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Prevention and Management of Soil Secondary Salinization in Paddy Field Irrigation Area

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Abstract By analyzing the process of soil salt accumulation in irrigation area, and discussing the change of irrigation and drainage methods for drought transformed into water, the control scheme of soil secondary salinization in Wujiazi Irrigation Area was analyzed concretely, and the experience was summarized. After in-depth discussion, the importance of irrigation and drainage methods in the prevention and control of soil secondary salinization in irrigation areas was analyzed.

Key words Paddy field irrigation area, Soil secondary salinization, Influence factors

1 Introduction

Irrigation area is the product of the joint development of water conservancy and agriculture. Most irrigation areas in China were built in the 1950s and the 1970s. Due to the limited scientific and technological conditions at that time and years of fatigue operation, most of the irrigation area projects in China are seriously aging and out of repair, in the state of extended service or operation with disease, resulting in serious waste of water resources in the irrigation area, low utilization rate of irrigation water, and significant decline in irrigation benefits[1]. Unreasonable irrigation tends to promote the accumulation of salt in groundwater and soil, thus causing soil secondary salinization.

2 Cause of soil secondary salinization in irrigated area

Soil secondary salinization in irrigation area refers to non salinized soil existing in arid and semi-arid areas due to different hydrogeological conditions. Due to the unreasonable irrigation by human beings, the salt in groundwater rises along the soil capillary pores and accumulates on the surface, resulting in soil salinization[2]. According to the statistics of FAO, 60% of the world irrigated land has been salinized to varying degrees[3]. The phreatic water moves up to the soil surface through capillarity. Under the conditions of high temperature, strong wind and dryness, it is quickly evaporated and transformed into water vapor, and enters the atmosphere, while the salt in it is retained in the soil, which is the main salt accumulation process of the soil. There are many factors leading to soil salinization, such as phreatic water depth, phreatic water salinity, rainfall, soil lithology and vegetation coverage. Related literature research shows that the amount or speed of salt accumulation in soil is non-linear with the salinity of phreatic water. The amount of salt accumulation increases with the increase of salinity, and the buried depth of phreatic water is inversely proportional to the amount of salt accumulation. The main causes of soil secondary salinization can be summarized as: flood irrigation and cascade irrigation; the land of large fields is uneven and the irrigation is uneven; too high fertilization amount; unreasonable crop farming system; land abandonment and channel leakage. The selection of irrigation mode is directly related to the water resource utilization efficiency and the possibility of soil secondary salinization[4].

3 Cases of large irrigation areas in Jilin Province

Wujiazi Irrigation Area is located in Zhenlai County of Jilin Province, and total area is 220 km^2, and the irrigation area introduces the water from the Nenjiang River for irrigation.

3.1 Irrigation and drainage mode of Wujiazi Irrigation Area

3.1.1 Irrigation and water diversion mode and canal layout. The water for the irrigation area is pumped from the end of the Baiyin River diversion canal by the water pumping station of Wujiazi Irrigation Area. The designed pumping flow of the pump station is 29.0 m^3/s. The terrain in the area is gentle, with a longitudinal slope of 1/4 500 - 1/8 000 in the north-south direction, and a ground elevation of 137.8 - 140.5 m. The general trunk is arranged in the middle of the irrigation area for gravity irrigation. One general trunk is arranged, and 4 main channels and 22 branch channels are set under the general trunk.

3.1.2 Drainage mode of irrigation area and drainage area. (i) Drainage scope. The west of drainage area is to the edge of the irrigation area, and the south takes Baiqi Highway as the boundary. The north is to south bank of the Erlongtao River, and the east is to Siping-Qiqihar Railway. Whole region is 20 km long from south to north, and 19 km wide from east to west. Drainage control area is 378.8 km^2.

(ii) Drainage mode. The drainage method is open ditch self

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drainage, and drainage control area is 378.8 km^2. According to the principle of preventing and controlling soil secondary salinization, the layout of irrigation canal system and terrain conditions, the irrigation area is arranged with 3 main ditches and 20 branch ditches. The drainage in Wujiazi Irrigation Area is smooth, which is conducive to lowering the groundwater level and preventing secondary salinization.

(iii) Drainage zone. Drainage zone of irrigation area: the flood in the irrigation area is discharged into the Erlongtao River. This area was originally a reed producing area in Zhenlai County. Since the 1980s, due to the construction of Tumuji Reservoir in the upstream Inner Mongolia, the Erlongtao River has almost been cut off for years, and the marsh rich in reeds in the drainage area has become a barren saline alkali land. These dried bubbles can be used as the drainage area, which can be naturally restored into reed wetlands, and can also purify the salt, nitrogen and phosphorus in the return water.

