A SIMPLE FIELD METHOD FOR DIAGNOSING SURFACE CRUSTING AND PREDICTING RUNOFF PRODUCTION IN DRY WEST AFRICA

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INTRODUCTION

Both herdsmen and farmers of the arid and semi-arid of West Africa live under the threat that the available land may contract evermore due to the continuing degradation of the environment. In these systems, desertification often appears as a deterioration in the structure of the soils (The World Bank, 1986). Surface crusting not only impedes seedling emergence but depletes also infiltration and water storage into the soils. However, the evidence of land degradation is difficult to assess since the first stages are uneasy to detect and gross distortions can be made therefore by different observers. Moreover, the question arises whether the environment has been irreparably altered or still has the capability to recover. The objective of this paper is to propose a simple method for diagnosing surface crusting considered as an index of land degradation and for predicting hydrological regimes.

MATERIALS AND METHODS

The core observations and experiments have been conducted for ten years in 11 watersheds : 8 located in Burkina Faso, 3 in Niger. Additional studies were implemented in the vicinity of three boreholes in Northern Senegal, in three watersheds in Mali and in a watershed of Northern Cameroon.

The survey method included three scale levels. The lowest level consisted in the unit surface, namely the largest area exhibiting uniform features. Its size could range from 1 m^2 to several km^2. A field data sheet was used to characterize the main features of the unit surface, known as greatly influencing the hydrological parameters (Albergel et al. 1986) : the herbaceous or the crop cover, the surface roughness, the faunal constructions (worms and termites), pedological characters such as the thickness, the porosity and the structure of the surface crust and the texture, the thickness and the possible hydromorphy of the soil. At a higher level, the repetition and combination of unit surfaces recreated with reasonable accuracy a larger unit we called the «soil surface features unit». Specific field data sheet helped describing features occurring at this scale : the cover, the density and the structure of the tree cover, the landform as well as large erosion features (rills and gullies). A third level was required for drawing up the maps of the largest watersheds of nearly 50 km^2. Then mapping units consisted of the combination of two or more soil surface features units.

Simulated rainfall experiments were conducted on 78 1m^2 plots representative of unit surfaces occurring in the selected sites. Kinetic energies of simulated rainfall were very similar to those of natural tropical rainfall (Asseline and Valentin, 1978). The runoff hydrograph was used to obtain the infiltration rate of the plot as a function of time. The sprinkling intensities and durations were based on an analysis of the rainfall events recorded in the study areas in order to approximate the 1-year and the 10-years storms. Every plot was exposed to a series of 1-year and 10-years storms, usually 6, separated by drying periods ranging from 3 to 84 hours. The cumulative height of simulated rainfall did not exceed the mean annual rainfall. The first run on each plot started under very dry surface conditions during the dry season. The runoff hydrographs were used to determine : (i) the preponding rainfall which is the height of rainfall infiltrated before runoff occurrence, (ii) the final infiltration rate for each rainfall intensity of each storm, considered as an acceptable approximation of the hydraulic conductivity when the antecedent moisture conditions are the wettest, (iii) the infiltration coefficient defined as the cumulative depth of infiltration divided by the cumulative depth of rainfall.

RESULTS

The detailed analysis of surface crusts based on field examinations led to the proposal of a morphological and genetical classification system which includes six main genetically related types of surface crusts. These are identified in reference to the nature of the outcropping microhorizon, the number of microhorizons and their continuity. The surface degradation involves the successional development of various types of crusts : (i) drying crust characterized by the outcropping of a single very fragile sandy microhorizon, with a massive structure, (ii) structural crusts composed of either one thick microlayer («structural 1») containing partially slaked aggregates, two microlayers («structural 2») : a sandy microhorizon, often massive and continuous overlaying a seal made of finer particles, or three microlayers («structural crust 3») which consists at the top of a coarse sandy microhorizon, then of a fine sandy microhorizon, with a massive and vesicular structure and finally at the bottom a plasmic seal with vesicular porosity, (iii) runoff depositional crusts formed under water flow with a usually marked vesicular porosity, (iv) erosion crust with only one single plasmic seal, smooth, rigid and often very thin which results from the evolution of structural crust once the above sandy microlayers have been removed by runoff and possibly by wind (Valentin, 1985), (v) sedimentation crust, often broken up into curled up plates, with the larger particles at the bottom and the finer elements at the top, giving thus an inverse vertical distribution to that found in structural 2 and 3 crusts, (vi) pavement or gravel crust consisting of a more or less dense surface layer of gravel and stone-size coarse material incorporated in a structural-like crust with generally three layers and a marked vesicular porosity.

