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Effects of Land Clearing and Subsequent Management on Soil Physical Properties

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ABSTRACT

Large scale, mechanized land clearing is common in the humid tropics even though little attention has been given to defining and solving soil problems that may be created. The purpose of this study was to evaluate various combinations of land clearing method, burning of vegetation, post clearing tillage, and soil management on soil physical properties of a forested Ultisol in the Amazon basin. Land clearing methods used were (i) slash, (ii) bulldozer clearing with a straight blade, and (iii) bulldozer clearing with a shear blade. Specific effects associated with clearing were mechanization, bulldozer blade type, burning, disking, and chiseling. Post clearing soil management systems isolated effects of bedding, liming, and fertilization. Soil physical properties were measured before clearing and 14, 29, and 98 weeks after clearing. Compaction increased bulk density (ρ_b) of the 0- to 15-cm depth for all clearing methods, but ρ_b of the 15- to 25- depth increased by 0.1 Mg m^{-3} only for the bulldozer cleared treatments. Soil texture of the 0- to 15-cm depth was not altered by land clearing. Gravimetric water content at soil matric potentials -10 to -2 kPa was greatest for the straight blade cleared soil. The infiltration rate 14 weeks after clearing decreased 37, 96, and 90% for soil cleared by slash, straight blade, and shear blade, respectively, as compared to initial conditions. Chisel plowing and disking the newly cleared land increased the infiltration rate compared with straight blade without chiseling. Detrimental changes in soil physical properties caused by clearing were minimized when post clearing management practices of bedding, fertilization, and liming were adopted.

Additional Index Words: slash and burn, continuous cultivation, humid tropics, mechanical land clearing, shear blade, bedding.

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LAND CLEARING IS THE FIRST STEP in establishing continuous cultivation in the humid tropics. Clearing with heavy machinery is rapid, results in a variable substrate for root growth, and often compacts the soil and increases bulk density (ρ_b) with concomitant reductions in macroporosity, infiltration rate, available soil moisture, and soil aeration (Lal and Cummings, 1979; Seubert et al., 1977; Sanchez and Salinas, 1981; van der Weert, 1974; van der Weert and Lenselink, 1972, 1973). Slash and burn clearing, on the other hand, is a much slower process but effects fewer detrimental changes in soil properties compared with mechanical clearing. Moreover, there is a beneficial addition of plant nutrients released in the ash during burning (Nye and Greenland, 1964; Brinkman and De Nascimento, 1973; Seubert et al., 1977; Silva, 1979).

It is possible that the tillage and soil management practices used after land clearing may be just as or even more important than the land clearing method itself with respect to altering soil physical properties. Hence, the objective of this study was to evaluate the effects of land clearing method and subsequent soil management on selected soil physical properties of a forested Ultisol in the Amazon basin.

METHODS

The study was conducted on a Yurimaguas soil (fine-loamy, siliceous, isohyperthermic Typic Paleudult) from July 1980 to July 1982 on a 20-yr-old secondary evergreen forest at the Yurimaguas Experiment Station (5° 45' S, 75° 5' W, 184 m above sea level) in eastern Peru. Mean annual temperature is 26°C with little monthly or daily variation. Average annual rainfall is 2250 mm with a dry period in June through August when average monthly precipitation is about 100 mm (Fig. 1). A 2.5-ha site with slope ranging from 2 to 4% was selected. Forest mensuration indicated 232 m^3 wood ha^{-1} for trees with diam. >32 mm.

Details concerning sampling times, plot sizes, and the experimental layout for one of the three replicated blocks are presented in Fig. 2. The following soil physical properties were quantified before clearing: infiltration rate, texture of the surface soil (0–15-cm depth), cone index (CI), bulk density (ρ_b), soil water characteristics, and wilting point at the 0- to 15-(upper) and 15- to 25-cm (lower) depths. Measurement methods are presented later.

