Low-Input Cropping for Acid Soils of the Humid Tropics

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A low-input cropping system has been developed at Yurimaguas, Peru, to serve as a transition technology between shifting and continuous cultivation for acid soils of the humid tropics. Principal features are slash-and-burn clearing, rotation of acid-tolerant upland rice and cowpea cultivars, maximum residue return, no tillage, and no lime or fertilizer applications. When yields decline as a result of increasing weed pressure and nutrient deficiencies, a kudzu fallow is grown for 1 year. Subsequent options include fertilizer-based continuous cultivation, pastures, or agroforestry. The system preserves some agroecosystem diversity and contributes toward a sustainable level of production and income for farmers in humid tropical regions.

STABLE ALTERNATIVES TO SHIFTING CULTIVATION ARE NEEDed for humid tropical locations where increasing demographic pressure no longer permits traditional slash-and-burn agriculture. In previous articles we have given an overall appraisal of soils of the tropics (*1*) and described fertilizer-based continuous cultivation technology as one soil management option (*2*). Subsequent research in the Amazon of Peru and Brazil has shown promise for an array of management options for humid tropical landscapes dominated by acid soils. Some of these options, shown in Fig. 1, are applicable to specific combinations of topography, soil type, and level of socioeconomic infrastructure development (*3, 4*). Acid soils, classified mainly as Ultisols and Oxisols, cover approximately two-thirds of the world's humid tropics (*5*). Differing management options have been developed for high base status, nonacid Alfisols and Andisols of the tropics where the subsoil is rich in bases that can be recycled (*6, 7*). In either acid or nonacid soils, evidence shows that continuous production of food crops is possible in the humid tropics with judicious use of lime, fertilizers, crop rotations, and soil conservation practices (*2, 6, 8, 9*). But it is unlikely that the majority of shifting cultivators in the humid tropics can readily switch to continuous production systems because of market infrastructure limitations. Intermediate systems of low-cost and low-input technologies might be useful as a first step to more permanent land use.

Low- Versus High-Input Approaches

Agronomists disagree about the use of the terms "high-input" or "intensive" systems on one side, and "low-input," "minimum-input," "zero-input," "alternative agriculture," and "resource-limited" systems on the other. For soil management purposes, high-input systems have been defined as those that aim to eliminate soil constraints to crop growth by appropriate levels of liming, fertilization, irrigation, or other purchased inputs (*10*). A large percentage of the world's food supply is produced according to this approach, both in the developed world and in the more fertile lands of the developing world. Conversely, low-input systems for acid soils are defined as the cultivation of plant species adapted to the main soil constraints, to minimize but not eliminate purchased inputs, and to maximize nutrient recycling (*10*). Low-input systems are therefore different from zero-input systems, such as the effective nutrient cycling that exists between native forests and acid tropical soils (*11*). Such zero-input systems operate as long as there is zero output away from the field, which is what happens in undisturbed natural systems. When farmers remove nutrients in their crop harvests, they tend to deplete available nutrient stocks and induce nutrient deficiencies in plants. In naturally fertile soils this process may take years, but in acid Oxisols and Ultisols it takes months (*12*). Nutrients removed by harvests must be replenished in order to have sustained production. Nutrients can be replenished by biological nitrogen fixation, lime, fertilizer applications, and organic inputs such as mulches or manures brought from outside the field. With the exception of biological nitrogen fixation, the other means involve direct cash or labor inputs, such as the purchase of fertilizers and their application costs, or the gathering, transport, and application of organic inputs. The low-input approach aims at minimizing but not necessarily eliminating the need for inorganic and organic inputs from outside the field.

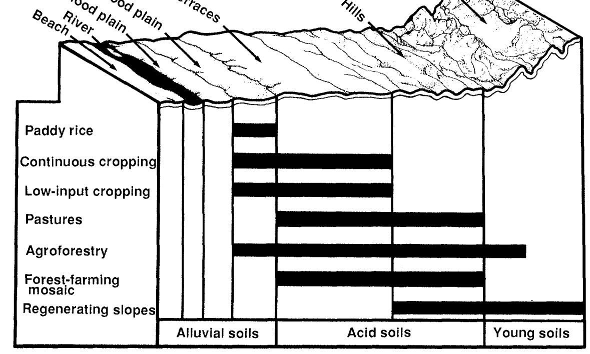

Fig. 1. Some soil management options for humid tropical landscapes dominated by Oxisols and Ultisols. [Reprinted from (*3*) with permission of the Management Entity, School of Agriculture and Life Sciences, North Carolina State University]

