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Agricultural Alternatives for the Amazon Basin

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In the Amazon Basin, US and Peruvian researchers have developed ecologically sound and economically valid technologies to produce annual crops continuously on acid and infertile soils normally under shifting cultivation. If farmers use these technologies, they could increase food production and help reduce deforestation.

In a study of the humid tropical ecosystems and especially lowland forests, the National Research Council (1982) concluded that these ecosystems "represent a very important, underexploited resource for tropical countries and that, as population pressures increase in these countries, rapid and extensive development will and must take place if even the currently inadequate standard of living in most countries is to be maintained."

Approximately one-third of the world's 1489 million hectares in the humid tropics lies within the Amazon Basin. Most of the basin devoted to annual crops is subjected to shifting cultivation, i.e., the land is cleared, one or two crops are grown on it, and the soil then lies fallow for several years.

Primarily two groups are responsible for clearing much of the Amazon Basin. Shifting cultivators do most of it in the tropical rainforests of the upper portion, and ranchers attempting to create pasture clear the seasonal semievergreen forest in most of the Brazilian or eastern portions (Hecht 1983, Myers 1980). Those areas now subjected to shifting cultivation need continuous cropping systems that provide "permanent field cultivation without first going through a sequence of increasingly shorter fallowing and associated environmental deterioration" (Denevan 1977).

With the long-term support of the United States Agency for International Development (USAID) and the more recent support of the Potash and Phosphate Institute (PPI), the Tropical Soils Research Program of North Carolina State University (NCSU) and Peru's Ministry of Agriculture through its National Agricultural Research and Promotion Institute (INIPA) have since 1971 been developing continuous cropping systems for the acid, infertile soils of the Amazon Basin and similar agroecological areas. These systems offer attractive alternatives to shifting cultivation.

THE AMAZON BASIN

Nearly 75% of the Amazon Basin contains acid and infertile soils classed as oxisols and ultisols (Sanchez et al. 1982). Although acidic and deficient in most nutrients, these soils are deep and usually well drained; they are red or yellow, and their physical properties are generally favorable for agriculture. In fact, they are strikingly similar to the predominant soils of the southeastern United States (Marbut and Manifold 1926; see Nicholaides et al. 1983 for more detail).

In the Amazon Basin the primary soil constraints to crop production are chemical (Table 1). Proper management can, however, overcome these chemical constraints, much as they have alleviated those in the southeastern United States.

Although only 8% of the Amazon Basin soils are estimated to be at extreme risk of erosion, 27% have slopes exceeding 8% (Sanchez et al. 1983). The structure of many of the basin's oxisols and some ultisols permit rapid water infiltration, thereby reducing runoff, but even those soils with less than 8% slope can suffer erosion if mismanaged. To allow more accurate predictions of susceptibility to erosion, we need a better inventory of the region's soil topography, perhaps one that divides the 0–8% slope category into two or even three subcategories. We estimate that as much as 40–50% of the basin's soils have at least a moderate erosion risk.

The fear that Amazon Basin soils will turn to brick when cleared (Friedman 1977, Goodland and Irwin 1975, Irion 1978, McNeil 1964, Posey 1982) is nothing more than a myth. Only four percent of these soils run such a risk (Table 1), and then only when the subsoil is exposed. Some seven percent of the soils in

Table 1. Gross estimates of major soil constraints to crop production in the Amazon Basin.*

Soil constraint†	Million ha	% of Amazon
Nitrogen deficiency	437	90
Phosphorus deficiency	436	90
Aluminum toxicity	383	79
Potassium deficiency	378	78
Calcium deficiency	302	62
Sulfur deficiency	280	58
Magnesium deficiency	279	58
Zinc deficiency	234	48
Poor drainage and flooding hazard	116	24
Copper deficiency	113	23
High phosphorus fixation	77	16
Low cation exchange capacity	71	15
High erosion hazard	39	8
Steep slopes (>30%)	30	6
Laterization hazard if subsoil exposed	21	4
Shallow soils (<50 cm deep)	3	<1

*Source: Nicholaides et al. 1983.
†Nutritional deficiencies of boron and molybdenum have also been noted in some Amazon Basin soils, but the data are too few for a quantitative estimate.

