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PEDOGEOCHEMISTRY OF CHINA AND ITS SIGNIFICANCE IN AGRICULTURAL PRODUCTION

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ABSTRACT: Pedogeochemistry of China is controlled by such factors as biology, climate, parent material, topography and anthropogenesis, and the different geochemical types are formed under the different conditions of soil formation which have different abundance levels of elements. The relationship between concentration of elements and plant growth and human health depends upon available forms of element in soils. While the factors affecting element availability are soil pH and Eh, tillage and fertilization by man besides element forms in soils. On the basis of pedogeochemical types and distribution, rational plantation and application of fertilizer to soils will be of great significance for sustainable development of agricultural production.
KEY WORDS: pedogeochemistry, spatial differentiation of elements, agricultural production

Soil is an epigenetic sphere having the densest biological mass and the highest biological energy, which is a basement providing the plant with water and nutrient. Soil is either the weathering product of rock or the natural material which contains various chemical forms of elements and has its genetic and developmental regularity (Gong, 1982; Fortescue, 1980; Kovda, 1973). So, to research pedogeochemistry is of great significance for developing agriculture and improving survival environment of human being. This paper will discuss the geneses and distribution of pedogeochemical types in China based on the previous work on pedogeochemistry by authors. Finally, the significance of pedogeochemistry on agriculture of China will be discussed.

I. GEOCHEMICAL GENESES, TYPES AND DISTRIBUTION OF SOILS IN CHINA

Seven geochemical types are identified in China based on the theory of pedogeochemical evolution which was put forward by V. V. Polynov, a pedo geochemist of former Soviet Union (Polynov, 1959; Perelman, 1975) and in combination with soil redox. They are saline, gyp-

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sic, carbonate, siallitic, ferrallitic, clastic and ferrolysed types (Gong, 1980; Gong and Luo, 1992). Further, four geochemical regions are determined on the basis of association and distribution of pedogeochemical types. They are saline, carbonate, siallitic and ferrallitic soil regions (Gong, 1980; Gong *et al*., 1992; Gong *et al*., 1994; Gong *et al*., 1986). Saline, carbonate, siallitic and ferrallitic soils are typical in the four soil regions, respectively, according to zonal distribution. There are also some soil types associated with local factors such as topography and parent material. The areas of different soil regions are shown in Fig. 1.

