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Effects of land-clearing method and soil management on crop production in the Amazon[1]

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ABSTRACT

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The success of intensive, continuous cropping of newly cleared land in the humid tropics is highly dependent upon the method of land clearing and subsequent soil management. The objective of this study was to evaluate the effect of different land-clearing regimes, including initial tillage after clearing and subsequent soil management, on crop performance on an Ultisol in the Amazon Basin of Peru. The study was conducted on a Yurimaguas soil (fine-loamy, siliceous, isohyperthermic Typic Paleudult) covered by a 20-year-old evergreen forest which was cleared at the start of the experiment. Land-clearing treatments included slash and burn, bulldozing with a straight blade, and bulldozing with a shear blade. Post-clearing tillage methods were chisel-plowing and disking. Post-clearing soil management practices (subplots) included: (1) flat-planted, no fertilizer or lime added; (2) flat-planted, fertilizer and lime incorporated; and (3) soil bedded at a 1.1-m spacing and fertilizer and lime applied, as in subplot 2. The cropping sequence was upland rice [*Oryza sativa* L.]–soybean [*Glycine max* (L.) Merr.]–corn [*Zea mays* L.]–rice–corn. In general, all crops showed a positive response to the post-clearing tillage practices of chiseling and disking. The post-clearing soil-management practice combining fertilization, liming, and bedding generally produced the highest yields of rice and corn. The greatest average relative grain-yields, in descending order, were produced by the following management systems: slash/burn/flat-plant/fertilizer/lime (94% average relative grain-yield) > slash/burn/bedded/fertilizer/lime (90%) > shear-blade/burn/disk/bedded/fertilizer/lime (88%) > shear-blade/burn/disk/flat-plant/fertilizer/lime (86%).

INTRODUCTION

The success of intensive, continuous cropping of newly cleared land in the humid tropics is highly dependent upon the method of land clearing, quality of the clearing operation, selection of post-clearing tillage, and soil manage-

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ment practices. Little information is available concerning crop yields as affected by various combinations of land-clearing method and post-clearing management practices. Research of this type is expensive, time-consuming and requires large parcels of land. One comprehensive study, conducted by Lal (1981) on Alfisols in Nigeria, showed that corn [*Zea mays* L.] grain-yield was generally higher on manually cleared no-till plots than on plots cleared using bulldozers or heavy machinery.

The use of heavy machinery in the mechanical clearing process has been reported to reduce crop yields compared with traditional slash-and-burn clearing (Ferreira and Destoca 1969; Seubert et al., 1977). Poor root development due to severe soil compaction caused by heavy land-clearing machinery was reported by Van der Weert (1974). In the absence of fertilization, cumulative nutrient depletion associated with intensive cropping of clear-felled or slash-and-burn-cleared land can lead to serious declines in production (Lal, 1981). The detrimental effect of mechanized clearing is partially offset by judicious use of fertilizers, but crop yields are not as great as those for slash-and-burn-cleared plots (Uribe et al., 1967; De las Salas and Folster, 1976; Seubert et al., 1977; Lal, 1981).

A comprehensive land clearing study was initiated in the Amazon in Peru in 1980 (Alegre et al., 1986, 1988). Various post-clearing management practices were used for each of three clearing methods: slash, bulldozer clearing with a straight blade, and bulldozer clearing with a KG blade. Compaction increased bulk density in the 0–15-cm depth for all three clearing methods, but increased bulk density in the 15–25-cm depth for only the machine-cleared methods. This compaction reduced infiltration rate to $\leqslant 10\%$ of the original infiltration rate. Chisel-plowing reduced bulk density in the 15–25-cm depth, thus increasing infiltration rate.

The purpose of this paper is to present crop performance data for the various combinations of land-clearing method, post-clearing tillage and soil management. Detailed results on temporal changes in soil physical and chemical properties as affected by various combinations of these practices were reported previously (Alegre et al.,1986, 1988).

