PA - AB J - 844

Effect of Land Clearing Method on Chemical Properties of an Ultisol In the Amazon

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ABSTRACT

This study quantified soil chemical properties as affected by land clearing method and subsequent soil management. It was conducted on a Yurimaguas soil (fine-loamy, siliceous, isohyperthermic Typic Paleudults) covered by a 20-yr-old evergreen forest in the Amazon Basin of Peru. The experimental design, a split plot replicated three times, included six main plot treatments: (i) slash and burn clearing; (ii) bulldozer clearing with a straight blade; (iii) straight blade clearing followed by chisel plowing 25 cm deep; (iv) bulldozer clearing with shear blade, vegetation burned, followed by disking 30 cm deep; (v) shear blade clearing and rototilling with a 10-KW tractor; and (vi) shear blade clearing, 30-cm-deep disking, followed by rototilling. Three post clearing soil management practices (subplots) were: (1) flat planted with no fertilizer or lime; (2) flat planted with fertilizer and lime applications incorporated, based on soil test recommendations; and (3) soil bedded at 1.1-m spacings, and fertilizer and lime applied as in Subplot 2. Five successive crops, rice (*Oryza sativa* L.)–soybean [*Glycine max* (L.) Merr.]–corn (*Zea mays* L.)–rice-corn were grown from July 1980 to July 1982. Soil samples collected before or just after harvest of the first, second, and third crops were analyzed for chemical properties. Burning dried vegetation resulted in higher concentrations of Ca, Mg, P, and K in the 0- to 45-cm soil layer. No significant differences due to main treatments were found for the other chemical properties. The pH of the surface soil increased from 4.0 to 5.2 for all limed subplots. Percent aluminum saturation decreased from 82 to 7%, and P, Ca, Mg, and effective cation capacity increased. The decrease in topsoil organic carbon at 14 wk for all mechanically cleared treatments was probably due to increased oxidation rates due to tillage and higher soil temperatures. Concentrations of Cu, Fe, and Mn in the soil were unaffected by treatment.

Dep. of Soil Science, Box 7619, North Carolina State Univ., Raleigh, NC 27695-7619. North Carolina Agric. Res. Serv. Journal no. 11021. Received 27 Apr. 1987. *Corresponding author.

Published in Soil Sci. Soc. Am. J. 52:1283–1288 (1988).

THE FOOD and Agriculture Organization of the United Nations estimates that 1622 million ha of potentially arable land are present in the humid tropics and that only about 17% of it was under cultivation in 1980 (Ofori et al., 1986). Couper et al. (1986) indicated that many questions remain regarding clearing of these lands without degrading the soils. Slash and burn (slash/burn) clearing, a practice commonly used in shifting agriculture in the humid tropics, is often replaced by mechanical clearing practices using large machinery, followed by continuous cultivation.

Mechanical clearing can have drastic consequences on soil structure, creating conditions unfavorable for root growth. Effects of various mechanical land clearing operations on physical and hydrological properties of soils in the humid tropics are well documented (Seubert et al., 1977; Lal and Cummings, 1979; van der Weert and Lenselink, 1972; Opara-Nadi et al., 1986).

