PN-AB3-652
74182

0038-075X/86/1425-0289$02.00/0
SOIL SCIENCE
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November 1986
Vol. 142, No. 5
Printed in U.S.A.

EFFECT OF LAND-CLEARING METHODS AND POSTCLEARING MANAGEMENT ON AGGREGATE STABILITY AND ORGANIC CARBON CONTENT OF A SOIL IN THE HUMID TROPICS[1]

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The objective of this study was to evaluate the effects of land-clearing methods and subsequent soil management on aggregate stability and soil organic carbon (OC) content in the 0- to 15-cm depth. The 2-yr-long study, beginning in July 1980, was conducted on Yurimaguas soil (fine-loamy, siliceous, isohyperthermic Typic Paleudult) in the Amazon jungle of Peru The site was initially covered with a 20-yr-old secondary evergreen forest. Land-clearing methods were: (1) slash-and-burn, with logs removed by hand, but stumps remaining in place; (2) mechanical clearing with a bulldozer with a straight blade; and (3) mechanical clearing with a bulldozer with a shear blade. Soil samples were taken before clearing and at 3, 8, and 23 mo after clearing. After the second soil sampling, various land-preparation techniques were superimposed upon the three clearing methods to give a total of six land clearing-soil management treatments. Each treatment was split in three subtreatments: (1) flat-planted with no fertilizer or lime, (2) flat-planted with recommended rates of fertilizer and lime, and (3) bedding with fertilizers and lime. The third and fourth sets of soil samples (8 and 23 mo after clearing) were taken prior to harvesting the first and fifth consecutive crops, respectively. Straight-blade clearing reduced mean weight diameter (MWD) and OC by 39 and 21%, respectively. The least change in these two soil properties occurred for slash-and-burn clearing, with an 11% reduction in MWD and no change in OC. No significant changes in the percentages of five water-stable aggregate size classes occurred between 8 and 23 mo after clearing. Soil-management practices, such as bedding and lime application, tended to maintain aggregate stability and OC levels of newly cleared land during the first 2 yr of continuous cropping.

Many well-drained Ultisols of the humid tropics have sandy A horizons and organic matter contents of 2% or less (Sanchez et al. 1982). When land is mechanically cleared for continuous cropping, the natural soil structure is often degraded and the organic matter content reduced, due to mechanical removal of topsoil from the cleared area, increased exposure, and postclearing management practices (Seubert et al. 1977).

Soil structure and aggregate stability are often directly correlated with organic carbon (OC) content. Structural attributes of soils important to crop production may be considered in terms of their porosity. Macropores are necessary for root growth, air exchange, and drainage. Smaller pores are directly related to "stronger" aggregates. Because smaller pores hold water more tenaciously than larger pores, they often are not well aerated, and their organic matter content may be higher (Lal and Greenland 1979). Whereas tillage operations can be used to modify soil structure and create a range of transmission pores in surface soils, the stability of aggregates depends largely on materials returned or added to the soil (Lugo-Lopez and Juarez 1959; Grohmann et al. 1966; Greenland 1981). Van Bavel (1949) suggested that, by characterizing the size distribution of aggregates in one single representative figure, it is possible to test a hypothesis about difference in structure between two soils or to correlate a certain treatment with aggregate size distribution.

Several studies have included examination of the effect of continuous cropping on aggregate stability. Aggregate stability has been reported to be reduced by cultivation (Moreau 1978). Gomes et al. (1978) reported that continuous cropping of an Ultisol in Brazil increased macroporosity, but did not alter microporosity. As a result, continuous cropping decreased aggre-

[1] Paper no. 9898 of the Journal Series of the North Carolina Agric. Res. Serv., Raleigh 27695-7601. Part of this study was funded by the U.S. Agency for International Development, Contracts AID/ta-C-1236 and DAN-1311-G-SS-1083-00.

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Received for publication 3 June 1985; revised 1 October 1985.

gate stability. Continuous cropping of an Alfisol and an Ultisol in Senegal for 15 yr decreased structural stability (Fauck et al. 1969).

The purpose of this research was to evaluate the effect of several land-clearing and soil-management practices on water-soluble aggregates and OC contents under a continuous cropping system in an Ultisol in Peru.