METHODS

The study was located in the humid tropics at Yurimaguas, Peru (5°45′S, 76°5′W) on a Yurimaguas soil (fine-loamy, siliceous, isohyperthermic Typic Paleudult). The 2.5-ha experimental site had a slope ranging from 2 to 5%. Prior to clearing, the site was covered with a 20-year-old evergreen forest with a biomass of 80–85 t ha^{-1}. Major vegetation species were *Cecropia scradifolia*, *Pollatestra discolor*, *Visnia cayenensia*, and *Croton* spp. Mean annual temperature is 26°C, with little daily or monthly variation. Mean annual

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rainfall is 2250 mm, with a dry period from June through August when mean monthly precipitation is about 100 mm.

The experimental design was a split-plot replicated three times. The six main-plot treatments consisted of various combinations of land clearing and post-clearing tillage (Table 1). Subplot treatments, randomly assigned within each whole plot, were various combinations of post-clearing management practices: (1) seeds planted on level soil (flat-planted) with fertilizer or lime added; (2) seeds flat-planted after inorganic fertilizer and lime were applied and incorporated by a rototiller at rates based on soil tests; and (3) soil bedded or ridged at 1.1-m spacings after inorganic fertilizer and lime were applied, as for subplot 2. Hereafter these subplot treatments will be denoted as F (flat-planted), FFL (flat-planted, fertilized, limed) and BFL (bedded, fertilized, limed), respectively. Subplot size was 25 m×6.5 m.

The cropping sequence was rice [*Oryza sativa* L.]–soybean [*Glycine max* (L.) Merr.]–corn [*Zea mays* L.]–rice–corn (Table 2). Inorganic fertilizer and dolomitic limestone application rates, applied before seeding each crop, are shown in Table 3.

Rice (cv. IR4-2) was planted on a 20-cm×20-cm grid. The beds for rice (subplot 3) were 15 cm high and were formed manually using a hoe. Rice in each subplot was hand-harvested on a 15-m^2 area, and grain-yield expressed at 13% moisture.

Soybean (cv. Jupiter) was inoculated with *Rhizobium japonicum* and seeded 10 cm apart in rows spaced 40 cm apart. Beds for soybean were 15 cm

TABLE 1

Description of main plot treatments

No.	Treatment[1]	Description
1	Slash/burn	Slash and burn; tree trunks removed by hand.
2	Straight blade	Cleared with Caterpillar D-6 bulldozer with a straight blade; trees mechanically windrowed.
3	Straight blade/chisel	Straight-blade clearing followed by chisel-plowing 25 cm deep, soil rototilled with 48-kW tractor.
4	Shear blade/burn/disk	D-6 bulldozer clearing with shear blade, vegetation burned, logs removed, disked 30 cm deep, rototilled with a 10-kW tractor before planting.
5	Shear blade	Clearing with shear blade, rototilled with a 10-kW tractor prior to planting.
6	Shear blade/disk	Clearing with shear blade, soil disked 30 cm deep, rototilled with a 10-kW tractor.

[1]Treatments 2 through 6 were planted using a hand-planter.

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TABLE 2

Chronological cropping sequence

No.	Crop	Date planted	Date harvested
1	Rice	28 Nov. 1980	30 March 1981
2	Soybean	27 May 1981	17 Sept. 1981
3	Corn[1]	30 Sept. 1981	18 Nov. 1981
4	Rice	20 Nov. 1981	23 March 1982
5	Corn	6 April 1982	16 July 1982

[1]A severe windstorm lodged this crop and no grain was produced.

TABLE 3

Application rates for inorganic fertilizer (kg ha^{-1}) and lime (t ha^{-1}) for each crop

No.	Crop	N	P	K	Mg	Lime
1	Rice	80	26	100	30	2.1
2	Soybean	20	26	66	40	1.5
3	Corn	100	26	100	30	–
4	Rice	50	13	50	–	–
5	Corn	100	26	100	30	1.0

high and were formed using a hoe. Soybean in each plot was hand-harvested from a 15-m^2 area, and grain-yield determined at 14% moisture.

