Remediation of saline soil using Apocynum Lancifolium and Chenopodium Album

Mukhamadkhan Khamidov
Tashkent Institute of Irrigation and Agricultural Mechanization Engineers

J. Beltrão
Universidade do Algarve

Apocynum Lancifolium and *Chenopodium Album* - Potential Species to Remediate Saline Soils

A. HAMIDOV[1], J. BELTRAO[2], A. NEVES[2], V. KHAYDAROVA[3], M. KHAMIDOV[4]

[1] Water Resources Management Department
Research Institute of Market Reforms of Uzbekistan
28 Avenue Halklar Dustligi, 700029 Tashkent
UZBEKISTAN
a_hamidov@yahoo.com

[2] Faculty of Engineering of Natural Resources (FERN)
University of Algarve
Campus de Gambelas, 8000-139 Faro
PORTUGAL
jbeltrao@ualg.pt maneves@ualg.pt

[3] Water Resources Department
Uzbek State Uzgipromeliovodhoz Institute
44 Navoiy street, 700011 Tashkent
UZBEKISTAN
khaydar@glb.net

[4] Faculty of Hydro-amelioration
Tashkent Institute of Irrigation and Melioration
39 Kary Niyaziy street, 700000 Tashkent
UZBEKISTAN
khamidov_m@mail.ru

Abstract: In semi-arid areas of Uzbekistan, rainfall is so scarce that irrigated agriculture is carried out by diverting Amudarya and Syrdarya rivers to farming areas. However, mismanagement of these water resources over the past forty years has threatened agricultural productivity. An elevated groundwater table associated with long-term irrigation and inappropriate drainage infrastructures have resulted in secondary soil salinization and major waterlogging problems. Rehabilitation of these salinized lands by means of installation of appropriate drainage infrastructures requires major financial investments. The potential capacity of *Chenopodium album* and *Apocynum lancifolium*, native naturally grown wild species, have been evaluated to its removal of ions from the salt-affected soils of Khorezm Region, northwest of Uzbekistan. Soil agro-physical and agro-chemical properties were determined to characterize the soil profile in the study area. Salt removal capacity and plant yield were determined. The results of investigation have clearly indicated that *Chenopodium album* produced the highest dry biomass 3.25 tons ha^{-1} and accumulated highest 569.6 kg ha^{-1} of salt. Hence, it can be used to rehabilitate salt-affected soils since this technique is low cost and could be used by farmers. Although, *Apocynum lancifolium* was developed in high saline soils, but had removed very low amount of salts and thus, can be considered as a salt-tolerant but not a salt-removing species.

Key-Words: Soil salinity, salt extraction, halophytic wild plants, phytoremediation, environmental pollution, crop yield

1 Introduction

Uzbekistan is one of the countries in Central Asia which is most heavily dependent on irrigated agriculture. The contribution of agriculture to the national economy is 24.1% of Gross National Product (GNP), 60% of foreign exchange receipts, and 45% of total employment [1]. The total land area of Uzbekistan amounts to 44.7 million hectares, of which 4.3 million hectares are potentially suitable for irrigation [2].

The most serious threat to agricultural production and ecosystem safety in the north of Uzbekistan is high salt accumulation to the soil. This has mostly resulted due to mismanagement of water and land resources over the last forty years [3]. Elevated water tables associated with the long-term irrigation and poor drainage systems have led to secondary salinization of crop lands and major waterlogging problems resulting in significant declining of cotton and wheat productions – dominant crops throughout the country [4]. When soils become highly saline, farmers tend to abandon the salt-affected fields resulting in large tracks of saline/waterlogged soils.

Khorezm region belongs to a semi-arid area which is badly affected by soil salinity of which the main causes are the geographical proximity to the ecologically degraded Aral Sea, poor irrigation management and inappropriate drainage infrastructures. In this region, soil salinity is controlled by leaching of the soil with extra freshwater resources. Annually, about 4300 m^3 ha^{-1} of water is applied for leaching on 85% of the irrigated land in Khorezm [5]. However, the intense use of this leaching technique attracted public awareness of environmental pollution and the impact on aquifers. Application of huge amounts of water to wash the salts from the soil in Khorezm led to raise the groundwater level near the surface resulting in large amount of salts moving from the lower soil strata to the surface layers [6]. Consequently, this strategy increases the risk of resalinization in the root zone [7]. As a result, soil leaching process has to be repeated every cropping season in order to avoid build-up of high salt concentrations. Furthermore, after leaching, water runs into the drainage systems and when the salt-contaminated drainage water returns to the river, it has severe impact on the ecosystems of the river and wetlands [8]. It can be presumed that drainage water contains not only salt but also pesticide residue, fertilizers, defoliants and other agrochemicals, which enter the rivers, destroys the fine balance of nature and deteriorates water quality in these water bodies.