METHODS

This experiment was established at the Yurimaguas Experiment Station (5°45′S, 76°5′W, 184 m above sea level) in the Amazon jungle in Peru. Mean annual temperature is 26°C and mean annual rainfall is 2250 mm. A 2.5-ha site, 1 to 4% slope, covered with a 20-yr-old secondary evergreen forest was selected. The soil belongs to the Yurimaguas series (fine-loamy, siliceous, isohyperthermic Typic Paleudult). Mensuration of the trees on the site, which ranged from 700 to 32 mm diameter at breast height, indicated 232 m^3 wood ha^{-1}. The experimental design was a split plot replicated three times.

Prior to clearing, approximately 1 kg of soil was removed from the 0- to 15-cm depth at 36 randomly located sites in the experimental area. Soil samples were air-dried, and the degree of initial aggregation and OC content were determined.

Aggregate stability was measured using a modified wet-sieving technique (Yoder 1936) employing the apparatus designed by Van Bavel (1952). Nests of sieves with openings of 0.10, 0.25, 0.50, 1.00, and 2.00 mm were used. The sieving apparatus, which contained six nests of sieves, had a vertical stroke of 12 mm at a rate of 30 strokes per min. For each sample, 30.0 g of air-dry soil material was passed through a 2-mm sieve, placed on the screen of a 1-mm sieve, allowed to soak for 5 min, and wet-sieved for 10 min. Soil material remaining on each sieve was oven-dried for 24 h at 105°C, weighed, and mechanically dispersed in a 10% sodium hexametaphosphate solution, and each fraction was sieved through the same nest of sieves to determine the size distribution of the sand fraction.

The percentage of water-stable aggregates for the ith fraction (AS_i) was computed according to Hillel (1980) as follows

$$AS_i = \frac{M_{soil,i} - M_{sand,i}}{M_{soil,t} - M_{sand,t}} \times 100 \qquad (1)$$

where $M_{soil,i}$ is the total mass of oven-dry soil material retained after wet-sieving for the ith fraction, $M_{sand,i}$ is the oven-dry weight of the sand for the ith fraction, $M_{soil,t}$ is the total mass of the whole soil sample (30.0 g), and $M_{sand,t}$ is the mass of sand in the whole soil sample.

Aggregate mean weight diameter (MWD) was calculated by

$$\mathrm{MWD} = \left(\sum_{i=1}^{n} x_i w_i \right) / \sum w_i \qquad (2)$$

where x_i is the mean diameter of the ith aggregate fraction, w_i is the mass of aggregates in that fraction, and $\sum w_i$ is the total mass of the sample (Van Bavel 1949). Geometric mean diameter (GMD) was calculated (Mazurak 1950) by

$$\mathrm{GMD} = \exp[(\sum w_i \log(x_i))/\sum w_i] \qquad (3)$$

Organic carbon content was determined by the Walkley-Black method (Allison 1965) on a subsample of each soil sample undergoing aggregate analysis.

The second set of soil samples for aggregate stability and OC determinations was taken 3 mo after clearing. The three land clearing treatments investigated were: (1) slash-and-burn, with logs removed by hand and stumps remaining in place; (2) mechanical clearing with a Caterpillar D-6 bulldozer with a straight blade; and (3) mechanical clearing with a D-6 bulldozer with a shear blade.[3] After the second sampling, land-preparation treatments were superimposed upon the three clearing methods, to give a total of six land-clearing and soil-tillage treatments as defined in Table 1.

Details concerning sampling dates, plot size, and experimental layout are presented in Fig. 1. The three subplot treatments are defined in Table 2. The third sampling for aggregate stability determination was performed 8 mo after clearing, immediately before harvesting the first crop, upland rice (*Oryza sativa* L.). The fourth sampling was taken 23 mo after clearing and prior to harvesting the last crop (*Zea mays* L.). Crop residue remained on the land after each harvest.

[3] The use of trade names implies neither endorsement by the North Carolina Agric. Res. Serv. of the products named nor criticism of similar ones not mentioned.