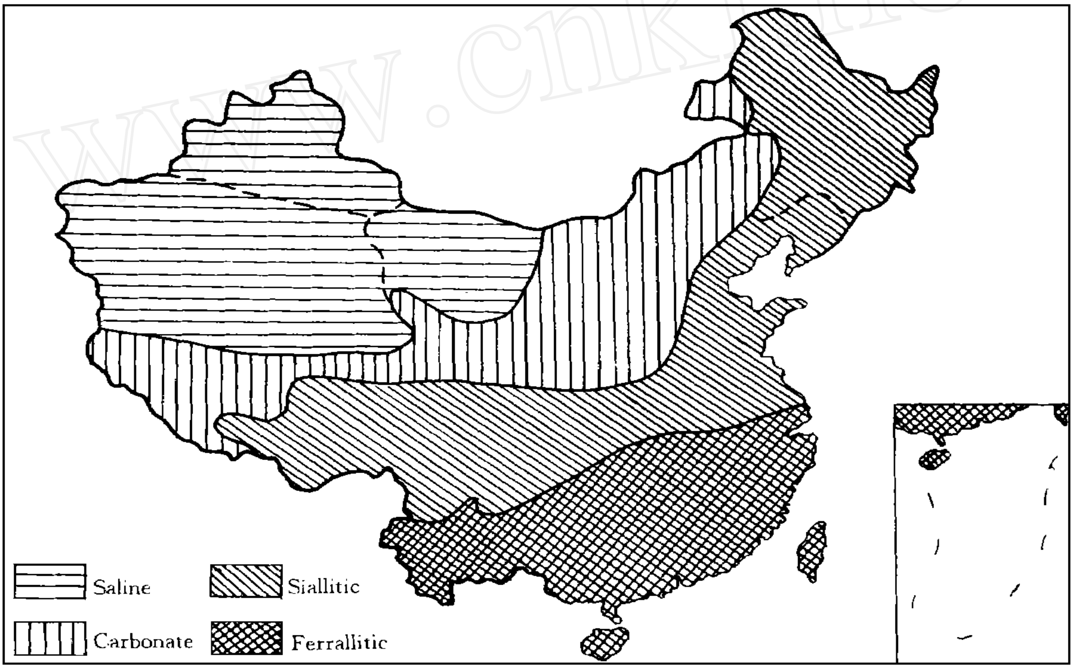

Fig. 1 Pedogeochemical regions of China

1. Saline Soil Region

The Saline soil region is distributed in the arid inland areas of the western China, including the northern Qinghai-Xizang (Tibet) Plateau, which makes up 27 % of the total land area of China (Gong *et al*., 1992; Gong *et al*., 1994). In this region soils appear alkaline, textures are coarser, mainly sandy and sandy loam, and secondary minerals are mostly hydromicas. Saline and gypsic soils are most commonly distributed in this region with siallitic and carbonate soils distributed in the alpine - subalpine area where the climate is moist. The soils are rich in salts, including chloride and sulfates, and in nitrate and borate in local areas. In the saline region, soils are generally rich in total and available sodium, potassium, boron and copper, while soils are rich in total phosphorous (P), lower in available P, resulting in that the deficient area of P comprises 63 % of the region (IANRR-CAAS, 1986) and is rich in water-soluble fluorine, especially in the alkaline soils (Huang *et al*., 1994; Gong *et al*., 1994). The deficient ele-

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ments in the soils include zinc, iron, manganese and iodine ——80 % of the soil are low in available zinc and manganese, and 50 % in available iron. Available selenium is also deficient in the region (Gong *et al*., 1994).

2. Carbonate Soil Region

This region extends from the Inner Mongolian Plateau to the Xizang Plateau, and is 23 % of the total land area of China. The soils appear alkaline, the texture is mainly loam and secondary minerals are hydromicas and/or chlorites. Carbonate soils are the main types in this region. Siallitic soils are formed under the condition of moisture in high altitudes. While saline and alkaline soils are often distributed in low altitudes. The soils are rich in carbonate (up to 20 %) so that the calcium-accumulating horizon appears in certain depth of soil profiles. In this region, the soils are also rich in total and available potassium and boron, and at same time rich in total P and poor in available P. The area of P deficiency may be up to 60 % of the total cropland area (IANRR-CAAS, 1992). Soils are also rich in water-soluble fluorine, especially the soda alkaline soils in depressions, so that fluorosis of humans and animals is common. Likely deficient elements of these soils are zinc, manganese, iron, molybdenum, iodine and selenium —— 80 % of the soils are low in available zinc, manganese, and iron.

3. Siallitic Soil Region

The region covers around 30 % of the total land area of China, extending from northeast to southwest in ribbon. The soil in the region are neutral or weakly acid. Textures are clay loam and the secondary minerals are principally 2:1 type layer silicates, such as montmorillonite, illite and vermiculite. The soluble salts and carbonates have mostly been lost through leaching from the soil, and this has led in particular to potassium deficiency in 47 % of the region. P availability in soil is reduced due to a decrease of free calcium and an increase in active iron and aluminum. By comparison with the carbonate soil region, there are fewer areas deficient in available zinc, manganese, iron and iodine and more areas deficient in boron, molybdenum, fluorine and selenium.

4. Ferallitic Soil Region

This region is in the tropical area south to the Changjiang River and covers about 18 % of the total land area of China. The soils are acid, clay in texture and the secondary minerals are mainly iron and aluminum sesquioxides, kaolinite, goethite, and gibbsite. The principal soil geochemical types are: ferrallitic soils, ferrolysed (paddy) soils which have been affected by human activities, and siallitic soils which are distributed in the local area. The soils are high in aluminum as well as free iron, the content of which is over 40 % of total iron in soils (Gong,

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1985). Under condition of abundant moisture and heat, the mobile elements such as potassium, boron and fluorine are strongly leached, resulting in a deficiency of these elements in soils of the region. The soils are not poor in total molybdenum and selenium, but availability of the elements is low. P in soils is in the Fe, Al-combining form, resulting in its poor availability. The deficiency area is around 46 % of the region (IANRR - CAAS). According to the statistic data, about 60 % of the region is deficient in potassium and 90 % in boron, molybdenum and fluorine. Trace elements such as zinc, copper, manganese and iron are richer in the soils of the region than those in other soil regions, and iodine is abundant.