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the southeastern United States run a similar risk (Sanchez and Buol 1975), and many of these soils have been farmed continuously for the past 200 years without problems. The soft, iron-rich subsoil material (plinthite), irreversibly hardens (laterizes) when exposed to air; preventing its exposure from topsoil erosion is thus the key to preventing laterization. Erosion that would result in laterization is unlikely since most of the susceptible soils occur only on flat, poorly drained landscapes (Sanchez et al. 1982).

Agricultural efforts should be and are concentrating first on those soils with no major constraints to crop production (six percent of the basin estimated by Sanchez et al. 1982). But continuous cropping technologies for the basin's acid, infertile soils are also urgently needed because the primary food crop production system on these soils is shifting cultivation, and the population pressures on them are increasing.

SHIFTING CULTIVATION

Shifting cultivation encompasses many variations practiced around the world, but in all instances, the soil remains fallow for a longer period than crops are grown on it (Moran 1981, Nicholaides 1979, Nye and Greenland 1960, Ruthenberg 1976, Sanchez 1976).

Clearing

In the slash-and-burn system used by most shifting cultivators in the basin, the larger trees and shrubs are cut when rainfall is low, allowed to dry, and then burned either in place or in piles of smaller trees and shrubs. Other shifting cultivators, such as those in the high rainfall areas of Ecuador's Amazon Basin, practice "slash-and-mulch"; they broadcast crop seed in the forest, cut the undergrowth, and use that vegetation as mulch instead of burning. Still another variation is used in the Xingu River area in the center of Brazil's Amazon Basin by the Kayopo Indians, who plant their root crops in the cleared forest before burning (Posey 1982); when burned, the root crops lose their greenery but not their underground root systems, which then absorb nutrients leached from the ash when the rains begin.

Cropping and Fallow

The basin's shifting cultivators most commonly plant some combination of rice, bean, maize, cassava, sweet potato, and plantain among the ash debris. After only one or two crops, however, especially on acid and infertile soils, yields decline drastically because of soil nutrient depletion. Weed competition becomes so great that the farmers abandon the land to a forest fallow, which normally lasts for 14–21 years. During that time soil fertility is regenerated by nutrient cycling of forest regrowth and litter. The land then is cleared again, cropped, and returned to fallow after one or two more crops.

Although this traditional form of shifting cultivation has been branded by Alvim (1978) as a guarantee of perennial poverty for those who practice it, it is ecologically sound and functional (Moran 1981, Nye and Greenland 1960). But increased population pressures, especially with the opening of the trans-Amazon highway and other roads (Moran 1981), are shortening both the forest fallow period and the regeneration process. Consequently, an ecologically sound cropping system is being converted into an unstable, unproductive one that bodes ecological disaster (Sanchez et al. 1982). The effect is especially pronounced on infertile soils—which make up three-quarters of the basin.

Some alternative cropping systems must therefore be made available if there is to be any chance of producing food on such soils while preserving the ecological integrity of the remaining undisturbed Amazonian rainforest.

CONTINUOUS CULTIVATION

The continuous cropping systems developed by NCSU's Tropical Soils Research Program and Peru's INIPA in the Amazon Basin near Yurimaguas, Peru, offer such alternatives.

Yurimaguas's climate and soil are representative of much of the basin's rainforest subregion (Figure 1). The town is the westernmost large fluvial port of the Amazon headwaters (5°45'S, 75°05'W; 184 m). Its annual mean temperature is 26° C, and it has a well-distributed mean annual rainfall exceeding 2200 mm. The sandy-loam surface soil over a clay-loam subsoil reflects a level and well-drained ultisol. Both the top- and subsoil have low cation exchange capacities and are very acidic; they also have toxic levels of aluminum and are deficient in most nutrients.

