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INITIAL SOIL QUALITY CONDITIONS ON THE TRANSAMAZON HIGHWAY OF BRAZIL AND THEIR SIMULATION IN MODELS FOR ESTIMATING HUMAN CARRYING CAPACITY

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Abstract : Agroecosystem models for estimating human carrying capacity require the simulation of initial soil quality to represent conditions before agricultural activities begin. This was done for a 23,600 ha section of the Brazilian Government's colonization scheme on the Trans. mazon Highway. The effect of variability in agricultural production on carrying capacity was a principal focus of the study. Factors influencing production, such as variability in initial soil quality, had to be reproduced in the modeling. The area's soils are extremely patchy, ranging from infertile areas of yellow latosol (OXISOL) and red-yellow podzolic (ULTISOL) to smaller areas of the relatively fertile *terra roxa* (ALFISOL). Maps were made based on 187 samples of soil in "virgin" forest, for pH, P, K, Ca^{++} & Mg^{++}, and Al^{+++}. Nitrogen, carbon, slope, and granulometric measures were also mapped. Occurrence frequencies for classes of pH, clay content, slope, carbon, and phosphorus were calculated from maps of 1180 quadrats, values for each 20 ha quadrat being considered those of the nearest sample. In modeling, the pH of the first small area or "patch" of soil simulated was established using the frequequency distribution, while values for subsequent patches were based on the previous value, using Markov matrices of transition probabilities for moves of 100 m between patches (derived from 46 pairs of samples), and of 500 m between adjacent has lots (derived from 164 pairs of samples). Total phosphorus, slope, carbon, and clay were generated from frequency distributions. Aluminum ion (Al^{+++}), concentration was calculated from a regression on pH and clay, while nitrogen was calculated from a regression on carbon and pH. The model reproduces observed variation at a scale of hundreds of of meters, together with the correlations existing between different soil quality characters. Soils are of fundamental importance in affecting variation in crop yields, which the simulation shows to have great impact on carrying capacity.

Résumé : Avec l'objectif d'estimer la capacité de charge humaine sur un aire de 23600 ha dans la zone de colonization gouvernementale de la Route Transamazonienne du Brésil, une méthode a été necessaire pour simuler la distribution initiale de la qualité du sol rencontré para les colons avant de comencer ses activités agricoles. L'effet de la variabilité de la production agricole sur la capacité de charge était le but principal de l'étude. A cette fin, il fallût reproduir dans les modeles les facteurs influençant la production, comme la qualité initiale du sol. Les sols de la zone sont extrèmement variés, des surfaces infertiles de latosol jaune (OXISOL) et podzolique rouje-jaune (ULTISOL), jusqu'á des surfaces plus petites de *terra roxa* (ALFISOL), relativament fertils. Des cartes ont été établies à partir de 187 echantillons de sol de forêt "vierge" pour le pH, P, K, Ca^{++} & Mg^{++}, et Al^{+++}. L'azote, le carbone, la peute, et des measures granulomètriques ont également été cartographiées. Les frequences de classes de pH, pourcentages d'argile, peute, carbone et le phosphore ont été calculés à partir de cartes de 1180 carrés de 20 ha, avec le valeur de chaque carré consideré celui de l'échantillon le plus proche. Pour modiliser, le pH de la premiere petite surface de sol ("patch") simulé était établi à partir des distributions de frequence, lorsque les valeurs pour les "patches" suivants étaient basées sur la valeur anterieure, employant des matrices Markov de probabilitées de transition, pour des distances de 100 m entre "patches" (basées em 46 paires d'echantillons), et de 500 m entre parcelles ad jacentes (bases en 164 paires d'echantillons), et de 500 me ntre parcelles adjacentes (basées en 164 paires de echantillons). Le phosphore total, la peute, le carbone, et l'argile ont été obtenues à partir des distributions de fréquences. Le teneur de ions aluminium (Al ++) ont été calculé à partir d'une régression des valeurs du pH et d'argile, alors que l'azote etait calculé à partir d'une régression des valeures du carbone et du pH. Le modèle reproduit la variation observée à l'echelle de quelques centaines de mètres, avec les correlations existentes entre les valeurs des différents facteurs de qualité de sol. Les sols sont très importants sur la variation de la production agricole, laquelle influence la capacité de charge humaine, comme l'a montré la simulation.

Resumen : Con el objetivo de estimar la capacidad de carga humana en una sección de 23,600 ha de la zona de colonización guvernamental de la Carretera Transamazonica del Brasil, se necesitó de un metodo para simular la distribuicion inical de la calidad de suelo encontrado por los colonos al llegar a la zona antes de iniciar sus actividades agricolas. El efecto de variabilidad de la productividad agricola sobre la capacidad de carga fué el principal enfoque de este estudio. Factores influenciando la producción, tal como variabilidad en la calidad inicial del suelo, tenian que ser reproducido en los modelos. Los suelos de esta zona son extrámiente variados, desde áreas infertiles de latosolo amarillo (OXISOL) y podzolico rojo-amarillo (ULTISOL), hasta áreas menores relativamente fertil de "terra roxa" (ALFISOL). Los mapas fueron hechos baseandose en 187 muestras de suelo de selva "virgen" para pH, P, K, Ca^{++} & Mg^{++}, y Al^{+++}. Nitrogeno, carbono, declividad, y medidas granulometricas tambien fueron mapeados. Frecuencias de ocurrencia de classes de pH, prcentaje de arcilla, declividad, carbono y fósforo fueron calculados de mapas de 1180 cuadrados de 20 ha cada uno, siendo el valor para cada cuadrado considerado el de la muestra más cercana. En el modelaje, el pH de las primera área pequeañ de tierra("patch") simulada, fué establecido a partir de las distribuiciónes de frecuencia, mientras valores para "patches" subsiquientes fueron basados en el valor previo, utilizando matrices Markov de probabilidades de transición, para mudanzas de 100 m entre "patches" ('basado em 46 pares de muestras), y de 500 m entre parcelas (adjacentes) (basada en 164 pares de muestras). Fósforo total, declividad, carbono, y arcilla fueron generados a partir de distribuiciones de frecuencias. La concentración de ionios de aluminio (Al^{+++}) fué calculado a partir de una regresión de los valores de pH y arcilla, enquanto nitrogeno fué calculado de una regresión de los valores de carbono y pH. El modelaj e reproduze la variación observada en una escala de centenas de metros, junto con las correlaciones existentes entre los valores de diferentes factores de calidad de suelo. Los son de suma importancia en la variación de produccion agricola, y la simulación los muestra tener grande efecto sobre la capacidad de carga humana.

