SOIL NUTRIENTS AND ANNUAL CROP YIELD PREDICTION FOR USE IN MODELING HUMAN CARRYING CAPACITY ON THE TRANSAMAZON HIGHWAY: SUMMARY OF PROGRESS

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I.) INTRODUCTION:

A.) OVERVIEW OF MODELING STRATEGY FOR SOILS:

Prediction of the probability distributions for yields from annual crops is a vital part of the effort to construct simulation models for a series of estimates of human carrying capacity in the colonization area along the Transamazon Highway. In modeling the yield a colonist attains when he plants a given crop, one must draw a value from a probability distribution describing his chances of attaining each possible yield. The mean and shape of this distribution will be dependent on such factors as the levels of various nutrients in the soil at the time of planting; attack of insects, vertebrates and diseases; the planting density, density of interplanted crops, and seed variety, as well as many other factors which are not considered in the present description of progress such as weedings, planting date, weather, etc. As a prerequisite to being able to use yield predictions based on these variables, one must be able to draw values for each variable from probability distributions which describe the chance that each condition will actually be encountered. With the exception of one disease attacking beans, and also with the exception of soils, these distributions can be estimated directly from the frequencies of occurrence in the data collected. More elegant derivations of the distributions are proposed for the bean disease and for soils.

In the case of soils this involves beginning with initial values for soil constituents (which are drawn from their own probability distributions describing the patchiness of the soils in the area), and then modifying these initial values during the course of the simulation run to mimic the effects of various treatments such as burns of different qualities, cropping with different crops, and fallowing. The probability that each of these treatments will occur, and the distribution of effects that will result from any given treatment, are themselves describable in terms of probability distributions.

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The inclusion of large numbers of probability distributions such as these in a computer model, and the keeping track of resulting changes in many different patches of soil and colonist's lots; is greatly facilitated by the SIMULA computer language (Burroughs Corp. 1972). The rendering of the model into this language has been begun and has generated unsightly piles of paper covered with chicken-scratchings called SIMULA diagrams. These will not be described in this description of progress.

B.) SUMMARY OF PROGRESS IN DATA COLLECTION:

The data presented in this description of progress provides support for the notion that probability distributions for annual crop yields can be constructed which, through the incorporation of effects from soil nutrients, can provide better predictions of the yields attained by colonists than would be attainable from probability distributions describing the yields directly without reference to soils. The establishment of relationships between soils and yields is essential if longterm effects of soil degradation are to be reflected in the behavior of the models. The great variability in yields observed on widely differing soils made it by no means obvious that any such relations would emerge. Since a great deal of effort had been absorbed by the soils portion of the data collection, some preliminary analysis was justified in order to satisfy myself that the prediction of yields from soils was a viable endeavour. Although some of the relations are better than others, the results are generally heartening.

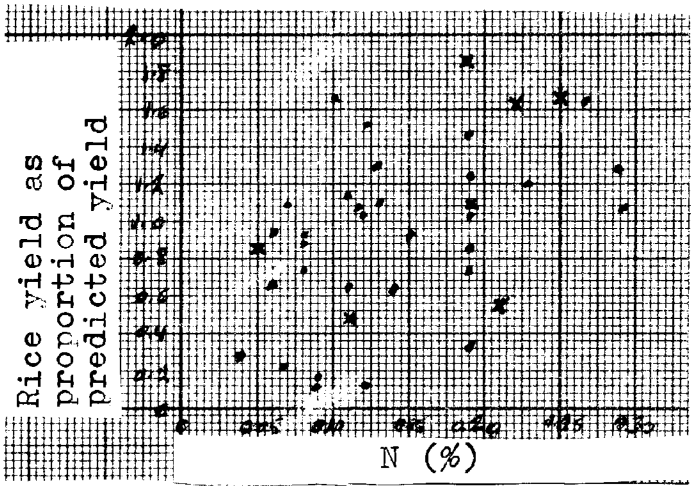
The soils data set includes data from soil samples in 388 locations. In order to establish the soils/yield relations the data sets for fields of each crop had to be culled savagely to remove fields which had unreliable information due to small area, incomplete information, or any of several other criteria. The culling procedure is described in the Appendix. This was an extremely painful process, since each soil sample represents several hours of hard labor.

The data will have to be subjected to a proper multilinear regression analysis incorporating the different variables after completion of field work. The present analysis involves adjustments of the data for effects of variety, planting density, and density of interplanted crop which were done by quick-and-dirty graphical methods which are detailed in the Appendix. These are not intended to be statistically rigorous.

Data is presented related to the prediction of yields of six annual crops: rice, maize, Phaseolus beans, Vigna cow-peas, bitter manioc, and sweet manioc. Best results were obtained for maize, but results for Phaseolus beans, sweet manioc, and bitter manioc look good with small sample sizes. Vigna cow-peas have not yet produced enough data to separate planting density from soils effects. Rice is the most difficult to predict from soils, but shows at least some indication of a relation with nitrogen. All other crops show their best relationships with pH. Information needed for modeling changes from initial soil conditions from burning, cropping, and fallowing have also been collected. Extensive data for prediction of burn qualities and the nutrient inputs that result from each type and quality of burn has been collected. This shows great difference in the frequency of different burn qualities between years, and at least between the extremes of burn quality shows differences in nutrient inputs. Some critical soils analysis results, such as organic matter, have not yet been returned from the laboratory. There are numbers of other variables both from soils analyses and from observations to be incorporated into the analyses. Even when all variables have been incorporated into the relations at each step from initial soils to crop yields, there is sure to remain a considerable amount of unexplained variance. The great variability in yields will be duplicated through stochastic terms in the modeling. The results support the emphasis which differences between years caused by weather, differences in the number of weedings or in man-days per hectare spent in weeding, and in man-days per hectare spent in "coivara" (piling up unburned branches to prepare the ground for planting), effects of differences in burn quality which are not reflected in the chemical analyses (such as the amount of unburned material left on the ground), and the age and previous history of the field. Differences can also be expected from variation in the number of seeds planted per hill, germination, and toppling. No adjustiments were made in the soil nutrient values to allow for different lengths of time and different intervening uses between the crop and the sampling date. However, those fields that were burned between the crop and the sample were kept separate and were included in the set of fields with "indirect" soils data along with fields where the sample came from another field in the same lot with a history similar to the one to which the yield figure applies.

Plots were made of rice yields versus the different nutrients for which soils results have been returned. No very convincing relations were found for pH, phosphorus, potassium, calcium and magnesium, and aluminum. The lack of a strong relation with pH and aluminum agrees with the observation that initial soil type seems to have relatively little effect on rice yields. Nitrogen, which is much less tightly correlated with soil type than are pH and Al^{+++}, shows some indication of a relation with rice yield, although no one variable can be expected to suffice for a prediction. The nitrogen relation is plotted below in Figure 1.

FIGURE 1: RICE YIELD VERSUS NITROGEN



× = indirect soils data

n = 39

With the effects of other nutrients incorporated into a multilinear regression model, plus some other non-soils effects and the planting density and interplanting corrections presently done with rough graphical methods, the relationship should improve. The results for organic matter, cation exchange capacity, and carbon are yet to be returned from the laboratory.

It is worth noting that the relation of mean rice yields and burn quality follows the same pattern as the relation between mean nutrient changes and virgin burns discussed later in Section III. Although not significant statistically, the means show better yields for class 2 and 3 burns than for class 0 and 1 burns, and the mean yields are slightly better for class 2 than for class 3 burns. The data is culled to the same standards as for the yield/nutrient relations, and yields are expressed as proportion of predicted yield based on the adjustments for variety, planting density and interplanting described in the Appendix. The relations between mean rice yields and virgin burn quality are shown below in Table 1.

