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"SALT REMOVING SPECIES – PHYTOREMEDIATION TECHNIQUE FOR UZBEKISTAN"

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This Master Thesis is dedicated to

Uzbekistan's Agriculture:

- hoping that this work could be a tool used for
  soil remediation research plans and crop management decisions
- expecting that further portuguese-uzbekistan projects
  can contribute to mitigating soil salinity and to maximizing crop yield profits

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RESUMO

As tecnicas convencionais para o controlo da salinidade do solo, nomeadamente a lixiviação do solo e o aumento da fertilização, são métodos usados para diminuir a salinidade do solo e aumentar a tolerância das culturas que se desenvolvem em solos salinos. Contudo, o uso intensivo destas tecnicas tem chamado a atenção pública para o problema da contaminação ambiental devido à salinização de camadas mais profundas do solo e dos aquíferos. Recentemente surgiu uma nova tecnica limpa e amientalmente útil, em que espécies removedoras de sal (iões) são plantadas ou semeadas nos solos salinos e têm sido utilizadas para remover o sal dos solos. A capacidade de remoção de sal de *Portulaca oleracea* Golden Purslane e sete plantas natives locais - *Tamarix hispida, Apocynum lancifolium, Glycyrrhiza glabra, Portulaca oleracea* Green Purslane, *Alhagi pseudalhagi, Karelinia caspia,* e *Chenopodium album* foram testadas neste estudo. Os ensaios de campo foram efectuados na região Khoresm, no norte do Uzbequistão, durante o Verão, o período mais sensível para os solos salinos. . A *Portulaca oleracea* golden purslane foi semeada em dois solos salinos diferentes, um deles regado e o outro de sequeiro. A colheita foi realizada duas vezes, ao longo da fase de crescimento e na da fase de frutificação da . *Portulaca oleracea* golden purslane. Os resultados mostraram que a cultura de sequeiro removeu uma quantidade mais alta de sais e a sua produção foi superior. Isto deve-se à ascensão da água capilar, que resultou numa contribuição significativa para as necessidades hídricas das plantas, aumentando a sua transpiração. A maxima remoção de sal variou de 496.6 a 511.3 kg ha^{-1} na fase de crescimento e na fase de frutificação da *Portulaca oleracea*, que eventualmente removeu cerca de 16.8 % do total de sais no solo, a 10 cm de profundidade. A mais eficiente planta nativa na remoção de sal foi a *C.album.* Esta planta removeu 538.4 a 596.6 kg ha^{-1} na fase de crescimento e na fase de frutificação, a uma profundidade de 25 cm, respectivamente, Este estudo mostrou que a *Portulaca oleracea* golden purslane (maior quantdade de sais) e a *Chenpodium album* (extracção mais profunda de sais) podem vir a ser potenciais espécies usadas para controlar e combater a salinidade nas regiões do norte do Uzbequistão e poderão também vir a ser integradas nos programas de cultivo e de rotação na para a remediação dos solos salinos.

Palavra-chaves: Salinização do solo, fitoremediação, espécise removedoras de sal, tecnicas convencionais, tecnicas limpas.

ABSTRACT

Conventional techniques, namely soil leaching and the use of enhancing fertilization are methods used to mitigate soil salinity and to increase the salt tolerance of agricultural crops grown in salt-affected soils. However, the intensive use of these techniques has also attracted public attention due to the environmental pollution caused and the contamination of groundwater resources. Recently, a new environmentally safe and clean remediation technique, whereby salt (ion) removing species are planted in the salt-affected soils, has been introduced to address salinity problems. The salt removal potential of *Portulaca oleracea* Golden Purslane and seven native naturally grown wild plants - *Tamarix hispida, Apocynum lancifolium, Glycyrrhiza glabra, Portulaca oleracea* Green Purslane, *Alhagi pseudalhagi, Karelinia caspia,* and *Chenopodium album* have been evaluated under this study. The field experiments were carried out in the Khorezm Region, in the northwest of Uzbekistan, during the summer, the most sensitive period for salt-affected soils. *Portulaca oleracea* golden purslane was planted in two different salt-affected soils, one field with irrigation and one without irrigation. The harvest was twice, in the developing and seedling stages of *Portulaca oleracea* golden purslane. The results have revealed that no irrigation was required to remove the highest soil salts and to obtain the highest biomass in *Portulaca oleracea* golden purslane. The capillary rise from groundwater played a significant role in meeting the demand of plants for water, increasing plant transpiration. The highest salt accumulation varied from 496.6 up to 511.3 kg ha^{-1} in the developing and seedling phases of *Portulaca oleracea*, which eventually, removed about 16.8 % of the total soil salts, at a depth of 10 cm. The most efficient wild plant in removing salts from the soil was *C.album.* This plant removed 538.4 up to 596.6 kg ha^{-1} at a depth of 25 cm, in the developing and seedling stages, respectively. The study indicated that *Portulaca oleracea* golden purslane (higher amount of salts) and *Chenopodium album* (deeper salts extraction) could become potential species used to control and to combat salinity in the northern part of Uzbekistan and could also be integrated into cultivation/rotation programmes to remediate saline soils.

Keywords: Soil salination, phytoremediation, salt removing species, conventional techniques, clean techniques.

OUTLINE OF THE THESIS

This thesis is structured into five sections. Firstly, a general introduction describing the background to agriculture in Uzbekistan, soil salinity and the aims of this study. Following this general introduction, the second section provides a summary of previous investigations conducted by other scientists on conventional and phytoremediation techniques used throughout the world to address soil salinity as well as in Uzbekistan. The aim is to facilitate understanding of the whole concept of salt removal species. Section 3 presents and discusses the geographical, climatic and other key characteristics of a field study in the Khorezm region of Uzbekistan. This section also describes the plantation of *Portulaca oleracea* golden purslane in two different salt-affected soils of the study region with two different irrigation practices to determine potential capacity to remove soil salts. Moreover, selection and analysis of native wild species are also explained in the current section. Section 4 provides details of the results obtained from the field experiments. Furthermore, biomass production and potential salt removal efficiencies of *P.oleracea* and other native naturally grown species are highlighted in this section. Section 5 provides overall conclusions and recommendations towards the remediation of soil salts in the northern part of Uzbekistan.

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I. General

P	Precipitation or rainfall (mm)
T	Air temperature (^{o}C)
RH	Air relative humidity (%)
ETp	Potential Evapotranspiration (mm) – sum of Evaporation from the soil and Transpiration from the crop
ECe	Electrical conductivity of soil solution at saturation point (dS m^{-1})
ECw	Electrical conductivity of water (dS m^{-1})
FAO	Food and Agriculture Organization of the United Nations (dimensionless)
GWT	Groundwater table (dimensionless)
UzRICG	Uzbek Research Institute of Cotton Growing (dimensionless)
DM	Dry matter (dimensionless)

II. Literature Review

RDI	Regulated deficit irrigation (dimensionless)
LR	Leaching requirement (dimensionless)
AW	Depth of irrigation water (mm $year^{-1}$)
ET	Total annual crop water demand (mm $year^{-1}$)
Yr	Relative crop yield (%)
b	Slope of relative yield (% per dS m^{-1})
a	Salinity threshold (dS m^{-1})
STI	Subsurface trickle irrigation (dimensionless)
kc	Water consumption rate (dimensionless)

III. Materials and Methods

K	Regional coefficient to calculate evapotranspiration (dimensionless)

B	Soil fraction weight (%)
P	Weight of appropriate soil fraction (g)
BD	Bulk density (g cm^{-3})
W	Soil sample weight (g)
C	Core sampler weight to measure bulk density (g)
V	Volume of core sampler (cm^3)
r	Core sampler radius (cm)
h	Core sampler height (cm)
A	Soil water content (%)
f	Infiltration rate (mm $hour^{-1}$)
Q	Cylinder water volume to compute infiltration rate (cm^3)
t	Time differences (min.)
S	Cylinder area (cm^2)
d	Cylinder diameter (cm)
m	Mass of soil (g)
θ_{wp}	Volumetric soil water content (m^3 m^{-3})
N	Total Nitrogen (%)
TDS	Total dissolved solids (%)
X	Ion contents in the soil (%)
E	Volume of water sample (mL)
M	Volume of soil+water sample solution (mL)
n	Molecular weight of ions (g mol^{-1})
a	Mass of beaker after water evaporated (g)
b	Tare weight of beaker (g)
L	Ion concentration (mg g^{-1})
F_c	Ion concentration given by atomic absorption spectrophotometry (mg L^{-1})
S_e	Extraction solution (L g^{-1})

III. Results and Discussions

SAR	Sodium adsorption ratio (dimensionless)
ESP	Exchangeable sodium percentage (%)

"The ground – is not only a huge property, but it is also a key factor of which this country depends".
I.A.KARIMOV
President of Republic of UZBEKISTAN

I - INTRODUCTION

Salinity stress is a key factor that limits crop production world-wide and is a constraint to economic development and to the environment. The economic impacts resulting from salinity are mainly associated with a decrease in the production capacity of land. The negative environmental impacts are most often the degradation of land, namely soil salination and groundwater contamination.

Soil salination is a major threat to the environment and is especially problematic where human interventions have disturbed natural ecosystems. Anthropogenic activities have increased soil salinity by changing the natural balance of the water cycle, by allowing excess recharging of groundwater and salt accumulation through its concentration (Justin Murphy, 1999). Moreover, groundwater contamination is also an important negative environmental impact, which is intensified by seawater intrusion in coastal zones (Ben Asher *et al.,* 2002).

With a land mass covering 447,400 square kilometer, Uzbekistan is one of the countries in Central Asia most heavily reliant on irrigated agriculture. The contribution of agriculture to the national economy is 24.1% of Gross National Product (GNP), 60% of foreign currency income, and 45% of employment (Uzgipromeliovodhoz, 2003). The total land area of Uzbekistan amounts to 44.7 million hectares of which 4.3 million hectares are potentially suitable for irrigation (Uzgipromeliovodhoz, 2003). Almost 85% of Uzbekistan's territory is covered by desert or semi-desert, including the largest desert in Central Asia, the

Kyzylkum Desert. The most serious threat to agricultural production and ecosystem safety in the north of Uzbekistan is high salt accumulation and secondary salinization of irrigated soil. This has mostly resulted due to the mis-management of water and land resources over the last forty years (Szabolcs, 1989). More than half of the 2.32 million hectares of irrigated land in Uzbekistan is salt-affected and the build-up salinity is seriously threatening agricultural productivity (ICARDA, 2002). Every year, 75 million tons of salt is spreading with a 1000 km radius and into other Central Asian countries (Shadimetov, 2006). The main causes for this are identified as the shrinking of the Aral Sea, seawater intrusion towards the land, long-term irrigation, inappropriate drainage systems and global climate changes.

Before the collapse of the Soviet Union in 1991, Uzbekistan was a major producer of cotton, which is one of the most salt-tolerant crops. In order to obtain an increasing amount of cotton, the country was using enormous amounts of water resources from the two main rivers – the Amudarya and the Syrdarya. These rivers supply the Aral Sea. Furthermore, farmers have been pursuing extensive agricultural development through the use of high levels of fertilizers and pesticides in order to increase crop productivity. The consequences of using enormous amounts of water resources and heavy application of chemicals has resulted in rising groundwater tables, salinization and the well-known ecological disaster around the Aral Sea (Toderich *et al.,* 2002). Moreover, low irrigation efficiencies – caused by unlined canals and a poor drainage networks – has led to major waterlogging and salinization that has now affected about 55 percent of irrigated land in the country (FAO, 1998).

Due to long-term irrigation and poor drainage systems, the salinity of irrigated areas in the northern part of Uzbekistan has amounted to 100 percent in the Khorezm region and to 94.3 percent in Karakalpakstan region (Uzgipromeliovodhoz, 2002).

The Khorezm region has been selected as the focus of this thesis study as it is one of the areas in Central Asia most strongly affected by secondary soil salinization. In this region, the dominant approaches adopted by farmers to mitigate salinity is to apply excessive amounts of water to salt-affected fields in order to leach the salts into the root zone allowing infiltration of salts to deeper layers. This approach has two potential outcomes – firstly, when there is an impermeable layer, salts are accumulated above this layer and secondly, when there is no impermeable layer, groundwater contamination can be observed (Ayers and Westcot, 1985; Ben Mechlia, 2002). When soils become highly saline, farmers tend to abandon the salt-affected fields resulting in large tracks of saline/waterlogged soils (Kushiev *et al.,* 2005).

An alternative approach used in the region to combat salinity and to maximize agricultural crop production is the heavy application of fertilizers; in this case the tolerance of plants to saline conditions is increased, but contamination by hazardous chemicals will also be increased due to the higher amount of fertilizers applied (Beltrao *et al*., 2002).

It was reported by World Bank that annually significant irrigated land is taken out of crop production due to salinization. The rehabilitation of these salinised areas requires major technical expertise and financial investment. The rehabilitation cost has been assessed by the World Bank to be more than USD $ 3 billion (World Bank, 2003).

In recent years, a new environmentally safe and clean technique known as phytoremediation has been introduced to address the salinity problem. This includes the introduction of salt (ion) removing species to control salinity and to maintain the

sustainability of landscapes and agricultural fields (Cuartero *et al.,* 2002; Shaaban & El Fourly, 2002). Phytoremediation is defined as the use of plants to remove pollutants from the environment and to render them harmless (Salt *et al.,* 1998). Large-scale decontamination of soils and underground water using phytoremediation techniques requires plants with high salt uptake rates, large biomass and tolerance to a wide array of environmental conditions and constraints. Moreover, the creation of highly productive fodder systems[1] through the establishment of palatable halophytes[2] has been shown to remediate saline/sodic soils[3] as well as provide an income resource to poor farmers (Hyder, 1981; Helalia *et al.,* 1992; Dagar *et al.,* 2004).

The best way 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, alkaline soils and infertile sandy soils. In addition, the use of halophytes has great potential for landscaping and building greenification[4] in high saline areas.

The main aim of this work is to develop recommendations for soil remediation for the northern region of Uzbekistan and to rehabilitate salt-affected soils using phytoremediation techniques. The specific research objectives are as follows:

- to evaluate *Portulaca oleracea* golden purslane in the salt-affected soils of northern Uzbekistan for its ability to remove salts;

[1] Any plants and crops that is used specifically to feed livestock, such as cattle, sheep, horses and chickens
[2] Salt tolerant species that have a good enough taste to be eaten or drunk
[3] A nonsaline soil containing sufficient exchangeable sodium (Na^+) to adversely affect crop production and soil structure under most conditions of soil and plant type. The sodium adsorption ratio of the saturation extract (SAR_e) is at least 13
[4] Beautify and sustain the nature with plants

- to identify the most suitable native plants for removing salts from the soil based on the morphological and physiological characteristics of the plants including dry matter production and ability to adapt to saline environments;
- to determine the amounts of salts (ions) accumulated by salt removing species;
- to improve the conventional techniques of soil in the local conditions of Uzbekistan; and
- to combine the new clean techniques with the old conventional techniques in order to establish the best balance between economical, environmental and social aspects, improving the sustainability of the ecosystem.

II – LITERATURE REVIEW

Soil salinity is of common occurrence in arid and semi-arid zones wherever irrigated agriculture has been practiced. According to several reports, there is a total area of 987.5 million hectares in the world occupied by problematic soils, and around 322.9 million hectares are considered as saline and sodic soils (Brinkman, 1980). As an example of this problem, Szabolcs (1989) reported that 10 percent of the world's arable land is on saline alkali soils. Soil salinization is a major problem in Uzbekistan and consequently, irrigated area is being tremendously damaged.

Broadly, many international researches indicated that salinity management can be considered in a two stage process: 1) Use of conventional techniques – soil leaching, combination of salts and fertilizers, subsurface trickle irrigation, and salt tolerant species, and 2) Application of new clean and environmentally useful techniques – salt removing species, drought tolerant crops and regulated deficit irrigation.

II.1 – Conventional Techniques

II.1.1 - Soil Leaching

Leaching is practiced for reclamation and for maintaining salt balance in the soil by irrigation water application (Pereira, *et al.,* 1996). Moreover, Gupta and Chandra (1972) stated that due to world shortages of freshwater, saving in freshwater can be achieved by performing part of the leaching with saline water which is less saline than the soil to be leached. Thus, it is important to establish the threshold salinities of water draining from the root zone to determine leaching requirements. Meanwhile, to estimate leaching requirements, both the irrigation water salinity (ECw) and the crop tolerance to soil salinity

(ECe) should be known, which can be estimated in the laboratory conditions. The necessary leaching requirement (LR) can be estimated for a particular crop by using the following equation (Rhoades, 1974; and Rhoades & Merill, 1976):

$$LR = \frac{ECw}{5 * (ECe) - ECw} \qquad \text{(II.1)}$$

where: LR - the minimum leaching requirement needed to control salts within the tolerance (ECe) of the crop with ordinary surface methods of irrigation

ECw - salinity of the applied irrigation water in dS m^{-1}

ECe - average soil salinity tolerated by the crop as measured on a soil saturation extract (dS m^{-1})

Moreover, the total annual depth of water that needs to be applied to meet both the crop demand and leaching requirement should be identified. The following equation can be used for that:

$$AW = \frac{ET}{1 - LR} \qquad \text{(II.2)}$$

where: AW - depth of applied water (mm $year^{-1}$)

ET - total annual crop water demand (mm $year^{-1}$)

LR - leaching requirement

In general, soil salinity in many other regions of Uzbekistan as well as in the study region is controlled by leaching of the soil with extra freshwater since the study region is highly affected by salinity (Fig. II.1). Djanibekov (2005) pointed out that on average, 4300 m^3 ha^{-1} of water is applied for leaching on 85 % of the irrigated land in Khorezm. However, intense use of this leaching technique attracted public awareness of environmental pollution and the impact on

Fig II.1 - Salinity Control by Leaching in the Experimental Field

aquifers. For instance, UKPC (2002) mentioned that 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. Consequently, this strategy increases the risk of resalinization in the root zone. As a result, soil leaching process has to be repeated every cropping season in order to avoid build-up of high salt concentration.

Furthermore, after leaching, water runs into the drainage systems and when the salt-contaminated drainage water returns to the Amudarya River, it has severe impact on the ecosystems of the river and wetlands. 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.

