MICROMORPHOLOGICAL CHARACTERISTICS OF NITOSOLS

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ABSTRACT

The concept of Nitosols was originally intended to include the well drained reddish coloured clayey soils of tropical and subtropical regions, characterized by a deeply developed B horizon that has a strong fine blocky structure with shiny ped faces.

The final definition of Nitosols as formulated in the Legend of the FAO-Unesco Soil Map of the World has been broadened and deviates considerably from the original concept.

A more refined definition was proposed by Sombroek and Siderius to group those tropical and subtropical soils that have the wide adaptability to crops and farming systems characteristic for Nitosols as contained in the original concept. To avoid misunderstanding, they proposed that these soils be termed Nitisols. This would imply the recognition of a Nito-argillic horizon, as a variant or subtype of the argillic B horizon, serving as a diagnostic horizon to classify Nitisols.

The present study is a first attempt to identify the micromorphological properties that are characteristic for the nito-argillic horizon. Thin sections of the B horizon of 21 soils, occurring in 15 different countries were investigated. All soils were classified as Nitosol according to the FAO-Unesco definition. Nine of these did not meet the requirements of Nitisols as proposed by Sombroek and Siderius.

The B horizon of the Nitisols, i.e. the nito-argillic horizon, could not be defined by a single property, but in all cases they showed a similar set of properties that seems to characterize this diagnostic horizon. The term Nitic Syndrome is proposed for this specific collection of properties.

INTRODUCTION

Throughout the tropics and subtropics large areas of well drained, very deep, dusky red to dark reddish or dark yellowish brown, clayey soils occur, that have a strongly developed fine blocky, or nutty, structure. The structural elements have very characteristic shiny surfaces that set these soils apart from other dark reddish coloured soils. The soils have a high aggregate stability, a friable consistence, a high porosity and a large moisture storage capacity. They are usually formed from easily weatherable basic parent materials, or other types of rock or sediments with basic volcanic ash enrichment, and occasionally on limestone. The crushed soil material tends to be magnetic and often reacts to hydrogen peroxide solution.

In tropical and subtropical regions they are among the most productive soils, as compared with other upland soils of these regions. Where used for subsistence farming, they can support high population densities, producing a great variety of food crops. Since last century, large areas of these soils have been used for commercial crops like coffee, cocoa, pineapple, etc.

At an early stage of soil mapping the importance of these dark reddish clay soils was recognized but their classification remained problematic because of the vague definitions. In the old system of the USDA they were called Reddish Brown Lateritic soils (BALDWIN et. al., 1938).

During the first stages of the preparation of the FAO-Unesco Soil Map of the World, the name Reddish Brown Lateritic soils was retained and split up into two units: those with a low base status, and those with a medium to high base status. In the fifth draft of the definition of soil units (DUDAL, 1968) the soils were included with the Acrisols and the Luvisols respectively, taking into account the presence of a textural differentation, but in a footnote their high level separation was already anticipated. It was recognized that some increase of the clay percentage with depth, and the presence of clay skins in the subsoil indicate that clay movement has taken place. It was felt, however, that these soils have many morphological characteristics in common with the Ferralsols which should set them apart from the Acrisols and Luvisols. But their favorable physical properties, and their often higher fertility, justify separation from the Ferralsols.

A separate soil unit with the name Nitosols was proposed. The name was derived from the Latin nitidus, meaning shiny, bright, lustrous, being connotative for the shiny ped faces which are characteristic for these soils.

The new major soil unit was accepted by the Advisory Panel of the Soil Map of the World project. However, the original concept was considerably broadened, allowing the inclusion of soils with less favorable properties and thus invalidating the initial signification of the soil unit. In the final definition (FAO-UNESCO, 1974) the essential diagnostic property of Nitosols is the argillic B horizon, which has a clay distribution where the percentage of clay does not decrease from its maximum amount by as much as 20 percent within 150 cm of the surface, and the CEC values which are not permitted to reach below 24 meq per 100 g clay, the latter being a non-intended by-effect of a last-minute widening of the definition of "ferric properties". Soils that have a mollic A horizon, or that do not have an argillic B horizon are excluded.

As a result, the Nitosols of the final FAO-Unesco Legend can now also include soils of a rather sandy texture and soils that have a pronounced textural change from the A to the B horizon. Also included are soils that have a low structure grade, a low structural stability, a very firm consistence, a low porosity or a very low inherent fertility. On the other hand, some soils that have all properties of the original concept have to be classified otherwise. The presence of a mollic A horizon, or of a B horizon which does not meet the requirements of an argillic B horizon excludes soils from Nitosols, placing them in the Phaeozems and Cambisols respectively, or in the Ferralsols on account of a low CEC (SOMBROEK and MUCHENA, 1979).

NITOSOLS AND THE NITO-ARGILLIC HORIZON

Through the adoption of the final definition (FAO-UNESCO, 1974) the concept of Nitosols has lost much of its relevancy. It has led to the search for characteristics that are quantifiable and at the same time form a better reflection of the original concept of Nitosols (SOMBROEK and SIDERIUS, 1978; SOMBROEK and MUCHENA, 1979). This was carried out by critical examination of soils that are exemplary in older systems, or that by consensus of participants in the field examinations during a number of recent international workshops key out as Nitosols, sensu stricto. The name Nitisols was proposed to avoid further misunderstanding (SOMBROEK and SIDERIUS, 1982).