The second set of soil physical property measurements, taken 14 weeks after clearing, but before planting the first crop, included ρ_b, soil water characteristics at the upper and lower depths, infiltration rate, and texture. The third set of measurements, taken 29 weeks after clearing (before harvesting the first crop), included ρ_b, soil water characteristics,

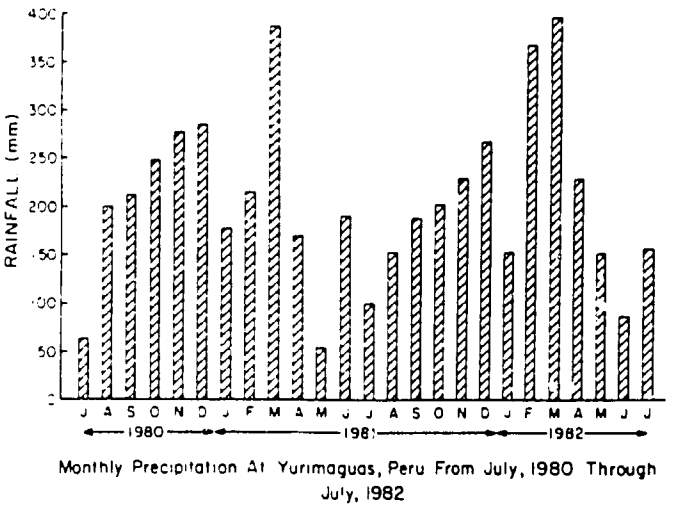

Fig. 1. Monthly precipitation at Yurimaguas, Peru from July 1980 through July 1982.

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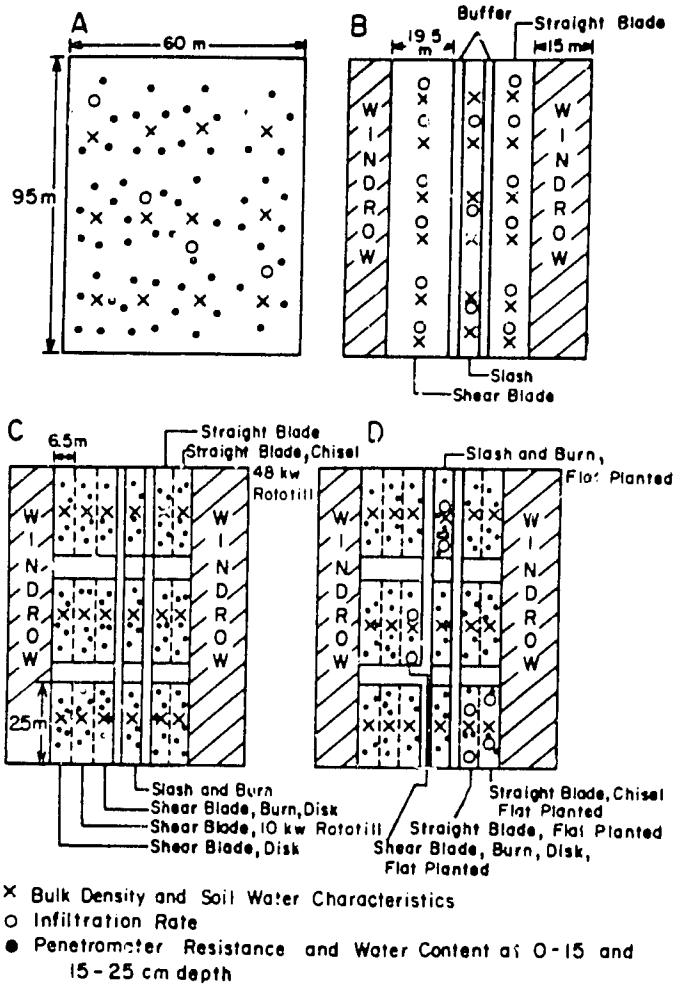

Fig. 2. Sampling points for soil physical properties in block 1 (one of three replicates): A) before clearing, B) 14 weeks after clearing; C) 29 weeks after clearing, and D) 98 weeks after clearing.

and CI at both depths. The final set of measurements was taken 98 weeks after clearing (before harvesting the fifth crop), and included infiltration rate and Db, soil water characteristics, and CI at both depths.

Two types of bulldozer blades were used. A straight blade is useful for road building but is considered undesirable for land clearing; however, due to its ready availability it is often used for this purpose. A shear blade is designed to shear trees near the soil surface, with minimal soil disturbance or mixing. A sharp projection called a "stinger" is located at one side of the curved shear blade and is used to splinter large trees to facilitate the shearing action.

The experiment utilized a split plot design with the whole plot factor arranged as a randomized complete block. Three blocks were used. The six randomly assigned whole plot treatments were various combinations (technology packages) of land clearing, vegetation burning, and post clearing soil tillage (Table 1).