Resumo : Com a finalidade de estimar capacidade de suporte humano, em uma área de 23.600 ha dentro da área de colonização do INCRA na Transamazônica, precisou-se de um método para simular a distribuição inicial de qualidade de solo encontrada pelos colonos ao chegar na área, antes do início das suas atividades agrícolas. Sendo que era de interesse o efeito sobre capacidade de suporte da variabilidade em produção agrícola, e portanto nos vários fatores que influem nesta produção, a variabilidade em qualidade de solo inicial tinha que ser reproduzida no modelo. Os solos da área são extremamente variados, desde áreas inférteis de latossolo amarelo (OXISOL) e podzolico vermelho-amarelo (ULTISOL), até áreas menores, de fertilidade relativamente alta, de terra roxa (ALFISOL). Mapas foram feitos baseando-se em 187 amostras de solo de mata "virgem" para pH, P, K, Ca^{++} & Mg^{++}, e Al^{+++}. Nitrogênio, carbono, declive, e medidas granulomêtricas também foram mapeados. Frequências de ocorrência de classes de pH, porcentagem de argila, declive, carbono e fósforo foram calculadas de mapas de 1180 quadrados de 20 ha, sendo o valor para cada quadrado considerado o da amostra mais próxima. No modelo, o pH da primeira área pequena de terra ("patch") simulada foi estabelecido a partir da frequência de distribuição, enquanto valores para "patches" subsequentes foram baseados no valor prévio, utilizando matrizes Markov de probabilidades de transição, para mudanças de 100 m entre "patches" (baseada em 46 pares de amostras), e de 500 m entre lotes adjacentes (baseada em 164 pares de amostras). Fósforo total, declive, carbono e argila foram gerados a partir de distribuições de frequências. O teor de ionios de alumínio (Al^{+++}) foi calculado a 'partir de uma regressão dos valores de pH e argila, enquanto nitrogênio foi calculado de uma regressão dos valores de carbono e pH. O modelo reproduz a variação observada numa escala de centenas de metros, junto com as correlações existentes entre valores de diferentes fatores de qualidade de solo. Os solos são de suma importância na variação de produções agrícolas e a simulação mostra seu efeito sobre a capacidade de suporte humano.

Key Words : Soil fertility, Amazon, Brazil, Tropical agriculture, carrying capacity, colonization, Tropical soils, stochastic modeling.

INTRODUCTION

Simulation of soil quality under "virgin" (1) forest encountered by colonists settled along Brazil's Transamazon Highway in the government colonization area near Altamira was needed as a part of modeling effort aimed at investigating factors affecting human carrying capacity (Fearnside 1978, nd-a). Soil fertility characters were important for predicting crop yields (e.g. Fearnside 1979a, 1980a, b), while topography and soil structure characters were needed for prediction of erosion Fearnside 1980c), which in turn affected the fertility indicators used in yield predictions, "Carrying capacity" refers to the density of the human population that can be suppoted in an area indefinitely at a given standard of living, granted assumptions regarding such factors as productive technology and consumptive habits. The models used were stochastic in nature (Fearnside 1979b, 1983), carrying capacity being operationally defined in terms of a gradient of probability of colonists failing to meet consumption and other standards with increasing population density. Variability in crop yields resulted in colonist failures; variability in factors affecting crop yields were therefore modeled in order to simulate this aspect of the colonists' agroecosystem. Soils in the area are extremely patchy, ranging from very poor to relatively fertile over a scale of hundreds of meters. The modeling strategy outlined in this paper replicates the patchy nature of initial soil quality distributions as a part of the larger carrying capacity estimation models.

The intensive study area for the carrying capacity estimation project is comprised of 236 colonist lots surrounding Agrovila Grande Esperança, located on the Transamazon Highway 50 km west of the town of Altamira, Pará. The area is in the well-drained upland (*terra firme*) interfluve between the Xingú and Tapajós Rivers, two southern tributaries of the lower Amazon. The center of the area is at 3°22' South Latitude, 52°38' West Longitude, and approximately 100 m altitude. Each colonist lot has 100 ha of land, with dimensions of 500 × 2000m if it fronts on the main highway or 400 × 2500 m if it fronts on one of the lateral feeder roads. The intensive study area includes the entire length of three lateral roads (15/17, 16/18, and 17/19), important in designing a study of this colonization zone where bands of soil of a given type often run parallel to the east-west direction of the main highway. The soils of the intensive study area are classified as yellow latosol (OXISOL) by the 1:250,000 map of Brazil's side-looking radar natural resource survey (Brazil, Projeto RADAMBRASIL 1974; folha SA. 22), but are placed in the red-yellow podzolic (ULTISOL) group in Falesi's (1972a: 49) more detailed survey of soils of the Transamazon Highway.

Infertile red-yellow podzolics (ULTISOLS) in the area are dystrophic (base saturation < 35%) soils derived from rocks of devonian origin in the Curuá formation (Falesi 1972a: anexo 2). During their long geologic history under high rainfall conditions, most available cations and other plant nutrients have been leached out of these ancient soils. The process of podzolization has resulted in migration of clay particles (which in most soils provide the binding sites for cations needed by plants) to lower horizons, giving these soils their diagnostic textural (clayey) B horizon.

Yellow latosol (OXISOL) has little differentiation between soil horizons. As with red podzolic, yellow latosols in this area derive from the upper devonian Curuá formation (Falesi 1972a: 67). The long time span over which the soil has evolved has resulted in leaching of most of the bases and removal of much of the silica from the entire profile, while iron and aluminum sesquioxides have concentrated in the lower layers (oxic or latosolic B horizon). However, oxic B horizons can also occur in ULTISOLS (Sanchez 1976: 64), and the lack of significant increase in clay content with depth remains the diagnostic criterion for OXISOLS.

On closer examination, the area appears to be a mixture of these two infertile types, together with patches of the richer *terra roxa* (ALFISOL). Distinguishing red-yellow podzolic (ULTISOL) from yellow latosol (OXISOL) requires comparison of granulometric information between upper and lower horizons. Of 22 profiles in non-*terra roxa* soils of the intensive study area for which this information is complete for both the uppermost (approx. 0-30 cm) and lowermost (approx. 70-100 cm) samples, 7 (32%) would be classed as yellow latosol (OXISOL) and 15 (68%) as red-yellow podzolic (ULTISOL) using the U. S. Soil Taxonomy criterion for ULTISOLS of at least a 20% increase in clay content in the lower horizon (U. S. Soil Conservation Service 1975).

The distinction between red-yellow podzolics (ULTISOLS) and yellow latosols (OXISOLS) is not believed to be an important one from the point of view of crop yields at the level of Transamazon Highway colonists. Both soil types are acid and infertile, and the differences in lower horizons have little impact on the shallow-rooted annual crops and pastures planted by the first wave of pioneer farmers. At a high level of generality, ULTISOLS are considered less appropriate for mechanization due to susceptibility to soil compaction and their frequent occurrence on more steeply sloping terrain than OXISOLS (Sanchez 1977: 539). Due to the tremendous variability in local conditions, however, such generalizations need to be carefully examined for applicability in any given agricultural situation before being used as a basis for counsel on specific management decisions. The complete range of slopes and granulometric characteristics observed on these soils within the intensive study area illustrates this well.

