In: J.I. Furtado (ed.) Tropical Ecology and Development: Proceedings of the Vth International Symposium of Tropical Ecology, 16-21 April 1979, Kuala Lumpur, Malaysia. International Society of Tropical Ecology (ISTE), Kuala Lumpur. 1383 pp.

Tropical Ecology & Development, 1980. pp. 1287-1295.

THE PREDICTION OF SOIL EROSION LOSSES UNDER VARIOUS LAND USES IN THE TRANSAMAZON HIGHWAY COLONIZATION AREA OF BRAZIL

P.M. Fearnside

National Institute for Amazonian Research (INPA)

P.O. Box 478, 69000 Manaus, Amazonas, BRAZIL

ABSTRACT

Soil erosion losses were predicted as a part of a larger study aimed at producing estimates of human carrying capacity for a part of the Transamazon Highway Colonization Area of Brazil. Erosion measurements were made under annual crops (upland rice, maize, beans, and manioc), black pepper, cacao, pasture, second growth, and virgin forest. Measurements are of the drop in soil surface levels, and therefore include soil compaction. Regressions were developed for prediction of erosion based on such variables as slope and soil clay content. The erosion prediction equations developed were used in computer simulations of the colonists' agroecosystem for carrying capacity by estimation. Erosion affects carrying capacity through its effect on soil fertility and thereby crop yields.

INTRODUCTION

An area of planned colonization on Brazil's Transamazon Highway near Altamira, Para offers a unique opportunity to study many aspects of the agroecosystems which were established by the colonists. The huge scale and rapid pace of settlement along the still-expanding network of pioneer highways in the Amazon makes erosion loss prediction urgent. Estimates of soil erosion losses were needed as a part of a study of human carrying capacity in a colonization area (Fearnside, 1978, 1979a, b). Carrying capacity depends on crop yields, which are influenced by soil fertility, which in turn are affected by erosion. Computer simulations were written modeling the agroecosystem, including a subroutine for soil erosion prediction. Inputs of land use, slope, soil, and weather information were generated in other parts of the program to reproduce the patterns found in field data. The simulations were stochastic in nature, including the probability distributions around the means of many important parameters.

Soil erosion research in Latin America has recently been reviewed by Lal (1977), who found no studies of erosion in Amazonian Brazil. The only other study involving erosion is that of Smith (1976), who made measurements of soil surface lowering in five plots under annual crops with slopes ranging from 8 to 15% over a six-month period during which 1683 mm of rain fell in the area, and the soil surface was lowered by 0.4-1.7 cm. General warnings of the danger of erosion in the Brazilian Amazon have been sounded before (Penteado, 1967), but no actual measurements were made. For the purpose of the carrying capacity simulations, there is a need to establish the relationships between rates of erosion and various other variables, preferably with separate relationships being derived for each of the land use types encountered in the study area.

MATERIALS AND METHODS

Data for the carrying capacity study, including soil, slope, land use, and other information, were collected during two years of field-work (1974-1976) in a 23,600 ha area surrounding Agrovila Grande Esperanca, 50 km west of Altamira. Erosion measurements were made in 1975, using a series of 705 stakes set out in 47 plots of 15 stakes each over a range of different slopes and land uses. Great care was taken in locating the plots to minimize the possibility of vandalism or other human disturbance. Plots were set out covering a maximum range of slopes in each land use, with five plots each in virgin forest, second growth, beans, maize, manioc, and pasture, three plots in cacao and black pepper, and 11 plots in rice. Plot slopes in the study ranged from zero to 89%.

Stakes were lengths of ¾ inch (1.9 cm) diameter plastic pipe hammered into the ground to a depth of 40 cm. In each plot the stakes were arranged in three rows of five stakes each with approximately two meters between stakes and ten meters between rows. The rows were oriented perpendicular to the fall line. Stakes on the ends of each row were one meter long, while stakes in the middle were 50 cm long. Each stake had a notch cut horizontally and set exactly even with the surface of the ground when the stakes were implanted. A vertical cut was also made to mark the center of each notch to facilitate measurement. The notch was oriented to face to the side (along the contour of the slope).

Plot slopes were measured in percent using a clinometer (Suunto) at each plot over the 20-meter length of the plot sighting on the one-meter-long end stakes of the top and bottom rows. Microrelief (stake slope) was measured at each stake by placing the clinometer on a 30 cm block of wood oriented along the steepest slope at the stake.

