DRY SOILS OF THE AFRICAN SAHEL

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INTRODUCTION

The African Sahel spreads from the Atlantic Ocean to the Red Sea, covering a distance of more than 3,000 km. It consists of thorn steppes fringed to the north by the Saharian desert and, to the south, by areas covered with shrub and tree savannas or with open woodland. The distance between northern and southern boundaries of the Sahel amounts to several hundred kilometers, ranging up to as much as 1,000 km. The northern and southern limits are best defined by climate. They are semi-arid areas with low rainfall; the mean annual rainfall ranges between 100 and 500 mm, and high mean average temperatures often exceed 40°C. The rainfall takes place during a single season and lasts for two to four months. Thus, the dry season is very long and the annual evapotranspiration is much in excess of the annual rainfall.

In comparing the Sahel with other semi-arid areas, in particular with the Mediterranean areas, it is important to note that rain is deposited during summer, that is to say during the hotter season with a high evapotranspiration. Though amount of rainfall is similar to that in other semi-arid areas, the available water budget of soils is even more deficient than in the Mediterranean areas where atmospheric water falls on winter crops. This is the reason why every exceptional drought, as it happened in the seventies, entails heavy consequences for the agricultural and pastoral economy of the Sahel. Taking the large acreage of the Sahel into account, we may say the climatic transitions are very gradual and the environment

is comparatively homogeneous. A highly changeable rainfall is none the less recorded in time and space.

STATE OF KNOWLEDGE OF SOILS

1:500,000 and 1:1,000,000 maps of soils exist in most Sahelian States, exclusive of Mali. A complete 1:200,000 coverage exists in Chad, except for desert areas. So, soils are rather well known as regards their typology and distribution (Audry, 1961 and 1967; Bocquier, 1973; Boulet, 1968 and 1976; Boulet et al., 1969 and 1971; Fauck, 1972 and 1978; Gavaud, 1968). In all cases, French classification is used.

In spite of the high homogeneity of climate, soil types vary. As a matter of fact, the types of parent materials are numerous, the most widespread being granites, shales, sandstone-like sedimentary rocks and arenaceous materials. The latter correspond to an important sand sheet which was emplaced 3,000 years B.C., i.e. after exsiccation (between 7,000 and 5,500 B.C.) of all the great Saharian lakes. That climatic change in the recent Quaternary period accounts for the extent of paleoclimatic inheritances in the Sahel, as the aridity of the recent Quaternary period has favoured the preservation of paleosoils, in particular iron pans and currently buried clay soils (Dutil, 1971; Maignien, 1960; Pias, 1966).

THE MAJOR SOIL GROUPS AND FAMILIES

The "moderately weathered", "subarid" and "nonleached tropical ferruginous" soils over arenaceous materials

All three soil types have developed over the arenaceous sheet of eolian origin. The latter is located in the driest areas of Sahel, but it can be traced from the Sahara to Sudanese areas which presently receive about one meter of rainfall. From the north to the south, the soils are increasingly differentiated into horizons and the mean depth increases from the so-classified "moderately weathered" to "tropical ferruginous" soils. The main reason for this is the gradual variation of climate data, but age differences between parent rocks are also considered. The pH decreases very gradually from north to south, from neutrality to about 6.0, and the organic matter content gradually increases, never rising above 1% in the uppermost horizons.

The moisture regimes are aridic in northern Sahel, progressively grading to ustic as rainfall and mean profile depth increase. Nevertheless, whether they are classified into "moderately weathered," "subarid" or even "nonleached tropical ferruginous" soils, the rates of permeability are similar in all cases--from 4 to 7 cm an hour--and the available water contents are very low--between 2 and 3%. In spite of the small available quantities, a deep percolation of water takes place, but the depth it reaches within the profiles varies a great deal every year, due to the amount of rainfall and, above all, to rainfall distribution in time. Using a lysimeter, this phenomenon could be watched and quantified (Bonfils et al., 1962; Chauvel and Charreau, 1972).