Terra roxa (ALFISOL) is much more fertile than the two other principal soil types. This soil is much more recent in origin than red-yellow podzolic (ULTISOL) and yellow latosol (OXISOL), being derived from igneous intrusions of diabasic rock that occurred during the Paranaense Diastrophism that shook much of Brazil during the mid-triassic (Falesi 1972a: 126). Having had less time to weather than the other two types, *terra roxa* (ALFISOL) of the Altamira area has retained more of its cations (base saturation > 35% for ALFISOLS). High iron content is responsible for its distinctive red appearance and name, literally meaning "purple earth". While formally identified by its sub-angular particle structure, *terra roxa's* superficial appearance and higher fertility make its presence readily apparent to colonists and others, although red-yellow podzolic can also be red in color (see Beinroth 1974 for explanation of Brazilian soil taxonomy). The principal element lacked by *terra roxa* is phosphorus, also lacking in red-yellow podzolic and yellow latosol. The higher pH, however, spares farmers with *terra roxa* the effects of the synergism between acidity and available phosphorus in most soils of the Amazon, where low pH renders unutilizable much of what little phosphorus exists (Kamprath 1973: 140). The high concentrations of toxic aluminum ions in the more acid soil types are not a problem in *terra roxa*. From the perspective of the colonist population of the Transamazon Highway, the problem with *terra roxa* is that its distribution is so limited that only a favoured few have the soil in their lots. A high density of sampling was undertaken in order to quantify this and other forms of fine scale variation, a reflection of the carrying capacity modeling effort having been directed at elucidating underlying properties of tropical agrosystems, rather than producing a survey of the largest possible area. In the present study, soil quality is mapped and simulated using the soil characters directly linked to agricultural productivity or soil erosion. Since productivity and erosion are affected far more by the characters of the soil's uppermost layer than by the profile characteristics determining soil taxonomic classification, only surface characteristics are simulated rather than soil taxonomic units.

METHODS

Surface samples (0-20 cm in depth) and soil profiles (0-100 cm in depth) were collected in the area between 1974 and 1976. Surface samples were taken using the methodology employed by the United Nations Food and Agriculture Organization (FAO) in the region: each sample is comprised of a composite of at least 15 cores taken with a tube-type soil sampler haphazardly throughout the "field" being sampled (or in the case of virgin forest, throughout an area roughly equivalent to a field). Where data from soil profiles were used, soil analysis values were used from the upper 30 cm of the profile. Profiles are taken at one location each using a soil auger, with samples analyzed at three to four depths. Samples were thoroughly mixed, and pieces of rock, lateritic concretions, wood, or charcoal removed before analysis. Samples were analyzed by the Brazilian Enterprise for Agriculture and Cattle Ranching Research (EMBRAPA) laboratory in Belém, Pará.

Methods used in the laboratory are described in detail by Guimarães *et al.* (1970). Briefly they are: North Carolina method for phosphorus; Kjeldhal method for nitrogen; Titurin for carbon; calcium and magnesium extracted with 1 N KCl and titrated with 0.025 N NaOH; potassium extracted with 0.050 N HCl and 0.024 N H_2SO_4 and determined in a flame photometer; pH determined in water with a

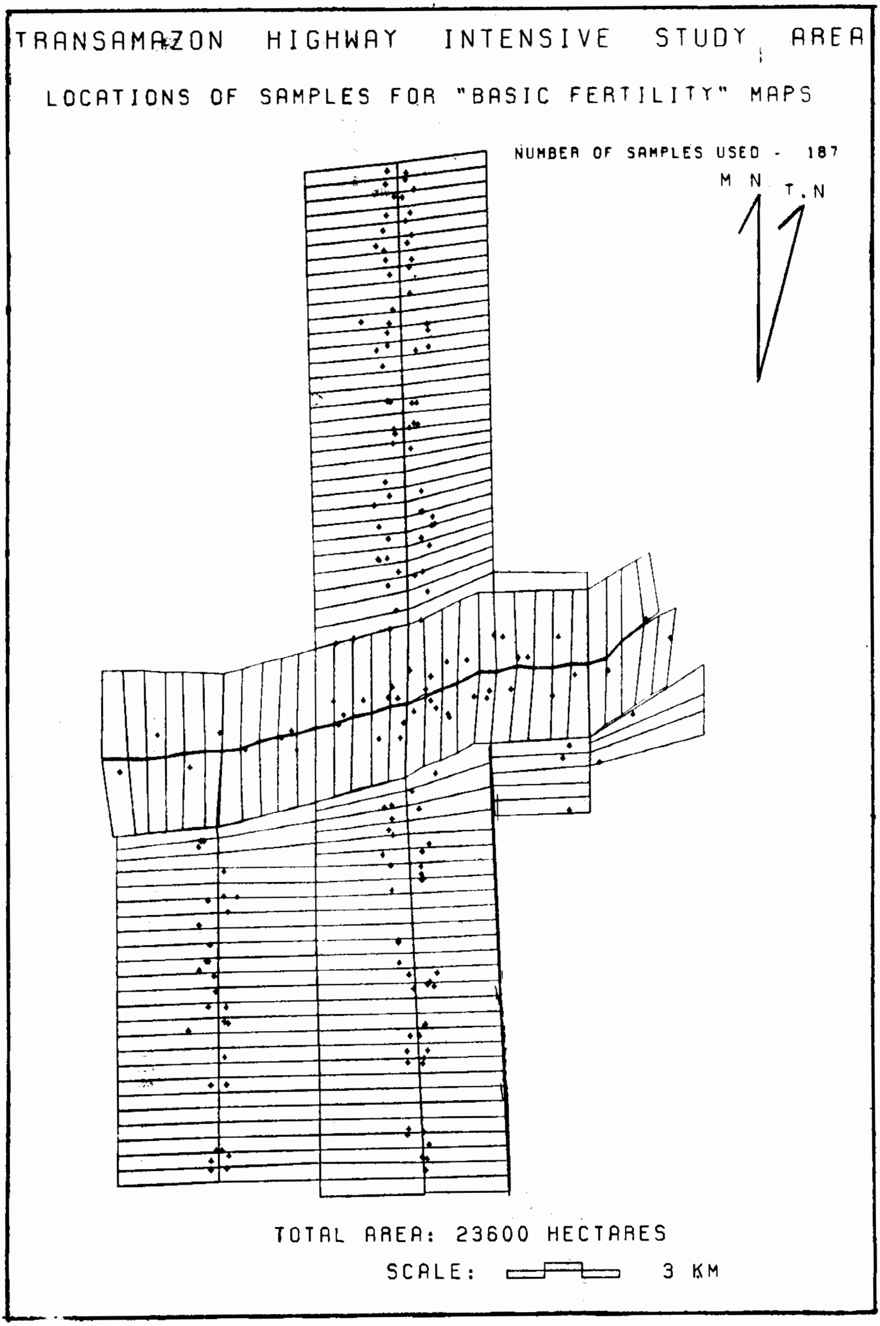

Fig. 1. Soil sample locations for "basic fertility" maps.