TABLE 1: RICE YIELDS FROM VIRGIN BURN QUALITY

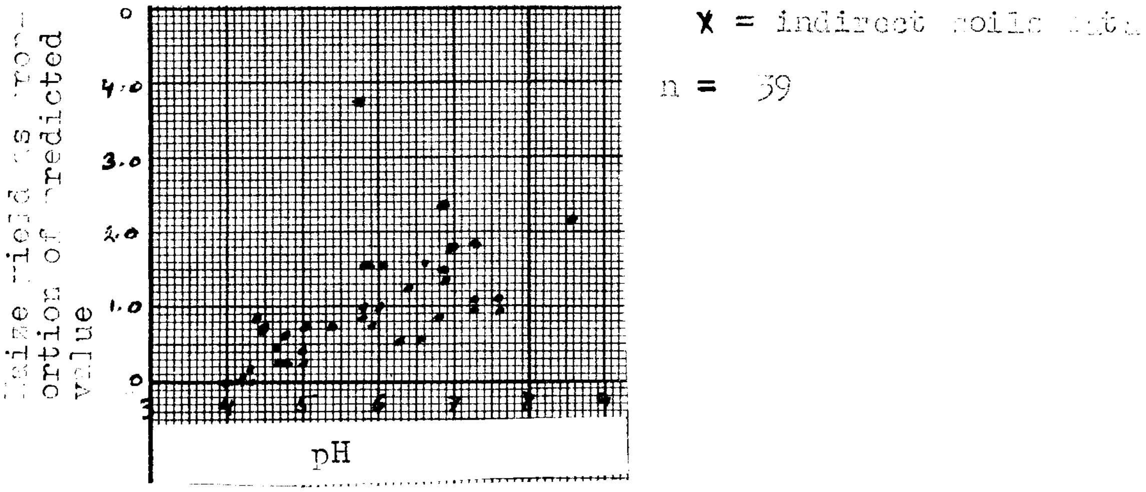
Burn quality	0	1	2	3
Mean rice yield (proportion of predicted yield)	0.35	0.99	1.05	1.03
Sample size	2	19	11	13

B.) MAIZE:

The maize yield data set was culled as described in the Appendix and corrections were made for planting density and density of interplanted crop, also as described in the Appendix. Planting density and density of interplanted crop vary widely with maize. The long list of non-soils-related variables on which information was collected bur for which no adjustments have been made in the present analyses is the same as that for rice.

Maize yields are generally much more cleanly linked to soil type than is rice. Poor soil can give stunted plants ca. only about a meter high at maturity that literally give ho yield at all. Maize shows a strong relationship with pH, as shown below in Figure 2. This comes as no suprise since pH is generally a good indicator of overall soil quality, being positively correlated with phosphorus and calcium and magnesium, and negatively correlated with toxic aluminum. As with rice, addition of other soils and non-soils variables should improve the predictive power of the relationship even more.

FIGURE 2: MAIZE YIELD VS pH



C.) PHASEOLUS BEANS:

Phaseolus vulgaris (feijão de arranca) has been far the most common bean species in the area, being planted about four times as often as *Vigna* (feijão da corda). This is largely because it is the species which has been distributed by INCRA, but also probably partly due to the fact that many colonists profess to prefer its taste, and it can give a much higher yield per hectare than *Vigna* provided it is not diseased. The disease restriction is a severe one, as *Phaseolus* in the area has proved to be very susceptible to the attack of the web blight fungus *Rhizoctonia microsclerotia* Matz (*Thanatephorus cucumeris* Frank), known in the area as "mela". Of 59 *Phaseolus* fields, 47 (80%) were attacked by *Rhizoctonia* and only 12 (20%) escaped attack. [illegible]-IPEAN publications cite factors influencing attack as length of the rainy season and spacement (Gonçalves, 1969), plus orientation of lines with respect to wind direction, *Phaseolus* variety and

Presence of spores in the soil from previous attacks on beans in the area (Albuquerque & Oliveira, 1973). Colonists claim planting date is important. The effects of previous bean plantings appears to be confirmed from data; of 50 *Phaseolus* fields where no beans had been previously planted on the site, 39 (78%) were attacked and 11 (22%) were not, while of 5 fields where beans had been planted all 5 were attacked.

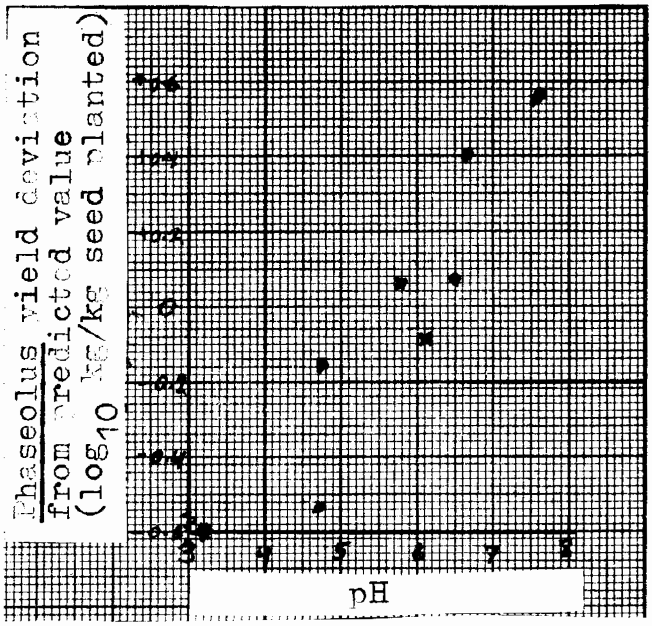
Rhizoctonia attack intensities were rated on a scale of zero to three for no disease, slight attack, moderate attack (or attacked without modifying description), and heavy attack. These very roughly correspond to 0%, 1-25%, 26-50%, and 51-100% of the plants being affected, but the data is mostly based on the colonist's testimony rather than direct observation. Bean yields decline steadily with increasing disease intensity, as shown below in Table 2.

TABLE 2: *PHASEOLUS* YIELDS FROM DISEASE INTENSITY

DISEASE INTENSITY	0	1	2	3
Phaseolus yield (kg/ha)	308	186	151	58
sample size	11	10	24	11

For the establishment of soils effects on *Phaseolus* yields, the culling procedure included the removal of all fields attacked by *Rhizoctonia* from the data set, as described in the Appendix. After a correction for planting density effects, predicted bean yields were calculated, also as described in the Appendix. Plots were made of bean yield as a [illegible] proportion of the predicted yield versus the various soil elements for which results have been returned. There appears to be a close relation with pH, which confirms the common saying among the colonists that "land that won't give maize won't give beans". The results are plotted below in Figure 3.

FIGURA 3: PHASEOLUS YIELDS VERSUS pH



x = INDIRECT SOILS DATA

n = 7

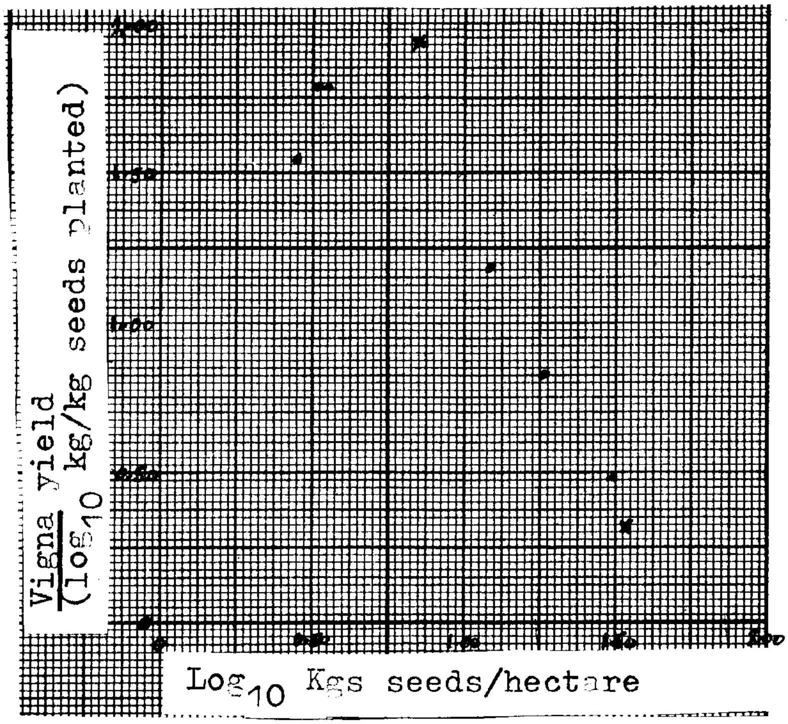
D.) VIGNA COW PEAS:

Vigna sinensis, the cow-pea or feijão da corda, has so far been less frequently planted than Phaseolus. Despite lower per hectare yields than Phaseolus when healthy, it has the distinct advantage of being more resistant to Rhizoctonia. Although Vigna plantations have been destroyed along with those of Phaseolus in other countries, as was the experience in Puerto Rico (Albuquerque & Oliveira, 1973, p.4), it has shown itself to be notedably more resistant in Pará (Gonçalves, 1969, p.3). This is confirmed from the data:

of 15 Vigna fields, only 2 (13%) were attacked, as contrasted with 80% attack in Phaseolus.

The data set was culled as described in the Appendix. An attempt was made to make a correction for the wide variation in planting density, which could be expected to mask any relationships between soils and yields. A plot of Vigna yield versus planting density appears to indicate a strong relationship, as shown below in Figure 4.