In the more humid southern Sahel, rainfall is fully absorbed in the sand and, as a result, small temporary water lenses are formed at depths ranging from 0.8 to 3 meters, i.e. in C horizons and in arenaceous materials. They are utilized by the roots of trees. As a matter of fact, we can observe in the Sahel a grass cover which is desiccated every year and a thorn tree and shrub savanna landscape in very open woodland formations. During the exceptional drought in the seventies, these water tables gradually dried up and a large part of the shrubs have died after the third or fourth year of abnormally low rainfall. Since the climate has become normal (we mean its data correspond to the average values computed over 50 years), the grass biomass has recovered its earlier level, but the shrub cover growth is late. This phenomenon has led many authors to speak of desertification.

Then, we can see that, in the scope of the utilization of Sahelian arenaceous soils, we can hardly make a distinction between "aridic" and "ustic." Even that slight difference is of low interest, as it does not emphasize the existence of water reserves occurring in the deep C horizons.

<u>The brown subarid soils</u>

The brown subarid soils are clay or sandy-clay soils. The 2-1 clay minerals are chemically rich and the pH is nearly neutral. The structure is unstable and the soils tend to surficial sealing during the dry season. As regards water balances, however, great differences can be observed. For instance, in northern Niger, where the mean annual rainfall is about 100 mm, clay soil areas covered by a very thin film of sand were prospected (Boulet, 1966). The low rainfall is fully absorbed, trapped in sand and to a great extent protected against evaporation. Water accumulates in the shrinkage cracks of clays lying under the sand film. The roots of schuwias, plants which make up good pasture lands for camels, take advantage of this particular morphology, which associates on the one hand chemical riches and on the other hand pockets of wet sand. These complex profiles are not easily classified in <u>Soil Taxonomy</u> because of their very specific water balance.

Much further south, on the contrary, under a more humid climate, the same brown subarid soils can remain dry for a long period of time in winter; the surficial crust which appears during the dry season brings about a significant runoff during the rains at the onset of the winter season, which come like a tornado on soils deprived of a grass cover (Boulet, 1974). In that case, the pedoclimate is aridic. A very surficial dressing, however, e.g. for cropping sorghum, modifies soil permeability to a great extent. Consequently, the regime may become ustic for the same group of soil. Soil dressing exerts a very important influence on moisture regime in semi-arid areas (Birot et al., 1970) and that possible modification was to be considered, for it may make a single soil pass from an aridic regime to an ustic regime.

<u>The "tropical ferruginous" soils</u>

The soil types classified tropical ferruginous soils (to be related to Alfisols) are various; their common feature is the prevalence of kaolinitic clay and the abundance of free iron, which is either fixed on the clays or individualized into patches or concretions and sometimes into duripans. The profiles are developed over two great families of parent rocks, on the one hand granitic rocks, on the other hand materials from the "continental terminal," i.e. primarily ferruginized sandstones and clay-sands.

The knowledge of the water balances in these soils is variable (Fauck, 1971); the main data were collected in an experimental station and the others during pedological prospecting. The scientists have tried to characterize the water balance of the soils on various scales from the catchment basin to the elemental plot. It was found that the irregularity of rainfall plays a major role by conditioning the runoff (Rodier, 1975). That issue was experimentally resumed, first in experimental runoff plots with weathering holes (Roose, 1979), then by using a rainfall simulator (Collinet and Lafforgue, 1979). Only a few types of ferruginous soils were studied, but a very marked variability of runoff can be recorded, depending on the vegetal cover conditions as well as on the type of soil utilization for agricultural or pastoral purposes. Consequently, the amounts of water which flow into the soils vary. In addition, the "splash" phenomenon, for lack of a vegetal cover, entails the generation of a comparatively impermeable surficial crust. That is why, depending on the year or on the vegetal cover, the regime of tropical ferruginous soils in the Sahelian area is either aridic or ustic.