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Perspectives of Farmers

In 1982 a group of North Carolina State University and Peruvian scientists interviewed shifting cultivators around Yurimaguas, Peru, a humid tropical area with a mean annual temperature of 26°C, annual rainfall of 2100 mm without a pronounced dry season, an elevation of 182 m, predominantly acid soils, tropical rain forest vegetation, and a shifting cultivation system in disequilibrium because of rapid population growth (*13, 14*). When asked what their most important agricultural wish was, the farmers' most common reply was "to grow a second crop of upland rice before abandoning the land." Rice (*Oryza sativa*) is the main cash crop of the region. After one harvest the land either reverts to forest fallow or is planted to cassava (*Manihot esculenta*) or plantain (*Musa paradisiaca*) and eventually fallowed. When asked what farmers perceived as the major impediment for growing a second rice crop, the answer was weed control. One farmer also indicated that a tropical kudzu (*Pueraria phaseoloides*) fallow could be an alternative to the secondary forest fallow. Armed with these perceptions and experience on how to grow crops continuously with appropriate fertilizers (*12*), scientists in the Tropical Soils Research Program began to design a low-input cropping system.

Selecting Acid-Tolerant Germplasm

The first step in the research program was to identify sufficiently acid-tolerant species and varieties that would produce acceptable yields without liming. Field research was conducted at the Yurimaguas Experiment Station. The soils used are fine-loamy, siliceous, isohyperthermic Typic Paleudults. They are well-drained, acid (*p*H values between 4.0 and 4.5, topsoil aluminum saturation ranging from 50 to 80%), and low in native fertility (*13*). Germplasm believed to have high yield potential under humid tropical conditions was collected from different countries and then tested in limed and nonlimed plots at aluminum saturation levels of 20 and 80%, respectively (*15*). Cultivars were considered highly tolerant if their yields in acid soils were 85% or more of those obtained in the limed plots. In addition, the absolute yields had to be agronomically attractive. The overall results indicate a high degree of acid tolerance in upland rice and cowpea (*Vigna unguiculata*), an absence of acid tolerance in the maize (*Zea mays*), soybean (*Glycine max*), and winged bean (*Psophocarpus tetraglobulus*) germplasm tested, and evidence of moderate tolerance in peanuts (*Arachis hypogaea*) and sweet potatoes (*Ipomoea batatas*) (*15*). We selected an upland rice-cowpea rotation, using germplasm from the International Institute of Tropical Agriculture in Nigeria, as the basis for the low-input cropping system. The acid tolerance of the selected cultivars, Africano Desconocido rice and Vita 7 cowpeas, has been confirmed in a wide variety of trials and farmers' fields in the Peruvian Amazon.

Table 1. Productivity of a low-input cropping system with cultivars (cv.) of seven crops during the first 34 months after cutting and burning a secondary forest at Yurimaguas, Peru.

Chronology			Grain yield (ton ha^{-1})	
Crop sequence	Planting date	Harvest date	Not fertilized system	Fertilized* system
Rice cv. Carolino	1 September 1982	17 January 1983	2.4	2.4
Rice cv. Africano	11 February 1983	11 June 1983	3.0	3.1
Cowpea cv. Vita 7	7 September 1983	11 November 1983	1.1	1.2
Rice cv. Africano	15 December 1983	23 April 1984	2.8	3.2
Cowpea cv. Vita 7	9 May 1984	23 July 1984	1.2	0.9
Rice cv. Africano	5 September 1984	2 January 1985	1.8	2.0
Rice cv. Africano	26 February 1985	30 June 1985	1.5	2.5
Total			13.8	15.3

*Fertilizer was applied only to the four Africano rice crops.

The First Cropping Cycle

One hectare of Ultisol with a topsoil clay content of 28% and a 10-year-old secondary forest fallow was slashed on 15 July 1982, allowed to dry, and burned in the traditional manner on 20 August 1982. Previous studies demonstrated that traditional slash and burn is the best land-clearing method (*16*). The entire hectare was planted to the Carolino upland rice variety and grown by traditional shifting cultivation. After the first harvest, the field was split in half, and a low-input trial was initiated with the Africano Desconocido rice variety. Half the field was not fertilized, whereas the other half received an application of 30 kg of nitrogen, 22 kg of phosphorus, and 48 kg of potassium per hectare when Africano rice was grown. After the burning, a total of seven crops, five of rice and two of cowpeas, were harvested during a period of approximately 34 months. No tillage or lime was used, and all crop residues were evenly distributed to the field. Commercially available herbicides (*17*) and manual labor were used to control weeds. System chronology is shown in Table 1. The seven crops occupied the land for 76% of the time. The average time interval between crops was 39 days, reflecting the field-size plots, farmer timing, and labor availability. The experimental design was considered to be completely randomized; ten crop yield and soil sample replicates were taken per treatment (*18*).