II.1.2 - Combination of Salts and Fertilizers

The application of fertilizers, namely nitrogen (N) and phosphorus (P) has become an alternative approach for farmers to combat soil salinity and to maximize agricultural crop production. Enhanced fertilization leads to increase of plant salinity tolerance.

Initially, Mass and Hoffman (1977) proposed that the effect of salinity on yield could be described with a piece-wise linear response function characterized by a salinity "threshold" value below which the yield is unaffected by soil salinity and above which yield decreases linearly as salt concentrations increase (Fig. II.2). Later on, Beltrao *et al.* (2002) have modeled the combined effects of salts and nitrogen (N) on the crop yield function and proved that tolerance (threshold salinity value) for N_1 is lower than for N_2, which means that relative yield maintains constant at 100% until C for N_1 and D for N_2 (Fig. II.3). On the

other hand, sensitivity (rate of yield reduction per unit of salinity) is larger for N_1 than for N_2, which interprets with the higher values of the salinity threshold, the relative yield decreases sharply until zero.

In addition, Mass and Hoffman (1977) proposed that relative crop yield Yr (%) for any given soil salinity exceeding the threshold could be calculated according to the following formula:

$$Yr = 100 - b(ECe - a) \qquad \text{(II.3)}$$

where: b - the slope represents the crop sensitivity (yield losses per unit increase of electrical conductivity).

a - the salinity threshold value (crop tolerance, expressed in dS m^{-1}).

ECe – the mean electrical conductivity of the saturated soil extract of root zone.

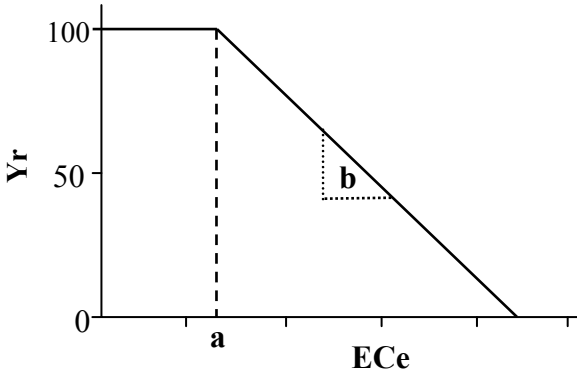

Fig. II.2 - Crop Relative Yield Affected by the Salinity of the Soil (Mass and Hoffman, 1977)

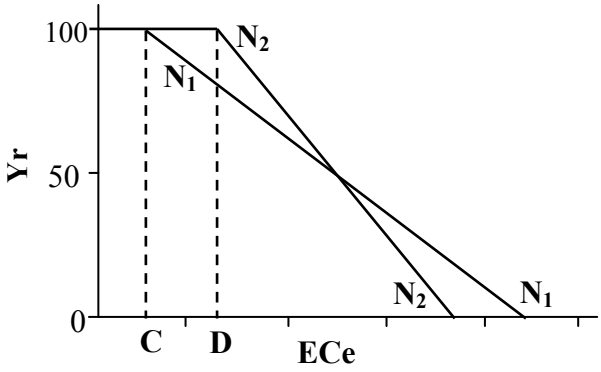

Fig. II.3 - Relative Yield Response to the Combined Effects of Salinity and Nitrogen (Beltrao *et al.,* 2002)

In addition, Achilea (2002) stated that constant application of potassium nitrate is an efficient method of preventing salinity-induced stresses in many crops. However, one of the main negative consequences of enhanced fertilization to mitigate soil salinity is to increase of environmental contamination through chemical hazards (Beltrao & Ben Asher, 1997).

II.1.3 - Subsurface Trickle Irrigation

The interest in subsurface trickle irrigation (STI) has increased significantly in recent decades primarily due to increased pressure to conserve water resources and to control

salinity. This conventional technique, the application of water below the soil surface through emitters, allows for the direct application of water into the plant root-zones achieving more manageable, balanced water distribution throughout a relative shallow soil profile, hence minimizing potential groundwater depletion (Gushiken, 1995). Furthermore, STI reduces losses to evaporation from the soil surface, economizes water resources, and less additional salts will be used. Lamm (2002) highlighted that STI technique is also useful for controlling weeds and the enhancement of plant growth, crop yield and quality.

However, Oron and Beltrao (1993) pointed out that the problem of groundwater contamination due to natural rain or artificial leaching remains. In addition, Lamm (2002) pointed out that SDI may restrict plant root development and tillage operation may also be limited by dripline placement.

II.1.4 - Salt Tolerant Species

In most developing countries, due to the expansion of population, fertile soils and fresh water resources are becoming insufficient. Besides, Shay (1990) mentioned that saline soil areas are continuously increasing throughout the world. About over 2 million hectares are affected by salinity in Uzbekistan. For the Solonchak soils to achieve economically viable and environmentally non-degradable land, many scientists have proposed to use salt tolerant species. The use of salt tolerant species, or halophytes, has great potential for landscaping and building greenification in the salt affected soils. Meanwhile, Lieth *et al.* (1997) stated that a number of halophytes are also useful for food, feed and ornamental purposes. Black (2004) pointed out that salt tolerant species have the ability to resist and grow under high winds, salt spray, alkaline soils[9] and infertile, sandy soil conditions.

[9] Soil containing soluble salts of magnesium, calcium, sodium, or the like, and having a pH higher than 7. Commonly found in low-rainfall regions.

In addition, Akjigitova (1981) and Hinsinger (1998) highlighted that halophytic plants are capable of producing high biomass production under saline conditions.

Mass and Hoffman (1977) divided the crops into four salinity rating groups: **sensitive, moderately sensitive, moderately tolerant** and **tolerant** (Table II.1).

Table II.1 - Threshold and Zero Yield Salinity Levels for four Salinity Groups

Salinity rating	**Threshold salinity dS m^{-1}**	**Zero Yield level dS m^{-1}**
Sensitive	1.4	8.0
Moderately sensitive	3.0	16.0
Moderately tolerant	6.0	24.0
Tolerant	10.0	32.0

Moreover, they described salinity groups by plotting its relative yield as a continuous function of average rootzone salinity ECe (Fig. II.4).

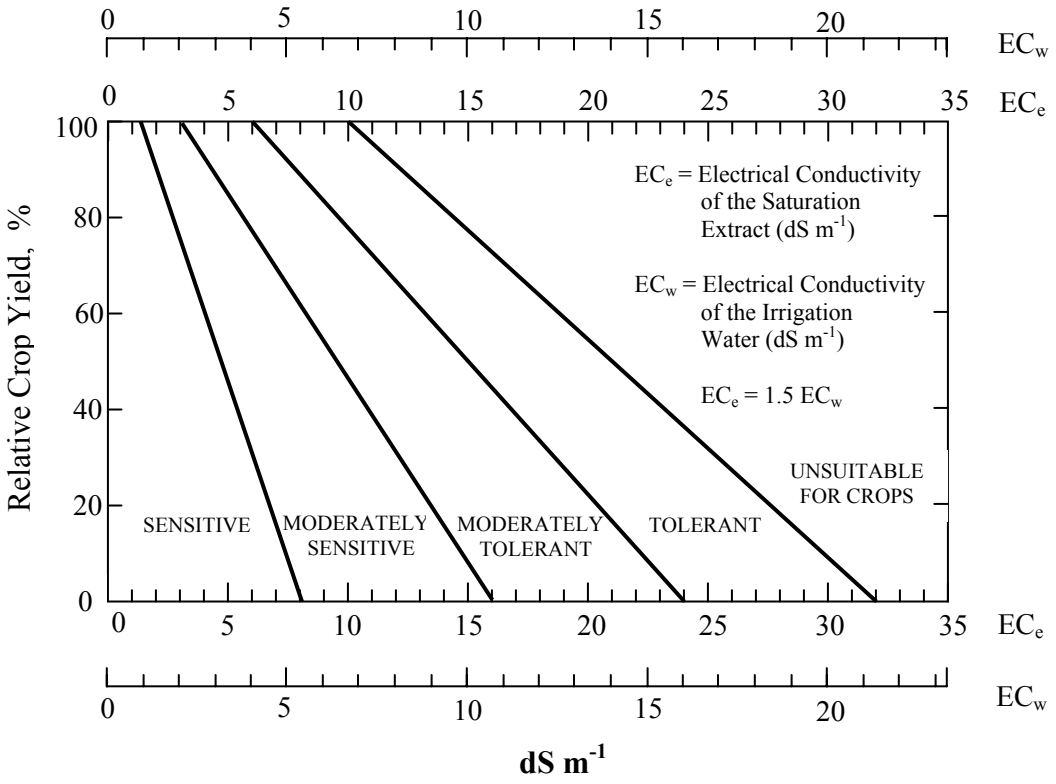

Fig. II.4 - Response of Relative Crop Yield (or Yield Potential) as a Function of Average Rootzone Salinity (ECe) Grouped According Relative Tolerance or Sensitivity to Salinity (Ayers & Westcot, 1985)

As seen, the use of salt tolerant species is a useful technique to combat with salinity in the salt-affected zones. However, Hamdy (2002) highlighted that it does not solve the problem of soil salinity and groundwater contamination.

II.2 - Clean and Environmentally Useful Techniques

II.2.1 - Salt Removing Species

Phytoremediation – salt removing species have become the best technique to remediate saline soils and decontaminate the environment (Anac *et al.,* 2005). Ebbs and Kochian (1997) pointed out that the ideal plant to remediate salt affected soils would be a high biomass producing crop that can not only tolerate but also accumulate the salts. High salt uptake species potentially could be integrated into cultivation/rotation programmes.

In recent years, Matjanova (1999) and Davletmuradova (2002) investigated naturally grown wild desert plants in Karakalpakstan (north of Uzbekistan) as potential salt removing species and proposed dividing them into five categories according to their halo-adaptation and halo-tolerance: hyper-halophytes (may accumulate 21-29 % of soluble salts from soil), euhalophytes (12 - 13 %), hemi-halophytes (10.2 - 10.9 %), halo-glycophytes (6.2 – 8.3 %) and glycophytes (3.6 – 5.1 %). However, the main concern of their research was ontogenetic[10] aspects of the wild species.

In general, this new technique to mitigate salinity is a powerful and environmentally clean tool to maintain the sustainability of the agricultural areas and landscapes (Neves *et al.,* 2005). However, there is lack of information regarding this technique, and, additional research is needed.

[10] Origin and development of individual plant species

II.2.2 - Drought Tolerant Species

Drought and high salinity are common stress conditions that adversely affect plant growth and crop production (Xiong *et al.,* 2002). In both cases, the ability of plants to take up water is restricted and this leads to reduction of growth rate. Moreover, as the global climate is rapidly changing towards longer dry seasons and infrequent rainfall, it is anticipated that such changes will affect water supply to the plants, especially in arid and semi-arid zones (Farooq & Azam, 2001). As Gassemi *et al.* (1995) pointed out, crop productivity in most of the areas has already been affected by salinity. Any further deterioration induced by drought might result in the collapse of agricultural systems. In recent years, many researchers stated that induction of drought tolerant species could potentially be the best method to avoid this.

Generally, "drought tolerant species" refers to plants which are associated with tolerance of water-deficit stress and well adapted to high temperatures and other abiotic stresses. Since they consume less water, naturally fewer salts will be infiltrated into the soil.

In reality, the most drought tolerant species are usually the plants native to the specific area. With the help of initiatives from the Ministry of Agriculture and Water Resources of Uzbekistan, drought tolerant species have been introduced into 500 hectares to afforest and to protect forest belts on the dried seafloor near the Aral Sea in the northern part of Uzbekistan.

II.2.3 - Deficit Irrigation

Intensive irrigation of agricultural crops with high level of water mineralization causes salts to accumulate in the root zones, which adversely affects the crop productivity. In order to reduce such negative impacts, a regulated deficit irrigation (RDI) technique was adopted to combat salinization in the arid and semi-arid environments by reducing the water application during certain growth stages of the crops (Cameron *et al.,* 2006). Furthermore, Ben Mechila (2002) pointed out that one way to control or at least to postpone salinization in horticulture is the use of RDI. He also mentions that development of small irrigation schemes in the saline soils could be the best way to manage the field properly. Occasional heavy rains may also help take salts from this small area to places where they can concentrate with a minimum effect on the natural resources. Meanwhile, Beltrao *et al.* (1999) proposed that RDI can be obtained in two cases: 1) decrease the amount of added salt by reducing irrigation water supply, which also improves agricultural productivity and, 2) apply minimal levels of water to obtain a good visual appearance (GVA) of the landscape.

The proper application of less water to the plants can generate significant savings in irrigation water allocation and apparently, less salts will be infiltrated (Kirda, 2000). Moreover, they classified some crops as tolerance to less irrigation water either throughout the growing season or at pre-determined growth stages taking into account yield response.

In addition, Costa *et al.* (2002) proved that application of minimal water level could be sufficient for some plants to obtain GVA of the landscape. For instance, they analyzed Bermuda grass and obtained good visual appearance where crop coefficient kc > 1.7 (kc - represents water consumption rate), and kc > 0.6 when potable water irrigation + nitrogen

was used. Fig. II.5 expresses grass response by the absolute yield Y and the water consumption by the crop coefficient.

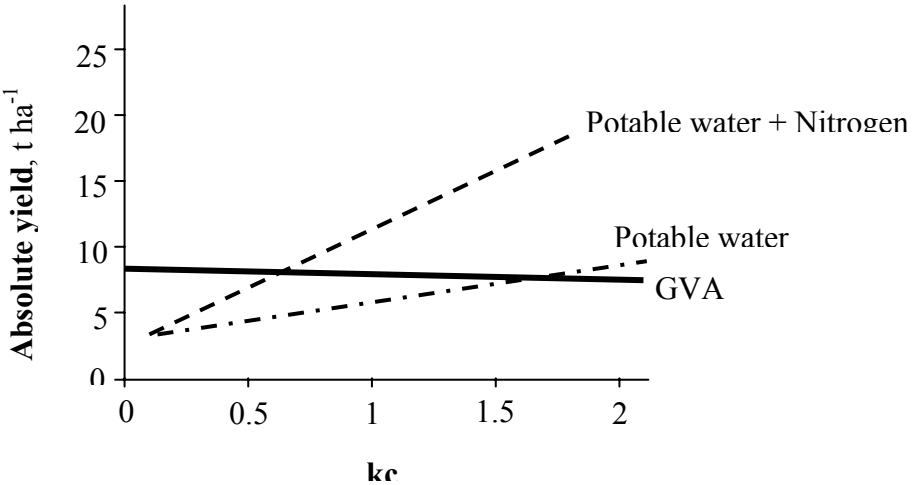

Fig. II.5 - Grass Response to Combined Effects of Potable Water Irrigation and Nitrogen Fertilization (Costa *et al.*, 2002)

III - MATERIALS AND METHODS

III.1 - Geographical Location

The study area is located 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 and 41.97 N and 60.21 and 62.18 E of the Greenwich meridian, or about 245 km south of the remainders of the Aral Sea (Fig. III.1).

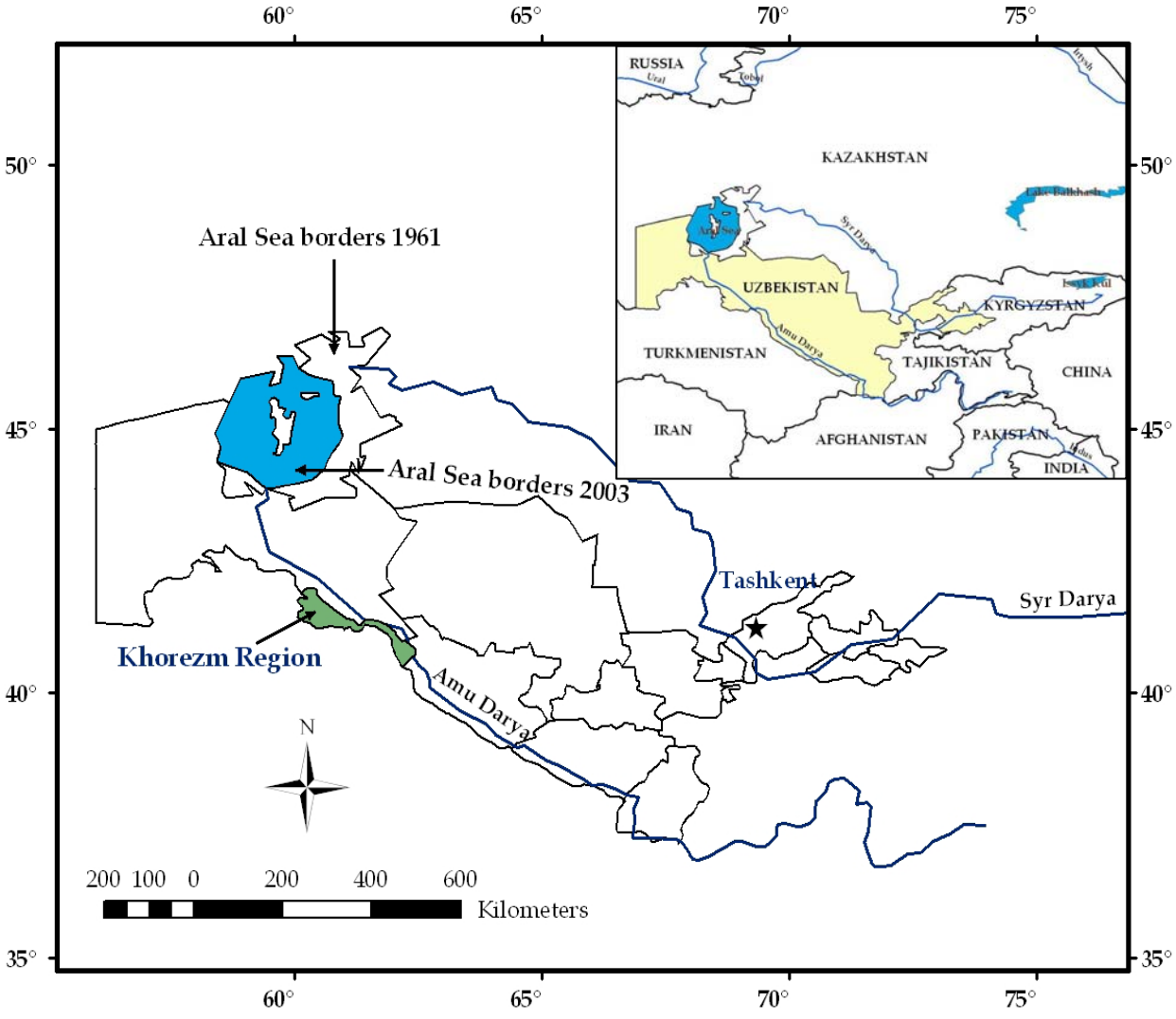

Fig. III.1 - Location of the Study Region

Amudarya River is a supplier of water for the whole Khorezm Region and in the last years, the water amount has been tremendously reduced because of intensive upstream utilization (Djalalov *et al.,* 2005). The river provides irrigation water for 231 000 ha of which more than 12 % are severely saline. The region contributes to 15% of the national Uzbekistan river water withdrawals. And water withdrawal for agriculture is estimated at 94% of the whole regional water withdrawals (Schieder, 2004).

