simulations, are highly unpredictable, making good burns a major agricultural problem and an important factor affecting human carrying capacity.

RESUMO

A alta variabilidade na qualidade da queimada de roças é crítica para produções das culturas entre colonos pioneiros localizados em lotes de 100 hectares na área de colonização da rodavia Transamazônica perto de Altamira, Pará, Brasil. Predição de qualidades de quimadas, baseada nas datas de derrubada ou roçagem e de queimada, e em dados meteorológicos, forma parte de uma simulação maior do agro-ecossistema dos colonos para a estimativa de capacidade de suporte humano e, em particular, para avaliar a importância da variabilidade em produções das culturas sobre a capacidade de suporte. A agricultura pioneira dos colonos tem sido baseada, em grande parte, em culturas anuais, tais como arroz de sequeiro, milho, feijão do sul, feijão da corda e mandioca. As culturas perenes e pastagens estão aumentando atualmente. As qualidades de queimada tanto de capoeira (pelo menos 8 meses sem cultivação) quanto de floresta "virgem" (não derrubada por colonos luso-brasileiros recentes) são predizidas usando análise discriminante a partir de precipitação, evaporação e insolação entre o corte e a queimada, e a partir da precipitação nos 15 dias anteriores à queimada. As simulações utilizam duas qualidades de queimada: boa e ruim, resumidas de uma taxonomia de queimadas mais completa com quatro níveis. A função discriminante para predição de queimadas virgens classifica corretamente 74% de 247 casos; a função para capoeira classifica corretamente 65% dos 54 casos. Os padrões meteorológicos, também modelados nas simulações de capacidade de suporte, são bastante imprevisíveis, fazendo com que queimadas ruins sejam um grande problema agrícola e um fator influente sobre a capacidade de suporte humano.

INTRODUCTION

In most studies of shifting cultivation systems, or other similar agricultural systems in tropical rainforest areas also characterized by the "slash-and-burn" feature of traditional shifting cultivation, the assumption is made that crop yields are constant from one year to the next. High variability in crop yields, as in the pioneer agriculture practiced by colonists settled along Brazil's Transamazon Highway, is itself a vital feature of this form of agriculture as a means of supporting human populations. Estimates of human carrying capacity based on the various forms of the "shifting cultivation formula," for example, generally ignored yield variability (1, 5, 7, 20), although allowance of additional crop area allocations as a safeguard against lean years is possible (2). Assessment of the effect of variability on human carrying capacity in the Transamazon Highway area required deriving quantitative relationships for modeling the causes of variation in crop yields, and incorporating these features into computer simulation models of the colonists' agroecosystem (8, 9, 15, 16).

The importance of burn quality as a factor affecting colonist agricultural production quickly became evident during two years of residence in the Altamira colonization area. Differences in crop growth and yield between fields with good and poor burns, or between small patches with better or poorer burns within a single field, are readily apparent. On the scale of the Altamira colonization area as a whole, rain during the normally dry July-September period in 1973 resulted in many colonists failing to obtain adequate burns, with the consequence that in 1974 they were either unable to plant or had a meager harvest which may also have been on a reduced area

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A good burn is necessary in order to remove the physical encumbrance of cut vegetation, to reduce losses to pests and weeds, and especially to increase soil fertility, and particularly to raise pH with a consequent reduction of toxic aluminum ion concentration and an increase in the abundance and availability of phosphorus. A survey of soils under "virgin" forest (uncleared by recent Luso-Brazilian colonists, as distinguished from possible past use by Amerindian groups) indicates that 78.5% of the area has a pH of less than 5.0 and 33.0% has a pH of less than 4.0, while 83.8% has total phosphorus of less than 1 ppm (12).

In most other parts of the world where existing studies of shifting or similar cultivation systems have been undertaken virgin soil pH and associated characters are substantially more favorable for agriculture than is the case in the Brazilian Amazon. Soils are better in this respect, for example, in the sites of shifting cultivation studies in various locations in Africa (22), Central America (24, 25), Sri Lanka (21), and New Guinea (4). In many African soils, burning has deleterious effects by raising pH levels sufficiently high that associated decreases in soil iron concentrations result in iron deficiencies (29). Although many accounts of shifting cultivation systems make no mention of variable burn quality as a problem, poor burns are of major importance in some areas (19).

Normal burning in Amazon soils is beneficial, although occasionally a burn is so intense that large logs are completely reduced to ashes, resulting in stunted crop growth in the places where the logs have burned. Later succession on an overburned site is also deflected, sometimes resulting in patches of ferns rather than woody second growth.