Yields of the seven continuous crops harvested within 3 years are shown in Table 1. A total of 11.5 ton ha^{-1} (measurements in metric tons throughout) of rice and 2.3 ton ha^{-1} of cowpea grain was produced without any fertilizer or lime additions on this soil, which had a *p*H of 4.5. The only purchased chemical inputs were locally available contact herbicides and insecticides. Similar results have been obtained in six other replicated trials at the Yurimaguas Station during the last 5 years. Such results contrast sharply with our experience with intensive cropping systems where crop yields approached zero if the soil was not limed or fertilized within 1 year (*2*). The use of aluminum-tolerant cultivars, maximum residue return, and zero tillage are believed to be responsible for this difference.

Essentially, no responses to the fertilizer applications to the Africano rice crops were observed during yields of the first six crops (Table 1). Both upland rice and cowpea yields are considered high, in contrast to the regional average of about 1 ton ha^{-1} for upland rice and about 0.3 ton ha^{-1} for cowpeas. A sharp yield response to fertilizer was observed in the seventh crop, rice (*19*).

Soil properties. Topsoil chemical properties indicate favorable changes from 3 to 11 months after burning in response to the nutrient value of the ash, particularly in increasing base status (Table 2). From 11 to 35 months little change in topsoil *p*H, organic matter, and exchangeable bases took place. There was a slight decrease in soil organic matter content, in contrast to the 25% decrease observed in similar soils under high-input systems at the same location (*2*). Residue return and absence of tillage are probably responsible for this less drastic decline.

By the 35th month there were significant decreases in available phosphorus and potassium, which reached values below their critical levels for the site, 12 mg dm^{-3} for phosphorus and 0.15 cmol dm^{-3} for potassium (Table 2). Nutrient additions in the fertilized plots, however, were apparently sufficient to offset this decrease. We assume, therefore, that the supply of nutrients for this system could be sustained by modest fertilizer applications.

Nutrient removal and cycling. The calculated nutrient accumulation by the seven crops (Table 3) is based on nutrient composition of Africano rice and Vita 7 cowpea grain, stover, and roots obtained in neighboring experiments (*20, 21*). Even though only the rice grain and cowpea pods were exported from the field, these harvested products represented considerable nutrient removals from the field during the 3-year period. The amounts of nutrients accumulated by the crops but returned to the soil as above- or below-ground organic inputs were larger than the amount removed, except for phosphorus. Crop residues plus root turnover returned to the soil 62% of the dry matter produced, 54% of the nitrogen, 70% of the magnesium, 89% of the potassium, 95% of the calcium, but only 38% of the phosphorus accumulated by crops. If we assume there was 100% fine root decomposition (*21*), root turnover accounted for a relatively minor proportion of amounts recycled. The actual amounts returned, therefore, are equivalent to an annual fertilization rate of 98-7-199-33-13 kg ha^{-1} of nitrogen, phosphorus, potassium, calcium, and magnesium, respectively. A proportion of the nitrogen returned as aboveground residue, however, may be lost, by denitrification on the mulch-soil surface interface, before it enters the soil. Biological nitrogen fixation by cowpeas may counteract such losses, but neither process was measured. Other nutrient inputs are likely to be transferred entirely to the soil. Phosphorus, therefore, appears to be the critical nutrient, since about two-thirds of the crop uptake was removed by the harvested products, giving this element the lowest recycling percentage and the lowest absolute amounts returned to the soil among the five nutrients evaluated.

Weed pressure. In our view, increasing difficulty of weed control was the single most important factor for the instability of this low-input system during its third year. The initial weed population was mainly broad-leaved, which is typical of shifting cultivation fields in the area. With time, the weed population gradually shifted to more aggressive grasses not subject to economically sound control by commercially available herbicides (*16*). Of particular importance was the spread of *Rottboelia exaltata*, a nonrhizomatous grass, particularly during rice growth. Cowpeas were more competitive with weeds than upland rice because they covered the soil surface more thoroughly.