Soil utilization in the semi-arid areas closely depends on the amount of water reserves (Dabin, 1969). Actually, the lower limit of moisture levels does not exceed a 70 cm depth below 800 mm average rainfall. In a number of "leached tropical ferruginous" soils, however, provisional oversaturation periods at medium depths generate hydromorphic phenomena. The occurrence of many other instances of hydromorphy in the semi-arid areas clearly evidences that the soil moisture regime is discontinuous and can vary to a considerable extent as a function of climate variations or environmental evolution. All things considered, the available water content, i.e. the difference between field capacity and wilting point, is more dependent upon the environmental conditions (irregularity of climate, condition of the vegetal cover, soil dressing, overgrazing) than upon soil type itself and its right place within the frame of a classification.

Planosols and Solonetz soils

They are soils with a contrasted texture, i.e. featured by sharp variations in clay contents between the successive horizons. They are developed over montmorillonitic clay weathering materials. The water dynamics depend on the specific morphology of the profiles, and the uppermost forty centimeters alone contain available water, whereas the lowermost horizons usually remain dry. Even the more humid Sahelian areas have an aridic moisture regime.

Vertisols

We shall only consider the nonhydromorphic Vertisols. The often thick profiles are developed over amphibole-containing materials from granite weathering, and the clay minerals are montmorillonites. It seems weathering was inherited from more humid paleoclimates. The abundancy of granulometric clay ranges between 30 and 50% in B horizons, but the uppermost horizons belong to various textural classes. All the Sahelian Vertisols are chemically rich soils but their moisture profile is aridic. pF 4.2 (wilting point) is only exceeded in the uppermost horizons, and the available water reserves are quite negligible. Nevertheless, when protected against overgrazing, these soils are gradually covered by a very noticeable herbaceous vegetation.

Moderately weathered fine gravelly soils

These shallow soils, fairly frequent over continental sandstones, are featured by surficial sandy textures and abundant ferruginous fine gravels in B horizons. Their moisture regime is poorly known, but probably aridic in the Sahelian areas. Towards the south, when rainfall increases, the fine gravelly soils are very much cultivated by village communities. As a matter of fact, they offer the advantage of being loose and, because of their great macroporosity in the fine gravel horizons, they house significant reserves of available water during rainy season. Thus, the regime grades very progressively from aridic to ustic. We cannot readily draw the limit within the frame of a classification, for environmental factors (geomorphology, vegetal cover) exert the greatest influence on the hydrodynamical characteristics.

CONCLUSIONS

In spite of the marked climatic heterogeneity, the dry soils of the African Sahel are very diversified. Their distribution primarily depends on the characteristics of parent rocks and climate data, in particular annual rainfall and duration of the dry season. But some paleofeatures have been preserved because of the greater aridity of present climate relative to the last few millenaries. Currently, no study could evidence that the aridity of climate is growing, even though certain cyclic variations result in exceptional droughts. The latter are alarming, for they affect environments where the population pressure grows rapidly and where the soils are increasingly put into requisition for grazing purposes or for such dry cultivation as millet or groundnut.

The knowledge of Sahelian soils and of their distribution is fairly good and a lot of maps have been issued. On the contrary, data regarding water balances are scarcer and we can hardly utilize these data for classification purposes. In addition, whatever the soils, the moisture budgets depend on several factors, above all on rainfall supply in quantity and intensity, then the soil type, and last the condition of vegetal cover and the place in the catenas. Some groups should be classified aridic (moderately weathered, brown subarid soils), other ones ustic (leached tropical soils over sandy-clay materials). Most often, however, a gradual transition from one regime to the other can be observed from northern to southern Sahel. Overgrazing and certain agricultural practices result in crust formation at the surface of the top horizon of many soils. It results in a significant runoff over the wide Sahelian glacis, and the actual reserves of available water are often smaller than the amount of water which the profiles can store. The moisture regimes are consequently altered, and an ustic soil type may become aridic during a few years. Knowing the moisture regime under natural vegetation is important, but it is as much required to assign a leading role in classification to the possible modification of such regime due to degradation of the structural qualities. This is a restraint on utilization related to soil features. In every semi-arid environment, water is the most limiting factor as regards development. In tropical semi-arid environments, with rainfall during the hot season, the structural qualities of uppermost horizons are the main criteria for soil characterization and classification. It is nonetheless necessary to enhance research about the hydrodynamical features of the major soil groups in the Sahel.

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