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Phytodesalination of a Salt-Affected Soil with Four Halophytes in China

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Abstract: In arid and semiarid regions of China, the decrease in agricultural production due to excessive salts is a very serious problem. Salt-affected soil distributes mainly at north, west, around Bohai Sea, and the mid-stream of the Yellow River. We could have ameliorated salt-affected soil such as alkali soil, saline-alkali soil by using flue gas desulfurization gypsums. Consequently, the effectiveness of these desulfurization by-products as soil amendments could be confirmed. However, soil containing much salt such as sodium chloride spreads widely in Tianjin city around Bohai Sea. In order to ameliorate this soil, it is necessary to remove much salt in soil at first. Phytodesalination refers to the use of halophytes to remove sodium from the soil. This plant-based method is of great importance especially for several developing countries. In this research, treatments by four halophytes, *Artemisia argyi* L., *Limonium bicolor* K., *Melilotus suaveolens* L., and *Salsola collina* P. were tested in pot experiment by using three salt-affected soils (Dagang district, Xiqing district and Jixiang county) in Tianjin. Soil properties were evaluated by pH, EC, ESP (exchangeable sodium percentage) and ions concentration (Na, Ca, Mg, Cl, HCO_3, CO_3 and SO_4) before and after plant growing. Consequently, Na and Cl concentrations and EC at all test pot decreased after the growth of halophytes, and Na concentration in two halophytes increased. Moreover, we could propose the new soil amelioration method to add desulfurization gypsum to soil after phytodesalinization because of both high pH and high ESP after treatment.

Key Words: Electrical conductivity, Halophyte, pH, phytodesalination, Salt-affected soil

1. Introduction

1.1. Soil problems in China

Soil salinity is a widespread environmental problem, particularly in arid and semi-arid regions of the world. This problem affects crop production on over 800 million hectares, or a quarter to a third of all agricultural land on earth (Szabolcs, 1989; Rengasamy, 2010). Salt-affected soils occur within the boundaries of at least 75 countries (Szabolcs, 1994), and these soils also occupy more than 20% of the global irrigated area (Ghassmi *et al.*, 1995).

China suffers from among the most severe land degradation problems in the world. The rapid increase in desertification since the 1970s and its tremendous impact on China's environment, society, and economy have received considerable attention. The area of salt-affected soil in China is about 9.9×10^5 km^2 (Wang *et al.*, 1993). Salt-affected soil distributes mainly at north, west, around Bohai Sea, and the mid-stream of the Yellow River. Tianjin's soil was classified as part of the sodic soil district around the Gulf of Pohai. The cultivated area is 4,856 km^2 and occupies about 41.3% of total area (National Bureau of Statistics of China, 2006). Almost all of this area is dry agricultural land. About 38% of the total cultivated area is salt-affected soil, which is classified as follows: slight (salinity = 0.1-0.2%), 54%; medium (salinity = 0.2-0.4%), 27%; heavy (salinity = 0.4-0.6%), 7%; and sodic soil (salinity > 0.6%), 12%. Soil salinization has progressed in Tianjin because of alkalization due to desalinization, groundwater capillarity, and irrigation. In particular, salt concentrations in the soils of the coastal area are higher than those of other areas in Tianjin. This soil was classified as salinized soil because the salt consists mostly of sodium chloride.

Sakai *et al.* studied the amelioration of salt-affected soil by using flue gas desulfurization by-products in China (2004, 2007, 2010). However, it is necessary to remove much salt in soil before ameliorating by using desulfurization by-products in soil that contains much salt such as sodium chloride.

Salinity is the major environmental factor limiting plant growth and productivity. Several methods were established to reclaim salt-affected soils and were grouped into hydraulic, physical, chemical, and biological approaches. The latter involves several techniques among which, phytodesalination refers to the use of Na-hyperaccumulating plants to remove sodium from the soil. This plant-based amelioration method is of great importance especially for several developing countries. China has about 430 halophytes species, which fall into 66 families and 198 genera (Zhao *et al.*, 2002). According to Qadir and Oster (2004), vegetative bioremediation is a function of four main factors: (1) CO_2 partial pressure within the root zone, (2) root proton release (in the case of N_2-fixing plants), (3) improvement of soil porosity by root expansion, and (4) shoot sodium content (removed by

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the harvest). Several authors encourage the use of Na^+ and Cl^- hyperaccumulating halophytes for soil desalination (Zhao, 1991; Keiffer and Ungar, 2002; Zhao *et al.*, 2005).