The region has become particularly vulnerable to short and long-term droughts, as a result during the 2000 and 2001 growing seasons resulted in major crop failures (WHO, 2001). Consequently, the agricultural Gross Domestic Product (GDP) has become one of the lowest in Uzbekistan (Djalalov *et al.,* 2005). Moreover, the socio-economic and public health situation in the region has been worsening due to geographical proximity to the ecologically degraded Aral Sea (Khamzina 2006).

Khorezm borders with Autonomous Republic of Karakalpakistan in the North and East, with Turkmenistan in the South and West, with the Bukhara region in the South and East. The population of the region is equal to 1 324 000 people, 24% of which reside in towns and the density is equal to 217,4 people per km^2 (Gulomov *et al.,* 2001). The population growth rate has averaged 2.8% over the past 11 years (MMS, 1999). The Khorezm region is divided into ten administrative districts with Urgench as the administrative center. The population of Urgench is equal to 139 000 people whereas experimental district's (Gurlan) population is around 27 300 people. About 80% of Khorezm's population resides in rural areas and is engaged in cotton production, which is the main cultivated crop for that region, followed by winter wheat, rice and various other crops.

III.2 – Climatic Conditions

The study area is situated in the Central Asian semi desert zone with an extremely continental climate (Glazirin *et al.,* 1999). Potential evapotranspiration exceed precipitation during the most parts of the year. It is also considered as daily temperature fluctuation region with long hot dry summers, infrequent rains in spring-autumn and very cold temperatures during winter. Annual precipitation of the region is determined as 100-120 mm, which falls mostly outside of growing season in autumn-winter period (Fig. III.2).

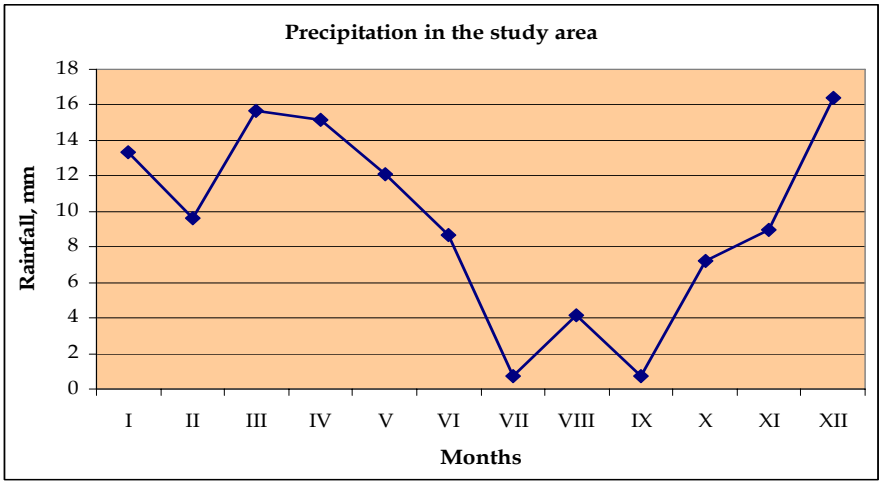

Fig. III. 2 - Average Monthly Precipitation for the Period of 2000-2006 in the Study Area (*Source:* Urgench Meteorological Station)

Local potential evapotranspiration (ET) is about 1,600 mm/year greatly exceeds precipitation (Glavgidromet, 2006). Thus, large scale irrigation for cultivated crops is essential to this area. The mean annual air temperature (T) is 13^{o}C, whereas monthly average maximum and minimum temperatures can reach + 37^{o} C and – 13^{o} C, respectively (Fig. III.3).

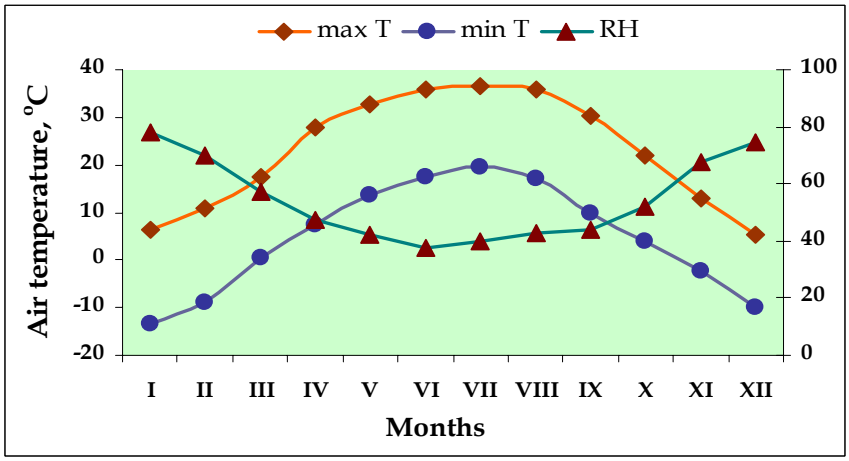

Fig. III.3 - Average Monthly Maximum and Minimum Air Temperatures (max T and min T) and Air Relative Humidity (RH) for the Period of 2000-2006 in the Study Area (*Source:* Urgench Meteorological Station)

During the experimental study, maximum daily T was 40,8°C whilst minimum was 7,7° C. The hottest month of experimental period was July with average maximum T of 34° C. Meanwhile, average monthly RH ranged from 38 to 47 % (Fig. III.4).

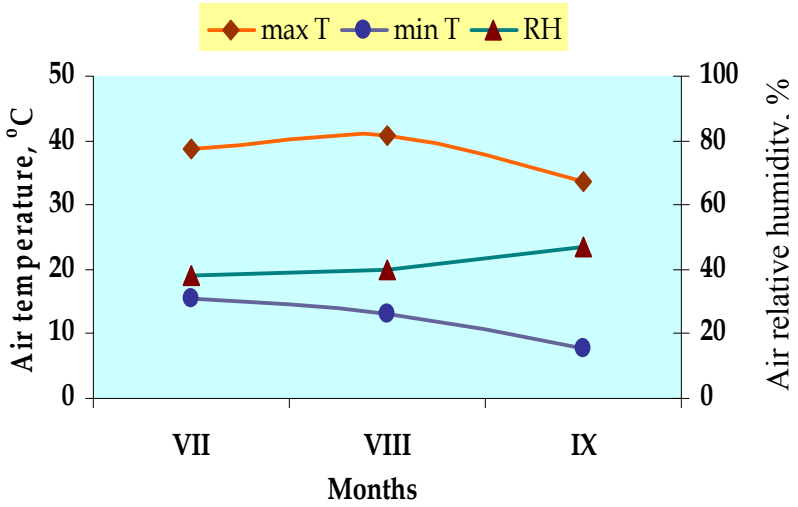

Fig. III.4 - Average Monthly Air Relative Humidity (RH), Maximum (max T) and Minimum (min T) Air Temperatures at the Experimental Site during July, August, September 2006 (*Source:* Glavgidromet, 2006)

Potential evapotranspiration (ETp) greatly exceeded from rainfall during the study period. Monthly rainfall varied from 0.5 to 1.4 mm, whereas ETp varied from 146.4 to 242.3 mm (Fig. III.5). The modern and accurate method to compute ETp is Penman-Monteith equation recommended by FAO-56 (Allen *et al.,* 1998). However, due to lack of meteorological data for the study site, Ivanov´s formula with a regional coefficient K of 0.8 was used to calculate ETp for the experimental periods (Clarke *et al.,* 1991). Meanwhile, Ivanov´s method was successfully adapted in the New Independent States (former Soviet Union countries):

$$ET_p = 0.0018 * K * (T + 25)^2 * (100 - a) \qquad \text{(III.1)}$$

where: ETp – potential evapotranspiration (mm)

T – average monthly air temperature, ^{o}C

a – average monthly air relative humidity, %

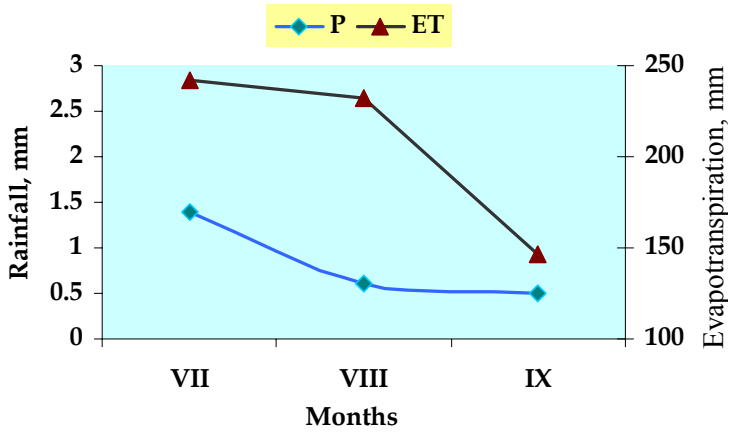

Fig. III.5 - Average Monthly Rainfall and Potential Evapotranspiration (ETp) on the Experimental Site during July, August, and September 2006 (*Source:* Glavgidromet, 2006)

It is interesting to note that the highest values both for rainfall and ETp were observed in July (Annex 1).

III.3 - Experimental Design and Plant Collection

Portulaca oleracea golden purslane seeds were planted in two different salt-affected soils of Khorezm Region and reported as field 1 and field 2 in this study. The size of the land was 16 m^2 for field 1 and 49 m^2 for field 2. Furthermore, field 3 was used for naturally grown wild species. The experiment was held in the lands of Vazir Water Users Associations (WUA), Gurlan city. In this study, field 1 was not irrigated while field 2 was irrigated twice with 0.78 dS m^{-1} salinity level of canal water. Irrigation was of 30 and 25 min duration which allowed the soil to be completely saturated and flow rates were 0.438 and 0.144 m^3 min^{-1}. A research was carried out for three months of summer period (July, August and September) and the duration of the experiment was 49 days for field 1 and 58 days for field 2.

The plants were harvested twice, in the developing and seedling stages of *Portulaca oleracea* golden purslane. Meanwhile, selected native naturally grown wild species were harvested at the same time of that *P.oleracea* golden purslane to evaluate their efficiency to remove salts.

In both cases, all plant samples were taken, plant height was measured, they were weighed, washed with tap water and distilled water, oven dried at 70^{O} C for 48 hours (Fig. III.6), re-weighed, finely ground in a mill and used for analysis of chloride (Cl^-), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and

Fig. III.6 - Plant Samples Dried in the Oven at 70^{o}C for 48 hours

magnesium (Mg^{2+}). The levels of Na^{+} and K^{+} were determined by flame photometry, whilst the remaining cations were assessed by atomic absorption spectrophotometry using a Shimadzu, AA-680 model spectrometer. Chloride (Cl^{-}) ions were determined in the aqueous extract by potentiometer using a Crison, pH meter GLP 22 after extraction in cold water.

III.4 - Soil and Water Measurement

Food and Agricultural Organization of the United Nations (FAO) have classified four different types of soil in Khorezm Region: mostly aridic and gleyic calcaric (sodic) Arenosols and calcaric Cambisols, whilst gleyic humus Fluvisols are commonly originated along the Amudarya River (Khamzina, 2006). In most cases, the thickness of alluvial sediments in or nearby to the river bed have 35-70 cm thick sands whereas former lake locations are characterized by loam and clay (Fayzullaev, 1980). Total Nitrogen and Phosphorus contents in these soil types are very low, usually ranging between 0.03 - 0.15% and 0.060 - 0.18%, respectively. Since the natural fertility of the soils in the region is relatively low, thus, heavy applications of chemical fertilizers are required in order to cultivate agricultural crops.

Soils were sampled by horizon (stratification) in three places of each site to describe the soil profile (Fig. III.7). Three 0.5 m deep pits were located in two *P.oleracea* fields, representing both ends and the middle of the experimental site, and one 0.5 m deep pit was dug in each field of naturally grown wild species. The soil sample was collected from 5 soil layers (0-10, 10-20, 20-30, 30-40, 40-50 cm) using auger to analyze for texture,

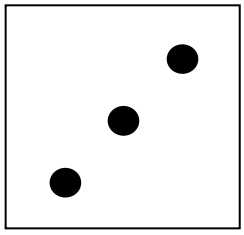

Fig. III.7 - Soil Sampling

bulk density, infiltration rate, wilting point, field capacity, total N as well as available P and K. Moreover, different soil depth samples (0-15, 15-30, 30-45 cm) were collected to determine soil salinity. Samples were collected from within and between rows of *P.oleracea* plants and combined.

The samples were analyzed by the Central Laboratory of the Uzbek Research Institute of Cotton Growing (UzRICG).

In order to measure the electrical conductivity (EC_w) of groundwater, irrigation water and drainage water, the water samples were taken from the experimental fields to the laboratory.

III.5 – Tested Crops

In order to study the potential capacity to remove soil salts, *Portulaca oleracea* Golden Purslane and seven native naturally grown wild plants - *Tamarix hispida, Apocynum lancifolium, Glycyrrhiza glabra, Portulaca oleracea (*Green Purslane*), Alhagi pseudalhagi, Karelinia caspia, Chenopodium album* were evaluated as to their efficiency to remove ions from the salt-affected soils of Khorezm Region (Table III.1).

Table III.1 - Investigated plants

Family	Genus	Species
Portulacacea	Portulaca	*Portulaca oleracea* L.
Tamaricaceae	Tamarix	*Tamarix hispida* – Willd.
Apocynaceae	Apocynum	*Apocynum lancifolium* L.
Asteraceae	Karelinia	*Karelinia caspia* (Pall.) Less.
Fabaceae	Glycyrrhiza	*Glycyrrhiza glabra* L.
Fabaceae	Alhagi Adans	*Alhagi pseudalhagi*
Chenopodiacea	Chenopodium	*Chenopodium album* - L.

Portulaca oleracea golden purslane is characterized by a short harvesting period and relatively resistant to salinity (Fig. III.8). It is widely used as food consumption in daily life of human. Leaves and stems of this plant can be eaten raw or cooked. The young leaves are a very acceptable addition to salads, their mucilaginous quality also making them a good substitute for okra as a thickener in soups (Grieve, 1984). Older leaves are used as a potherb. Furthermore, in many places of the world, particularly in Central Asia, chopped leaves of the *Portulaca oleracea* is used in the national food "samsa".

Additionally, it has medicinal importance, e.g. the leaves of *Portulaca oleracea* are a rich source of omega-3 fatty acids, which is thought to be important in preventing heart attacks and strengthening the immune system. A tea made from the leaves is used in the treatment of stomach aches and headaches. The leaves can be harvested at any time before the plant flowers; they are used fresh or dried. However, this remedy is not given to pregnant women or to patients with digestive problems (Brown, 1995).

Fig. III.8 – *Portulaca Oleracea* Golden Purslane in Study Area

Moreover, the selected *Tamarix hispida* crop is characterized as an easily grown plant, succeeding in most soils and tolerant of saline conditions (Fig. III.9). It grows well in heavy clay as well as sandy soils. It is also tolerant of maritime winds and dry soils when grown near the coast, plants require a moister soil and shelter from cold drying winds when they are grown inland in

Fig. III.9 - *Tamarix Hispida* in Study Area

non-saline soils because they use soil salt that are found in saline soils to help them reduce transpiration (Bochansev *et al.,* 1955). This plant is mainly used to stabilize the soil and also to make a good shelter hedge in coastal gardens. The plant can be found in East and Central Asia – Caspian Sea to Manchuria.

Apocynum lancifolium is a wild halophytic species widely distributed in the northern part of Uzbekistan (Fig. III.10). The stems of this plant are from 80 to 200 cm tall, glabrous except for inflorescences; braches and branchlets whitish gray, terete, finely striate. This plant can be found in the salt-barren zones, desert margins, alluvial flats, riversides.

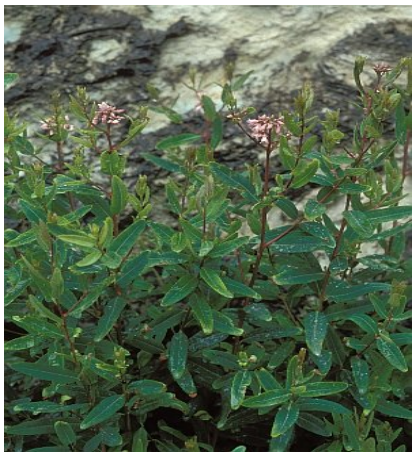

Fig. III.10 - *Apocynum Lancifolium*
Source: *Japanese website*

The strong bast fibers obtained from the inner bark are used in making cloth, strings, sails, fishing nests, and high-quality paper. The leaves yield up to 5% gum, which is used for making rubber, and a medicine used as a sedative and to treat hypertension. The species has fragrant flowers and is grown as a honey plant (Bondarenko *et al.,* 1961).

The physical characteristics of the *Karelinia caspia* is: stems from 50 to 100 cm length (Fig. III.11). The calathidiums are cylindrical, width 4-8 mm, length 10-15 mm. Flowers are pink-lilac in color. Cypselas are wedge-shaped, slightly arcuated with vague blunt and puce color. Pappus is almost 10 times

Fig. III.11 - *Karelinia caspia* in Study Area

longer than cypsela (Bondarenko *et al.*, 1962). It can be found in the salt marshes, coastline and riversides, usually occurs as weed in the abandoned lands, and also cultivated in saline lands. Furthermore, it can serve as animal grazing, particularly sheep, goat and cow feed.