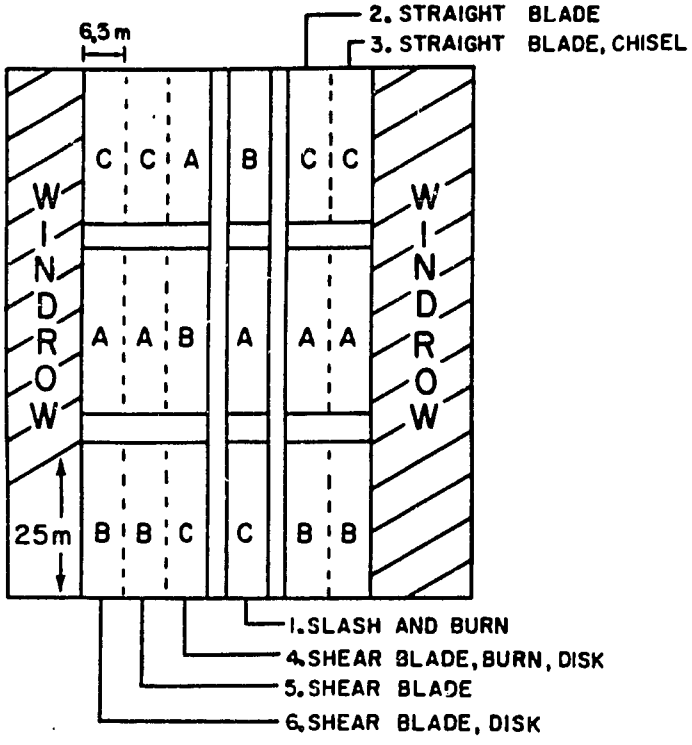

Fig. 1. Experimental layout for Block I of land clearing study. Subplots: (A) fertilized, flat; (B) fertilized, bedded; and (C) nonfertilized, flat.

Various investigators have reported that clearing with burning decreased soil acidity and increased amounts of exchangeable cations when compared to methods without burning (Nye and Greenland, 1964; Uribe et al., 1967; Boyle, 1973; Brinkman and do Nascimento, 1973; Seubert et al., 1977; Lal and Cummings, 1979). Silva (1978) reported no significant differences in acidity or nutrients when comparing slash/burn with other mechanical clearing methods on an Oxisol with a secondary forest. Nye and Greenland (1964) observed rapid losses of nutrients by leaching and erosion during the first year following cultivation of newly cleared Ustalfs in Ghana; a substantial loss of K and Mg, but a smaller loss of Ca, occurred the second year. Large increases in leachate concentrations of K, Mg, and NO_3 occurred 2 yr after cutting and burning a secondary forest on an Oxisol near the Rio Negro in the Amazon basin (Uhl and Jordan, 1984). Kang and Juo (1986) indicated that more pronounced changes in soil chemical properties occur in Ultisols and Oxisols as compared to Alfisols.

The objective of this study was to evaluate temporal changes in soil chemical properties effected by different combinations of land clearing method and subsequent soil management for intensive, continuous cropping of an Ultisol in the humid tropics. Effects of these same treatments on soil physical properties were reported previously (Alegre et al., 1986).

METHODS

The study was conducted on Yurimaguas soil from July 1980 to July 1982 on a 20-yr-old secondary evergreen forest at the Yurimaguas Experimental Station (5°45′ S, 76°5′ W, 184 m above sea level). Mean annual temperature is 26 °C with little daily variation. Mean annual rainfall is 2250 mm with a dry period from June through August when mean monthly precipitation is about 100 mm. Detailed monthly precipitation data during the study were reported by Alegre et al. (1986). Aboveground vegetation on the site before clearing was estimated to be 80 to 85 Mg ha^{-1}. Major vegetation species were *Pollatestra discolor, Cecropia scradifolia, Croton* sp., and *Visnia cayenensis*. Additional details about the site, soil, land clearing treatments, and fertilizer and lime rates are reported elsewhere (Alegre et al., 1986), but are repeated in an abbreviated form below.

The experimental design was a split plot replicated three times. Six main plot treatments (Fig. 1) were various combinations of land clearing and soil tillage:

1. Slash and burn, tree trunks removed by hand;
2. Mechanical clearing (Caterpillar[1] D-6 bulldozer) with a straight blade, trees mechanically windrowed;
3. Straight blade clearing followed by chisel plowing 25 cm deep, soil rototilled with a 48 kW tractor before planting;
4. D-6 bulldozer clearing with shear blade, vegetation burned, logs removed, and soil disked 30 cm deep, and rototilled with a 10 kW tractor before planting;
5. Clearing with shear blade, rototilled with 10 kW tractor prior to planting; and
6. Same as Treatment 5 except that soil was disked 30 cm deep after clearing.

A shear blade is designed to shear trees at the soil surface with minimal soil disturbance.

Three post clearing soil management practices (subplots) were:

1. Flat planted, no fertilizer or lime added;
2. Flat planted, rototiller incorporated fertilizer and lime based on soil tests; and
3. Soil bedded by hand hoe at 1.1-m row spacings, fertilizer and lime applied at the same rate as for Subplot 2.

