Chapter 8. LEACHING LOSSES AND IMPROVEMENT OF SAVANNA AND FOREST SOILS

Perhaps as much as 75% of the central lowland region of tropical America has soils that may be described as leached acid soils or run a severe risk of further chemical degradation if used unwisely. These include a large percentage of the Oxisols, Ultisols, and Spodosols and some Alfisols and Inceptisols. Land clearing practices, cropping patterns, and soil amendments and fertilizers may degrade, maintain, or even improve soil fertility. Consequently, this chapter considers some of the underlying principles that are emerging concerning the management of the fertility of these soils, especially as they relate to the comparison of savanna and forest conditions.

Propensity of Soils to Leach

Leaching in soils is sometimes referred to as "chemical erosion." It may be defined as the movement of nutrients in soil solution away from the rhizosphere, the region of soil in which plant roots are found. To fully appreciate the susceptibility of a soil to leach if used for a specific purpose, the interactions of climate, vegetation, soil biotic factors, and mineralogical status must be considered.

While climate, vegetation, and soil biotic factors are universally accepted as variables, it is not so well recognized that the soil mineralogical status is also a variable. The clay fractions of many soils have both positively and negatively charged surfaces; these charges, measured in terms of their effective cation-exchange capacities, are pH-dependent.

Variable Charge Soils

As shown by Cochrane et al. (I 98 1), many of the soils of the region classify as variable charged (Map 23). A proportion of these soils may in fact have a subsoil horizon that is negatively charged according to the delta pH test, pH H'O - pH KCI. (If negative, soils are negatively charged; if positive, soils are positively charged.) It is assumed that such horizons have a greater capacity to retain anions than cations. Fortunately, as shown by Map 24, the comparative extension of these soils is not great. Nevertheless, they serve to emphasize that the charge characteristics of many soils of the region are a variable. This picture contrasts with many temperate regions of the world where soil parent materials are often relatively young and the principle clay minerals are the 2: 1 types. These have virtually a permanent negative charge, or at least one which is not greatly affected by variations in pH, ionic strength, or the dielectric constant of the soil solution.

The variable-charge exchange-capacity of many tropical soils has been studied by many authors including van Raij and Peech (1972), Gillman (1974), Keng and Uehara (1974), ElSwaify and Sayeth (1975), Gallez et al. (1976), Gillman and Bell (1976), Morais et al. (1976), and Cochrane and Sousa (1984) for Brazilian soils. The latter workers have developed a simple methodology for measuring cation- and anion-exchange capacities and both exchangeable cations and anions in acid mineral soils that provides a new approach for approximating soil surface variable-charge exchange-capacity analyses to field conditions. Tropical soils have by and large been formed from old weathered materials and are usually rich in residual materials, principally kaolinitic type clays and iron and aluminium oxides. As emphasized by Gillman (1979) the surface charge of their clays are dependent on pH, ionic strength, dielectric constant, and even the counterion valency of the soil solution.

Leaching anions. Because of the variable-charge exchange-capacity nature of many of the soils in the region, they have both a cation-exchange capacity and an anionexchange capacity; the former is responsible for retaining nutrient bases, principally Ca++, Mg++, K+, Na+, Mn++, Al+++, and the latter anions including NO,-, SO,--, HCOI-, and Cl. In the soil solutions, the main anions are NO,- and SO,--, with lesser amounts of Cl- and HCO3-, although the amounts of free bicarbonate Ions that can exist in acidic solutions, except just on the acid side of neutrality, are extremely small (Nye and Greenland, 1965).

If nitrates, sulphates, or chlorides are added to the soil solution, some will be absorbed, depending on the anion capacity of a soil. However, most will remain in the soil solution where they must always be balanced by cations. The main cations that balance these anions in soil solution are Ca++, Mg++, K+, and H,O+, with Al. . . becoming important in soils with pH lower than 5.3. Conversely, if cations are added to the soil, some will be absorbed on the soil surfaces, but the remainder will stay in solution, where they must be balanced by anions. In other words, for any soil, the total concentration of cations in the soil solution depends on the total concentration of anions, and vice-versa; they must balance.

Changing charge characteristics. To complicate matters, the addition of significant quantities of nutrient cations and anions, and particularly soil amendments lime, can produce a change in the charge characteristics of many of these soils; this will modify the ability of a soil to restrain the loss of nutrients through leaching. Unfortunately, studies of the effect of soil amendments on the surface charge of the soils are still virtually at the "identification of a potential problem" stage, and much work needs to be done before the full implications of the phenomenon can be translated into practical farming terms.

Organic Matter

Other ways exist to modify the cation-exchange capacity of a soil; the incorporation of organic matter is an example. There are many practical farming experiences of successful soil management through draconian measures involving the incorporation of organic matter, but there are examples of successful management with minimal input, such as the use of single superphosphate in Planaltina, Brazil. What is evident is that it is difficult to get something for nothing, and that it is easy to lose inputs if too much of the wrong type is applied.