FIGURE 4: VIGNA YIELD VERSUS PLANTING DENSITY

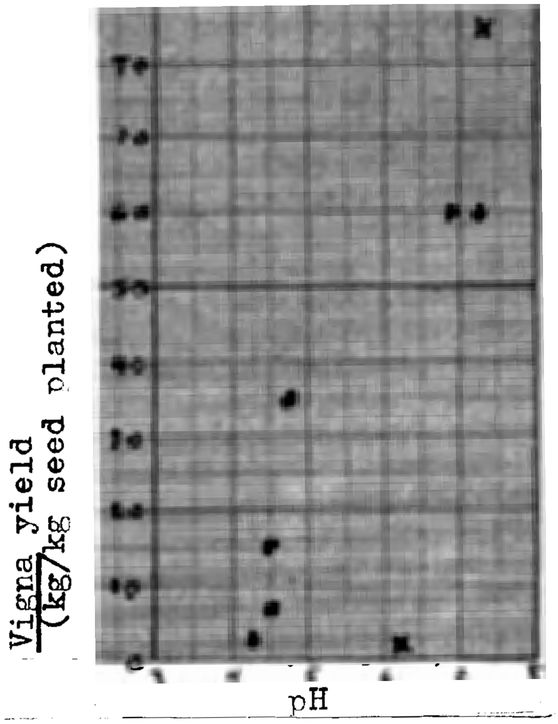


x = INDIRECT SOILS DATA

n = 8

Unfortunately, there is an inverse correlation in the data between planting density and pH, with the fields with the smallest planting densities by chance also having the highest pH values. This makes the separation of the two effects impossible with the present small data set. As with Phaseolus, pH appears to have the greatest predictive power for yield, as far as can be told with the small data set and with data uncorrected for planting density. The data is plotted below in Figure 5.

FIGURE 5: VIGNA YIELD VERSUS pH



X = indirect soils data

n = 8

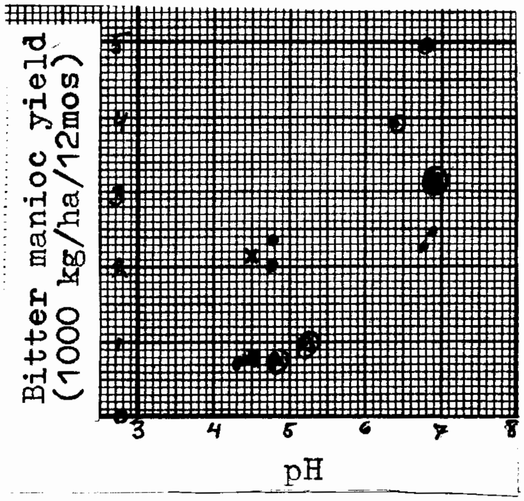
E.) BITTER MANIOC:

Bitter manioc (mandioca brava) is a traditional crop supplying the farinha (grated, leached, and heat-dried manioc) which is ubiquitous in the Amazonian diet. It has the advantage over most other crops of being relatively free from attack of insects, vertebrates, and disease, as well as avoiding labor and storage problems by being harvestable year round.

Manioc is known to be relatively tolerant of poor soil conditions, which is one reason for its widespread use, but it is not unresponsive to soils effects. Although manioc gives a better yield with good soil it still gives something with poor soil. This, when combined with the fact that much of the labor requirement involved is related to the production rather than the area, as in transporting the tubers and processing the farinha. Area-related work is relatively small since the felling is often done first for another crop such as rice, and the manioc shades the ground reducing the requirement for weeding during much of its vegetative cycle. The fact that one may get less yield per hectare or that one may have to wait longer for the tubers to reach an adequate size does not detract too much from the attractiveness of manioc as a crop. Studies in the literature indicate that manioc is usally grown in soil with pH ranging from 4 to 5 (Albuquerque, 1970, p. 37), but quotations for the "ideal" pH are typically on the order of 5.5-6.5 (Almeida & Canécchio Filho, 1972, p. 160).

The data was culled and adjusted for months to harvest as described in the Appendix. The data presented below in Figure 6 appear to show a relation with pH, although it should be noted that some of the extreme data points are from small fields. Due to the small data set, points from a variety of marginal categories have been included and marked with different symbols as explained in the legend for Figure 6.

FIGURE 6: BITTER MANIOC YIELD VERSUS pH



x = Indirect soils data

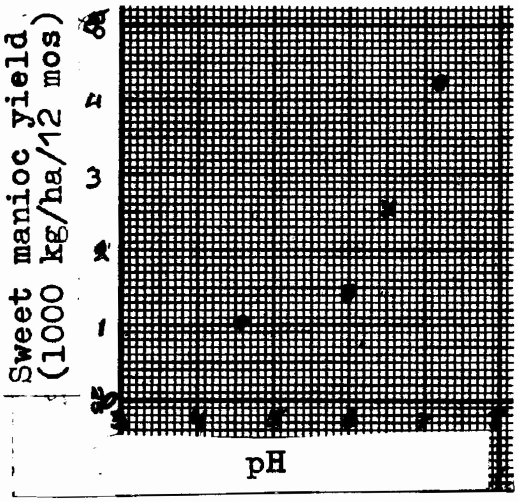
▲ = unknown or mixed varieties (probably or mostly bitter)

● = area less than 0.6 ha.

while 10 bitter manioc fields had a mean yield of 2807 kgs/ha/12 mos. growth.

The data was culled as described in the Appendix. Of the soils data returned so far, the relation for pH looks the best. The four data points plotted below in Figure 7 look encouraging for the prediction of yield from pH, although the sample size is obviously miniscule.

FIGURE 7: SWEET MANIOC VERSUS pH



× = indirect soils data

n = 4

III.) PREDICTING SOIL NUTRIENT INPUT FROM BURN QUALITY:

A.) VIRGIN BURNS:

In order to make the yield/soils relationships useful for estimating carrying capacity on must be able to estimate the probability distributions for the soil qualities [illegible] [illegible] on which the colonist will be planting. This entails predictions based on the initial soil quality modified by subsequent burns, crops, and fallow periods.

Burn quality appears to have a marked effect on soil nutrient inputs. Burns were divided into three types: burns of virgin forest, second growth burns, and pasture burns. Nutrient inputs from virgin

There are a variety of other soils effects that can influence manioc production. Soil with poor drainage has resulted in losses from root rot for several colonists. Clayey soil which hardens in the dry season has caused losses from the tubers breaking off in the ground during the harvest for one colonist. Other soils nutrients for which results have not yet been returned from the laboratory, such as organic matter, may prove to be good predictors of yield. Organic matter has been stated to have a positive effect on production in the literature (Almadeia & Canécchio Filho, 1972, p.160). Some colonists have planted manioc a second time in the same place, although the area is not yet old enough to have yield results from the second plantings; however, it is common knowledge among the old settlers I talked with in the area North of Altamira (and is the experience in other areas in Amazônia as well) that subsequent manioc crops are much reduced since manioc "takes a lot from the soil". The literature confirms this: in another terre firme location elsewhere in Pará manioc yields are reported as 20-25% lower in plantings from cleared second growth than from cleared virgin forest of very advanced second growth (Vieira et.al., 1967, p. 14). It is therefore expected that the addition of other soil nutrients, such as organic matter, to a multilinear regression model should result in good predictions of manioc yields from soils if enough data can be gathered.

F.) SWEET MANIOC:

Sweet manioc (macaxeira) is also common in the area. Sweet manioc produces smaller yields than bitter manioc; 9 fields of sweet manioc had a mean yield of 1566 kgs farinha/ha/ 12 mos. growth, and second growth burns are discussed below; data on pasture burns are too scarce to merit this as yet. Burn qualities were rated on a scale of 0 to 4 for increasing intensity, with an additional category of "none" for fields that were cleared with no burn attempted. Table 3 below described the burn quality class definitions for virgin burns:

TABLE 3: BURN QUALITY CLASSIFICATION FOR VIRGIN BURNS

Burn quality	definitions
none	no burn was attempted (an therefore no date for burning)
0	burn attempted (therefore with burn date) but did not burn. There may be some blackened bark and burned leaves, but the ground remains "raw". Usually colonist cannot plant. "não 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 [illegible] ruim"; "só pecou 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."

If the coivaras (piles of branches) are burned, this is included in the above classification which is an evaluation of the final condition of the field at the time of planting.