Hereafter, these subplot treatments will sometimes be denoted by F (flat), FFL (flat, fertilized, limed), BFL (bedded, fertilized, limed), and the mean of the two fertilized and limed subplot treatments by FL.

The cropping sequence was rice-soybean-corn-rice-corn. The first crop was planted 28 Nov. 1980 and the last crop harvested 16 July 1982. Soil samples were taken at three depths (0–15, 15–30, and 30–45 cm) and on four dates (prior to clearing, 14, 29, and 98 wk after clearing). The latter three samplings were done after the crop matured or immediately after harvest. For each depth, five subsamples were composited, passed through a 2-mm sieve, and stored in cloth bags in a laboratory until analyzed.

Fertilizer applications prior to seeding the first crop (rice) were 80 kg N ha^{-1}, 26 kg P ha^{-1}, 100 kg K ha^{-1}, and 30 kg Mg ha^{-1}. Fertilization of the second rice crop was 50, 13, and 50 kg ha^{-1} of N, P, and K, respectively. Fertilizer applied prior to seeding soybean was 20, 26, 66, and 40 kg ha^{-1} of N, P, K, and Mg, respectively. Fertilizer rates for the first and second corn crops were 100, 26, 100, and 30 kg ha^{-1} of N, P, K, and Mg, respectively. Dolomitic limestone was applied at rates of 2 and 1.5 Mg ha^{-1} prior to planting the first and second crops, respectively. An additional lime application of 1.0 Mg ha^{-1} preceded planting of the last corn crop.

Ash samples for total nutrient analysis were taken immediately after burning. A 0.1- by 0.1-m square wooden frame was placed on the soil surface and ashes were removed from the 0.01-m^2 area with a stainless steel spoon. Ten random subsamples from each burned plot were composited and weighed after oven drying to constant weight at 70 °C.

Organic carbon (OC) content of the 0- to 15-cm soil sam-

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

ple was determined by the Walkley-Black procedure (Hunter, 1974). Total soil N was determined using a modification of the semimicro Kjeldahl technique described by Bremner (1960). Available P, exchangeable K, Zn, Cu, Mn, and Fe were extracted from the soil using modified Olsen extractant (with addition of EDTA) according to the International Soil Fertility Evaluation and Improvement Laboratory procedures (Hunter, 1974). Extracted P was determined colorimetrically by the molybdenum blue method; extracted K, by flame photometry. Exchangeable Ca, Mg, Al, and exchangeable acidity were extracted with 1 mol kg^{-1} KCl (Hunter, 1974). Calcium, Mg, and Al in the extract were determined by atomic absorption. Effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable Al, Ca, Mg, and K. Exchangeable acidity was determined by titration with standardized 0.01 mol kg^{-1} NaOH using a phenophthalein indicator. Aluminum saturation was expressed as percentage of exchangeable Al divided by ECEC. Micronutrient cations were determined by atomic absorption. Exchangeable H was not determined because it is known to be very low in this soil (Tyler et al., 1978).

Results were analyzed by analysis of variance where whole plot treatments had a randomized complete block arrangement. Split plot treatments were randomized within each main plot. Statistically significant differences are based on LSD values at the 5% probability level.

RESULTS AND DISCUSSION

Slash/burn clearing is the traditional and common practice for agricultural production in the Amazon Basin. Consequently this method is taken as the control against which all other practices are compared. Soil chemical concentrations measured prior to clearing show that plant nutrients at three depths were very low, whereas percent Al saturation was >87% (Table 1). The very high standard deviation associated with some chemical species (Mg at the 0- to 15-cm depth and Ca, K, and Zn at the 15- to 30-cm depth) indicate that considerable variability existed; this variability is probably related to differences in vegetation amounts and its distribution at the randomly chosen sampling locations. No significant differences were found for any initial nutrient level among replications for any main or subplot treatment. Statistical analysis of the data showed no differences in chemical properties among treatments at the 15- to 30- and 30- to 45-cm depths and will not be discussed.

