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EFFECT OF PUMPED-WELL IRRIGATION AND DRAINAGE ON THE MELIORATION OF SALT-AFFECTED SOILS

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ABSTRACT

Well irrigation and drainage, adopted for the improvement of salt-affected soils in China, has been beneficial in recent years. In regions where the groundwater is fresh or contains few minerals, well irrigation can simultaneously lower the groundwater level, leach the salts downward from the soil, alleviate the harmful effects of flooding, and promote the salt-leaching effect by natural precipitation. In regions where the groundwater is highly mineralized, extraction and drainage of the highly mineralized groundwater by well can control the groundwater level and replenish the groundwater layer by irrigation with fresh water diverted from rivers, so as to accelerate salt-leaching from soil and prevent secondary salinization of soil. But well drainage cannot replace ditch drainage. Generally, a combination of well drainage and ditch drainage should be adopted to improve salt-affected soils. The distribution of wells is discussed, as is their construction appropriate to the local economic and natural conditions of salt-affected soil regions of China. According to the soil and hydrogeological conditions of the salt-affected soil regions in China, there are three patterns of well application for the improvement of salt-affected soils: (1) a combination of well irrigation and well drainage in regions where the groundwater is fresh or contains only small amounts of minerals; (2) a combination of deep and shallow wells in regions that have mineralized groundwater; and (3) shallow well drainage in regions of highly mineralized groundwater.

INTRODUCTION

Salt-affected soils are widely distributed in arid and semiarid regions of northern, northwestern, and northeastern China, as well as in the coastal region and the Qing-hai-Tibet Plateau. Improvement and utilization of various types of salt-affected soil are important problems in the agriculture of China. Since the People's Republic was established in 1949, soil scientists, agronomists, hydrologists, and hydrogeologists have conducted extensive research on the formation and melioration of salt-affected soils and have suggested guidelines for integrated control and improvement of salt-affected soils, according to local conditions, on the basis of drainage. Significant progress has been achieved under these guidelines.

At the beginning of the 1960s, because of extensive secondary salinization induced by excessive irrigation by gravity in the region, irrigation had to be stopped temporarily, and much attention was devoted to drainage, which led to significant progress in controlling secondary salinization. However, in the area with a gently sloping or depressed surface, where the runoff of surface and groundwater was obstructed because of the poor drainage, sloping surface, and impermeable solum, open-ditch drainage by gravity could not always lower the groundwater level and regulate the regime of water-salt balance. In the middle of the 1960s, pumped-well irrigation and drainage was first adopted and applied in Huang-Huai-Hai Plain. It had a very marked effect on the control and improvement of drought, flooding, salinization, and alkalization. At present, this approach has become popular in various areas of the country that have salt-affected soils. Different types of pumped-well irrigation and drainage, combined with ditches and canals, have been developed in various regions with salt-affected soils, in accordance with their actual local conditions.

CHARACTERISTICS AND EFFECT OF PUMPED-WELL IRRIGATION AND DRAINAGE

The effect of pumped-well irrigation and drainage on the integrated control of disasters is shown in Fig. 1. The favorable effect of pumped-

