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RECENT ADVANCE IN STUDIES ON PHYSICAL PROPERTIES OF RED SOILS IN CHINA

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A b s t r a c t. The present paper deals with the brief review of studies on the physical properties of red soils in China since 1960. The important effect of soil structure on the fertility of red soils is described. Meanwhile it was shown that although in some clayey red soils the clay particles (<0.001 mm) can amount to 40-50 %, a series of physical behaviours of these soils are quite different from those of clayey soils distributed in the temperate zone, for instance, red soils have a great water retention capacity, but their water supplying capacity is lower. The available moisture of these soils under the range from -30 kPa to -1.5 MPa water potentials is about 10 %. This is an important reason inducing red soils to be liable to drought during the growing period of crops. Results also show that the clayey red soils have good tilth properties due to the presence of a great amount of water stable microaggregates in these soils.

K e y w o r d s: red soils, soil structure, soil water

INTRODUCTION

Red soils are distributed widely in southern China. Their covering area approaching to 2.03 mln km^2, amounts to 20 % of the total land of this country. These soils are important resources for the exploitation and utilization of agriculture and forestry in the tropics and subtropics of China, capable of sustaining two or three crops annually, and suitable for planting rice, wheat, maize, soybean, peanut and other tropical crops. Great achievements in the plantation of rubber tree, development of tropical and subtropical crops and increase of food production have been gained since 1950. The degradation of soil resources in this region, however, is remarkable due to the unreasonable exploitation and utilization of these soils. Although the hydrothermal conditions in this region are favourable, with the annual precipitation amounting to 1 200-2 500 mm, which is usually more than the annual evaporation rate, the uneven distribution of the rainfall in a year appears due to the influence of the monsoon. There is always severe drought and high temperature in summer and early autumn, and flooding, low temperature hazard in early spring, which is the major constraint affecting the agricultural production. In view of what has been mentioned, how to transform these unfavourable natural factors into better condition for the crop growth is an important and urgent problem in the face of the soil physicists. In recent years some researches on soil physical properties concerning the production of agriculture and forestry in this region have been done by Chinese scientists. In the present paper two main aspects - soil structure and soil water are reviewed briefly.

SOIL STRUCTURE

The study on the structure of red soil was started in 1960 with a view towards improvement of low yield factors of red soils -

acid, infertile, compact and easy to drought. Because the soil compaction and drought are closely related with soil structure, extensive investigation of this problem was began in 1980.

Change of structure after exploitation of virgin red soils

The structural characteristics of three series of red soils are examined. Latosol series derived from the basalt weathering product in the tropics, lateritic red soils derived from the granite weathering product in the southern subtropics and red soils derived from the Quaternary red clay in the middle subtropics of China. Table 1 shows that the stability of soil structure decreased after the exploitation of the virgin red soils due to the decrease of amorphous sesquioxides and clay particles functioning as inorganic cementing materials, and the increase of the activity of clay particles (ratio of plastic index to clay particle content). This change, however, depends on the soil management; where there is an adoption of good management or the paddy cultivation, if allowed by the natural and economic conditions, the soil structure gains recovery because of an increase or regeneration of organic cementing materials. Under such conditions the structural coefficient and content of water stable aggregates increased again remarkably. Moreover, the formed aggregates are not only water stable, but also rich in nutrients, and the porosity of the inner aggregates with different sizes were improved apparently [2,18,20]. It implies that there are two different ways in the developing soil structure in red soils after their exploitation. One is a good way, when the cultivated soils are continuously enhanced by organic cementing material under the reasonable cropping systems, the other is an unfavourable way as the soils are subjected to rough cultivation and management; as a result, soil structure degraded gradually and was liable to lead soil and water loss.