There are several management practices to remediate the salinized soil and to maintain the sustainability of agricultural lands [9, 10, 11]. However, some of them are not suitable in local conditions because of economical and practical difficulties. The best way to avoid salinization and to maximize agricultural crop productivity in the salt-affected soils is to apply the environmentally safe and clean techniques. One of them is phytoremediation when the salt removing species are being used to remediate the saline soils and decontaminate the environment [12]. The ideal plant to remediate soil salts would be a high biomass producing crop that can not only tolerate to high salinity but also accumulate a high amount of salts [13]. One of the ways to select salt removing species is to assess native naturally grown halophytic species since the salt tolerance of a plant relates to its resistance and ability to grow under conditions of high winds, salt spray and infertile sandy soils.

The main aim of this study was to evaluate the potential capacity of *Chenopodium album* and *Apocynum lancifolium*, naturally grown wild species, to remove ions from the salt-affected soils of Khorezm Region and their productivity to create the highly productive fodder crops.

2 Materials and Methods

A field experiment was established in the Gurlan district, Khorezm Region, northwest part of Uzbekistan, in the lower reaches of Amudarya River (100 meters above sea level), which is the major water source for all water sectors in Khorezm. The region covers an area of about 6,100 km^2 and is spread between 40.49-41.97 N and 60.21-62.18 E of the Greenwich meridian, or about 245 km south of the remainder of the Aral Sea. The region is characterized by an extremely continental climate with long hot dry summers, infrequent rains in spring-autumn and very cold temperatures during winter. Annual precipitation of the region is estimated as 100-120 mm, which falls mostly outside of growing season in autumn-winter period (Fig. 1). The potential evapotranspiration is about 1,600 mm $year^{-1}$ and greatly exceeds rainfall [14]. Thus, large scale irrigation for cultivated crops is essential to this area.

The experiment was carried out during the summer, 2006 in the field that had been abandoned due to the high saline soils. During the experiment, maximum daily air temperature was 40^{o}C, while minimum was 7.7^{o}C. The hottest month of experimental period was July with average maximum air temperature of

34°C. Meanwhile, average monthly air relative humidity ranged from 38 to 47%.

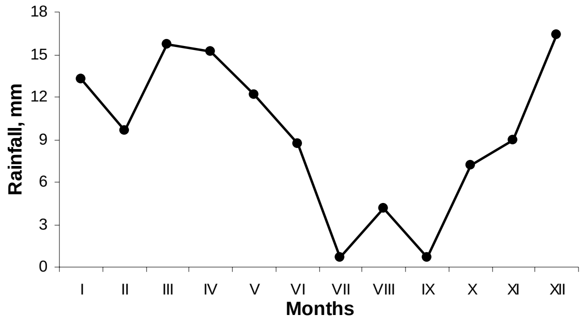

Fig. 1 - Average Monthly Precipitation for the Period of 2000-2006 in the Study Area (*Source:* Urgench Meteorological Station)

Chenopodium album (Fat Hen) belongs to the Chenopodiacea family and is a fast-growing, upright, and weedy annual species of goosefoot. While *Apocynum lancifolium* belongs to the Apocynaceae family and is a perennial shrub species that reaches to a height of 2 m.

The soil samples were taken from 5 soil layers (0-10, 10-20, 20-30, 30-40, 40-50 cm) to determine the general soil agro-physical and agro-chemical characteristics. To determine the salt removing capacity, the soil samples were taken from 3 soil layers (0-15, 15-30, 30-45) and were collected for each experimental field with different plant species. The samples were analyzed in the laboratory of Uzbek Research Institute of Cotton-Growing in Tashkent Region, Uzbekistan.

A whole plant was taken, plant fresh weight and height was measured, divided into shoots and roots, washed up with tap water and distilled water, oven dried at 70°C, re-weighed and ground. The plant ions were determined at the Campus of Gambelas of the University of Algarve, Portugal.

Specifically, the soil samples were air-dried and passed through a 2.0 mm sieve pores. Soil texture was determined according to the United States Department of Agriculture (USDA) soil texture triangle method. The soil salinity was determined according to the Machigin's (1963) method using an aqueous extract of the soil (ratio 1:5, i.e. 30 gram of air-dry soil and 150 mL of distilled water) [15]. This USSR classification of soil salinity, used in Central Asia, based on laboratory measurements of the Total Dissolved Solids (%), was converted according to FAO classification, in electrical conductivity of saturated soil extract (ECe).

The Kjeldahl digestion method was used for total nitrogen and the Machigin's method was applied to determine available phosphorous in the soil [16]. The total humus content was determined according to Turin's method using potassium chromate solutions [17].

