Intensity and duration of waterlogging under rice crop estimated by micromorphology and mineralogy

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Abstract
Three Hydragric Anthrosols were examined in the south-central part of China. Soils are under the rice crop at the present time, which means the periods of waterlogging. The use of carbonate waters and the lime input into the soils resulted in the carbonatization i.e. in higher pH and formation of the specific iron-carbonate concretions in the upper part of the soils. Different macro and microfeatures were described in the soils according to their geomorphology, water regime and history of the land use. Modern and relict features were identified.

Key Words
Stagnic Anthrosols, gleyic features, Fe Mn and calcite pedofeatures, evolution.

Introduction
Rice is one of the most demanding plants in the world for food production, especially in Asian countries. Rice growth requires a certain period of submerged conditions which may be of various lengths up to the whole vegetation period. Sometimes soils under rice are referred as cultural hydromorphic soils. Artificial flooding necessary for rice culture creates certain changes especially in the surface and subsurface horizons, such as formation of a plough pan consequent to puddling; formation of surface gley; translocation of iron and manganese from the surface layer. Additional modifications may be caused by terracing and binding of rice fields. One may expect similar morphology and characteristics of soils under rice due to similar land use and extended waterlogging. Meanwhile soils with various initial properties and formed on different parent material may be used as the basis for rice cultivation. This means the difference in their texture, clay mineralogy, horizonation, chemical properties etc. Also the variation of submerging, the specificities of crop rotation, even the slight difference in geomorphology and microclimate may result in variable soil attributes and in particular variable expression of the redoximorphic features, different rate of carbon cycling and ability to storage. The aim of this research was to estimate the role of physiography in functioning of artificially waterlogged soils under rice crops.

Methods
Soils were studied, described and sampled in the soil pits up to the depth 80-110 cm, depending on the level to the perched ground waters. Samples from each horizon were taken for the regular chemical analyses. Undisturbed oriented soil samples were collected in the special boxes for the preparation of thin sections according to the standard procedure of impregnation by resin and polishing up to the 30 µn thickness (Bullock *et al.* 1985). Thin sections were described in planar and cross polarized light (XPL) using the optical microscope NIKON ECLIPSE E200 under the manifestations x40 to 80. Nodules collected from the soil pits were powder crushed in the mortar and studied by XRD method using Karl Zeiss Jenna X-Ray diffractometer XZG-4A. Diagnostics of the minerals was performed on a standard base (Soil mineralogy 1989).

Results
Three soils under rice crop were described and sampled in Guilin prefecture, Guangxi autonomous region in south-central part of China (GR-02: 25^{o} 03’20.3 N, 110^{o}14’23.9 E; GR-03: 25^{o} 58’762 N, 110^{o}20’623 E; and GR-04: 25^{o} 22’59.8 N, 110^{o}18’36.4 E). All three soils have iron-carbonate segregations above the plow pan, increase of $CaCO_3$ up to 25% in the topsoil and pH ranging from 7.6 to 8.3, which permitted to classify the soils as Recalcaric Hapli-Stagnic Anthrosols according to Chinese Soil Taxonomy (2001) or as Hydragric Anthrosols according to WRB (2006).

Recalcaric Hapli-Stagnic Anthrosols cover a total area of about 700 000 ha in the southern China where they are formed on alluvial deposits of various age under humid subtropical climate with MAT > +20^{o}C and MAP above 1500 mm. Secondary carbonatization of these soils is due to the anthropogenic input of lime powder. The other sources of calcium carbonates are the ground waters coming from the Karst region nearby.

Field morphology and especially micromorphology in thin sections revealed common and specific features of all three soils under study in general chemical properties, and in particular in gleyization features and carbonate pedofeatures. Upper parts of the soils (up to 50 to 80 cm depth) reflect the high degree of the anthropogenic impact which strongly changed the initial soil properties due to waterlogging, input of the organic matter and lime powder. This resulted in particular in the increase of organic carbon, pH and silt fraction, formation of dense plow pan horizon. Specific hard segregations were described in the upper part of all three soils below the plow pan, which were expected to be secondary carbonate segregations formed as a result of lime input. The segregations have various sizes from 2-3 cm to 3-5 mm in diameter. They are more or less associated with iron according to variation of color from white or pale to ochre, rusty and red. Degree of gleyic features varies from weak olive-grayish color of the matrix to strongly expressed gray-bluish horizon. Bottom part of all three soils has grayish and orange-reddish fragmentary coatings around the aggregates.