It is well known that the distribution of some soil types depends on the bioclimatic conditions, which is called zonality. The stability of soil structure is also related with zonality because the structural stability depends on the soil constitution, in particular, on the constitution of soil cementing materials which are usually weathering products resulting from the bioclimatic conditions. It can be also seen from the table that the content of amorphous sesquioxides, as inorganic cementing material, in the surface layer of virgin red soils decreased from the tropical to the

Table 1. Changes of structural stability of red soils after exploitation

Soil sample and depth (cm)	Organic carbon (%)	Clay particle (%)	Clay activity (%)	Amorphous Fe_2O_3 (%)	Amorphous Al_2O_3 (%)	Water stable aggregate >0.25 mm (%)	Structural coefficient*
Latosols							
virgin (0-25)	2.21	56.5	0.26	7.49	3.97	90.8	93.1
upland (0-16)	1.41	50.8	0.26	2.47	3.83	70.4	84.6
paddy (0-16)	3.53	46.9	0.45	-	-	-	87.5
Lateritic red soil							
upland (0-11)	1.32	22.9	0.31	2.37	0.77	33.2	73.3
ibid (11-30)	0.45	25.0	0.60	2.68	1.31	-	-
Red soil							
virgin (0-5)	1.14	32.8	0.37	0.74	-	73.6	88.4
upland (0-16)	0.66	8.7	0.53	0.74	-	28.4	70.0
paddy (0-14)	2.08	12.8	0.80	0.26	-	58.0	96.0

* Structural coefficient = (1-a/b)·100 %, where a=content of clay particles (<1μ) obtained from microaggregate analysis, b=content of clay particles obtained from mechanical analysis.

middle subtropical areas, with the highest in latosols in the tropics and the lowest in red soils in the middle subtropics. In contrast, the activity of clay particles in these soils increased from the tropics to the middle subtropics [12]. It implies that the stability of soil aggregates caused by the inorganic material becomes relatively weak from the tropics to the middle sutropics. In addition, the composition of organic cementing material in these soils to north becomes more complex from south to north. For instance, the ratio of humic and fulvic acids in free and weakly combined organic cementing material of 3-1 mm water stable aggregates attains 0.10 for latosols, 0.13 for lateritic red soils and 0.21 for red soils. The ratio of humic and fulvic acids in paddy soils derived from the Quaternary red clay in the middle subtropics can amount to 1 [12]. Consequently, from the viewpoint of the soil zonality, strengthening the stability of soil structure from the tropics to the middle subtropics through the increase in organic cementing material is essential, in particular, for the middle subtropics, because in red soils of that zone the inorganic cementing material is remarkably less than that in latosols. In addition, the activity of clay particles in former soils is higher than that in latter, which is unfavourable to the formation of water stable aggregates.

Effect of soil structure on soil fertility

The soil structure plays an important role in regulating water and nutrient supplying status of soil. The study shows that the saturated hydraulic conductivity (K_{10})[1] of upland red soil with good structure increased five times, the evaporation rate from surface layer of that soil in 12 hours decreased by two thirds, and the content of available moisture is higher, as compared to those of upland red soil with unfavourable structure [17]. They are remarkably beneficial for the acceptance of more rainfall and increase in the water preserving and supplying capacity of the soil. In red soils with good structure the fixed rate of phosphorous by soil is less than that in red soils with unfavourable structure. Moreover, the fixed phosphorous by soil is easily released into soil solution [16]. Results also indicate that the migration of phosphate in red soils differs from the various structural conditions of soil. Both the soil moisture and bulk density have significant influence on self-diffusion (Ds) of phosphate in red soils. The greatest is the influence of soil moisture condition on the P-diffusion under appropriate bulk density of 1.35 g/cm^3 for lateritic red soil and red soils, but it decreased remarkably with the increase in soil bulk density up to 1.65 g/cm^3. However, for latosols no appropriate values of bulk density have been found, the rate of P-diffusion declined along with the increase of bulk density from 1.20 to 1.65 g/cm^3 [10]. Consequently, protecting water stable aggregates in red soils from deterioration and creating of an appropriate bulk density and moisture are favourable for the increase of the phosphate movement in soil and promotion of the efficiency of phosphorous fertilizer in the tropical and subtropical red soils [10]. In addition, in red soils with good structure the retention capacity of the NH_4-N is higher than that in soil with unfavourable structure [16].