There is a large variance in burn quality, both within years and between years. The quality of the burn depends largely on the weather in the time before the burn is attempted. This varys from year to year with the amount of rain received during the dry season, and also varys between colonists who clear and burn on different dates. If the felled field is burned before it has had time to dry, the burn will be bad and attempts at re-firing generally fail. If it is left too long before burning, the leaves will fall off the downed trees and the burn will also be poor. Colonists also commonly observe that burn quality depends on the size of the clearing and on the slope. If a small clearing is made which is surrounded by forest, or if the clearing is in the bottom of a valley, the wind circulation will be poor and a poorer burn will be obtained. Slope and area information has been recorded, but not yet analyzed. Data has been collected on felling and burning dates, which will be used in conjunction with weather data to predict burn quality probability distributions. There is also some data for burn qualities in older fields going back as far as 1912, but without felling and burning dates. These will also be used with weather data. Table 4 below presents data on burn quality for 254 fields, and demonstrates the wide variation both between colonists and between years for burn quality.

TABLE 4: VIRGIN BURN QUALITY FREQUENCIES 1971-1974

YEAR		BURN QUALITY					Total
		0 or none	1	2	3	4	
1971	no.	3	10	9	9	0	31
	%	10%	32%	29%	29%	0%	100%
1972	no.	5	15	9	34	1	64
	%	8%	23%	14%	53%	2%	100%
1973	no.	37	39	9	29	0	114
	%	33%	34%	8%	25%	0%	100%
1974	no.	2	14	11	17	1	45
	%	4%	31%	25%	38%	2%	100%

Once the probability of achieving a given burn quality has been estimated, one must be able to estimate the probability distribution for the nutrient input that will result. The data in Table 5 below shows the mean nutrient input values (used field value - virgin pair value) for the 6 nutrients for which soils results have been returned so far.

TABLE 5: SOIL NUTRIENT CHANGES FROM BURN QUALITY FOR VIRGIN BURNS

ELEMENT		BURN QUALITY				
		0 or none	1	2	3	4
P (ppm)	change	+1	+1	+3	+2	+98
	n	(20)	(52)	(29)	(54)	(1)
K (ppm)	change	+10	+20	+26	+24	+424
	n	(20)	(52)	(29)	(54)	(1)
Ca^{++} & Mg^{++} (milliequiv/ 100 g)	change	+0.6	+0.6	+2.1	+0.6	+4.6
	n	(20)	(52)	(29)	(54)	(1)
Al^{+++} (milliequiv/ 100 g)	change	-0.3	-0.2	+0.2	-0.1	-1.1
	n	(20)	(52)	(29)	(54)	(1)
pH	change	+0.2	+0.7	+1.5	+0.6	+4.7
	n	(20)	(52)	(29)	(54)	(1)
N (%)	change	0	0	+0.01	-0.01	-0.01
	n	(14)	(21)	(28)	(54)	(1)

The table shows that, although overall better burns (classes 2 & 3) give bigger nutrient inputs than poorer burns (classes 0 & 1), this pattern is not followed when the burn qualities are considered separately. With the exception of aluminum (for which a negative change is desireable) class 2 burns produced larger average improvements than did class 3 burns. This is corroberated by a similar pattern being found for second growth burns (discussed in the next section) and by the same pattern being found in rice yields as was shown in Table 1 on page 7. This receives some support from the literature as well. Nye & Greenland (1960, p. 70-72) found a variety of claims in the literature regarding nitrogen changes following burning, most of which showed either a slight decrease or no significant change. They also found that the heating of the soil usually reduces the microbal populations at first followed by an increase to levels higher than those before burning; the rate of nitrogen mineralization paralleling these population changes is considered to be one of the more important changes in soil fertility from heating (Nye & Greenland, 1960, p. 72). One might expect this effect to be greater with hotter burns.

Although the table shows only means, there is considerable variance in the nutrient input for each burn quality. All fields were less than four years old and none had been burned a second time. Only virgin burns are included in the data in the table. It should be noted that no correction has been made for possible nutrient changes related to the time between burning and sampling or from different cropping and fallowing treatments. If nutrients decrease with time, the differences between 0 or 1 burns and 2 or 3 burns may be greater than indicated by Table 5. This can be seen from Table 4, where class 2 or 3 burns are about evenly distributed between older fields (71 and 72 burns) and younger fields (73 and 74 burns), while about 3/4 of the class none, 0, or 1 burns are concentrated in the younger fields.

B.) SECOND GROWTH BURNS:

Second growth burns were classified in a manner analagous to that already described for virgin burns. The data set of paired agricultural field and second growth samples is much smaller than that for virgin burns, having 22 pairs of samples, for which soils results have been returned for only 12 pairs.

Although the sample sizes are very small, the results for different burn qualities appear to follow the same pattern as was found for virgin burns, with class 2 and 3 burns showing bigger improvements in soil nutrients than class 1, and class 2 burns showing bigger improvements in the soil than either class 1 or class 3. Aluminum, which was the only element not to follow this pattern for the virgin burns, falls into the pattern shown by the other elements in the case of second growth burns. The mean soil nutrient changes (agricultural field value - second growth pair value) are shown below in Table 6.

TABLE 6: SOIL NUTRIENT CHANGES FROM BURN QUALITY FOR SECOND GROWTH BURNS

ELEMENT	BURN QUALITY 1	2	3
P (ppm)	-4	+4	+2
K (ppm)	+9	+52	+50
Ca^{++} & Mg^{++} (milliequiv/ 100 g)	+0.3	+1.0	+1,0
Al^{+++} (Milliequiv/ 100g)	0	-0.3	-0.2
pH	+0.3	+1.1	+0.7
N (%)	-0.02	+0.05	-0.02
SAMPLE SIZES	(7)	(1)	(4)

All of the second growth stands represented in Table 6 were less than two years old at the time of burning, and all of the agricultural field samples were taken less than 6 months after burning. Because the results from burning of older second growth stands have not yet been returned from the laboratory, no relation between second growth age and nutrient input can be established here. However, it is interesting to note that a comparison of tables 5 and 6 shows that mean nutrient inputs from burning these young second growth stands are of comparable magnitude to inputs from virgin burns.

Although the heights of second growth stands were soil samples were taken were measured, and in some cases of older second growth there is diameter information as well, it is hoped that the estimation of nutrient input to be expected from burning second growth of different ages can be estimated directly from the soils results of the agricultural field / second growth pairs in order to bypass the need to include biomass considerations directly in the modeling. The feasibility of this will have to await the release of the results for the older second growth stands from the laboratory, as well as increasing the sample size.

IV.) PREDICTING SOIL NUTRIENT CHANGES FROM CROPPING AND FALLOWING:

After calculating the soil conditions after burning, the value for any given nutrient in the soil at the time of planting should be calculable in a simulation by drqwing appropriate modifying terms from probability distributions for the effects of different crops and lengths of fallow. These distributions must be derived from datq on each treatment.

The data sets relevant to deriving the probability distributions for cropping and fallowing treatments are of four types: 1) comparison of agricultual field nutrents with paired virgin samples, 2) comparison of agricultual fields which were made from cleared second growth with samples from paired locations in second growth of the same age and use history, 3) comparison of paired samples where the second sample is a return sample taken in the same location as a previous sample, and 4) information on erosion under different treatments which can be used to predict soil nutrient changes which would follow the removal of superficial layers.

A.) COMPARISON OF AGRICULTURAL AND FALLOW FIELDS WITH PAIRED VIRGIN SAMPLES:

This is the largest data set related to predicting nutrient changes, and has 170 pairs of fields in which there has been only one intervening burn between the virgin condition and the "used" field. The land use history of each site has been recorded. The data will have to be stratified for burn quality (or lumped combinations of burn qualities where appropriate) and a proper multilinear regression analysis done on each soil nutrient as a function of number of months under each treatment. The data set will have to be culled first to include only those treatments for which there is a reasonalble sample size available. Changes in soil nutrients under fallowing will be treated in the same way as the other cropping treatments.

Even with stratification of the data for burn quality, the relations from treatments of cropping and fallowing may well be obscured in this data set by the tremendous variation in nutrient inputs from the burn. Plots were made of all of the nutrients for which soils results have been returned versus the months since last burn. Burn qualities were kept separate on all the plots. In the case of pH a separation was also made between those fields that had been planted every year with annual crops and those that had only been planted one year and then left fallow; this did not reveal any useable relationship. Of the plots of nutrient change (used field value - virgin pair value), the plots of aluminum and phosphorus show themost convincing trends; aluminum increasing (which is a deterioration of soil quality) and phosphorus decreasing with time since last burn. There is plenty of scatter in the points, however. For the two soil characters in the yield prediction section, pH and nitrogen, the amount of scatter makes statements as to trends hazardous. The 42-month time span available in the colonization area is probably not enough to reveal long term trends, but the results from the series of samples from the older settled area North of Altamira with fielxs as old as 1904 should help in this regard once the results are returned.