Where erosion or pavement crusts sealed exposed B-horizons, recovery appeared as debatable but in other cases, surface crusting processes remained revertible (Valentin, 1985).

The factors influencing infiltration arranged in a hierarchical sequence led to a classification of unit surfaces (fig.1). The ranges of the main associated hydrological parameters are presented in figure 2. Faunal activity and surface crusting are crucial factors for modeling infiltration. Furthermore, the time sequence degradation which is often observed within a single cropping season can be as severe as in uncultivated areas over a longer period of time. In this respect, the development of vesicular porosity, readily observable in the field within the surface crusts, provides a valuable index to assess the degradation intensity in the cultivated plots. The infiltration parameters can be assessed for a larger number of surface units, provided additional criteria are used as modifiers (Casenave and Valentin, 1989a) : vegetation cover, topsoil texture and surface roughness. The validity of this system was tested on 22 other plots not included in the primary sample and located near Agadez (Niger), in northern Burkina Faso and in northern Cameroon. The estimated infiltration coefficients were accurate for 18 plots whereas for 4 plots the deviations ranged from 8 to 17%.

Also this model was tested on plots located under higher mean annual rainfall (1,000-1,200 mm) : 17 in northern Togo and 8 in northern Ivory Coast. The estimated values of 16 plots fitted within the predicted ranges of the infiltration coefficient. A detailed study (Valentin et al. in press), carried out in the humid savannah zone of Ivory Coast (mean annual rainfall 1,350 mm) showed that this model could be satisfactorily used ($r^2 = 0.73$) on 24 cultivated plots (cassava, groundnut and rainfed rice). On 38 natural plots, this model was still valid ($r^2 = 0.81$), provided two new types of uncrusted unit surfaces had been defined, with and without free gravel at surface.

Combining the different amounts of runoff from the various surface units within the mapping units, the total amount of runoff could be assessed for the whole catchment. The calibration coefficients of this simple model varied between 0.45 to 1.39 depending on the watershed (Albergel, 1987), which was less than the calibration coefficients required for previous models. Several other studies have demonstrated the efficiency of this surface features based approach in improving the hydrological models (Casenave and Valentin, 1989b), in assessing the runoff production in water-harvesting systems (Serpantié and Lamachère 1989) as well as for crop water budget models (Vacksmann 1988). Of equal interest is the use of the morpho-genetical classifications of surface crusts and surface units in diagnosing desertification. The various surface crusts can be used as indicators of the earlier stages of land degradation (drying crust, structural crusts), of erosion (runoff depositional crust, erosion crust and sedimentation crust), or of pronounced if not irreversible deterioration (pavement crust). Given the state of a surface features unit at a given period, it is possible to conceive its probable evolution according to various scenarios based upon hypotheses on rainfall and land use systems. Moreover, this method enables the prediction of the associated hydrological changes (Albergel and Valentin in press).

DISCUSSION AND CONCLUSION

Except in a water-haversting system, surface degradation is greatly damageable for pastoral and agricultural systems since it gradually reduces infiltration and promotes self-accelerating erosion. Damages due to drought alone are most often revertible due to the capacity of the arid environment to recover. Accelerated deterioration of the topsoil, as induced by misuse or overuse of the environment, makes the recovery processes more questionable since biological productivity can be hampered for the forseeable future. In this respect, the lack of faunal constructions at the soil surface (worms casts, ants or, under dryer conditions, termite constructions) can be considered as a valuable indicator of degradation. The successional stages of the various surface crusts helps in identifying the degree of desertification, particularly the abundance of vesicular porosity and the extension of erosion and pavement crusts. Furthermore, such an approach provides quantitative data to be incorporated in water-balance and hydrological models.