Treatment 1 was slashed by hand, the vegetation burned, and the remaining tree trunks removed by hand but the stumps left in place. Treatment 2 was cleared with a Caterpillar[3] D-6 bulldozer with a straight blade, and the trees windrowed. Immediately before planting, the soil was rototilled using a 10 kW tractor. Treatment 3 was similar to

[3] The use of trade names in this publication does not imply endorsement by the North Carolina Agric. Res. Serv. of the products named for criticism of similar ones not mentioned.

Table 1. Land clearing method, vegetative burning, and soil tillage treatments.

Treatment number	Clearing method	Vegetation burned	Tillage
1	Slash	Yes	None
2	Straight blade	No	Rototill
3	Straight blade	No	Chisel, rototill†
4	Shear blade	Yes	Disk, rototill‡
5	Shear blade	No	Rototill
6	Shear blade	No	Disk, rototill‡

† 48 kW rototiller, all others with 10 kW rototiller.
‡ Disking by bulldozer.

Treatment 2 except the soil was chisel-plowed to the 25-cm depth and rototilled with a 48 kW tractor before planting. Treatment 4 was cleared with a D-6 bulldozer with a shear blade, vegetation burned, logs removed by bulldozer, and the soil disked 30 cm deep. The soil was rototilled with a 10 kW tractor before planting. For Treatment 5, the soil was cleared by shear blade and rototilled with a 10 kW tractor before planting. Treatment 6 was similar to Treatment 5 except that the soil was also disked to the 30-cm depth.

Three post clearing soil management practices were investigated. These subplot treatments, which were randomly assigned within each whole plot, were: (i) seeds planted on level soil (flat planted) with no fertilizer or lime applied; (ii) seeds flat planted with fertilizer and lime applied at rates based on soil tests and incorporated by a rototiller; and (iii) soil bedded or ridged at 1.1-m spacings with fertilizer and lime applied as for subplot (ii) above. Hereafter, these three post clearing soil management subplot treatments will be denoted by F, FFL, and BFL, respectively. Subplot size was 25 m by 6.5 m. The cropping sequence was upland rice (*Oryza sativa* L.)–soybean [*Glycine max* (L.) Merr.]–corn (*Zea mays* L.)–rice–corn. The first crop was planted on 28 Nov. 1980; the last, 6 Apr. 1982.

Cone index (CI), defined as the force required to push a penetrometer through an increment of soil divided by the projected cross sectional area of the penetrometer tip, was measured with a Soiltest model CN-970 proving ring cone penetrometer. Cone diam was 11.8 mm, and the cone angle was 30°. Bulk density was determined on 76-mm high by 76-mm diam undisturbed soil cores (Uhland, 1950). The soil water characteristic for each core was determined at soil matric potentials of 0, −0.03, −5.7, −8.7, −12.7, −17.8, −22.9, −33.0, and −43.2 kPa. The pore neck diameter (d) for each applied matric potential was calculated by

$$d = 400S \cos\theta / \rho_w gh \qquad [1]$$

where S = surface tension of water at 20°C, ρ_w = density of water, g = gravitational acceleration, h = soil water pressure head in m of water, and θ is the contact angle which was assumed to be zero.

Infiltration rate was measured in the field with a double ring infiltrometer having inner and outer ring diameters of 0.30 and 0.60 m, respectively. Wilting point was estimated using disturbed soil samples in a pressure chamber at −1500 kPa pressure.

RESULTS AND DISCUSSION

Soil Texture

Particle size distribution of the 0- to 15-cm depth after clearing was not significantly different as affected by clearing method (Table 2). It is assumed that soil texture of the slash treatment was identical to texture of the entire area before clearing because no soil mixing occurred during slash clearing. Based on the work of Seubert et al. (1977), the clay content of the upper

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Table 2. Mean and SD of clay, sand, and silt separates in the 0- to 15-cm depth of Yurimaguas soil as affected by clearing method.