Micromophology revealed a set of common features in all three soils including low content of the organic matter; increased silt content, carbonate impregnation and crystallitic b-fabric in the top horizons due to the lime input; common iron and iron-manganese nodules and segregations of various form, size and density together with the iron-free bleached zones and illuviated clay in the bottom part; humus-silty infillings; variety of calcite and complex iron-calcite nodules and pedofeatures (Figure 1 a-h). Some of them are of modern pedogenic origin, while the others may be also interpreted as relic features from previous stages of pedogenesis in drier and better drained environment, which are under degradation in present conditions. Both morphology and micromorphology suggest that various expressions of the described common features are explained by specificity of pedogenesis in each soil due to the difference in their parent material, geomorphology, history of the land use, length of waterlogging resulted in the various degree of clay, iron and carbonates mobility.

X-ray diffraction of powdery-crashed segregations identified their quartz-calcite or calcite-quartz composition with various ratios of gibbsite, goethite, hematite, lepidocrocite, chlorite and kaolinite as secondary components. Gibbsite as a mineral known to be common in Oxisols and Ultisols is believed to be the relic mineral indicating high degree of weathering under the excessive drainage environment of the past. Accumulation of various iron oxides and oxyhydroxides in form of nodules is mostly expressed in the upper horizons, which is explained by higher pH due to lime input there, while in the bottom part of the profiles iron is presented in form of soft impregnations and iron-clay coatings indicating higher iron mobility there (Figure 1 g, h).

Conclusions

Redoximorphic features associated with the excess of water under rice crop have various manifestations in the three soils under study. We interpret these differences by the different history of pedogenesis before the beginning of rice cultivation accompanied by excess of water, and by different intensity of current waterlogging in those three soils. As a result, we found two soils to be relatively similar, and the third soil quite different in its redoximorphic features, small size of Fe-carbonate segregations and strong degree of gleyization.

Macro- and micromorphic attributes reflect the combination of modern features associated with wetland conditions and relic features, which could be formed before rice cultivation. Specific iron-carbonate segregations were identified as modern wetland feature. They have the maximal size in soils with the most contrast water regime i.e. not only wet state, but pronounced dry period. The permanently wettest soil with highest perched water has the smallest iron-carbonate segregations, but at the same time contains abundant undifferentiated iron segregations of various morphologies (flakes, rings, impregnated plant residues, soft and hard typical nodules, iron associated with illuviated clay) in bleached iron-free zones, and evidence of the destruction of the lithogenic reddish iron-rich fragments. Differences in soil functioning resulted in the increased storage of inorganic carbon associated with iron-carbonate nodules in two of the investigated Irragric Anthrosols, while the third soil has limited potential to the carbon storage.