3.1.3 Field drainage mode. The surface lithology of the irrigation area is mainly composed of Quaternary Upper Pleistocene low liquid limit clay (1.7 – 6.4 cm in thickness), silty fine sand and fine grained soil sand, basically with a double-layer structure of fine upper and coarse lower. Permeability coefficient of low liquid limit clay is $2.3 \times 10^{-6} - 5.7 \times 10^{-4}$ cm/s. The drainage effect of the shaft will be limited due to the small permeability coefficient of the land surface. In middle and eastern zones of the irrigation area, the terrain is relatively high, and the natural slope of the ground is relatively large, and the drainage conditions are smooth. The western and northern marginal areas are flat and low-lying, which can meet the daily drainage requirements. Therefore, horizontal drainage is adopted.

3.1.4 Well – canal combined irrigation. (i) Role of developing well irrigation area. While fully utilizing the water of the Nenjiang River to develop paddy fields, the irrigation area also properly develops and utilizes the groundwater resources to reduce the groundwater level, prevent the soil secondary salinization in the irrigation area, and play a comprehensive role in removing waterlogging, preventing waterlogging, controlling alkali and improving soil. The combination of well and canal irrigation can effectively reduce the shallow groundwater level and prevent the soil secondary salinization in the irrigation area.

(ii) Technical conditions for groundwater exploitation. The phreatic water in Wujiazi Irrigation Area exists in the Quaternary Upper Pleistocene alluvial fine sand layer. The thickness of this layer is 11.5 m, and permeability coefficient is generally 5.7×10^{-3} cm/s. The phreatic aquifer has poor water yield. The surface layer in this area is low liquid limit clay, and permeability coefficient is 10×10^{-6} cm/s. Technical conditions for groundwater exploitation in the irrigation area are shown in Table 1.

Table 1 Technical conditions for groundwater exploitation in the irrigation area

Zone code	Type of groundwater exploitation	Reasonable well spacing//m	Suitable well depth//m	Average water inflow of single well//m^3/d	Aquifer age
I	Pore phreatic water	800 – 1 000	20 – 50	27.9	$Q_2 + Q_3$
	Pore confined water	600 – 1 000	80 – 90		
			(30 – 60 in some areas)	2 592.0	Q_1
II	Pore phreatic water	800 – 1 000	20 – 50	31.0	$Q_2 + Q_3$
	Pore confined water	500 – 1 000	60 – 100		
			(30 – 60 in some areas)	1 005.6	Q_1
III	Confined water between pores and fissures	700 – 1 000	50 – 75	722.4	K_2S

(iii) Layout of well irrigation area. In order to effectively reduce the shallow groundwater level and prevent soil secondary salinization, the well irrigation area is concentrated in the low-lying areas of each branch canal.

(iv) Irrigation area, well spacing and quantity of single well. Wujiazi Irrigation Area uses the combination of well irrigation and canal irrigation. 120 wells are arranged in total, and they are distributed in 120 km^2 of zone where the terrain is relatively low. Annual water consumption is more than 2 million m^3.

(v) Well type design. Tube well is used, and well depth is 80 m, and pipe diameter is 20 cm.

4 Control plan of soil secondary salinization in Wujiazi Irrigation Area

4.1 Using salt washing measures Wujiazi Irrigation Area is irrigated by the Nenjiang River. Mineralization degree of the Nenjiang River water is 0.1 g/L, and it belongs to low-salinity water quality. Groundwater salinity in Wujiazi Irrigation Area is 0.24 – 0.30 g/L. From the salt content of irrigation water, the salt content of the Nenjiang River water is lower than that of groundwater in the irrigation area. At present, using the Nenjiang River water to irrigate paddy fields can wash the salt and alkali in the soil to achieve the purpose of washing salt and pressing alkali, which is conducive to soil improvement in the irrigation area.

4.2 Strengthening field management (i) Increasing forest network coverage. It should plant trees at the edge of the field. Use tree roots and transpiration, groundwater is drained, and water level is lowered. It should implement water-saving irrigation and strictly control irrigation water consumption.

(ii) Drying the field at the end of tillering stage. It should reduce the groundwater level to the designed drainage depth (0.4 – 0.6 m) within 3 – 5 d during the drying period.

(iii) Controlling the drainage depth (groundwater level). The drainage ditches in the irrigation area are mainly used to discharge storm runoff and daily drainage of the irrigation area. In order to avoid secondary salinization caused by irrigation, the

groundwater level should be controlled at the critical depth (Table 2). The critical depth of groundwater in the final fixed drainage ditch shall not be less than 1.2 m, and the ditches at all levels are self draining open ditches.