Clearing

Choosing a land-clearing method is one of the most important steps affecting crop productivity of these infertile soils. Seubert et al. (1977) found that crop yields on soil cleared by the traditional slash-and-burn method were greater than those on the same soil cleared by bulldozer: The ash made good fertilizer, and burning did not lead to compaction or topsoil displacement comparable to bulldozing. The authors concluded that the slash-and-burn system was best for most farmers on acid and infertile soils unless they could afford the additional fertilizer,

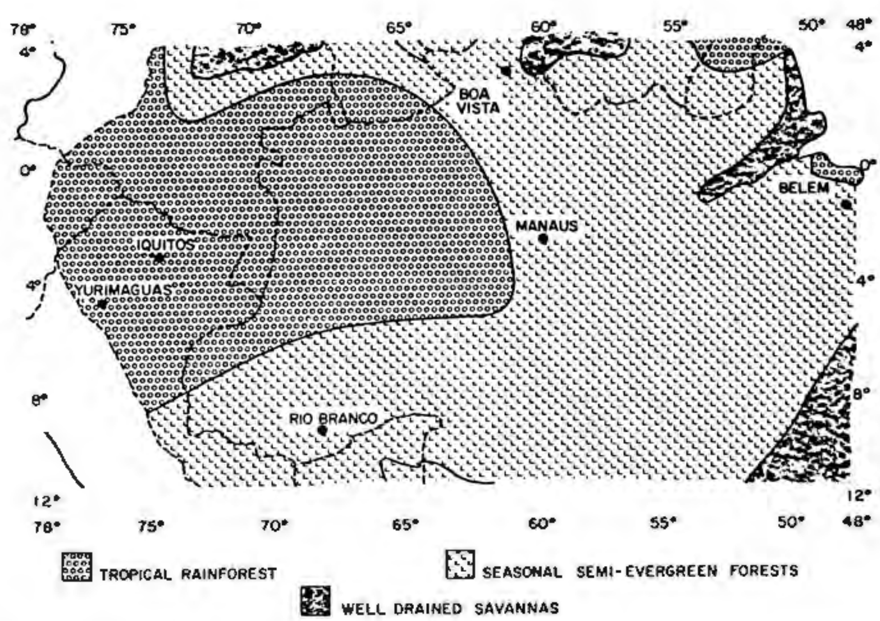

Figure 1. Map of the three major climatic-vegetative subregions in the Amazon Basin. Adapted from Nicholaides et al. 1983.

dicola) for these lands (Toledo and Serrao 1982). Promising germplasm is adapted to ultisols with pH 4.0 and 80% Al saturation and requires only 11 kg P ha^{-1} as simple superphosphate. Combinations of these and other legume-grass pastures have been (Ara et al. 1983) and are being tested under grazing pressure, though the results are not yet definitive.

Agroforestry on Sloping Soils

Using indigenous and sometimes imported tree species is important for the shifting cultivators of the Amazon Basin. The International Council for Research on Agroforestry (ICRAF) is collaborating on research in Yurimaguas and other basin areas to combine annual crops with food-producing trees (peach palm, *Guilielma gasipaes*), oil (oil palm, *Elaeis guyanensis*), and pulpwood (*Gmelina aborea* and *Pinus caribea*). An acid-tolerant *Parkia* species is also being investigated as an alternative to the non-acid-tolerant *Leucaena leucacoephalia*. Brazilian agricultural agencies and the University of Wisconsin are developing other innovative agroforestry systems and approaches for similar soils near Manaus (Denevan et al. 1984, UEPAE/EMBRAPA 1979–1981).

Paddy Rice on Alluvial Soils

Those relatively fertile alluvial soils in the Amazon Basin that flood only rarely have great potential for food production. Their proximity to natural transportation routes makes them even more important. The paddy rice research begun at Yurimaguas in 1981 is developing suitable production technologies for these alluvial soils (Bandy and Benites 1983). Soon after this research began, a spontaneous cooperative of some 35 farm families sprang up across the river from Yurimaguas to produce paddy rice. Now, several hundred hectares of fertile alluvial land are under cultivation by this cooperative, which plans to expand greatly.