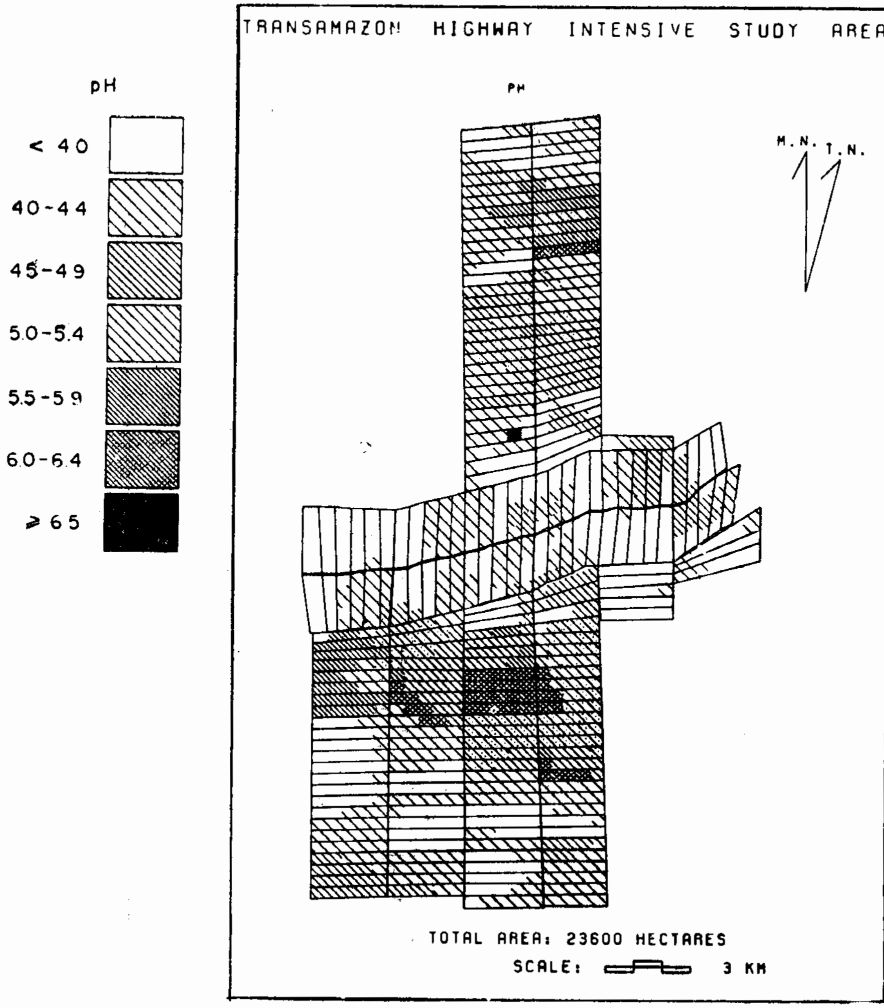

Fig. 2. Map of pH in virgin soil.

Clay content and slope are assigned based on the frequencies of the classes for these parameters (Fig. 11) and the means and standard deviations of values within each class.

Aluminum content is calculated based on the pH and clay content values already assigned. The regression equation expressing this relationship is:

$$Y=11.43-7.68 \ln A-6.27\times10^{-2}B \quad \text{(Equation 1)}$$

($P<0.001$, $r=0.73$, $SE=1.56$, $N=118$ virgin forest samples) where: Y=Aluminum (Al^{+++} in meq/100g); A=pH; B=total clay (%).

The expected value for Aluminum based on Equation 1 is then altered to reflect the variability found in the original data set using the standard error of the estimate.

Carbon is then assigned based on the frequencies in the soil maps made for the study area (Fig. 11) and the mean and standard deviation within each class.

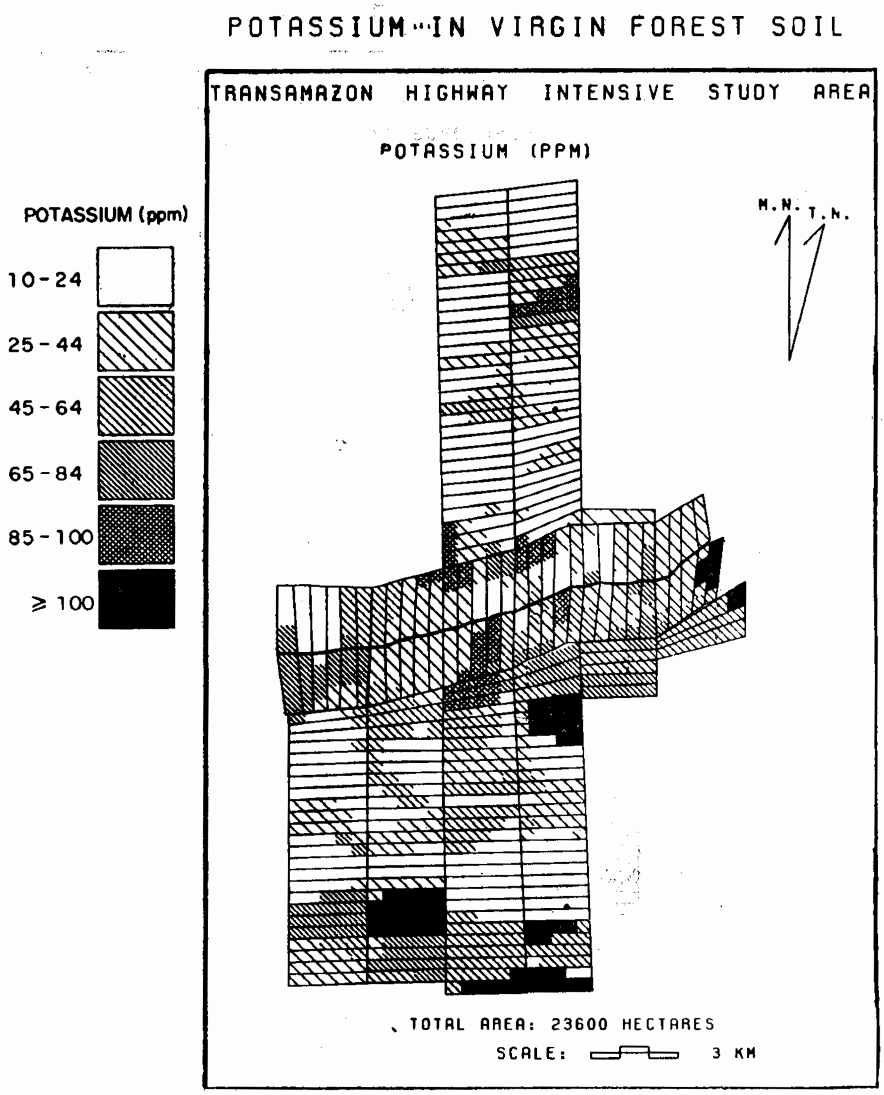

Fig. 4. Map of potassium concentration in virgin soil.