Plant materials were extracted to measure chloride (Cl^-), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) concentrations. Chloride was extracted using cold water at room temperature (23-25°C), according to the procedure proposed by Drew and Saker (1984), whereas the cations were extracted by a dry-ash method at 550°C incinerator using a Thermolyne, Type 1500 Furnace [18, 19].

Sodium and potassium concentrations were quantified by flame photometry, while calcium and magnesium levels were measured by atomic absorption spectrophotometry using a Shimadzu, AA-680 model spectrometer. Chloride levels were determined in the aqueous extract by potentiometer using a Crison, pH meter GLP 22 with a selective chloride electrode (Mettler Toledo 302 ISE Reference Electrode) after extraction in cold water.

Statistical analyses were made with SPSS 14.0 for Windows (SPSS, 2005) computer program. One-way analyses of variance (ANOVA), least significant difference and Duncan's multiple-range tests ($P<0.05$) for comparison between mean values of three replicated chloride ions were conducted.

3 Results and Discussion

3.1 Soil Physical and Chemical Properties

General soil physical characteristics of the experimental site showed that the soils are partially stratified. According to the USDA classification [20], the topsoil layer (0-10 cm) was light loamy whereas the subsoil layers (10-50 cm) contained more sands, thus was classified as sandy loam. The bulk density averaged 1.60 g cm^{-3} within 0-50 cm soil depth.

It is known that the growth and development of crops depend on the availability of nitrogen, phosphorous and humus contents in the soil. The total nitrogen (*N*) in the soil, available phosphorous (P_2O_5) and humus content in the investigated field is displayed in Fig. 2. According to Krasnouhova's classification, available humus content in the investigated field is very low [21]. Meanwhile, total *N* and P_2O_5 were also very low in the experimental fields according to Musaev's classification [22].

The electrical conductivity of soil (ECe) mostly corresponded to the degree of salinity ranging between moderate and high according to classification of Abrol *et al.* [23]. Nevertheless, values above 10 dS m^{-1} have been observed (Table 1).

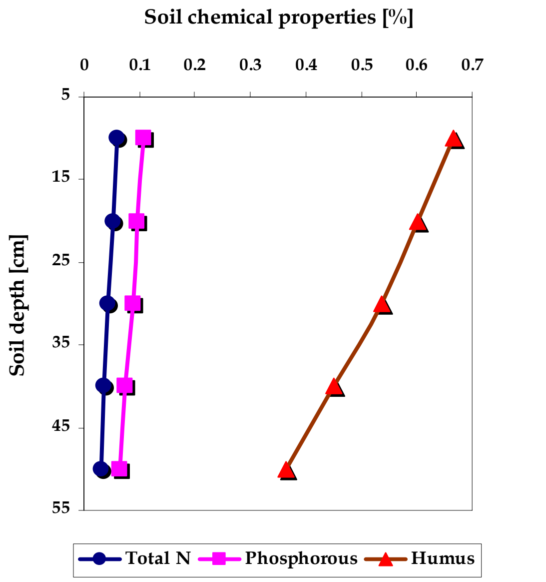

Fig. 2. Content of Total Nitrogen, Available Phosphorous and Humus in 0-50 cm soil depth

Such deviations towards a strong degree in soil salinity were more prominent for the *Apocynum lancifolium* field.

Table 1. Soil Salinity in the Experimental Field

Plant species	Soil depth, [cm]	*TDS*[1] *[%]*	FAO classification *ECe* [dS m^{-1}]
Chenopodium album	0-15 15-30 30-45	1.323 0.925 0.520	10.58 7.40 4.16
Apocynum lancifolium	0-15 15-30 30-45	1.650 1.425 1.362	13.20 11.40 10.90

[1]Total dissolved solid

It should be stated that due to accessibility and adequate quality of the groundwater resources, the plant species grown in soil with ECe levels over 10 dS m^{-1} did not show any visual symptoms of stress to soil salinity.

As it is known, high sodium concentration in the soil adversely affects to the development of plant roots. Moreover, high sodium can cause soil structure deterioration and water infiltration problems. Thus, sodium levels in soil were analyzed using Sodium Adsorption Ratio (SAR) equation [24]. Here, sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) ion concentrations are given in milliequivalent per liter (meq L^{-1}).

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (1)$$

According to the results, SAR values in *Chenopodium album* soils averaged 1.37, while 6.83 in *Apocynum lancifolium* soils within 45 cm soil surface. Davis *et al.* (2006) pointed out that if the SAR value is above 13, sodium can cause problems for plants and soils. In this study, the SAR values were below 13 and no significant sodium effect was observed [25].

