Agricultural Water Management 156 (2015) 19–29

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Desalination of saline farmland drainage water through wetland plants

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ARTICLE INFO

Article history:
Received 29 May 2014
Accepted 2 March 2015
Available online 16 April 2015

Keywords:
Saline water discharge
Salt removal
Typha spp.
Phragmites communis
Potamogeton crispus

ABSTRACT

To protect against soil secondary salinization, a desalination process for farmland drainage using wetlands was evaluated. In this study, the desalination effects of different plants in Chagan Lake were analyzed. A field experiment was conducted in the Qianguo irrigation district to choose the most efficient desalting plant by comparing the biomass contents and the ash rates of *Typha* spp., *Phragmites communis*, *Phragmites japonica* Steud. var. *prostrata* (Makino) L. Liu, *Medicago sativa* Linn., *Lemna minor* L. and *Potamogeton crispus. Typha* spp., *Phragmites communis* and *Potamogeton crispus* performed best among tested species in removing salt from saline farmland drainage. According to the calculated ash rates and ion contents, the amount of salt removed by reaping reed and cattail accounted for 10–26% of the salt in the drainage. The removal efficiencies of Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-} and $SO_4{}^{2-}$ ions are 9–15% per year. A constructed wetland containing 233–288 km^2 of *Typha* spp. is required so that the removal efficiency of these six ions can be more than 80%.

1. Introduction

Saline land, as a kind of land resource, is being paid more and more attention to its improvement and utilization these days. It is estimated that there are 9.5×10^8 ha saline area worldwide, accounting for 7.26% of the total land area on earth (Malcolm and Sumner, 1998). In China, the total saline area is 1.0×10^8 ha (Xiong, 2005), accounting for about 10% of that of the world, while 80% of which has not been modified and developed (Song, 2009). Songnen Plain, with 3.2×10^6 ha saline area which accounts for 19% of the total plain area, is one of the five salinization land distribution areas in China (Li, 2000). Salinity in Western Songnen Plain experienced a complex geological transformation, related to the factors of stratum, hydrogeological conditions, groundwater runoff and surface runoff, tectonic framework, etc. Salinization of Qianguo and Da'an areas were attribute to historical reasons of Da'an ancient river channel – the role and processes of its tectonic movements provides salt sources and a means of transport for the formation of salinity and to create salt accumulation environment.

Songnen Plain, which soil salinity was reduced by going through irrigation leaching, achieved the goal of graining production of 15 billion kilograms in Northeast China (Yang and Liang, 2007). The total construction area of changing saline to paddy was 3.41×10^5 ha. Rice cultivation can be used to treat the saline land in the Songnen Plains, opening up the area affected by salinity for land development and leading to construction around the irrigation area in the western part of the northeast. However, surveys found that because of the lack of supporting evaluation for drainage water treatment, the problem of soil secondary salinization increased. The secondary salinization turned non-saline–alkali soil into saline–alkali soil, and the crop yield decreased (Yang et al., 2009). Therefore, problem in the treatment of saline farmland drainage water must be solved for the vicious circle of regional agricultural development and ecological environment improvement. As a result, food production can be expanded while the surrounding environment is well protected (Yang and Liang, 2007; Li et al., 2009). To avoid the secondary salinization of soil, this project proposed to use wetland as receiving area of saline water. On the one hand, retreated saline water was used to irrigate the wetlands; on the other hand, the treated discharge water of the wetlands can be recycled in the saline area to keep a sustainable use of saline water.

Chagan Lake, as broad as 480 km^2, covers two counties and one city in the west of Jilin province: Qianguo County, Qian'an County and Da'an city (Li, 2013). Chagan Lake is a national nature reserve and also a saline wetland recorded in the list of China's wetland. The whole lake is 37 km long from south to north, 17 km wide from

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http://dx.doi.org/10.1016/j.agwat.2015.03.001
0378-3774/

east to west, with meandering Lake Shoreline 128 km long, known for fishery production, agricultural production and natural resort (Sun, 2014).

The south part of the Chagan Lake, which is considered as the core area of the Chagan Lake reserves, is about 3.33×10^3 ha and has a water capacity of 7×10^8 m^3 (Zhang et al., 2013). It is a main bird habitat. Because of its biological abundance and various aquatic plants such as *Typha* spp., *Phragmites communis* and the *Potamogeton crispus*, etc., the south of Chagan Lake is the return water intake area of the Qianguo irrigated regions named as the paddy field of saline–alkali soil in Songnen plain. About 1.3×10^8 m^3–2×10^8 m^3 of drainage water from the saline–alkali soil in the Qianguo irrigated region flows into the south of Chagan Lake every year. Qianguo irrigated region, which the Yinsong channel flows by, has an area of 1285.7 km^2 and 41.7% of the total area is salinization land (Qin et al., 2002).

There is a controversy on whether to discharge recycled water from the saline–alkali paddy field into the Chagan Lake wetland reserve. The consenters think that the drainage water from saline–alkali soil could provide water to the Chagan Lake wetland, which is beneficial to the wetland ecosystem restoration; while the oppositions think that recession salinity from the saline–alkali paddy field is so high that it can cause adverse effects to the Chagan Lake wetland ecosystem. Therefore, a better choice is to select the south of Chagan Lake carrying large amounts of drainage water from the saline–alkali soil as the research object.

