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Rationally Utilizing Water Resources to Control Soil Salinity in Irrigation Districts

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ABSTRACT

In the arid, semi-arid and semi-humid regions in the northern part of China, the cause of soil salinization in canal irrigation districts lies in the excessive irrigation water application which makes the groundwater level rise and causes intensified evaporation of phreatic water and salt accumulation to surface soil. To control soil salinity in irrigation districts the irrigation water application should be regulated according to the agricultural water demand, the salinity in root zone of soil should be controlled under the threshold of crops salt tolerance and the groundwater depth should be kept in a proper dynamic state. The practice in the Huang-Huai-Hai Plain, Henan People Victory Canal, Shaanxi Jinghuiqu Canal and Xinjiang Wujiaqu Canal irrigation districts show that carrying out the conjunctive use of surface and groundwater is the principal approach for soil salinity control in irrigation districts and full development of the benefits of water resources. It is recommended that the water volume diverted from the Yellow River be appropriately reduced, the well irrigation be developed instead of irrigation using water diverted from the Yellow River in the Huang-Huai Plain to the south of Yellow River, the groundwater in the canal irrigation districts be actively developed and utilized, and the surface and groundwater in irrigation districts be optimally regulated and rationally utilized.

SOIL SALINIZATION IN IRRIGATION DISTRICTS

The soil salinization in irrigation districts is a world problem. As much as half of all the existing irrigation systems in the world are more or less under the influence of secondary salinization, alkalization and waterlogging (Szabolics, 1985). The problem of soil salinization almost exists all over the canal irrigation districts in the arid, semi-arid and semi-humid regions in the Northern part of China.

At the end of 1950's and the beginning of 1960's, secondary salinization in large area appeared in irrigation districts due to the development of irrigation using water diverted from the Yellow River, reservoirs and water stored in plain area in the Huang-Huai-Hai Plain. The area of salt-affected soil expanded to 4.13 million hm^2 in 1961 from 2.72 million hm^2 in 1958, an increase of 52% (Wang et al., 1993). The secondary salinization of soil occurred or has been developing in Hetao irrigation districts using water diverted from the Yellow River in Ningxia and Inner Mongolia, Shanxi irrigation districts in river valley basin, Shaanxi irrigation districts in Guanzhong basin and Xinjiang canal irrigation districts. Soil salinization has destroyed the land resources in irrigation districts, decreased the benefits of yield increase resulted from irrigation and caused serious losses to agriculture. In the past 30 years, the total area of abandoned land due to soil salinization caused by irrigation almost equals that of the new reclaimed land in the Farm of Xinjiang Production and Construction Corps. The basic cause of soil salinization in irrigation districts is the excessive irrigation water application. When the groundwater recharge volume is larger than the discharge volume under the conditions of drainage difficulty, the groundwater level will rise by big margin resulting in intensified evaporation of phreatic water and salt accumulation to surface soil. It will also make waterlogging more serious in rainy season in semi-humid region. In Inner Mongolia Hetao irrigation district, the annual water diversion was 5 billion m^3 but only 430 million m^3 was drained off, less than 1/10 of the total. In Shaanxi Jinghuiqu canal irrigation district, the groundwater depth was 15-30 m in the past. Since 1932, water has been diverted from the Jinghe River for irrigation. In 1954, the groundwater level rose by 10-24 m, and in the area of 30% of the irrigation district, the groundwater depth was shallower than the critical depth. Consequently, there occurred secondary salinization in large area (Zhang, 1990). In the Farm of Xinjiang Production and Construction Corps, the groundwater depth was 7 m in the farmland belonging to the 141^{st} and 142^{nd} Regiments in 1950's. After river water was diverted for irrigation, the groundwater depth rose to 1.0-1.25 m in 1989, and the soil salinization became very serious,

Table 1. Salt Content of Saline-alkali Land in the Farm of Xinjiang Production and Construction Corps

	Farmland belonging to:		
	141^{st}Regiment	No.2 Battalion 142^{nd}Regiment	No.5 Battalion 142^{nd}Regiment
0-30 cm (%)	1.4	3.3	1.9
30-60 cm (%)	0.9	2.1	1.3
60-100 cm (%)	1.4	1.4	1.5
Groundwater depth (m)	1.25	1.0	1.2
Mineralization (g L^{-1})	34.3	28.8	31.7

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the salt content of saline-alkali land in soil body (1 m) was 1-2%, and in that of 0-30 cm reached 1.3-3.3% (Table 1).