To allow a more precise classification the concepts of Nito-argillic horizon and Nitic Properties were proposed (SOMBROEK and SIDERIUS, 1982). The nito-argillic is conceived as one of the variants or subtypes of the argillic B horizon. The main diagnostic criteria of this horizon are the high clay content, which should not decrease significantly to a great depth, and the strong fine blocky structure with shiny ped faces. The blocky elements are in fact neither subangular (i.e. "round") nor angular (i.e. "scaloped"), but square-edged ("nutty" or "polyhedral"). Kaolinite or meta-halloysite is dominant and there is more than 5 percent dithionite-extractable iron. It has been proposed that the nito-argillic horizon meets the following requirements (SOMBROEK and LIPS, 1985):

A nito-argillic horizon is a mineral horizon that is formed below a mollic, umbric, or ochric A horizon, but it may occur at the surface if the soil has been partially truncated. The nito-argillic horizon has the following properties:

1. A clay percentage of at least 40 percent.
2. A pronounced stage of weathering expressed by a silt/clay ratio of 0.4 or less (silt fraction = 20 - 2 micrometre).
3. A kaolinitic and/or halloysitic clay mineralogy, expressed by a SiO_2/Al_2O_3 ratio of the clay fraction below 2.5, or a cation exchange capacity of 36 meq/100 g clay or less (by NH_4OAc at pH 7.0 method, corrected for organic matter where necessary), or both.
4. A clay percentage that does not decrease from its maximum by more than 20 percent; a diffuse to gradual horizon boundary or a transitional horizon or horizons between the A and the B horizon and a clay percentage in the upper part of the B horizon that does not exceed the clay of the A by more than 20 percent.
5. Dominantly (more than 50 percent) moderately to strongly developed very fine to medium angular blocky structure (polyhedral) with, at least in the deeper part of the horizon, shiny ped faces, which can only partly be ascribed to illuviation argillans.

6. A high aggregate stability, expressed by a structure index (fraction of the total clay that cannot be dispersed by simple shaking with water) of 90 percent or more, when the percentage C is less 0.5.
7. A content of free iron of more than 5 percent (by dithionite).
8. A minimal thickness of 100 cm.

The present micromorphological study aims at the characterization of the soil material of nito-argillic horizons.

MATERIALS AND METHODS

Thin sections of the B horizon of 21 soils, occurring in 15 different countries were investigated. The countries are: Australia, Brazil, Cameroon, China, Ghana, Indonesia, Italy, Jamaica, Kenya, Mozambique, Nigeria, South Africa, Thailand, the U.S.A. and Zambia. All 21 soils were classified as Nitosol according to the FAO-Unesco definition (FAO-UNESCO, 1974). Nine of these did not meet the requirements of Nitisols as proposed by Sombroek (SOMBROEK and LIPS, 1985).

Large thin sections (15 x 8 cm) were prepared, following the procedure described by JONGERIUS and HEINTZBERGER (1975). This includes the impregnation of the samples with an unsaturated polyester resin (Synolite 544). After hardening, the specimen were sawed, ground, and polished to a thickness of 20 μm. Investigation was carried out with a Leitz Orthoplan polarizing microscope, using transmitted and incident light, and magnifications ranging from 100:1 to 1000:1. The descriptive terminology follows that proposed by BREWER (1976).

RESULTS

Thin sections of the B horizon of the investigated Nitisols did not reveal a specific micromorphological property that could be used to define the nito-argillic horizon. However, a set of features was found common to all of them, that seems to characterize this diagnostic horizon. BUOL and ESWARAN (1978) described a combination of properties, characteristic of the oxic horizon, which was called the Oxic Syndrome. Likewise, the present set of micromorphological properties could be termed the Nito-argillic Syndrome.

Tentatively, the nito-argillic syndrome includes the combination of the following features:

1. the s-matrix consists of homogeneous red or yellowish red plasma with common very fine particles of organic material, showing Munsell hues of 2.5 YR to 7.5 YR in plain light and 10 R to 2.5 YR between crossed polarizers. There are only few sand-sized and very few silt-sized skeleton grains. The mineralogy of the sand is mostly quartz, but some feldspars or other weatherable minerals may be present. The related distribution is invariably porphyroskelic.

   The plasma generally is weakly or very weakly birefringent. Most often the material has a weak, in few cases moderately developed argillasepic, in-masepic or inundulic fabric. Some specimens, taken from the deep part of the horizon show a weak ortho-bimasepic fabric. Papules, in various degrees of deformation, occur throughout the s-matrix in most specimens.

2. Macroscopic inspection of the thin sections reveals the very strong influence of animal activity. Abundant pedotubules indicate that the soil material has almost completely been reworked by soil animals, such as termites.