The objective of our research is to examine salt-affected soil amelioration in Tianjin by using four halophytes.

2. Materials and Methods

2.1. Site location

Tianjin is situated in the northeastern part of North China Great Plain, bordering the Bohai Sea in the east, leaning against the Yuanshan Mountain in the north, with its terrain traversing the Haihe River through north and south. It has become the hub of communications of North China and the gateway of the capital city. The climate in Tianjin is warm, semi-dry to humid and monsoon with typical features of the warm temperature zones. The average temperature in January is 1ºC high and –8ºC low, the average temperature in July is 31ºC high and 23ºC low. Annual rainfall is on average 560 mm, 80% of which falls between June and September. Due to the cold winter and hot summer, usually two crops are grown each year, one from late winter until summer and another from late summer until winter. In arable fields traditionally irrigated winter wheat is grown from November until June, followed by rain-fed maize from June until September/October. In horticulture a wide variety of crops is grown. In winter many crops are protected with plastic against the cold wind (Duart and Corré, 2003).

2.2. Halophytes

Artemisia argyi L. is an herbaceous perennial plant growing in forest side, waste land, orchard and nursery, propagated by seed and rhizome (Zhang and Hirota, 2000). The height is from 20 cm to 120 cm. The leaves have been used for a long time as a traditional Chinese medicine to treat many diseases such as asthma (Zheng *et al.,* 2004).

Limonium bicolor K. is perennial weed growing in seashore, sand dune and grassland of alkaline soil, propagated by root and seed (Zhang and Hirota, 2000). It is a halophytic flowering plant species that is tolerant to a wide range of harsh environments (Bouchereau *et al.*, 1999), indicating that it has developed molecular and physiological systems to adapt to adverse stress conditions. It is a desirable plant for studies characterizing genes and mechanisms responsible for plant stress tolerance (Ban *et al.*, 2011). The height is from 20 cm to 70 cm. Radical leaf is obovate-spoon form, 2-7 cm length. This plant has the cymose panicle on top of stem, white sepal, and yellow petal.

Melilotus suaveolens L. is annual or winter annual weed growing in mountainous district, circumference of arable land, roadside, river side and bush, propagated by seed. The height is from 60 cm to 90 cm and leaf is ternately compound leaf. Leaflet is oblong-oblanceolete and yellow papilionaceous flower attach racemosely on leaf axil (Zhang and Hirota, 2000).

Salsola collina P. is common annual weed of up-land field and orchard, growing in alkaline soil and dry land, propagated by seed. Stem is branching at lower part and leaf is columnar, succulent. Flowering time is in July-October, spike on upper part of branch (Zhang and Hirota, 2000).

2.3. Sampling and Measurement methods

Soil samples were collected in Dagang district (DG), Xiqing district (XQ), and Jixiang county (JX) of Tianjin. Seeds of four halophytes, (A): *Artemisia argyi* L., (B): *Limonium bicolor* K., (C): *Melilotus suaveolens* L., and (D): *Salsola collina* P. were collected on the Tianjin Agricultural University Campus in Tianjin, China. Twenty healthy seeds were planted in each of three pots (25 cm in diameter and 20 cm in height) as replicates for each treatment in a greenhouse. In the pot test, 4 kinds of wild halophytes were cultivated in 3 kinds of salt and alkali soils selected from the wastelands of Dagang district, Xiqing district and Jixian county of Tianjin city. Plants were grown in a temperature (18-32ºC) and humidity (50-70%) controlled greenhouse. To compare the effects of salinity on three soils, the height and stem diameter of plants were measured together with soil properties. Soil samples were dried (45ºC) in 48 hours, ground using a pestle and mortar, and passed through a 1 mm sieve before the all chemical analysis. Soil properties (pH, EC, CEC, exchangeable Na, soluble ions such as Ca, Mg, SO_4, CO_3, HCO_3, Cl) before and after growing these plants were measured. The pH, electrical conductivity (EC), and solution cations were measured using 1:5 water extracts. The cation exchange capacity (CEC) was determined using 1 N NaOAc at pH 8.2. Ca^{2+}, Mg^{2+} and SO_4^{2-} contents of soil solution were measured by titration with ethylene diamine tetraacetate. CO_3^{2-} and HCO_3^- in the saturated paste extracts were determined by titrimetric method using 0.010N H_2SO_4. Cl was determined by titration using 0.005N $AgNO_3$ solution. Plant samples were dried, ground, and analyzed for Na and K contents using a 0.5% HNO_3 solution and measured by titration.