At present, most of the salinity wastewater treatment methods are physical and chemical treatments, including electro dialysis, reverse osmosis, distillation and ion exchange, etc. (Lu et al., 2005; Fan, 2003; Darwisha et al., 2009). Yao (2004) has used a membrane integrating micro filtration, ultrafiltration and reverse osmosis to study the treatment of high-salinity wastewater. The research indicated that the desalination rate could reach 96.5% when the salt content of the wastewater was 2000–5000 mg L^{-1}. The desalination rate of electro dialysis could be as high as 99.3%, but the cost was relatively higher. To remove salt from the saline farmland drainage, Lee et al. (2003) have studied the saline farmland drainage treatment using a reverse osmosis membrane. The research showed that the treatment efficiency of the ESPA-1 and NF-90 membrane was higher with a desalination rate of 95% when the concentration of sodium was 1150 mg L^{-1}. In Egypt, desalting processes are widely used for farmland drainage treatment, including electro dialysis, reverse osmosis and ultrafiltration. Abulnour et al. (2002) has demonstrated that the biological ultrafiltration membrane system is the cheapest method by comparing the economy of various different methods. The system uses microfiltration/ultrafiltration scheme in the pretreatment, then followed by reverse osmosis. The saline water from the reverse osmosis is further treated to increase system recovery. However, these techniques are still problematic due to complex operation and high cost. Membrane treatment has problems with membrane fouling and concentrated water treatment. The high salt concentration and complex ion composition in the concentrated water result in unsatisfactory treatment efficiency (EI-Zanati and EI-Khatib, 2007; Gilron et al., 2000).

In general, the best way to improve the saline–alkali land is to grow salt-tolerant plants, because halophytes have good absorption of salt. In a saline environment, halophytes can absorb salt from their growing environment to reduce the intracellular water potential for remitting salt stress so that the trans-membrane transport of water flows in a favorable direction for cell growth. For example, Zhang (2005) studied the cultivation of salt tolerant species including *sainfoin*, *Medicago sativa* Linn., *Symphytum officinale*, *Coronilla varia*, and *Festuca arundinacea Schreb*, on saline farmland. The results show that halophytes have an obvious desalination effect, and the desalination rate of halophytes can reach 31.1% and 19.1% in a saline soil layer of 0–20 cm and 0–100 cm, respectively. Similarly, this paper presents a study that uses haloduric hydrophytes to absorb salt and remove salinity of drainage water. Halophytes have an aptitude for salt absorption (Zhao et al., 2002; Ren et al., 2004). Lymbery et al. (2006) from Australia has studied the use of *Juncus* sp. to address the saline–alkali farmland, and the results showed that the desalination rate can reach as high as 54.8%. Yang et al. (2004) used the mode of fish-rice-reed-cattail to improve soda saline–alkaline land. The results showed that the desalination effects of cattail and reed were much better. The purpose of these studies was to investigate salt removal in saline–alkali soil using halophytes. Therefore, using halophilous hydrophytes to remove the salt from farmland drainage water may be a better choice.

In order to find a new way to manage the drainage water from saline–alkali land, this paper analyzed the desalination effect of different aquatic plants in Chagan Lake. A field experiment was conducted in the Qianguo irrigation district to choose the most efficient desalting plant by comparing the biomasses and the ash rates of *Typha* spp., *Phragmites communis*, *Phragmites japonica* Steud. var. *prostrata* (Makino) L. Liu, *M. sativa* Linn., *Lemna minor* L. and *Potamogeton crispus*.

2. Materials and methods

2.1. Description of the experimental site

The study area is located at Chagan Lake near the Da'an irrigation district. Chagan Lake is the main receiving area for the saline farmland drainage water from the Qianguo irrigation area, and the annual yield of drainage water from the Songhuajiang channel flowing into the Chagan Lake is approximately 1.3×10^8–2×10^8 m^3. The area of Chagan Lake is large, and the water quality and quantity are stable. The climate of Chagan Lake is semi-arid sub-humid continental monsoon. There are 2906 h of sunshine in Chagan Lake area all year round, and the annual solar radiation is 517.5 kJ/cm^2. So this region has abundant light resource. The annual average air temperature of the Chagan Lake area is 5.0 °C, with a lowest temperature of −30.9 °C and a highest temperature of 33.9 °C. The frost-free periods are 141 days and the average evaporation values for the experimental area is 1466 mm per year.

The total area of the Qianguo irrigation district is 1285.7 km^2 and the salinization of land accounts for 41.7% of the total irrigation area. Generally speaking, the areas of the saline soil on both sides of the Songhua River channel (paddies drainage main channel in Fig. 1) are large, and the salinity-alkalinity of the irrigation district drainage water is high. Chagan Lake, the main receiving area for the saline farmland drainage water from the Qianguo irrigation area, has diverse species of biomes. Many aquatic plants grow in Chagan Lake, such as *Typha* spp. and *Phragmites communis*. Furthermore, the difference in the salt content between southern part and northern part of the lake is large enough to study the desalination of halophytes growing in different environments. Experimental zone geographic locations are shown in Fig. 1.

2.2. Methodology

According to the recession mechanism of rice paddies in saline–alkali land and to ensure the continuity and periodicity of the sampling, the sampling frequency of the water and soil was set as follows: twice in the wet period (late July and early September), twice in the level water period (middle of May and middle of June) and once in the drought period (middle of November). According to the plant growth cycle, the plant sampling was set in the level