Little information exists on variability in burn quality, or the effects of this feature on shifting and pioneer cultivation systems. Nye and Greenland's (22) classic literature review on shifting cultivation mentions that "the thoroughness with which the burn is carried out will also determine to some extent the qualities of nutrients added to the soil," but located no data to quantify differences. Sánchez' (28) review states simply: "the intensity of the burn is no doubt a major variable (for soils nutrient additions). Unfortunately no data are available on this aspect."

The effect of burn quality on soil fertility changes has been incorporated into simulation programs for the Transamazon Highway agroecosystem. Burn qualities enter regressions for predicting fertility changes under burning as dummy variables (16). Predicting burn qualities from weather data and from information on clearing and burning behavior of colonists is necessary to provide inputs for these soil fertility change calculations.

Study Area

The study was conducted in a 23 600 ha area of 100 ha colonist lots in the Altamira Integrated Colonization Project (PIC–ALTAMIRA), in the Altamira-Itaituba stretch of the Transamazon Highway (BR-320). The study area is centered on Agrovila Grande Esperança, 50 km west of the town of Altamira, at latitude 3° 22" south, longitude, 52° 38" west. The area is in the Municipio of Prainha, State of Pará, Brazil, with an altitude of approximately 100 meters above sea level. The climate is classified as Aw in the Köppen system (23), with a 36-year average annual rainfall of 1.7 m (6). Precipitation is highly variable from one year to the next both in quantity and timing (13). Most soils are poor red-yellow podzolics (Ultisols), but there are some patches of much better **terra roxa** (Alfisol). Colonists cut and burn virgin forest in a manner similar to that under traditional shifting cultivation, and clear second growth of all ages. They do not leave land fallow for long periods with the intention of continuing future cycles of annual crops alternating with fallow as a long term land use practice (14).

METHODS

Data on precipitation come from the Brazilian Agricultural Research Agency (EMBRAPA) experiment station located 23 km west of Altamira (27 km east of the study site), with the exception of a few days of missing information for which data were used from the Meteorology Department weather station in Altamira. Information on insolation and evaporation comes from the Altamira station. A series of Fortran programs made a variety of preliminary calculations, including totals of rainfall and other measures between clearing and buring dates.

Burn qualities and clearing and burning dates were obtained from the colonists through questionnaires applied in association with soil samples. Any information relative to burn quality observable in the field at the time of sampling was also recorded. Questionnaires used in the study were applied between June 1974 and August 1976, but colonist responses include information on burns beginning with the start of settlement in the area in 1971. Colonists' memory of this information in these early years of colonization was quite good. Regular visits to the study area between 1978 and 1987 have confirmed that the observed pattern of variable burn quality continues.

Table 1. Burn quality classification for virgin burns.

Burn quality	Definition
none	No burn was attempted (therefore no date for burning).
0	Burn attempted (therefore with burning date) but did not burn. There may be some blackened bark and burned leaves, but the ground remains "raw". Usually the colonist cannot plant. "Nao queimou".
1	Bad burn. Only leaves and small twigs burned. Only maize can be planted without a great deal of *coivara* (piling up unburned material to clear land for planting). "*Queimou ruim*. *Sapecou as folhas*."
2	Patchy burn. A mixture of class 1 and 3 patches where fire burned with varying intensity. Can be planted with *coivara*. "*Mais ou menos queimou*. *Queimou variado*."
3	Good burn. Burned wood as well as twigs and leaves, although larger logs are invariably only partly burned. Can be planted with rice with no or very little *coivara*. "*Queimou bem*."
4	Overburned. Large logs burned completely to ashes. This "burns the earth" and results in stunted crops. "*Queimou até que queimou a terra*."

Interviews with older residents in the traditional farming area near Altamira reveal a similar pattern dating back to the 1930s.

Burn qualities were classified by type and quality. Burn types were virgin forest, second growth or *capoeira* (defined as at least eight months uncultivated), weeds or *palhada* (defined as between two and eight months uncultivated), and pasture. Burn qualities were divided into six levels, including two non-burned categories (Table 1). In data analysis and simulation these burn qualities were condensed into two categories: "bad" (classes 0 and 1) and "good" (classes 2 and 3).

Data were analyzed using discriminant analysis (26), with the Michigan Interactive Data Analysis System (18). Subsequent modeling uses the KPROG2 program for human carrying capacity estimation (9).

RESULTS AND DISCUSSION

Virgin Forest Burns

Burn qualities in fields felled from virgin forest can be predicted based on weather between felling and burning dates. Months of felling are given in Table 2, together with the distribution of days between felling and burning.