scale soil maps existing for the region for making specific management recommendations. The tremendous number of samples that would be needed to map a significant portion of Amazonia at a scale appropriate for such decisions insures that this situation will continue for many years. Significant improvements in knowledge of the region's soils could be achieved, however, as the store of data continues to increase and through better integration of existing soil information. The need to be able to simulate the scale of patchiness in soil quality is urgent if models are to be possible which allow responses to these factors in planning decisions. The more usual assumption is that soil qualities are uniform, a view encouraged not only by the misleading

CALCIUM AND MAGNESIUM IN VIRGIN FOREST SOIL

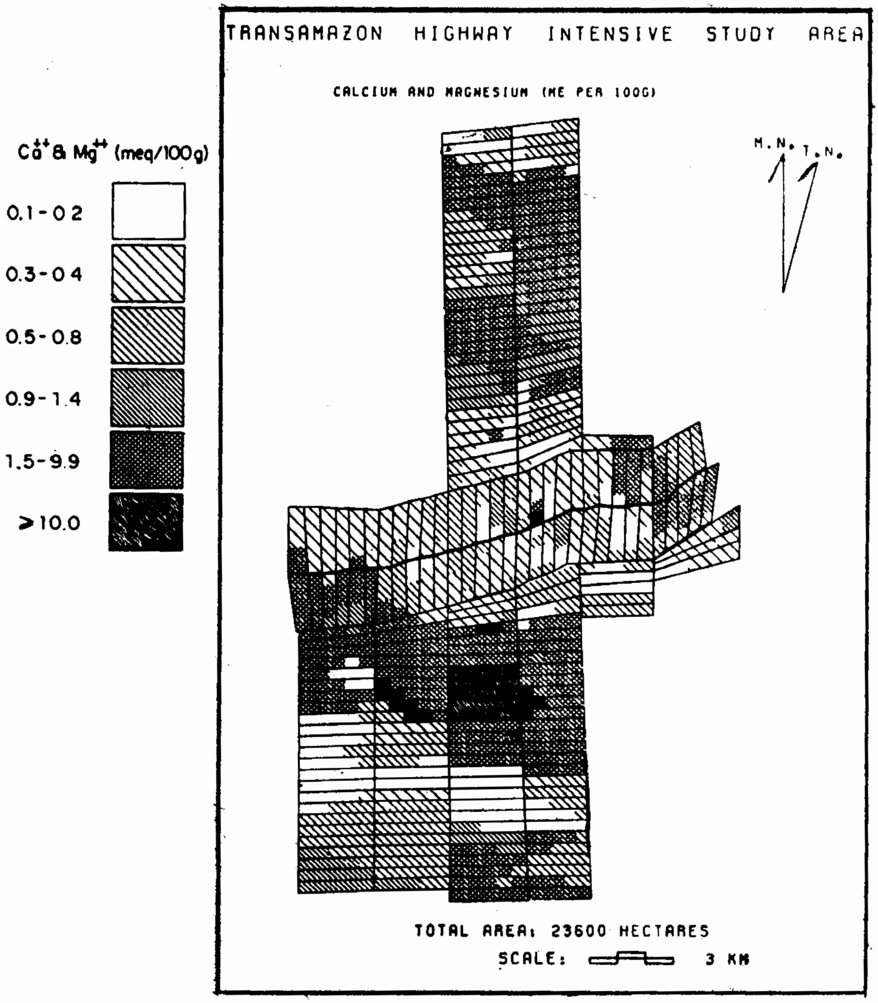

Fig. 5. Map of calcium and magnesium ion concentration in virgin soil.

nature of available maps and the lack of specific knowledge of areas for which plans are being laid, but also by the lack of understanding of how to interpret and incorporate such detailed information into planning were it to become available.

The scale of patchiness makes stochastic modeling appropriate, as do the wide differences between the more and less fertile patches. The maps of soil parameters reveal that the same lot often has more than one soil type (especially in the parts of the maps where sampling denstiy is greatest). Patchiness is actually more than is shown in the maps, due to the relatively sparse density of sampling over a significant portion of the study area. The matrices of transition probabilities, however, preserve this patchiness, as they are based on transitions observed between actual samples rather than mapped quadrats. It should be emphasized that the sample

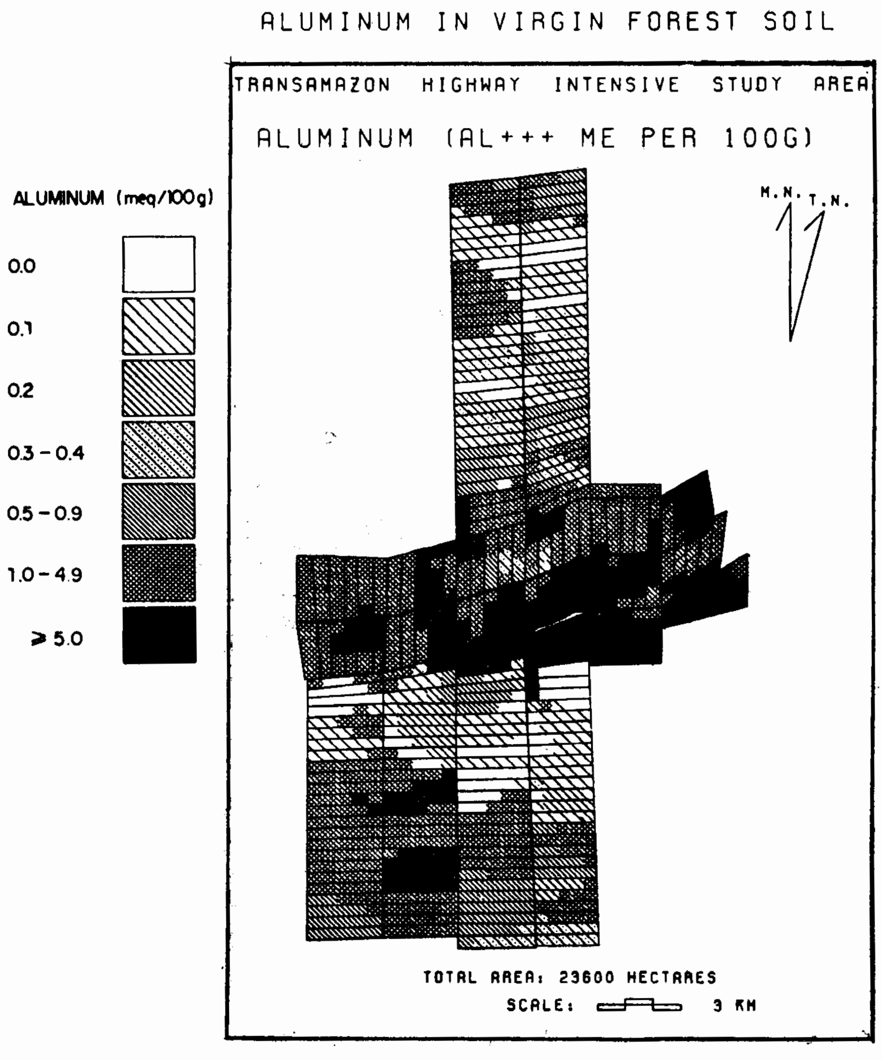

Fig. 6. Map of aluminum ion concentration in virgin soil.

sizes in the present study are exceedingly small. The pH class transition probability matrix for 100 m moves is particularly unreliable for this reason, as indicated by the fact that for 2 of the 7 classes the probability of staying in the same category is lower than for the corresponding 500 m move (Table 1).

