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Causes of farmland salinization and remedial measures in the Aral Sea basin—Research on water management to prevent secondary salinization in rice-based cropping system in arid land

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ARTICLE INFO

Article history:
Accepted 11 March 2006
Published on line 21 April 2006

Keywords:
Secondary salinization
Water management
Water and salt balance
Central Asia
Arid land
Rice-based crop rotation system

ABSTRACT

In the Lower Syr Darya region of the Aral Sea basin, secondary salinization of irrigated lands has been a crucial problem. To clarify the mechanism of secondary salinization, studies on water and salt behavior were conducted in an irrigation block where a rice-based cropping system has been practiced. Results of on-site studies are summarized as follows: (1) since the performance of land-leveling for rice cultivation was extremely poor, the water level was maintained high enough to submerge the highest portion of each plot, and this causes wastage of irrigation water and salt accumulation. (2) A large portion of water introduced to rice plots tends to be released into field drains. (3) Due to excessive irrigation of rice plots with slightly saline river water, dissolved salts were mainly deposited in upland plots in the block and its periphery. Changes in salt accumulation rates were dependent upon the scale of annual changes in the farmland areas that were converted from the upland condition to submerged condition in a process of crop rotation. (4) A remarkable finding was obtained on salt behavior in saturated shallow soil layers of rice plots. An initial decrease in soil water salinity in the shallow layer is due to the leaching effects of infiltration during the initial stage, and the subsequent gradual increase is more likely a consequence of mixing with the saline water that remains in the finer soil pores combined with the concentration effects of crop water uptake, and the upward flow from the lower layers due to occasional interruption and resumption of irrigation water supply. (5) Because seepage water from rice plots flows underneath the field drain, the rise of the groundwater table and salt accumulation were accelerated in the adjacent upland plots. Thus, mixed cropping with rice and upland crops based on a crop rotation system in an irrigation block accelerates waterlogging and salt accumulation in upland plots. Based on these results, several remedial measures were recommended to overcome problems on secondary salinization as follows: (1) avoid mixed cropping with rice and upland crops, and unify either upland crops or rice in an irrigation block to control groundwater table; (2) decrease conveyance and field application losses through improved canal construction and management performance, introduction of canal lining, and improved land-leveling performance; (3) maintain and operate drainage canals

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0378-3774/$ – see front matter
doi:10.1016/j.agwat.2006.03.007

to enhance function, particularly installation of subsurface tile drainage for enhancing subsurface drainage function and management of drainage outfall for minimizing environmental degradation caused by saline drainage water in the downstream area; (4) develop a design and management technique of evaporation pond for better effluent management and reuse of drainage water at the outfall of each irrigation block; (5) reduce the water supplied for rice and its use for other crops, or returning the saved water to the river for downstream users including returning to the environment; (6) conclude international water and/or drainage rights agreements among riparian countries and enactment of a basin-wide management regulation to control water withdrawal and drainage.

1. Introduction

The lower river basin of the Syr Darya, which rises in the Tien Shan Range, meanders mainly in lowland deserts that receive a low precipitation of 100–200 mm year^{-1} and finally flows into the Aral Sea. Water withdrawals for irrigated lands along the river have been conducted since the 1960s. Irrigated agriculture of rice-based cropping system in the Kzyl-Orda region of the Lower Syr Darya is important to both the national and regional economy. Since rice is a high water-consuming crop, water withdrawals have sharply increased with an increase in the area planted with rice. The sizable discharge of drainage from irrigated lands has also sharply increased the river water salinity level. Under these conditions, the salinity of the lower reaches of the Syr Darya has increased from 0.4–0.6 g L^{-1} to 1.3–2.0 g L^{-1} in the last three decades (Dmitriev, 1995).

Also, due to excessive and inefficient water use, secondary salinization (irrigation-induced salinization) of lands exists in irrigated areas in the region. The estimated average water distribution and delivery efficiency for the Lower Syr Darya basin is 0.64, and the estimated irrigation application efficiency is 0.60 (EC, 1995). Thus, the overall irrigation efficiency is extremely low (0.38); approximately 62% of the withdrawn water is estimated to be lost before it reaches the field and becomes available for use in crop production. These water losses raise the level of the groundwater table and cause waterlogging and land salinization. Salt accumulation in farmlands results in an increase in abandoned lands and environmental degradation in the region.

A large part of these problems is attributable to the poor water management of canals and fields under large-scale canal irrigation systems. Thus, proper water management is essential for preventing secondary salinization and sustainable agriculture in the region. In this study, based on the analysis on water and salt behavior in an irrigation block located in the Kzyl-Orda region of the Lower Syr Darya, we attempted to identify the causes of secondary salinization and suggest remedial measures to overcome the problems from the viewpoint of water management.

2. Materials and methods

2.1. Outline of study area

Shamenov kolkhoz (originally a collective farm during the ex-USSR era, was privatized after independence, and hereinafter called kolkhoz) located in the Kzyl-Orda state of Kazakhstan, which is a rice bowl in the Lower Syr Darya basin, was selected as the study area (Fig. 1). Although the kolkhoz has a gross area of 19,000 ha, only 1900 ha or 10% of the area was sporadically reclaimed for agricultural purposes. Land reclamation was conducted mainly in water-accessible areas with comparatively low and flat topography. The areas with poor water accessibility due to undulating topography were left as wastelands. Of the 1900 ha of reclaimed and later cultivated areas in the kolkhoz, an area of 600 ha has been abandoned due to severe salt accumulation. The phenomenon of salt accumulation showed a tendency to concentrate in small localized spots within irrigated blocks. When the soil salinity reached a certain level in some of the areas of limited crop production, they were abandoned. This situation is commonly observed in many kolkhozes in the state.

The study area has a continental climate. Average annual precipitation is 120 mm, which is partial to spring and fall. Average annual potential evapotranspiration is 2000 mm. Despite the high latitude (45°N), the summer is extremely hot with an average temperature of 27 °C and a maximum temperature in excess of 40 °C. Winter is extremely cold with an average temperature of −5 °C and a minimum temperature below −25 °C. For the normal growth of rice, the cropping season must be set from late April to early September. Since there is no effective rainfall during the rice cropping season, irrigation is a prerequisite for growing rice.

For the study on water and salt balance, Yeltai block (Fig. 2) was selected as the study area. Irrigation water for the block is transported through the Yeltai Canal, which is diverted from the main canal (Communism Canal) in the kolkhoz. The Yeltai Canal separates into two branch canals—the Northern Branch Canal for the Northern Sub-block and Southern Branch Canal for the Southern Sub-block. Surface and subsurface drainage water from farmlands is collected by the main drain (Yeltai drain) and drained off to the tributary of the Syr Darya river. Out of the block area of 827 ha, an area of 716 ha was cultivated. The remaining 111 ha, including roads, canals, and drains, was not allotted for cultivation either because it was designated inappropriate for the purpose at the time of development (101 ha) or because it was abandoned later (10 ha). This block is characterized as well-consolidated, i.e., irrigation canal and drainage systems are set independently, and every individual plot has access to a field canal and a field drain,