Table 2 Critical depth of groundwater m

Soil quality	Critical depth of groundwater			
	<2	2 – 5	5 – 10	>10
Sandy loam and light loam	1.8 – 2.1	2.1 – 2.3	2.3 – 2.6	2.6 – 2.8
Medium loam	1.5 – 1.7	1.7 – 1.9	1.8 – 2.0	2.0 – 2.2
Heavy loam and clay	1.0 – 1.2	1.1 – 1.3	1.2 – 1.4	1.3 – 1.5

(iv) Irrigation and drainage mode combining well and canal. In the alluvial plain irrigation area, the groundwater aquifer has good hydraulic conductivity. In the fresh water area suitable for well drilling, surface water and groundwater are jointly used through different irrigation and drainage modes according to local conditions, mainly including the combination of well and canal, well irrigation and drainage. Through the above irrigation and drainage methods, on the one hand, the groundwater can be reduced to a greater depth to reduce evaporation and prevent salt return. On the other hand, groundwater aquifers can be fully utilized to regulate and store groundwater recharge by precipitation and irrigation.

① Irrigation and drainage mode of well and canal combination in non salinization area. Average rainfall in Wujiazi Irrigation Area is 411.2 mm, and it is dry and rainless area. Rainfall has limited recharge to groundwater, which is mainly supplied by canal irrigation water. Due to the low land use coefficient in this region, a considerable part of the groundwater recharge obtained from the irrigation area will be consumed by the ecological water consumption of non cultivated land, and the recoverable water volume of groundwater is less than that of semi-arid and semi-humid areas. In order to control soil salt accumulation and alleviate water resource shortage in groundwater fresh water area, the irrigation and drainage mode of well and canal combination, irrigation instead of drainage, and joint use of surface water and groundwater is adopted. This model can effectively control the groundwater level and prevent salt accumulation in the root layer.

Under the condition of combination of well and canal, irrigation supplies part of groundwater, and it is reused for irrigation. The amount of surface water irrigation is reduced, and the surface water contains a certain amount of salt. When the groundwater is not discharged, the salt is retained in soil after soil evaporation and crop evapotranspiration. Therefore, in the long run, it is necessary to extract some groundwater while well irrigation and discharge it through branch ditches and bucket ditches to reduce salt accumulation and prevent soil salinization.

② Irrigation and drainage mode of well and canal combination in salinization area. It has been successful in Hebei and other places to combine well and canal irrigation in salinization areas. In areas with good water conductivity of groundwater aquifers, surface water irrigation and shaft drainage or well and canal combined irrigation, and well irrigation instead of drainage can be adopted. Canal water is used in the seedling stage of crops, and after the seedling stage, underground brackish water or brackish water mixed with channel fresh water is used for irrigation. Due to the high salt content of brackish water and saline water used for irrigation, the irrigated river water will also bring a certain amount of salt. In these areas, agricultural ditches or bucket ditches need to be built in the fields to drain the groundwater. When necessary, special wells need to be used to extract a part of the groundwater with high salinity and drain it out of the area through the bucket ditches and tributaries to maintain the balance of salt.

5 Conclusions

(i) soil secondary salinization is mainly caused by various human factors or changes in natural conditions, and unreasonable irrigation system and imperfect water diversion and drainage projects. (ii) In the process of water diversion and irrigation, the phreatic level in the irrigation area has been raised and exceeded the critical phreatic level, which makes the phreatic water continuously evaporate, and a large amount of salt accumulates on the surface. For the critical groundwater level, it is easy to determine the exact critical depth of groundwater on the wasteland soil that is not affected by man-made measures. However, under the influence of man-made cultivation and irrigation, it increases the complexity of the dynamic change of salt in the soil, so it is difficult to find the exact value of the critical depth of groundwater. (iii) The water source of Wujiazi Irrigation Area is surface water with low salinity, so the degree of secondary salinization is relatively low. The impact of secondary salinization on agricultural production can be reduced by strengthening drainage and well irrigation. (iv) The salinization zone in the irrigation area has poor infiltration capacity, high salinity and large salt content of groundwater, so it is not suitable to combine well and canal irrigation and drainage in the early stage. After a period of operation in the irrigation area, the salinization situation in the area has been improved. At this time, the well and canal combined irrigation and drainage mode, irrigation instead of drainage can be considered, which could greatly reduce the water diversion and drainage, save water, and reduce the cost of pumping and drainage, reflecting the advantages of well and canal combination and irrigation instead of drainage.

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