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"Methodological Problems to Evaluate Soil Physical Degradation"

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I -3 Soil degradation processes and methodology to evaluate relevant parameters

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SOIL DEGRADATION PROCESSES AND METHODOLOGY TO EVALUATE RELEVANT PARAMETERS

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INTRODUCTORY REMARKS

Soil degradation refers to the reduction in soil quality in relation to crop productivity. It is a complex process in which several factors, natural and human induced, contribute to the loss of productive capacity. Although it is a site specific problem, the effects of soil degradation processes extend beyond the original site and represent a considerable cost to society.

The various forms of soil degradation, mainly derived of the use and management given to the land, have become the major constraint for further expansion and intensification of agriculture in the whole World, and specially in tropical and subtropical regions. One of the most widespread and harmful soil degradation processes, with faster rates in the increasingly mechanized cropping systems, is physical degradation, mainly manifested through problems of compaction, sealing and crusting, and water and wind erosion. Although the main forms and processes of soil physical degradation are relativelly well known, *there are only very general estimates of the actual and potentially affected areas, of the rates and risks of degradation processes, and of the accompanying losses of productivity.* Therefore, ***it is required to develop and test new methodologies, at both laboratory and field levels, to evaluate the actual problems and to assess the vulnerability of soils to physical degradation under different climates, topography, and management practices.***

Crop yield and sustained productivity have been the measurements commonly used to assess land use limitations and effects of soil degradation, but more quantitative characterization and prediction of the affected soil physical properties are required. The experimental analysis of the dynamics of soil degradation processes and their effect on crop productivity can be carried out through the instalation of experimental plots, but on the other end, for diagnostic purposes, the availability of specific data on semipermanent soil characteristics may be used to infer the relevant soil physical properties using statistical models. Methods should be developed for use by soil surveyors in doing the required observations and descriptions of soil horizons. Although modern indirect techniques like remote sensing, computerized data processing, and simulation models, may help in the required evaluations, they will always require of accurate direct measurements. Given the large spatial and temporal variability in most of the soil physical properties, there will be required many replicate measurements, with the least possible variability due to the measuring procedure or device itself.

METHODOLOGICAL PROBLEMS TO EVALUATE SOIL PHYSICAL DEGRADATION

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INTRODUCTION

Soil degradation is a complex process in which several factors contribute to the reduction of its productive capacity. It represents the most serious limitation for the production of the future food requirements of mankind (Brady, 1986). Previous projections of production potentials in the yet unexploited World land reserves in the tropics generally have failed because the effects of soil degradation were ignored. Some of the effects of soil degradation on crop production have been partially masked through improved technological imputs, with increases in environmental problems and costs of production.

The processes of soil physical degradation are mainly manifested through problems of compaction, sealing and crusting, and water and wind erosion. It has been questioned (Dudal, 1979) if the information given by the traditional soil surveys and classification systems is suficient to make interpretations which have adequate predictive value in relation to soil physical degradation processes. Methodology for an appropiate quantitative characterization and prediction of the affected soil physical properties, is required to evaluate the actual problems, and to assess the vulnerability of soils to different processes of degradation. The measurementes will generally require many replications, both in space and time, due to the common large spatial and temporal variability (Warrick and Nielsen, 1980) in soil physical properties. Geostatistical interpolation of these soil physical variables (van Beurden and Riezebos, 1988) may be therefore a better alternative, than conventional methods, for mapping degradation hazards.

The methods to assess soil degradation have been clasified (FAO, 197ɜ) as direct observations and measurements, remote sensing techniques, mathematical models, and parametric methods.

PROCESSES OF SOIL PHYSICAL DEGRADATION

Soil compaction has been identified as one of the leading causes of soil physical degradation threatening future crop productivity World-wide, because it has the potential to affect crop growth and production directly, and also indirectly increasing the danger of soil erosion, water-logging, and/or water runoff. Excessive compaction is probably more extensive than ever before because of increasing use of heavy tillage and harvesting machinery, and also because of more intensive soil use. Additionally, large areas of soils in tropical rainforests have been reported damaged by compaction due to careless mechanical land clearing procedures.