3.2 Crop Yield and Vegetative Growth

Results related to quantitative yield have shown that *Chenopodium album* had the highest biomass production as to comparing to *Apocynum lancifolium* (Fig. 3). The yield of *Chenopodium album* was 3.25, while *Apocynum lancifolium* had 1.84 t ha^{-1} (dry matter) at harvest time.

Furthermore, the analysis of plant height data revealed that *Chenopodium album* stem height reached a mean value of 0.82 m at the harvest time while a mean root length was 0.25 m. The stem length of *Apocynum lancifolium* was like the *Chenopodium album*, i.e. 0.85 m, but the root length was longer about 0.55 m.

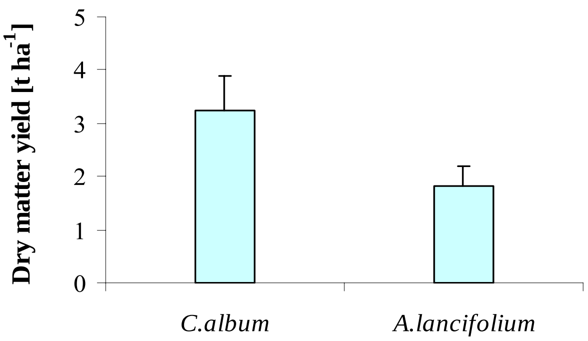

Fig. 3 - Dry Matter Yield for Investigated Plants in Khorezm Region

3.3 Salt Extraction

Capacity of the wild plants to remove chloride, sodium, magnesium, calcium and potassium ions is shown in Fig. 4. It is clear from the figure that *Chenopodium album* is the most effective in removing chloride ions from the soil of experimental fields. According to the results, *Chenopodium album* have removed up to 105 (±3.99) mg g^{-1}, while *Apocynum lancifolium* up to

49 (±2.47) mg g^{-1} dry matters of chloride ions. Moreover, sodium extraction was also higher in *Chenopodium album* averaged 33.6, whereas *Apocynum lancifolium* removed only 12.1 mg g^{-1} dry matter. Potassium and magnesium concentrations were higher in the *Chenopodium album* tissues, while calcium concentration was higher in *Apocynum lancifolium* plant tissues.

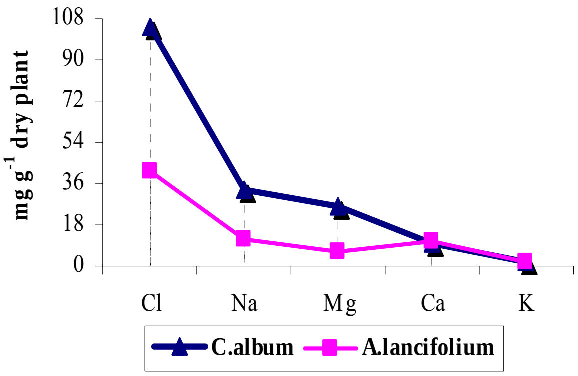

Fig. 4 – Salt (Cl^-, Mg^{2+}, Ca^{2+}, Na^+, K^+) Contents in the Tissues of Wild Plants

The data have also revealed that *Chenopodium album* was the most efficient wild plant in removing total ions, which eventually accumulated 569.6 kg ha^{-1} and removed 1.47% of salts from the soil. The root depth was about 0.25-0.30 m, thus, it can only remove the salts within that profile (Table 2). On the other hand, *Apocynum lancifolium* was the least efficient wild species in removing soil salts. The tissues of *Apocynum lancifolium* accumulated 130.3 kg ha^{-1} and eventually it removed 0.12% of total ions within 0.55 cm soil depth.

Table 2. The Potential Capacity of Wild Species to Remove Soil Salts

Plants	Root depth [m]	Salt extraction [kg ha^{-1}]	Soil salt removal [%]
C.album	0.25	569.6	1.47
A.lancifolium	0.55	130.3	0.12

It is interesting to note that *Apocynum lancifolium* was developed in high saline soils but had removed very low amount of salts, and thus can be considered as a salt-tolerant but not a salt removal species. In contrary to that, *Chenopodium album* was developed in relatively low saline soils but had extracted the highest amount of salts from the soil and therefore, can be considered as a potential salt removal species.

4 Conclusions

It can be concluded that:

- salt-affected soils of Khorezm region has very low nutritional balance;
- native plants are highly adapted to the local climatic and edaphic conditions;
- *Chenopodium album* and *Apocynum lancifolium* have different capacities in removing chloride, sodium, magnesium, calcium, and potassium ions from soil;
- the most efficient wild species in removing total soluble salts was *Chenopodium album*;
- *Apocynum lancifolium* can be used as a salt-tolerant species but is not effective as a salt-removal species;
- *Chenopodium album* can be used for salt removing on the salt-affected soils and can also be incorporated into crop rotation programme

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