PN-AAJ-624
74078

Reclamation of an Ultisol Damaged by Mechanical Land Clearing

J. C. ALEGRE, D. K. CASSEL, AND D. E. BANDY

Reprinted from the *Soil Science Society of America Journal*
Volume 50, no. 4, July-August 1986
677 South Segoe Rd., Madison, WI 53711 USA

Reclamation of an Ultisol Damaged by Mechanical Land Clearing[1]

J. C. ALEGRE, D. K. CASSEL, AND D. E. BANDY[2]

ABSTRACT

Mechanical land clearing in 1972 of a Yurimaguas soil (fine-loamy siliceous, isohyperthermic Typic Paleudult) located in the Amazon Basin of Peru resulted in compacted soil that was abandoned for continuous crop production in 1974. The purposes of this study were to reclaim this abandoned land for continuous cultivation and to evaluate temporal changes in soil physical properties with time after reclamation treatments began. In February 1980, guinea grass [*Panicum maximum* L.], which covered the compacted soil, was cut by hand, dried, and burned. The following eight reclamation treatments were imposed: (1) control (no till), planted with a planting stick; (2) rototill (12 kW) and stick planted; (3) rototill (48 kW); (4) chisel plow 25-cm deep, rototill (48 kW); (5) controlled traffic (i.e., assignment of pathways for foot traffic); (6) bedding with hoe and planted with stick; (7) simulated subsoiling to 25 cm with a tile spade; and (8) mulching (mulch applied when seedlings were 10- to 25-cm high). The following soil physical properties were quantified several times during the study: infiltration rate, cone index (CI), bulk density (ρ_b), and the soil-water characteristic. The crop rotation during the 2-yr-long period was rice (*Oryza sativa* L.)-soybean [*Glycine max* (L.) Merr.]-corn (*Zea mays* L.)-soybean-corn-rice. Compared to the control treatment, all others decreased ρ_b and CI and increased infiltration rate, macro porosity, and total porosity in the 0- to 15-cm depth. Only chisel plowing and simulated subsoiling alleviated the detrimental effects of the compacted soil below 15 cm. Infiltration rate at the conclusion of the experiment for the control treatment was 9 mm h^{-1} compared to 148 mm h^{-1} for the chisel plow treatment. Yield responses were greater for chiseling and simulated subsoiling. For example, the average relative grain yield for each of the three crops was 100% for chiseling; for no-till, relative yields were 69, 23, and 20% for rice, soybean, and corn, respectively. We conclude that compacted soils similar to the Yurimaguas series can be reclaimed for continuous cropping by using deep tillage practices such as chisel plowing and subsoiling.

Additional Index Words: **bulk density, slash and burn, mulch, soil-water characteristic, cone index, simulated subsoiling, bedding, chisel plow.**

Alegre, J.C., D.K. Cassel, and D.E. Bandy. 1986. Reclamation of an Ultisol damaged by mechanical land clearing. Soil Sci. Soc. Am. J. 50:1026-1031.

SLASH AND BURN CLEARING is a common practice in the Amazon Basin. Trees are felled by ax or chainsaw, left to dry for 3 weeks or longer, and the dried vegetation is burned. This labor-intensive practice is very time-consuming, but causes little physical damage to the soil.

Various mechanical land clearing methods have been proposed to replace the slower manual slash and burn method. Mechanical methods usually employ a crawler tractor and such tools as a straight blade, shear blade, or tree pusher with or without a front-mounted root rake (Webster and Wilson, 1980; Hulugalle et al., 1984). One effect of using heavy machinery to clear land is soil compaction, which reduces root penetrability, aeration, infiltration rate, water permeability, and crop yield (van der Weert and Lenselink, 1972, 1973; van der Weert, 1974; Seubert et al., 1977).

Both surface and subsurface compaction often occur when mechanical clearing is done when the soil is too wet. Clearing land under this condition is common because contractors are typically paid by the area cleared, not by the time required to clear a given parcel of land. When compaction is limited to the surface soil, good soil structure can often be restored by shallow tillage. However, if severe subsurface compaction occurs, the damage is less easily rectified (Greenland, 1977). Subsoil compaction can be loosened by deep chiseling, subsoiling, or other forms of deep tillage (Charreau and Nicou, 1971; van der Sar, 1976; Trouse, 1979; Kamprath et al., 1979). Presumably, if soil is severely compacted during mechanical land clearing, it can be reclaimed and maintained in a condition suitable for continuous crop production.