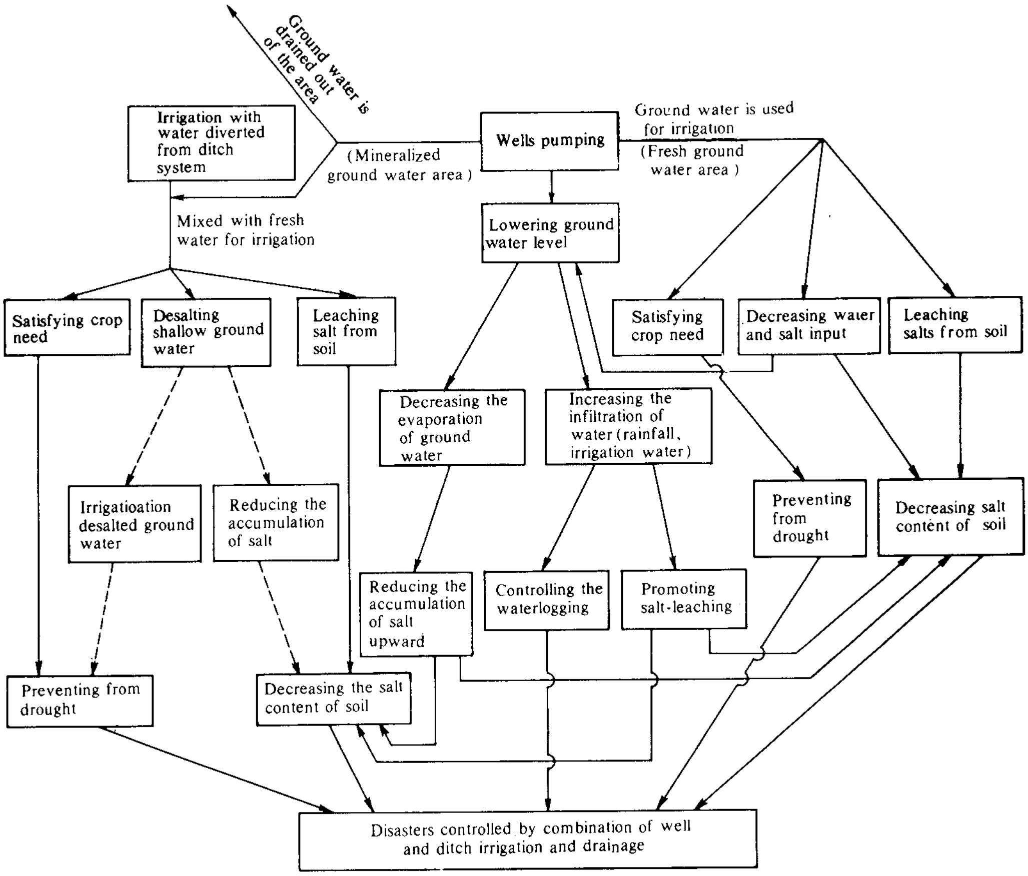

FIG. 1. Schematic diagram of the effect of pumped-well irrigation and drainage on the control of drought, flooding, salinization, and alkalization.

well irrigation and drainage on the control of soil salinization is realized mainly by lowering the level of the groundwater by pumping. When groundwater low in minerals is abundant, pumped-well irrigation can not only supply the water required by crops in a drought season, but can also lower the groundwater level markedly and leach the salts downward in the soil (Tables 1 and 2). Significant lowering of the groundwater level is conducive to increasing both the percolation rate of surface water and the soil's storage capacity for water, which will decrease the harmfulness of flooding and waterlogging and will facilitate the leaching of salts by natural precipitation. Where the groundwater is highly mineralized, it should not be pumped up from wells for irrigation, and it should be drained away so as to lower the groundwater level, which may provide favorable conditions for leaching salt from the soil by rainfall and fresh irrigation water. At the same time, this may alleviate the harm caused by flooding and waterlogging. Under this condition, a large amount of fresh irrigation water and natural precipitation percolated downward into the soil may steadily form a fresh water stratum on the original highly mineralized groundwater layer. Thus it can be seen that the application of pumped wells for irrigation and drainage leads to the regulation of the water-salt regime in soil and groundwater and the control of salinization of the soil. In China, salt-affected soils are distributed mostly on alluvial plains and basin plains and are usually characterized by a thick soil solum and poor water permeability. In addition, there are often interbedding layers of clay in the profile that may interrupt the hydrodynamic connection between the upper and lower layers of the sola. Therefore, the specific yield of a well is not large, and the action radius of a well is usually less