II. DISTRIBUTION AND AVAILABILITY OF ELEMENTS IN SOILS OF CHINA

1. Regional Distribution of Elements

1.1 Zonal distribution of elements

From the above discussion of the characteristics of the soil geochemical region, availability of some elements are zonally distributed. (1) Availability of K, B and F is in the order of the saline > carbonate > siallitic > ferrallitic soil regions. (2) Availability of Zn, Mn and Fe is in the order of the ferrallitic > siallitic > carbonate > saline soil regions. (3) Availability of Mo is in the order of the saline, carbonate > siallitic > ferrallitic soil regions. These are shown in the figure on grade distribution map of some elements in various geochemical regions (Fig. 2) (Gong *et al*., 1992).

1.2 Local distribution of elements

In limited area of a geochemical region, spatial differentiation of some elements also took place due to water and clay concentration in depression resulting from undulating topography. For example, the salts in soils are accumulatively distributed according to their solubility from the Qilian Mountain. to Juyanhai Lake, that is, in the order of $CaCO_3$, $CaSO_4$, $NaSO_4$ and NaCl from the foot of the mountain to the lake (Gong, 1980), showing the local distribution of elements in saline soil region. In subtropical area, parent material is another important factor affecting element distribution besides topography. The ferrallitic soil derived from granite is rich in Zn, the ferrallitic soil derived from arenaceous shale in B, and phyllite and slate in Mn.

1.3 Circular distribution of elements

Generally, the circular distribution of soil nutrient is formed around a town and a village. The nearer an area to a town, the higher its soil nutrients, especially organic matter, N. P and K. The circular distribution of mineralizing elements may be formed around a mine and a smeltery. Furthermore, environmental pollution inevitably was brought about with industrial development, resulting in that the circular distribution of some pollutants was formed around a factory and a city.

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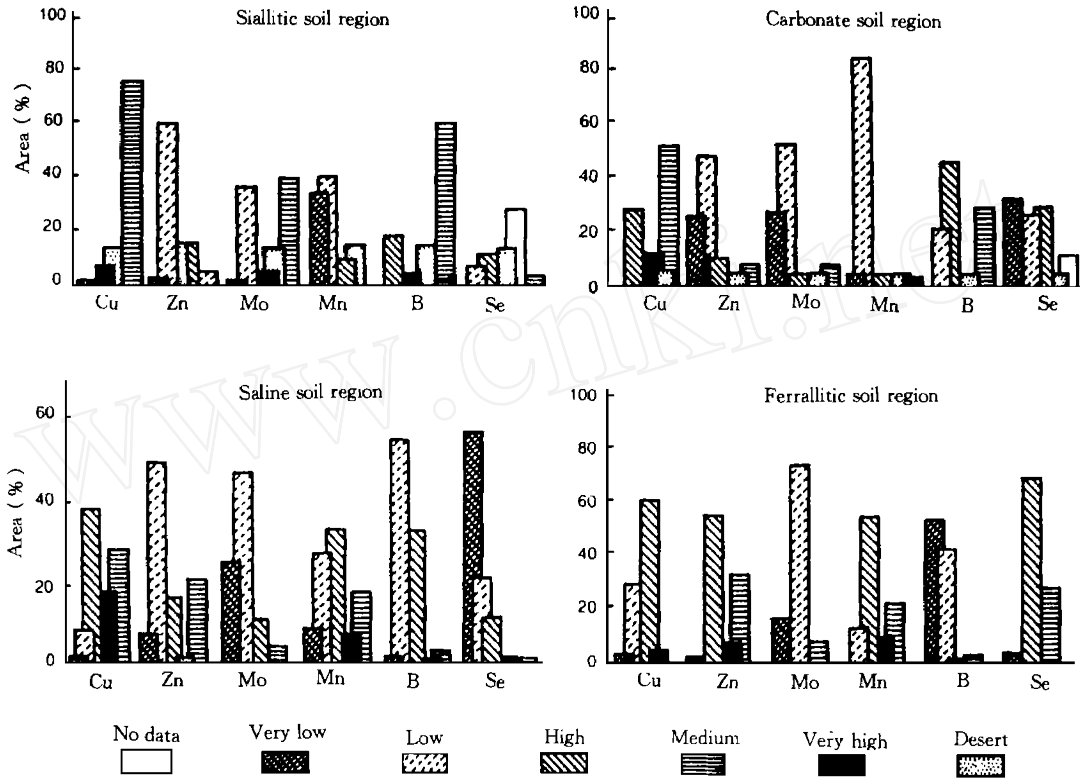