The objectives of this study were (i) to evaluate various techniques for reclaiming, for continuous cropping, land that was previously damaged by mechanical clearing and (ii) to assess the rates of change of selected soil physical properties in response to different land reclamation techniques.

METHODS

This study was conducted from February 1980 to March 1982 in the humid tropics at Yurimaguas, Peru (5°45′S, 76°5′W, 184 m above sea level). The Yurimaguas soil (fine-loamy, siliceous, isohyperthermic Typic Paleudults) had been compacted during land clearing in 1972 using a bulldozer with a straight blade (Seubert et al., 1977). Most of the bulldozed land was then cropped to upland rice (*Oryza sativa* L.), corn (*Zea mays* L.), and soybean [*Glycine max* (L.) Merr.] During the following 2-yr period, the infiltration rate for the bulldozed land remained at 1 mm h^{-1} as compared with the rate of 118 mm h^{-1} for the slash and burn cleared land. Soil bulk density at the 0- to 2-cm depth after 2 yr was 1.54 Mg m^{-3} for the mechanically cleared site as compared to 1.24 Mg m^{-3} for soil cleared by the slash and burn method. Unfertilized crop yields at this time were reduced to 33% of those for crops grown on slash and burn cleared land (Seubert et al., 1977). Because of this continuously decreasing

[1] Contribution from the Dep. of Soil Science, North Carolina State Univ. Paper no. 10056 of the Journal Series of the North Carolina Agric. Res. Service, Raleigh, NC 27695-7601. This study was funded in part by U. S. Agency International Development, Contracts AID/ta-C-1236 and DAN-1311-G-SS-1083-00. Received 9 Aug. 1985.

[2] Visiting Assistant Professor, Professor, and Visiting Associate Professor of Soil Science, North Carolina State Univ., Raleigh, NC 27695.

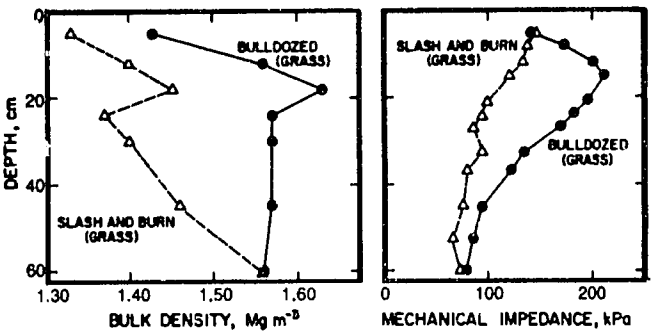

Fig. 1. Bulk density and mechanical impedance from the 0- to 60-cm depth before the land reclamation study began.

crop performance, the bulldozed land was abandoned in 1974. Since that time the land had been covered with guinea grass (*Panicum maximum* L.).

Selected soil physical and chemical properties of the previously bulldozed and abandoned land were characterized in 1979. A compacted zone between the 15- and 45-cm depth, as evidenced by an increase in bulk density and penetrometer resistance, was found for the mechanically cleared soil covered with grass (Fig. 1). Pertinent soil chemical data are shown in Table 1. Exchangeable acidity increased with depth and exchangeable Al saturation exceeded 60% at all three depths.

In February 1980, guinea grass, which covered the entire experimental area, was cut by hand, dried in place, and burned. Eight land reclamation treatments were installed in a randomized complete block design with four replications. Each treatment is described in Table 2. Plot dimensions were 4 by 10 m. Treatments 1 and 6 required no mechanized tillage equipment whereas treatments 2, 5, and 8 required small power machinery. Treatments 3 and 4 required a 48-kW tractor to pull the tillage implements. Chisel plow shanks spaced 30 cm apart extended 25 cm below the soil surface and physically disrupted the compacted soil to this depth. Because treatment 7 would require a more powerful tractor than was available, subsoiling was simulated by loosening the soil to the 30-cm depth with a tile spade at the positions where the rows would be planted later (Gooderham, 1976). The no-till treatment was a facsimile of the traditional slash and burn clearing method used in the area; it received no tillage and seeds were dropped into small holes made with a sharp pointed stick (planting stick). Dry plant material at the rate of 2 Mg ha^{-1} was brought in from outside the plot boundaries to serve as mulch for treatment 8.