Glycyrrhiza glabra is one of the most widely used species of *Glycyrrhiza*. It is used traditionally to relieve coughs and sore throats, and against gastric inflammation. One of the main active ingredients is *glycyrrhizin*, which has a cortisone-like effect and, additionally, is 50 times sweeter than sucrose (Borisova *et al.,* 1955). Apart from its medicinal applications, it is employed as a flavoring agent in sweets and tobacco, and as a foaming agent in fire extinguishers and beer (*WWF*). The plant is 1.2-1.8m tall, leaves pinnate with 9-17 leaflets and flowers pale blue, pea-like. It is widely distributed in Eurasia, including the Mediterranean region, China, India, Central Asia and western Siberia.

Alhagi pseudalhagi is a noxious weed[13] in the US but a medicinal plant in the Asia (Fig. III.12). This green shrub is to 1 - 2 m tall, with simple leaves, many thorny branches, and an extensive root system. Plants spread rapidly by clonal vegetative reproduction from vigorous rhizomes. This desert plant introduced from the Mediterranean region and Central Asia. The whole plant is diaphoretic, diuretic, expectorant and laxative. Oil from the leaves is used in the treatment of rheumatism. The flowers are used in the treatment of piles (Bown, 1995). Extensive rhizomes present. Woody root system can grow more than 2 m

Fig. III.12 - *Alhagi pseudalhagi*
Source: *AIS/NWI*

[13] It is a plant which is harmful to living things, injurious to health

deep and to a distance of 8 (12) m or more in all directions. Rhizomes at depths to 1.5 m produce new shoots and deep vertical roots at about 1-1.5 m intervals.

Chenopodium album (Fat Hen; also called white goosefoot, lamb's quarters, or pigweed), is a fast-growing, upright, weedy annual species of goosefoot, very common in temperate regions, growing almost everywhere in soils rich in nitrogen, especially on wasteland. Its pollen can contribute to hayfever-like allergies. It tends to grow upright at first, reaching heights of 30-80 cm, but typically becomes recumbent after flowering (due to the weight of the foliage and seeds) unless supported by other plants (Bochansev *et al.,* 1953). Fat Hen can be eaten as a vegetable, either steamed in entirety, or the leaves cooked like spinach as a leaf vegetable. Each plant produces tens of thousands of black seeds. These are very nutritious, high in protein, vitamin A, calcium, phosphorus, and potassium. Quinoa is a closely related species grown specifically for its seeds (www.wikipedia.org). As the common name suggests, it is also a very good feed (both the leaves and the seeds) for chickens (hens) and other poultry. Furthermore, according to the PFFD report, the plant can be discovered around the world.

Native naturally grown *Portulaca oleracea* green purslane was also assessed to its potential salt removal capacity (Fig. III.13). The whole characteristics of this purslane are the same as of golden purslane but it is more unpleasant. This green purslane is mainly used as poultry feed in Central Asia.

Fig. III.13 - *Portulaca Oleracea:* Green Purslane in Study Area

The below table summarizes the use of all the investigated plants in the daily life (Table III.2).

Table III.2 – Benefits of investigated plants

Species	Uses
Portulaca oleracea L.	• Leaves and stems can be eaten raw or cooked • Salad • Leaves as a potherb • "Samsa" • Prevents heart attacks • Strengthens the immune system
Tamarix hispida – Willd.	• Stabilizes the soil • Makes a good shelter hedge
Apocynum lancifolium L.	• Making cloth, strings, sails, fishing nets, high-quality papers • Sedative and treat hypertension
Karelinia caspia (Pall.) Less.	• Animal grazing
Glycyrrhiza glabra L.	• Relieve coughs and sore throats • Flavoring agent in sweets and tobacco • Foaming agent in fire extinguisher and beer
Alhagi pseudalhagi	• Diaphoretic, diuretic, expectorant and laxative • Rheumatism treatment and treatment of piles
Chenopodium album - L.	• Goosefoot, lamb's quarters or pigweed • Vegetable • High in protein, vitamin A, calcium, phosphorous and potassium • Food for chicken and other poultry

III.6 - Laboratory Analysis of Soil-Plant-Water

III.6.1 - Physical-Chemical Analytical Methods for Soil

The soil samples were analyzed for physical and chemical properties in the field and laboratory conditions. The methods of the analysis are described below.

III.6.1.1 – Texture

Soil texture was determined according to the Kachinskii pipette method (Plusnin *et al.*, 1974). A weighed 20 gram of air-dried soil placed into porcelain flask. 12 mL of sodium oxalate solution along with 8 mL of deionized water was added to the flask. The sample was mixed and transferred into the 250 mL flask filled with deionized water to heat up. After cooling, the sample was transferred to the 1 L cylinder flask to quantify the soil texture through titration. The flask was filled with deionized water and mixed carefully. The cylinder flask was installed into the titration device and through pipettes the device took the sample from the flask with 20-25 mL volume.

In total, the soil was differentiated into seven size classes with the following diameters: > 0.25; 0.25-0.1; 0.1-0.05; 0.05-0.01; 0.01-0.005; 0.005-0.001; <0.001 mm according to Kachinsky´s method and converted to the American texture classification (Annex 3). The first two fractions were determined through washing the sieves whereas the last four through pipettes. The fraction weight of 0.1-0.05 mm calculated with the difference between initial soil sample weight (20 g) and sum of six fractions. The calculations of soil fraction weights B (%) was performed using following equation:

$$B = \frac{P * 100 * 1000}{20 * 25} \qquad \text{(III.2)}$$

where: P – weight of appropriate fraction (g)

20 – amount of soil samples (g)

25 – volume of pipette (mL)

1000 – volume of cylinder (mL)

Moreover, the following equation was applied to calculate first two fractions (> 0.25; 0.25-0.1), washed in sieves:

$$B = \frac{P * 100}{20} \quad \text{(III.3)}$$

where: B – content of fraction (%)

P – weight of fraction (g)

20 – amount of soil samples (g)

In addition, the fraction 0.1-0.05 mm was quantified by the difference between soil sample weight and sum of obtained fraction.

III.6.1.2 – Soil Water Content

The soil moisture at the nonsaline wilting point (WP) and at the field capacity (FC) was determined for field 1 and field 2 by gravimetric method (Annex 3) and was calculated at the field (Beltrao, 1996; Ben Asher, 2002). The samples were analyzed by gravimetric method and later on, converted into a volumetric basis by considering the bulk density of the respective soil layers (determined in the soil pits).

III.6.1.3 - Bulk Density

The soil bulk density (BD) was determined using core sampler to inquire the soil compactness (Blake & Hartge, 1986). The soil samples were collected from 10, 20, 30, 40, 50 cm depths using shovel and core sampler (Fig. III.14). A core weight recorded, soil moist along with core was recorded, moist soil

Fig. III.14 - Determination of Soil Bulk Density using a Core Sampler and a Shovel

placed into the tin cans, transferred to the laboratory, the tin cans and soil weighed, oven-dried at 105^{o}C for 6 hours, cooled in a desiccator and reweighed. The following equation was used to calculate the bulk density (BD), expressed as g cm^{-3}:

$$BD = \frac{(W - C) * 100}{(100 + A) * V} \quad \text{(III.4)}$$

where: W – soil sample weight (g)

C – core weight (g)

A – gravimetric soil moisture (%), determined using soil moist and oven-dry weight

V – volume of core (cm^3)

r – core radius = 3.75 cm

h – core height = 5 cm

III.6.1.4 - Infiltration Rate

The infiltration rate was measured for field 1 and field 2 using cylinder infiltrometer to know the velocity at which water moves into the ground (Pankov, 1957). Field 3 was analyzed for soil texture and thus, was not measured for infiltration rate in this study. It is known that infiltration rate is directly correlated with texture and can be predicted by looking at the soil texture results.

Infiltration rate was measured by the depth (in mm) of the water layer that can enter the soil in one hour. A cylinder with the diameter of 22.5 cm was hammered into the soil in the experimental fields. The timber was used to protect the ring from the damage during hammering. The cylinder was kept vertically,

Fig. III.15 - Determination of Infiltration Rate in the Investigated Field

so approximately 15 cm was left above the ground. Additionally, 55 cm cylinder was constructed an earth bund around the 22.5 cm cylinder to the same height as the cylinder and placed the hessian inside the infiltrometer to protect the soil surface when pouring the water (Fig. III.15).

Afterwards, the water was poured into the cylinder and to the space between the two cylinders. The time was recorded to know the infiltration rate. After 4-5 minutes, the drop in water level in the inner cylinder was recorded and water added to bring the level back to approximately the original level at the start of the test. The test was continued about 6 hours while keeping the water level the same over the same time interval, but as the time goes on the interval between readings was extended (e.g. 20-30 minutes). Meantime, infiltration volume was recorded each time of water adding. The final infiltration rate (f), expressed as mm h^{-1}, was calculated as following:

$$f = \frac{(Q * 10)}{(S * t)} * 60 \qquad \text{(III.5)}$$

where: Q – cylinder water volume (cm^3)

t - time differences (min.)

S – inner cylinder area (cm^2), determined through $S = \frac{\pi * d^2}{4}$ equation

d – inner cylinder diameter = 22.5 cm

III.6.1.5 - Total Nitrogen

The Kjeldahl method was used to determine total nitrogen (N) in the soil (McGill & Figueiredo, 1993). The soil samples were air-dried, ground and sieved before analysis.

This method is divided into three phases:

- Digestion – 1 gram of sieved soil placed in a dry digestion tube. 5 mL of deionized H_2O was added and swirled to wet all the soil. Then, 25 mL of concentrated H_2SO_4 was added and placed into the digestion block in 450^{o}C for 4 hours.

- Distillation – the digested samples were transferred to a distillation flask, which was connected to the steam distillation apparatus. Samples were neutralized with sodium hydroxide. In order to receive and keep the N distilled, 10 mL of 4% (weight/volume) boric acid was added to the flask.

- Titration – the distillate was titrated with 0.01 M sulphuric acid. The color changed at the end point from green to pink. The following equation was used to compute total N (%) in the soil:

$$N = \frac{V * f * 0.28}{\text{m}} * 100 \qquad \text{(III.6)}$$

where: V – volume of H_2SO_4 spent in the titration (mL)

f – H_2SO_4 concentration (M)

m – mass of the sample (g)

0.28 – 1 mL of 0.01 M H_2SO_4 is equivalent to 0.28 mg of N

III.6.1.6 - Potassium and Phosphorus

Machigin method was used to determine available potassium and phosphorus in the soil of experimental area (Radov *et al.,* 1971). Five grams of sieved soil were placed into a 250 mL conical retort and filled up with 100 mL of 1% (w/v) ammonium carbonate solution. The suspension was shaken for about 5 minutes and stored for 24 hours. During this time it was shaken every 6 hours. Afterwards, the suspension was filtered and the filtrate was analyzed for potassium (K^+) by flame-photometry.

In order to analyze phosphorus, the filtrate was decolorized by adding dilute sulphuric acid and 0.5 M potassium permanganate solutions. The mixture was then boiled for 2 minutes. After adding 1 mL of 10 % (w/v) glucose, the solution was cooled and neutralized with 10 % (w/v) Na_2CO_3 solution in the presence of an indicator. In addition, to the 50 mL of colorless mixture, 2 mL of molybdenum reagent solution and 0.5 mL stannous chloride were added. After 5 minutes, the phosphorus was analyzed colorimetically.

III.6.1.7 - Salinity

The analysis for determining soil salinity was conducted according to 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). The sample solution was 4 times shaken for 1 minute at a 30 minute interval and allowed to stay 24 hours in order the soil to settle (Fig. III.16). Afterwards, the solution was filtered and prepared to quantify for total dissolved solids (TDS) and salt ion compositions (Cl^-, Na^+, K^+, Ca^{2+}, Mg^{2+}) at the UzRICG laboratory (Annex 4).

Fig. III.16 - Soil Extraction

This USSR classification of soil salinity, used in Central Asia, based on laboratory measurements of the TDS (%), was converted according to FAO classification, in electrical conductivity of saturated soil extract (ECe). The standard unit for ECe is deciSiemens per meter (dS m^{-1}).

III.6.1.7.1 - Chloride

Potassium chromate was used as an indicator in the determination of chlorides in the soil by titration with standard $AgNO_3$ solution (Machigin, 1963). This method is called the Mohr method of determining Cl^- and is based on the formation of a red precipitate of silver chromate (Ag_2CrO_4) at the end point, after all the Cl^- has been precipitated as white AgCl. To 10 mL of the sample solution, 2-3 drops of 10% (w/v) K_2CrO_4 solution was added and titrated with 0.01 N of $AgNO_3$ until the appearance of a reddish color (Fig. III.17). The following equation was used to quantify Cl^- content (X), expressed in percentage, in the air-dried soil:

Fig. III.17 - Quantification of Ions in the Soil using Titration Method

$$X = \frac{a * 0.00035 * 100 * E * 100}{M * W} \qquad \text{(III.7)}$$

where: a – volume of 0.01 N $AgNO_3$, spent for titration (mL)

0.00035 – this amount of gram Cl^- corresponds 1 mL 0.01N $AgNO_3$

E – volume of water sample (mL)

M – volume of sample solution (mL)

W – amount of soil sample (g)

III.6.1.7.2 - Sodium and Potassium

The analyses of Na+ and K+ in the soil were performed using flame photometry method (Samokhvalov *et al.,* 1999). Standard solutions were prepared and calibration curves were

plotted. For sodium, NaCl 0.005 *N* was used and 0.2923 g of dried NaCl was dissolved in one liter of extracting solution. For potassium, KCl 0.005 *N* was used and 0.3728 g of dried KCl was dissolved in one liter of extracting solution. In the case of high concentrations of K^+ and Na^+, appropriate dilutions with extracting solution were performed. Obtained results were converted into percentage using Annex 5 and 6.

III.6.1.7.3 - Calcium and Magnesium

The Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) concentrations in the in the examined soil profiles of the experimental fields were determined by titration method (Machigin & Protasov, 1963). To determine the sum of Ca^{2+} and Mg^{2+}, 10 mL of the sample solution was taken and diluted with distilled water. After addition of 5 mL of ammonium chloride and 2-3 drops of darkish chromogen, the mixture was titrated with 0.05 *N* Trilon B solution until the appearance of a blue color.

To quantify Ca^{2+} separately, 10 mL of the sample solution was taken and diluted with distilled water. After the addition of 2 mL of potassium hydroxide, the mixture was titrated with 0.05 *N* Trilon B solutions until the appearance of a violet color.

Mg^{2+} was quantified by subtraction of the result of Ca^{2+} from the result of Ca^{2+} + Mg^{2+}. The following equation was used to perform calculation:

$$Ca + Mg(mg / eqv.) = \frac{0.05N * \mathrm{E} * 100}{\mathrm{M} * \mathrm{W}} \qquad \text{(III.8)}$$

In order to convert into percentage based, the molecular weight (n) of ions was used:

$$\frac{mg / eqv. * n}{1000} \qquad \text{(III.9)}$$

III.6.1.7.4 - Total Dissolved Solids

Gravimetric method was used to measure total dissolved solids (often abbreviated TDS), which is the most accurate and involve evaporating the liquid solvent to leave a residue (Position Paper, 2003). In order to measure TDS, 20 mL of sample solution was placed into a 100 mL beaker and allowed the liquid to evaporate in the oven at 105^{o}C for 3 hours. When the beaker was dry, it was cooled in a dessicator and reweighed. The following formula was used to calculate TDS, expressed in percentage (Annex 4 a):

$$TDS = \frac{(a - b) * E * 100}{M * W} \qquad \text{(III.10)}$$

where: a – mass of beaker after water evaporated (g)

b – tare weight of beaker (g)

E – volume of water sample (mL)

M – volume of sample solution (mL)

W – amount of soil sample (g)

III.6.2 - Chemical Analytical Methods for Plants

Plant materials were extracted to measure chloride, sodium, potassium, calcium and magnesium concentrations in a Laboratory of the University of Algarve (UALG). Chloride was extracted using cold water at room temperature (23-25^{o}C), according to the procedure proposed by Drew and Saker (1984), whereas the cations were extracted by a dry-ash method at 550^{0}C incinerator using a Thermolyne, Type 1500 Furnace (Yeo & Gullasch, 1977).

In the case of chloride, a 100 mg of ground shoot material was stirred in a glass vial with 50 mL of deionized water at room temperature (23-25^{o}C) using three replicates. The supernatant was filtered and stored in a volumetric flask (Fig. III.18).

1 gram of ground shoot material was weighed, placed into a glass liquid scintillation vial and ashed in a muffle furnace for 6 h at 550^{0}C to measure cations. After cooling, the ash was dissolved with 10 mL of 0.1 *N* HCl solutions in a heater. The samples were filtered and filled up with deionized water until 100 mL in a volumetric flask.

Fig. III.18 - Extraction of Plant Samples

III.6.2.1 – Chloride

The potentiometric method, pH/mV meter, was used with double Junction Reference Electrode and Chloride Ion Electrode to measure Cl^- concentrations in the dry matter (Fig. III.19). By serial dilution of the 1000 ppm standards, 100 and 10 ppm chloride standards were prepared. 2 mL of a Ionic Strength Adjuster (ISA) was added per 100 mL of standard. Using the semi-logarithmic graph paper, the mV reading (linear axis) was plotted against the concentration (log axis).