The literature on changes in pH demonstrates the wide variety of possible behaviors. Most, but not all of the studies show the increase in pH with burning found here, some then find a decrease over the next four years but some do not. Decreases are more likely to show up after the first four years. Of the pre-1960 studies reviewed by Nye & Greenland (1960, pp. 100-103), two show increases in pH in the first four years following burning, and two show no change; of the studies which permit separate conclusions about results after the fourth year, three showed decreases in pH and one showed an increase. Harris (1970, p. 490) in a study of 27 samples from the Upper Orinoco of Venezuela finds mean pH values for four study areas all increase with clearing, but two of the areas then show continued increase in the first three years after burning and then start to decrease, while one decreases steadily both in the first three years and thereafter. Cunningham (1963, p. 341) in a study of 8 plots in Ghana finds decreases in pH over 3 years. Krebs (1975, p. 386) in a study of 10 fields with 4 samples from each in Costa Rica does not find the normal pH increase with clearing; pH decreases after clearing, then increases to the fourth year, and then declines over a 22-year time span in sugar cane, but not with coffee or pasture. Samples taken during my own study in Costa Rica (Fearnside, 1972) show indications of a decline in pH over a 4-year range, but the regression is non-significant (p=0.13) and the sample size is miniscule (n=7 used field/virgin pairs).

The literature with regard to nitrogen changes generally shows decreases in nitrogen with clearing and over the first 4 years thereafter. Nye & Greenland's (1960, pp. 100-103) review shows a consistant pattern of decreases. Nye & Greenland (1964, data presented in Williams & Joseph, 1970, p. 142) found a decrease with burn followed by a continued decrease over two years in a study done in Ghana. Cunningham (1963, p. 339) found a decrease over a 3-year time span. Krebs (1975, p. 384) found a decrease with clearing and over the first four years, but no continued decrease over the 22-year span of field ages.

B;) COMPARISON OF AGRICULTURAL FIELDS WITH PAIRED SECOND GROWTH SAMPLES:

Some of the data from pairs of agricultural fields and second growth samples where the second growth has the same age and history as the agricultural field may be useable in estimating the effects of subsequent cropping and fallowing. The analysis would be analagous to that for agricultural fields paired with virgin samples. As shown earlier in Table 6, burn quality effects follow the same pattern for second growth burns as they do for virgin burns. One would also expect the nutrients removed through cropping and fallowing following these burns to follow the same pattern.

C;) COMPARISON OF RETURN SAMPLES WITH PREVIOUS SAMPLES FROM THE SAME LOCATION:

The locations of all soil samples taken have been noted to facilitate returning to the same locations for second soil samples. So far there are only 8 pairs of return samples with previous samples, and only 3 of these have had the soils results returned to date. The sample size for this data set will increase considerably as return samples are taken in all of the 47 locations of the erosion plots, plus in as many other previously sampled fields as time permits.

It is hoped that this data set will prove the most reliable for predicting soil nutrient changes under cropping and fallowing treatments, since the tremendous variance from intervening burns will not be present as in the case of comparisons of agricultural field and paired virgin or second growth samples. Also, the taking of samples from the same location will decrease any variance added by small differences in soil type between agricultural fields and adjacent paired virgin or second growth [illegible] locations.

D.) SOIL NUTRIENT CHANGES DUE TO EROSION:

As erosion procedes to remove the upper layers of soil, the nutreint content of the layers which are subsequently exposed can be expected to differ from that of the original upper layers. Although it has been suggested that erosion can often serve to improve the quality of the surface layer by removing weathered material (Sanchez & Buol, 1975, p. 600), this result would not be expected here. Soil profiles from the area with analyses done at various depths up to 120 cms, such as those described in Falesi's (1972) survey of soils on the Transamazon Highway, invariably show poorer soil quality as one descends to the lower layers. The uncovering of these lower layers should result in a decline in soil quality.

Erosion is being measured through a series of 705 stakes set out in 47 plots of 15 stakes each over a range of different slopes and land uses. The stakes are lengths of plastic pipe which are hammered into the ground to a depth of 40cms. In each plot the stakes are arranged in 3 rows of 5 stakes each with approximately 2 meters between stakes and 10 meters between rows. The rows run perpendicular to the fall line. Stakes on the ends of each row are one meter long, and while stakes in the middle are 50 cms long as an economy measure since the stakes are not cheap. Each stake has a notch cut horizontally and set exactly even with the surface of the ground when the stakes were implanted. There is also a vertical cut to mark the center of each notch to facilitate measurement. The notch is oriented to face theside (facing along the contour of the slope). Slopes were measured with a clinometer at each plot over the at least 20-meter range of the plot. Microrelief was also measured at each stake by placing the clinometer on a 20-cm -long block of wood oriented along the steepest slope at that scale at each stake. Soil samples were also taken at each plot, with the cores making up the composite sample coming from the base of each stake. Measurements of erosion will be made by measuring the distance from the center of the notch to the ground for each stake. Variations of the notched-stake method have been used by a variety of other workers.

None of the stakes have yet been measured for erosion, but casual observation of some of them indicates that erosion of over a centimeter is commonplace. This is sure to play a key role in the longterm future of the system.

An effort was made to keep all the plots on clayey soils, with the exception of one series of 5 plots under rice which was put on sandy soil for the estimation of soil type effects by comparison with a parallel series for rice on clay. The overall slopes of the plots under different treatments are shown below in Table 7.

TABLE 7: SLOPES AND LAND USE OF EROSION PLOTS

	LAND USES									
SLOPES	virgin	second growth	Beans	Rice (sand)	Rice (clay)	Maize	Pasture	Manioc	Cacao	Black pepper
	1%	4%	5%	0%	0%	1%	2%	2%	2%	1%
	8%	13%	14%	10%	8%	9%	10%	7%	17%	9%
	19%	21%	29%	16%	22%	20%	22%	13%	35%	29%
	39%	40%	35%	35%	38%	47%	37%	25%		
	55%	62%	51%	34%	65%	70%	58%	40%		
					89%					

V.) INITIAL SOILS SURVEY INFORMATION:

In order to predict crop yields from soils in modeling carrying capacity, one must begin with starting values for the various soil nutrients, and then modify these as the run procedes according to the different burning, cropping, and fallowing treatments applied. Soil quality varies enormously; pH values in virgin forest, for example, range from 3.8 to 7.1. The initial soil types represented in a colonist's lot must be drawn from probability distributions which reproduce both the relative overall extent of each soil type and the scale of patchiness of soils in the area. Once the quality of the first hectare in a lot is known, a probability distribution reflecting the patchiness of the area should describe the chance that the next hectare will be of the same or of a different type. These distributions must be derived from information from a large number of samples, since the patches of soil are quite small in the area and often result in more than one soil type in any given lot.

The data set so far consists of the samples I have taken from 388 different locations in 87 lots. Within the 215-lot "intensive study area", 81 lots, or 38% have been sampled. The virgin samples from these lots will be the main source of information on initial soil qualities.

In addition to the samples I have taken myself, there is also a set of 353 samples from 246 lots taken by the colonists themselves under the supervision of the extension workers of the Association for Credit and Rural Assistance (ACAR-PARÁ) in conjunction with applications for financing of permanant crops. Of these, 41 are from lots in the intensive study area for which I do not yet have my own samples, which brings the total of lots for which some soils information is available to 57% in the intensive study area.

There is also a little information available from the literature, including the profiles in Falesi (1972) and a little data presented in the report of the radar-based [illegible] natural resources survey which includes a large-scale soils map (Projeto RADAM, 1974). There are also several soils surveys which have been done in the area of the Transamazônica for which the results are not yet available, including one by F.A.O. in Belém and two by graduate students: one by Emilio Moran of the Anthropology Department of the University of Florida and one by Nigel Smith of the Geography Department at the University of California at Berkeley.

All of these surveys have samples taken by different methodologies. My own follows the methodology used by F.A.O. in Belém for fertility samples. Each sample is a composite of 15 cores taken from different locations in the field and covers only the top 20 cms of soil. This is the layer most relevant to crop production. Information from lower depths would be useful in the formal identification of soils types, which in some cases requires comparison of the different horizons. It would also be useful in conjunction with the erosion data. The decision to concentrate on surface fertility samples was a wise one however, as otherwise the large sample size attained would not have been possible; moreover the data would have been less useful in investigating both the soils/yield relations and the inputs from different burn qualities. Some deeper samples may yet be taken in the locations of the erosion plots, but much of the information that would have come from a [illegible] study concentrating on full soil profiles will have to be deduced from the published surveys.