TABLE 1

Effects of pumped-well irrigation and drainage of soil in the experimental areas

Exp. area	Exp. period	Depth of groundwater, m		Salt content in soil		
		Before well pumping	After well pumping	Thickness of soil layer, m	Average desalinization rate, %	Period
Bazhou Farm, Xinjiang	1967–1972	1.5–2.5	1.8–3.2	1.0	42.8	1963–1971
101 Farm, Xinjiang	1966–1976	0.5–1.0	2.3–3.0	1.5	37.8–67.5	1972–1976
Gahai Farm, Qinghai Province	1968–1975	0.5–2.4	1.0–3.0	1.2	66.3–75.5	1971–1972
Fengqiu County, Henan Province	1965–1973	1.5–2.0	3–6	1.0	57.1	1965–1973
Nanpi County, Hebei Province	1974–1977	1.0–2.5	1.8–3.2	1.0	61.3	1976–1977
Quzhou County, Hebei Province	1973–1977	1.5–3.0	2.5–4.0	2.0	35–77	1975–1976

TABLE 2

Variation of salt content of soil in Shengshuiguan after well irrigation and drainage

Soil depth, cm	Date			Desalinization rate, %, 1965–1973
	June 1965	June 1970	May 1973	
0–5	1.17	0.10	0.04	96.6
5–20	0.27	0.09	0.05	81.5
20–40	0.24	0.07	0.07	70.8
40–70	0.24	0.09	0.09	62.5
70–100	0.20	0.13	0.13	35.0
100–130	0.13	0.27	0.11	15.4
130–160	0.12	0.23	0.10	16.7
160–200	0.12	0.18	0.12	0
200–250	0.12	–	0.14	−16.7
250–300	0.11	–	0.19	−72.7
Depth of desalinization, m	–	1.0	2.0	–

than 300 m. From the viewpoint of integrated control of such disasters as drought, flooding, salinization, and alkalization, the arrangement of pumped wells and the structural patterns of the well are characterized as follows:

(1) Pumped wells are usually distributed densely and are shallow in depth; generally, the well spacing is 200 to 500 m, and well depth is 20 to 60 m.

(2) According to different hydrogeological conditions, multiple wells are used to increase the yield and to lower the groundwater level. Cylindrical wells or tube wells with an internal diameter of 30 to 80 cm are generally used. In areas with poor hydrogeological conditions, vacuum-tube wells, driven-vacuum wells, radial collector wells, or combination wells are used, although in areas of abundant groundwater with a higher water table, the brick open well, of which the diameter is greater than 1 or 2 m, is also used.

(3) Materials used for well walls are easy to obtain, convenient to prepare, and low in cost. Gravel or crushed stone cement strainers are usually used when the well depth is less than 50 to 60 m, and bricks are used when the well depth is less than 20 m.

Experience has showed that while a well is pumping groundwater for irrigation, it can simultaneously lower the groundwater level and play a role in soil drainage. However, it cannot take the place of ditch drainage completely. In an area that has highly mineralized groundwater, the highly mineralized groundwater pumped up must be drained by ditches. With regard to soil waterlogging, a well cannot take the place of a ditch system to drain the water off in time. Even in an area predominated by pumped-well irrigation and drainage, a horizontal ditch drainage system should also be built for draining the runoff. Generally, in an area predominated by well irrigation and drainage, ditch irrigation is also necessary. In an area irrigated with groundwater, the volume of groundwater pumped is so large that a cone depression often forms in the water table, greatly lowering the groundwater level. For example, in the western Xinxang district of Henan Province, the groundwater level had been dropping progressively since well irrigation was developed in 1965, and, in 1973, the groundwater level of the center of the cone was 7 to 8 m lower than it had been in 1965 (Salt-Affected Soils Research Group 1975). Therefore, it is necessary to divert river water for irrigation and, at the same time, recharge the groundwater and control the groundwater level to an appropriate depth to prevent salinization of the soil. In areas where the groundwater is too mineralized to be used for irrigation, the main effect of the pumped well is to drain off the highly mineralized groundwater, which may lower the groundwater level. Therefore, it is more necessary to divert river water through a ditch system for irrigation and leaching salts from the soil and desalinization of groundwater. Chinese agricultural practice shows that various patterns of integrating wells and ditch irrigation and drainage, adopted according to the different local conditions and in combination with reasonable measures of agriculture and forestry, may steadily promote soil fertility and effectively control and prevent salinization in the soil.