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TABLE 1

Land-clearing and soil tillage treatments

Treatment no.	Treatment	Description
1	Slash/burn	Slash and burn; tree trunks removed by hand; planted with stick
2	Straight blade	D-6 bulldozer with straight blade; trees immediately windrowed; rotovated land with 14-hp tractor; plant with Planet, Jr.
3	Straight blade/chisel	D-6 bulldozer with straight blade; trees immediately windrowed; land chisel plowed, rotovated with 65-hp tractor; planted with Planet, Jr.
4	Shear blade/burn/disk	D-6 bulldozer with shear blade; vegetation dried on land, burned, then logs removed by bulldozer; disked with bulldozer; 14-hp rotovator; plant with Planet, Jr.
5	Shear blade	D-6 bulldozer clearing with shear blade; rotovated land with 14-hp tractor; plant with Planet, Jr.
6	Shear blade/disk	D-6 bulldozer with shear blade; disk with bulldozer; 14-hp rotovator; plant with Planet, Jr.

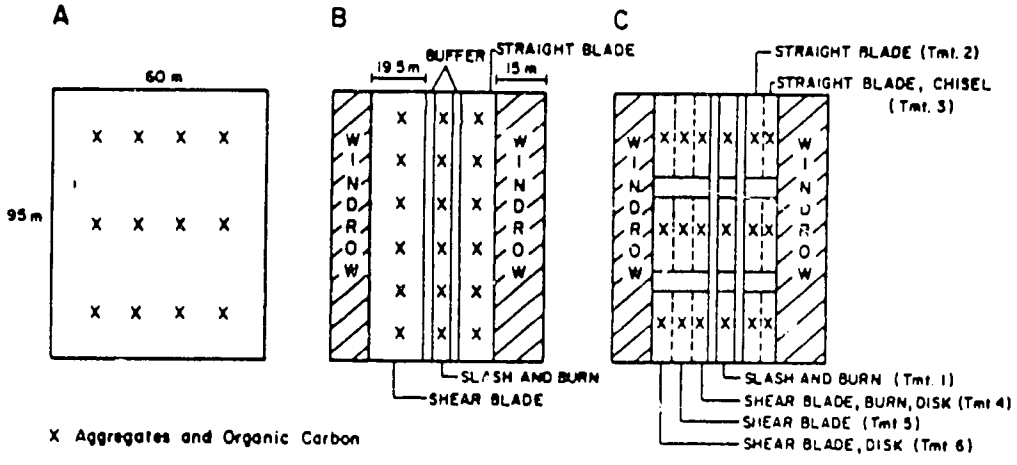

FIG. 1. Soil sampling pattern at different times for measurements of aggregate stability and organic carbon content: A, first sampling (before clearing); B, second sampling (3 mo after clearing); C, third (8 mo after clearing) and fourth (23 mo after clearing) samplings.

RESULTS AND DISCUSSION

Aggregate stability

The percentage of water-stable aggregates in each of the five fractions before clearing and for each of the three land-clearing treatments 3 mo after clearing are shown in Fig. 2. Straight-blade clearing resulted in the greatest decrease in the 2- to 1-mm and 1- to 0.5-mm fractions and the greatest increase in the <0.10-mm fraction.

Many of the larger aggregates were crushed or, in some cases, pushed into windows during straight-blade clearing. The 0.25- to 0.50-mm aggregate fraction did not change as a result of clearing; this fraction is highly correlated with air porosity and water-holding capacity and tends to be quite stable (Henin and Gras 1972).

TABLE 2

Land-management subtreatments imposed on the various land-clearing and soil-tillage treatments

Subtreatment	Description
1	Flat-planted; no fertilizer or lime added
2	Flat-planted; fertilizer and lime added based on soil test
3	Bedded at 1.1-m spacing; fertilizer and lime added based on soil test

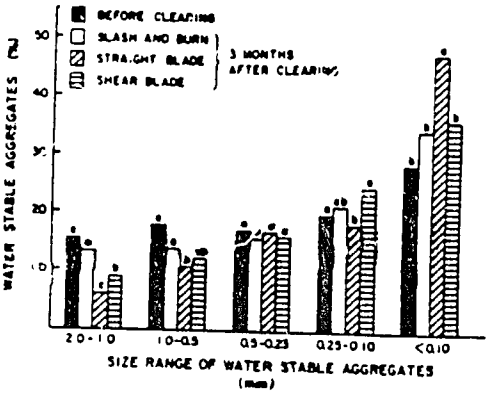

FIG. 2. Percentage of water aggregates before clearing and 3 mo after clearing affected by land-clearing method. For each aggregate class, columns with the same letter are not significantly different at the 5% level by the Waller-Duncan multiple comparison test.