   The microstructure is characterized by the occurrence of weakly to strongly developed micropeds, with a size of 100 to 250 µm. This type of structure has been described by various authors who studied strongly weathered red tropical clays (e.g. see BEAUDOU, 1972; VERHEYE and STOOPS, 1975; PEDRO et al., 1976; MULLER, 1977; BUOL and ESWARAN, 1978; STOOPS, 1983).

   Various stages of the development of this kind of structure, as described by MULLER (1977), have been observed during the present study. Most commonly the micropeds occur as discrete or welded bodies in random or clustered distribution, associated with large compound packing voides. It is evident that the activity of soil animals has greatly contributed to the individualization of the micropeds, creating the high porosity of the soil material.

3. Skins of oriented clay (micro-laminated ferri-argillans) have been found in all nito-argillic horizons. Most thin sections show well developed, moderately thick (up to 50 µm), strongly oriented argillans on the walls of voids, either occurring throughout the whole thin section, or, more often in a few isolated clusters only. Commonly the colours of these ferri-argillans, if observed in plain transmitted light, are lighter and

have yellower hues than those of the s-matrix, suggesting a lower content of iron compounds.

In addition to these well developed argillans, all thin sections of the studied nito-argillic horizons show very thin, sometimes almost imperceptible, strongly oriented void argillans. They may have a thickness of no more than 2 or 3 μm and can be mostly observed throughout the whole thin section (photo 1 and 2). Since they are very characteristic for these horizons a special name: Lepto-coatings may be justified.

Between crossed polarizers the lepto-coatings appear as thin birefringent fringes, lining the walls of the voids. If observed in plain light, they seldom can be recognized since the layered fabric and the fine material that are characteristic for argillans, cannot be distinguished because the skins are too thin.

It may be a point of discussion whether these thin argillans are stress phenomena or depositional features. However, their gradual transition, in many places, into thicker clearly recognizable argillans, and their close concordance with the walls of voids that have very irregular shapes are indications that these are due to the oriented deposition of silicate clay. It is clear, however, that stress has modified some of these coatings afterwards.

It should be noted that argillans not necessarily are the result of clay illuviation, i.e. translocation of silicate clay from the A into the B horizon (FITZPATRICK, 1984). The degree of textural differentiation in the majority of the Nitisols excludes illuviation as a dominant soil forming process. Notably the lepto-coatings could very well be the result of local reorganization of the material within the horizon.

The omnipresence of the lepto-coatings in the nito-argillic horizons, combined with the occurrence of surfaces of weakness in the s-matrix due to the sepic plasmic fabric, may be held responsible for the shiny ped faces which characterize nito-argillic horizons in the field.

The lustrous appearance of the B horizon of Nitisols has been the subject of earlier studies. JONGERIUS (cited in SOMBROEK and SIDERIUS, 1977) signalled the presence of micro-cutans in thin sections of a number of relevant B horizons and described them as "thin, non-oriented shiny coatings of mainly iron oxide at the exterior of primary peds". His findings were mainly based on preliminary SEM-EDAX research which also showed that micro-cutans in the B horizon of Nitisols have aluminium contents that are too high to be characteristic for the presence of clay minerals only (JONGERIUS, unpublished).

A specific process, not yet described, was thought to be responsible for the genesis of these micro-cutans (SOMBROEK and SIDERIUS, 1977). It was suggested that a movement of oxides from within the soil material to the exterior of the peds would create the shiny surfaces. Tentatively the term "metallization" was proposed by them as connotative for both the metallic shiny aspect of the peds and the apparent predominance of metal oxides (SOMBROEK and SIDERIUS, 1977).

However, it seems that the micro-cutans described by Jongerius differ from the lepto-coatings as described in the present paper since the latter show a strong birefringence, indicative of strong orientation. Initial SEM-EDAX spot analysis of soil material from a Nitisol from Kenya showed that the smooth faces of a structural aggregate with shiny faces have Si/Al ratios indicative of clay minerals. Iron was detected also, but the contents were significantly lower than in those parts of the sample where the smooth faces were absent. These findings support the micromorphological observations mentioned above.

All B horizons of the investigated Nitisols revealed the nito-argillic syndrome. Some of the Nitosols which did not meet the requirements of the Nitisols, also showed the nito-argillic syndrome. These Nitosols, however, were too sandy, or the B horizon did not have the thickness required for Nitisols. The other remaining Nitosols studied have very different micromorphological characteristics.

CONCLUSIONS

The main diagnostic property of Nitisols is the nito-argillic horizon. This horizon is characterized by a specific set of micromorphological properties, the Nito-argillic Syndrome. Tentatively, this syndrome includes the combination of the following features:

1. The microstructure is characterized by the dominance of weakly to strongly developed micropeds, strongly disturbed by soil animals.

2. The s-matrix consists of red to yellowish red plasma with a low birefringence. Plasmic fabrics are weakly developed. There are few sand-sized skeleton grains and there is very little silt. The mineralogy of the skeleton grains is dominantly quartz but some weatherable minerals (e.g. feldspars) may be present.
3. Well developed ferri-argillans are always present, but their quantity may vary from few to many.
4. Very thin ferri-argillans (lepto-coatings) are common to abundant throughout the horizon. This seems to be the most characteristic of the nito-argillic horizon.

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