Fig. 2 The abundance and proportions of some trace elements in different soil regions

2. Spatial Differentiation of Some Elements

2.1 *Phosphorous*

The total P contents in soils of China range from 0.2 g/kg to 1.0 g/kg. The total P content in saline soil region ranges from 1.0 g/kg to 1.8 g/kg, that in ferrallitic soil region is 0.13 - 0.26 g/kg, and that in carbonate soil region is around 1.0 g/kg. However, available P in soils of China is low because it is in the form of Ca-bound in the northern part of China and in the form of Fe and Al-bound in the southern part of China. However, available P in saline and carbonate soil region is generally higher than that in siallitic and ferrallitic soil region.

2.2 *Potassium*

In ferrallitic soil region of southeast China, there are less K-bearing primary minerals such as feldspar and mica in soils due to strong weathering, resulting in that total K may be low to 0.5 g/kg and available K is less than 100 mg/kg. This region is the poorest in K. In siallitic soil region, the K content has a wide range, 5 - 30 g/kg for total K and 100 - 200 mg/kg for available K. However, there are part of soils being deficient in K. In carbonate and saline soil regions, there are more K-bearing minerals and relatively higher K content in soils due to weak leaching. The contents of total K range from 12.5 g/kg to 30.0 g/kg, available K from 120

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mg/ kg to 130 mg/ kg.

2.3 *Boron*

The total boron contents in soils of China range from trace to 500 mg/ kg, having an average of 64 mg/ kg. The saline and carbonate soil regions belong to B-rich regions ranging from 10 mg/ kg to 260 mg/ kg. Boron mainly appears in water-soluble form and is easily concentrated in depression. The hallosols in south Xizang, for instance, have the range of 26.0 - 89.6 mg/ kg, the halosol in north Xizang Plateau is up to 200 mg/ kg, and Aridic orthic Hallosols at Aiding Lake of Turpan, Xinjiang, up to 300 mg/ kg (Huang *et al.*, 1993). While the siallitic and ferrallitic soil regions belong to B-deficient regions, and the content of available B of most soils is lower than critical value of plant growth, i.e., 0.5 mg/ kg.

2.4 *Zinc*

The average total zinc content of soils in China is 74 mg/ kg. The total Zn in soils of saline region is in the range of 35 - 150 mg/ kg, however, the soils are deficient in available Zn, so are the soils of carbonate soil region (Liu *et al.*, 1984; Liu *et al.*, 1986). The available Zn in siallitic soil region is richer in west of the region and poorer in east of the region. The total Zn in soils of ferrallitic region is in the range of 56.50 - 146.32 mg/ kg, is richer in soils developed from basalt and limestone and poorer in soils derived from sandstone. The available Zn in the region has a wide range from 0.43 mg/ kg to 1.72 mg/ kg.

2.5 *Copper*

The average total copper content in soils of China is 27 mg/ kg. The range of total copper content in soils of saline region is 0.5 - 50 mg/ kg. That of ferrallitic region 12.68 - 168.32 mg/ kg, of which the ferrous ferrallitic soil derived from basalt in subtropical area has the highest content and the siallic ferrallitic soil derived from granite and geneiss lowest (Liu *et al.*, 1984; 1986). The availability of Cu in soils depends on soil organic matter, texture and pH. The Cu carbonate may be formed in calcareous soils, but, Cu deficiency of plant uncommonly takes place due to less requirement amount. The available Cu of most paddy soils is abundance, with the average of 2.01 - 2.37 mg/ kg. The Cu concentration in soils is significantly related to soil parent materials and zonal distribution less appears.