IMPLICATIONS

Increasing population pressure and demand for food in the Amazon Basin will accelerate clearing of the region's forests from both spontaneous and government-directed colonizations. Development, extension, and use of agronomically and economically feasible continuous cropping technologies provide an alternative heretofore unavailable for local shifting cultivators. By continuously cropping their lands, these farmers could increase food production in the region while preserving much of its ecological integrity. But doing so will require the cooperation of the indigenous people, settlers, and the region's governments. The improved Yurimaguas technology provides a means for making rational decisions; it does not guarantee such decisions will be made. Yet the only way to prevent widespread ecological damage caused by trying to produce food or create pastures with inappropriate methods is to develop and make available appropriate technologies for continuous crop, pasture, and agroforestry production.

In addition to the technology developed by the Yurimaguas Program, proper weed control technologies, lower-input technologies, improved pasture production, and agroforestry systems must also be developed. Also needed are technologies for continuously cropping the Amazon Basin's relatively level oxisols. Several organizations, including a cooperative NCSU/EMBRAPA-UEPAE/Rockefeller Foundation program located near Manaus, Brazil, are exploring these technologies (Smyth and Bastos 1984), but several more years of research are required before any of the systems developed can be extended to that subregion's farmers.

The value of long-term field research cannot be overemphasized. Second- and third-generation problems do not appear in the first years of continuous cultivation. Some of the answers to the problems of longer-term continuous cultivation on these soils might never have been found if the initial research of the NCSU/INIPA team had been deemed a success and ended after one, two, or even eight years.

Limitations

The NCSU/INIPA research has concentrated on nearly level soils, avoiding the erosion hazards of cultivating sloping lands. The continuous cropping technologies described here are thus not directly applicable to all the basin's ultisols and oxisols; adaptation and modification of the improved Yurimaguas technology is needed for more sloping lands. Perhaps terracing, mulching crop residues, contour cropping, alley cropping, or even strip cropping annual crops with trees or grasses might address these issues. We believe it is better to leave pristine the forest on the sloping soils and concentrate food production on the level, well-drained 17 million hectares of fertile soils and on the level, well-drained 207 million hectares of acid and infertile soils of the Amazon Basin. Some farmers, however, do not have that option.

Before other attempts to implement it are made, the improved Yurimaguas technology should be tested through site-specific trials. Testing should include crop species, varieties, rotations, planting dates, and different fertilization and liming rates. Some soil fertility evaluation and improvement service will be needed to assist farmers in changing from shifting to continuous cultivation.

There are socioeconomic limitations as well. Socioeconomic conditions in Yurimaguas indicate the technologies are economically feasible; however, demand, limited markets, different cost:price ratios, government policy changes, and many other factors could make the technology economically unattractive. Site-specific economic interpretations will thus be necessary for any region considering adopting the improved Yurimaguas technology.

Potential

Once its limitations are realized and successfully addressed, the improved Yurimaguas technology can provide the basin's indigenous people, settlers, and governments with the means to increase food production while sparing many thousands of hectares of forest. We hope that our work will be used first to improve the lot of the shifting cultivators already in the basin and not as a basis for beginning massive new colonization schemes, although that possibility certainly exists.

The Amazon Basin farmers do not clear the forests because they enjoy it. Anyone who has seen or participated in slash-and-burn clearings learns that it is excruciating work. Repeating this system every two years is back-breaking. Farmers clear the rainforests because they need to produce food for their families and their livelihood. If they can produce more food more economically with less work, they will do so without hesitation. If they cannot, then we will see the Amazon Basin's forests continue to fall under their axes. For certain areas, the improved Yurimaguas technology offers an agronomically, economically, and ecologically attractive alternative to that grim scenario.

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became more deficient in P and more acidic, with exchangeable Al increasing and Ca and Mg decreasing; organic C also decreased. Nutrient depletion was reflected in declining corn and soybean yields in the respective corn-peanut-corn and soybean-rice-soybean rotations (Table 3). In the second year, yields declined even further in the traditional system as depletion of soil nutrients became more severe.