TABLE 3

Mean weight diameter (MWD), geometric mean diameter (GMD), and organic carbon (OC) before and 3 mo after land clearing in Yurimaguas, Peru

		MWD $\bar{X}$	MWD SD	GMD $\bar{X}$	GMD SD	OC $\bar{X}$	OC SD
		mm				%	
Before clearing[a]		0.484 ± 0.090a[c]		0.556 ± 0.060a		1.04 ± 0.20[c]	
3 mo after clearing	Slash/burn[b]	0.424 ± 0.098a		0.516 ± 0.068a		1.05 ± 0.10a	
	Straight blade[b]	0.292 ± 0.063b		0.439 ± 0.037b		0.82 ± 0.17b	
	Shear blade[b]	0.358 ± 0.073ab		0.485 ± 0.042ab		0.87 ± 0.20ab	

[a] Mean of 36 measurements.

[b] Mean of 18 measurements.

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

TABLE 4

Mean percentage and standard deviation of stable aggregates for the six land-clearing and soil-tillage treatments combined at 8 and 23 mo after clearing

No.	Treatment	2-1 mm	1-0.5 mm	0.5-0.25 mm	0.25-0.1 mm	< 0.1 mm
		%				
1	Slash/burn	10.6[a] ± 5.6	15.7 ± 5.1	18.5 ± 4.7	19.0 ± 8.4bc[c]	35.2 ± 11.5ab
2	Straight blade	8.4 ± 3.9	14.5 ± 3.5	18.4 ± 3.4	24.5 ± 10.0ab	34.2 ± 10.1ab
3	Straight blade/chisel	7.6 ± 4.6	13.3 ± 3.7	19.6 ± 4.6	20.6 ± 6.4bc	37.8 ± 11.4a
4	Shear blade/burn disk	10.6 ± 2.7	16.7 ± 2.8	18.9 ± 2.3	26.9 ± 5.1a	27.7 ± 7.3b
5	Shear blade	9.4 ± 4.5	15.7 ± 3.9	19.6 ± 4.4	18.4 ± 4.9c	36.9 ± 9.0ab
6	Shear blade/disk	8.3 ± 4.1	16.6 ± 4.8	18.4 ± 3.8	23.6 ± 7.2abc	32.9 ± 10.2ab
		NS	NS	NS		

[a] Means all based on 36 measurements.

[c] Means in a given column followed by the same letter are not significantly different at the 5% level by the Waller-Duncan multiple comparison test. NS indicates nonsignificant differences.

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Mean weight diameter and GMD before and 3 mo after land clearing are shown in Table 3. Measured values for these parameters before clearing are assumed to be in equilibrium with environmental conditions prevailing in the secondary forest. MWD and GMD were not affected by slash-and-burn clearing. The trend was for MWD and GMD for the straight blade to be significantly lower than for the slash-and-burn method, but not for shear-blade clearing. Only mechanical clearing with the straight blade resulted in a significant reduction in MWD and GMD. Topsoil removal and compaction associated with cutting the larger roots and removing debris from the surface resulted in the destruction of many of the larger aggregates for the straight-blade-clearing method. Suebert et al. (1977) reported significant disturbance and compaction of the same soil series caused by straight-blade clearing. The exposed soil resulting from straight-blade clearing is very susceptible to erosion for 2 to 4 wk until natural vegetation regrowth or planted crops provide a soil cover.

Analysis of variance of the soil aggregate data revealed that no significant changes in the percentage of aggregates in the five classes occurred between the third and fourth samplings. Pooled data for these two samplings are shown in Table 4. Although some significant differences among treatments existed for percentage of aggregates in the two smaller classes, these differences tended to be small. The slash-and-burn and shear-blade-cleared treatments were among those treatments that had the lowest amounts of 0.25- to 0.1-mm aggregates; these two treatments were disturbed the least during clearing. The low percentage of <0.1-mm aggregates for treatment 4 undoubtedly is a result of organic matter loss upon burning, coupled with destruction of larger aggregates by disking.

Continuous cropping did not cause further destruction of soil aggregates. Temporal effects on the distribution of water-stable aggregates, averaged across all land-clearing and tillage treatments and all land management systems, are shown in Table 5. Only the percentage of aggregates in the 0.25- to 0.1-mm fraction changed significantly during the 15-mo continuous cropping period (between 8 and 23 mo), and it changed by only 4%. Upon reexamination of Fig. 2, one can see that the 2- to 1-mm aggregate fraction decreased as a result of clearing, not as a result of continuous cropping.