Nutrient Content of Ash

Concentrations and amounts of various nutrients derived from burned and partially burned leaf, stem, and litter for the slash/burn and shear blade/burn treatments are presented in Table 2. These nutrients were released from 7.5 and 6.6 Mg ha^{-1} of ash (not significantly different) for the slash/burn and shear blade/burn treatments, respectively. High standard deviations for all measurements may be due to contamination of ash samples by mineral soil material during sampling, to nonuniform distribution of quantity and type of vegetation on the land and to incomplete burning. Only the amounts of Ca, Mg, Cu, and Zn were significantly greater for the slash/burn compared with shear blade/burn treatment. Amounts of nutrients were higher than those previously reported for a slash/burn cleared Yurimaguas soil (Seubert et al., 1977). Amounts of Ca and Mg derived from the ash of the slash/burn method were 131 and 68 kg ha^{-1}, respectively, and taken together were equivalent to approximately 600 kg ha^{-1} of dolomitic limestone; Ca and Mg amounts for the shear blade/burn method were equivalent to approximately 350 kg ha^{-1} of dolomitic limestone.

Table 1. Mean and standard deviation (in parentheses) of selected chemical species and effective cation exchange capacity in Yurimaguas soil prior to land clearing.

Depth	Acidity	OC	Total N	Exchangeable Al	Exchangeable Ca	Exchangeable Mg	Exchangeable K	Exchangeable ECEC	Available P	Available Zn	Available Cu	Available Fe	Available Mn	Al saturated
cm	pH	g kg^{-1}		cmol$_c$ kg^{-1}					mg kg^{-1}					%
0–15	4.1† (0.2)	10.4 (0.20)	1.06 (0.20)	3.02 (1.26)	0.20 (0.06)	0.13 (0.15)	0.08 (0.03)	3.43 (1.28)	8 (2)	1.4 (0.7)	0.8 (0.6)	770 (290)	2.5 (1.4)	87 (6)
15–30	4.2 (0.2)	–	–	3.30 (1.12)	0.20 (0.20)	0.07 (0.03)	0.09 (0.14)	3.66 (1.14)	6 (3)	1.9 (1.5)	0.8 (0.3)	743 (206)	1.0 (0.9)	90 (8)
30–45	4.2 (0.2)	–	–	3.26 (0.92)	0.16 (0.06)	0.07 (0.03)	0.06 (0.02)	3.54 (0.91)	5 (3)	1.8 (1.5)	0.8 (0.3)	774 (236)	1.9 (1.1)	91 (3)

† Each value is the mean of 54 measurements.

Table 2. Nutrient content of the ash of a 20-yr-old secondary evergreen forest for two land clearing methods at Yurimaguas, Peru.

Nutrient	Concentration units	Slash/burn Concentration	Slash/burn Amount	Shear blade/burn Concentration	Shear blade/burn Amount
			kg ha^{-1}		kg ha^{-1}
N	g kg^{-1}	9.5 (5.0)†	75 (51)	9.5 (3.9)	64 (29)
P	mg kg^{-1}	2600 (800)	19 (5)	2000 (1900)	14 (13)
K	cmol$_c$ kg^{-1}	31.3 (26.7)	89 (74)	12.1 (4.6)	31 (13)
Ca*	cmol$_c$ kg^{-1}	43.5 (2.0)	131 (19)	32.5 (8.5)	88 (30)
Mg*	cmol$_c$ kg^{-1}	38.3 (7.0)	68 (19)	20.0 (7.1)	33 (14)
Mn	mg kg^{-1}	1400 (400)	10.3 (2.9)	800 (400)	5.2 (2.7)
Fe	mg kg^{-1}	2600 (200)	20 (15)	3300 (2100)	23 (15)
Cu*	mg kg^{-1}	55 (10)	0.4 (0.1)	30 (16)	0.2 (0.1)
Zn*	mg kg^{-1}	66 (27)	0.7 (0.4)	42 (20)	0.3 (0.2)
Dry matter	–	–	7500 (948)	–	6600 (848)

* Significant differences between the two land clearing methods at 5% level by the LSD test.
† Each value is the mean of nine measurements. The standard deviation is given in parentheses.