The relationships between soil characters found here are known for tropical soils generally (e.g. Sánchez 1976). The negative logarithmic relationship of aluminum ion concentration with pH is well known, as is the positive relation of calcium and magnesium ion concentraion with pH. The relative constancy of C/N ratios in many tropical soils indicates the close link between these elements. The regressions incorporated in the algorithm for initial soil quality generation in the carrying

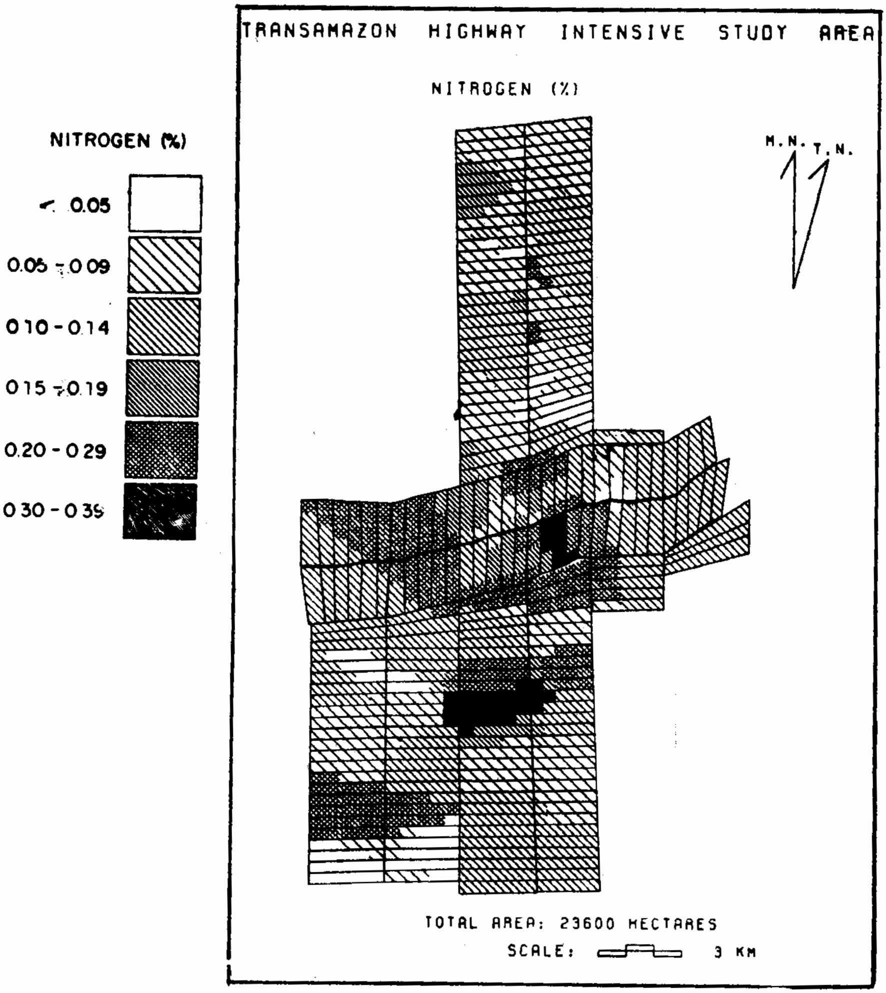

Fig. 7. Map of total nitrogen concentration in virgin soil.

capacity simulation model preserve these interrelations, contributing to the realism of simulated soil qualities. The simulated soils are predominantly infertile, as they are in the study area and throughout most of Amazonia (5). They are not without patches of markedly better soil, however. Patches of the relaively fertile *terra roxa* (ALFISOL) are agriculturally important in the Transamazon Highway colonization area at Altamira, although their extent is quite limited in relation to the total area. They are most prevalent in the areas of km 20-33 and km 63-112 west of Altamira, both outside of the present intensive study area. These two concentrations of *terra roxa* have received a disproportionate share of government and other research in the Altamira-Itaituba area, such as that of agricultural experiment stations at km 101 and km 23 (Viégas and Kass 1974), economic surveys of Homma (1976) and Homma *et al.* (1978) at km 90, and the major stuides of Moran (1976, 1978 at km 23 and Smith (1981) at km 90.

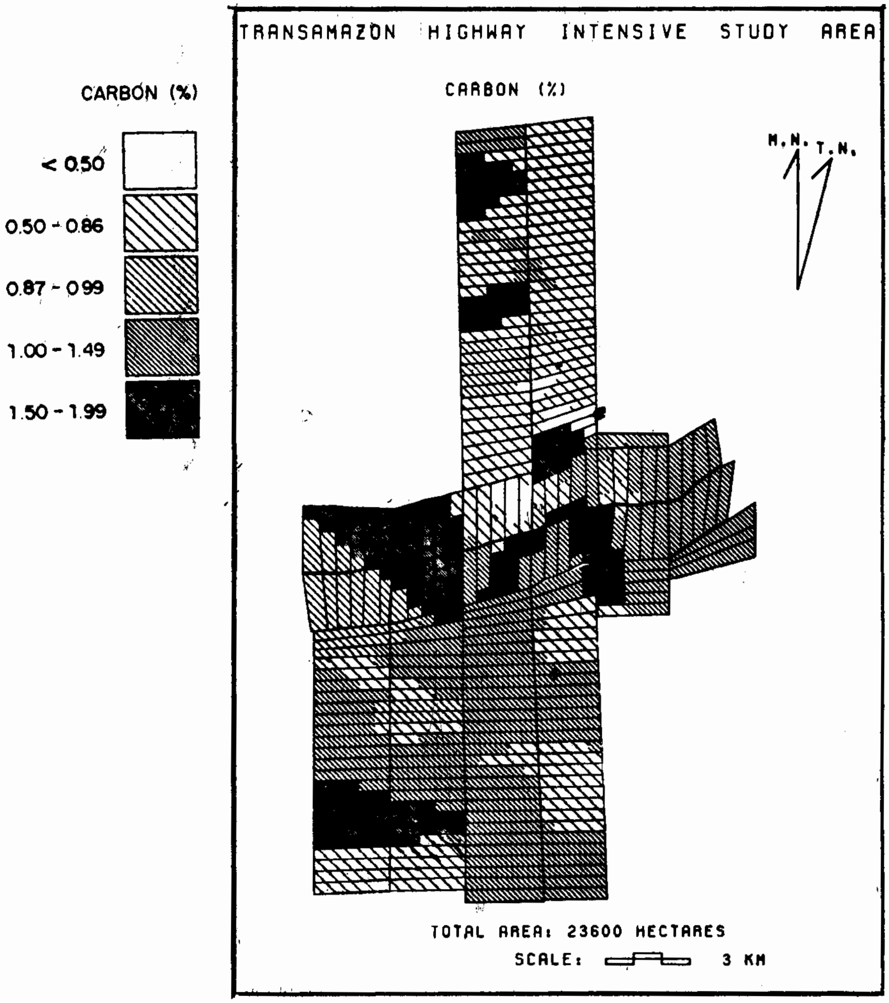

Fig. 8. Map of total carbon concentration in virgin soil.