Land clearing method	Soil separate		
	Clay	Sand	Silt
	%		
Slash by hand	10 (4)†a‡	63 (6)a	27 (5)a
Bulldozer with straight blade	11 (4)a	66 (9)a	23 (6)a
Bulldozer with shear blade	8 (5)a	66 (12)a	26 (8)a

† Each value is the mean of 18 measurements; SD is shown in parentheses.
‡ Means in a given column with the same letter are not significantly different at the 5% level by the Waller-Duncan Multiple Comparison test.

depth of soil cleared by the straight blade was expected to increase as a consequence of removing A horizon material and mixing A and B horizon material, but this did not occur. Nominal depth of the A horizon was 25 ± 10 cm. Our observations lead us to believe that topsoil removal and the mixing of topsoil and subsoil during clearing is probably more a function of the bulldozer operator than of the clearing method itself.

Bulk Density

Bulk density at the 0- to 15-cm depth prior to clearing was 1.16 ± 0.09 Mg m^{-3}. Clearing tended to increase the variation in bulk density (Table 3) as indicated by the generally higher standard deviations (SD). Compaction occurred for slash clearing due to foot traffic during the slashing and trunk removal processes. The greatest increase in ρ_b at 0- to 15-cm depth occurred for straight blade clearing, but it was not significantly different from the shear blade and slash methods. This lack of difference among clearing methods is attributed to the high variability of measured ρ_b for the mechanical methods. Bulk density in the 15- to 25-cm depth increased for both types of mechanical clearing, but not for slash clearing.

Bulk density at the two depths for all six whole plot treatments 15 d before harvesting the first (29 weeks after clearing) and last crops (98 weeks after clearing) are shown in Table 4. No differences existed in the upper depth prior to harvesting the first crop, but in the lower depth, greater ρ_b values were observed for

Table 3. Mean ρ_b and SD (in parentheses) of Yurimaguas soil prior to and 14 weeks after land clearing, but before planting the first crop.

Time	Clearing method	Depth (cm)	
		0 to 15	15 to 25
		Mg m^{-3}	
Before clearing†		1.16 (0.09)B¶	1.39 (0.08)B
Fourteen weeks after clearing:‡	Slash	1.27 (0.07)a§A	1.37 (0.10)b B
	Straight blade	1.42 (0.12)a A	1.49 (0.12)a A
	Shear blade	1.28 (0.25)a A	1.50 (0.15)a A

† Each value is the mean of 36 measurements.
‡ Each value is the mean of 18 measurements.
§ For the 14 weeks data, means in a given column with the same letter are not significantly different at the 5% level with the Waller-Duncan multiple comparison test.
¶ A t-test was used to compare each mean for each treatment at 14 weeks with the mean before clearing; unlike upper case letters for each comparison indicates a significant difference at the 5% level.

two of the shear blade cleared treatments as compared to the slash/burn treatment. After 98 weeks the ρ_b of the upper depth for the slash/burn treatment was significantly less than ρ_b of the two straight blade cleared treatments. Bulk density of the lower soil depth was significantly greater for all mechanized methods as compared to the slash/burn treatment.

Bulk density of the 0- to 15-cm depth at 29 weeks after clearing for the BFL management treatment was significantly less than that of FFL (Table 5), whereas no difference was observed between F and FFL, thus indicating a tillage effect but no fertilizer effect. No ρ_b differences were found among subplot treatments at the lower soil depth at 29 weeks or for either depth prior to harvesting the last crop. The whole plot by subplot treatment interaction was not significant for any depth or date.

Cone Index and Soil Water Content

Cone index data were subjected to a $\log_{10}$ transformation prior to statistical analysis because CI measurements were found to be log normally distributed. Prior to clearing, CI was slightly, but not significantly, greater for the 0- to 15-cm depth compared to the 15- to 25-cm depth (Table 6). As expected, $\log_{10}$CI was

Table 4. Mean ρ_b and SD (in parentheses) of Yurimaguas soil at two depths for two times as a function of land clearing method, vegetation burning and soil tillage treatment.