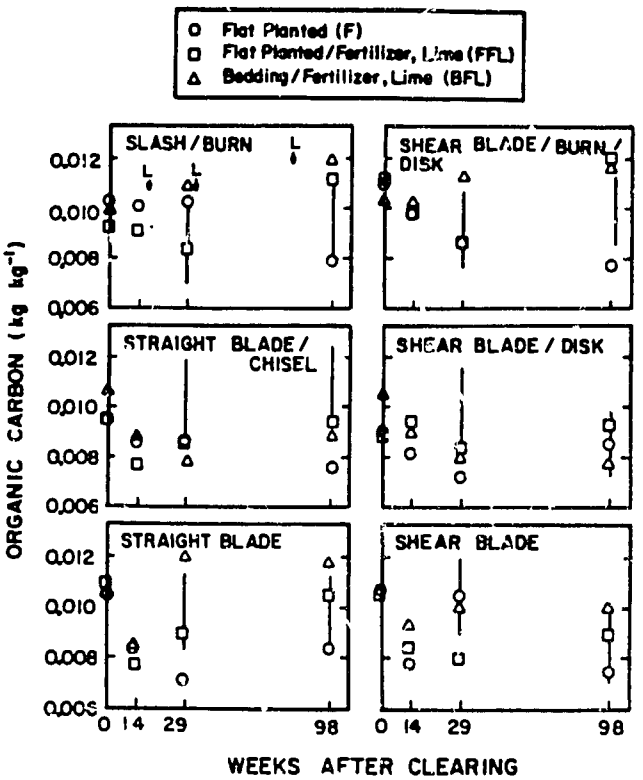

Fig. 2. Organic carbon content in the 0- to 15-cm depth (topsoil) vs. time after clearing. Arrows with L shown in upper left hand graph indicate times of fertilizer and lime application. Vertical bars are LSD (0.05) values for subplot effects.

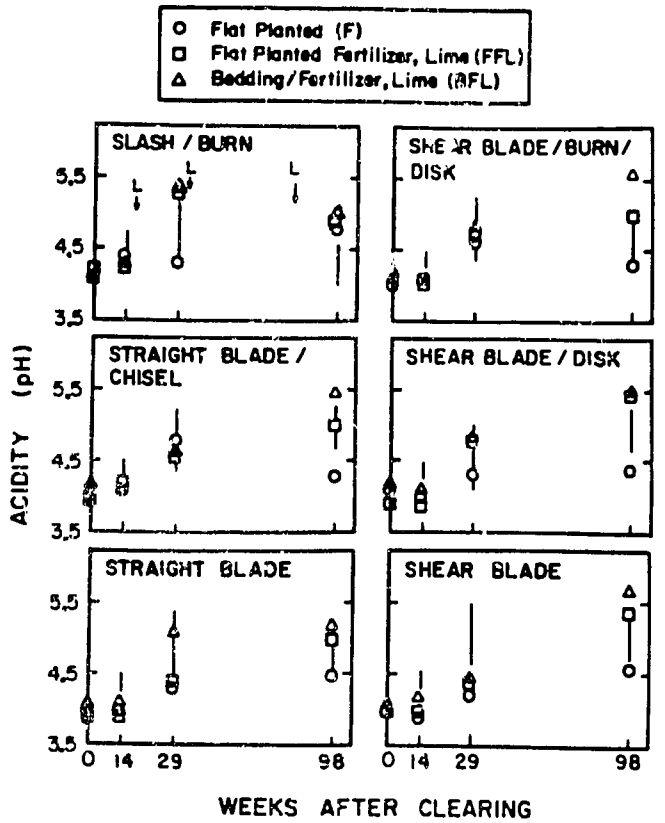

Fig. 3. Soil acidity (pH) in the 0- to 15-cm depth (topsoil) vs. time after clearing. Arrows with L shown in upper left hand graph indicate times of fertilizer and lime application. Vertical bars are LSD (0.05) values for subplot effects.