One can calculate (Fearnside, nd-a) that *terra roxa* occurrences crossing the Transamazon Highway account for a total of 76.8 km of the portion of road surveyed by Falesi (1972a) (6). Since other surveys indicate that none of the remainder of the approximately 3000 km of the highway lying within Amazonia is *terra roxa*, this represents 2.6% of the highway. Of the colonized portion of the Transamazon Highway between Marabá and Itaituba, this represents 7.0% of the roadside. In Brazil's *Amazonia Legal* or "Legal Amazon", the 10,000 km of this soil estimated to exist (Falesi 1974b) represent only 0.2% of the region. Using virgin forest soil pH values of at least 5.5 as an approximate indicator of *terra roxa*, 9% of the present study area is of this soil type, making it roughly representative of colonized areas on the highway. The fact that 33.0% of the soil in the study area

GRANULOMETRIC ANALYSIS SOIL MAP FROM ALL SAMPLES

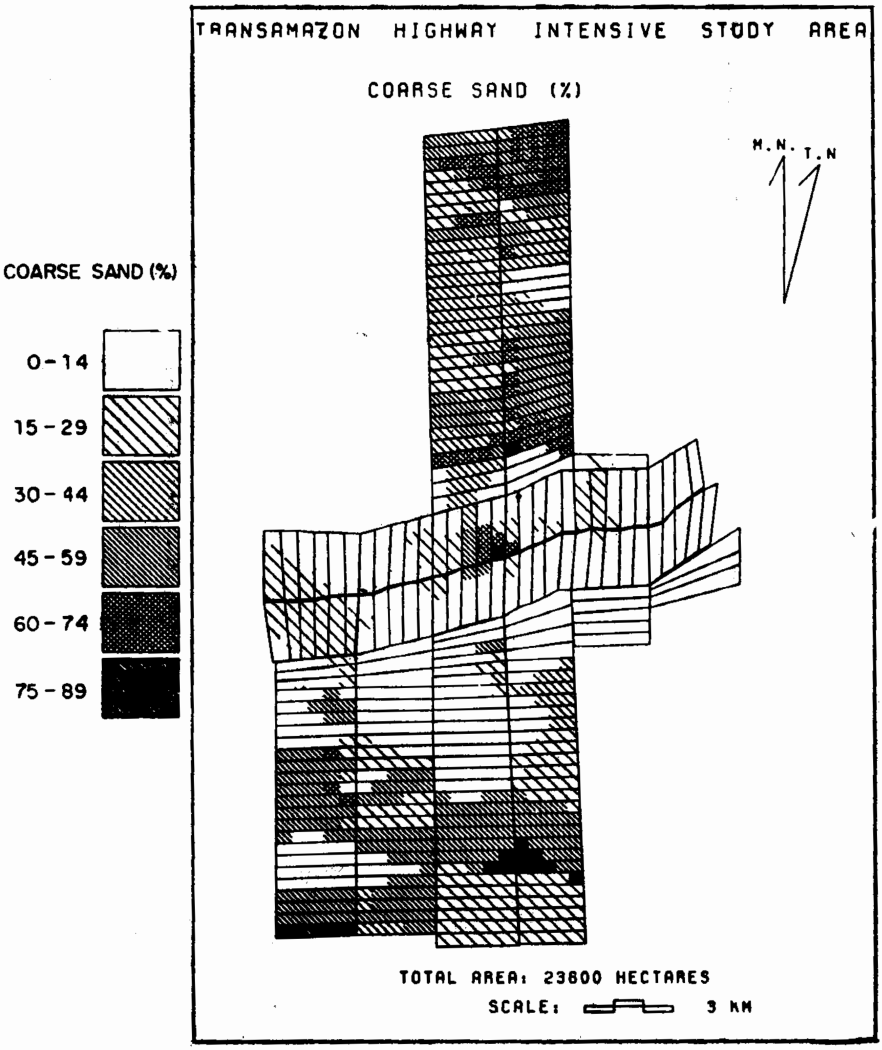

Fig. 9. Map of coarse sand fraction.

has pH less than 4.0, and 63.2% has pH lower than 4.5, indicates the extreme poverty of most of the soil. The scale of patchiness of these radically different soil quality classes with respect to the size of colonist lots is extremely important for the agricultural success of individual farmers. Preserving this fine scale spatial variation is

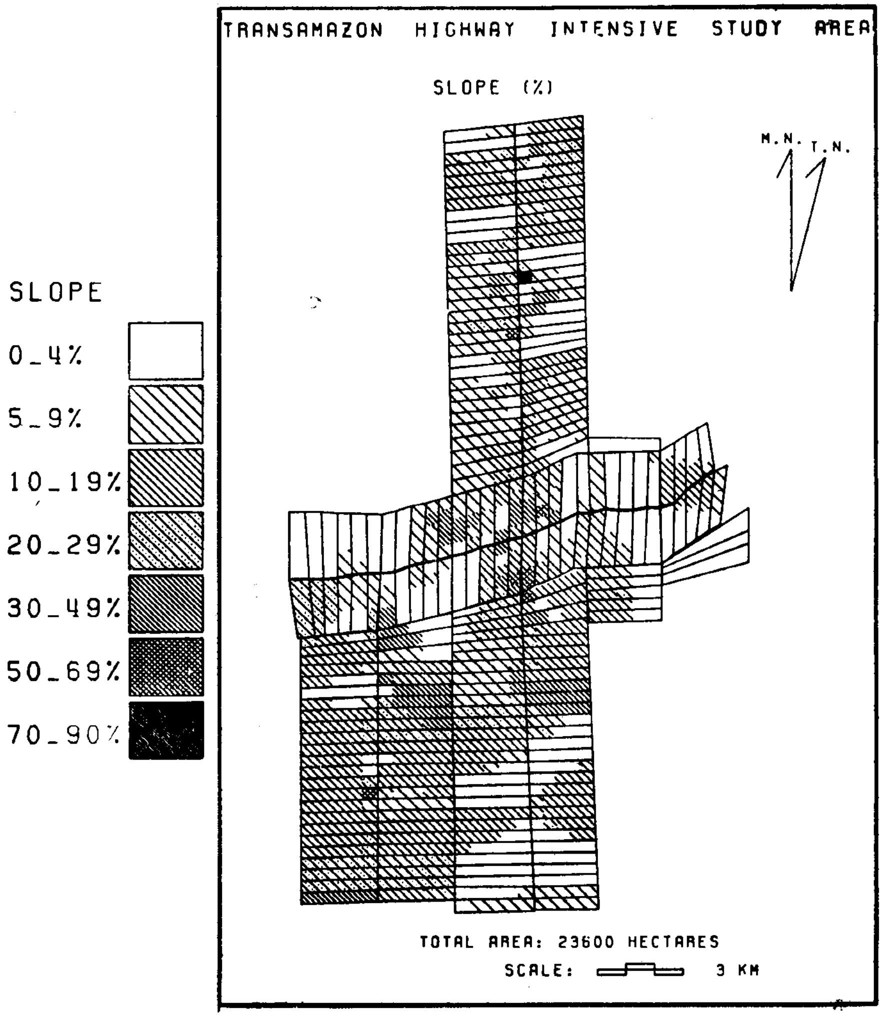

Fig. 10. Map of slope.

therefore an important feature of the models for estimating human carrying capacity Where possible, patchiness in soil quality must be estimated with respect to colonis lots in pre-colonization studies.