3. Results and Discussion

3.1 Soil Analysis

The chemical properties (pH, EC, ESP, and CEC) of three pot test soils (Dagang (DG), Xiqing (XQ), and Jixian (JX)) are shown in **Table 1**. Soil pH, EC and ESP in DG soil have the highest values among three soils. XQ soil has high ESP value

Table 1. Chemical properties of Dagang, Xiqing, and Jixiang soils.

	pH [-]	EC [dS/m]	ESP [%]	CEC [cmol/kg]
Dagang (DG)	8.5	57.0	66.2	15.6
Xiqing (XQ)	8.2	10.8	51.4	4.0
Jixian (JX)	7.6	5.9	1.5	23.1

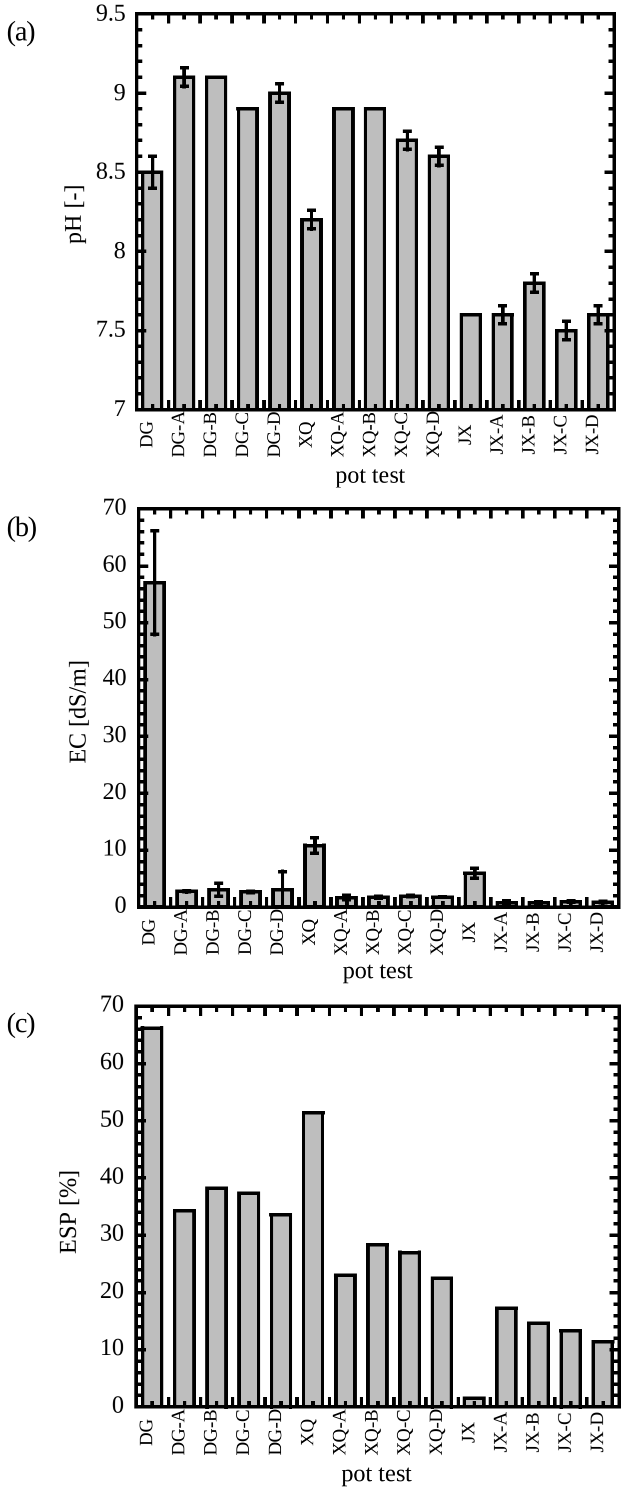

Fig. 1. Changes in soil pH, EC, and ESP in each pot test before and after the growth of four halophytes. (Site: Dagang (DG), Xiqing (XQ), Jixiang county (JX), Halophytes (A): *Artemisia argyi* L., (B): *Limonium bicolor* K., (C): *Melilotus suaveolens* L., (D): *Salsola collina* P.)

because of low CEC value. JX soil has the largest CEC and lowest values in pH, EC, and ESP.