APPLICATION OF PUMPED-WELL IRRIGATION AND DRAINAGE UNDER DIFFERENT HYDROGEOLOGICAL CONDITIONS

Due to different soil and hydrogeological conditions in various areas, different patterns of well irrigation and drainage have been adopted. There are three patterns in the application of wells for irrigation and drainage in China.

(1) Well irrigation in combination with well drainage in areas of fresh groundwater or groundwater with low mineral content

In the upper and middle parts of the alluvial plain and in the area under which lies the buried river, runoff proceeds unobstructed, the soil is generally of good permeability, and there are rarely impermeable compact interbedded layers of clay in the solum; both the shallow and deep groundwater are fresh (<1 g/L) or contain few minerals (1 to 2 g/L) and can be used for irrigation. Due to the variation of the meso- or microrelief, soil salinization often takes place in the margins of the depression and the positive element of the microrelief. Salts are heavily concentrated in surface soils, much less so in subsoils. The development of soil salinization in this area is mainly by soil waterlogging and the destruction of the original balance of water and salt in soil, which was caused by extensive gravity irrigation without reasonable drainage. The development of pumped-well irrigation may greatly decrease the input of water and salt and lower the groundwater level. An appropriate increase of irrigation can leach the salts downward in saline soils during the course of normal irrigation. Well irrigation combined with well drainage is the most economic and effective application of the pumped well, and it is now applied extensively in China. In Fengqiu County of Henan Province, 4800 wells were built between 1965 and 1974, after which the high level of groundwater was controlled and about 14 000 ha of salt-affected soils (mostly secondary salinized soil) in the county were reduced by 80%, due to the application of pumped-well irrigation and drainage in combination with other reasonable measures of hydraulic engineering and agriculture. Experimental results of the Shengsuiyuan Irrigation Experiment Area of the county, conducted by Institute of Soil Science, Academia Sinica, showed that the groundwater level started to fall markedly since the beginning of well irrigation and drainage in 1965, and the year-round level of groundwater was controlled between 3 and 6 m during 1967 to 1969 (Fig. 2). Salts moved downward 1 m below the soil surface (Table 2).

The depth and spacing of pumped wells in these areas are dependent on the buried depth and yield of the water-bearing layer, and the action radius of a well should also be taken into account. In an area with a shallow water-bearing layer and a large groundwater yield, the depth of wells adopted is generally about 30 m, and the spacing of these wells is 400 to 600 m. In an area with a deep water-bearing layer and a small groundwater yield, the depth of wells should be 40 to 60 m, and the spacing should be 200 to 400 m (Salt-Affected Soils Research Group 1975; Research Institute Irrigation 1977; Institute of Soil Science 1978).

(2) Shallow pumped wells in combination with deep pumped wells in areas of shallow mineralized groundwater

In lower parts of plains and depressions, the shallow groundwater (mineralization is usually 2 to 10 g/L) is generally not suitable for direct irrigation, though the deep ground water (as much as 100 m beneath the surface), which is fresh or alkaline and has few minerals, can be used for irrigation. In these areas, shallow