Soil-Water Percolation

Leaching cannot occur unless water percolates through soil. The amount of percolation will depend on the physical properties of soil that enable them to hold and otherwise restrain water movements away from them, the climatic water balance, and the type of vegetative covering and its stage of growth.

Soil moisture-holding capacities vary considerably. Although clay soils generally hold more moisture than sandy soils, many clayey Oxisols have soil moisture-holding capacities approaching those of light-textured soils. In fact, the low moisture-holding capacities of Oxisols in the isothermic savannas of Central Brazil exaggerate the impact of the so*called veranicos,* or Indian summers, the irregular periods of drought occurring during the wet season.

Climatic water-balance patterns, as already emphasized in Chapter 3, vary from ecosystem to ecosystem; clearly in the context of percolation, these must be qualified by the soil moisture-holding capacities.

The type of vegetation or crop covering, its stage of growth, and the rate at which it transpires (or, to put it crudely, how it pumps water out of a soil) will have a significant effect on the rate of soil-moisture percolation. Transpiration will obviously proceed apace during periods of high potential evapotranspiration, and vice-versa, always providing that soil moisture is not limiting. The "root-room" of a soil, or the suitability of the soil for root development in both a physical and chemical sense, will affect percolation and consequently leaching losses, particularly if roots can penetrate deeply. A good vegetative cover is obviously a prerequisite to ameliorate water percolation and consequent loss of nutrients.

Nitrogen Flushes and Leaching

Nitrogen flushes were first described by Hardy (1946). These occur in tropical soils with a marked dry season. They often follow a pattern of gradual nitrate build-up in the dry season, a rapid but short-lived increase at the start of the wet season, and a rapid tapering off as the dry season progresses. Flushes are most marked in ustic moisture conditions.

It is probable that the rapid build-up of microbial activity, particularly nitrifying bacteria at the start of the wet season, is associated with N mineralization (Birch, 1958); this proceeds faster at the lower C:N ratios resulting from a dry-season period. More recently, Semb and Robinson (1969) have proven that nitrification can take place at the very low soilmoisture tensions (below 15 bars) found in subsoils during the dry season.

Wild (1972) showed that nitrates move upward from the subsoil to the topsoil during the dry season. Conversely, Semb and Robinson (1969) found NO,- movements to the subsoil after the initial "flush" at the start of the wet season; as the excess of nitrates must be balanced by nutrient cations, the phenomenon could result in considerable soil leaching (losses of cations as well as valuable N), unless plant roots can absorb soil moisture and so avoid a permanent loss of nutrients from the plant rhizosphere. Interestingly, Kinjo and Pratt (1971) indicate that nitrate leaching may be reduced if the subsoil has a degree of anion-exchange capacity.

Leaching Trends in Savannas and Forests

Although few studies have been recorded in tropical America, there is evidence that nitrates will move with percolating soil moisture, beyond the main actively growing rhizosphere, soon after the start of the wet season, in savanna conditions (J. Salinas, CIAT, pers. comm.). It is probable that this phenomenon aggravates the very leached, acid condition very commonly found in these regions. The nitrates and accompanying cations percolate down the soil profile faster than the main body of roots grows, or faster than those which survive the dry season can absorb soil moisture. Once grass roots are well established, losses are considerably reduced; however, by that time the main effect of the "flush" of nitrates is over.

In contrast to savannas, Nye and Greenland (1960) report that there are many studies on forest soils which indicate a minimum of leaching beyond the rhizosphere. The reasons for this are threefold. First, the main body of tree roots does not die back in the dry season, as is common with grasses; therefore, they afford a more efficient mechanism to absorb percolating water. Second, much moisture, at least that from light rainfalls, is held on the leaves of trees and absorbed directly, or is absorbed by the leaf litter; consequently, the amount of water physically entering the soil is reduced. Third, with the exception of a proportion of the semi-evergreen seasonal forests, the dry season is generally not so severe under forest as under savanna conditions, and thus there is a lesser build-up of nitrates in the topsoil. It is evident, therefore, that forest vegetation provides a very efficient system of nutrient re-cycling, which largely avoids a net leaching of plant nutrients.

It should also be noted that not only are forests much more effective in recycling nutrients than savannas, but also they provide a much greater storehouse for nutrients. In a certain sense, they may be described as being able to "leach" soils: they have a maximum ability to withdraw nutrients from a soil and use them to produce biomass. Recycling nutrients via leaf fall and tree aging and decay is probably only a casual phenomenon. Consequently, under their native vegetation, many forest soils are as chemically poor as their savanna counterparts derived from similar parent materials.