ECONOMIC FEASIBILITY

The improved Yurimaguas technology for the corn-peanut-corn rotation gave the highest net revenue per hectare, exceeding a 600% return (Bandy et al. 1980); this technology and rotation on a 1.5 ha farm, using US $180 (half borrowed at 64% interest) and the labor of the farm family alone provided an annual net income of US $2797. The average farm family's net income in the Yurimaguas area is US $750.[2]

ADOPTING IMPROVED PRACTICES

After the first year, all initial farmers in the project used improved seeds and insecticides. Ten adopted the improved plant-spacing techniques, six adopted weeding at critical times, five adopted fertilizers, and none adopted lime. Since many of the farmers' plots were on soils with relatively high Ca levels, the need for lime developed more slowly than on the more acid soils.

Although we had planned for only three consecutive crops in these demonstrations, three farmers wanted to continue and did so for a second year; one continued into the third year, stopping only after he had grown seven consecutive crops on soils that could not have produced more than two or three under the traditional system.

The initial 11 farmers are respected community leaders, so now their neighbors are learning from them. Several small farmers in the area are pioneering the continuous cropping technology on areas greater than the recommended 1.5 ha; one farmer is cropping 3 ha with hired labor and has increased his net worth. In the second year of the demonstration project, 5 more small farmers participated, and in the third year, 19 more; all had results similar to the initial 11.

[2] D. Hernandez and A. J. Coutu, unpublished data. North Carolina State University, Raleigh.

In 1980, a joint INIPA, Ministry of Education, and NCSU project used the same type of demonstration systems at 27 rural schools in the Yurimaguas region to reach more small farmers and their families. The students, their families, and teachers planted and managed the plots with NCSU supervision. After the first year, over half the 626 families in the project said they would be willing to use at least some of the improved Yurimaguas technology on their own lands.[3] Availability of credit and fertilizer has increased somewhat, and some roads and marketing facilities have improved, at least partly because the Peruvian government has responded favorably to the improved Yurimaguas technology.

The region's small farmers now have a continuous cropping alternative enabling them to farm their infertile lands permanently and economically. Some small farmers in the Peruvian jungle are beginning to learn these technologies from the Peruvian extension service. In addition, the improved Yurimaguas technology is being tested in other areas of the humid tropics including Manaus, Brazil, and the transmigration areas of Sumatra, Indonesia. This is only a beginning, but a solid one.

CONTINUED AND NEW RESEARCH

The results of these projects are important, but they do not provide all the answers for changing the region's predominant agricultural practice from shifting to permanent cultivation. The NCSU/INIPA team and others are investigating several complementary options for sustained agriculture in the upper Amazon Basin, including low-input systems for annual crops on level soils, low-input legume-grass pastures on sloping soils, agroforestry on sloping soils, and paddy rice on alluvial soils.

Low-input Systems for Annual Crops on Level Soils

Special emphasis is being given to developing annual crop systems with less input than those we have described, including:

- Evaluating crop species and varieties for tolerance the toxic acidity produced by soil aluminum. Determining tolerant species and varieties could reduce liming needs. Promising rice and cowpea varieties from germplasm supplied by the International Institute for Tropical Agriculture (IITA) have been identified by Piha and Nicholaids (1983).
- In collaboration with the International Fertilizer Development Center (IFDC), evaluating various rock phosphates as substitutes for phosphate fertilizers. Soil acidity dissolves the rock phosphorus, making this essential element for crop production available in these soils (Bandy and Leon 1983). Rock phosphate could be used with Al-tolerant crop varieties.
- Using organic inputs to supplement inorganic fertilizer. Mulching crops with residues from previous crops or from guinea grass *(Panicum maximum)* has increased yields of corn, had little or no effect on soybeans and peanuts, and had some detrimental effects on upland rice (Valverde and Bandy 1982). Green manurings of crops with kudzu *(Pueraria phaseoloides)* have given crop yields comparable to those with complete fertilization (Wade 1978). However, the inordinate amount of labor required has made this an unattractive approach for small farmers. Composts from crop residues and residual fertility from fertilizers reduced yields only 20% compared to complete fertilization for the first four crops (Bandy and Nicholaides 1983). However, on the sixth and subsequent crops, K fertilizer had to be added with the compost to maintain high yields. Again, high labor requirements may restrict this practice.

[3] J. R. Benites, unpublished report. North Carolina State University, Raleigh.