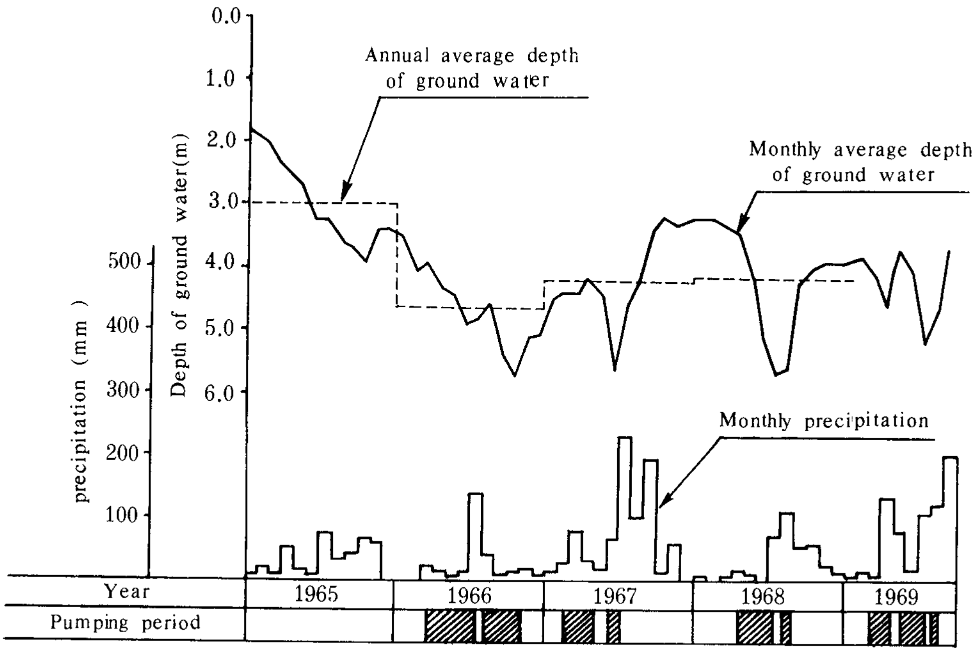

FIG. 2. Precipitation, pumping period, and variation of groundwater level of the experimental area.

pumped wells should be adopted in combination with deep pumped wells. The shallow well is used for pumping mineralized groundwater to lower the groundwater level, and the deep well is used to pump fresh or lowly mineralized groundwater from the deep water-bearing layer for irrigation and leaching of salts. But in this case, measures for preventing soil alkalinization must be adopted. In areas where irrigation water resources are insufficient and the mineralization of the shallow groundwater is not so high, mineralized groundwater may be mixed with fresh water for irrigation or may be used alternately with fresh water for irrigation, but the times of irrigation should be limited. It is necessary to divert fresh water to make up the deficiency of well irrigation and to desalt the shallow groundwater, if possible. In these areas, the depth of shallow pumped wells is 20 to 40 m, and it should be less than the depth of impermeable interbedded layers of clay in case they exist. If there is an impermeable interbedded layer of clay in the solum above 10 to 20 m, little effect of shallow well drainage will be found on the control of the groundwater level; it is necessary to adopt combination wells and radial collector wells or pipe drainage. The well spacing should be determined in accordance with the permeability of the solum and the requirement of controlling the groundwater level. The depth and spacing of deep pumped wells should be determined on the basis of the depth and yield of the water-bearing layer. An experiment at Nanpi County, conducted by the Research Institute of Water Conservancy of Hebei Province, showed good results from shallow wells with a depth of 20 m and a spacing of 240 to 300 m, as well as deep wells with a depth of 250 to 450 m and a spacing of 1000 to 1500 m; about two-thirds of the 100 ha of salt-affected soils were successfully improved between 1974 and 1977. Analytical data from groundwater samples collected from 42 observation sites indicated that the desalinization rate of groundwater was 2 to 75%, and the yield of winter wheat was increased by 10 to 30% due to irrigation with mixed water containing 3 to 5 g of salt per liter.[1]

(3) Shallow pumped-well drainage in highly mineralized groundwater areas

In coastal and inland arid depression areas, the mineralization of groundwater is more than 10 g/L, and the fresh groundwater is buried very deeply (below 300 to 400 m), less in storage, and cannot be used for irrigation. Soils in these areas

[1] Data of Research Institute of Water Conservancy of Hebei Province, 1977.