Method and treatment		29 weeks after clearing		98 weeks after clearing	
No.	Description	0 to 15 cm	15 to 25 cm	0 to 15 cm	15 to 25 cm
		Mg m^{-3}			
1	Slash/burn	1.17†(±0.10)a‡	1.37 (0.10)b	1.32 (0.04)c	1.38 (0.04)b
2	Straight blade	1.26 (±0.16)a	1.44 (0.19)ab	1.42 (0.06)ab	1.56 (0.15)a
3	Straight blade/chisel	1.25 (±0.09)a	1.49 (0.09)ab	1.46 (0.11)a	1.57 (0.07)a
4	Shear blade/burn/disk	1.18 (±0.11)a	1.45 (0.15)ab	1.34 (0.11)bc	1.52 (0.11)a
5	Shear blade	1.28 (±0.24)a	1.52 (0.12)a	1.32 (0.12)bc	1.58 (0.04)a
6	Shear blade/disk	1.31 (±0.14)a	1.56 (0.16)a	1.33 (0.11)bc	1.57 (0.06)a
		Significance level			
Comparison	Effect				
1 vs. 4	Hand vs. mechanical	NS	NS	NS	0.05
4 vs. 6	Burning	NS	NS	NS	NS
6 vs. 5	Disking	NS	NS	NS	NS
5 vs. 2	Blade type	NS	NS	NS	NS
2 vs. 3	Chiseling	NS	NS	NS	NS

† Each value is the mean of 9 measurements in cores of 76 by 76 mm.
‡ Means in a given column with the same letter are not significantly different at the 5% level by the Waller-Duncan multiple comparison test.

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Table 5. Mean ρ_b and SD (in parentheses) of Yurimaguas soil at two depths for two times as a function of post clearing soil management.

Subplot treatment	29 weeks after clearing		98 weeks after clearing	
	0 to 15 cm	15 to 25 cm	0 to 15 cm	15 to 25 cm
	Mg m^{-3}			
Flat planted (F)	1.30†(0.14)a‡	1.47 (0.18)a	1.36 (0.12)a	1.52 (0.12)a
Flat planted, fertilizer, lime (FFL)	1.28 (0.13)a	1.49 (0.13)a	1.37 (0.10)a	1.54 (0.11)a
Bedding, fertilizer, lime (BFL)	1.14 (0.13)b	1.46 (0.13)a	1.36 (0.10)a	1.52 (0.10)a

† Each value is the mean of 18 measurements.
‡ Means in a given column with the same letter are not significantly different at the 5% level by the Waller-Duncan multiple comparison test.

Table 6. Mean CI, mean $\log_{10}$ CI, and mean soil water content for two depth increments of Yurimaguas soil before clearing.†

Depth	CI	$\log_{10}$ CI	Soil water content
cm	kPa		g g^{-1}
0 to 15	745 (410)‡	2.809 (0.239)	0.226 (0.054)
15 to 25	684 (435)	2.771 (0.227)	0.225 (0.037)

† Each value is the mean of 180 measurements.
‡ Standard deviations are shown in parentheses.

negatively correlated with water content: correlation coefficients were −0.5 and −0.7 for the upper and lower depths, respectively, and both correlations were significant at the 5% level.

$\log_{10}$CI values 29 weeks after clearing in the 0- to 15-cm depth for the slash/burn treatment were significantly greater than those measured in two of the shear blade treatments and the straight blade treatments (Table 7). The high $\log_{10}$CI values for the slash/burn and shear blade/burn/disk treatments were the result of burning. Soil water content was uniform among all treatments when CI measurements were taken.

$\log_{10}$CI and water content at the two depths 29 weeks after clearing for each soil management treatment are shown in Table 8. $\log_{10}$CI in the upper depth was less for BFL as compared to FFL. The beds in BFL, constructed with hand hoes, minimized aggregate destruction. Foot traffic of farm laborers was a significant factor in compacting the soil surface and increasing mechanical impedance of the flat planted land. The laborers did not walk on the beds when weeding. The difference in $\log_{10}$CI between BFL and FFL had disappeared at 98 weeks. No differences in $\log_{10}$CI were found in the surface 0- to 15-cm depth due to the additions of fertilizer and lime nor in the 15- to 25-cm depth for either bedding or chemical amelioration. Although small differences in water content were measured at both depths (Table 8), they are thought not to be large enough to effect significant differences in $\log_{10}$CI.

Soil Water Characteristics and Pore Size Distribution

The soil water characteristic for the 0- to 15-cm depth prior to clearing is shown in Figure 3A. The vertical bar through each point is two SD units long. We consider the amount of water held between matric

Table 7. $\log_{10}$ CI and soil water content for the 0- to 15-cm depth of Yurimaguas soil 29 weeks after clearing as a function of land clearing method, vegetation burning and soil tillage treatments.