TABLE 5

Effect of time on water-stable aggregates

Time	Crop	2-1 mm	1-0.5 mm	0.5-0.25 mm %	0.25-0.1 mm	<0.1 mm
Before clearing	Secondary forest	15.6[a] ± 4.0b[b]	18.0 ± 4.7a	17.1 ± 4.1a	20.3 ± 6.4b	29.0 ± 8.8b
8 mo after clearing	Rice	9.[illegible] ± [illegible]9b	15.9 ± 4.1a	18.8 ± 4.1a	20.0 ± 6.8b	35.2 ± 11.8a
23 mo after clearing	Corn	8.8 ± 3.9b	14.9 ± 3.7a	19.0 ± 3.8a	24.3 ± 8.1a	32.9 ± 8.6a

[a] All means based on 54 measurements.
[b] Means in a given column followed by the same letter are not significantly different at the 5% level by the Waller-Duncan multiple comparison test.

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TABLE 6

Mean weight diameter and geometric mean diameter prior to harvesting the first and fifth crops for the six land-clearing and soil-tillage treatments

No.	Treatment	First crop (8 mo after clearing)				Fifth crop (23 mo after clearing)			
		MWD		GMD		MWD		GMD	
		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
		mm							
1	Slash/burn	0.417 ± 0.130[a]		0.527 ± 0.088		0.378a ± 0.063		0.500 ± 0.032	
2	Straight blade	0.372 ± 0.090		0.496 ± 0.058		0.359 ± 0.059		0.497 ± 0.031	
3	Straight blade/chisel	0.336 ± 0.079		0.486 ± 0.067		0.351 ± 0.095		0.480 ± 0.055	
4	Shear blade/burn/disk	0.417 ± 0.056		0.519 ± 0.045		0.418 ± 0.050		0.538 ± 0.032	
5	Shear blade	0.407 ± 0.114		0.517 ± 0.069		0.362 ± 0.026		0.483 ± 0.020	
6	Shear blade/disk	0.373 ± 0.077		0.502 ± 0.059		0.382 ± 0.068		0.513 ± 0.042	

[a] No significant differences (0.05 level) among treatments or treatment by time interaction exist.

TABLE 7

Effect of different land-management practices on soil organic carbon content in March 1981 before harvesting rice (8 mo after clearing) and in June 1982 before harvesting corn (23 mo after clearing)

Subtreatments	Organic carbon content			
	March 1981		June 1982	
	$\bar{X}$[a]	SD	$\bar{X}$[a]	SD
Flat planted, no fertilizer or lime	0.88 ± 0.28ab[b]		0.80 ± 0.19b	
Flat planted/fertilizer, lime	0.84 ± 0.19b		1.01 ± 0.26a	
Bedding/fertilizer, lime	1.01 ± 0.32a		1.03 ± 0.28a	
Mean[c]	0.91 ± 0.28		0.95 ± 0.26	

[a] Mean of 18 measurements.

[b] Means in a column followed by the same letter are not significantly different at the 5% level by the Waller-Duncan multiple comparison test.

[c] Mean of 54 measurements.

Mean weight diameter and GMD prior to harvesting rice and corn for each of the six treatments are presented in Table 6. The replicated measurements for each treatment exhibited very high variability, as indicated by the standard deviations. Compared with the state of aggregation before clearing (Table 3), there was a decrease, although small in some cases, in MWD and GMD for all treatments. On the other hand, comparison of MWD and GMD values for straight-blade-cleared soil in Table 6 with straight-blade-cleared soil 3 mo after clearing (immediately before planting) (Table 3) shows that continuous cropping increased aggregate stability. There were no significant differences among subtreatments for aggregation.