In addition to the elements which have been discussed in the foregoing sections (P, K, Ca^{++} & Mg^{++}, Al^{+++}, pH, and N), several other analyses have been done on my samples. These include a granulometric analysis which gives percentages of coarse sand, fine sand, silt, and total clay. This should be particularly useful in interpreting the erosion data . There is also a group of three analyses called the "lateritic complex", which consists of percentages of SiO_2, Al_2O_3, and Fe_2O_3. Results which have not yet been returned from the laboratory include analyses for carbon, organic matter , exchangeable bases (Ca^{++}, Mg^{++}, Na^{+}, & K^{+}), and cation exchange capacity. All analyses are being done at the laboratory of the Empresa Brasileira de Pesquisas Agropecuárias--Instituto de Pesquisas Agropecuárias do Norte (EMBRAPA-IPEAN) in Belém. Methods used are described in detail in Guimares, et.al, (1970).

Information from the chemical analyses, plus the information on land use and burning history mentioned earlier, is supplemented by several other observations made for each sample. These include (1) measuring the slope with a clinometer, which will be essential for modeling erosion, (2) observeable erosion such as gulleying, (3) drainage, (4) soil depth if there is a solid layer of rock or lateritic concretions near the surface (as sometimes occurs), (5) the superficial appearance of the soil (a rough soil type based on color and sand versus clay content), (6) observations on rock outcrops and the number and depth of rocks encountered in taking the 15 soil cores, and (8) in some fields notes have also been made on the relative hardness of the soil. The increasing compaction of the soil in older fields and in pasture is readily observable and may prove very troublesome to colonists in the future. With only a few exceptions a photograph has also been taken of the site of each soil sample.

VI.) CONCLUSIONS:

Although not all results are equally clear-cut, the results so far are encouraging in showing that annual crop yields on which the colonists depend heavily can be largely predicted from information on soils, insects, and disease when corrections are made for variety, planting density, and density of interplanted crop. When a full analysis is possible incorporating the variables which were measured but not included in the present analysis, as well as minimizing distortions from the rough non-rigorous techniques used here, better relationships should emerge. More data, particularly data from the older fields and from return samples taken in previously sampled locations should contribute greatly to the establishment of relationships between the various cropping and fallowing treatments and soils changes. The measurements on the erosion plots are yet to be made, and these also should fill in a vital set of relationships in the modeling of future soil quality changes. Establishment of relationships in the chain of events from initial soil condition under virgin forest, to the condition after receiving inputs from burning, and finally to the condition after modification by subsequent cropping, fallowing, and second-growth burn treatments should permit computer simulation of these events over an extended period. This forms a key part of the overall modeling strategy for estimating carrying capacity for human populations in the Transamazon Highway colonization area.

VIII.) APPENDIX DESCRIPTION OF ADJUSTMENT AND SELECTION PROCEDURES FOR DATA USED IN PREDICTING CROP YIELDS FROM SOILS

A.) RICE:

1.) CULLING THE DATA SET:

The rice yield data set was first culled to remove all fields planted with the Barbaria variety rice distributed by INCRA in 1973. This variety had been brought from Bernambuco with no previous testing in the area, and proved to be succeptible to the fungal disease *Helminthosporium oryzae*, Van Breda de Haan. Removing these fields left 105 fields in the data set with information on rice yields, 85 of which had "direct soils data", meaning that the sample was taken in the exact location of the field and the field had not been burned between the rice crop and the sampling date. Twenty fields had "indirect soils data", meaning either that the sample came from a similar adjacent field in the same lot, or that the field had been burned between cropping and sampling. Fields with "indirect soils data" are marked with an "x" symbol in Figure 1. The 105 fields were then culled to 44 based on the criteria described below. Of the 44 fields, 38 have had the nitrogen results returned from the laboratory and are plotted in Figure 1; the remaining 6 fields have not had nitrogen results returned yet.

The fields were culled to remove all fields with areas less than or equal to one hectare. The smaller fields show much more erratic per hectare yields. There may actually be greater variance in yields of smaller fields, certainly dramatic differences in rice growth can be observed on a micro-scale of a few meters due to patchy burns. However, much of the greater variance in small field yields is clearly due to greater error in estimating the production and the field area, since the farmer is likely to round off the area to the nearest tarefa and the production to the nearest saco.

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The data set was further culled to remove all fields with questionable yields, where the colonist contradicted himself in describing either the area or the production or the information needed to make the adjustments for planting density, variety, and density of interplanted crop.

Also removed were all fields where yields from interplanted and not interplanted sections, or from sections planted with different varieties, could not be separated.

All fields planted with/for which insufficient information was available for making the variety adjustment were also removed. This necessitated removing all fields planted with varieties other than IAC-1246, Canela de ferro, and IAC-101 due to the lack of information from experiment station variety trials.

Fields interplanted with anything other than maize were also removed. This included fields with manioc, manioc and maize, pasture, fruit trees, and even bananas. Of these the manioc and maize removal represents the most important restriction. There is not enough data to be able to make the necessary adjustments to include this combination, and it would be a fairly complicated relationship to unravel since variation in the planting dates of the different plants, whether the manioc is trimmed back, etc. are also important. This combination is extremely common in the older settled area North of Altamira, and I think my data will show that its use is increasing among the colonists of the Transamazônica. As of now it is still too rare to produce adequate amounts of data to make the correction.

2.) ADJUSTING PREDICTED RICE YIELDS FOR SEED VARIETY AND PLANTING DENSITY:

Adjustments for seed variety were made by interpolating from graphs I made by plotting data from the EMBRAPA-IPEAN experiment station at Km. 350 (presented in Villegas & Kass, 1974. p. 7). The relationships thus derived were as follows:

for IAC-1246: $y = 27.9x$ for $x \leq 111$

EQN. 1 $y = 8.72x + 2166$ for $111 < x \leq 222$

for canela de ferro:

EQN. 2 $y = 20.5x$ for $x \leq 111$

$y = 2278$ for $111 \leq x \leq 222$

where y = the yield in kgs/ha

x = planting density in 1000 hills/ha

It should be noted that these relations are derived from very few data points. At least other variables such as number of seeds per hill (all 5 seeds/hill), planting and harvest dates, weather, weedings, chemical treatments, and soil (all latosol amarelo) are all controlled, which increases the credibility of the small number of points considerably.

The IAC-1246 data comes from an experiment which was specifically designed to test for planting density effects, but has only three points including the origin. Three other experimental plantings of IAC-1246 at the same density as one of the density plantings gave yield values in the same range. For the canela de ferro relation there was no experiment run at km. 350 to test for planting density effects, so a control plot from another experiment was used, giving two points including the origin. However, a planting density experiment was run on canela de ferro at the Taracuateua experiment station in the Zona Bragantina (Lopes et.al., 1973). This gives yields much lower than those obtained for canela de ferro at km. 350, but the form of a plot of five points (including the origin) made from the data presented in Lopes et.al. (1973) shows very little crowding effect up to 1.11×10^5 hills/ha, followed by a very slight net decline in yield over the range from 1.11×10^5 to 2.22×10^5 hills/ha.

This steady rise and then plateau form is what was used in the canela de ferro adjustment equations given above, scaled for the yields at km. 350 to make them comparable to the IAC-1246 data.

For the variety IAC-101 which was distributed in the area by INCRA in 1972 and is still a fairly common variety there has never been any experiment station testing done in the area. The yields attained by colonists, however, seem to be comparable to those attained from IAC-1246 (which is not the case with the traditional variety canela de ferro). The equations derived for IAC-1246 were therefore used for IAC-101 as well.

For the measurement of rice planting density the data was obtained in two ways. In the cases where the rice was standing in the field, or where the stumps of the harvested rice were still present, I measured the spacements directly for a number of hills, and then later made the appropriate calculations to obtain the number of hills/ha. When this was impossible, as when the rice crop had been planted in another year, the planting density had to be estimated from the kgs of seeds planted per hectare. A plot was made of planting density on kgs seeds/ha for 42 points where the planting density had been measured in the field. An eye-fit "regression" was then used to derive planting densities for fields where only the kgs seeds/ha was known. The relation used was:

EQN. 3 $y = 3.9\,x$

where y = the planting density in 1000 hills /ha

x = kgs rice seeds planted per hectare.

3.) ADJUSTING PREDICTED RICE YIELDS FOR DENSITY OF INTERPLANTED CROP:

Since there have been no experiment station trials results available which could be used for making an adjustment for the effects of different densities of interplanted crop, another eye-fit "regression" had to be used. There has been one experiment station trial done comparing one density of interplanting with no interplanting. The report (Viégas & Kass, 1974) unfortunately does not mention the planting density used and all of the technical people involved in the experiment have been transferred away to other locations. I hope to be able to get this out of the archives of the field station later.