CONTROLLING IRRIGATION WATER APPLICATION ACCORDING TO AGRICULTURAL WATER DAMAND

To control soil salinity in irrigation districts the excessive irrigation water application should be controlled and reduced. The purpose of irrigation is to make up the deficiency of natural rainfall, and solve the contradiction between the non-uniform distribution of precipitation in time and space and the water demand of crops in their growth period. The exact agricultural water demand is the essential basis for irrigation water application control. According to the results of investigation and experiment, the agricultural water demand (weighted average of evapotranspiration in cultivated and uncultivated land) in dry land crops region in the Huang-Hai-Hai Plain where crops yield achieved 6,000-7,500 kg hm^{-2} (Tian, 1998) is 550-650 mm in the Haihe River Plain to the north of Yellow River, where local annual precipitation was 500-600mm, water deficit of agriculture was 50-100 mm, which corresponds to 750-1500 m^3 hm^{-2} in cultivated land (land use is 0.67). But now the irrigation water diverted from the Yellow River reached 5,400 m^3 hm^{-2}, which is 2-6 times of the water deficiency.

In Shaanxi Lechuang located in Loess Plateau, the annual precipitation is 620 mm, the water demand for wheat growth is 490 mm, the rainfall in the growth period is 250 mm, the water supply from soil is 150 mm, and the water deficiency is 90 mm. The crops yield with an experiment making up water of 1,050 m^3/hm^2 corresponds to that with the traditional irrigation water application of 2,250 m^3/hm^2 (Li, 1984). The agricultural water demands in the Hetao irrigation districts of Ningxia and Inner Mongolia are: 500 mm for dry land crops and 600-650 mm for rice, the local precipitation is 150-200 mm, so the water deficiency is 300-350 mm in dry land crops area and 450 mm in rice area, corresponding to 4,500-5,200 m^3/hm^2 and 6,750 m^3/hm^2 in cultivated land (Tian, 1998). Now the actual irrigation water application reached 12,000-15,000 m^3/hm^2, which is 1-2 times of the water deficiency. The excessive irrigation water application caused a lot of water replenished to groundwater and much salt accumulated to surface soil through evaporation of phreatic water. Therefore, controlling and reducing the excessive irrigation water application is the key for soil salinity control in irrigation districts.

REGULATING SALT-WATER DYNAMIC STATE OF SOIL AND GROUNDWATER

The soil salinity control in irrigation districts requires controlling the salinity in root zone of soil within the threshold of crops salt tolerance, to enable the salt dynamic state to achieve the balance in one year and many years without salt accumulation, and regulating the groundwater depth in a proper dynamic state without salt accumulation and waterlogging (Fang and Chen, 1997). The semi-humid region can be represented by the Huang-Huai-Hai Plain. The annual precipitation there is 500-700 mm, of which 70% concentrate in July and August, the desirable dynamic state of groundwater depths in different seasons within one year are as follows: 1. In dry season (Sept. to next May), the groundwater should be kept at the critical depth for the prevention of salt accumulation (2-3 m), so as to reduce the evaporation of phreatic water as much as possible; 2. Before rainy season (June), it should be regulated to the depth for waterlogging prevention and rainwater storage (4-6 m), so as to increase the recharge of rainfall infiltration as much as possible and reduce the surface runoff. Thus the waterlogging can be prevented, and the functions of salt leaching and freshening of groundwater quality by summer rainfall can be strengthened; 3. In rainy season (July to August), it should be kept at the depth for wet resistance (0.5-1.0 m), i.e. within 2 days the excessive rain water accumulated on surface should be drained off, and the groundwater table raised by rainfall infiltration should drop below the wet resistant depth, without occurrence of waterlogging (Fang and Chen, 1997). The requirement for regulating groundwater depth dynamic state in the arid region can be represented by the Hetao irrigation districts in Ningxia and Inner Mongolia. The annual precipitation there is only 150-200 mm, and water diverted from the Yellow River is used for irrigation, the requirement for groundwater table regulation is the process of groundwater depth dynamic state with basically stable salt content of soil which is not harmful to crops all the year round (Table 2), making the root-zone with favorable environment of moisture, fertility, air and heat (Tan, 1981).