The cropping sequence is shown in Table 3. Tillage was repeated before each successive crop was seeded. Prior to planting upland rice (cv. IR 4-2) on 2 February, all plots received lime at the rate of 1.0 Mg ha^{-1} and were fertilized at rates of 80, 44, 66, and 12 kg ha^{-1} for N, P, K, and Mg, respectively. The sixth crop, rice, received fertilizer at the same rate as the first crop. Seed spacing was 0.20 by 0.20 m when seeded with the planting stick; for all other treatments, rice was seeded with a Planet Jr.[3] in a continuous row with rows spaced 0.20 m apart. Each rice crop was hand-weeded twice. Rice straw and grain were harvested from 15 m^2 of area in each plot and the grain yield expressed at 13% moisture.

The second and fourth crops in the rotation, soybean (cv. Jupiter), received fertilizer at rates of 20, 44, 66, and 24 kg ha^{-1} for N, P, K, and Mg, respectively. The seed was inoculated with *Rhizobium japonicum* (Nitragin). Seed spacing was 0.40 by 0.05 m when stick planted; for the other treatments, soybean was seeded at the identical population

[3] The use of trade names in this publication does not imply endorsement by the North Carolina Agric. Res. Serv. of the product named nor criticism of similar ones not mentioned.

Table 1. Soil chemical properties prior to installing land reclamation treatments on Yurimaguas soil.

Depth	Acidity	Exchangeable acidity	Ca^{2+} + Mg^{2+}	Available P	Al Sat.	Organic C
cm	pH	— cmol (+) kg^{-1}	—	mg kg^{-1}	%	mg kg^{-1}
0-15	4.5	1.87	1.10	6.5	62.9	0.0114
15-30	4.5	2.82	0.64	2.3	81.5	–
30-45	4.4	3.30	0.35	1.3	90.4	–

Table 2. Reclamation treatments imposed on Yurimaguas soil damaged by mechanical land clearing in 1972.

1. Control, no till: cut grass and burn, plant with stick.
2. Rototill (12 kW): cut grass and burn, rototill, and plant with stick.
3. Rototill (48 kW): cut grass and burn, rototill, and plant with hand planter.
4. Chisel plow: cut grass and burn, chisel plow to 35-cm depth, rototill (48-kW tractor), plant with hand planter.
5. Controlled traffic: cut grass and burn, rototill (12 kW), and plant with hand planter; pathways for foot traffic were assigned.
6. Bedding: cut grass and burn, bedded with hoe, and plant with stick.
7. Simulated subsoiling: cut grass and burn, simulate subsoil operation with shovel, rototill, and plant with hand planter.
8. Mulching: cut grass and burn, rototill, and plant with hand planter; mulch was applied when seedlings were 0.1- to 0.3-m tall.

Table 3. Cropping sequence for six crops in the land reclamation study.

Crop	Planting date	Harvest date
Rice	2 Feb. 1980	6 June 1980
Soybean	20 June 1980	15 Oct. 1980
Corn	7 Nov. 1980	16 Feb. 1981
Soybean	20 Mar. 1981	7 July 1981
Corn	24 July 1981	10 Nov. 1981
Rice	26 Nov. 1981	3 Mar. 1982

using a Planet Jr. in rows spaced 0.40 m apart. Each soybean crop was hand-weeded once. The harvested area was 15 m^2. Grain yield was expressed at 14% moisture.

The third and fifth crops, corn (cv. Amarillo Planta Baja), received 0.50 Mg ha^{-1} of lime and 100, 44, 66, 12, and 20 kg ha^{-1} for N, P, K, Mg, and S, respectively. Seed spacing for all plots was 0.80 by 0.20 m. Corn was harvested from a 14.4-m^2 area and grain yield expressed at 15% moisture.

The following soil physical properties were quantified several times during the study: infiltration rate, cone index (CI), bulk density (ρ_b), and the soil water characteristics at the 0- to 15- and 15- to 25-cm depth. The first set of measurements was taken before harvesting the first crop (121 d after planting, hereafter denoted as the "121-d" sampling), the second set before harvesting the second crop (251 d); the third set before harvesting the third crop (375 d); and the fourth and final set before harvesting the sixth crop (755 d). *Cone index* is defined as the force required to push the cone of the Soiltest model CN-970 penetrometer through an increment of soil divided by the projected cross-sectional area of the penetrometer tip. Cone diameter was 11.8 mm and the cone angle was 30°. Twenty measurements were taken for each treatment at the 0- to 15- and the 15- to 25-cm depth for each sampling date. Bulk density for each treatment was determined on eight undisturbed soil cores, having dimensions of 76-mm height by 76-mm diam, within the 0- to 15-cm depth and four cores from the 15- to 25-cm depth for each sampling date.