Corn [cv. Amarillo Planta Baja (local variety)] was seeded at 20-cm intervals in rows 80 cm apart. Beds for the corn crop were 25 cm high and were formed with a hand hoe. Corn was hand-harvested from a 15-cm^2 area, and grain-yield expressed at 15% moisture. Because a severe windstorm lodged the first corn crop at anthesis, no grain was harvested but dry-matter of the tops was measured.

Weeding for all crops was manual, as needed.

RESULTS

Rice

Grain-yield of the first rice crop was greater for the slash/burn effects compared to all others (Table 4). Even though inorganic fertilizer and lime were applied to this treatment, it also benefitted from the nutrients released by burning the slash. The shear-blade/burn/disk treatment also benefitted from nutrients in the ash, and produced the second highest rice yield. Even when no fertilizer was added (subplot F), both the slash/burn and the shear-blade/burn/disk treatments produced higher rice yields compared to the other four treatments.

TABLE 4

Grain-yields (t ha^{-1}) and orthogonal contrasts for two rice crops

No.	Whole-plot treatment	Subplot treatment			
		F	FFL	BFL	Mean
First crop					
1	Slash/burn	3.11	3.56	3.98	3.55 a[1]
2	Straight blade	0.91	2.75	3.38	2.35 cd
3	Straight blade/chisel	1.14	2.84	2.85	2.28 cd
4	Shear blade/burn/disk	2.39	3.06	3.68	3.04 b
5	Shear blade	1.27	3.02	3.20	2.49 c
6	Shear blade/disk	0.91	2.58	2.74	2.07 d
	Mean	1.62 C[1]	2.97 B	3.30 A	
Fourth crop					
1	Slash/burn	0.75	3.48	2.82	2.35 b
2	Straight blade	0.26	1.56	2.00	1.27 d
3	Straight blade/chisel	0.70	3.04	2.91	2.22 b
4	Shear blade/burn/disk	1.58	3.44	2.96	2.66 a
5	Shear blade	0.97	2.13	2.28	1.80 c
6	Shear blade/disk	0.63	1.33	1.96	1.47 b
	Mean	0.81 B	2.58 A	2.49 A	

Orthogonal contrasts for main plot effects		**First crop**	**Fourth crop**
1 vs. 2,3,4,5,6	Hand vs. mechanical	**	**
4 vs. 6	Burning	n.s.	**
6 vs. 5	Disking	*	*
5 vs. 2	Blade type	n.s.	*
2 vs. 3	Chiseling	n.s.	**
Orthogonal contrasts for subplot effects			
FFL, BFL vs. F	Fertilizer and lime	**	**
FFL vs. BFL	Bedding	*	n.s.

*,**, *F*-tests significant at 5 and 1% probability level, respectively.

[1]For each crop, means within a given column with the same small letter and in a given row with same capital letter are not significantly different at the 5% level with the Waller-Duncan Multiple Comparison test.

Grain-yield for the second rice crop (fourth consecutive crop in the rotation) was greatest for the shear-blade/burn/disk treatment followed by the slash/burn and the straight-blade/chisel treatments (Table 4). In general, grain-yields averaged across all whole-plot treatments for each subplot treatment were 0.5–0.8 t ha^{-1} less for the fourth crop than for the first crop. Subplot BFL produced the highest yield for both rice crops, although yields of FFL and BFL were not significantly different for the fourth crop. Soil in the

beds maintained good structure, due in part to the fact that field laborers never walked on the soil in the elevated beds.

Orthogonal contrasts show that yield for the slash/burn treatment was significantly greater than for all other treatments combined. The response to burning for the fourth crop is probably related to nutrient availability, but Alegre et al. (1988) found no differences between these two treatments in the levels of P, K, Ca, Mg, or pH in the 0–15-cm soil depth. The shear-blade/disk treatment resulted in a significantly lower grain-yield than shear-blade clearing without disking. The disk operation compacted the soil below the coulters while loosening the surface soil (Alegre et al., 1986). No yield difference for the first crop was found between the shear-blade and straight-blade treatments. However, for the fourth crop, rice yield for the shear-blade treatment was 0.23 t ha^{-1} greater than for the straight-blade treatment. Loosening the soil with the chisel plow immediately after clearing with the straight blade had no effect on yield of the first rice crop, but effected a 0.95 t ha^{-1} yield advantage for the fourth crop.