Soil pH, EC, and ESP in test pot before and after the growth of halophytes were measured (**Fig. 1(a), (b), (c)**). In pot test in Dagang soil and Xiqing soil, pH values after the plant growth increased compared with that before growth (Fig. 1(a)). In the case of pot test in Jixian, pH values in *Artemisia argyi* L. (A) and *Salsola collina* P. (D) is almost the same as the value before the growth, and pH value is slightly higher in the case of *Limonium bicolor* K. (B) and is slightly lower in *Melilotus suaveolens* L. (C). In the all cases of *Limonium bicolor* K. (B), soil pH after the growth was increased (Fig. 1(a)).

Soil EC decreased drastically after the growth of four halophytes in three salt-affected test soils (Fig. 1(b)). Soil ESP decreased in the case of both DG soil and XQ soil after the growth of four halophytes (Fig. 1(c)). By contrast, ESP in JX soil increased after the growth. The increase of the hydraulic conductivity due to the root growth allows the leaching of Na^+ below the effective rooting depth. As a result, the drastically decrease of EC value after the halophyte growing could be confirmed. Moreover, salt-affected soils, especially, sodic soils are ameliorated by the provision of a readily available source of Ca^{2+} to replace excess Na^+ on the cation exchange complex. The displaced Na is leached from the root zone through the application of excess irrigation water.

3.2. Plant analysis

The height and diameter of stem of four halophytes after four months were measured (**Figs. 2 and 3**). In Figures 2 and 3, the measurement results in normal soil (CK) (CEC = 73.0cmol/kg, ESP = 8.2%) were added to results of halophyte A, B, and C. The height and diameter of stem of A in pot test was lower and smaller than that of CK. In the case of C, the height and diameter of stem was higher and bigger than that of CK. In halophyte B, the height was almost the same value, but the stem diameter increased with the increase of soil EC. Therefore, the growth of *Limonium bicolor* K. (B) accelerates with the increase of salt concentration and has the possibility of absorbing salts in soil.

The correlation coefficients of Na and K concentration in halophyte with the diameter of stem were significant (**Figs.** 3 and **4**): 0.809** and 0.836**, respectively (P values < 0.05*, 0.01**).

4. Conclusion

Four halophytes were effective for amelioration the salt-affected soil that contains much salt and confirmed the good correlation between the growth of halophytes and Na and K content in halophytes. Moreover, we propose the new soil amelioration method to add desulfurization gypsum to soil after

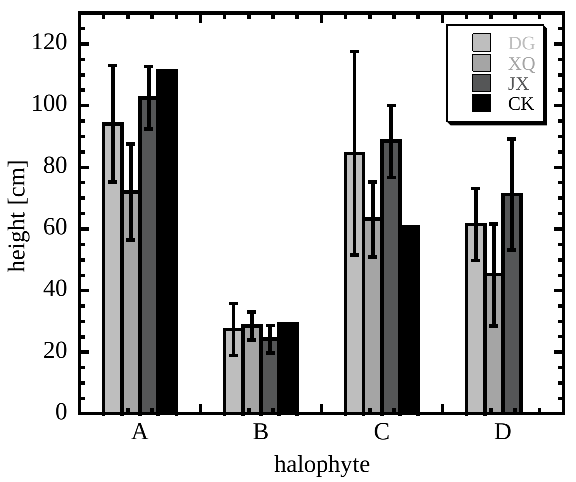

Fig. 2. Comparison of the height of halophytes after the growth.

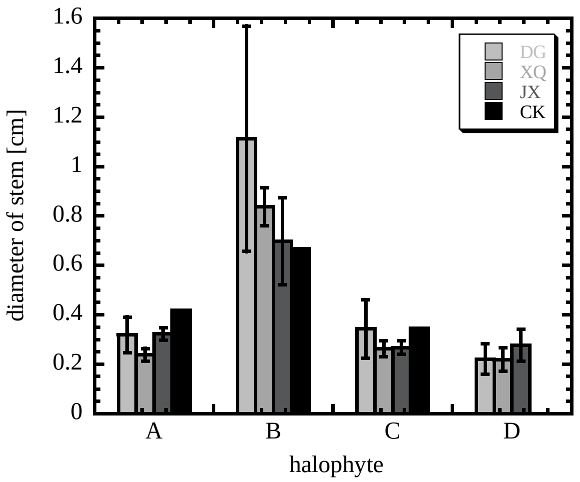

Fig. 3. Comparison of the diameter of stem of halophytes after the growth.