The soil-water characteristics for each undisturbed soil core were determined at soil-water potentials of 0, −0.02, −5.7, −8.7, −12.7, −17.8, −22.9, −33.0, and −43.2 kPa. The pore neck diameter, d, is given by

$$d = 4\, S \cos \theta / \rho_w\, g\, h \qquad [1]$$

S = surface tension of water of 20°C, ρ_w = density of water,

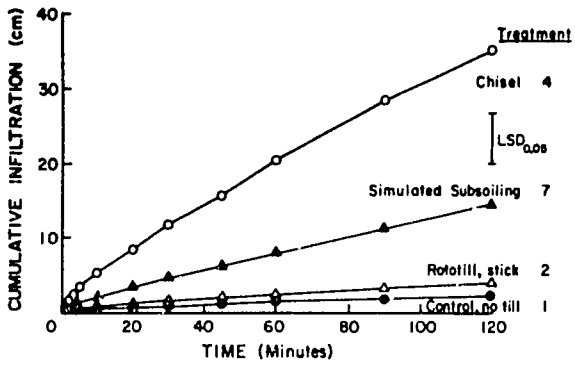

Fig. 2. Cumulative infiltration for selected treatments after growing six consecutive crops (after 755 d).

g = gravitational acceleration, h = soil-water pressure head in centimeters of water, and θ is the contact angle assumed to be equal to zero. Infiltration rate was measured with a double ring infiltrometer having inner and outer ring diameters of 0.30 and 0.60 m, respectively. Cumulative infiltration during a 2.00-h period was measured after the soil had been prewet by rainfall. Eight replicate infiltration measurements were taken for treatments 1, 2, 3, and 4 at the conclusion of the study (755 d).

Penetrometer resistance from the 0- to 60-cm depth for several pedons was measured with a Soiltest blunt-tipped pocket penetrometer. Small, 16.0-cm^3 undisturbed soil cores were taken adjacent to the location of the penetration measurements; ρ_b and water content were determined on these samples. Thirty-two penetrometer resistance, ρ_b, and water content measurements were taken at each depth for the fourth sampling date for treatments 1, 2, 4, and 7.

Corn root length was determined at tasseling for the third crop. A 170-cm^3 soil sample was collected from each of the 0- to 20-, 20- to 40- to 60-cm depths using a bucket auger. Four replicate samples were collected for each of three positions (row, 20 cm to the right of the row and 20 cm to the left of the row) for each treatment. Root length was determined by the modified line intersect method described by Sartain and Kamprath (1975).

RESULTS AND DISCUSSION

Infiltration

Cumulative infiltration vs. time for selected treatments 755 d after the study began is shown in Fig. 2. Because infiltration measurements were so time-consuming and the variability so high, we were able to thoroughly evaluate only four treatments. The control treatment (treatment 1) had the very low infiltration rate of 9 mm h^{-1}. Shallow rototillage did not increase the infiltration rate significantly (14 mm h^{-1}) because the action of this tillage operation did not extend deep enough to loosen soil below 10 to 15 cm. Simulated subsoiling and chisel plowing increased cumulative infiltration because both tillage operations extended below 15 cm and disrupted the compacted soil.

Cone Index, Soil-Water Content, and Bulk Density

Cone index measurements were log normally distributed and transformed by taking $\log_{10}$ of each CI value prior to statistically analyzing the data. Differences among treatments after 121 and 251 d were not significant for $\log_{10}$CI at the 0- to 25-cm depth. Soil-water content and $\log_{10}$CI for the 0- to 25-cm depth before harvesting the third (375 d) and sixth (755 d) crops are given in Table 4. The no-till control and the bedded treatment had consistently greater $\log_{10}$CI values. The bedded treatment was tilled (hoed) by hand to a maximum depth of 10 cm and thus did not alter the compacted soil below 10 cm. The chisel plow and the simulated subsoil operations resulted in consistently lower $\log_{10}$CI values because the soil was disrupted throughout the 25-cm depth. The lower $\log_{10}$CI values found for the chiseled and subsoiled treatments agree with the observation that the infiltration rates were also higher for these two treatments. Although soil-water content was significantly different among treatments, we believe these differences to be too small to greatly affect the measured CI values.