The "regression" used was fit from a plot of rice yields (expressed as proportions of predicted yield from variety and rice planting density) versus the density of interplanted crop. There were 75 points, which had been culled only to remove fields interplanted with other than maize. A decrease in yield with increased interplanting is evident, although there is plenty of scatter in the points as one would expect given the number of uncontrolled variables. The relationship estimated from this graph which was used to make the interplanting adjustiments was:

<u>EQN</u>: <u>4</u>

$$y = -0.03094\,x + 0.495$$

where y = the multiplier to adjust predicted rice yields for interplanting (the rice yield as a proportion of the predicted yield from variety and rice planting density)

x = density of interplanted crop (maize) in 1000 plants per hectare.

B.) MAIZE:

1.) CULLING THE DATA SET:

Yield data is available for 89 maize fields, 82 of which have had the basic fertility soils results returned so far. Of the 82, 25 have only indirect soils data and 57 have direct soils data. These were culled as described below to 8 and 39 fields respectively. The 39 fields with direct soils data are plotted in Figure 2.

For the final plot of maize yield versus soils the following were excluded: 1) all fields with areas less than one hectare, 2) all fields with questionable yields or conflicting answers regarding information needed to make the adjustments for planting density and interplanting, 3) all fields with incomplete information for making the density and interplanting adjustments, 4) fields which the colonist said were totally destroyed by rats (2 of 44 fields), and 5) fields in which the seeds did not germinate (2 of 44 fields).

2.) ADJUSTING PREDICTED MAIZE YIELDS FOR PLANTING DENSITY:

There have been no experiment station tests run on the Transamazônica to determine the effects of different planting densities on maize yields, so another eye-fit "regression" was employed. A plot was made of 22 points for non-interplanted maize of maize yield per 1000 plants versus maize planting density. The data show the expected dedline in yield/1000 plants as density increases, but given the number of uncontrolled factors, it comes as no suprise that there is plenty of scatter in the points. The rough "regression" fit from the plot and usee to make the planting density adjustments was:

EQN. 5 $$y = 215 - 10.5\,x$$

where y = the maize yield in kgs/1000 plants (the "predicted yield from maize density"(PYMD))

x = maize planting density in 1000 plants per hectare.

There did not appear to be sufficient difference between varieties to justify making a correction. This is supported by the fact that variety trials done on Terra Roxa Estruturada and Podzólico Vermelho Amarelo at the EMBRAPA-IPEAN experiment station at km. 23 showed no significant differences between any of the varieties tested (Viegas and Kass, 1974, p. 25).

As with rice, planting density could be measured directly only for maize crops that were still in the field at the time of sampling.

Planting densities for crops in previous years were estimated from an eye-fit "regression" of maize planting density on kgs seeds per hectare. A plot of 29 points of fields with areas greater than or equal to 0.5 hectare yielded the following:

EQN. 6 $y = 537.5\ x$

where y = the maize density in plants per hectare

x = kgs maize seeds planted per hectare

3.) ADJUSTING PREDICTED MAIZE YIELDS FOR DENSITY OF INTERPLANTED CROP:

Adjustment of predicted maize yields for density of interplanted crop was made using another eye-fit "regression". A plot was made of 39 points of the proportional deviation of the maize yield from the yield predicted on the basis of maize planting density alone ((actual-predicted)/predicted , where predicted is from Equation 5) versus the interplanted crop density. Again, a decline in yield as interplanted crop density increased was evident, although there was a good deal of scatter in the points. The relationship estimated from the plot and used for the adjustments was:

EQN. 7 $y = -0.00685\ x$

where y = the proportional deviation in kgs/1000 maize plants from the value predicted from the maize planting density relation ((actual - predicted)/predicted).

x = interplanted crop density in 1000 plants/ha.

Modifying this to give a predicted maize yield in kgs/ha one obtains:

EQN. 8 $P = (-0.00685\ ICD + 1)(PYMD)(MD)$

where P = predicted yield in kg/ha from maize density and density of interplanted crop

ICD = interplanted crop density in 1000 plants/ha.

PYMD = predicted yield in kgs/1000 plants from maize density (from Equation 5)

MD = maize planting density in 1000 plants/ha

C.) PHASEOLUS BEANS:

1.) CULLING THE DATA SET:

There is yield data available for 69 fields, 58 of which have had basic fertility soils results returned. The 69 fields include 37 with direct soils data and 32 with indirect soils data. The data set was first culled to remove all fields with any Rhizoctonium or which had no information regarding Rhizoctonium attack. This reduced the sample size to 12 fields. Fields with incomplete information for making the adjustments for planting density (kgs seeds/ha) were removed, along with fields with areas less than 0.5 ha. This reduced the data set to 7 fields, 2 of which had only indirect soils data. Fields with indirect soils data are marked with an "x" symbol in Figure 3.

2.) ADJUSTMENT FOR PLANTING DENSITY:

Plots were made of yield on planting density expressed as kgs seeds planted per hectare. No attempt was made to adjust for effects of different varieties of Phaseolus due to the small sample size, nor was any correction made for the different seed weights of the various varieties. A log-log plot of yield/kg seeds planted versus kgs seeds planted / hectare appeared to give the best fit, although the small number of data points makes it likely that the eye-fit"regression" obtained will be modified slightly when more data points are added. Nonetheless, there is a clear negative relation between planting density and yield/kg. seeds. The fit for Vigna beans with the same log-log transformation appears very good, adding indirect support for using the same transformation on the Phaseolus data. The eye-fit regression obtained for Phaseolus was:

EQN. 9 $y = 1.62 - 0.6807\, x$

where y = Phaseolus yield as $\log_{10}$ kg/kg seeds planted

x = $\log_{10}$ kgs seeds planted per hectare

This equation was then used to calculate predicted Phaseolus yields for each data point given the planting density that had been used.

D.) VIGNA COW PEAS:

1.) CULLING THE DATA SET:

Culling was done using the same criteria as with Phaseolus: fields with disease attack, fields with incomplete information, and fields with areas less than 0.5 ha were removed. This reduced the initial sample size of 16 fields to 8, including 2 with indirect soils data. The fields with indirect soils data are marked with an "x" symbol in Figures 4 and 5.

2.) ADJUSTING FOR PLANTING DENSITY:

Plots were made of yield in kgs/kg seed planted versus planting density expressed as kgs seeds planted per hectare. No attempt was made to adjust for differences between different varieties of Vigna. A log-log transformation was found to give an excellent fit, as shown earlier in Figure 4. As explained in the text, an unfortunate correlation between planting density and pH made it impossible to separate the two effects using predicted yields derived from the planting density relation.

E.) BITTER MANIOC:

The data set for bitter manioc yields includes 10 fields, plus an additional 3 fields of unknown manioc variety (which are probably bitter) and 3 fields with a mixture of sweet and bitter manioc which are at least half bitter. Three of the bitter manioc fields and one of the unknown variety fields had indirect soils data, and are marked with an "x" symbol in Figure 6. The fields with unknown or mixed varieties are distinguished in Figure 6 with triangle symbols. Basic fertility soils results have been returned for all of the fields.

It was evident that the wide variation in months to havest had a great effect in the resulting yield in kgs of farinha per hectare. Yields were therefore standardized as yields in kgs farinha/ha/12 months growth. A plot of yield standardized for growth period versus months of growth did not reveal a decline in output that would warrant making a correction for the range of 12-30 months, with 17 points in that range. It is common knowledge among the colonists that if manioc is left too long it gives less, so more points may make a refinement for months of growth possible. In addition to giving less yield, the older manioc tubers are more woody and give poor quality farinha. For fields with less than twelve months growth it was clear that the yield per twelve months growth figure was affected, and these points were culled from the data set.

No correction was made for planting density. A plot of nine points of yield/hectare/12 months versus planting density in plants per hectare indicates that there may be a slight decline in yield over the range of densities used, but not enough to justify making a correction. If a correction were made, the data set would have to be further culled to remove fields with incomplete information on planting density, which would further reduce the sample size since the technique used with other crops to estimate planting densities from seeds planted per hectare for crops of previous years is not possible with manioc, which is planted from cuttings.

The smaller fields have not been culled from the data set but are distinguished in Figure 6 by circles.