Fig. III.19 - Determination of Cl^- in DM using Potentiometric Method

The curve was extrapolated down to about 1 ppm to build up a calibration curve. Afterwards, to the dry 100 mL beaker, 50 mL of sample and 1 mL of ISA was added. The baker was placed into the magnetic stirrer. The electrode tips were placed into the solution and when the reading was stabilized, the mV reading was recorded. The concentration of chlorides in the dry shoot material was determined directly from the calibration curve with the unit of parts per million (ppm). Later, the ppm (equal to mg L^{-1}) unit was converted to mg g^{-1} unit using the following equation:

$$\mathbf{L = F_c * S_e} \qquad \text{(III.11)}$$

where: L – chloride concentration, expressed as **mg g^{-1}**

F_c – chloride concentration given by the machine, expressed as **mg L^{-1}**

S_e – extraction solution, expressed as **L g^{-1}**; $S = \frac{0.05L}{0.1g}$

III.6.2.2 - Sodium and Potassium

Flame photometry (FP) method was used to measure Na^+ and K^+ in the dry shoot material. In order to calibrate FP, a series of standard solutions were prepared containing exact and increasing amounts of a cation over a selected range. Moreover, standard concentrations were prepared using sodium or potassium standard solutions, i.e. to the 10 mL of sodium or potassium standard solution (1000 ppm) added 90 mL of deionized water to make 100 ppm solution. Afterwards, 2, 4, 6, 8, 10 mL of the 100 ppm solutions of K^+ and Na^+ were taken separately into 100 mL volumetric flask, filled with deionized water and read for calibration curve (Annex 7). After the calibration curve, the samples were placed into the machine. The necessary dilutions of the samples were prepared according to the results given by the FP machine. The machine has given in absorption and based on curve, it was

changed into concentrations (ppm or mg L^{-1}). The units were converted into mg g^{-1} using equation III.14.

III.6.2.3 - Calcium and Magnesium

Flame atomic absorption spectrophotometry (AAS) method was used to measure Ca^{2+} and Mg^{2+} concentrations in the dry-shoot material (Fig. III.20). Several standard solutions were prepared using a 1000 ppm calcium or magnesium standard solution. To prepare the standards, 5 mL of strontium chloride ($SrCl_2$) and 1 mL of 3 *N* HCl were added to each sample. The calibration curve was obtained using standard solutions (Annex 7). Moreover, to the 2 mL of extracted sample 50 mL of deionized water was added along with 5 mL $SrCl_2$ and 1 mL of 3 *N* HCl. Appropriate dilutions were made in case of high concentrations of the analyzing ions.

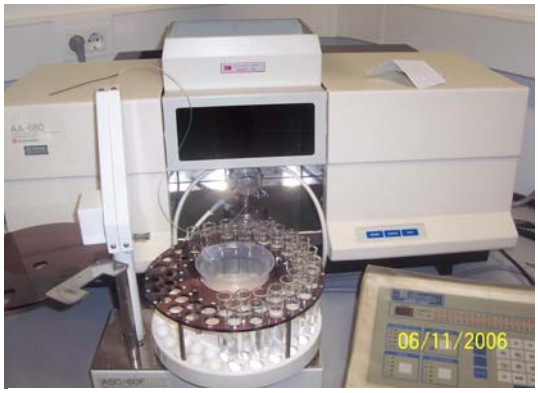

Fig. III.20 - Determination of Ca^{2+} and Mg^{2+} in DM using AAS Equipment

III.6.3 - Chemical Analytical Method for Water

III.6.3.1 – Water Mineralization

The groundwater table was examined to assess irrigation performance and contribution to crop soil-water requirement. To examine groundwater table, six samples were taken using auger equipment: 3 in field 1 and 3 in field 2 (Fig. III.21).

The sampled irrigation and drainage water and groundwater were measured in the laboratory of UzRICG using titration method for salt (HCO_3^-, Cl^- and TDS) content (Machigin, 1963). 5 mL of water samples were poured into 100 mL flasks. The method of extraction and quantification was the same as used in soil salinity. At the end of the experiment, the results were obtained in g L^{-1}. In the case of TDS, 50 mL of water was placed into the oven at 105^{o}C for 3 hours to evaporate the water. The residue weight left after water has evaporated was recorded and the value was multiplied into initial water sample to obtain g L^{-1} unit.

Fig. III.21 - Groundwater Sample from the Soil Pits of Experimental Fields

Later, this USSR classification to determine water mineralization based on laboratory measurements was converted, according to FAO classification, in electrical conductivity of water (ECw) and recorded as dS m^{-1}.

III.7 - Statistical analysis

The data were subjected to standard analyses of variance using the One-Way ANOVA procedure of the SPSS 14.0 for Windows (SPSS, 2005) to compare mean values of Cl^- concentrations, obtained through potentiometric method, with two different harvested months. Differences at the $P \leq 0.05$ level were used as a test of significance and means were separated using the Duncan post hoc t-test (Annex 15).

Moreover, data of dry yield of plant samples was modeled using a linear regression equation, i.e. it was assumed that dry yield is a linear function and individual independent variables set as Cl^-, Ca^{2+}, Mg^{2+}, Na^+, K^+ concentrations and extraction of ions kilogram per hectare, which thought to be main parameters accounted for the changing of dry matter in the salinized lands of experimental field. The full derivation of this regression modeling technique is described in the Annex 15 (a & b).

IV - Results and Discussions

IV.1 - Soil Characteristics in the Experimental Area

The experimental area covered three fields in the region. As it was mentioned in the previous section, the following general investigations were carried out in each field to determine the soil characteristics: soil profile, bulk density, infiltration rate and soil water content. Furthermore, agrochemical properties and soil salinity were also assessed. The findings are described below.

IV.1.1 – Texture

The soil profile investigation showed that the soils in the study areas are partially stratified. According to Kachinsky´s classification (Handbook on Soil Science, 1980) the topsoil layer (0-20 cm) and middle layers (30-40 cm) of field 1 was medium loamy (Fig. IV.1, Annex 2). In field 2, the topsoil layer (0-30 cm) was heavy loamy whereas the subsoil layers (30-50 cm) contained more silt and sand, thus were classified as medium loamy. Meanwhile, field 3 had a lighter texture (loamy light topsoil followed by loamy sandy subsoil).

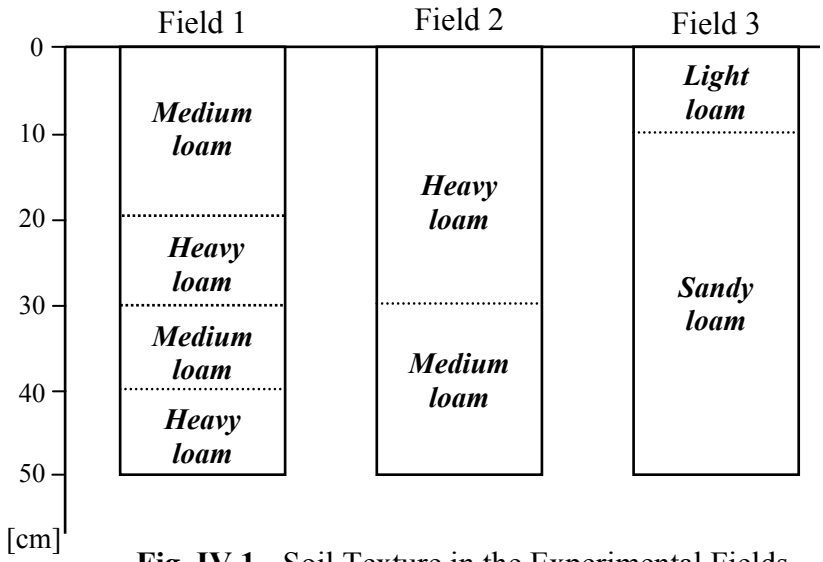

Fig. IV.1 - Soil Texture in the Experimental Fields

In addition, based on FAO (1998) classification and the results obtained, the soil of field 1 can be classified as Fluvisols with histic horizon having fluvic soil material starting within 25 cm from the soil surface and continuing to a depth of at least 50 cm from the soil surface. It should be noted that due to influence from the river, the soils always in change and thus, named as alluvial soils.

Due to a heavy textured surface horizon, field 2 classified as Fluvisols with takyric horizon, which mainly occurs under semi-arid conditions. On the other hand, because of sandy and highly saline soils, field 3 was classified as Solonchak with calcic horizon having high calcium and salt content in the surface horizons.

IV.1.2 - Bulk Density

The soil bulk density data is shown in Annex 2. As can be seen in this table, the soil bulk density of field 2 ranged from 1.41-1.44 g cm^{-3} and averaged 1.43 g cm^{-3} over the examined profiles. For instance, in the topsoil layer from 0-10 cm, the density was 1.41 g cm^{-3}, whereas the deeper subsoil layer from 10-30 cm, an increased of density 1.43 g cm^{-3} was observed. In the subsoil layer from 30-50 cm, the density was 1.44 g cm^{-3}. Based on these results, this field can be characterized as a heavy loamy soil, with slow water movement between soil particles, high bulk density, soil water holding capacity is low and irrigation periods are long.

On the other hand, with a fluvisols histic horizon soil structure, field 1 had lower bulk density than field 2. In the first 0-10 cm of soil depth, the bulk density was 1.35 g cm^{-3} and in the deeper soil layer, a higher bulk density was observed. Likewise, at 10-20 and 20-30 cm soil depth, the bulk density was 1.36 and 1.37 g cm^{-3}, respectively. In the 30-50 cm subsoil layer, the bulk density was observed as 1.39 g cm^{-3}. An average, the bulk density of

the 0-50 cm soil layer was 1.37 g cm^{-3}. This data shows that the soil is middle loamy, the soil water holding capacity is high, water fills the soil particles rapidly and infiltrates to the impermeable layer, and irrigation is required frequently.

Furthermore, field 3 had sandy soils, thus, higher bulk density was observed. For instance, for the 0-50 cm soil depths, the soil bulk density averaged 1.60 g cm^{-3}. As can be seen in Annex 2, the bulk density under the investigated fields was lower in the topsoil layers and increased with the depth of profiles. Generally, bulk density is related to soil texture and eluvia processes in the soil. It can be presumed, from the experimental results, that the volumetric weight of soil in field 1 could be appropriate and satisfactory to the growth and development of *Portulaca oleracea* as well as other potential salt-removing plants.

IV.1.3 – Infiltration Rate

Previous investigations showed that bulk density is related to water infiltration (Revut, 1962; Voronin, 1996). The compaction of the soil leads to a decrease in the infiltration rate (Cheshev *et al.,* 1978). The investigated soils were characterized by different percolation rates. The water infiltration was significantly higher during the two hours of experimental period in field 1 compared to field 2. The infiltration rate in field 1 ranged between 13.6-173.5 mm h^{-1} and averaged 45.3 mm h^{-1} during an experimental period of six hours, which illustrates that a water layer of 45.3 mm on the soil surface, will take one hour to infiltrate (Fig. VI.2). During the early stages of infiltration, the highest infiltration rate was observed due to dry soil. As time went on, the water from the soil surface infiltrated more slowly because the air in the pores was replaced by water and eventually reached a steady rate.

In principal, infiltration rate depends on soil texture and soil structure, and is the best way of categorizing soils from an irrigation point of view. In the field 1, obtained results showed

that with the medium loamy soil, irrigation water should be applied frequently since water is soaked/absorbed by the soil rapidly.

On the other hand, infiltration rates in field 2 were observed to be relatively low compared to field 1, ranging between 2.0-52.5 mm h^{-1} and averaging 11.4 mm h^{-1} during the study six hours period. Therefore, it can be stated that the soil was at a saturation point where the macropores and micropores are full of water. More details on infiltration rates for the two experimental sites are reported in Annex 8.

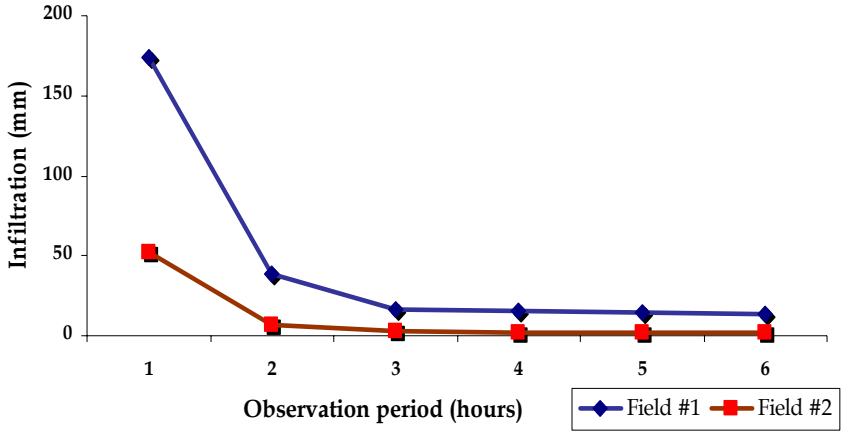

Fig. IV.2 - Soil Infiltration Rate Determined at two Locations of Experimental Site

IV.1.4 – Soil Water Content

In the field 1, the volumetric soil water content at nonsaline wilting point ranged between 0.210-0.281 m^3 m^{-3} and averaged 0.259 m^3 m^{-3} over the examined soil profiles (Annex 3). This means that below this point the availability of soil water to the plant roots is limited. This is known as called hydroscopic water condition. It is interesting to note that topsoil layers had lower values compared to deeper layers, which illustrates that upper layers have drier soil and plants withdrew water rapidly. Meanwhile, volumetric soil water content at field capacity (FC) varied from 0.281 to 0.304 m^3 m^{-3} and averaged 0.290 m^3 m^{-3} in field 1.

It should be pointed out that topsoil layers showed higher values of field capacity (FC) than subsoil layers requiring higher irrigation amounts in upper layers.

Moreover, field 2 results showed that the volumetric soil water content values at wilting point is closer to volumetric soil water content at field capacity, which illustrates the soil contains excess water. For instance, volumetric soil water content at wilting point ranged between 0.283-0.313 m^3 m^{-3} and averaged 0.292 m^3 m^{-3}, while FC ranged between 0.298-0.319 m^3 m^{-3}, averaging 0.305 m^3 m^{-3}, which can be interpreted as the maximum amount of water the soil can hold. Monitoring soil water content is essential in this field to optimize crop production, conserve water, reduce environmental impacts and save money.

In addition, soil water content data in the fields investigated helps to improve irrigation decisions such as how much water to apply and when to apply it, to match water applied irrigation with crop water requirements and thus avoiding over-irrigating the crop.

IV.1.5 – Agrochemical Properties

It is known that the growth and development of crops depend on the availability of nitrogen, phosphorus, humus and other elements in the soil. The total nitrogen (N) in the soil, available phosphorus (expressed as P_2O_5) and humus content in the investigated fields are summarized in Fig. IV.3. As can be seen in Fig. IV.3, the content of total N, available P_2O_5 and humus in the field 1 soils were higher than in other fields. Furthermore, upper layers of soils had higher content of nutrients in all experimental fields.

It can be noticed that the highest amount of potassium (140 mg K_2O kg^{-1}) was found in the topsoil layers of field 1 and the lowest (40 mg kg^{-1}) in the subsoil layers of field 2 and 3 (Annex 9). Likewise, upper layers showed higher concentrations of K_2O than subsoil layers.

In general, the clay soils contain more nutrients whereas sandy soils are poor in organic matter, nitrogen and mineral nutrients. Meanwhile, loam soils have an intermediate position regarding soil properties and are usually more fertile than sandy soils. Since the soils of investigated fields have a silt-sand texture, they are poor in nutrients thus heavy application of fertilizers is essential in order to increase crop productivity.

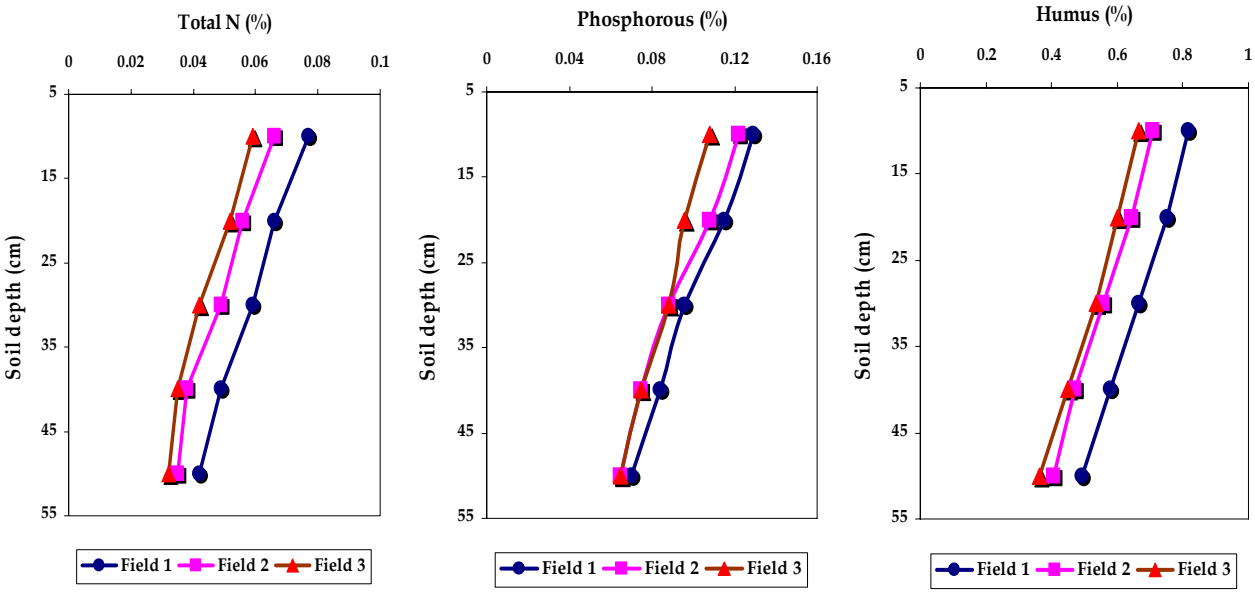

Fig. IV.3 - Content of Total Nitrogen (%), Available Phosphorus (%) and Humus in 50 cm Soil Depth

IV.1.6 - Salinity

The soil solution in the experimental fields had higher salt concentrations than irrigation water. The electrical conductivity of soil ECe (expressed as dS m^{-1}) examined during the experimental period mostly corresponded to the degree of salinity ranging between slight and moderate (FAO classification, 1985). However, values above 8 dS m^{-1} have been observed. Such deviations towards a strong degree in soil salinity were more prominent in the fields with naturally grown plant fields (Fig. IV.4).

For instance, the degree of salinity in field 1, averaged over the 0-45 cm soil profile could be classified as low saline with an average electrical conductivity of 1.20 dS m^{-1}. It should be pointed out that, before plantation, the field 1 was properly leached from the salinity and used as a pasture for animal feed. Thus, the soil salinity in this field was lower compared to other investigated fields.