The effect of time (or cropping) on $\log_{10}$CI and soil-water content at the 0- to 25-cm depth are given in Table 5. These results appear erratic in that $\log_{10}$CI measured at 251 d was significantly less than the value measured at 121 d. The $\log_{10}$CI increased between 251 and 375 d and had the same value at 755 d as at 375 d. Hence, $\log_{10}$CI was the same at 121 and 755 d. These measurements, taken each time at water contents as close to in situ field capacity as possible, allowed us to observe the effect of continuous cropping on soil strength. In general, no great change in $\log_{10}$CI occurred with time. On the contrary, the changes that did occur appear to be more dependent on the crop, the number of passes of farm machinery and/or the number and frequency of laborers walking on the soil surface, and the soil-water content when this compaction occurs. Moisture content at the time of measurement is also important. The $\log_{10}$CI values at 375 and 755 d are not significantly different, yet the highest

Table 4. Effect of reclamation treatment on $\log_{10}$ CI and water content at the 0- to 25-cm depth before harvesting the third (375 d) and sixth (755 d) crops.

Treatment	Third crop		Sixth crop	
	$\log_{10}$ CI†	Water content	$\log_{10}$ CI	Water content
	kPa	kg kg^{-1}	kPa	kg kg^{-1}
Control (no till)	3.20 ± 0.14a*	0.174 ± 0.033b	3.18 ± 0.13a	0.190 ± 0.017bc
Rototill (12 kW)	2.99 ± 0.12c	0.180 ± 0.015ab	2.96 ± 0.15bc	0.205 ± 0.016ab
Rototill (48 kW)	2.97 ± 0.13c	0.181 ± 0.015ab	3.01 ± 0.19b	0.197 ± 0.026abc
Chisel plow	3.01 ± 0.19bc	0.172 ± 0.014b	2.87 ± 0.23c	0.191 ± 0.019bc
Controlled traffic	2.99 ± 0.13c	0.179 ± 0.013b	3.01 ± 0.17b	0.196 ± 0.019abc
Bedding	3.08 ± 0.16b	0.172 ± 0.016b	3.15 ± 0.15a	0.186 ± 0.016c
Simulated subsoiling	2.99 ± 0.19c	0.176 ± 0.018b	2.93 ± 0.16bc	0.190 ± 0.016bc
Mulching	2.98 ± 0.18c	0.019 ± 0.014a	2.98 ± 0.18b	0.208 ± 0.016a

* Means with the same letter in a given column are not significantly different with the Waller-Duncan multiple comparison test.
† Mean and standard deviation of 80 measurements.

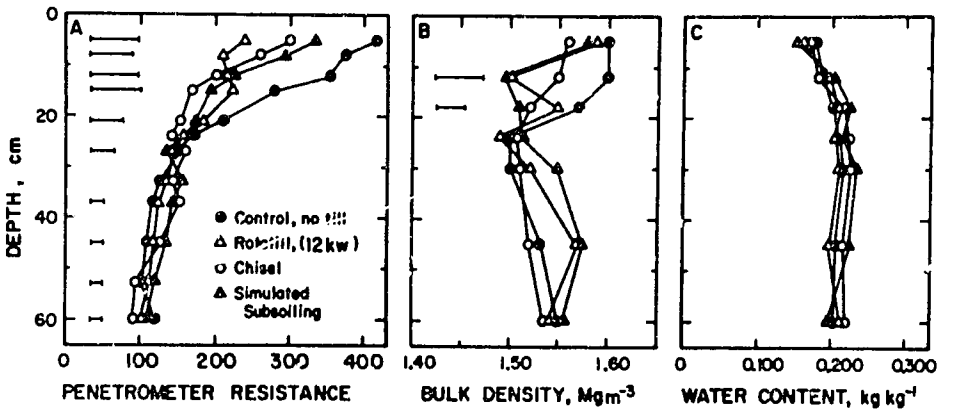

Fig. 3. Penetrometer resistance, ρ_b, and water content profiles for Yurimaguas soil for selected treatments in the reclamation study after 755 d of continuous cropping (six crops). Horizontal bars are the $LSD_{0.05}$ that compare differences among treatments for each depth.

water content occurred at 755 d. It is likely, therefore, that the soil was more compacted at 755 d than at any other time since the reclamation treatments were imposed. Data for the time means for bulk density in Table 6 support this viewpoint.

No significant difference in ρ_b at the 0- to 15-cm depth was observed among treatments for the 121- and 251-d samplings (Table 6). Variability of measured ρ_b values was high for both sets of measurements. Much of this variability had disappeared by the 375-d sampling when significant differences were found. The bedded treatment had the lowest ρ_b value primarily due to the fact that the field laborers did not walk on the beds. Bulk density before starting the study was 1.44 Mg m^{-3}. Tillage treatments effected an initial decrease in ρ_b of the 0- to 15-cm depth, which in turn increased with time during the continuous cropping period. When the topsoil was continuously tilled 3 times yr^{-1}, ρ_b increased because soil structure was periodically destroyed.