Low-input Legume-Grass Pastures on Sloping Soils

Much of the Amazon Basin has been cleared for pasture in response to a heavy demand for beef products (Caufield 1985). But many of the attempts to establish pastures fail, with adverse ecological consequences. The region badly needs improved pasture technologies.

Low-input technologies to produce legume-grass pastures are being developed by the NCSU/INIPA Yurimaguas Program primarily for use on acid and infertile soils on sloping lands. The International Center for Tropical Agriculture (CIAT) has selected acid-tolerant species of legumes (*Desmodium ovalifolium, Centrosema pubescens, Stylosanthes guianensis* and *capitata, Pueraria phaseoloides*) and grasses (*Brachiaria decumbens, Andropogon gayanus, Panicum maximum* and *humi-*

Organic matter in the soil decreased by 25% during the first year but reached a new equilibrium level beginning the second year. Such declines occur in traditional slash-and-burn clearing as well. Continuous crop production, however, maintained the level of organic matter reached after the initial slash-and-burn clearing.

According to soil and plant analyses, phosphorus and magnesium became deficient in the second year; six months later, a calcium deficiency was found. In year four, zinc was deficient, and after eight years, manganese deficiency was suspected. Deficiencies of molybdenum have occasionally been suspected in grain legumes. After ten years of continuous cultivation, therefore, deficiencies of all essential soil nutrients except iron and chlorine have been found in the crops grown on this ultisol.

Complete Treatment

The Yurimaguas research has shown that the fertilizer and lime needs for continuous agriculture on these soils do not exceed those for crop production on ultisols in other parts of the world. After the first crop on a slash-and-burn clearing, chemical fertilizers, whether inorganic or organic, must be used to produce and sustain moderately high yields. The lime and fertilizer recommendations in Table 2 are site-, crop-, and climate-specific, but they give an indication of the fertilizers required for continuous crop production on these soils.

A common concern expressed in the literature is that soil degradation increases with cultivation in the humid tropics (Friedman 1977, Goodland and Irwin 1975, Irion 1978, McNeil 1964). In the Yurimaguas study, however, soil chemical properties improved with continuously cropped rotational systems that were intensively managed and appropriately fertilized (Sanchez et al. 1982, 1983, Villachica 1978).

The topsoil pH was increased from 4.0 before clearing to a favorable 5.7 after seven years of proper liming and fertilization (20 consecutive crops). Organic matter decreased during that time by 27%, 93% of that during the first year. Liming also decreased the percent Al saturation from a toxic 82% to a negligible 1% and increased Ca levels nearly twentyfold. Although Mg levels fluctuated over time, they doubled after seven years of fertilizing and cropping. Despite adequate K fertilizer, however, exchangeable K levels did not increase, suggesting that in addition to uptake by crops, some K leached into the subsoil. The effective cation exchange capacity (ECEC), a measure of the soil's capability to retain cations against leaching, significantly doubled to 5.5 cmol (+) l^{-1} after seven years of cropping with lime and fertilizer. The soil P, Zn, and Cu levels were increased by fertilization from below their critical levels to well above them.

The acid subsoils in the basin's oxisols and ultisols frequently block root development. These soils' high Al saturation and low exchangeable Ca levels prevent crop roots from penetrating and thereby using available subsoil moisture; the plants become drought stressed during rainless periods (Bandy 1976, Gonzalez et al. 1979, Ritchey et al. 1980). Deep lime placement, instead of normal or shallow placement, enabled corn roots to grow into the subsoil and use its moisture (Bandy 1980). If, however, calcium moves into the subsoil, deep lime placement is unnecessary. During eight years of shallow lime and fertilizer placement in Yurimaguas, the constraints of acid subsoils were alleviated by Ca and Mg leaching, which resulted in increased Ca and Mg levels and decreased percent Al saturation (Sanchez et al. 1982, 1983).

Appropriate fertilization, liming, and continuous cultivation thus chemically improved rather than degraded this Amazon Basin ultisol.