Measurements of erosion were made by measuring the distance from the center of the notch to the soil surface at each stake using a ruler graduated in millimeters. Erosion measurements with any of the following disturbances or special circumstances were excluded from the analyses: (1) stake stepped on (by man or animals), (2) stake burned affecting mark, (3) soil level changed by hoeing, (4) soil by stake pushed up by root growth, (5) soil level disturbed by chickens or other animals, (6) stake in gully, (7) stake in deposition in wake of a root, (8) stake buried due to manioc harvesting, (9) pigs in erosion plot, (10) stake level otherwise disturbed by man, (11) soil level otherwise disturbed by man.

A soil profile was taken at each plot at the time of installation using a one meter soil auger. Surface fertility samples were taken at installation and measurement: these were composites of 15 cores 0-20 cm in depth taken from the neighbourhood of each stake. Soil analyses were done by the Center for Research and Cattle Ranching in the Humid Tropics (CPATU) in Belem; laboratory methods are described by Guimaraes et al. (1970).

Soil compaction was measured in wet soil using a cone-tipped spring penetrometer, with ten measurements taken at each stake. Bulk density was measured by removing approximately two kg of soil from the top 10 cm by pounding a metal cylinder (7 cm diameter) into the ground several times. Density samples were air dried and weighed on a spring balance accurate to 5 g.

The lengths of the slopes above the erosion plots were measured, with separate measurements recorded if there were either a noticeable change in slope or a change in land use.

Meteorological data were taken from the government meteorological station nearest the study area. This is usually the CPATU station located 23 km west of Altamira, although sometimes the Department of Meteorology station in Altamira is the nearest source.

Land use was assigned to fields using the land use at the time of maximum rainfall in a 24 hour period.

Manipulation of data and a variety of calculations were made using a series of FORTRAN programs written for the purpose (Fearnside, 1979c). Statistical analyses were done using the Michigan Interactive Data Analysis System (Fox and Guire, 1976). Residuals of all regressions were examined to verify lack of dependence on the magnitudes of the independent variables.

RESULTS

The characteristics of the erosion plots and study area are summarized in Table 1. Several of the variables which are expected to be good predictors of erosion based on soil loss equations developed in other parts of the world (as reviewed by Hudson, 1977) are known only at the plot level rather than for individual states. Hence, regressions including these variables could only be performed using plot level data where sample size permitted. These include soil clay content, bulk density, plot means for compaction (penetrometer measurements), rainfall in the observation interval, rainfall while bare or in annual crops, and plot slope. Lengths of slopes are also considered a plot level character, even though three slightly different values are applied to stakes within each plot. Maximum rainfall in 24 hours is the same for all plots in the year of study. Stake level information includes stake erosion, stake slope, and stake mean of compaction.

Regressions on individual annual crops, reveal similar relations of erosion and slope. All plots either in annual crops or bare (defined as less than 60 days after harvesting) at the time of maximum rainfall in a 24 hour period are lumped to obtain the following regression:

$$Y = 0.164\ A + 1.88 - 10^{-3}\ B + 1.43$$

where Y = plot erosion (mm/year)
A = plot slope (%)
B = rain while bare or annual crops (mm)

($P < 0.0001$, $r = 0.89$, $r^2 = 0.79$, SE = 2.13, N = 17 plot means). Variables not included in the regression are found to be insignificant.

For erosion under black pepper individual stake measurements are used. The regression equation obtained is:

$$Y = 0.712\ A + 6.05$$

where Y = stake erosion (mm/year)
A = stake slope (%)

($P < 0.001$, $r = 0.55$, $r^2 = 0.30$, SE = 6.10, N = 39 stakes).

Erosion under other land uses could not be predicted using the regressions of available data. Mean stake erosion under (1) young cacao is 10.0 mm/year (SD = 8.3, N = 40 stakes), (2) weeds (defined as fallow from two to eight months inclusive) is 8.1 mm/year (SD = 5.4 N = 56 stakes), (3) second growth (defined as over eight months fallow) is 6.9 mm/year (SD = 8.7, N = 68 stakes), (4) pasture is 6.7 mm/year (SD = 11.8, N = 105 stakes), and (5) virgin forest is 7.5 mm/year (SD = 5.1, N = 75 stakes). The means of stake erosion for weeds, second growth, pasture, and virgin forest are not significantly different, but the variances are significantly different ($P < 0.0001$, $F = 25$, df = 3,144710).

Stake slopes (within 30 cm of each stake) can be generated from slope over the entire erosion plot (approximately 20 meters) using the following regression equation:

$$Y = 0.462\ A + 3.13$$

where Y = stake slope (%)
A = plot slope (%)

($P < 0.001$, $r = 0.89$, $r^2 = 0.80$, SE = 4.94, N = 705 stakes. 47 plots, df = 45).