Compaction implies a decrease in volume, or increase in density, as a soil response to external forces. Therefore, the primary effect of soil compaction is to reduce pore volume and to cause a redistribution amongst pore size groupings. These changes will affect, to a greater or lesser extent, air capacity and gaseous exchange, water retention, hydraulic conductivity, soil strength, and mechanical impedance to root growth. Indirectly, it will also affect many soil chemical and biological processes. For each crop, growing stage, soil, and climatic regime, there is an optimum level of compaction for maximum crop yield.

The degree of compaction or compactness, useful to diagnose root impedance, may be characterized by several parameters, measured with different, non standardised, procedures, such as:

Strength - Penetration resistance - Penetrometers

Porosity - Bulk density
- Soil cores
- Field excavations
- Surface gamma-neutron gauge

Size,number,distribution and continuity of pores

Direct measurements
- Thin sections with dye tracers
- Mercury intrusion porimeter
- Scanning electron microscopy
- Gamma-ray computed tomography

Indirect measurements
- Water flow
- Chemical transport

Observation of rooting patterns

Sampling of roots

The susceptibility to compaction or compactability will be useful to identify and characterize soils susceptible to strength problems, in order to anticipate the required management and potential rooting restrictions. It depends on soil type, moisture content, and initial compactness, and is frequently determined in the laboratory by several, non standardised methods, as:

Uniaxial compresion tests

Empirical models, based on soil characteristics, to predict bulk density (Larson et al, 1986)

Indices of aggregate stability, derived from laboratory measurements

Regresion equations or theoretical models, with an empirical approach, to estimate the change in bulk density and water content, have been recently proposed (McBride, 1989) for soil compactability assessment.

When exposed surface soil aggregates are disintegrated under the impact of raindrops, the dispersed finer fractions of soil material are redeposited on the soil surface in a denser arrangement, or move downward with percolating water to fill the soil pores, forming what is called a seal. This more or less compacted surface layer may drastically reduce water infiltration (sealing effect), causing water-logging, or runoff in sloped areas. The subsequent drying phase results on crust formation, which may offer mechanical resistance to seedling emergence. As a consequence, a degraded surface soil, with low stability to the process of sealing, not only reduces soil water storage by reducing water infiltration, but may also increase, specially in combination with high intensity rainfall, the rate of erosion, through increased runoff. Poor yields may result, both by poor crop stands due to reduced emergence of seedlings, or due to shortage of water held in the soil, and/or limited aeration. Besides structural seals and crusts formed as a result of water drop impact, there are depositional ones, formed by transport and deposition of fine particles by surface flow. Due to the degradation process of sealing, soil surface conditions are frequently more important than underlying soil permeability for infiltration of water from short-term concentrated rainfall events.

Simulation of soil sealing and crusting is generally done with the use of rainfall simulators, to study their effects on infiltration, runoff, and seedling emergence, both at laboratory and field levels. From these values there have been developed indices of sealing (Pla, 1985) and crusting. The differences in sealing and crusting susceptibility among soils, may also be evaluated this way. Crust strength in relation to emergence of seedlings has been estimated with the modulus of rupture test, and with mechanical probes and penetrometers. Subsequent micromorphological studies, using thin sections and scanning electron micrographs, may help to a better understanding of the processes of seal and crust formation.

Removal of topsoil, whether by erosion or by levelling or terrace construction, is a process of soil physical degradation generally resulting in reduced crop productivity. Loss of plant nutrients, reduced water holding capacity, and lower stability of surface soil structure, are the main causes. Soil erodibility is a quantitative measure of the inherent susceptibility to erosion by water or wind. The main approaches for the determination of soil erodibility by water are:

Long term measurements of soil loss under natural rainfall

Soil loss measurements under simulated rainfall

Use of predictive regression equations based on easily measured soil parameters

The best laboratory based indices are the ones that give more weight to dynamic soil properties relevant to the erosion process, like the soil's resistance to raindrop impact and surface flow. Empirical erodibility values, to be used in the so called Universal Soil Loss Equation (USLE)

(Wischmeier and Smith, 1978), have generaly been derived from the results of the three approaches. Recently, more process-based models are being developed to improve the empirical USLE model, providing a more quantitative understanding of soil susceptibility to erosion.

METODOLOGICAL PROBLEMS AND REQUIREMENTS

One of the present methodological problems to assess soil degradation processes is that still many soil physical properties associated with the development or recovery of degradation are imprecisely defined and not completely understood. Therefore, they cannot be properly quantified, and much less used for precise calculations and predictions.