Method and treatment No.	Description	$\log_{10}$ CI	Soil water content
		kPa	g g^{-1}
1	Slash burn	2.746†(0.296)a‡	0.232 (0.022)a
2	Straight blade	2.575 (0.410)bc	0.215 (0.026)a
3	Straight blade chisel	2.547 (0.338)bc	0.207 (0.032)a
4	Shear blade burn disk	2.698 (0.252)ab	0.217 (0.029)a
5	Shear blade	2.534 (0.413)c	0.214 (0.032)a
6	Shear blade disk	2.451 (0.312)c	0.208 (0.041)a

† Each value is the mean of 27 measurements.
‡ Means in a given column with the same letter are not significantly different at the 5% level by the Waller-Duncan multiple comparison test. Standard deviations are shown in parentheses.

Table 8. $\log_{10}$ CI and soil water content for the 0- to 15- and 15- to 25-cm depths of Yurimaguas soil 29 weeks after clearing for three soil management treatments.

Subplot treatment	$\log_{10}$ CI	Soil water content
	kPa	g g^{-1}
0- to 15-cm depth		
Flat planted (F)	2.681†(0.338)a‡	0.211 (0.036)b
Flat planted, fertilizer, lime (FFL)	2.635 (0.324)a	0.226 (0.225)a
Bedding, fertilizer, lime (BFL)	2.460 (0.358)b	0.209 (0.030)b
15- to 25-cm depth		
Flat planted (F)	2.763 (0.286)a	0.216 (0.027)b
Flat planted, fertilizer, lime (FFL)	2.761 (0.289)a	0.226 (0.027)a
Bedding, fertilizer, lime (BFL)	2.817 (0.302)a	0.218 (0.023)b

† Each value reported is the mean of 54 measurements.
‡ Means with the same letter for a particular depth in a given column are not significantly different at the 5% level by the Waller-Duncan multiple comparison test.

potentials of −13 to −1,500 kPa to approximate the plant available water holding capacity before clearing and it is equal to 0.187 m^3 m^{-3}. The diameter of the largest pore neck which retains water at the applied soil water pressures is also shown in Fig. 3A. Pores with neck diameters >23 μm are drained at *in situ* field capacity.

The soil water characteristics at the 0- to 15-cm depth 14 weeks after clearing are presented in Figure 3B. Treatments with straight blade clearing had greater soil water contents at soil water pressures <−2 kPa when compared to treatments with slash/burn or shear blade clearing. These higher water contents are attributed to the destruction of macropores by compaction which in turn increased the volume of micropores. This same trend was present for the soil water characteristics for the 15- to 25-cm depth 14 weeks after clearing (Fig. 3C).

The soil water characteristic for the 0- to 15-cm depth for the three soil management subtreatments 29 weeks after clearing are shown in Fig. 3D. Subtreatment BFL, which had the lowest ρ_b (Table 5), had the greatest total porosity and greatest volume of large pores. There was no significant main treatment by subtreatment interaction for the soil water characteristic.

Infiltration Rate

The mean infiltration rate before clearing was 420 mm h^{-1} over a 2-h period (Fig. 4A). Mechanical clear-

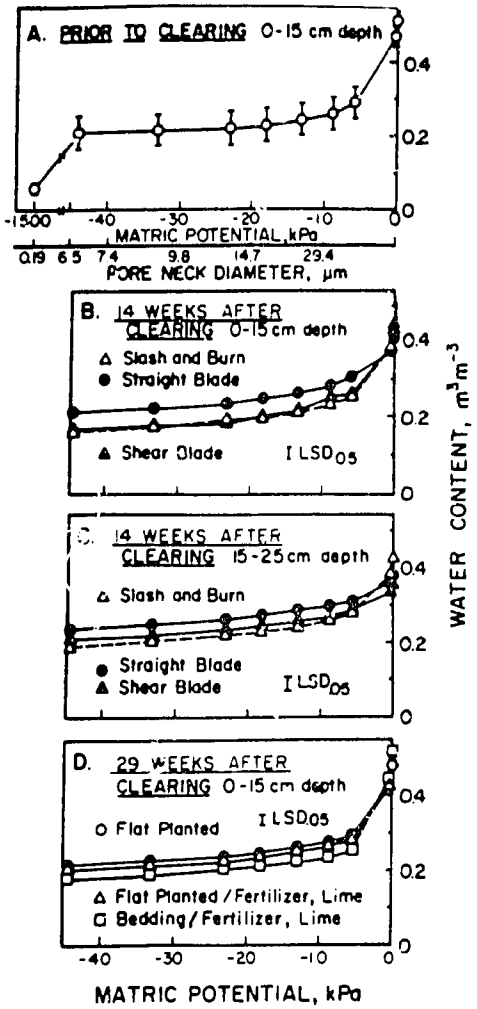

Fig. 3. Soil water characteristics of the 0- to 15- and 15- to 25-cm depths of Yurimaguas soil.