Microaggregates

Due to the influence of peculiar bioclimatic condition in the tropics and subtropics, red soils contain more amorphous sesquioxides with strong cementing action and 1:1 type clay mineral with lower expansibility in water, which gathers the individual soil particles into the extreme strong water stable aggregates in diameter of 1-0.01 mm, usually so called 'pseudo sand', amounting to 50-90 % [5,15]. A great deal of water stable

1 K_{10} — saturated hydraulic conductivity under 10 °C water temperature.

microaggregates causes a series of the physical properties of clayey red soils to be quite different from those of clayey soils distributed in the temperate zone. For instance, in clayey red soils the content of clay particles (<1 μm) can approach 40-50 %, the modulus of rupture of soil, however, is lower, amounting to 0.3 MPa, while that of yellow brown earth approaches 0.7 MPa, even though the clay content in the latter soil is only a half of that in the former soil. The soil adhesion of red soil is lower at about 1.5 kPa, while that of other clayey soil is about 2.0-2.5 kPa. The plastic index of red soils is usually less than 15, while that of other clayey soils approaches to 30 [13]. Moreover, there is a positive correlation between the soil plastic index and the clay content in soils [9], but no such relation is found in clayey red soils [13]. In accordance with Skempton's study (1953), the effect of the cohesion force on shear strength intensifies with the rise in the activity of clay particles. In red soil, however, the activity of clay particles is so low that its effect is less, while the internal friction force may amount to 80 % or more of the soil shear strength [14]. All these behaviours indicate that the mechanical properties of red soils are similar to those of sandy soils, even though the content of clay particles in these soils is high.

Many reports concerning the problem of structure formation of soil in the tropical and subtropical areas have been made in the published literature. Up to now, there is still lacking in the identified understanding of the concept about this problem [11]. Recent study indicates that the microaggregate of <0.25 mm in diameter mainly depends on the cementing action of clay particles and amorphous sesquioxides, the formation of macroaggregates of 0.25-10 mm in diameter is closely related with the interaction among the soil particles, inorganic and organic cementing materials [12,18,19]. It is well known that due to the low expansion potential and lacking in the freezing and thawing stresses in red soils the creating and maintaining of soil structure and its stability by means of the physical forces in the tropics and subtropics are negligible. Consequently, the formation of structure is mainly through the chemical and biological forces, in particular, the latter, such as the action of the plant roots and soil fauna. Increase in fresh organic matter content in these soils is an important practice not only as food of soil fauna, but as a good structural conditioner as well [6,12,19].

Scientists knew well that the loamy soils are liable to be managed. Up to know, however, change of soil texture on a large scale by any economical means is impossible. Therefore, the successful management of clayey red soils, like elsewhere, mainly determines the creating and maintaining of soil structure so as to form optimum physical conditions of soil.

SOIL WATER

Study of this problem in the tropics and subtropics of China began in 1980 [3]. Recent investigations show that the shortage of water supply to crop growth in northern arid and semiarid areas of China mainly depends on the lower annual precipitation, but in hilly regions of southern China, the water problem in the agricultural production is complex. It is related closely with the water shortage of the short period, the unfavourable water supply capacity of soil and relief factor etc. [13].

Water characteristics and supply capacity

The red soils with clay texture have a great water retention capacity amounting to 40-50 % under -2 kPa water potential, 30-40 % under -10 kPa and 25-30 % under -30 kPa, respectively. The available moisture in these soils, however, is lower because of their heavy mechanical composition and considerable amount of water stable aggregates [14]. It is usually about 10 %, while that of clayey soils distributed in the temperate zone may attain 20 % [8]. Low available moisture is an important reason inducing red soils to be liable to drought while is caused by the physical properties of soil.