2.6 *Iron*

The total Fe content in soils is much higher than that of requirement amount for plant growth. The average total iron content in soils of China ranges from 1% to 5% (Liu *et al.*, 1984; 1986). The Fe availability of soils in saline and carbonate soil regions is low, with the range of 0.3 - 15.1 mg/ kg, due to the formation of stable compounds combining iron and carbonate and hydroxyl ion under the condition of high soil pH, while that of siallitic and ferrallitic soil region, with the range of 13.23 - 23.87 mg/ kg, is relatively higher because the immobile Fe^{3+} in soils is easily reduced into labile Fe^{2+} under the condition of strong acid.

2.7 *Manganese*

The total Mn content in soils of China ranges from 10 mg/ kg to 9478 mg/ kg, with the average of 845 mg/ kg. The content variation among different soil types, even same soil type is

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very great. In saline soil region, the total Mn content ranges from 12 mg/kg to 300 mg/kg. The total Mn content in soils of ferrallitic soil region is obviously higher than that of saline soil region, which depends on parent materials. The highest content is in the soils derived from basalt with the average of 1745 mg/kg and the lowest in the soils derived from granite and genesis with the average of 305.75 mg/kg (Liu *et al*., 1984, 1986). The availability of Mn is mainly controlled by soil pH. The mobile Mn^{2+} is gradually oxidized into immobile Mn^{3+} and M^{4+} with an increase of soil pH, resulting in weak availability of Mn in calcareous soils. Conversely, the immobile high valence Mn ion is easily transformed into labile low valence Mn under the conditions of low soil pH and reduction, resulting in strong availability. Therefore, the available Mn of soils are deficient in saline and carbonate soil region, and rich in ferrallitic and siallitic soil region except for the Huang-Huai-Hai Plain where there are more calcium carbonate in soils.

2.8 Molybdenum

The total Mo contents in soils of China range from 0.1 mg/kg to 6 mg/kg, with an average of 1.7 mg/kg. The soils in the southern part of China is low in total Mo, with the range of 0.47 - 2.30 mg/kg. Availability of Mo is controlled by soil pH, having an increase with the increase of soil pH. Therefore, the soil in saline soil region is high in available Mo, with the range of 0.01 - 1.00 mg/kg, while the ferrallitic soils and paddy soils derived from various parent materials in the southern part of China is low in Mo, with the average of 0.05 mg/kg. The Mo in soils of carbonate soil region is close to that of saline soil region, but there are still larger area being deficient in Mo and that of siallitic soil region is similar to ferrallitic soil region.

3. The Factors Affecting Element Availability

The factors affecting element availability in soils include chemical forms of an element, soil texture, organic matter, pH, Eh, etc. Forarable soils, the change of availability of nutrient is considerably affected by the ratio of fertilizer input and output besides the factors above-concerned. Based on the estimation (Lu, 1990), the consume time-limitation of available N, P and K in soils is 20 - 40 years, 10 - 20 years and 80 - 130 years, respectively, under the condition of unamended fertilizers. Availability of nutrient increases when input of fertilizers is more than output under the condition of fertilizer amendment. Conversely, availability of nutrient decreases when input is less than output. The input of potassium in China, for example, was about 6.347 million tons in 1985 while the output was about 11.846 million tons per year. About 46 % of the output was deficient. Therefore, the area of soils in K-deficient is being more and more extended. In the 1960s, only a few experiments testified that the soils in the southern part of China could be deficient in K (Xie, 1994). Nowadays, however, the area of K-deficient soils in south China is up to 73 %, that in southwest China 54 %, and that in the middle and lower reaches of the Changjiang (Yangtze) River where was thought not to be defi-

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cient in K is 43 %. In saline soil region, to apply K fertilizer to soils has significantly positive effect on crop production, especially to sandy soils.

III. AGRICULTURAL SIGNIFICANCE OF PEDOGEOCHEMISTRY IN CHINA

1. To Improve Crop Production Through Application of Fertilizers According to Soil Types

The yield level of crop increased by 42.8 % from 1978 to 1984, i.e. from 2535 kg/ha to 3615 kg/ha through increasing the rate of chemical fertilizer by more than one time. However, The yield level only increased by 14.6 % through increasing the rate of fertilizer by 81 % from 1984 to 1993. Obviously, the proportion of input to output decreased (Lu, 1990; Xie, 1994; Lin, 1991). Therefore, balance fertilization is an important pathway in agricultural production. Authors put forward the following suggestions based on pedogeochemistry of China.