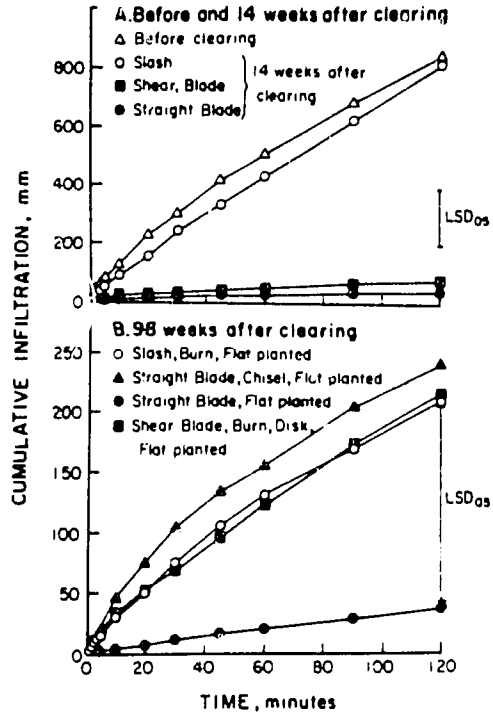

Fig. 4. a) Cumulative infiltration of Yurimaguas soil before and after clearing for three land clearing methods; b) cumulative infiltration for selected land clearing-tillage treatments 98 weeks after clearing.

ing with both the straight blade and the shear blade significantly reduced infiltration rate. Mean infiltration rates during the first 2 h of infiltration were 304, 14, and 32 mm hr^{-1} at 14 weeks after clearing for the slash, straight blade, and shear blade methods, respectively. Because infiltration measurements were so time consuming, it was not possible to measure cumulative infiltration for all mainplot-subplot combinations. However, measurements were replicated six times for the four combinations measured (Fig. 4B). Continuously cropping the Yurimaguas soil for 98 weeks after straight blade clearing and with no subsequent land treatment before flat planting (Treatment 2, F) resulted in a low infiltration rate. The same straight blade clearing method coupled with chisel plowing prior to flat planting (Treatment 3, F) resulted in a cumulative infiltration value similar to that for the slash/burn treatment (Treatment 1, F).

During the 84 week-long period of continuous cropping, cumulative infiltration over a 2-h period decreased from 800 to 200 mm for the slash/burn treatment (compare Fig. 4A and 4B). On the other hand, cumulative infiltration increased for the shear blade/burn/disk (Treatment 4, F) and the straight blade/chisel treatments.

CONCLUSIONS

Based on the sequentially monitored soil physical property data collected under continuous cropping—after imposing six different land clearing-burn-soil tillage combinations as main treatments and three post clearing management systems as subtreatments—we conclude that the greatest change in soil physical properties occur during the land clearing process. From a crop production viewpoint these changes tend to be negative, i.e., they degrade the land in that crop production is decreased if no effort is made to improve the resulting poor soil physical conditions. The least amount of soil physical property deterioration occurred for the slash/burn combination. Chiseling or disking tended to alleviate some of the poor soil physical conditions resulting from the mechanical land clearing operation. For example, the infiltration rates for soil cleared by the mechanized methods were increased by disking and chisel plowing prior to planting the first crop. Changes in physical properties under continuous cropping were minimized when the soil was bedded using a hand hoe. Compaction of both the topsoil and subsoil was less for the bedding system when no mechanization was used for land preparation.

Penetrometer resistance and bulk density of the topsoil increased with time after continuous cropping. This was true even for slash/burn clearing when flat planted, fertilized and limed: soil properties for this treatment underwent gradual deterioration as indicated by an increase in bulk density of the topsoil and a reduction in infiltration rate. Of the mechanical methods examined, we believe the best alternative to

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slash/burn clearing of a secondary forest is the combination of mechanical (shear blade) and traditional practices (burn).

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