Organic Carbon and Total Nitrogen

Organic carbon in the 0- to 15-cm depth was not significantly affected by land clearing treatment. In general, OC was lower for the unfertilized subplot as compared to fertilized and limed subplots (Fig. 2). A significant reduction in OC (averaged across all three subplots) was measured 14 wk after clearing for the straight blade, straight blade/chisel, and shear blade treatments. These means are not shown in Fig. 2, nor will treatment means for a given time be presented for other soil properties; instead, subplot by time means for one or more main treatments will be presented and discussed. Presentation of data in this manner allows one to evaluate the temporal manner in which selected nutrients were affected by various subplot treatments. The decrease in topsoil OC for all mechanically cleared treatments at 14 wk may result from increased oxidation rates due to tillage and higher soil temperatures. In addition, some OC on the soil surface was removed during clearing with the straight blade. Ninety-eight weeks after mechanical clearing, the OC levels for subplots FFL and BFL exceeded that of subplot F for the slash/burn and shear blade/burn/disk treatments.

Total N (not shown) had an overall treatment mean of 1.0 g kg^{-1} and was not affected by land clearing treatment.

Acidity (pH) and Percent Aluminum Saturation

Acidity (pH) and percent Al saturation were not affected by main plot treatments. The pH increased at 29 and 98 wk for fertilized and limed subplots for all clearing methods (Fig. 3). Mean pH (averaged for FFL and BFL across all treatments) increased from 4.0 to 5.2 after 98 wk, indicating that repetitive small lime applications were effective in reducing soil acidity.

Percent Al saturation in the topsoil was directly related to acidity. For example, percent Al saturation at 29 wk for the shear blade/burn/disk treatment was lower for FL compared to subplot F (Fig. 4A). After 29 wk, percent Al saturation began to increase for subplot F, but continued to decrease for FL.

Exchangeable Calcium and Magnesium

Exchangeable Ca was significantly greater for slash/burn compared to straight blade/chisel and shear blade treatments. Exchangeable Ca in the 0- to 15-cm depth vs. time after clearing for the shear blade/burn/disk treatment, which was intermediate with regard to exchangeable Ca concentration, is shown in Fig. 4B. As expected, Ca concentration remained low when no lime was applied, whereas concentration continued to increase with time for limed subplots combined. Little exchangeable Al remained in the topsoil at 98 wk.

Transport of Ca into the subsoil occurred for limed subplots for all six land clearing treatments. Mean concentration of exchangeable Ca in the 15- to 30-cm depth for the two limed and fertilized subplots increased sevenfold over the initial concentration by 98 wk after clearing (Fig. 5). In addition, Ca concentration for subplots FL increased nearly fivefold at the 30- to 45-cm depth.

Downward movement of Mg also occurred for all

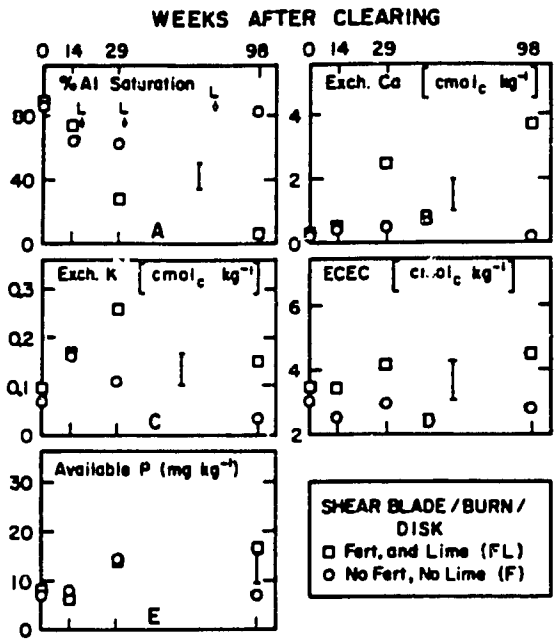

Fig. 4. (A) Percent aluminum saturation, (B) exchangeable calcium, (C) exchangeable potassium, (D) ECEC, and (E) available phosphorous in the 0- to 15-cm depth (topsoil) vs. time after clearing with shear blade/burn/disk treatment. Arrows with L shown in upper left hand graph indicate time of fertilizer and lime application. Vertical bars are LSD (0.05) values for subplot effects.