Studies on weed control in low-input systems at Yurimaguas indicate that the absence of tillage and burning promotes weed buildup (*16*). Rice straw mulch may reduce weed growth in cowpeas, but cowpea residues do not have the same effect on rice, perhaps because of the fast decomposition rate of cowpea residues. Mt. Pleasant (*17*) concluded that six crops is a realistic estimate of the duration of the upland rice-cowpea low-input system in terms of economically sound weed control in Yurimaguas.

Economics. The summary of cost records in this 1-ha experiment for the first seven crops in the plots without fertilization is shown in Table 4. Labor inputs for the first crop include land clearing; thus the subsequent crops average half of the first crop's labor. Returning and redistributing crop residues averaged 10 man-days ha^{-1}, or approximately U.S.$20 per hectare per crop. Another major labor input was that of boys who were hired to keep the birds away from the crops near harvest time. The next major cost items were interest on crop loans from the agrarian bank and government fees for receiving and processing rice at the mills. Shifting cultivators routinely obtain bank loans that are used primarily as an advance on their labor. Interest charges fluctuating from 40 to 101% on an annual basis in local currency reflect the high inflation rate in Peru, which averaged 125% annually during the study period. Even in U.S. dollar terms the indirect costs averaged about 30% of the total production costs. In contrast, the cost of purchased chemical inputs (herbicides and insecticides) and other items (seed, bags, and thresher rent) comprised 8 and 19% of the total production costs, respectively. Since most shifting cultivators have no title to the land they use, no land costs were included in this estimate.

The low-input system without fertilizer applications was highly profitable, averaging net returns of U.S.$1144 per hectare per year or a 121% return over total costs (Table 5). The low-input system with fertilizers was also quite profitable, averaging an annual net return of U.S.$1125 per hectare and a 100% return over total costs. Fertilizers accounted for 9% of the total cost in the system, and also resulted in additional labor, interest, thresher use, and transport costs. The low-input system either with or without fertilizers was more profitable than traditional shifting cultivation (Table 5).

Transition to Other Systems

This low-input system, therefore, is a transitional technology in both agronomic and economic terms. After 3 years, the field is devoid of felled logs and most of the remaining tree stumps are sufficiently decomposed to be destroyed easily. The land-clearing process is thus complete, providing several options to the farmer, such as the following: (i) to put the land into a managed fallow and then start a second cropping cycle; (ii) to plow, lime, fertilize, and rotate crops intensively; (iii) to establish pastures; and (iv) to use an agroforestry system.

The experiment described above was modified to address some of these options after the seventh crop harvest in July 1985. The 1-ha

Table 2. Topsoil (0 to 15 cm) fertility dynamics within the first 35 months of the low-input cropping system on an Ultisol at Yurimaguas, Peru. Mean of 50 samples per treatment. The coefficients of variation (CV) were as follows: *p*H, 6%; Al, 46%; Ca, 46%; Mg, 41%; K, 43%; ECEC, 9%; Al saturation, 37%; available P, 39%; and organic matter, 20%. Comparisons for least significant differences (LSD) and CV do not include sampling at 3 months after clearing. ECEC, effective cation and exchange capacity.

Months after burning	Fertilized	*p*H (H_2O)	Exchangeable (cmol dm^{-3}) Al	Ca	Mg	K	ECEC (cmol dm^{-3})	Al saturation (%)	Available P (Olsen) (mg dm^{-3})	Organic matter (%)
3	No	4.4	1.10	0.30	0.09	0.13	1.62	68	20	2.12
11	No	4.6	1.46	0.92	0.28	0.19	2.85	51	13	2.06
	Yes	4.7	1.14	0.97	0.27	0.19	2.58	45	18	2.07
35	No	4.6	1.65	1.00	0.23	0.10	2.99	53	5	1.92
	Yes	4.6	1.23	1.16	0.20	0.16	2.76	44	16	1.77
LSD*		0.1	0.25	0.17	0.04	0.03	0.20	7	2	0.15

*The LSD are for comparing two sampling dates within a treatment at $P = 0.05$.

Table 3. Total dry matter and nutrient accumulation by five rice and two cowpea crops harvested in 35 months without fertilization.