A highly significant response to fertilizer was found for both rice crops, but only the first crop responded to bedding.

Soybean

Dry soil conditions and poor-quality seed resulted in unacceptably poor seed germination and, subsequently, a poor soybean stand. Grain-yields (Table 5) were considerably lower than the 2.5-t ha^{-1} mean yield obtained on other studies in the locality. Only the slash/burn and shear-blade/burn/disk treatments had mean yields greater than 1.5 t ha^{-1}.

Orthogonal contrasts show that the grain yield of 1.53 t ha^{-1} for the slash/burn treatment was significantly greater than the 1.22 t ha^{-1} mean for all other treatments combined. Shear-blade/burn/disk resulted in a 0.31 t ha^{-1} yield increase over that of shear blade alone. No yield difference existed between the shear-blade and straight-blade treatments, a result similar to that for the first rice crop. This result was not expected because more soil compaction occurred and more topsoil was removed during straight-blade clearing as opposed to shear-blade clearing (Alegre et al., 1986). Chisel-plowing following straight-blade clearing increased grain-yield 0.38 t ha^{-1} over straight-blade clearing alone, even though bulk density at the 15–25-cm depth of both treatments was similar (1.45–1.52 t m^{-3}; Alegre et al., 1986). A highly significant response to inorganic fertilizer and lime was found, but there was no response to bedding.

Corn

A severe windstorm destroyed the first corn crop before grain was pro-

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TABLE 5

Grain-yields (t ha^{-1}) and orthogonal contrasts for soybean

No.	Whole-plot treatment	Subplot treatment			
		F	FFL	BFL	Mean
1	Slash/burn	0.42	2.32	1.86	1.53 ab[1]
2	Straight blade	0.10	1.03	1.50	0.88 d
3	Straight blade/chisel	0.32	1.44	2.03	1.26 abc
4	Shear blade/burn/disk	0.48	2.17	2.05	1.57 a
5	Shear blade	0.18	1.37	1.87	1.14 cd
6	Shear blade/disk	0.12	2.01	1.56	1.23 bc
	Mean	0.27 B[1]	1.72 A	1.81 A	

Orthogonal contrasts for main plot effects		Second crop
1 vs. 2,3,4,5,6	Hand vs. mechanical	*
4 vs. 6	Burning	**
6 vs. 5	Disking	n.s.
5 vs. 2	Blade type	n.s.
2 vs. 3	Chiseling	*
Orthogonal contrasts for subplot effects		
FFL, BFL vs. F.	Fertilizer and lime	**
FFL vs. BFL	Bedding	n.s.

*,**, *F*-tests significantly at 5 and 1% probability levels, respectively.
[1]Means in a given column followed by the same small letter and means in rows followed by the same capital letter are not significantly different at the 5% level by the Waller-Duncan Multiple Comparison test.

duced. No significant difference in yield of the harvested stover was found for the four highest-yielding treatments: straight blade/chisel; shear-blade; shear-blade/disk; and shear-blade/burn/disk. The lowest yield of 1.38 t ha^{-1} occurred for straight-blade clearing (Table 6).

Grain-yield for the fifth crop was greater for the slash/burn and shear-blade/burn/disk treatments as compared to all others (Table 6). Yields of the fertilized and limed treatments exceeded those of subsistence agriculture in the area. Yields for the BFL subplots (> 2.8 t ha^{-1}) were similar to the long-term mean grain-yield of other experimental corn fields in the Yurimaguas locality (Sanchez et al., 1983). A positive yield response to bedding was obtained for all treatments receiving either disk or chisel-plow tillage immediately following clearing. This response is puzzling because bulk density, measured when the fifth corn crop was harvested, was not different for treatments 2 through 6 and no difference in bulk density was found across subplot treatments (Alegre et al., 1986); nor was mechanical impedance a factor (Alegre et al., 1988). In the absence of fertilizer and lime, most seedlings in subplot F died within