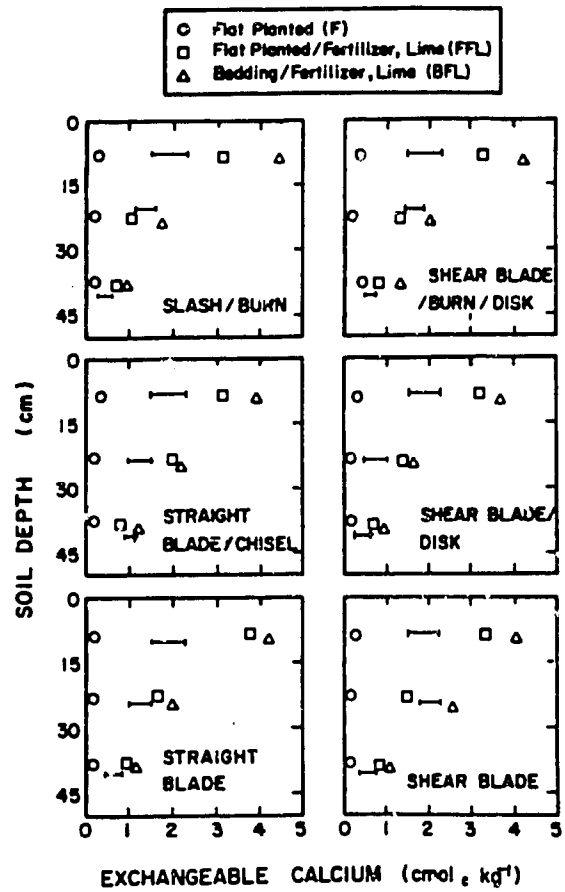

Fig. 5. Exchangeable calcium in the 0- to 15-, 15- to 30-, and 30- to 45-cm depths 98 wk after clearing. Horizontal bars are LSD (0.05) values for subplots.

land clearing–subplot treatments (Fig. 6). Concentration of exchangeable Mg in the 15- to 30-cm depth at 98 wk for limed subplots was three times greater than its initial concentration. Concentrations were always higher in the bedded soil, a result of concentrating Ca and Mg in the bed when the beds were formed. The top of the bed was taken as the reference point for soil depth measurement. Both factors tend to increase Ca and Mg concentrations compared to the flat planted subplots.

Exchangeable Potassium

Exchangeable K concentration at 14 wk was significantly greater for the slash/burn and shear blade/burn/disk treatments because it was released from the vegetation upon burning (Tables 1 and 2). The K levels for the three subplots for the slash/burn treatment (not shown) were above the critical level for plant growth of 0.2 cmol$_c$ kg^{-1} (Hunter, 1974) but after 29 wk had decreased below the critical level for subplot F. The K level never did attain the critical level for subplot F of the shear blade/burn/disk treatment (Fig. 4C). The K levels for all treatments and subplots were below the critical level after 98 wk. It is possible that levels of K $\geq$ 0.2 cmol$_c$ kg^{-1} were not found because measurements at 29 and 98 wk were taken at the end of the growing season when the crop was mature and a significant amount of K had been removed from the soil by plant uptake or by leaching.

Effective Cation Exchange Capacity

The ECEC levels were inherently low in this soil because of kaolinitic clay mineralogy and low organic matter and clay contents. The ECEC at the 0- to 15-cm depth was unaffected by main treatment, but was significantly increased by 20% for fertilized and limed subplots. This increase is attributed to an increase in the amount of pH dependent charge as a result of increasing soil pH by liming (Fig. 4D).

Phosphorous

Available P concentration was significantly higher for the slash/burn treatment. Available P in the 0- to 15-cm depth for fertilized and limed subplots of the shear blade/burn/disk treatment (Fig. 4E) increased with time after clearing. Only treatments with burning had significantly higher P levels after 14 wk when no fertilizer or lime was applied. Only the slash/burn method had a P level above the critical level of 15 mg P kg^{-1} (Cano, 1973) at 29 wk and this value declined rapidly in unfertilized treatments. In general, P fertilization maintained the P level for all treatments just above the critical level.