Figure 3 shows penetrometer resistance measured by the blunt tipped penetrometer (PR), ρ_b, and soil-water content profiles measured after growing six crops (755 d). Penetrometer resistance decreased significantly at the 0- to 5-, 5- to 10-, and 10- to 12-cm depth for rototilled, chiseled, and simulated subsoil tillage when compared with the no-till control (Fig. 3A). A significant difference in PR in the 12- to 21-cm depth occurred only for the chisel treatment; the low PR was due to the more uniform, deep tillage effected by chisel plowing.

Bulk density at the 12-cm depth was significantly lower for the rototill, chisel, and simulated subsoil treatments as compared with the no till treatment (Fig. 3B). At the 18-cm depth only the chisel and simulated subsoil treatments had significantly lower ρ_b values than the no till treatment. No ρ_b differences were observed for any other depth. Water content (Fig. 3C) did not differ significantly among treatments for any depth.

Soil-water Characteristics and Pore Size Distribution

The soil-water characteristics for the 0- to 15-cm depth were determined before the study and after 121, 251, 375, and 755 d. Soil-water content values averaged across all treatments for a given soil-water pressure are shown in Fig. 4. An increase in volume wetness (θ) at pressures < -2 kPa occurred for all times compared to the initial values.

Tillage increased the volume of macropores and de-

Table 5. Effect of time (or cropping) on $\log_{10}$ CI and water content at the 0- to 25-cm depth.

Time	Crop	$\log_{10}$ CI	Water content
days		kPa	kg kg^{-1}
121	Rice	3.00†b*	0.175c
251	Soybean	2.96 c	0.172d
375	Corn	3.02 a	0.178b
755	Rice	3.01 ab	0.195a

* Means with the same letter in a given column are not significantly different at the 5% level by the Waller-Duncan multiple comparison test.
† Each value is the eman of 320 measurements.

Table 6. Bulk density of undisturbed soil cores from the 0- to 15-cm depth before harvesting crops for the different land reclamation treatments.

Treatment	121 d	251d	375d	755d	Mean
	Mg m^{-3}				
Control (no till)	1.37† ± 0.14	1.39 ± 0.07	1.51 ± 0.05a*	1.55 ± 0.02	1.44a
Rototill (12 kW)	1.34 ± 0.08	1.38 ± 0.10	1.46 ± 0.08ab	1.45 ± 0.04	1.40ab
Rototill (48 kW)	1.39 ± 0.08	1.41 ± 0.11	1.49 ± 0.08ab	1.47 ± 0.10	1.43a
Chisel plow	1.34 ± 0.13	1.31 ± 0.09	1.49 ± 0.05ab	1.47 ± 0.09	1.40ab
Controlled traffic	1.33 ± 0.18	1.36 ± 0.07	1.47 ± 0.06ab	1.42 ± 0.14	1.36ab
Bedding	1.26 ± 0.11	1.32 ± 0.10	1.36 ± 0.08c	1.44 ± 0.06	1.33c
Simulated subsoil	1.33 ± 0.11	1.42 ± 0.08	1.50 ± 0.05ab	1.49 ± 0.02	1.43a
Mulching	1.27 ± 0.17	1.32 ± 0.08	1.46 ± 0.03b	1.41 ± 0.04	1.36bc
Time means	1.33 ± 0.12C	1.36 ± 0.09B	1.47 ± 0.07A	1.46 ± 0.08A	

* Means within a given column with the same lowercase letter, and time means followed by the same uppercase letter, are not significantly different at the 5% level by the Waller-Duncan multiple comparison test.
† Mean of eight measurements.

Table 7. Effect of reclamation treatment on grain yield of six consecutive crops at Yurimaguas, Peru.

Treatment	Rice (1st crop)	Soybean (2nd crop)	Corn (3rd crop)	Soybean (4th crop)	Corn (5th crop)	Rice (6th crop)
	Mg ha⁻¹					
Control	2.08	0.32c*	0.70c	0.49d	0.64e	1.44d
Rototill (12 kW)	2.24	1.16ab	2.66ab	1.23bc	2.41cd	2.51bc
Rototill (48 kW)	2.15	0.98ab	2.51ab	1.04c	2.38cd	2.29bc
Chisel plow	1.99	1.40a	3.22a	2.05a	3.45a	3.12a
Controlled traffic	2.19	0.79b	2.16b	1.09c	2.12d	2.16c
Bedding	1.56	1.01ab	1.16c	1.43bc	2.10d	2.51bc
Simulated subsoiling	2.15	1.27a	3.25a	1.61ab	3.06ab	2.57bc
Mulching	1.63	1.16ab	3.13a	1.47bc	2.74bc	2.67b

* Means within a given column with the same letter are not significantly different at the 5% level by the Waller-Duncan multiple comparison test.