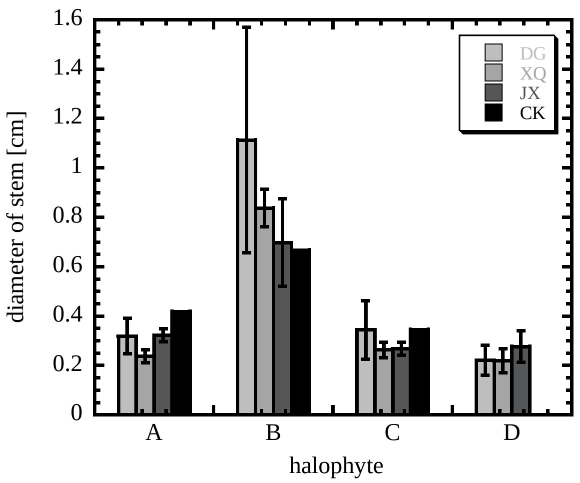

Fig. 4. Concentrations of Na and K in four halophytes after the growth.

phytodesalinization because of both high pH and high ESP after treatment.

References

Ban Q., Liu G., Wang Y. (2011): A DREB gene from Limonium bicolor mediates molecular and physiological responses to copper stress in transgenic tobacco. *J. Plant Physiol.*, **168**: 449–458

Bouchereau A., Duhazĕıa C., Martin-Tanguya J., Guĕıganb J.P., Larher F. (1999): Improved analytical methods for determination of nitrogenous stress metabolites occurring in Limonium species. *J. Chromatogr. A*, **836**: 209–221

Duart N.M., Corré W.J. (2003): *Development of sustainable vegetable production in Tianjin (China): report of a monitoring study*. Plant Research International B.V., Wageningen

Ghassemi F., Jakeman A.J., Nix H.A. (1995): *Salinisation of Land and Water Resources: Human Causes, Extent, Management and Case Studies.* CABI Publishing, Wallingford, United Kingdom.

Keiffer C.H., Ungar I.A. (2002): Germination and establishment of halophytes on brine-affected soils. *J. Appl. Ecol.*, **39**: 402-415

National Bureau of Statistics of China, (2006); *China Statistical Yearbook*. China Statistical Press

Qadir M., Oster J.D. (2004): Crop and irrigation management strategies for saline sodic soils and waters aimed at environmentally sustainable agriculture. *Sci.Total Environ.*, **323**: 1-19

Rengasamy P. (2010): Soil processes affecting crop production in salt affected soils. *Funct. Plant Biol.*, **37**: 613-620

Sakai Y., Matsumoto S., Sakadata M. (2004): Alkali soil reclamation with flue gas desulfurization gypsum in China and assessment of metal content in corn grains. *Soil Sediment Contam.*, **13**: 65-80

Sakai Y., Liu D., Sakadata M. (2007): Continuity Assessment of Desulfurization Gypsum as an Alkali Soil Amendment in Northeastern China. *Journal of Ecotechnology Research*, **13**: 127-131

Sakai Y., Aihara T., Yamamoto T., Sakadata M. (2010): Evaluation of Soil Properties and Additional Application of Desulfurization Gypsum in an Area of No Amelioration after an Initial Application in Sodic Soil of China. *Kagaku Kogaku Ronbun.*, **36**: 275-280

Szabolcs I. (1989): *Salt-affected soils*. Boca Raton, FL, USA: CRC Press.

Szabolcs I. (1994): Soils and salinization. *In* Pessarakli M. Eds., *Handbook of Plant and Crop Stress, 1st edition*, Marcel Dekker, New York. 3-11

Wang Z.Q. (1993): Saline Soil in China, Science Press, Beijing

Zhang Z.P., Hirota S. (Eds) (2000): *Chinese Colored Weed Illustrated Book*. Institute for the Control of Agrochemicals, Ministry of Agriculture, P.R.China, and the Japan Association For Advancement of Phyto-Regulators.

Zhao K, Fan H, Ungar I.A. (2002): Survey of halophyte species in China. *Plant Sci.*, **163**: 491-498

Zhao K.F., Fan H., Song J., Sun M.X., Wang B.Z., Zhang S.Q., Ungar I.A. (2005): Two Na^+ and Cl^- hyperaccumulators of the Chenopodiaceae. *J. Integr. Plant Biol.*, **47**: 311-318

Zheng X., Deng C., Song G., Hu Y. (2004): Comparison of Essential Oil Composition of Artemisia argyi Leaves at Different Collection Times by Headspace Solid-Phase Microextraction and Gas Chromatography-Mass Spectrometry. *Chromatographia*, **59** (11/12): 729-732