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SUMMARY

Extensive field work including a detailed environmental survey and hydrological experiments enabled us to propose a simple method to diagnose land degradation and to predict the associated changes in hydrological regimes. This system is mainly based upon the identification of the type of surface crust as refered to a morphogenetical classification system. Such morphological and quantitative data are used to characterize the successional stages of land degradation in terms of infiltration and runoff production. Several main scale levels were considered from the 1 m^2 to the watershed of several tenth of km^2. Already this system has been validated in several countrie of West Africa.

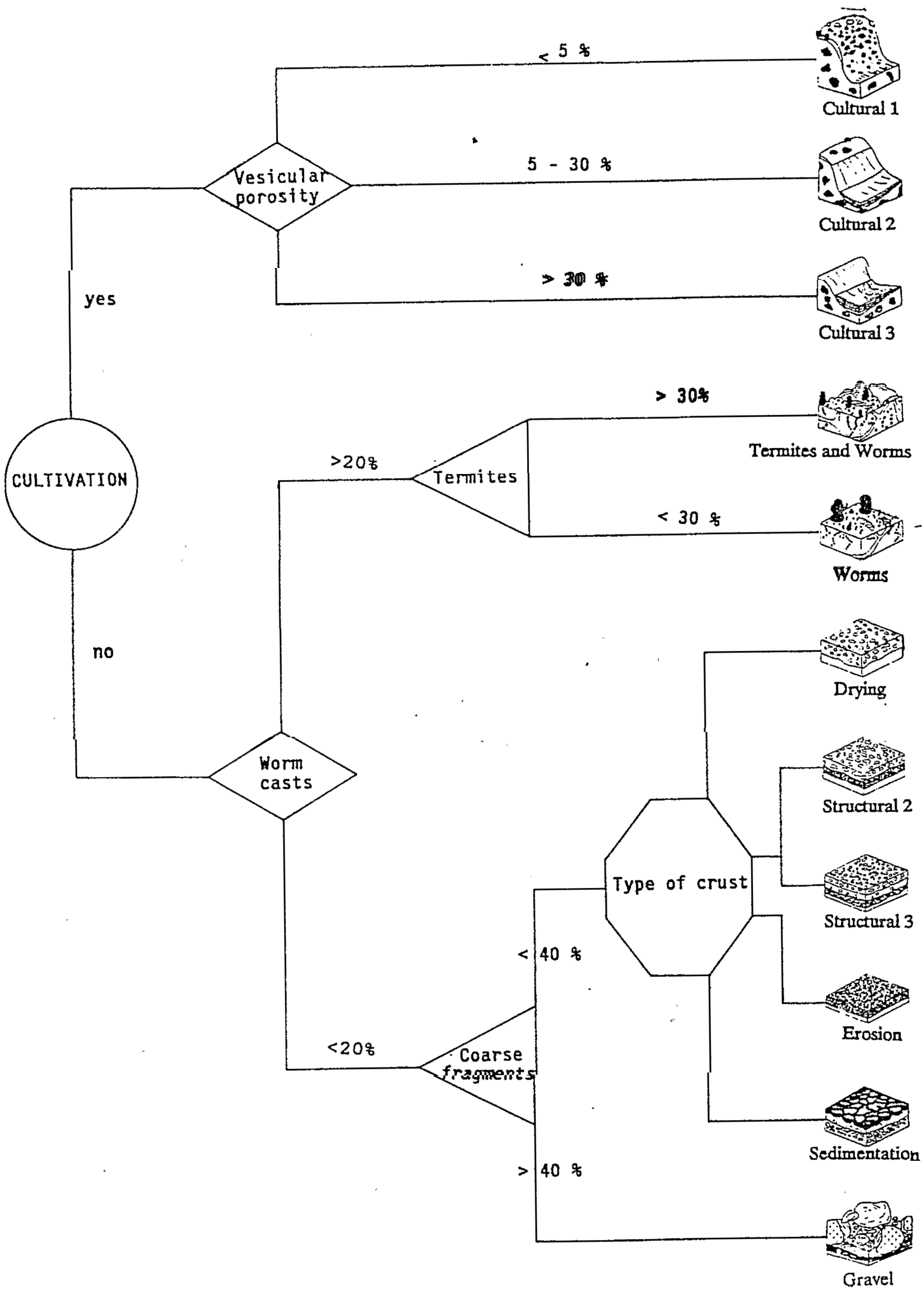

Figure 1. Key to the main Sahelian unit surfaces.
(after Casenave and Valentin, 1989)