Comparative figures of nutrients stored in forests versus savanna vegetation are not available for the region, but data from the African continent (Vine, 1968) would indicate that forests may store up to 10 times the amounts of nutrients stored by savannas. This, however, varies between forests and according to the arboreal content of savannas; Vine records figures to show that savannas with a high arboreal content have a greater reservoir of plant nutrients than do the open grassland types.

Fertility Improvement in Savannas and Forests

It is good sense to ensure that nutrients stored in biomass are returned to soils by burning and producing ash, if lands are to be cleared of their original vegetation and used for agriculture. This simple stratagem has been used by tropical bush farmers for thousands of years. This is particularly important in the case of forests, but may also be of significance in savannas with a considerable arboreal biomass content, such as the Cerradgo.

Nevertheless, for most savannas, which do not have a significant biomass, improvement of their soils, if these are weathered and leached, must largely rely on correcting toxicity problems and fertilization. Care must be taken in fertilization and the application of amendments to avoid significant losses of the original costly inputs. Further, excess liming has often been responsible for inducing nutrient deficiencies, especially of Zn (Spain, 1976).

The "nitrogen flush" effect is particularly severe in savanna regions; fertilization and soil-amendment practices such as liming are best designed to take this phenomenon into account. Crops and pastures should be selected and managed, insofar as it is possible, to help avoid excess nitrate leaching at the start of the dry season. Nitrogen fertilizer treatments for many crops may best be delayed until after the effect of the initial nitrogen flush has passed. Conversely, in liming practices to ameliorate high soil Al levels for those crops sensitive to Al or to overcome Mn toxicity problems, advantage may. be taken of the nitrogen flush to help with the incorporation of Ca deeper into the soil profile. In such cases, lime should be incorporated at the start of the wet season or, if feasible, before the start of the wet season. Work to improve management practices through a better understanding of the nitrogen flush and anion leaching generally could lead to higher, more stable production in the savannas.

In contrast with many savanna soils, weathered, leached forest soils can usually be significantly improved by the incorporation of nutrients stored in their biomass through burning. Experiences in the clearing of forests has been detailed in Cochrane and Sánchez (1982). One of the most spectacular demonstrations of the effect of burning after cutting in situ has been recorded by Falesi (1976). Table 8-1 records data from Falesi's work (Serrão et al., 1978) in which semi-evergreen seasonal forest growing on an Oxisol near Paragominas, along the Belém-Brasilia highway, was cut, burned, and transformed into pasture. The marked improvement in topsoil chemical properties is evident; burning and the incorporation of ash completely changed nutrient properties.

What is of even more interest is that these changes persist for many years under grass cultivation, with the exception of P levels. Probably soil N is largely tied up by the grass, and little leaching takes place. The climatic regime in this circumstance would also help avoid the excessive nitrogen flush effect of the savannas.

Not all results related to burning forests and the subsequent management of improved soil fertility are as promising as those indicated from Falesi's work, as demonstrated by Cochrane and Sánchez (1982). It is probable that tropical rain forests present a more difficult situation, partly due to the problems of burning these forests in their more humid climate. Nor is it implied that cutting and burning even semi-evergreen seasonal forests will solve soil fertility problems for all crops. As indicated by Morán (1977), cutting and burning forests growing on soils with a higher fertility status due to better parent materials, specifically the Alfisols of Altamira along the transamazonic highway of Brazil, results in much better crops than cutting and burning forests on intrinsically less fertile lands. The fundamental fertility of a soil will have a very significant effect on crop production, and the selection of superior soils in both savanna and forest circumstances will facilitate farming success.

Table 8-1. Average chemical composition of the topsoil (0-20 cm) of an Oxisol under semi-evergreen seasonal forest and *Panicum maximum* pastures of different ages in the proximity of Paragominas, Pará, Brazil.

Topsoil	Clay	OM	N	pH (H_2O)	Exchangeable $Ca^{++}+Mg^{++}$	Al^{+++}	Available K	P	Al Sat.
		(%)			(meq/100 g)		(ppm)		(%)
Forest	65	2.79	0.16	4.4	1.47	1.8	23	1	53
1 year pasture	50	2.04	0.09	6.5	7.53	0.0	31	10	0
3 years pasture	60	3.09	0.18	6.9	7.80	0.0	78	11	0
4 years pasture	55	2.20	0.11	5.4	3.02	0.2	62	2	6
5 years pasture	50	1.90	0.10	5.7	2.81	0.2	66	3	6
6 years pasture	51	1.90	0.09	6.0	3.84	0.0	74	7	0
7 years pasture	48	1.77	0.08	5.7	2.61	0.0	47	1	0
8 years pasture	52	1.69	0.08	5.4	2.10	0.0	39	1	0
9 years pasture	50	2.34	0.11	5.9	4.10	0.1	70	2	2
11 years pasture	45	3.37	0.15	6.0	4.10	0.0	86	1	0
13 years pasture	62	2.80	0.20	5.6	4.80	0.0	54	1	0

Source: Serrão et al, 1978.