FARMER ACCEPTANCE

The true test of any improved technology for continuous cropping in the Amazon Basin is its acceptance by the shifting cultivators. In 1978, the NCSU/INIPA team began a series of demonstration plots with several three-crop-a-year rotations on selected shifting cultivators' field near Yurimaguas (Bandy et al. 1980). The plots were cultivated according to the farmers' traditional system, improved agronomic practices without lime or fertilizer, and improved agronomic practices with moderate liming (1 t $CaCO_3$-equivalent ha^{-1} yr^{-1}) and fertilization (60 kg N ha^{-1} for rice and corn only, 35 kg P ha^{-1} $crop^{-1}$, and 22 kg Mg ha^{-1} $crop^{-1}$). We considered this last system equivalent to the "complete" treatments developed at the Yurimaguas Agricultural Experiment Station, although fertilization rates were lower; we dubbed the system "improved Yurimaguas technology." The rotations were planted on slash-and-burn forest clearings on land that had lain fallow one to ten years; the soils were similar to and somewhat more fertile than the station's.

The results were impressive. Cumulative grain yields using the "improved Yurimaguas technology" ranged from 7.5 t ha^{-1} yr^{-1} to 11.4 t ha^{-1} yr^{-1} (Table 3). The shifting cultivators' yields usually range from 1 t ha^{-1} to 1.5 t ha^{-1} (Smith 1981). Soil nutrients were depleted in the traditional system by crop removal and loss of ash liming after three consecutive crops. In that system, soils

Table 3. Average cumulative grain yields (t ha^{-1}) of 11 small farmer–managed continuous cropping demonstration trials from July 1978–June 1979 near Yurimaguas, Peru.*

Production system	Crop rotation											
	Corn-Peanut-Corn			Total	Peanut-Rice†-Soybean			Total	Soybean-Rice‡-Soybean			Total
Traditional	2.44	1.10	1.77	5.31	0.97	1.91	1.34	3.53	1.43	1.91	1.15	4.49
Improved, no lime or fertilizer	3.81	1.36	2.73	7.90	1.22	3.56	1.98	6.76	2.09	2.25	1.89	6.23
Improved, with lime and fertilizer	5.12	1.62	4.66	11.40	1.49	4.53	2.75	8.77	2.73	2.53	2.22	7.48

*Source: Bandy et al. 1980.
†Rice in the traditional system is the Carolino variety; in both improved systems, it is IR 4-2.
‡Rice in all systems is the traditional Carolino variety.

lime, and tillage to compensate for the disadvantages of bulldozed clearing (Alegre et al. 1983). The crucial question then became how to keep these slash-and-burn clearings continually productive.

Cropping Continuously

The climate and rainfall in the Yurimaguas area permit production of up to three crops a year without planting a second crop within one already growing (overlapping relay cropping). Five crops a year are possible by growing several crops at the same time, or intercropping, (Wade 1978), but farmers of the region are beginning to prefer rotational monocultures, such as upland rice–maize–soybean and upland rice–peanut–soybean. Monocultures without rotations do not produce sustained high yields because of disease and insect buildup.

To date, 25 consecutive crops of the upland rice–peanut–soybean rotation have been harvested from the same fields since they were slash-and-burn cleared in October 1972 (Figure 2; Nicholaides et al. 1983). Without fertilizer and lime, yields declined almost to zero after the third crop in the upland rice–corn–soybean rotation. Average annual grain yield of the "complete fertilization treatment" for each three-crop-per-year rotation was 7.5 t ha^{-1} since clearing, indicating that on some of the basin's most acid and infertile soils, moderately high yields of annual crops can be sustained over at least ten years when adequate lime and fertilizer are used (Table 2). Modifications needed in fertilization with time of cropping are still being defined.

These systems are as economically feasible as they are agronomically productive. The rice-peanut-soybean rotation gives a net return of US $2.91 for each $1.00 invested in the purchase and transportation of fertilizer and lime at 1977 Yurimaguas prices.[1]

Table 2. Lime and fertilizer requirements* for continuous cropping of a three-crop-per-year rotation of rice-maize-soybean, or rice-peanut-soybean on an ultisol of Yurimaguas, Peru.†