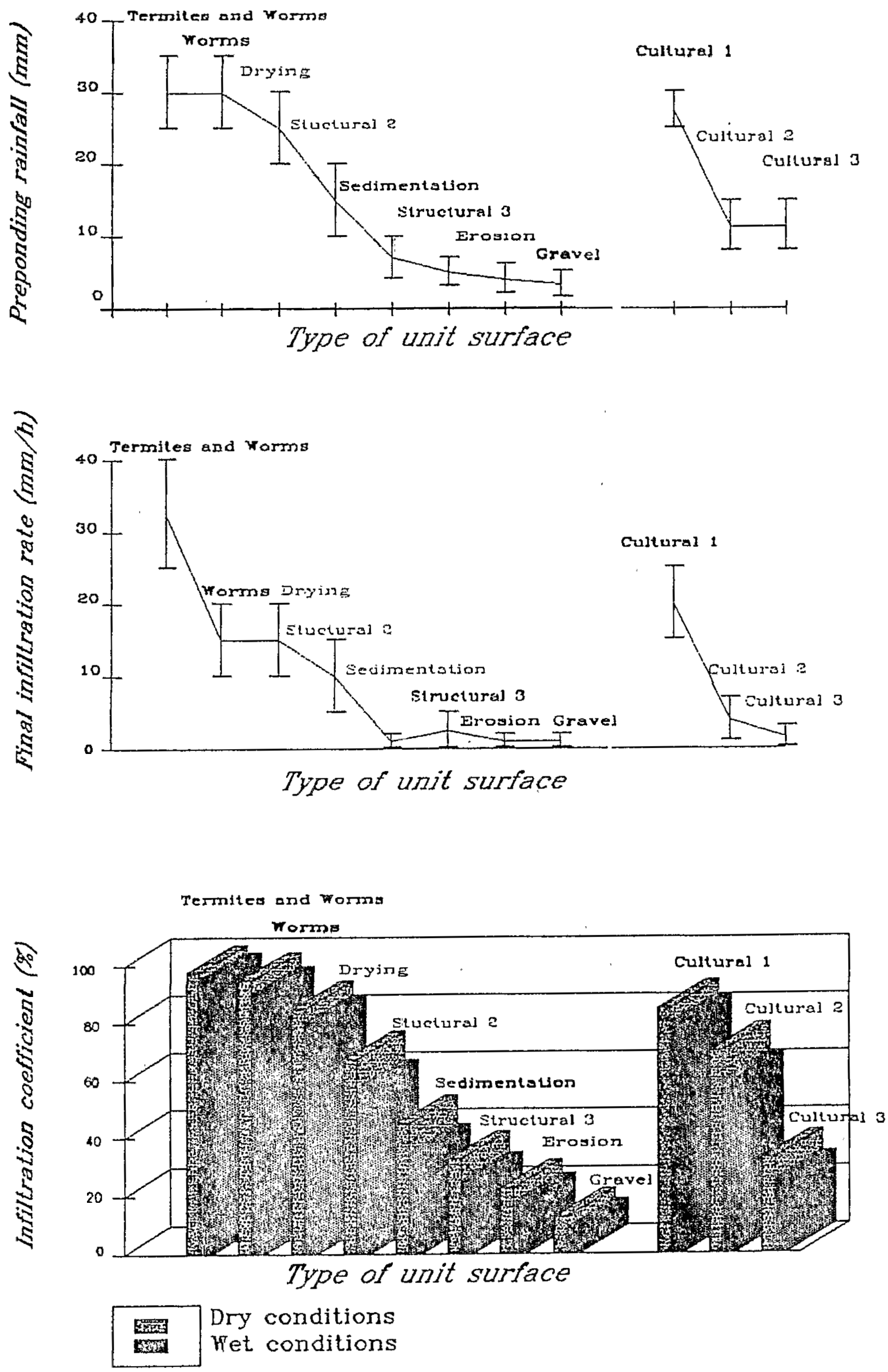

Figure 2. Main hydrological parameters of the various unit surfaces.