Plant parts	Dry matter* (ton ha^{-1})	N	P	K (kg ha^{-1})	Ca	Mg
Grain and pods	14.2	250	34	73	5	18
Straw or stover	18.1	232	15	565	80	35
Roots	5.2	63	6	44	18	5
Total	37.5	545	55	682	103	58

*Based on mean grain:straw ratios of 0.84 for rice and 0.52 for cowpea; mean cowpea pod weight of 0.032 ton ha^{-1} per crop, and fine root biomass of 0.65 and 0.97 ton ha^{-1} per crop for rice and cowpea in the top 30 cm of soil (*20, 21*).

field was divided into eight 1250-m^2 plots, providing four treatments in a randomized complete block design with two replications. The replicates were located on the previously fertilized and unfertilized treatments in order to block the residual effects. Two treatments were designed to test the weed control factor by continuing the low-input system (cowpea-rice-cowpea); a third was planted to kudzu fallow, and the fourth was planted to a high-input system.

Continuing the low-input system. Previous crop yields suggested that the system collapsed after the seventh crop (Table 1). This observation was confirmed by growing three more crops with a weed control variable: full weed removal at economically unrealistic levels versus the conventional treatment. The full treatment consisted of eliminating weeds by a preemergence application of 2.25 kg ha^{-1} of the active ingredient of metolachlor plus 2.5 liter ha^{-1} of paraquat, followed by 0.28 kg ha^{-1} of the active ingredient of sethoxydim, supplemented by handweeding as needed. The actual cost of this treatment was U.S.$225 per hectare per crop, an unrealistic level. The conventional treatment was the preemergence application of 1.5 liter ha^{-1} of 2,4-dichlorophenoxy acetic acid followed by 2.5 liter ha^{-1} of paraquat 5 days later, and no handweeding, with a total cost of $25 per hectare per crop. Both weed control plots received the same application of fertilizers to rice as stated previously, in order to eliminate phosphorus and potassium deficiencies.

Grain yields of the eighth, ninth, and tenth consecutive crops under conventional weed control were low with cowpeas, and practically zero with rice (Table 6). When weeds were totally removed, yields of the ninth (rice) and tenth (cowpea) crops reached acceptable levels. Consequently, it seems that the collapse of the system is directly related to weed control problems.

Kudzu fallow and a second crop cycle. Traditional shifting cultivation involves a secondary forest fallow period of 4 to 20 years, supposedly to replenish soil nutrient availability and control weeds, although the processes involved are not well understood (*20*). Farmer experience around Yurimaguas indicates that a minimum desired age of fallow is about 12 years, but population pressures effectively reduce this period to an average of 4 years (*14*). Slashing and burning young forest fallows result in faster grass weed invasion than would occur in older fallows because the weed seed pool declines with age (*22*). Considering the limited likelihood of long secondary fallow periods in humid tropical areas in developing countries, the need for an improved fallow is apparent. Following a farmer's suggestion, Bandy and Sanchez (*23*) studied the use of tropical kudzu (*Pueraria phaseoloides*) as a managed fallow. Unlike its temperate-region counterpart (*Pueraria lobata*), tropical kudzu does not produce storage roots and therefore is easy to eradicate by slash and burn. Kudzu fallows were grown in previously cultivated fields. In the most infertile and compacted soils of Yurimaguas, kudzu is slow to establish and initially shows several classic nutrient deficiency symptoms, but within 3 months a complete canopy is attained, the kudzu leaves become dark green, and weeds are smothered. Aboveground dry matter and ash biomass accumulation by kudzu peaks at about 2 years (*23*).

The same kudzu ecotype was seeded in this low-input experiment, on 28 August 1985, after harvesting the seventh rice crop, which was heavily infested with *Rottboellia exaltata* and other weeds. No fertilizers were added to the kudzu plots, but the tall *Rottboellia* plants were handweeded one time. As before, kudzu was slow in establishing, but within 3 months it had developed a complete ground cover and a surface litter layer. Kudzu was slashed with machetes on 13 September 1986; after 10 days of dry weather, it was burned in a total time of 4 minutes for the 1250-m^2 plots. Ash sampled 1 day after the burn contained considerable amounts of nutrients, which were incorporated into the soil by the first rains.

Africano rice was planted 3 days after the kudzu burn and harvested on 22 January 1987. It received the 30-22-40 kg ha^{-1} of nitrogen, phosphorus, and potassium just as the previous rice crops. Grain yields were the highest obtained to date at this site (3.9 ton ha^{-1}). These yields were partly due to favorable rainfall distribution

Table 4. Labor input, production costs, and revenues incurred in the low-input system with seven crops without fertilization.