Organic carbon

Topsoil OC content before clearing was 1.04% (Table 3). Neither slash-and-burn nor shear-blade clearing altered OC content, but straight-blade clearing decreased it to 0.82%. This result was anticipated because straight-blade clearing generally removes some of the surface soil and litter, which has the highest OC content, whereas shear-blade clearing minimizes the removal and soil and litter. Correlation coefficients for MWD and GMD with OC 3 mo after clearing were 0.55 and 0.56, respectively; both correlations were significant at the 1% level. Organic carbon contents for the three soil-management systems before harvesting the first and fifth crops are shown in Table 7. The bedding/fertilizer, lime system maintained a significantly higher OC content than flat-planted, no fertilizer, or lime system throughout the 23 mo and five crops. This result is probably due to higher yields obtained with the bedding/fertilizer lime subtreatments (Alegre, J. C. unpublished results), and therefore the incorporation of more crop residue into the soil. Correlation of both MWD and GMD with OC was significant at the 5% level.

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The OC content for the flat-planted (nonfertilized) subtreatment decreased from 1.04% before clearing to 0.80% in June 1982; this is a 24% decrease in OC. Very low dry matter production, coupled with almost no return of crop residue to the soil, contributed to this OC reduction; OC content, however, tended to increase between 8 and 23 mo after clearing in the flat-planted/fertilizer, lime treatment.

We believe, based on the results of this study, that slash-and-burn and possibly KG blade clearing, followed by proper land-management practices, including the use of adequate amounts of fertilizer and lime, can satisfactorily maintain structural aggregation and topsoil organic carbon levels. Greater changes in aggregate stability occurred when the soil was cleared mechanically. Traditional slash-and-burn clearing caused the least structural degradation, and the straight-blade treatment caused the most. The most stable aggregates occurred in the 0.25- to 0.50-mm fraction, and the percentage of this fraction remained invariant during near 2 yr of continuous cropping. Organic carbon content declined only when no fertilizer or lime was added and subsequent crop production did not return much OC to the soil.

REFERENCES

Allison, F. E. 1965. Organic carbon. *In* Methods of soil analysis, pt. 2. C. A. Black (ed.). Am. Soc. Agron., Madison, Wis., pp. 1367–1378.

Fauck, R., C. Moureaux, and C. Thomann. 1969. Changes in soils of Sefa (Casamance, Senegal) after fifteen years of continuous cropping. Agron. Trop. (Paris) 24:263–301.

Gomes, A. S., J. F. Patella, and E. A. Pauletto. 1978. Effects of cropping system and duration of cultivation on the structure of a red-yellow podzol. Rev. Bras. Ciencia Solo 2(1):17–21.

Greenland, D. J. 1981. Soil management and soil degradation. J. Soil Sci. 32:301–322.

Grohmann, F., J. Bertoldo de Oliveira, and J. Pereira de Quiroz. 1966. Influencia da abubacão nas caracteristicas dos agregados do solo da seria Chapadão (Latossolo Roxo) Bragantia, vol. 25, no. 24, Outubro, pp. 263–276.

Henin, S., and R. Gras. 1972. El Perfil Cultural. Ed. Mundi. Prensa, Madrid.

Hillel, D. 1980. Fundamentals of soil physics. Academic Press, New York.

Lal, R., and D. J. Greenland (eds.). 1979. Soil physical properties and crop production in the tropics. Wiley, New York.

Lugo-Lopez, M. A., and J. Juarez, Jr. 1959. Evaluation of the effect of organic matter and other soil characteristics upon the aggregate stability of some tropical soils. J. Agric. Univ. Puerto Rico 43(4):268–272.

Mazurak, A. P. 1950. Effect of gaseous phase on water-stable synthetic aggregates. Soil Sci. 69:135–148.

Moreau, R. 1978. Effect of mechanical loosening and water infiltration on the structural stability of a ferralitic soil in central Ivory Coast. Orstom Ser Pedologie (1978) (1654), pp. 413–424.

Sanchez, P. A., M. P. Gichuru, and L. B. Katz. 1982. Organic matter in major soils of the tropical and temperate regions. *In* Non-symbiotic nitrogen fixation and organic matter in the tropics. Trans. 12th Int. Congr. Soil Sci. New Delhi, 1:99–114.

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

Van Bavel, C. H. M. 1949. Mean weight diameter of soil aggregates as a statistical index of aggregation. Soil Sci. Soc. Am. Proc. 14:20–23.

Van Bavel, C. H. M. 1952. Compact wet-sieving apparatus for soil aggregate analysis. Agron. J. 44:97–98.

Yoder, R. E. 1936. A direct method of aggregate analysis and a study of the physical nature of erosion losses. J. Am. Soc. Agron. 28:337–351.

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