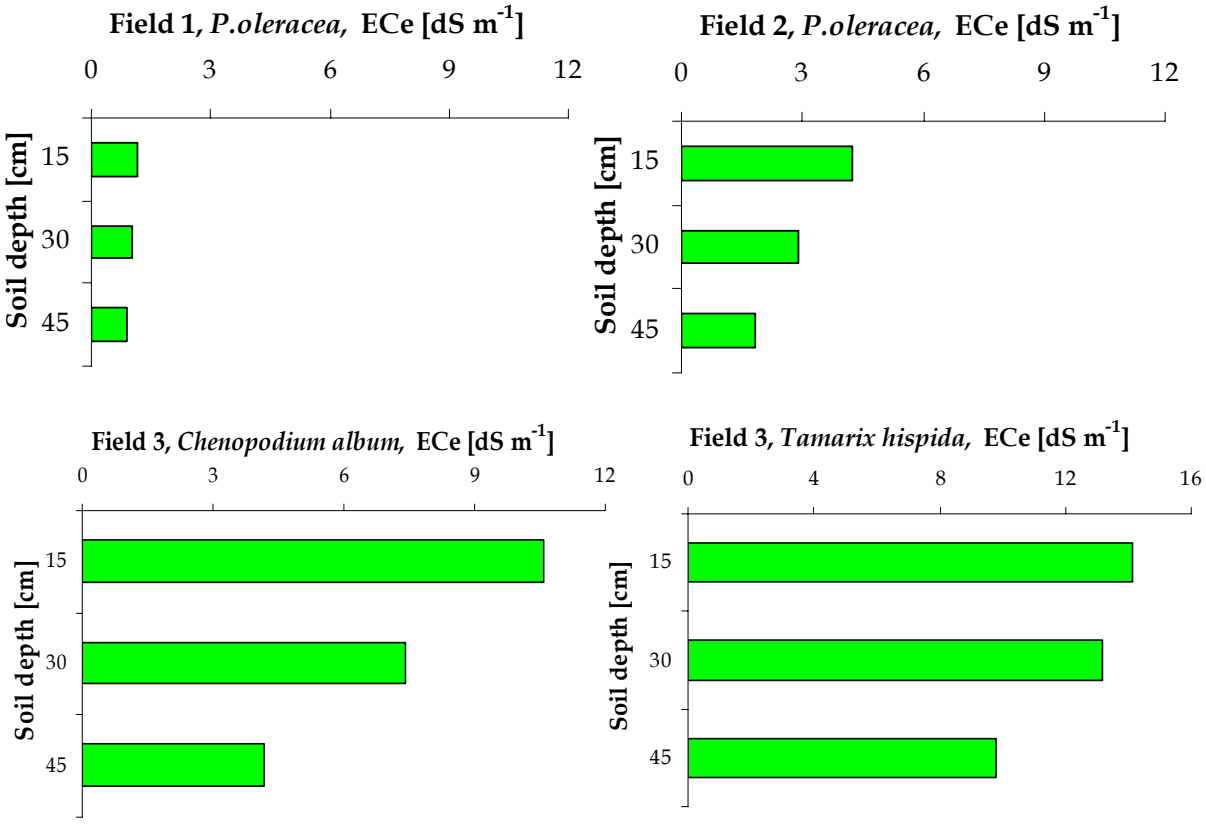

Fig. IV.4 - Electrical Conductivity of Soil Saturated Extract [dS m^{-1}] from the Monitored Fields (average values for fields 1 and 2)

Furthermore, adequate soil moisture conditions during the growing season of *P.oleracea* and input of highly saline groundwater to the plant roots, field 2 classified as slight to moderate degree of soil salinity ranging between 1.48-5.50 dS m^{-1}. In all cases, the upper layers had higher salt concentrations than subsoil layers (Annex 4).

In field 3, the highest degree of soil salinity in a 0-15 cm soil layer was 14.4 dS m^{-1} (highly saline) in the *T.hispida* field whereas the lowest degree of 9.78 dS m^{-1} was observed in the *G.glabra* field at the same soil profile. It should be stated that due to accessibility and adequate quality of the groundwater resources in this field, the plant species exposed to soil ECe levels over 8 dS m^{-1} did not show any visual symptoms of salt stress. Elsewhere, Bochansev *et al.* (1955) highlighted that *T.hispida, C.album* and *K.caspia* have highest adaptation to grow in saline environments and can be considered as halophyte species.

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 in our study to identify the specific soil problems and its severity using Sodium Adsorption Ratio (SAR) equation (Richards, 1954). Here, sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) ion concentrations are given in milliequivalent per liter (meq L^{-1}):

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \qquad \text{(IV.1)}$$

According to the results, SAR values for field 1 and field 2 averaged 1.1 and 3.35, respectively, within 45 cm soil surface (Annex 10). Meanwhile, high SAR values observed in the naturally grown fields. For instance, the highest 6.83 SAR was observed in *Apocynum lancifolium* soils, within 0-45 cm soil subsurface layers. Davis *et al.* (2006) highlighted that if the SAR value is above 13, sodium can cause problems for plants and soils. In our experimental sites, the SAR values were below 13 and no significant sodium effect was observed.

Moreover, Richards (1954) proposed soil exchangeable sodium percentage (ESP) using SAR to classify soils. The following equation was used to calculate ESP (%):

$$ESP = \frac{[100 * (-0.0126 + 0.01475 * SAR)]}{[1 + (-0.0126 + 0.01475 * SAR)]} \quad \text{(IV.2)}$$

The results showed that field 1 had lower ESP values than field 2 (Annex 10). However, as was the case in SAR, field 3 plants had the highest ESP. Average highest ESP 7.6 was observed in *G.glabra* field over the examined 45 cm soil profile. It should be stated that according to Richards (1954) soil classification, none of the investigated fields had significant sodic problems.

IV.1.7 – Depth and Mineralization of Groundwater

According to the results, the high groundwater table was observed in field 2 ranging between 56-61.5 cm within the soil pits (Annex 14), probably due to either inefficient drainage or drainage that is artificially blocked by farmers in order to raise either drainage water or the groundwater table to meet the crop water requirement. The farmers within the area of field 2 highlighted that the area sometimes faced irrigation water shortages and thus, groundwater resources is used as a source of moisture for crops. It should be pointed out that application of irrigation water could also have influenced to the increase of GWT in field 2. On the other hand, in spite of leaching activities in field 1 before the experiment, the groundwater table was far from the soil surface ranging between 108 and 115 cm within the soil pits.

Meantime, the mean electrical conductivity of the groundwater was 11.2 dS m^{-1} for field 2 and 6.2 dS m^{-1} for field 1. According to Rhoades *et al.* (1992), the groundwater of field 1

could be classified as moderate while field 2 as highly saline. The main reasons for high groundwater ECw in field 2 could have been: higher soil osmotic potential than matric pressure and improper drainage systems causing a rise in GWT.

IV.2 - Experiments with *Portulaca Oleracea* Golden Purslane

IV.2.1 – Crop Yield and Vegetative Growth

Despite the fact that the field 2 was irrigated during the vegetation period, the biomass of *P.oleracea* at the harvest time was very low averaging from 411 to 489 kg ha^{-1} dry matter in August and September, respectively (Annexes 11a & 11b). It can be presumed that other factors significantly influenced the decrease of production of biomass at field 2. These could have been: higher degree of soil salinity, higher rate of upward water movement from a shallow water table and no plucking the weeds after the irrigation. Interestingly, with no irrigation of field 1, high biomass production of *P.oleracea* averaging from 3507 to 3948 kg ha^{-1} DM was obtained. These results are confirmed by previous research implemented by the UzRICG (Kurambaev, 1969), which found that without irrigation the high crop (e.g. cotton) production can be obtained when the groundwater table (GWT) is at 1-1.2 m depth and only slightly saline. Moreover, before the experiment, field 1 was used as a pasture for cattle and sheep and the input of manure from these animals might have positively influenced to the higher production. On the other hand, field 2 was used to produce maize and fertilization was not done effectively. In addition, field 2 GWT was shallow, which caused anaerobic conditions and hampered the development of the *P.oleracea* root system. These aspects have already been studied in several crops, where the development was

adversely affected with a significant decrease in production due to shallow GWT (Torres & Hanks, 1989; Beltrao *et al.,* 1996).

In addition, a mean length of *P.oleracea* was measured in field 1 and 2 at harvest during the experiment to identify the vegetative growth (Fig. IV.5 & IV.6). At field 1, a mean length of *P.oleracea* averaged between 12.7–19.7 cm at harvest in August and September, respectively, whereas at field 2 it varied from 14.5 to 17.8 cm at the harvest time.

Fig. IV.5 - Measurement of *P.oleracea* Height on the Monitored Fields

Moreover, the roots of the plant varied from 5-10 cm in both experimental fields. It should be pointed out that the higher degree of soil salinity in field 2 did not greatly affect to the plant height.

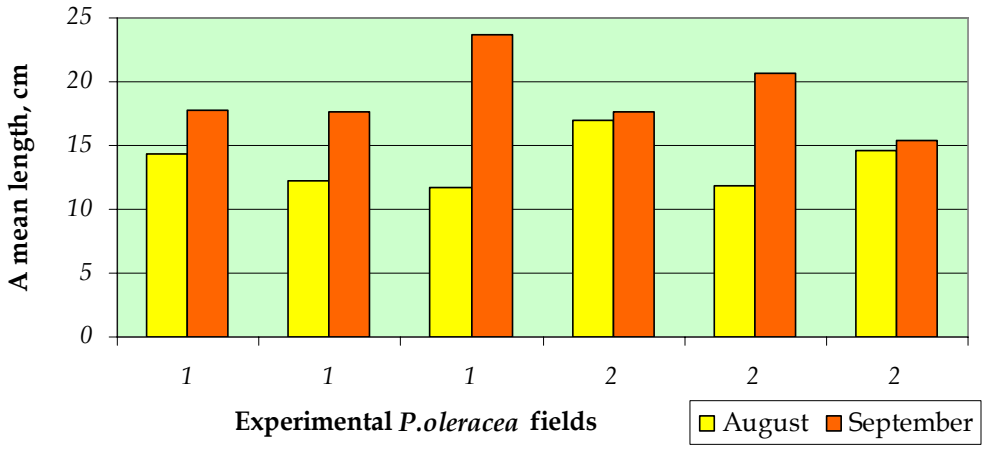

Fig. IV.6 - A Mean Length [cm] of *P.oleracea* Golden Purslane in Three Different Plots of the two Experimental Fields at Harvest

IV.2.2 – Salt Accumulation

The analysis revealed that *P.oleracea* tissues accumulated the largest amounts of chloride and magnesium in field 1 (Annex 12). Moreover, sodium and calcium concentrations were also relatively high in this field. The highest chloride ion concentration was accumulated by *P.oleracea* in field 1 and ranged between 64.16-75.63 mg g^{-1} DM, and averaged 71.10 mg g^{-1} DM in August harvest (Table IV.1). Furthermore, it was observed that the uptake of chloride (Cl^-) by examined species in the September harvest was lower, and ranged between 64.70-72.73 mg g^{-1} DM, and averaged 69.4 mg g^{-1} DM. Meanwhile, the magnesium varied from 42.02-48.49 mg g^{-1} DM, and averaged 44.54 mg g^{-1} DM in August harvest. The magnesium concentration also decreased in the September harvest, and ranged between 35.05-42.02 mg g^{-1} DM and averaged 37.86 mg g^{-1} DM. The sodium and calcium concentrations varied between 9.54-8.19 mg g^{-1} DM and 12.9-11.1 mg g^{-1} DM over the examined period. In addition, Potassium showed considerably low accumulation varying from 3.7-2.83 mg g^{-1} DM at the harvested periods. The results also showed the slight decrease of some ions in the month of September.

Interestingly, at field 2, *P.oleracea* tissues accumulated largest amounts of chloride and sodium while magnesium and calcium concentrations were rather low. For instance, sodium ranged between 18.65-31.51 mg g^{-1} DM and averaged 26.40 mg g^{-1} DM in the August harvest, while the September harvest showed slight decreases in sodium uptake, ranging between 18.08-33.09 and averaging 24.85 mg g^{-1} DM. Furthermore, chloride accumulation averaged from 59.9 to 56.7 mg g^{-1} DM in August and September, respectively. In addition, higher accumulation of Cl^- and Na^+ in the tissues of *P.oleracea* plants in moderately saline soil can mean this plant is a relatively a salt removal plant since

soils contain mainly NaCl. As was the case in field 1, the potassium concentration in field 2 was low varying from 3.1 to 2.5 mg g^{-1} DM in August and September, accordingly.

Table IV.1 – Chloride Content (mg g^{-1} DM) in the Tissues of *P.oleracea* in Khorezm Region. Values are Means and Standard Deviations of Three Treatments

Date	Field	Plot	Cl^-
20.08.06	1	1	75.63 ± 3.76
20.08.06	1	2	73.60 ± 3.98
20.08.06	1	3	64.16 ± 4.22
20.08.06	2	1	54.23 ± 3.55
20.08.06	2	2	59.83 ± 5.45
20.08.06	2	3	65.73 ± 2.66

Date	Field	Plot	Cl^-
21.09.06	1	1	72.73 ± 2.60
21.09.06	1	2	70.80 ± 3.89
21.09.06	1	3	64.70 ± 4.03
21.09.06	2	1	52.73 ± 4.40
21.09.06	2	2	54.50 ± 3.85
21.09.06	2	3	63.10 ± 2.19

In many cases of our results, August period extracted higher amounts of ions than September due to several factors: 1) plant transpiration and soil evaporation are higher in August because of higher radiation (temperature and light); 2) air relative humidity is higher in September.

In addition, the extraction of total soluble salts by *P.oleracea* was similar in both fields (Fig. IV.7). As can be seen from Fig. IV.7, on average, the plant can extract from 141.8 to 129.4 mg g^{-1} DM in field 1 over the examined period. In field 2, it averaged between 120.5-113.8 mg g^{-1} DM in August and September, correspondingly.

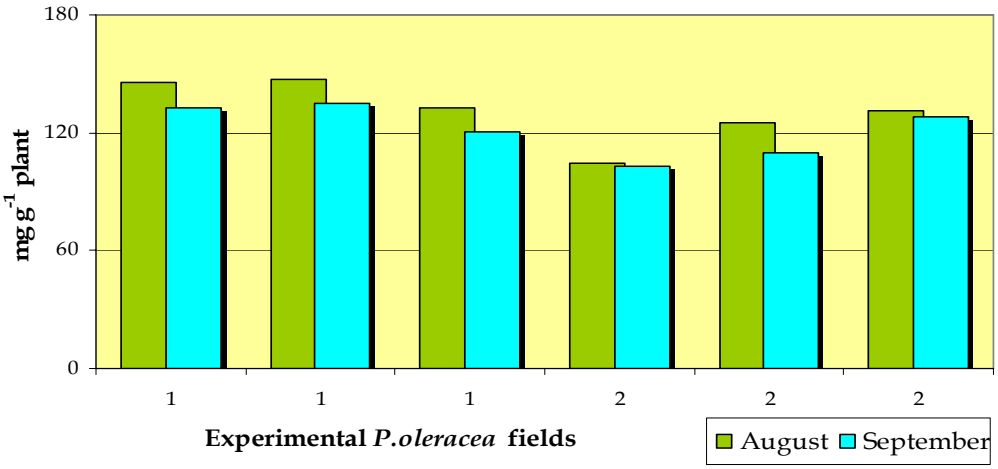

Fig. IV.7 – Concentration of Ions [mg g^{-1}] in the Dry Shoot Material of *P.oleracea* Golden Purslane in the Khorezm Region

Despite low soil salinity levels in field 1, the higher salt uptake, on average, 496.7 kg ha^{-1} was obtained in August, while 511.3 kg ha^{-1} in September (Fig. IV.8). As shown in Fig. IV.8, average salt accumulation of *P.oleracea* in field 2, in terms of kilogram per hectare, was decreased drastically ranging between 49.6-55.5 kg ha^{-1} during the examined period, most probably due to low biomass production.

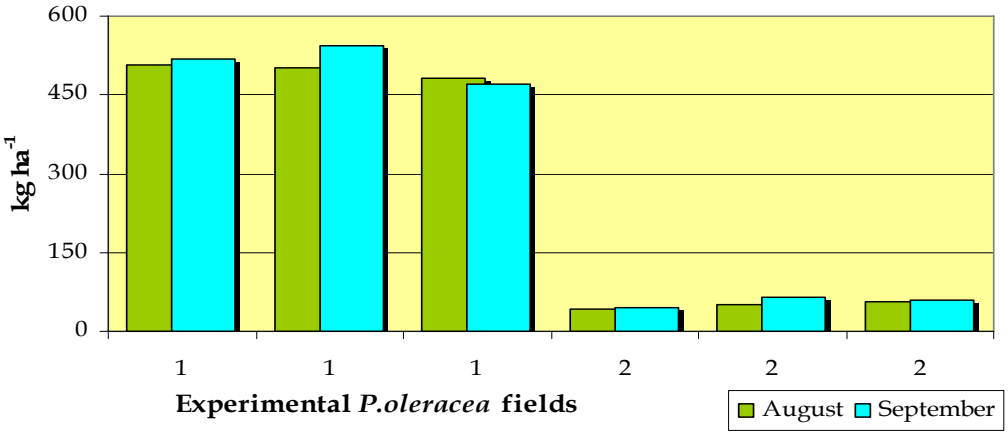

Fig. IV.8 – Extraction of Salts from the Soil (kg ha^{-1}) using Dry Matter of *P.oleracea* Golden Purslane in the Khorezm Region

This evergreen *P.oleracea* species showed to be relatively tolerant to saline conditions and can be planted as ornamentals without irrigation. Furthermore, due to higher capillary rise of groundwater and the lack of plucking weeds after irrigation, field 2 had produced lower amounts of dry matter. Furthermore, as stated earlier, field 1 produced higher plant density than field 2, because field 2 was sparsely populated compared to field 1 (Fig. IV.9 a, b).

Fig. IV.9 (a) - *P.oleracea* at Field 1

Fig. IV.9 (b) - *P.oleracea* at Field 2

Meanwhile, our analysis showed that *P.oleracea* accumulated 16.81 % of the total soil salts. It should be pointed out that *P.oleracea* can remove the salts only from 5-10 cm of soil surface because of its root length (Table IV.2). Due to low plant density and high soil salinity, the extraction of salts from the soil was much lower in field 2.