In the eastern part of Huang-Huai-Hai Plain, owing to the increasing exploitation of groundwater year by year, with the exploited groundwater volume exceeding the recharged volume, the groundwater level dropped continuously. At the beginning of 1990's, the shallow groundwater depth dropped to 6-8m before rainy season in the area to the east of South Grand Canal. In order to supplement the water source to the

Table 2. Requirement for Regulating Groundwater Depth Dynamic State in Hetao Irrigation Districts in Ningxia and Inner Mongolia

Stage of Irrigation	Time	Groundwater Depth (m)
Start of thawing	Early March to early April	2.0-2.4
Start of spring irrigation	End of April	2.1-2.3
End of first watering	first 10 days of May	1.2-1.5
End of Summer irrigation	Last 10 days of July	1.2-1.5
Start of winter irrigation	End of October	2.2-2.65
End of winter irrigation	Middle 10 days of November	1.3-1.5

eastern part of Haihe River Plain, water was diverted from the Yellow River in Shandong to Hebei Province every winter (November to next February). The total amount of diverted water was 0.4 billion m^3 in 1994-1995, a small part of which was used for winter irrigation and the main part was stored in canals, ditches and ponds to recharge the groundwater. The groundwater depth returned to 2-3m from previous 5-6m before rainy season. No salinization occurred and sufficient water was stored for spring irrigation. Thus, the exploitation of shallow groundwater has been taken as the basis for irrigation and diverting Yellow River flow in winter as its supplement, to regulate the groundwater depth at 3-6m in one year running, a strategic groundwater storage can be maintained.

Owing to the variability of weather the precipitation distributed unevenly between years. In the Huang-Huai-Hai Plain, the exploitable groundwater resources differ greatly between wet year and dry year. It is necessary to exploit more groundwater for drought mitigation in dry year, but less groundwater for irrigation due to abundant rainfall in wet year. Therefore, the exploitation of groundwater in great quantity or even over exploitation can be allowed in dry year, and more rainwater can be used to recharge groundwater in wet year. The pluriennial regulation of groundwater to make up the water deficiency in dry year with the water surplus in wet year should be carried out.

DEVELOPING AND UTILIZING GROUNDWATER IN CANAL IRRIGATION DISTRICTS

There had occurred secondary salinization in large area in irrigation districts due to irrigation with excessive diverted or stored water in the Huang-Huai-Hai Plain. Since 1965, comprehensive control for flood, waterlogging, drought, and salinity has been carried out. To control the Haihe River, the main drainage river course has been dredged and additional outlets to sea have been opened up to drain off flood, excessive rainwater, and saline groundwater. Water storage in plain area has been stopped and river flow diversion has been controlled to decrease the recharge to groundwater, thus further development of secondary salinization has been prevented. Since the beginning of 1970's, well construction has been developed in large scale, a lot of groundwater has been exploited and utilized and the groundwater depth dropped gradually. In the central and eastern parts of the Huang-Huai-Hai Plain, where occurred serious salinization and waterlogging in the past. With the exploitation and utilization of groundwater including brackish water for irrigation, the groundwater depth could be regulated below 3-5 m before rainy season. Not only the secondary salinization has been eliminated, but also part of the old saline-alkali land has been reclaimed. The area of salt-affected soil in the Huang-Huai-Hai Plain reduced to 2.09million hm^2 in 1980 from 4.13 million hm^2 in 1961, a decrease of 50% (Wang et al., 1993).

The drop of groundwater level also created the conditions for waterlogging control. The years from 1974 to 1977 were all wet years with an average precipitation of 750 mm. The groundwater depth before rainy season was only 1.1 m in the area of water stored by rivers and canals in the region to the east of South Grand Canal. When a rainstorm with a rainfall of 102 mm came in the rainy season 1977, there occurred waterlogging with a runoff of 47 mm. However, groundwater depth before rainy season was 4.6 m, when a rain storm with a rainfall of 189 mm came in 1987, all rain water infiltrated under ground to recharge the groundwater without any waterlogging (Fang and Chen, 1997).