Most of the methods presently available to measure soil physical parameters, related to the effect of degradation processes on root development, are not fully adequate for such purpose, because they were initially developed for engineering tests. Therefore, direct observations of the patterns of root development should be the focus of most studies, together with the measured indirect indicators of soil quality. Moreover, the measurements of soil physical properties and observations of root patterns have little value unless the impact of those conditions on the yield of the crop can be determined.

The methods and techniques applicable for predicting soil physical behaviour under field conditions should allow simple and direct measurements based on comprehensive physical relations, and should take into consideration the dynamic aspect of the soil physical properties, specially the ones depending on soil structure. These properties should be also quantified in terms of the dynamic action of root growth. The forces applied in the laboratory may attempt to simulate those found in the field under natural or cropped conditions. However, with the appropiate calibration and validation under field conditions, the laboratory methods may provide very useful information for diagnostic purposes,and for guiding management practices to prevent degradation processes. In any case, the choice of conditions for the measurement of soil physical properties, under laboratory or field conditions will be largely determined by the purpose of the test. A full standardisation of the methodology is not possible, because the method used should be in any case relevant to the objectives of the study

Although some basic studies of soil physical properties associated with the processes and effects of degradation make use of sophisticated means, there is an urgent need for more rapid, simple, and inexpensive field and laboratory methods and tools, so that many replicate measurements can be made on each soil unit and management conditions, taking into consideration the strong spatial variability of soil physical properties. Considering that the root system only occupies a very small fraction of the soil volume, the size of the samples has also to take into account such variability. Because of the strong dependence of most soil physical properties on soil water content, it is essential that under field conditions, accurate measurements and records of moisture be made at the same time.

Simulation models may be very useful to predict long term effects of degradation processes, which would be imposible to obtain by monitoring due to economical and practical limitations. They are used both to provide information about the expected effects of new soil management practices, and for rational planning of short-term field experiments. The feasibility and validity of computer-simulation models for defining soil-water regimes and associated qualities such as moisture deficits, aeration status, and workability, has been demostrated in several studies (Pla, 1988; Wósten and Bouma, 1985; Jacobsen and Dexter, 1987). They incorporate measured physical properties and rooting depths, for different climates and soil physical conditions, representative, or product of different soil management practices and degradation processes.

REFERENCES

Brady,N.C. 1986. Soil and World food supplies. Trans.13th Int. Cong.Soil Sc. Hamburg (FRG). I:61-79.

Dudal,R. 1979. Adequacy of soil surveys and soil classification for practical application in developing countries. Proc. 2nd Int. Soil Classification Workshop. Dept. Land Development. Bangkok(Thailand). I:9-23.

FAO. 1979. A provisional methodology for soil degradation assessment. FAO. Rome (Italy). 84p.

Jacobsen,B.F., and A.R.Dexter. 1987. Effect of soil structure on wheat growth, water uptake, and grain yield. A computer simulation model. Soil Tillage Res. 10:331-345.

Larson,W.E., S.C.Gupta, and W.B.Voorhees. 1986. A model for predicting soil compaction. Trans.13th Int.Cong.Soil Sc. Hamburg (FRG). V:290-300.

McBride,R.A. 1989. Estimation of density-moisture-stress functions from uniaxial compression of unsaturated structured soils. Soil Tillage Res. 13:383-397.

Pla,I. 1985. A routine laboratory index to predict the effects of soil sealing on soil and water conservation. In (Callebout et al, ed.) Assessment of Soil Surface Sealing and Crusting. Univ. of Gent (Belgium). 154-162.

Pla,I. 1988. Soil moisture constraints for dryland corn and sorghum production in Venezuela. Proc.Int.Conf. on Dryland Farming. Amarillo (USA). (in press)

Van Beurden,S.A., and H.Th.Riezebos. 1988. The application of geostatistics in erosion hazard mapping. Soil Technology. 1:349-364.

Warrick,A.W., and D.R.Nielsen. 1980. Spatial variability of soil physical properties in the field. In(Hillel,ed.) Applications of Soil Physics. Academic Press. New York(USA). 319-344.

Wischmeier,W.H., and D.D.Smith. 1978. Predicting rainfall erosion losses. Agriculture Handbook No 537. USDA. Washington D.C. (USA). 58p.

Wósten,J.H.M., and J.Bouma. 1985. Using simulation to define moisture availability and trafficability for a heavy clay soil. Geoderma 31:187-197.