In simulation, burn qualities can be predicted using simulated weather data for the Altamira area, and Fisher's discriminant functions for "good" burns (qualities 2-3 of Table 1) and "bad" burns (qualities 0-1). The discriminant analysis with the two equations is shown in Table 3. If, when appropriate weather values are substituted in these two equations the "good" burn equation gives a greater value than the "bad" equation, then a good burn is

Table 2. Virgin forest felling, monthly distribution.

Item	May	June	July	August	September	October	November	December	Total
Number	1.0	2.0	16.0	31.0	180.0	82.0	37.0	14.0	363
%	0.3	0.6	4.4	8.5	49.5	22.6	10.2	3.9	100

Mean days between felling and burning = 44.1 (SD = 65.3, N = 138).

Table 3. Virgin burn quality prediction discriminant analysis.

Variable	Coefficients	
	Bad burn	Good burn
Constant:	−6 1617	−7 5752
Rain between felling and burning (mm)	0 0032459	0 0012662
Evaporation between felling and burning (mm)	−0 0035933	−0 000052735
Insolation between felling and burning (hours)	0 0034928	0 0025793
Rain in 15 days previous to burn (mm)	0 076949	0 088626
Evaporation in 15 days previous to burn (mm)	0 15809	0 01827
Insolation in 15 days previous to burn (mm)	0 038381	0 031593
General variances	$2\ 43 \times 10^{22}$	2.26×10^{20}
Sample sizes	76	171

Equality of covariances: df = 21, 83234 F = 22 47
Mahalanobis distance: $D^2 = 0\ 686$
F statistic = 5 89
Significance < 0 0001 in bath

predicted This correctly predicts burn quality in 74% of the cases (Table 4) In the remaining 26% of the cases the opposite burn quality occurs

Second Growth Burns

Burns in fields in second growth can be predicted in a way similar to that used for virgin burns Distributions of cutting and burning dates are given in Table 5, together with the distribution of days between cutting and burning.

Discriminant functions for "good" (class 2 and 3) and "bad" (class 0 and 1) second growth burns are given in Table 6 These equations correctly predict 65% of 54 cases of second growth burns As with virgin burns, the remaining fraction of cases is predicted incorrectly. In simulating this process, randomly selected cases –in the proportion each outcome is predicted incorrectly– are assigned to the opposite burn quality (Table 7).

Although a substantial part of the variability in burn quality is explainable in terms of the meteorological variables used in this analysis, much variability remains unexplained. Weather information from a location closer to the fields studied would undoubtedly improve burn quality predictions, since precipitation and other characters are quite patchy in the area. Unfortunately, the disappearance of a shipment of rain gauges made this impossible in the present study Information on additional weather

Table 4. Observed and predicted virgin burn qualities.

Predicted burn quality	Observed burn quality		Total
	Bad[1]	Good[2]	
Bad[1]	15	3	18
	(83.3%)	(16.7%)	(100%)
Good[2]	61	168	229
	(26.6%)	(73.4%)	(100%)
Totals	76	171	247

Number correctly predicted is 183 of 247 cases or 74%.

1 "Bad" burns are lumped class 0 and 1 virgin burns
2 "Good" burns are lumped class 2 and 3 virgin burns

Table 5. Second growth cutting and burning montly distributions.

Item	Month								Total
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	
Cutting									
Number	1	8	8	39	24	20	10	1	111
%	0.9	7 2	7.2	35 1	21 6	18 0	9 0	0.9	100
Burning									
Number	0	0	4	10	50	37	13	5	119
%	0	0	3 4	8.4	42 0	31 1	10 9	4 2	100

Mean days between cutting and burning = 52 6 (S D = 96 1 N = 79)

characters, such as wind speed, might also be helpful, but obtaining more localized information, especially on precipitation, is a higher priority. The three characters used (precipitation, evaporation, and insolation) are highly intercorrelated. although all contribute to the prediction Information specific to the field's location for a single easily-measured variable, such as rainfall, might produce better results than more complete information from a more distant weather station

Many other factors contribute to variability in burn quality. The strength and direction of the wind at the time of burning appear to be important, as does the size of the clearing, large clearings burning better than small ones. In most cases a colonist must burn all of his clearing in a given year at the same time, in order to maximize the area being burned and thus minimize the chance of fire inadvertently entering areas that have been cut but are not yet ready for burning (thus making proper burning virtually impossible later). The result is that colonists wait as long as they dare prior to the onset of the rainy season before burning, so that as large an area as possible can be cleared in the time available. The institutional complication of bank loans for clearing usually not being liberated until after the proper time for clearing has passed, also contributes to the tendency to burn late in the season. Since the area's rainy season does not begin on an accurately predictable date, in contrast, for example, with many Asian monsoon climates, colonists frequently wait until optimal burning time has passed. Colonists must wait long enough after clearing before burning in

Table 6. Second growth burn quality prediction discriminant analysis.