Zinc, Copper, and Iron

Although differences in Zn concentration in the ash were found between slash/burn and shear blade/burn treatments, no differences in soil Zn concentration were found among main plot treatments. All soil Zn concentrations were above the critical level of 1 mg kg^{-1} (Osiname et al., 1973). Available Cu level was nearly identical to the critical level of 1 mg kg^{-1} (Hunter, 1974) for all treatments and subplots. The Cu level changed with time only for the unfertilized straight

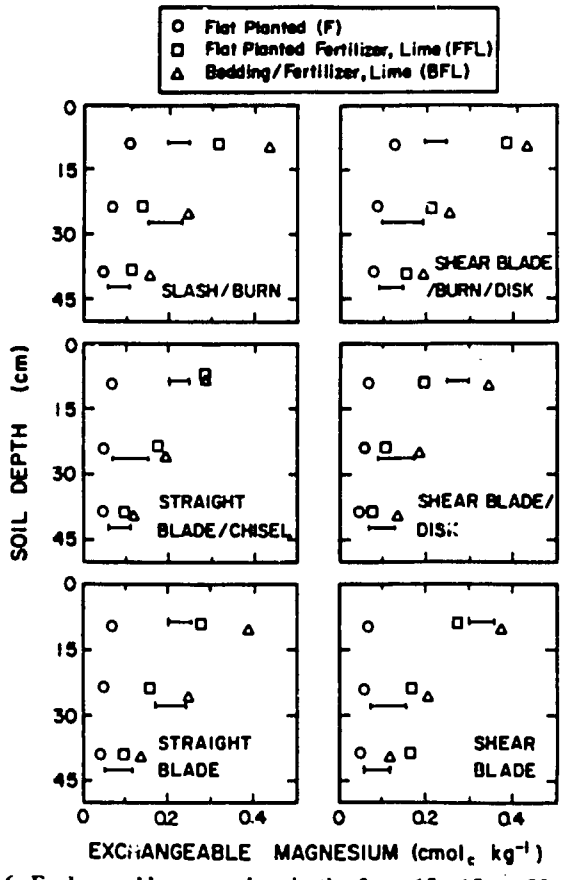

Fig. 6. Exchangeable magnesium in the 0- to 15-, 15- to 30-, and 30- to 45-cm depths 98 weeks after clearing. Horizontal bars are LSD (0.05) values for subplot effects.

blade treatment. Available Fe levels for all main and subplot treatments were far above the critical level of 10 mg kg^{-1} (Hunter, 1974). Significant differences among treatments and subplots were found, but were not significant from the critical nutritional standpoint.

Manganese

Available Mn for the main plot treatments with burning was significantly greater at 29 wk compared to its initial level. Later the level declined below the reported critical level of 5 mg kg^{-1} (Hunter, 1974). The Mn levels were below the critical level for all main plot treatments without burning, yet no Mn deficiency was observed upon inspection of crop foliage. Induced Mn deficiencies, i.e., an imbalance of Mn due to a very large Fe/Mn ratio, has been reported for this soil with its low buffering capacity and may be expected to occur in the future on this and similar newly cleared soils (Sanchez et al., 1983).

PRACTICAL IMPLICATIONS

Few chemical properties were affected significantly by land clearing method and post clearing soil management. In general, Ca, Mg, K, and P levels increased for the first 29 wk following traditional and mechanical clearing involving burning. No significant changes in macronutrient levels occurred for clearing methods with no burning. Judicious additions of lime and fertilizer to the soil maintained nutrients at apparently adequate levels. Fertilized and limed subplot treatments tended to maintain higher levels of nutrients in the topsoil and reduced the rate of net OC loss. Soil concentrations of Cu, Fe, and Mn were unaffected by clearing method, but Zn increased in the 0- to 15-cm depth for slash/burn clearing.

It is our belief that fertilizer and lime will be required for this and similar soils to produce the first crop after clearing if vegetation is not burned on the land during the clearing process. Fertilizer and lime were not required until the second crop for slash/burn clearing. In time, downward transport of Ca and Mg from applied liming materials may improve chemical properties of the subsoil and enhance deeper rooting.

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