Labor, costs, and revenues	Crop sequence: Rice	Rice	Cowpea	Rice	Cowpea	Rice	Rice
Labor (man-day ha^{-1})	172	79	99	79	99	79	79
Cost (U.S.$ ha^{-1})							
Labor	380	140	113	134	167	130	95
Herbicides	21	21	25	26	25	24	25
Insecticides	0	11	14	14	13	0	0
Seed	19	17	75	18	51	16	17
Bags	16	18	8	20	7	18	50
Thresher rent	0	34	0	38	0	34	80
Transport to market	12	12	14	14	14	12	14
Loan interest and fees	135	80	86	105	108	111	225
Total cost	583	333	335	369	385	345	506
Revenue							
Grain produced (ton ha^{-1})	2.44	2.99	1.10	2.77	1.19	1.84	1.52
Price (U.S.$ ton^{-1})	321	281	1420	305	1127	265	274
Gross revenue (U.S.$ ha^{-1})	783	840	1562	845	1341	488	416
Net return (U.S.$ ha^{-1})	200	507	1227	476	956	143	−90
Net return/cost (%)	34	152	366	129	248	41	−18

for rice growth, as evidenced by similar rice yields obtained in other experiments at that time, but they were also a result of the absence of significant weed pressure. The 1-year kudzu fallow therefore effectively suppressed weed growth in a way far superior to the herbicide combinations attempted to date. A subsequent crop of upland rice was grown without any fertilization, and it averaged 1.9 ton ha^{-1}, an adequate yield for the time of planting.

Changes in topsoil chemical properties in the kudzu fallow plots at the end of the first cropping cycle, after 1 year of kudzu fallow (1 day before burning), and after the first harvest of the second cropping cycle are shown in Table 7. The effect of the kudzu fallow on topsoil chemical properties includes a significant decrease in exchangeable calcium and potassium, presumably owing to plant uptake, with no changes in acidity, aluminum saturation, or available phosphorus. Topsoil properties at 54 months after burning, representing seven crop harvests, 1 year of kudzu fallow, and one crop harvest afterward are as good or better than 3 months after burning the original forest (Table 2). Topsoil organic matter contents have increased, probably as a result of the kudzu fallow litter inputs. The second cropping cycle is being continued in order to determine how long these effects will last; however, in this cycle no additional fertilizer is being applied, and weed control will be only at the conventional level.

High-input crop production. Another option is for the low-input system to serve as a 3-year transitional period to intensive, fertilizer-based, continuous cropping systems for areas that have developed a sufficient road, credit, and market infrastructure to make this possibility attractive. In these areas the fields are ready for mechanized tillage, provided that slopes are suitable, because most of the felled vegetation has decomposed. One treatment of this field experiment was tilled to 25 cm with a 50-hp tractor, limed and fertilized according to soil test levels and previous experience, and planted to a maize-maize-soybean rotation. Maize yields were normal for high-input systems for the planting season (3.9 and 2.9 ton ha^{-1}) (*24*), whereas soybean yields were slightly lower than normal (1.9 ton ha^{-1}). The system appears stable and of similar productivity to long-term high-input systems grown at Yurimaguas (*2, 25*). A combined total of 8.6 ton ha^{-1} of high-value grain (maize plus soybeans) was produced in approximately 15 months. Total productivity of the entire sequence was 22.4 ton ha^{-1} of grain in 4 years and 4 months, or 5.2 ton ha^{-1} per year. In order to decrease weed infestations, it may be advisable to use the kudzu fallow before shifting to high-input cropping.

Legume-based pastures. Pastures for beef and milk production are an attractive option in the Latin American humid tropics and one in particular need of improved technology because of widespread pasture degradation. The low-input system can also serve as a precursor to establishing improved, acid-tolerant pastures, beginning with the clearing of secondary forests. Income-generating food crops can be grown, and the pasture species may be planted either vegetatively or by seed under a rice canopy. Several combinations of persistent, acid-tolerant grasses and legumes have produced high and sustained live-weight gains of the cattle in Yurimaguas for 6 years (*26*). The kudzu fallow itself could be used as a pasture in rotation with grass-based pastures. Since weed encroachment is a major limiting factor in pasture establishment, it may be advantageous to limit the number of crops to minimize the weed buildup that occurs during the sixth and seventh crops. Planting kudzu fallow, burning it after 1 year, and then establishing the pastures may be a better approach.