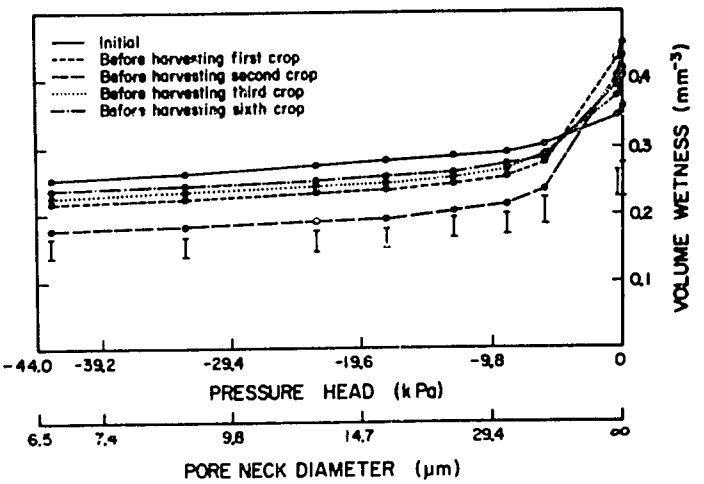

Fig. 4. Soil-water characteristics of the 0- to 15-cm depth of Yurimaguas soil. Vertical bars show the $LSD_{0.05}$ for each pressure.

creased the volume of micropores. The smallest volume of micropores, arbitrarily defined as those pores that drain at soil-water pressures <-4.9 kPa, was measured prior to harvesting the second crop (251 d) after which time it began to increase. This behavior is probably due to the effect of tillage before seeding each crop, a process that encourages aggregate destruction.

Grain Yield

Grain yields for the six crops are given in Table 7. The first rice crop was the only crop that did not have significant yield differences among treatments. Initially the soil structure was good in the surface soil of the no-till treatment due to aggregation effected by the 5-yr growth of guinea grass on the site. Guinea grass has been reported to increase organic C content and improve soil physical properties such as hydraulic conductivity and water-holding capacity of Alfisols of western Africa (Kang and Yunusa, 1977). The low rice yield for the bedded treatment probably resulted from a lower seeding rate compared to all other treatments. Rice plants did not grow well on the edges of the beds because roots were often exposed. The mulch treatment, which also had a low yield, had competition from grass that germinated from seed carried onto the plots during the mulching process.

Rice yields for the sixth crop did respond to reclamation treatment. Yield for the no-till treatment was significantly lower than all others and the highest yield was obtained for the chiseled treatment.

Table 8. Corn (third crop) root length vs. depth as affected by land reclamation treatment.

Treatment	Depth 0 to 0.2 m	0.2 to 0.4 m	0.4 to 0.6 m	Mean
	km m⁻³			
Control (no till)	20.7†	3.1	0.0	8.0‡
Rototill (12 kW)	42.7	7.1	1.6	17.1
Rototill (48 kW)	34.6	3.8	2.1	13.5
Chisel plow	45.8	22.2	11.3	26.4
Controlled traffic	44.2	5.5	2.7	17.5
Bedding	31.5	4.0	1.8	12.4
Simualted subsoiling	38.5	18.3	8.3	21.7
Mulching	35.9	9.8	2.0	15.9
$LSD_{0.05}$				
Treatment =	5.0			
Treatment × depth =	8.6			

† Each value is the mean of 12 measurements.
‡ Mean of 36 measurements.

Table 9. Effect of land reclamation treatment on relative grain yield for each crop.

Treatment	Rice	Soybean	Corn	Mean
	%			
Control	69†	23	20	37
Rototill (12 kW)	93	69	76	79
Rototill (48 kW)	87	59	73	73
Chisel plow	100	100	100	100
Controlled traffic	85	54	64	68
Bedding	80	71	49	67
Simulated subsoiling	92	83	94	90
Mulching	84	76	88	83

† Each value is the mean of the relative yield for two crops.

The second and fourth crops (soybean) had significantly lower yields for the no-till treatments than for all others (Table 7). Yields for both crops were poor, but those for the second crop were generally lower than the fourth due to drought and poor germination. Nevertheless, a response to chiseling and simulated subsoiling was observed. Mulching showed no yield advantage over the unmulched treatments even though the weather was dry. Lack of mulch response is probably associated with weed problems stemming from the applied grass mulch.