Results also show that the form of the water characteristic curves of red soils with clay texture is quite different from common clayey soils, but just similar to that of sandy soils. At the beginning of dehydration the specific water capacity of red soils (SWC) decreased rapidly. When water potential (WP) decreased from -10 kPa to -30 kPa, SWC reduced by an order of magnitude of 10^{-1}. When WP decreases to -50 kPa and -100 kPa, SPC is reduced by an order of magnitude of 10^{-2} and 10^{-3}, respectively. In the latter case, although the soil moisture is not too low, due to the hard release of water from soil matrix the crop roots are already difficult to uptake water and liable to drought, which is another reason inducing red soils to be liable to drought caused by the physical properties of red soils[2].

Water infiltration

Water infiltration of soil is one of the most important physical factors affecting water storage in red soils. Generally it is favourable in clayey red soils because there are a great deal of water stable aggregates and the aeration pore space in these soils. The saturated hydraulic conductivity (K_{10}) is higher and fluctuated in a range of 2.3-14.7 cm/h, while that in clayey soils distributed at the plain of northern China ranges only 0.78-1.08 cm/h^2 [8]. However, once the crust is formed on the surface soil resulting from destruction of soil structure or the fine soil particles slaked from aggregates are leached down to block the transmission pores, the infiltration rate reduced apparently. In that case K_{10} in surface layer of red soils amounts only to one third of that in undistributed sublayers of the same profile[3]. Study on the spatial variability of physical properties of red soils show that K_{10} of these soils mainly depends on the macropores of >0.02 mm in diameter [4]. Therefore, preventing the surface soil from crusting, maintaining better soil permeability and increasing infiltration rate are the most available ways to increase the effective use of water resources in this area.

Water storage in red soils

Water storage in red soils mainly depends on the atmosphere factors (especially rainfall), relief, surface mulching status and the physical properties of soil. The annual precipitation in the hilly region of central China is even more than the annual evaporation, the former usually exceeds the latter by about 300 mm per year. However, due to uneven distribution of the precipitation in a year and different plant covers the water storage in red soils is diverse from different seasons even under similar relief condition. More amount of the available moisture storage in the middle subtropics appears in spring, containing about 100 mm in soil depth of 1 m. From middle July to October the available moisture storage in 1 m depth decreased, amounting to 50 mm or less. In particular, the negative values of the available moisture storage in 0-20 cm or 0-50 cm depth have always appeared in those seasons. The water shortage in a short period may severely induce crops to die from drought.

However, it is interesting to find that there is more water storage in deep layers of red soils even after dry season. The available moisture storage in both soil depth of 1-2 m and 2-3 m amounts to 100-200 mm[4]. This phenomenon is related probably with the good water permeability and the lower unsaturated

2 Xu X.Y., Yao X.L.: Physical properties of red soils and its effect on water availability. Trans. Int. Symp. 'Development of Grasses in the Region of Red Soils of Southern China', 1991 (in press).

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hydraulic conductivity of red soils. The macropores constructed by the different arrangements of water stable aggregates promotes water percolation, on the other hand, as soon as the surface soil is dried, a natural mulching preventing water loss from the surface evaporation is formed. Besides, after leaching down of gravitational water in profile the unsaturated hydraulic conductivity is dropped down rapidly, which is available for preserving water in soil. How to use the water stored in deep layer of red soils plays an important part in the alleviation of the drought occurring in summer and autumn.

CONCLUSIONS

1. The structure of red soils in the tropics and subtropics is favourable. Even though the texture of these soils is rather heavy, their tilth property is still good because of the great amount of water stable aggregates in soils. As soon as the soil structure is destroyed, the tilth of these soils becomes unfavourable.

2. The clayey red soils have a great water retention capacity. However, their available moisture is lower due to the hard release of the water adsorbed on the surface of soil particles and within microaggregates. Besides, the water supply capacity is also lower because the specific water capacity in the case of unsaturated condition dropped down rapidly along with the dehydration. Both lower available moisture and lower water supplying capacity are the important reasons inducing red soils to be liable to drought.

3. The available moisture storage in upper layers of red soils always appears negative in value in dry season. However, there is still rich moisture in the deep depth of 1-3 m in that time. How to utilize this part of water resources to alleviate the drought is an important research subject.

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