Table IV.2 - Removal of Soil Salts, using *P.oleracea* Plant in two Different Experimental Fields

Field №	Root depth [m]	TDS [g kg^{-1}]	BD [kg m^{-3}]	Soil salts [kg ha^{-1}]	Plant salt accumulation [kg ha^{-1}]	Removal of salts from soil [%]
1	0.10	1.46	1350	2957	497	16.81
2	0.10	5.30	1410	11210	50	0.45

IV.3 - Experiments with Native Wild Species

IV.3.1 – Crop Yield and Vegetative Growth

According to the results of experiment, *C.album* had the highest biomass production amongst native wild species ranging between 2689-3243 kg ha^{-1} DM in August and September, respectively (Annex 11a and 11b). Moreover, *T.hispida* had produced slightly lower biomass production than *C.album* with the potential yield of 1889-2062 kg ha^{-1} DM. The less efficient crops, in terms of yield productions, were native *P.oleracea*, *A.lancifolium*, *K.caspia*, *G.glabra* and *A.pseudalhagi*. In addition, the data showed a yield reduction in September harvest as comparing to August for native *P.oleracea* and *G.glabra*, probably due to climatic parameters such as low light intensity and low air temperature during September. Previous results show (Khamidov *et al.,* 2005) that the experimental region is often leached in the end of vegetation period, i.e. in the autumn, because of higher soil salinity in that period. Thus, lower biomass production could have been obtained in the autumn season.

The analysis of the plant height data showed that *C.album* height reached a mean value of 65 cm in the August harvest but was as high as 82 cm in the September harvest (Annex 13). However, a mean highest value was obtained for *A.lancifolium* varying from 95 to 85 cm at harvest. In general, the plant height was not greatly affected by the soil salinity even with the highest salt concentration level of 13 dS m^{-1}. This indicates that the plant height is not extensively influenced by salinity of soil or GWT. However, greater improvement of the plant height could be attained under either irrigation or/and fertilization.

IV.3.2 – Salt Accumulation

T.hispida, *K.caspia* and *C.album* were found to be the most effective in removing chloride ions from the soil in naturally grown wild species field (Table IV.3). The following efficient species were native *P.oleracea*, *A.pseudalhagi*, *G.glabra* and *A.lancifolium*. Furthermore, the analysis revealed that sodium concentration were relatively high for *T.hispida*, *C.album* and *K.caspia* plant species ranging between 32.53, 38.74 and 40.09 mg g^{-1} DM in the August period (Annex 12). However, in the September period there showed a slight decrease 25.87, 33.66 and 26.43 mg g^{-1} DM, respectively for the above-mentioned species. *P.oleracea* green purslane, *C.album* and *K.caspia* showed higher values in accumulation magnesium content. Since the organic matters of the soils in the investigated area are relatively low, the potassium concentrations in the plant tissues were also low.

Table IV.3 – Chloride Content (mg g^{-1} DM) in the Tissues of Wild Plant Species in Khorezm Region. Values are Means and Standard Deviations of Three Treatments

Date	Plants	Cl^-	Date	Plants	Cl^-
20.08.06	Nat. *P.oleracea*	57.90 ± 3.04	21.09.06	Nat. *P.oleracea*	58.43 ± 3.81
20.08.06	*T.hispida*	120.03 ± 2.40	21.09.06	*T.hispida*	119.13 ± 2.95
20.08.06	*A.lancifolium*	37.53 ± 3.26	21.09.06	*A.lancifolium*	41.30 ± 2.47
20.08.06	*K.caspia*	115.03 ± 4.36	21.09.06	*K.caspia*	108.30 ± 3.31
20.08.06	*G.glabra*	43.76 ± 2.56	21.09.06	*G.glabra*	39.36 ± 4.47
20.08.06	*A.pseudalhagi*	53.40 ± 3.85	21.09.06	*A.pseudalhagi*	48.86 ± 1.78
20.08.06	*C.album*	111.03 ± 2.31	21.09.06	*C.album*	104.5 ± 3.99

In addition, capacity of the wild plants to remove salts from the soil is shown in Fig. IV.10. It is clear from the figure that three species *C.album*, *K.caspia* and *T.hispida* have high potential to accumulate soluble salts. Native *P.oleracea* and *A.pseudalhagi* showed relatively low removal of salts from the soil. It is interesting to note that *A.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.

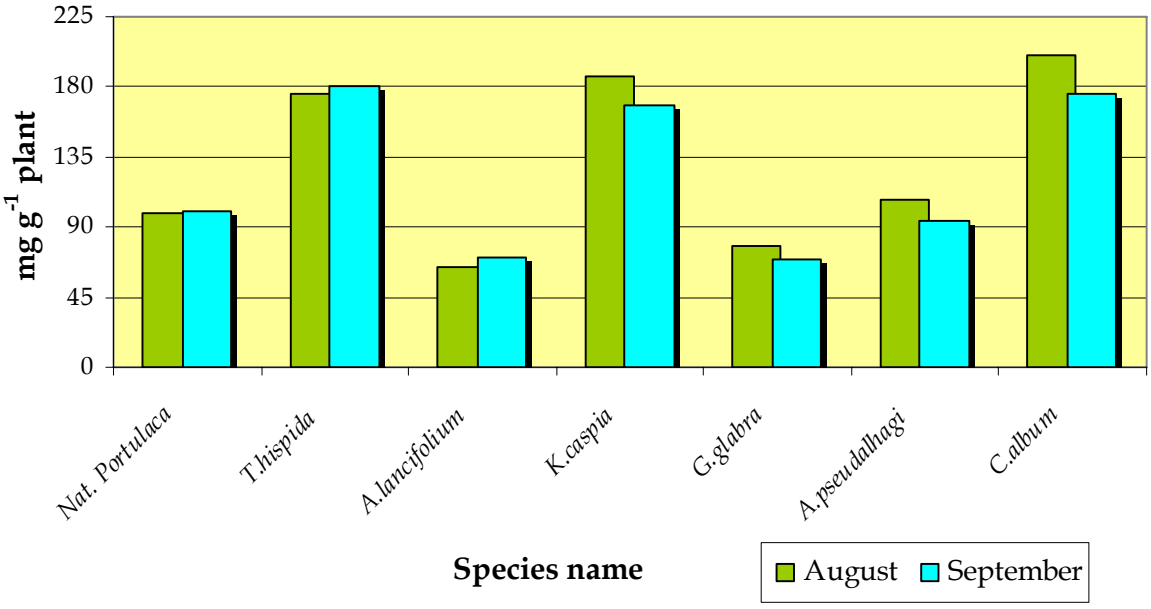

Fig. IV.10 - Accumulation of Ions (mg g^{-1} DM) by the Wild Species of the Khorezm Region

The most efficient wild plant in removing salts from the soil was *C.album* which removed between 538.4-569.6 kg ha^{-1} in August and September, respectively (Fig. IV.11). Furthermore, *T.hispida* and *K.caspia* accumulated between 330.8-370.9 kg ha^{-1} and 271.5-275.5 kg ha^{-1} during August and September periods. The least efficient native wild species were identified as *A.pseudalhagi*, *G.glabra* and *A.lancifolium* where they removed less than 150 kg ha^{-1}. Meanwhile, *P.oleracea* green purslane showed slight lower ion accumulation ranging between 204.4-200.8 kg ha^{-1} during August and September periods.

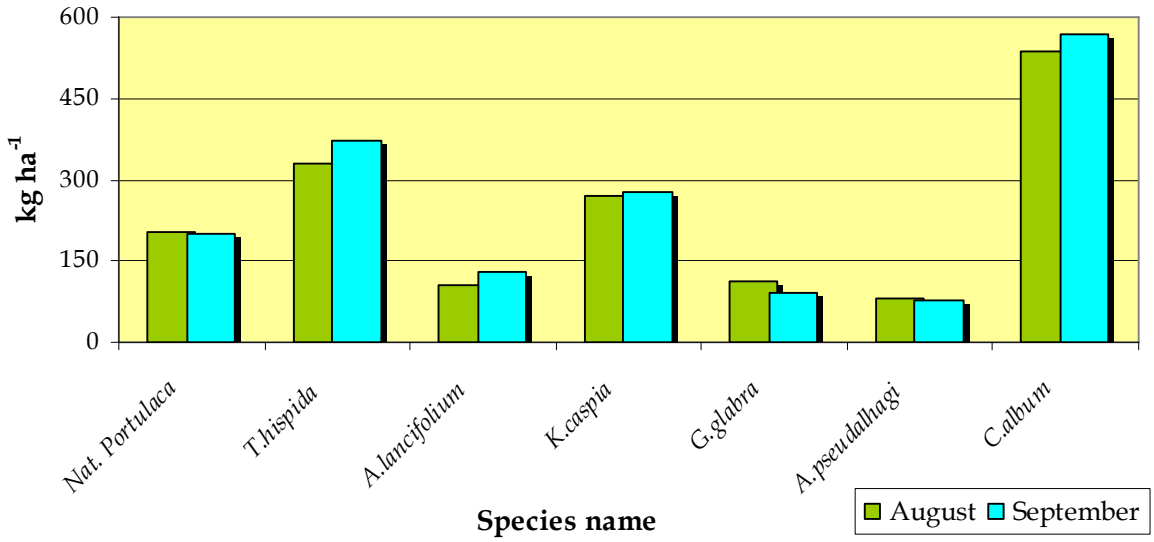

Fig. IV.11 - Removal of Total Ion Concentrations (kg ha^{-1} DM) by the Wild Species of the Khorezm Region

In addition, *C.album* showed the highest accumulation of salts (1.45 %) from the soil on the percentage basis. Because its root depth is about 25-30 cm, it can only remove the salts within that profile (Table IV.4). Followed efficient species were *K.caspia*, *T.hispida, G.glabra* and *A.lancifolium.*

Table IV.4 - Removal of Soil Salts, using Wild Species in the Experimental Fields

Plants	Root depth [m]	TDS [g kg^{-1}]	BD [kg m^{-3}]	Soil salts [kg ha^{-1}]	Plant salt accumulation [kg ha^{-1}]	Removal of salts from soil [%]
C.album	0.25	9.23	1590	36689	538.4	1.47
K.caspia	0.20	16.50	1560	38610	271.5	0.70
A.lancifolium	0.55	9.70	1602	85467	106.7	0.12
T.hispida	0.50	15.46	1602	123835	330.8	0.27
G.glabra	0.30	10.57	1590	50419	112.1	0.22

V – CONCLUSIONS AND RECOMMENDATIONS

In arid areas, drought and salinity are the key factors that responsible for limiting crop productivity. Uzbekistan's Khorezm region is a semi-arid area which is badly affected by soil salinity of which the main causes are the mismanagement of water and land resources over the past forty years as well as poor drainage infrastructures. As long as these problems continue to intensify, the health and livelihood of the population of the region will be threatened and the land and water resources irreversibly affected.

Conventional techniques, namely leaching and use of enhancing fertilization have been used to mitigate soil salinity and to increase the salt tolerance of agricultural crops. However, the intense use of these conventional techniques has also attracted public attention due to environmental pollution and contamination of groundwater resources. The phytoremediation technique has become an efficient method to cope with soil salinity in developed countries. More recently, this method has been applied to the northern region of Uzbekistan with the hope of remediating saline soils and helping to maintain the sustainability of agricultural lands. Moreover, as cotton is the dominant crop in the Khorezm region and low yields of cotton are mostly caused by salinity, the introduction of salt removing species could potentially create both environmental and economic solutions, provided that they can be used as vegetables, ornamentals or fodder, and could also be integrated into cultivation/rotation programmes to remediate temporarily saline soils.

The findings from eight investigated species indicated that annual *Portulaca oleracea* golden purslane is the most potential salt (ion) removal species in the Khorezm region of Uzbekistan. In general, the ideal multipurpose plant species should have a combination of the following features: ability to remove high levels of ions from the soil; high biomass

production potential; a short vegetation period; low water consumption; good acceptance by local consumers as a leafy vegetable; tolerance to drought and hot conditions; and easy crop management. Taking into consideration all these parameters of the ideal multi-purpose plant species and the results of the field experiments, the *P.oleracea* golden purslane has the highest potential to mature in salt-affected soils, to remove high levels of salts from the soil and to develop on both loamy and sandy soils, which represent the dominant soil textures in the region.

However, in the experimental area in field 2, high capillary water rise from a shallow groundwater table significantly contributed to soil moisture conditions and to the biomass production of the *P.oleracea*. Many scientists have pointed out that capillary rise may have a negative effect on yield, when the groundwater table is about 0.6 m from soil surface. This research proved that due to a shallow groundwater table (~ 0.6) and applied irrigation water in field 2, the plant density and biomass production was significantly low.

On the other hand, no irrigation was required for obtaining the highest biomass production in field 1 when the water table remained at a depth of about 1.1 m, and slightly saline, during the cropping season. It can be concluded that upward flow from shallow water is a significant component in the irrigation water balance of crops as well as optimization of crop productivity.

Furthermore, the analysis showed that among the native wild plants, grown on the salinized soils, *Chenopodium album, Tamarix hispida* and *Karelinia caspia* accumulated the highest ion concentrations and can be widely cultivated in the Khorezm region to remediate saline soils. Furthermore, native plants have the advantage of being highly adapted to the local climatic and edaphic contaminated conditions.

However, a major negative aspect of annual *P.oleracea* was its root profile because it can only remove ions within 15 cm of the soil surface. On the other hand, the findings from native plants revealed that perennial *C.album, K.caspia*, *T.hispida, G.glabra* and *A.lancifolium* species were able to remove less salts but from much deeper layers - up to 50 cm.

Previous investigations in the Mediterranean area have shown that annual *Tetragonia tetragonioides* and perennial *Atriplex prostrata* crops produced the highest biomass and were efficient crops to remove ions from salt-affected soils. For instance, Beltrao *et al.* (2006) found that *Tetragonia tetragonioides* produced 4200 kg ha^{-1} DM and removed up to 700 kg ha^{-1} NaCl in Portugal, whereas Cuartero *et al.* (2002) successfully tested *Atriplex prostrata* in Spain, which produced a biomass of 14 tons ha^{-1} DM and removed about 2 tons ha^{-1} ions. In this study, *Portulaca oleracea* produced about 3950 kg ha^{-1} DM and removed about 500 kg ha^{-1} ions. Therefore, in future investigations, we need to assess other crops, such as *Tetragonia tetragonioides* and *Atriplex prostrata* for their efficiencies to remove ions from the saline soils.

Nevertheless, the phytoremediation technique is not the sole method to prevent soil salinity and to optimize crop productivity. Economically, soil leaching and combined effects of fertilizers and salts have been an efficient method to control salinity because they are easier and cheaper than phytoremediation. In the leaching process, ions move from upper layers to deeper layers and may reach the aquifers, which is a negative environmental consequence. The plants can be produced but this has a negative impact on deeper soil layers and aquifers. The phytoremediation technique is an environmentally cleaner and safer method but is not always economically feasible. Thus, the best way to remediate soil salinity in the agricultural areas of Khorezm Region and to maintain the natural environment in good

condition is to combine both conventional and phytoremediation techniques in order to achieve economic, environmental and social sustainability. However, additional research is needed and encouraged on these topics, in particular, how to develop the phytoremediation method into more a economically feasible technique for the remediation of saline soils.

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ANNEXES

Annex 1. Daily meteorological information in the investigated area for the three experimental months, 2006

Urgench meteorological station, № 4166060

Date	Air temperature, °C						Average air relative humidity, %			Average wind speed, m s^{-1}			Precipitation, mm		
	July		August		September		July	August	September	July	August	September	July	August	September
	max	min	max	min	max	min									
1	34.7	21.1	32.5	15.1	30.0	19.2	45	43	34	2.1	2.8	5.4			
2	36.4	21.7	34.5	20.2	28.1	13.2	47	36	31	2.3	3.8	5.6			
3	38.7	21.4	36.0	18.7	27.8	12.1	41	38	32	1.8	2.5	3.6			
4	33.8	22.5	37.5	20.5	30.7	11.8	32	40	36	5.9	2.4	3.1			
5	28.9	18.3	33.5	18.8	32.5	13.8	47	39	38	3.5	3.0	2.6			
6	32.2	19.0	34.5	16.4	32.8	13.5	31	43	51	3.5	2.6	2.0	0		
7	32.8	18.3	36.0	18.8	33.7	14.9	29	38	40	3.7	1.8	1.9			
8	34.2	19.3	37.9	19.2	29.3	16.9	28	43	48	4.1	1.9	3.0			
9	33.9	20.9	40.8	20.8	29.0	13.8	28	37	52	4.1	2.0	3.0			
10	32.0	18.9	35.9	23.9	29.0	13.9	28	39	52	4.5	4.3	1.4			
11	32.0	17.2	36.8	18.9	30.0	13.7	29	32	50	4.4	4.0	1.0			
12	28.6	15.8	37.9	22.0	31.4	16.2	41	35	53	3.6	3.1	2.0			
13	30.2	15.5	40.4	21.5	22.5	15.6	43	39	56	3.4	2.8	2.8			0
14	32.9	18.7	35.3	22.7	24.0	10.4	37	43	52	2.9	2.8	2.3			
15	33.8	18.9	31.2	18.8	25.2	8.5	46	41	51	1.9	3.4	2.3			
16	35.3	20.6	28.3	13.8	20.7	10.5	39	35	56	3.0	3.6	2.3		0.6	0.5
17	36.4	20.5	29.4	13.2	18.2	11.2	37	39	68	1.6	2.6	3.4			
18	37.6	21.5	31.6	14.2	19.3	7.7	35	37	55	3.0	3.1	1.8			
19	37.0	21.9	34.4	15.8	22.4	8.4	38	36	52	2.6	2.5	2.6			
20	37.3	20.6	36.4	15.8	24.0	8.2	40	38	59	2.4	2.5	1.6			
21	38.8	21.6	37.9	19.9	25.7	9.2	39	36	52	2.0	2.4	2.4			
22	37.9	24.1	37.4	19.3	26.0	8.6	42	38	45	3.4	2.1	3.5			
23	32.3	20.3	37.5	19.4	27.0	9.4	30	39	44	3.9	2.1	3.6	0.6		
24	32.4	18.6	38.1	19.7	26.0	8.9	32	39	41	3.8	1.6	3.1			
25	33.6	17.8	36.4	19.6	27.1	8.8	35	49	40	3.8	2.0	2.1			
26	38.1	19.8	32.8	17.9	28.6	9.3	36	44	41	3.8	3.3	2.1			
27	32.7	18.7	33.5	16.5	29.7	12.2	37	42	44	4.4	2.8	2.1			
28	34.2	17.1	33.9	18.4	26.7	13.7	43	51	43	1.9	2.0	3.1			
29	34.8	19.7	36.1	18.8	20.1	6.7	56	50	46	1.9	1.8	2.5	0		
30	32.0	21.8	36.5	17.5	21.7	4.9	39	51	38	4.0	1.8	2.9	0		
31	29.8	18.2	37.4	17.7			47	39		4.6	1.9		0.8		