DISCUSSION

The "erosion" measurements used, based on changes in the soil surface level, include the results of soil compaction as well as true erosion. Measurements of erosion through wiers and settling basins may avoid this complication, but may reduce the amount of data collectable both on erosion and other aspects of the agroecosystem. The notched stake method proves adequate for use in predicting soil fertility changes, although more refined methods are needed for other purposes. Most of the lowering of soil surface observed is believed to be due to erosion rather than compaction.

Plot slope is preferable to stake slope for erosion prediction, although stake slopes are used in the case of land uses where data limitations prevented the use of plot-level characters. In order to obtain more general results which can be applied with greater confidence to other areas, a greater range of total rainfalls and rainfall intensities are needed. More detailed site-specific meteorological data, especially of rainfall intensity, will undoubtedly allow more powerful predictions to be developed. The disappearance of a shipment of raingauges prevented this in the case of the present study.

Although the sand and clay contents of the soil vary considerably between plots, a greater range of values, together with a greater sample size, will probably allow the inclusion of this factor in the regression equations. Greater clay content is expected to result in more erosion through reduction of water percolation and therefore increased runoff. Soil compaction should have the same effect, and a greater range of values and more data will probably allow this to be included. Such increases in the number of variables will make the extension of the calculations to other areas more reliable.

In the Transamazon Highway area, erosion results in lowered soil fertility. The deeper horizons in soil profiles in the area have lower fertility than the surface (Falesi, 1972; Fearnside, 1978). Much of the fertility available to crops comes from the ash produced by burning, which is also removed by erosion. The possibility of erosion improving soil fertility by exposing less weathered material (Sanchez and Buol, 1975) does not apply here.

The question of erosion under pasture is one of particular importance because of the rapid increase in the amount of pasture in the Brazilian Amazon. Brazilian institutions influential in planning future Amazonian development schemes believe that pasture offers "complete protection from erosion" (Brasil, Empressa Brasileira de Pesquisa Agropecuaria (EMBRAPA); Instituto de Pesquisa Agropecuaria do Norte (IPEAN) 1974: 43).

Several workers have found erosion under tropical pastures. Daubenmire (1972) has shown that Hyperrhenia rufa pasture in Costa Rica with 1900 mm/annum rainfall and 9% slope shows 11 cm of erosion during the lifespan of the oldest plants in a 22-year-old pasture. Erosion losses are estimated by examination of differences in height between pebbled surfaces inside hummocks of grass and the areas between hummocks. Since the grass hummocks may not be as old as the pasture itself, the rate of erosion may have been even higher than the 5 mm/year that these measurements imply. Comparison of erosion rates under pasture and virgin forest has been made by Scott (1975) in eastern Peru, using dams and settling basins to measure erosion; indicating some erosion under pasture and none at all under virgin forest. The lack of significant difference in mean erosion in pastures and virgin forest in the present study, does not indicate that erosion does not occur in pastures. The variance in erosion under pasture is extremely high, the value for the standard deviation being almost twice the value of the mean. Many stakes show considerable erosion under pasture. Gullying can also be a severe problem in pasture, especially since the pasture grass most commonly planted (Panicum maximum) grows in separated hummocks with bare spaces between.

CONCLUSIONS

The results of this study indicate that erosion poses a potential threat to soil fertility in Brazil's Transamazon Highway Colonization Area. Erosion is worst under annual crops, and also is quite severe under black pepper. Erosion may also be a potential problem under pasture, especially erosion through gullying. Equations have been developed for the prediction of laminar erosion for use in predicting soil fertility changes as a part of a simulation of the colonists' agroecosystem.

ACKNOWLEDGEMENTS

Funds for the project came from National Science Foundation dissertation improvement grant GS-42869, a Resources for the Future predoctoral fellowship, two fellowships from the Institute for Environmental Quality, the University of Michigan, and the Programa do tropico umido of the Conselho Nacional de Desenvolvimento Cientifico e Tecnologico. None of the views expressed are the responsibility of the organizations which have supported the project.

REFERENCES

Brasil, Empressa Brasileira de Pesquisa Agropecuaria (EMBRAPA). Instituto Nacional de Pesquisa Agrpecuaria do Norte (IPEAN), 1974. Solos da Rodovia Transamazonica; Trecho Itaituba-Rio Branco; Relatorio Preliminar. Embrapa-IPEAN, Belem, 53 p.

Daubenmire, R., 1972. Some ecologic consequences of converting forest to savana in northwestern Costa Rica. Trop. Ecol., 13, 31-51.

Falesi, I.C., 1972. Solos da Rodovia Transamazonica. Instituto de Pesquisa Agropecuaria do Norte (IPEAN) Bolotim Tecnico No. 55, IPEAN, Belem, 196 p.