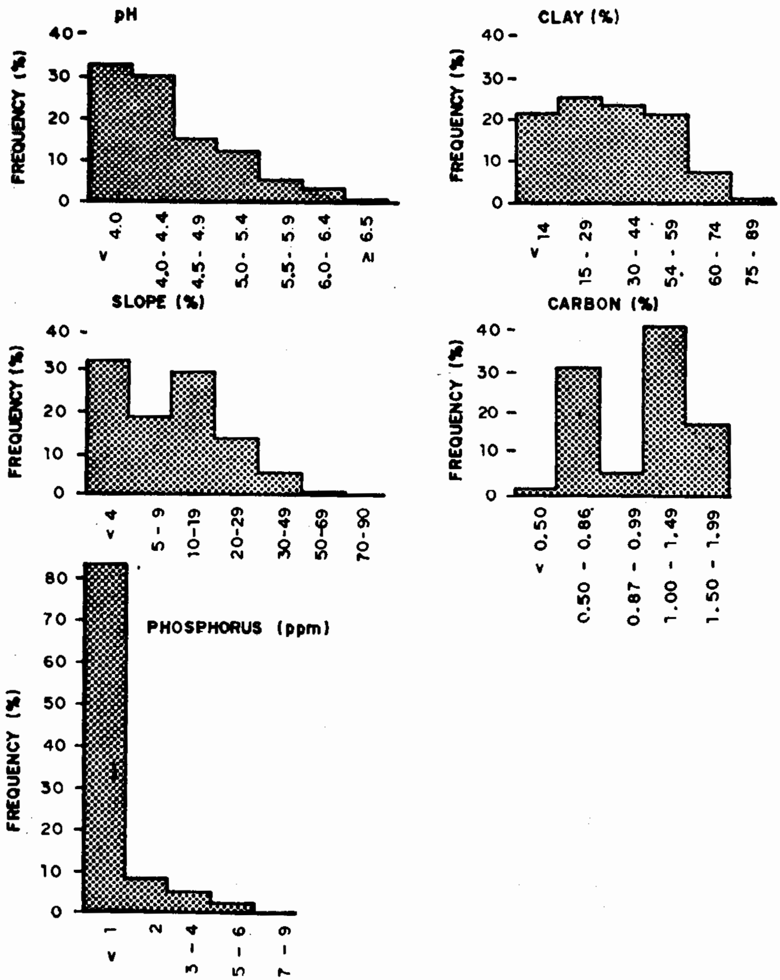

Fig. 11. Observed distributions of independently modeled soil characters in the intensive study area.

CONCLUSIONS

1.) The scale of spatial variation in soil quality and interrelations between soil quality parameters can be simulated in stochastic models.

2.) The soils in the Transamazon Highway colonization area are generally very poor, but agriculturally important occurrences of better soil types do exist. Modeling the pattern of occurrence of soil quality classes is an essential part of human carrying capacity estimation.

TABLE 1. *Transition Probabilities for Virgin Soil pH*

Beginning pH Class	Ending pH Class ≤3.9	4.0—4.4	4.5—4.9	5.0—5.4	5.5—5.9	6.0—6.4	≥6.5	Sample size
				move of 100 meters (1)				
≤3.9	0.00	0.33	0.00	0.33	0.33	0.00	0.00	3
4.0—4.4	0.09	0.73	0.09	0.00	0.00	0.00	0.09	11
4.5—4.9	0.00	0.17	0.33	0.00	0.50	0.00	0.00	6
5.0—5.4	0.09	0.00	0.00	0.36	0.36	0.18	0.00	11
5.5—5.9	0.11	0.00	0.33	0.44	0.00	0.11	0.00	9
6.0—6.5	0.00	0.00	0.00	0.40	0.20	0.40	0.00	5
≥6.5	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1
				move of 500 meters (2)				
≤3.9	0.40	0.43	0.09	0.06	0.00	0.00	0.03	35
4.0—4.5	0.25	0.43	0.15	0.08	0.08	0.02	0.00	61
4.5—4.9	0.12	0.36	0.24	0.08	0.12	0.08	0.00	25
5.0—5.4	0.12	0.29	0.12	0.24	0.24	0.00	0.00	17
5.5—5.9	0.00	0.25	0.15	0.20	0.30	0.10	0.00	20
6.0—6.4	0.00	0.20	0.40	0.00	0.40	0.00	0.00	5
≥6.5	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1

(1) calculated from samples which are 100 meters from each reference sample ± 100 meters.
(1) calculated from samples which are 500 meters from each reference sample ± 100 meters.

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NOTES

(1) "Virgin" forest is used here to mean forest not previously cleared by colonists, and showing no readily apparent signs of disturbance. Amerindian populations had occupied the region for millennia prior to the recent colonization initiative, and so these forests are unlikely to be truly virgin in the sense of never having been disturbed by humans (see Smith 1980).

(2) Ca^{++} & Mg + does not contribute to yield predictions because of its close link with pH. Ca^{++} & Mg^{++} in virgin soil can be predicted from the regression :

$$Y=2.841\ A-10.610$$

$$(P<0.001,\ r=0.71,\ SE=2.08,\ N=187)$$

where :

$Y=Ca^{++}$ & Mg^{++} (meq/100 g); $A=pH$.

The excluded granulometric characters (coarse sand, fine sand, and silt) are all correlated with the total clay content. Potassium in agricultural fields (after burning) is generally sufficiently high that it does not limit crop yields, especially given the very low levels of other nutrients such as phosphrous.

(3) Organic matter is not considered independently, as the EMBRAPA laboratory estimates this by simple multiplication of the percentage total carbon by the constant 1.72, a standard practice (Young 1976 : 102).

(4) Using 0.25 ha patches (corresponding to 50 m moves) rather than 1 ha patches (corresponding to 100 m moves) in carrying capacity estimation runs means that probabilities of transition out of any given class are overestimated.

(5) see Irion (1978), Van Wambeke (1978), Sombroek (1966), Bennema (1975), Falesi (1967, 1972a, b; 1974a, b), Camargo and Falesi (1975), Brazil, DNPEA (1973a, b). Brazil, IPEAN (1967), Verdade (1974) and Vieira *et al.* (1971).

(6) Camargo and Falesi's (1975 : 39) rough estimate of 100 km or 8% of the highway length appears high.

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