TABLE 3

Specification and efficiency of pumped wells under different hydrogeological conditions in areas of highly mineralized groundwater

Locality	Profile status	Mean permeability coefficient of solum, m/day	Well depth, m	Well spacing, m	Yield of well, m/h	Action radius, m
Dongtai, Jiangsu	Upper 20 m of solum is mostly light texture	1.6–1.9	20–30	400–500	10–30	300
Hangjinhouqi, Inner Mongolia	Upper 10 m of solum is interlayers of clay and sand with poor permeability under which the solum is sandy in texture with good permeability	Poor permeable layer 0.08 Permeable sandy layer 3.72	35–40	400–500	30	230–260
Dayuzhang Irrigation Area, Shandong	Upper 20 m of solum is interlayers of clay and sand; impermeable interbedded layer of clay 2–7 m thick lies 10–20 m deep	0.7	20–30	200	5–10	60

have a high content of salts. In the arid and semiarid areas, it is necessary to divert water for irrigation, leaching the salts, lowering the groundwater level, and desalting the groundwater. The coastal and semiarid areas do not require lowering the groundwater level or leaching salts, but drainage is necessary to preclude waterlogging. Our experience has showed that horizontal ditch drainage by gravity cannot by itself meet the needs of lowering the groundwater level and improving the soil. Therefore, open-ditch drainage must be combined with shallow well drainage. Wells are mainly used to drain the highly mineralized groundwater and to lower its level, and diverted fresh irrigation water and rainfall can be used to feed the groundwater and to promote the desalinization of the groundwater.

Based on different hydrogeological conditions, there are three different approaches in these areas. First, where the region has a permeable solum, no impermeable interbedded layers of clay in the solum, and a good hydrodynamic connection between upper and lower water-bearing layers, well pumping can lower the groundwater level in a larger area, and it may also play an important role in the drainage and desalinization of the upper soil layer. For example, the results of an experiment at the Xincun Production Brigade, conducted by the Water Conservancy Experimental Station of Dongtai County, Jiangsu Province, showed that under pumped-well drainage, and through rice cultivation for 1 year, the salt content of the upper soil layer of 90 cm decreased from 0.3 to 1.5% to less than 0.2%, and the desalinization rate ranged from 30 to 90%.[2] Secondly, in other regions the solum is composed of different textures, the upper layer (from several meters to more than 10 m) is clay or clayey loam with poor permeability, the lower layer is a sand with good permeability, and the groundwater in the lower layer is semipressure water. The shallow groundwater in the upper layer of the solum is fed by the semipressure water in the lower layer, which often leads to the failure of horizontal drainage. Under this condition, well pumping should be applied to drain the semipressure water and reduce its pressure. When the water pressure head is lower than the shallow groundwater, the shallow groundwater may percolate downward, and its level can be lowered. The experiment at Sandaoqiao in Hangjinhouqi County, conducted by the Inner Mongolian College of Agriculture and Animal Husbandry and other units, proved the effectiveness of drainage by pumped wells 30 to 40 m deep on lowering the groundwater level.[3] Third, where the solum has poor permeability and an impermeable interbedded layer of clay is

[2] Data from Water Conservancy Experimental Station of Dongtai County, Jiangsu Province, 1977.

[3] Data from Department of Irrigation and Water Conservancy, Inner Mongolian College of Agriculture and Animal Husbandry, 1979.

situated in the upper solum of 10 to 20 m, and there is little hydrodynamic connection between the upper and lower solum, well pumping of the groundwater from the lower water-bearing layer situated below the impermeable interbedded layer of clay is usually ineffective on the drainage and desalinization of the upper soil layer. Experimental results obtained from the Irrigation Area of Dayuzhang in Shangdong Province illustrated that fact (Table 3) (Dai 1980.)

For well drainage, motor-driven pumps should be used to draw up the groundwater. The cost of operating and managing wells used mainly to pump highly mineralized groundwater will be very high; therefore, it is necessary to investigate the hydrogeological condition of various areas and identify their suitability and economic benefit before the pumped well is built. The experiment in Dayuchang Irrigation Area by the Research Institute of Water Conservancy of Shandong Province has showed that where the solum has poor permeability or where impermeable interbedded layers in the solum occur, well drainage is often ineffective, and the open ditches used for drainage are also liable to collapse. Then pipe drainage or pipe drainage combined with mechanical drainage is markedly effective for desalinization of the soil, in the event that it cannot be drained by gravity.

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