Agroforestry. The low-input cropping system is a good way of providing cash income and ground cover during the establishment phase of tree plantations. The decision, however, has to be made early in order to plant the tree crops shortly after clearing and burning the secondary forest. Unless liming is contemplated, the choice of tree crops should be limited to acid-tolerant ones. Examples of acid-tolerant crops for industrial purposes are rubber (*Hevea brasiliensis*), oil palm (*Elaeis guineensis*), and guarana (*Paullinia cupana*); for food production, peach palm (*Bractis gasipaes*); for alley cropping, *Inga edulis*. Woody species known to be sensitive to soil acidity, such as *Theobroma cacao* and *Leucaena leucocephala*, should be avoided.

The low-input system has been used successfully in nearby experiments for the establishment of peach palm and multipurpose tree production systems that include fast-growing (*Inga edulis*) and slow-growing (*Cedrelinga cataeniformis*) species (*27*). For peach palm, seedlings are transplanted with the first rice crop. Within 18 months, the peach palm produces too much shade for further crop growth; kudzu is then planted as an understory (*28*).

Although agroforestry systems are generally believed to be soil-protecting, most trees develop a full crop canopy much more slowly than annual crops (*29*). Consequently, a rapidly established ground

Table 5. Cumulative production costs and returns incurred with seven crops in 3 years in the low-input system with and without fertilization and under shifting cultivation.

Costs and revenues	Low-input system				Shifting cultivation	
	Not fertilized		Fertilized			
	U.S.$ ha^{-1}	Percent	U.S.$ ha^{-1}	Percent	U.S.$ ha^{-1}	Percent
Cost						
Labor inputs	1159	41	1185	36	380	65
Chemical inputs						
Fertilizers	0	0	292	9	0	0
Herbicides	167	6	167	5	21	4
Insecticides	39	2	27	1	0	0
Other inputs						
Seed	213	7	213	6	19	3
Bags	137	5	140	4	16	3
Thresher use	186	7	189	5	0	0
Transport to market	92	2	96	3	12	2
Loan interest and fees	850	30	1017	31	135	23
Total cost	2843	100	3326	100	583	100
Revenue						
Gross revenue	6275		6688		783	
Net return	3432		3362		200	
Net return/cost		121		101		30

cover is highly advantageous in the humid tropics. This can be achieved by the acid-tolerant, low-input cropping or by establishing acid-tolerant, legume ground covers.

Ecological Implications

The low-input system has several potentially positive environmental impacts. It provides a low-cost alternative for shifting cultivation in highly acid soils. To produce the grain yields reported in Table 1, a shifting cultivator would need to clear about 14 ha in 3 years, in comparison to clearing 1 ha once, by means of the low-input system. Furthermore, the use of secondary forest fallows instead of primary forests is emphasized, although the system should work well starting from primary forest.

Erosion hazards are largely eliminated by the absence of tillage and the presence of a plant canopy on the soil surface, be it slash-and-burn debris, crop canopies, crop residue mulch, or a managed fallow. Nutrient recycling is maximized, but nutrients exported as grain must be replenished by outside inputs in soils low in nutrient reserves. Perhaps just as importantly, the low-input system does not lead the farmer into a corner; it provides a wide range of options after the first cropping cycle is complete.

Current Research

Although the feasibility of the low-input cropping system during the first cropping cycle followed by a managed fallow period has been demonstrated, information about the second cropping cycle is limited to two crop harvests. It cannot be stated at this point that a modified form of shifting cultivation with a 3:1 crop to managed fallow ratio is feasible on a long-term basis. More in-depth knowledge of weed population shifts and fertility dynamics is needed. Zero tillage poses a major constraint to long-term weed control. Soil data have been confined to readily determined chemical parameters; the physical and biological dynamics of soil are being intensively studied now. Tropical kudzu is but one of several promising species for managed fallows, and others are being investigated in terms of above- and below-ground biomass accumulation, nutrient cycling, and weed suppression (*30*). The management of organic inputs and soil organic matter is being researched (*31*).

The effect of age of fallow also needs to be studied in greater detail. What are the tradeoffs with a longer fallow? Can the weed problem be reduced by shortening the time period between harvesting and planting? A 39-day average interval allows plenty of time for weed regrowth.

The nutrient recycling aspects seem to be working well except for possible inefficiencies in nitrogen. Denitrification losses from residues left on the soil surface need quantification; the nitrogen loss by burning a kudzu fallow must be considerable. Biological nitrogen fixation by cowpeas and kudzu may counteract this effect, but its extent has not been quantified. Even though this Ultisol is not classified as a high-phosphorus fixer (*12*), this element is the least recycled because of grain export. Phosphorus fertilization will likely be needed. Other nutrients, however, may be more critical in different soils.