Variable	Coefficients	
	Bad burn	Good burn
Constant:	– 0 32692	– 1 0033
Rain between cutting and burning (mm)	0.00048378	–0 0033761
Evaporation between cutting and burning (mm)	– 0 013939	–0 020641
Insolation between cutting and burning (hours)	0 0029030	0 00060930
General variances	$8\ 92 \times 10^{11}$	1.29×10^{13}
Sample sizes	31	23

Equality of covariances: df = 6, 15499 F = 5 78 Significance < 0.0001
Mahalanobis distance: D^2 = 0 566
F statistic = 2 39
Significance = 0 0793

Table 7. Observed and predicted second growth burn qualities.

Predicted burn quality	Observed burn quality		Total
	Bad[1]	Good[2]	
Bad[1]	26	14	40
	(65.0%)	(35.0%)	(100%)
Good[2]	5	9	14
	(35.7%)	(64.3%)	(100%)
Totals	31	23	54

Number correctly predicted is 35 of 54 cases or 65%

1 "Bad" burns are lumped class 0 and 1 second growth burns.
2 "Good" burns are lumped class 2 and 3 second growth burns

order to allow vegetation to dry. At the same time, a limit to the time one can wait is imposed by leaves falling off felled trees, rendering proper burning more difficult if delayed too long. The skill of the colonist in timing and executing the burn can be important. Better burns are obtained by felling in a circular pattern, so that the edges of the clearing have dried the longest and the fire converges on the center where vegetation is greenest.

Size of trees, especially in second growth, may be important, but attempts to quantify these effects have so far proved unsuccessful. Differences do exist between burns of "second growth" (at least eight months old) and "weeds" (between two and eight months old). Weed burn quality can be predicted from a similar discriminant analysis, but the weed burn quality prediction subroutine was removed from the carrying capacity simulation program when additional soil data revealed that burn quality ceased to have a significant effect on soil fertility changes in the case of weed burns. Burning of weeds, which occurred in 27.1% of 48 cases, has a significant effect on soils as compared with unburned cases (16). Pasture burns are not explicitly modeled, but regular burning of pastures at 2-3 year intervals is implied in soil changes occurring under pasture in the region (11).

The importance of crop yield variability for human carrying capacity makes the effect of variable burn quality a key factor in the colonists' agroecosystem, so far largely based on annual crops. To the extent that current trends are leading to replacement of annual cash crops with pasture and perennial crops in the area (10), burn quality will have a lesser role in the future. Annual crops for subsistence plantings in the Transamazon Highway area, and the annual cropping characterizing pioneer farming in the rapidly expanding agricultural frontier throughout Amazonia, insure that variable burn quality will continue to be a major preoccupation of farmers in these areas.

CONCLUSIONS

Burn quality in agricultural fields cleared from virgin forest and second growth can be simulated from information on clearing behavior and weather.

Burn quality represents an important link between highly variable weather patterns in the Transamazon Highway area and the great variability noted in crop yield obtained by colonists. These variable yields, in turn, have shown themselves to affect the area's carrying capacity for human populations.

LITERATURE CITED

1. ALLAN, W. 1949. Studies in African land usage in Northern Rhodesia. Rhodes Livingstone Papers no. 15

2. ALLAN, W. 1965. The African husbandman. New York, Barnes and Noble. 505 p.

3. CARNEIRO, R.L. 1960. Slash-and-burn agriculture: a closer look at its implications for settlement patterns. In Men and cultures: selected papers of the fifth international congress of anthropological and ethnological sciences. Ed. by A.F.C. Wallace. (1956, Philadelphia), Philadelphia, University of Pennsylvania Press. p. 229-234.

4. CLARKE, W.C. 1971. Place and people: an ecology of a New Guinea community. Canberra, Australian National University Press. 265 p.

5. CONKLIN, H.C. 1959. Population-land balance under systems of tropical forest agriculture. Proceedings of the Ninth Pacific Science Congress (Bangkok) 7:63

6. FALESI, I.C. 1972. Solos da Rodovia Transamazônica. Belem, Brazil, Instituto de Pesquisas Agropecuárias do Norte. Boletim Técnico no. 55. 196 p.