Input‡	Rate per ha	Frequency
Lime	3 tons $CaCO_3^-$-equivalent	Once each 3 years
Nitrogen	80–100 kg N	Rice and maize only, split applications preferable
Phosphorus	25 kg P	Each crop
Potassium	100–160 kg K	Each crop, split applications preferable
Magnesium	25 kg Mg	Each crop, unless dolomitic lime is used
Copper	1 kg Cu	Once each year or two
Zinc	1 kg Zn	Once each year or two
Boron	1 kg B	Once each year or two
Molybdenum	20 g Mo	Mixed with legume seed during inoculation

*Depend on soil test analysis and recommendations.
†Source: Nicholaides et al. 1982.
‡Calcium and sulfur requirements are satisfied by lime, simple superphosphate, and Mg, Cu, and Zn carriers.

EFFECTS ON SOIL PROPERTIES

As with crop production anywhere, nutritional needs and consequent lime and fertilizer applications for crops in the upper Amazon Basin can be determined only by soil and plant sampling and testing. In Yurimaguas, researchers set up control plots that never received fertilizer or lime, simulating the first two or three crops of traditional shifting cultivation, and "complete" plots that received the best fertilization and liming as established by soil and plant analyses and the program staff's accumulating experience.

Control Treatment

In the control plots, which were cleared by burning, ash produced a temporary increase in overall soil fertility (increased pH, total nitrogen, available phosphorus, exchangeable potassium, calcium, magnesium, and some micronutrients) and a concomitant decrease in exchangeable aluminum to below toxic acidity levels (Sanchez et al. 1983). The first crop, upland rice, did not suffer from fertility limitations. Within eight months, however, nitrogen and potassium deficiencies were apparent. Some deficiencies of sulfur, copper, and boron were also noted.

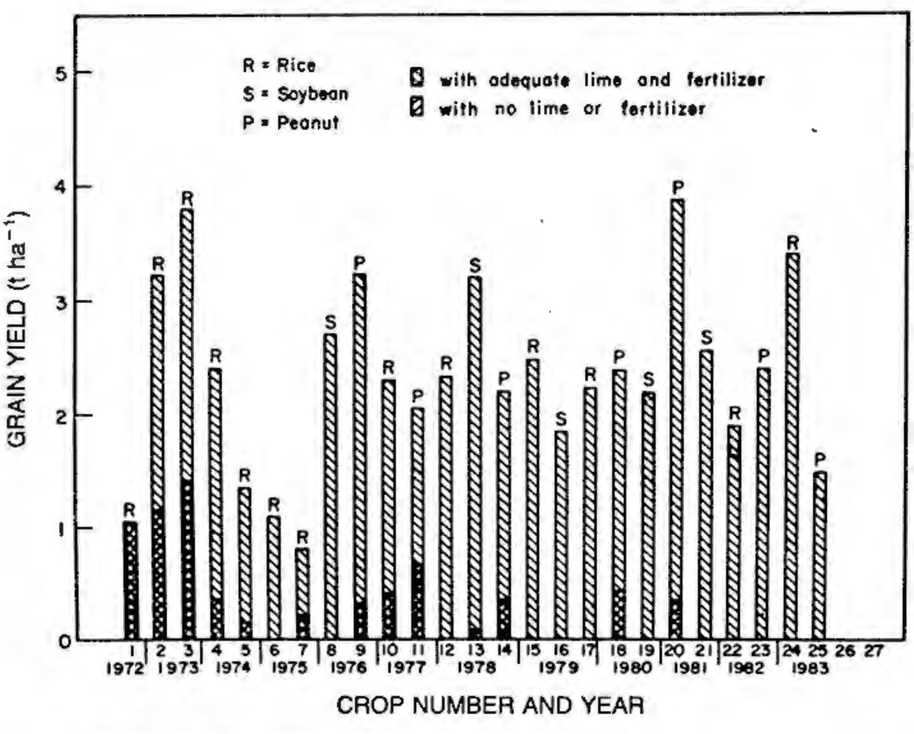

Figure 2. Yield record of a continuously cultivated rotation of rice-peanut-soybean in an ultisol of Yurimaguas, Peru, with and without complete fertilization and liming. Adapted from Nicholaides et al. 1983.

[1] D. E. Bandy, unpublished data. North Carolina State University, Raleigh.

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