Limitations of the Study

We have demonstrated the agronomic and economic feasibility of this transition technology at Yurimaguas. Its basic components (slash-and-burn clearing, acid-tolerant cultivars, zero tillage, maximum residue return, minimum fertilization, and weed eradication by managed fallows) may be applicable in much of the humid tropics, but the choice of crop species and varieties, managed fallows, and duration of the system are probably site-specific. When the system was replicated at a sandier site in Yurimaguas, the cropping period was reduced from seven to five crops. The difference between the soils is only topsoil texture (loamy sand versus sandy loam), and they are otherwise identical at the family level of soil taxonomy. The Fertility Capability Classification system (*32*), however, did distinguish between these two soils at the highest categorical level. This technical soil classification system could be helpful in identifying soil constraints that may affect the performance of low-input cropping systems in other soils.

Table 6. Grain yields of three additional crop harvests in the low-input system at two levels of weed control. NS, not significant.

Crop sequence	Planting date	Harvest date	Weed control level: Conventional (ton ha^{-1})	Weed control level: Full (ton ha^{-1})	LSD (P = 0.05) (ton ha^{-1})
Cowpea cv. Vita 7	19 August 1985	31 October 1985	0.58	0.58	NS
Rice cv. Africano	9 January 1986	9 May 1986	0.09	1.60	0.19
Cowpea cv. Vita 7	15 July 1986	25 September 1986	0.43	0.82	0.26

Table 7. Changes in selected topsoil (0 to 15 cm) chemical properties before and after 1 year of kudzu fallow and after harvest of subsequent crop. Plots did not receive fertilizers during the first cropping cycle. The CV were as follows: *p*H, 4%; Al, 25%; Ca, 35%; Mg, 32%; K, 9%; Al saturation, 21%; available P, 48%; and organic matter, 15%.

Plot status	Months after burning	*p*H (H_2O)	Exchangeable (cmol dm^{-3}) Al	Exchangeable Ca	Exchangeable Mg	Exchangeable K	Al saturation (%)	Available P (Olsen) (mg dm^{-3})	Organic matter (%)
End of first cropping cycle (seven crops)	35	4.5	1.9	0.98	0.10	0.26	50	4	1.92
After 1 year of kudzu fallow (before burning)	52	4.5	1.8	0.60	0.09	0.13	68	7	
At first harvest of second cropping cycle	54	4.8	1.6	1.05	0.18	0.23	52	14	2.44
LSD (P = 0.05)		0.2	0.3	0.25	0.05	0.05	11	6	NS

Germplasm selection for acid tolerance continues at Yurimaguas (*33*). The most promising results are with acid-tolerant grain sorghums selected by Gourley and Flores (*34*). Selection continues with upland rice, particularly for high grain quality and milling percentage, attributes deficient in the prototype variety, Africano Desconocido. Selection for cowpea cultivars that develop a closed canopy in less time than the present ones is also desirable. Breeding for acid soil tolerance of maize, soybeans, and other important tropical crops that are acid-sensitive is being carried out throughout the world.

Low-input cropping is viable when initial conditions are favorable in terms of nutrient inputs from the ash and low-weed pressure found in a 10-year-old secondary forest. This system is unlikely to perform as well in nutritionally depleted, compacted, or weedy soils that are a product of mismanagement. The duration of the cropping period is probably a function of initial soil conditions and of processes related to fertility depletion and weed populations. A network of validation trials throughout the humid tropics, with the use of locally adapted cultivars, would help ascertain the applicability of this transition technology between shifting and continuous cultivation.

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18. Based on the coefficients of variation (CV) and protected least significant differences (LSD) for treatment means, the experimental error estimate appears reasonable when using the above design; samples within treatments did not result in an error that is biased downward (L. A. Nelson, personal communication).
19. Although a significance test between fertilized and unfertilized crop yields for each harvest was not possible, the following model was fitted to the increasing differences (delta) between treatments over time with rice: $e^y = e^{b_1 \text{time}} \cdot e^{b_2 \text{time}^2}$, where y is delta yield (tons per hectare), time is months after burning, $b_1 = -2.465$, and $b_2 = 1.540$ are coefficients estimated from the data. An estimate of error of 0.091 (in log delta scale) was obtained by using this model (L. A. Nelson, personal communication).
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