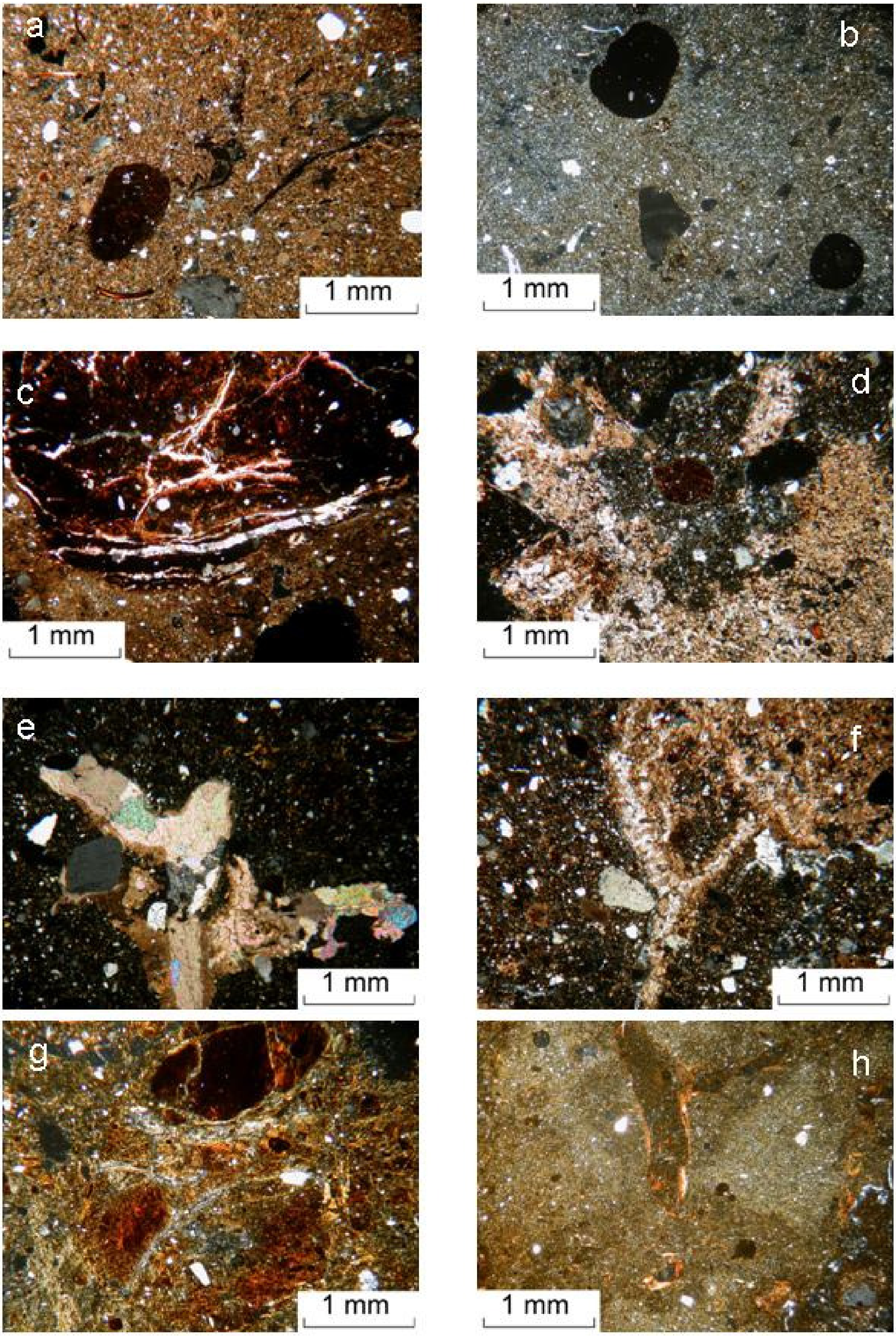

Figure 1. (a) GR-02 0-17 cm: Modern typic Fe-nodule and common ferruginisation of plant debris in humus-clay iron-carbonate groundmass; (b) GR-04 36-38 cm: Bleached iron-free silty-clay groundmass with modern rounded typic Fe-nodules; (c) GR-02 20-30 cm: Relict Fe-nodule with calcite filling the internal fissures; (d) GR-03 18-26 cm: Interpedal Fe nodule inside carbonate-free silty-iron-clay groundmass surrounded by sparite infillings; (e) GR-03 26-32 cm: Extra coarse sparite infillings in carbonate-free groundmass; (f) GR-03 18-26 cm: Sparite infilling along the intra-aggregate pores and microsparite impregnation of the groundmass; (g) GR-03 90-100 cm: Destruction of relict Fe-nodule, strong orientation of bleached plasma due to gleyization; (h) GR-04 70-80 cm iron redistribution with the formation of common compound Fe-clay coatings and Fe-humus clayey infillings in the voids associated with bleached zones. (all in XPL).

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