No distinction was made between the different varieties of bitter manioc. No distinction was made between "farinha branca" (white farinha "seca" preferred by Northeasterners which has a lower market price) and "farinha puba" (yellow farinha "dagua" preferred by Paraenses which has a higher market price and is made by a different process involving removing the husks by allowing the tubers to "rot" while soaking in water). Only farinha was considered, ignoring other useable manioc products such as leaves (rarely used in the area), stems, starch (fécula), and juice (tucupí).

f.) SWEET MANIOC:

The sweet manioc data set contains nine fields, eight of which have had basic fertility soils results returned. These include two fields with indirect soils data. All of the fields have growth periods in excess of 12 months, so no culling needed to be done on this score. Fields with areas less than 0.8 hectares were removed from the data set, reducing the number of useable fields to four. The inaccuracies from small fields can be expected to be greater for sweet manioc than for bitter manioc, since the colonist often pulls out a few plants throughout the year either to eat boiled or fryed, or to feed to pigs. This drain would have a greater proportionate effect on small plantings than on larger ones, which makes the higher area standards necessary for sweet manioc. Only data on manioc converted to farinha was used in the analysis. No corrections were made for planting density. Yields were standardized for growth period and expressed as kgs farinha/Ha/ 12 months growth; no further correction for months of growth was made to allow for decreasing growth rate with time.

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REGRESSION: RICE YIELD AS PROPORTION OF PREDICTED VERSUS SOIL                 08/03/76          PAGE   12

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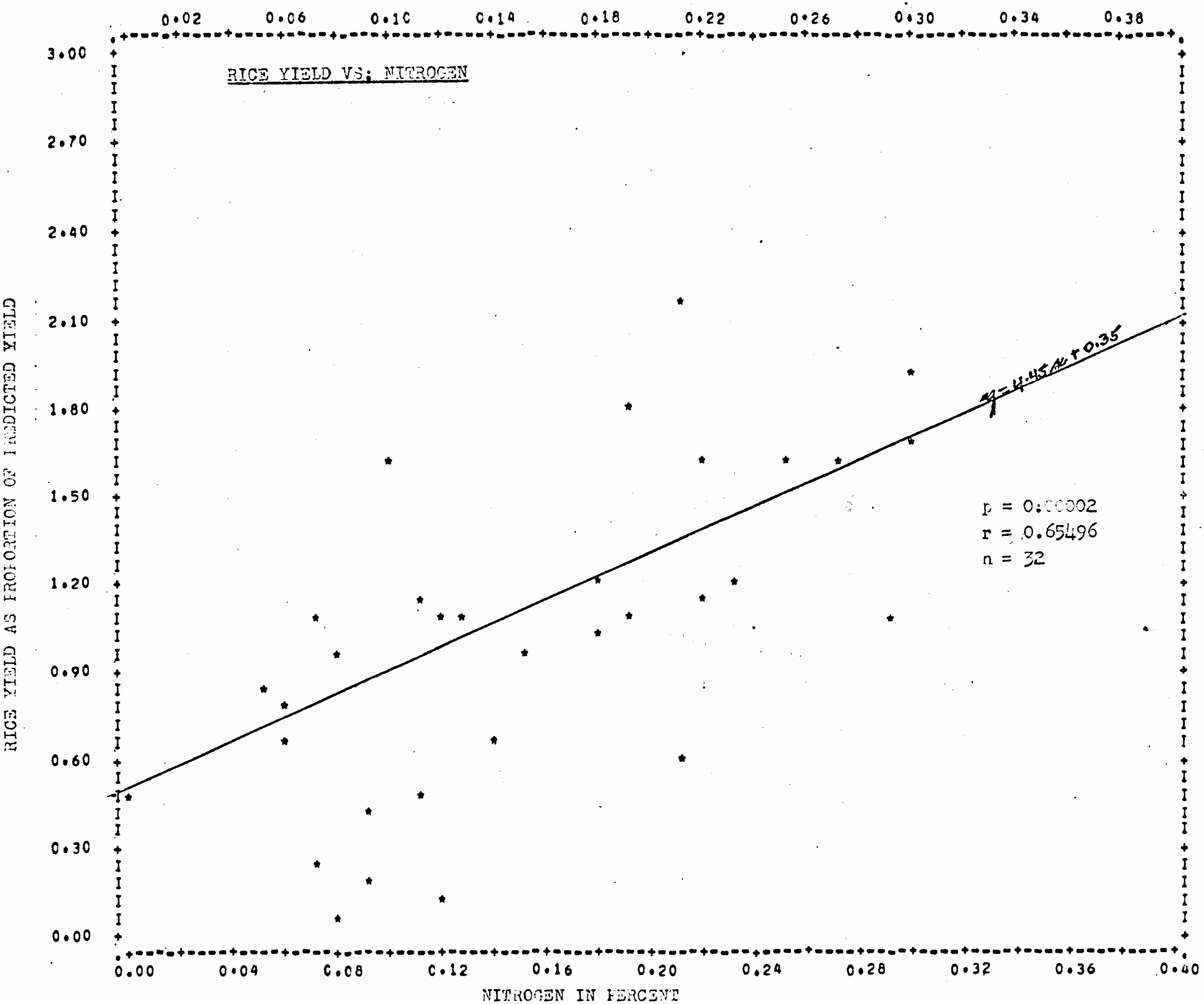

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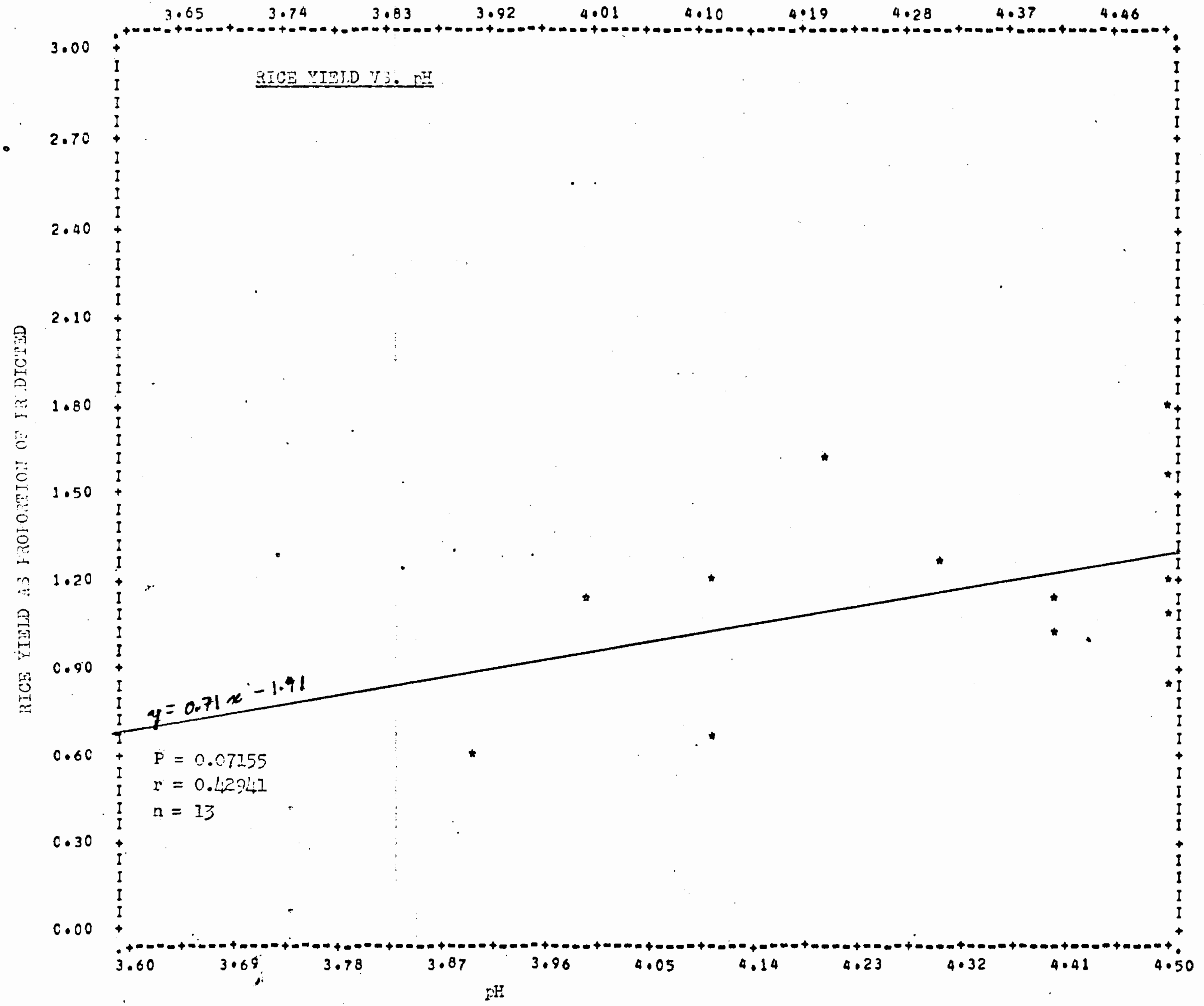

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REGRESSION: RICE YIELD AS PROPORTION OF PREDICTED VERSUS SOIL                    08/03/76          PAGE    6

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