The People Victory Canal Irrigation District is the largest Yellow River diversion irrigation district on the lower reaches of the Yellow River. After a lot of water had been diverted for irrigation, the groundwater depth rose to 1.3-1.5 m in 1961 from 3-4 m in 1958, the area of salt-affected soil has enlarged by 200%. After this, the river flow diversion was controlled. At the same time combination of well irrigation and canal irrigation was developed to carry out the conjunctive use of surface and groundwater. The ratio of the exploited groundwater and the water diverted from the Yellow River was 42:58. The groundwater table was controlled below 2 m, and the secondary salinization was reclaimed rapidly (Yuan, GY. et al. 1982).

In Shaanxi Jinhuiqu Canal Irrigation District, the area of secondary salinization accounted for 30% of the total area of farmland in 1954, after having diverted water from the Jinghe River for irrigation since 1932. From the beginning of 1960's, well irrigation was developed, the total area of well irrigation combined with canal irrigation reached 73,333 hm^2 in 1970's. In spring, the groundwater table rose to the peak and salt accumulation appeared seriously, during that period well group irrigation was adopted, well irrigation and canal irrigation was used alternately to prevent salt accumulation. In summer, well irrigation was mainly used to lower groundwater table and prevent waterlogging. In winter, as the river flow is sufficient, canal irrigation was used for salt leaching and fresh water recharging. The annual exploitation of groundwater was 0.11-0.13 billion m^3, the groundwater table rise was restrained, and the secondary salinization was under control, thus promoting the increase of agricultural production. In the irrigation district, the cultivated area accounted for 2.4% of the total in the province, the total grain production accounted for 5.4%, and the total amount of commodity grain accounted for 11% (Zhang, 1990).

The Wujiaqu Canal Irrigation District belonging to the 6th Division of Xinjiang Production and Construction Corps began to use water diverted from rivers for irrigation in 1951. The groundwater depth rose to 0.5-1.0 m, the secondary salinization became more serious year after year. The salt-affected soil area was only 427 hm^2 in 1957, up to 1963 it increased to 14,267 hm^2. The area of farmland with poor harvest accounted for 10-20% of the total sown area every year. The unit grain yield decreased to 930 kg hm^{-2} in 1962 from 1,975 kg/hm^2 in 1950. Since 1965 well irrigation has been developed, the annual exploitation of groundwater was 0.12-0.15 billion m^3, accounting for 80% of the total irrigation water application. Up to 1988, the total accumulated groundwater exploitation was 1.699 billion m^3, the groundwater depth gradually declined to 3-5 m (Table 3). Now the soil salinity of whole sown area has reduced to less than 0.2%, the land has become non-salinized farmland

Table 3. Groundwater Table Drop Caused by Well Irrigation and Well Drainage in Xinjiang Wujiaqu Canal Irrigation District

	Farmland belonging to		
	101st Regiment	102nd Regiment	103rd Regiment
Number of wells	103	129	130
Exploitation of Groundwater(10^8 m^3)	2.26 (1965-1988)	2.47 (1965-1988)	2.67 (1975-1983)
Previous Groundwater Depth(m)	0.8 (1965)	1-2 (1965)	1.5-2.0 (1975)
Groundwater depth(m)	7.64 (1985)	3-4 (1988)	3.5-5 (1988)

with higher and stable yield. The unit yield reached 4,200 $kghm^{-2}$, 4.7 times the yield in 1963 (Capital Construction Department of 6th Division of Xinjiang Production and Construction Corps, 1990).

CONCLUSION AND RECOMMENDATION

In irrigation districts the excessive irrigation water application made the recharge to the groundwater more than its drainage, caused the groundwater level rise, the intensification of evaporation of phreatic water and the salt accumulation to surface soil which resulted in soil salinization in large area. The key to solve the problem of soil salinity control in irrigation districts is to rationally develop and utilize water resources. The irrigation water application should be regulated and controlled according to the agricultural water demand. The conjunctive use of surface and groundwater should be carried out. The groundwater depth should be kept in proper dynamic state.