TABLE 6

Stover yield (t ha^{-1}; third crop) and grain-yield (t ha^{-1}) and orthogonal contrasts for corn

No.	Whole-plot treatment	Stover			
		F	FFL	BFL	Mean
Third crop (Stover)					
1	Slash/burn	0.33	4.63	3.17	2.71 b
2	Straight blade	0	1.60	2.54	1.38 c
3	Straight blade/chisel	0.13	5.16	4.33	3.21 a
4	Shear blade/burn/disk	0.76	5.14	4.15	3.35 a
5	Shear blade	0.20	4.49	4.25	2.98 ab
6	Shear blade/disk	0.19	4.81	3.67	2.89 ab
	Mean	0.27 C[1]	4.31 A	3.69 B	
Fifth crop (Grain)					
1	Slash/burn	0.39	2.86	3.30	2.18 a
2	Straight blade	0	1.47	1.18	0.88 c
3	Straight blade/disk	0	1.85	2.87	1.58 b
4	Shear blade/burn/disk	0.04	2.45	2.82	1.77 ab
5	Shear blade	0	1.36	1.76	1.04 c
6	Shear blade/disk	0	0.94	1.95	0.96 c
	Mean	0.07 C	1.82 B	2.31 A	

Orthogonal contrasts for main plot effects		**Fifth crop**
1 vs. 2,3,4,5,6	Hand vs. Mechanical	**
4 vs. 6	Burning	**
6 vs. 5	Disking	n.s.
5 vs. 2	Blade Type	n.s.
2 vs. 3	Chiseling	**
Orthogonal contrasts for subplot effects		
FFL, BFL vs. F	Fertilizer and lime	**
FFL vs. BFL	Bedding	**

**, *F*-test significant at 5 and 1% probability level, respectively.
[1]Means for a given harvest in columns followed by the same lower case letter and means in rows followed by the same capital letter are not significantly different at the 5% level by the Waller-Duncan multiple comparison.

15 days. The higher grain-yield in subplot BFL as compared to FFL is attributed to better seedling vigor, better rooting distribution, and the concentration of applied fertilizer and lime effected by forming the beds after the chemicals were applied. Soil aggregation as measured by wet-sieving was better in the beds (Alegre and Cassel, 1986). The slash/burn treatment with BFL management provided the best soil physical conditions, thereby resulting in less lodging and higher yields. Physical properties of the subsoil for the slash/burn treatment were never altered from their initial condition by land-clear-

ing, tillage, or post-clearing soil management, and therefore provided a favorable root environment.

The orthogonal contrasts in Table 6 show that the corn grain-yield of 2.18 t ha^{-1} for the fifth crop for the slash/burn treatment was greater than the mean yield for all other treatments combined. No yield difference due to disking was found, but burning effected a 77% yield increase. Use of the chisel plow to alleviate compaction immediately after clearing still provided a yield advantage for the fifth crop. As stated previously, no measurable differences in bulk density or mechanical impedance were detected at this time (Alegre et al., 1986). Yield was not affected by blade type. In general, the practice of bedding produced higher yields than flat-planting, but this result was inconsistent and varied with crop.

DISCUSSION

In an attempt to evaluate each whole plot treatment for the entire study, relative grain-yield (RGY; %) for each grain crop was calculated for each of the 18 whole plot-subplot combinations by

$$RGY = (Y_{t,s}/Y_m) \times 100 \quad (1)$$

where $Y_{t,s}$ is the yield for a particular whole-plot treatment (t) by subplot treatment (s) combination, and Y_m is the maximum yield for the 18 combinations. The use of relative yields, while helpful for comparisons, does not give any indication of overall actual yields as affected by treatment. Relative grain-yield values are helpful in assessing overall patterns in crop yield and, for this reason, results for the six higher-yielding systems are presented in Table 7. Of the 18 combinations, the maximum yield for each grain crop always occurred for either flat-planted/fertilized treatments or bedded/fertilized slash/burn treatments (denoted as 1-FFL and 1-BFL, respectively, in Table 7). However, the two shear-blade/burn/disk treatments (4-FFL and 4-BFL) and the straight-blade/chisel treatment (3-BFL) also gave respectable overall performance compared to the maximum-yielding slash/burn treatments. From a practical standpoint, it is significant that chisel-plowed land cleared by straight blade coupled with planting on beds (3-BFL) increased mean RGY for the four crops over that of treatment 2-FFL from 51 to 83%.