1.1 Balance fertilization based on regional characteristics of pedogeochemistry

The soils in ferrallitic soil region are seriously deficient in P, parts of the soils in other soil regions, including saline soil region are also deficient. The K-deficient soils spread from ferrallitic to siallitic, carbonate soil regions, even saline soil regions. So, application of P and K fertilizer should be emphasized when the rate of nitrogen fertilizers was increased.

1.2 Balance fertilization based on different soil types

Micronutrient deficiency in some soil types often confines the potential of other chemical fertilizers on crops with the development of agricultural production. Therefore, application of micronutrient will get good effect on the basis of pedogeochemistry of soil types, for example, application of B fertilizer on rape and Mo fertilizer on legume in ferrallitic soil region, application of Mn fertilizer on wheat and soybean and Zn fertilizer on corn and rice in siallitic and carbonate soil region, application of Zn, Fe, and Mn fertilizers in saline soils can make, to some extent, good contribution to crops.

1.3 Balance fertilization based on soil pH

Soil pH frequently affects the availability of some nutrients. In ferrallitic soil region, the high pH soils derived from calcareous parent materials are deficient in Zn and deficiency of some nutrients could be caused in the low pH soils due to strongly liming. Suitable rate of micronutrients such as Zn and Fe should be applied.

1.4 Balance fertilization based on soil redox condition

Similarly, soil redox condition influences the availability of some nutrients. The availability of P, for instance, could be improved under the reduction of waterlogging. Therefore, the soils planting xerophytic crops in winter could apply more P fertilizer which can continue to be used when rice is transplanted later. This is a good measurement of P applicationin ferrallitic and siallitic soil regions.

1.5 Balance fertilization based on special requirement of crops

Tobacco is a plant which needs more K. Generally speaking, the high quality tobacco can

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be obtained when the K application amount reach 2 - 3 times of its optimal requirement amount. Therefore, K application is an important measurement to improve quality of tobacco in the soil where is generally thought to be not deficient in K (Cao *et al*., 1994). The ferrallitic soils planting citrus are deficient in not only N, P and K, but also Ca, Mg, B and Zn. Application of these elements can improve the yield and quality of citrus and correct the disorder of citrus which is caused by nutrient deficiency (Ouyang, 1990).

2. To Develop the Famous-Local-Superior Agricultural Products through Rational Plantation

The rational plantation is an important measurement of developing potentials of soil production based on distribution of soil types, which is greatly important for developing the famous-local-superior agricultural products. At present, the quality of some products such as citrus, apple, tobacco, tea and Chinese herbal medicine decrease due to neglecting rational plantation in the process of production, influencing greatly the economic benefits of these products. On the basis of previous work, the high quality tea grew in soils with acid, high-K and Si, and abundance available Zn, Cu and B (Gong, 1994). The high quality tobacco grew in soils with neutral, low carbonate, high available K, B, Mn, Cu and Zn (Cao and Hu, 1994). The high quality citrus grew in soils with acid-neutral, abundance Ca and Mg, and available Zn, Cu, Mo and B (Ouyang, 1990). If we can extend the production of the famous-local-superior agricultural products according to pedogeochemistry tremendous economic benefits will be produced. This is an effective pathway escaping poverty and acquiring wealth in some areas.

3. Rational Utilization of Soil Nutrition

To utilize rationally nutrient resources based on element cycling characteristics in soils is an effective pathway for solving the problem of short supply of some fertilizers. Among necessary nutrients for crop growth, rational utilization of K is extremely important because K is a critical element for improving yield and quality of crops, meanwhile, K is a short resource in China. Currently, there are at least three methods to solve the problem.

1) To use the recycling of crops. Statistic data show that the K_2O content in the rice stem was 1.2% - 3.0%, the wheat stem 0.6% - 2.5%, and corn stem 0.5% - 2.5% (Lin *et al*., 1991), being an important K resource. About 50% of economic and effective measurement.

2) To use K-rich parent material or rock. Besides developing K fertilizer resources in salt lake, in the area of short supply, some parent materials and rocks such as argillaceous shale and granite can be used and applied on the spot throught technical treatment of improving its availability.

3) To use K-accumulating plant. K-accumulating plants such as sunflower and sugarcane are planted in K-rich soils, then processed or extracted into fertilizers and applies in K-deficient

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soils.

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