Corn showed the same general responses as soybean, with no-till having the lowest yield and the two deep tillage methods the highest. Corn root length data for the third crop are shown in Table 8. For all treatments, the highest root length occurred in the 0- to 20-cm depth, but root length in the 20- to 40-cm depth was significantly greater for the chisel plow and sim-

ulated subsoiled treatments than for all other treatments. Few roots penetrated below 40 cm for any treatment but this is especially true for the no-till control. These data support the idea that the deep-tillage operations improved the poor physical properties in the compacted subsoil and thereby allowed deeper and denser rooting.

Relative yield for the three crops for each reclamation treatment are summarized in Table 9. The greater relative yields were obtained for the deep tillage practices. Chisel plowing consistently produced the greatest yield and no-till the lowest.

Based on the soil physical properties, yield and root response data collected in this study, we believe that reclamation of soils similar to this compacted Yurimaguas soil can be attained using deep tillage and adequate fertilization. Compared to no-till, all treatments decreased ρ_b and CI and increased infiltration rate, the macro porosity, and total porosity in the 0- to 15-cm depth. However, only the two deep-tilled treatments alleviated the subsoil compaction. Tillage was effective in incorporating fertilizer and lime throughout the tilled layer. For all crops following the first rice crop, the soil physical properties for the no-till treatment were not conducive to root proliferation and even though fertilizer and lime were applied, this treatment yielded poorly. The first rice crop for the no-till treatment yielded well because it benefited from good soil structure in the 0- to 12-cm depth as a result of the guinea grass cover. It is possible that guinea grass would be beneficial in promoting regeneration of soil structure in the surface of compacted soils. However, deep tillage is necessary in deeply compacted soils to obtain soil structure conducive to root growth below the 15-cm depth.

REFERENCES

Charreau, C., and R. Nicou. 1971. L'amelioration du profil cultural dans les sols sableux et sablo-angileux de la zone topicale seche Ouest-Africaine et ses incidences agronomiques. Agron. Trop. (Paris) 26:1183–1247.

Gooderham, P.T. 1976. The effect on soil conditions of mechanized cultivation at high moisture content and of loosening by hand digging. J. Agric. Sci. 86:567–571.

Greenland, D.J. 1977. Soil damage by intensive arable cultivation: Temporary or permanent? Philos. Trans. R. Soc. London 281:193–207.

Hulugalle, N.R., R. Lal, and C.H.H. Ter Kuile. 1984. Soil physical changes and crop root growth following different methods of land clearing in western Nigeria. Soil Sci. 138:172–179.

Kamprath, E.J., D.K. Cassel, H.D. Gross, and D.W. Dibb. 1979. Tillage effects on biomass production and moisture utilization by soybean on Coastal Plain soils. Agron. J. 71:1001–1005.

Kang, B.T., and M. Yunusa. 1977. Effect of tillage methods and phosphorus fertilization on maize in the humid tropics. Agron. J. 69:291–294.

Sartain, J.B., and E.J. Kamprath. 1975. Effect of liming a highly Al-saturated soil on the top and root growth and soybean nodulation. Agron. J. 67:507–510.

Seubert, C.A., P.A. Sanchez, and C.V. Valverde. 1977. Effects of land clearing methods on soil properties and crop performance in an Ultisol of the Amazon Jungle of Peru. Trop. Agric. (Trin.). 54:307–321.

Trouse, Jr., A.C. 1979. Soil physical characteristics and root growth. p. 319–325. *In* R. Lal and D.J. Greenland (ed.) Soil physical properties and crop production in the tropics. John Wiley & Sons Inc., New York.

van der Sar, T. 1976. Tillage for dry annual crops in the humid tropics. Surinaamse Landbouw. 24(2–3):93–98.

van der Weert, R. 1974. Influence of mechanical forest clearing in soil conditions and the resulting effects on root growth. Trop. Agric. (Trinidad) 51:325–331.

van der Weert, R., and K.J. Lenselink. 1972. The influence of mechanical clearing of forest on some physical and chemical soil properties. Surinaamse Landbouw 20:2–14.

van der Weert, R., and K.J. Lenselink. 1973. The influence of mechanical clearing of forest on plant growth. Surinaamse Landbouw 21:100–111.

Webster, C.C., and P.N. Wilson. 1980. Agriculture in the tropics. Longman, Inc., New York.

7