Based on intensive soil sampling including bulk-density and mechanical-impedance measurements before and after land clearing, soil compaction caused by the mechanical land-clearing equipment was found to be the most limiting factor affecting crop growth (Alegre et al., 1986). From this standpoint, shear-blade clearing was superior to straight-blade clearing, because the former caused less mixing of the surface and subsurface soil horizons and resulted in less surface and subsurface compaction. Compaction influences

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TABLE 7

Relative grain-yields (RGY; %) for crops for selected land-clearing/tillage/soil-management combinations

No.	Whole-plot treatment	Subplot	Rice (1st crop)	Soybean (2nd crop)	Rice (4th crop)	Corn (5th crop)	Mean
1-FFL	Slash/burn	FFL	89	100	100	87	94
1-BFL	Slash/burn	BFL	100[1]	80	81	100	90
2-FFL	Straight blade	FFL	69	44	45	45	51
3-BFL	Straight blade/chisel	BFL	72	88	84	87	83
4-FFL	Shear blade/burn/disk	FFL	77	94	99	74	86
4-BFL	Shear blade/burn/disk	BFL	92	88	85	85	88

[1]Maximum grain-yields for the 1st, 2nd, 4th and 5th crops were 3.98, 2.32, 3.48, and 3.30 t ha^{-1}, respectively.

soil air/water relationships which may constrain crop production primarily due to root-growth limitations (Trouse, 1979). Positive yield responses to chisel-plowing and disking alleviated some of the compaction that occurred during the clearing operation. This effect occurred for all groups.

Slash/burn clearing resulted in higher yields of rice, corn, and soybean as compared to mechanized clearing. Crop response to nutrients from the ash for the two treatments employing burns (slash/burn and shear-blade/burn/disk) was highly effective for the first rice crop, but decreased rapidly for successive crops. Yield of the first crop (rice) was not increased by fertilizer and lime applications for those treatments involving the burn. The same response was found by Seubert et al. (1977) for slash/burn clearing. In general, when burning is used after clearing, little or no fertilizer or lime will be required for the first crop, although subsequent crops should be fertilized and limed according to soil test recommendations. It will be beneficial to apply lime before planting the first crop so that it has time to react and increase soil pH for the second crop. While minor compaction of the soil surface occurred under slash/burn clearing (Alegre et al., 1986), severe deterioration of soil physical properties did not occur. Bedding the soil provides good drainage during the wetter periods and, in this particular study, it generally increased crop yields, but the yield increases could not always be attributed specifically to decreased bulk density or mechanical impedance (Alegre et al., 1986).

In a somewhat analogous land-clearing study on an Alfisol in Nigeria (Lal, 1981), corn yield was not affected by three land-clearing methods (D-6 bulldozer; manual clearing by chain-saw followed by burning; and manual clearing by chain-saw followed by removal of large tree trunks and branches), but was affected by post-clearing soil management which included two tillage regimes and two fertilizer levels. For the present study, the clearing and tillage operations were combined in the whole-plot treatments. When this point is

considered, the results of this study agree with those of Lal (1981), except that his corn yields were about 2 t ha^{-1} greater.

Of the mechanical land-clearing/tillage methods examined in this study, the shear-blade/burn/disk treatment produced the highest rice, soybean, and corn yields. For slash/burn clearing, bedding by hoe was beneficial because the beds reduced the amounts of compaction by foot traffic during hand-weeding operations.

Based on the results of this study, we believe the best mechanized-clearing system for Yurimaguas and similar soils is the shear-blade/burn/disk coupled with the application of fertilizer and lime, and formation of beds prior to seeding. In addition, we believe that any mechanical clearing procedure used on Ultisols should be followed by some form of secondary tillage, preferably deep tillage, to alleviate compaction incurred during the clearing operation.

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