7. FEARNSIDE, P.M. 1972. An estimate of carrying capacity of the Osa Penninsula for human populations supported on a shifting agriculture technology. In Report of research activities undertaken during the summer of 1972. Ed. by Organization for Tropical Studies. San José. C.R. p.486-529

8. FEARNSIDE, P.M. 1978. Estimation of carrying capacity for human populations in a part of the Transamazon highway colonization area of Brazil. Ph.D. Dissertation. Ann Arbor. University of Michigan. 624 p.

9. FEARNSIDE, P.M. 1979. The simulation of carrying capacity for human agricultural populations in the humid tropics: program and documentation. Manaus, Bra., Instituto Nacional de Pesquisas da Amazônia. 546 p.

10. FEARNSIDE, P.M. 1980a. Land use allocation of the Transamazon Highway colonists of Brazil and its relation to human carrying capacity. In Land, People and Planning in Contemporary Amazonia. Ed. by Barbira-Scazzocchio, F. Cambridge University. England, Cambridge. Centre of Latin American Studies Occasional Paper no. 3. 313 p.

11. FEARNSIDE, P.M. 1980b. The effects of cattle pastures on soil fertility in the Brazilian Amazon: consequences for beef production sustainability. Tropical Ecology 21(1):125-137.

12. FEARNSIDE, P.M. 1984a. Initial soil quality conditions on the Transamazon Highway and their simulation in models for estimating human carrying capacity. Tropical Ecology 25(1):1-21.

13. FEARNSIDE, P.M. 1984b. Simulation of meteorological parameters for estimating human carrying capacity in Brazil's Transamazon Highway colonization area. Tropical Ecology 25(1):134-142.

14. FEARNSIDE, P.M. 1984c. Land clearing behaviour in small farmer settlement schemes in the Brazilian Amazon and its relation to human carrying capacity. In Tropical Rain Forest: The Leeds Symposium. Ed. by A.C. Chadwick. S.L. Sutton. Leeds, U.K. Leeds Philosophical and Literacy Society. 335 p.

15. FEARNSIDE, P.M. 1985. A stochastic model for estimating human carrying capacity in Brazil's Transamazon Highway colonization area. Human Ecology 13(3):331-369

16. FEARNSIDE, P.M. 1986. Human carrying capacity of the Brazilian rainforest. New York, Columbia University Press. 293 p.

17. FEARNSIDE, P.M. Burn quality prediction for simulation of the agricultural system of Brazil's Transamazon Highway colonists for estimating human carrying capacity. In Ecology and Resource Management in the Tropics. Ed. by K.C. Misra, H.N. Pandey, S.R. Govil. Varanasi. India. Bhargava Book Depot. v. 2. (In press)

18. FOX, D.J.; GUIRE, K.W. 1976. Documentation for MIDAS. Ann Arbor, University of Michigan Statistical Research Laboratory. 203 p.

19. FREEMAN, J.D. 1955. Iban agriculture, a report on the shifting cultivation of hill rice by the Iban of Sarawak. London, England. Colonial Research Studies. v. 18, 148 p.

20. GOUROU, P. 1966. The tropical world: Its social and economic conditions and its future status, 4 ed. New York, Longman. 196 p.

21. JOACHIM, A.W.R.; KANDIAH, S. 1948. The effect of shifting (Chena) cultivation and subsequent regeneration of vegetation on soil composition and structure. Tropical Agriculturalist 104:3-11.

22. NYE, P.H.; GREENLAND, D.J. 1960. 1960. The soil under shifting cultivation. Harpenden, U.K. Commonweath Agricultural Bureaux of Soils, Technical Communication no. 51. 156 p.

23. PEREIRA, F.B.; RODRIGUES, J. de S. 1971. Possibilidades agro-climáticas do Município de Altamira (Pará). Departamento de Assuntos Universitários. Belém, Brazil, Escola de Agronomia da Amazônia. Boletim no. 1. 46 p.

24. POPENOE, H. 1959. The influence of the shifting cultivation cycle on soil properties in Central America. Proceedings of the Ninth Pacific Science Congress (Bangkok) 7:72-77.

25. POPENOE, H. 1960. Effects of shifting cultivation on natural soil constituents in Central America. Ph.D. Dissertation in Agronomy. Gainesville, University of Florida. 154 p.

26. RAO, C.R. 1973. Linear statistical inference and its applications. 2 ed. New York, John Wiley.

27. RAPPAPORT, R.A. 1968. Pigs for the ancestors: ritual in the ecology of a new Guinea people. New Haven, Connecticut, Yale University Press. 311 p.

28. SANCHEZ, P.A. 1976. Properties and management of soils in the tropics. New York, John Wiley. 618 p.

29. SANCHEZ, P.A.; BUOL, S.W. 1975. Soils of the tropics and the world food crisis. Science 188:598-603.