The volume of irrigation water diverted from the Yellow River should be reduced appropriately. The fact that the canal seepage and water application exceeded agricultural water demand not only caused serious water waste, but also raised the groundwater level and caused secondary salinization of soil. The actual irrigation water application in irrigation districts using water diverted from the Yellow River in Ningxia, Inner Mongolia, Shandong and Henan exceeded the agricultural water deficiency by one to several times. The irrigation water diverted from the Yellow River was 28 billion m^3, which accounts for 92% of the total amount of water diverted, thus this is the main cause of the occurrence of water interception in the Yellow River. Since 1972, water interception has often appeared in the Yellow River, especially in 1990's water interception almost occurred in every year. In 1997, the water interception of the Yellow River occurred in the reach with a length of 780 km from the river mouth to Kaifeng city Henan Province. The water interception lasted 228 days in the whole year at the Lijing Hydrology Station. According to the local agricultural water demand, the volume of diverted water could be reduced at least by one half. The total volume of irrigation water depletion and run off drained in rainy season correspond to that of irrigation water diverted from the Yellow River in the irrigation districts in Henan and Sandong Province. The precipitation in the Huang-Huai Plain is 650-1000 mm which can meet the agricultural water demand. The non-uniform distribution of rainfall in time and space can be regulated by well irrigation. The irrigation districts to the south of Yellow River can use well water for irrigation instead of water diverted from the Yellow River. There is 5 billion m^3 of unexploited groundwater in the irrigation districts along the Yellow River in Shandong and Henan provinces of the lower reaches of the Yellow River, if one half of which were exploited, the water amount diverted from the Yellow River could be reduced by 2.5 billion m^3, and the water interception of the Yellow River would be not occurred in lower reaches year by year. The so saved volume of water diverted form the Yellow River can be sent to the region to the north of Yellow River or the down stream region in even more serious shortage of water for irrigation or other use.

The groundwater in the river flow irrigation districts should be exploited actively in case the exploitation is feasible. Generally, there are better shallow groundwater resources in such districts due to the constant recharge to the groundwater by river flow. The exploitable groundwater resources in Xinjiang are 25.2 billion m^3, but only 3.7 billion m^3 have been exploited. Most of the groundwater resources in Hetao irrigation districts using water diverted from the Yellow River in Ningxia and Inner Mongolia had not been exploited and utilized. The actual exploitation of groundwater only accounts for 1/3 of the exploitable groundwater resources in the North Huaihe River Plain. In these regions, the groundwater should be exploited and utilized actively and the water volume diverted from rivers should be reduced, and the conjunctive use of surface and groundwater should be carried out. That is the principal approach for soil salinity control and full development of benefits of water resources in irrigation districts.

The surface and groundwater should be optimally regulated and rationally utilized. In Inner Mongolia irrigation districts, the spring irrigation always started after May 1 due to waiting for the water diversion from the Yellow River. As that period was the raging stage of salt accumulation, it had no choice but to use a large "1st watering" for salt leaching. Actually it is better to use Groundwater for irrigation in spring thus the groundwater depth can drop, the salt accumulation can be restrained, and the irrigation can be done with appropriate water volume and in good time without the restriction of water diversion form the Yellow River. In the Ningxia irrigation districts, the groundwater was drained by pumps through wells after winter irrigation using water diverted from the Yellow River. Actually a lot of fresh water was drained off. In winter it is suitable to use water diverted from the Yellow River for irrigation, salt leaching, and fresh water supplement, the groundwater should not be pumped off after irrigation by river flow. In irrigation districts, the exploitation and utilization of groundwater should be taken as the basis for irrigation and with surface water as its supplement. The shallow groundwater aquifer should be used as an underground water reservoir for regulating rainfall, surface water, groundwater and soil water. The groundwater depth should be kept in proper dynamic state, so as to make the process of desalinization by leaching stronger than that of salinization by evaporation, to achieve the comprehensive control of drought, waterlogging, and salinization in irrigation districts and to bring about the full development of benefits of water resources manifested by yield increase.

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