Fearnside, P.M., 1978. Estimation of carrying capacity for human populations in a part of the Transamazon Highway Colonization Area of Brazil. University of Michigan Ph.D. dissertation in Biological Sciences, University Microfilms, Ann Arbor, Michigan, 624 p.

Fearnside, P.M., 1979a. A stochastic model for the estimation of human carrying capacity in a part of the Transamazon Highway Colonization Area of BRASIL. (to be published).

Fearnside, P.M., 1979b. The simulation of carrying capacity for human agricultural populations in the humid tropics: program and documentation. (in preparation).

Fearnside, P.M., 1979c. Data management package for carrying capacity estimation in the humid tropics: program and documentation. (in preparation).

Fox, D.J. and Cuire, K.E., 1976. Documentation for MIDAS. 3rd ed. September 1976. University of Michigan Statistical Research Laboratory, Ann Arbor. 203 p.

Guimaraes, G. de A., Bastos, J.B. and Lopes, E. de C., 1970. Metodos de analise fisica, quimica e insturmental de solos. Instituto de Pesquisa Agropecuaria do Norte (IPEAN), Serie: Quimica de Solos 1(1), 108 p.

Hudson, N.W., 1977. The factors determining the extent of soil erosion. pp. 11-16. In: D.J. Greenland and R. Lal (eds.) Soil conservation and management in the humid tropics. John Wiley and Sons, New York, 283 p.

Lal, R., 1977. Review of soil erosion research in Latin America. pp. 231-40 In: D.J. Greenland and R. Lal eds.) Soil conservation and management in the humid Tropics. John Wiley and Sons, New York, 283 p.

Penteado, A.R., 1967. Problemas de colonizacao e de uso da terra na Regiao Bragantina do Estado do Para. Universidade Federal do Para, Belem, 488 p.

Sanchez, P.A. and Buol, S.W., 1975. Soils of the tropics and the world food crisis. Science 1-8: 598-603.

Scott, G.A.J., 1975. Soil profile changes resulting from the conversion of forest to grassland in the Montana of Peru. Great Plains-Rocky Mountain Geographical Jour. 4, 124-30.

Smith, N.J.H., 1976. Transamazon Highway: a cultural-ecological analysis of colonization in the humid tropics. University of California Ph.D. dissertation in Geography, Berkeley, 372 p.

COMMENTS

K.F. Wiersum: (1) To what extend are Pin measurements comparable to Plot measurements; early Indonesian data did not show any correlation between data obtained by both methods.

(2) Care must be taken that erosion rates in forest under good conditions is not compared to bad land-use practices; with good grass management practices, erosion will not take place compared to bad grass management practices.

P.M. Fearnside: (1) Stake ("pin") measurements can be expected to be highly correlated with the plot measurements, however such a correlation would not be statistically valid since the plot means are calculated from the stake measurements. If an independent measure of plot erosion is available, such as settling basin data, then such a correlation would be valid. I would expect an independent erosion measure to correlate well with stake measurements for land uses such as annual crops, which show a strong relation between erosion (as measured by stakes) and slope, but not for land uses such as virgin forest where this relation is weak or nonexistent.

(2) True, care must be taken in comparing erosion data under good and bad land use practices either under forest or pasture. In this case both the forest and the pasture must be considered as under "good" practices, since the forest was undisturbed and the absence of livestocks, have ensured that per hectare pasture stocking rates in the Transamazon Highway Colonization Area have remained quite low during the first few years of colonization.

Table 1 : Erosion Plot characteristics

Item	Units	Sample size	Mean	Standard Deviation
Plots in annual crops at time of maximum rainfall				
Soil bulk density	g/cm^3	18	1.237	0.192
Length of first slope above plot	meters	18	52.1	71.2
Length of second slope above plot	meters	11	86.2	35.9
Length of third slope above plot	meters	3	98.0	46.6
Total length of slopes above plot	meters	18	84.8	99.2
Total clay in soil	%	17	33.5	12.7
Total rainfall in measurement interval	mm	18	1406.9	210.1
Maximum rainfall in 24 hours	mm	18	86.0	-
Rain while bare or annual crops	mm	17	891.0	544.2
All plots				
Soil bulk density	g/cm^3	47	1.188	0.148
Length of first slope above plot	meters	47	47.9	49.0
Length of second slope above plot	meters	27	61.3	40.9
Length of third slope above plot	meters	8	79.0	39.0
Total length of slopes above plot	meters	47	74.8	75.4
Total clay in soil	%	45	34.2	12.8
Total rainfall in measurement intervals	mm	41	1408.2	182.9
Maximum rainfall in 24 hours	mm	41	86.0	-