Source: Glavgidromet (2006), Tashkent

Annex 2. Soil physical properties of the study site in the Gurlan district, Khorezm Region

Field №	Soil depth, cm	Bulk density [g cm^{-3}]	*Fraction weight (mm) in %*								Kachinsky classification	Fraction content by USA texture triangle [mm]			American classification
			>0,25	0,25 -0,1	0,1 - 0,05	0,05 -0,01	0,01- 0,005	0,005- 0,001	<0,001	Physical clay [%]		Sand 0.05- 2.0	Silt 0.002- 0.05	Clay <0.002	
1	0-10	1.35	2.24	16.98	13.88	22.32	11.50	17.40	15.68	44.58	Medium loam	35	47	18	Loam
1	10-20	1.36	3.98	16.29	13.81	22.34	12.66	14.14	16.78	43.58	Medium loam	33	48	19	Loam
1	20-30	1.37	2.15	11.49	18.70	22.40	12.64	18.06	14.56	45.26	Heavy loam	33	51	16	Silt loam
1	30-40	1.39	1.65	13.66	16.01	26.90	9.78	17.72	14.28	41.78	Medium loam	32	51	17	Silt loam
1	40-50	1.39	5.07	15.78	4.27	28.20	11.64	19.78	15.26	46.68	Heavy loam	26	57	17	Silt loam
2	0-10	1.41	3.14	9.70	12.92	22.34	14.18	20.42	17.30	51.90	Heavy loam	27	55	18	Silt loam
2	10-20	1.43	1.40	8.24	16.66	18.10	14.48	23.78	17.34	55.60	Heavy loam	27	53	20	Silt loam
2	20-30	1.43	0.93	8.49	17.82	27.62	5.72	23.72	15.70	45.14	Heavy loam	28	54	18	Silt loam
2	30-40	1.44	1.97	7.66	20.55	26.24	10.80	17.38	15.40	43.58	Medium loam	31	52	17	Silt loam
2	40-50	1.44	0.79	9.13	23.48	26.70	9.50	15.40	15.00	39.90	Medium loam	34	50	16	Silt loam
3	0-10	1.56	1.04	2.85	37.34	35.82	4.70	4.61	13.64	22.95	Light loam	41	43	16	Loam
3	10-20	1.62	0.52	3.98	52.48	30.98	3.20	3.08	5.76	12.04	Sandy loam	57	37	6	Sandy loam
3	20-30	1.60	1.63	3.55	40.14	42.42	3.34	3.56	5.36	12.26	Sandy loam	46	48	6	Sandy loam
3	30-40	1.60	0.82	5.20	43.52	39.32	3.26	3.34	4.54	11.14	Sandy loam	50	44	6	Sandy loam
3	40-50	1.63	0.59	3.83	46.84	37.50	2.68	3.16	5.40	11.24	Sandy loam	52	43	5	Sandy loam

Annex 3. Volumetric soil water content on the monitored fields of Khorezm Region

Field №	Soil depth, cm	Volumetric soil water content [m^3 m^{-3}]		
		Wilting point (WP)	Field capacity (FC)	Available water holding capacity (AWHC)
1	0-10	0.210	0.304	0.094
1	10-20	0.258	0.286	0.028
1	20-30	0.265	0.281	0.015
1	30-40	0.279	0.288	0.009
1	40-50	0.281	0.292	0.011
2	0-10	0.313	0.319	0.006
2	10-20	0.287	0.300	0.013
2	20-30	0.283	0.300	0.017
2	30-40	0.288	0.308	0.020
2	40-50	0.287	0.298	0.012

Annex 4. Chemical soil properties of the study site in the Gurlan district, Khorezm Region

Field №	Soil Pit №	Soil depth, [cm]	Water extract 1:5, content in:								FAO classification *ECe* [dS m^{-1}]
			TDS [%]	[%]							
				HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+	
1	1	0-15	0.150	0.033	0.007	0.066	0.020	0.009	0.007	0.0025	1.20
1	1	15-30	0.127	0.033	0.007	0.049	0.020	0.006	0.005	0.0015	1.02
1	1	30-45	0.108	0.033	0.007	0.035	0.015	0.006	0.004	0.0015	0.86
1	2	0-15	0.138	0.030	0.007	0.060	0.020	0.006	0.008	0.0025	1.10
1	2	15-30	0.120	0.030	0.007	0.045	0.015	0.006	0.008	0.0015	0.96
1	2	30-45	0.117	0.030	0.007	0.044	0.015	0.006	0.007	0.0010	0.94
1	3	0-15	0.150	0.033	0.014	0.059	0.020	0.009	0.008	0.0015	1.20
1	3	15-30	0.135	0.033	0.011	0.049	0.020	0.006	0.007	0.0015	1.08
1	3	30-45	0.117	0.030	0.011	0.038	0.020	0.003	0.007	0.0015	0.94
2	1	0-15	0.287	0.030	0.032	0.133	0.045	0.009	0.025	0.0030	2.30
2	1	15-30	0.222	0.030	0.028	0.097	0.030	0.009	0.023	0.0020	1.78
2	1	30-45	0.205	0.030	0.028	0.083	0.025	0.009	0.022	0.0020	1.64
2	2	0-15	0.615	0.030	0.056	0.344	0.095	0.030	0.041	0.0080	4.92
2	2	15-30	0.403	0.030	0.046	0.205	0.055	0.021	0.034	0.0035	3.22
2	2	30-45	0.185	0.030	0.035	0.056	0.020	0.006	0.025	0.0020	1.48
2	3	0-15	0.688	0.030	0.056	0.383	0.115	0.024	0.050	0.0050	5.50
2	3	15-30	0.455	0.030	0.049	0.235	0.065	0.018	0.045	0.0025	3.64
2	3	30-45	0.287	0.030	0.049	0.118	0.035	0.012	0.035	0.0020	2.30
3	CA	0-15	1.323	0.027	0.112	0.783	0.245	0.064	0.052	0.0060	10.58
3	CA	15-30	0.925	0.027	0.070	0.551	0.180	0.048	0.018	0.0040	7.40
3	CA	30-45	0.520	0.024	0.035	0.307	0.100	0.027	0.011	0.0025	4.16
3	KC	0-15	1.155	0.024	0.042	0.758	0.250	0.048	0.019	0.0020	9.24
3	KC	15-30	1.003	0.024	0.025	0.668	0.240	0.030	0.011	0.0020	8.02
3	KC	30-45	0.753	0.024	0.021	0.485	0.175	0.024	0.007	0.0015	6.02
3	AL	0-15	1.650	0.021	0.578	0.504	0.230	0.103	0.160	0.0075	13.20
3	AL	15-30	1.425	0.021	0.455	0.504	0.190	0.094	0.145	0.0045	11.40
3	AL	30-45	1.362	0.021	0.438	0.478	0.180	0.088	0.145	0.0040	10.90
3	TH	0-15	1.768	0.024	0.455	0.744	0.260	0.103	0.160	0.0100	14.14
3	TH	15-30	1.647	0.024	0.385	0.729	0.250	0.082	0.160	0.0090	13.18
3	TH	30-45	1.222	0.024	0.210	0.630	0.165	0.076	0.110	0.0060	9.78
3	GG	0-15	1.328	0.033	0.560	0.294	0.150	0.082	0.185	0.0060	10.62
3	GG	15-30	0.787	0.030	0.263	0.246	0.085	0.057	0.090	0.0050	6.30
3	GG	30-45	0.473	0.030	0.140	0.155	0.055	0.030	0.052	0.0050	3.78

Annex 4 (cont.) Soil salinity classifications according to different organizations

a) USSR classification based on laboratory measurements (%):

Salinity level	**Cl^-**	**Na^+**	**Total dissolved solid**
Non saline	< 0.01	< 0.023	< 0.3
Low saline	0.01 - 0.035	0.023 - 0.046	0.3 - 0.5
Moderately saline	0.035 - 0.070	0.046 - 0.092	0.5 - 1.0
High salinity	0.070 - 0.140	0.092 - 0.184	1.0 - 2.0
Severely saline	> 0.140	> 0.184	> 2.0

b) FAO (USDA) classification:

Salinity level	**Degree of crops sensitivity**	**Electrical conductivity of saturated soil extract *ECe* (dS m^{-1})**
Non saline	very sensitive crops	0 - 2
Low saline	sensitive crops	2 - 4
Moderately saline	mildly sensitive crops	4 - 8
High salinity	mildly resistant crops	8 - 16
Severely saline	resistant crops	> 16

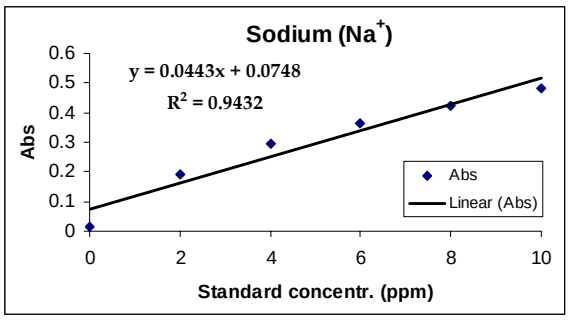
Annex 5. Calculation table for Na^+ content in the soil based on calibration curve

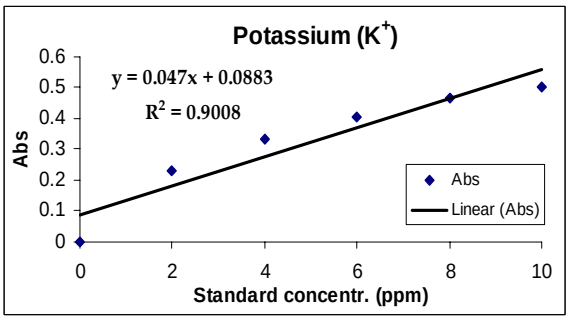
Flame photo-metry result	Reference solution mg L^{-1}	Without dilution		Dilution 5+45		**Flame photo-metry result**	Reference solution mg L^{-1}	Without dilution		Dilution 5+45	
		%	m/eqv.	%	m/eqv.			%	m/eqv.	%	m/eqv.
1	1	0.0005	0.022	0.002	0.108	**34**	36	0.018	0.781	0.090	3.906
2	2	0.0010	0.043	0.005	0.217	**35**	38	0.019	0.825	0.095	4.123
3	3	0.0015	0.065	0.007	0.326	**36**	40	0.020	0.868	0.100	4.340
4	4	0.0020	0.087	0.010	0.434	**37**	42	0.021	0.911	0.105	4.557
5	5	0.0025	0.108	0.012	0.542	**38**	44	0.022	0.955	0.110	4.851
6	6	0.0030	0.130	0.015	0.651	**39**	46	0.023	0.998	0.115	4.991
7	7	0.0035	0.152	0.017	0.76	**40**	48	0.024	1.042	0.120	5.208
8	8	0.0040	0.174	0.020	0.868	**41**	50	0.025	1.085	0.125	5.425
9	9	0.0045	0.195	0.022	0.977	**42**	50	0.026	1.128	0.130	5.642
10	10	0.0050	0.217	0.025	1.085	**43**	54	0.027	1.182	0.135	5.859
11	11	0.0055	0.239	0.027	1.194	**44**	56	0.028	1.215	0.140	6.076
12	12	0.0060	0.260	0.030	1.302	**45**	58	0.029	1.259	0.145	6.293
13	13	0.0065	0.282	0.032	1.410	**46**	60	0.030	1.302	0.150	6.510
14	14	0.0070	0.304	0.035	1.519	**47**	62	0.031	1.367	0.155	6.836
15	15	0.0075	0.326	0.037	1.628	**48**	64	0.032	1.389	0.160	6.944
16	16	0.0080	0.347	0.040	1.736	**49**	66	0.033	1.432	0.165	7.161
17	17	0.0085	0.369	0.042	1.845	**50**	68	0.034	1.476	0.170	7.378
18	18	0.0090	0.391	0.045	1.953	**51**	70	0.035	1.519	0.175	7.595
19	19	0.0095	0.412	0.047	2.062	**52**	72	0.036	1.562	0.180	7.812
20	20	0.0100	0.434	0.050	2.170	**53**	74	0.037	1.606	0.185	8.029
21	21	0.0105	0.456	0.052	2.278	**54**	76	0.038	1.649	0.160	8.246
22	22	0.0110	0.374	0.055	2.409	**55**	78	0.039	1.693	0.195	8.465
23	23	0.0115	0.499	0.058	2.541	**56**	80	0.040	1.736	0.200	8.680
24	24	0.0120	0.521	0.060	2.628	**57**	82	0.041	1.779	0.205	8.897
25	25	0.0125	0.542	0.062	2.716	**58**	84	0.042	1.823	0.210	9.114
26	26	0.0130	0.564	0.065	2.848	**59**	86	0.043	1.866	0.215	9.331
27	27	0.0135	0.586	0.068	2.979	**60**	88	0.044	1.910	0.220	9.548
28	28	0.0140	0.608	0.070	3.067	**61**	90	0.045	1.953	0.225	9.765
29	29	0.0145	0.629	0.072	3.154	**62**	95	0.048	2.062	0.237	10.308
30	30	0.0150	0.651	0.075	3.286	**63**	100	0.050	2.170	0.250	10.850
31	31.5	0.0157	0.684	0.079	3.461	**64**	105	0.525	2.278	0.262	11.392
32	33	0.0165	0.716	0.082	3.592	**65**	110	0.055	2.387	0.275	11.935
33	34.5	0.0172	0.749	0.086	3.767	**66**	115	0.058	2.496	0.288	12.478

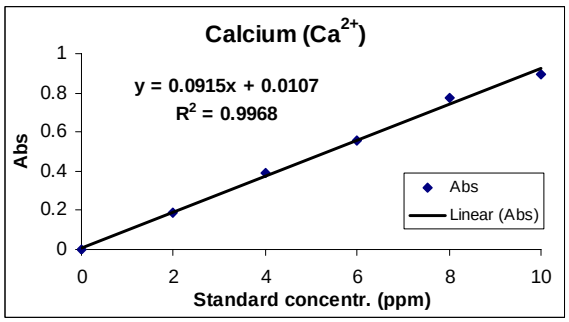
Annex 6. Determination of K_2O in the soil based on calibration curve

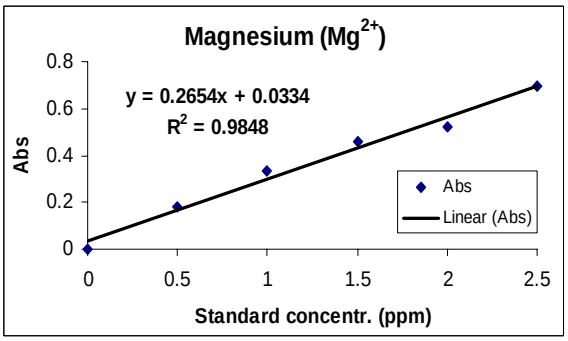
Flame photometry result	Reference solution mg L^{-1}	%	m/eqv.		**Flame photometry result**	Reference solution mg L^{-1}	%	m/eqv.
1	1	0,0005	0,013		**24**	24	0,0120	0,308
2	2	0,0010	0,026		**25**	25	0,0125	0,321
3	3	0,0015	0,034		**26**	26	0,0130	0,333
4	4	0,0020	0,052		**27**	27	0,0135	0,346
5	5	0,0025	0,064		**28**	28	0,0140	0,359
6	6	0,0030	0,077		**29**	29	0,0145	0,372
7	7	0,0035	0,090		**30**	30	0,0150	0,385
8	8	0,0040	0,103		**31**	31	0,0158	0,405
9	9	0,0045	0,115		**32**	32	0,0165	0,423
10	10	0,0050	0,129		**33**	33	0,0172	0,441
11	11	0,0055	0,141		**34**	34	0,0180	0,461
12	12	0,0060	0,154		**35**	35	0,0190	0,487
13	13	0,0065	0,167		**36**	36	0,0200	0,513
14	14	0,0070	0,179		**37**	37	0,0210	0,538
15	15	0,0075	0,192		**38**	38	0,0220	0,564
16	16	0,0080	0,205		**39**	39	0,0230	0,590
17	17	0,0085	0,218		**40**	40	0,0240	0,615
18	18	0,0090	0,231		**41**	41	0,0250	0,641
19	19	0,0095	0,244		**42**	42	0,0260	0,667
20	20	0,0100	0,256		**43**	43	0,0270	0,692
21	21	0,0105	0,269		**44**	44	0,0280	0,715
22	22	0,0110	0,282		**45**	45	0,0290	0,744
23	23	0,0115	0,295		**46**	46	0,0300	0,769

Annex 7. Standard calibration curve from flame photometry and atomic absorption spectrophotometry to analyze Na^+, K^+, Ca^{2+} and Mg^{2+} contents in the dry shoot material of investigated plants









Annex 8. Soil infiltration rate determined at two locations of the experimental site

Date	Field №	Times of observation	Time period		Cylinder water volume		$S = \pi r^2$	Infiltration rate (mm h^{-1})	m^3/ha/h
			minute	minutes (t)	cm^3	Q			
23.08.06	1	9:00							
23.08.06	1	9:05	5	5	130	130		39.3	393
23.08.06	1	9:10	5	10	100	230		34.7	347
23.08.06	1	9:20	10	20	130	360		27.2	272
23.08.06	1	9:30	10	30	150	510		25.7	257
23.08.06	1	9:45	15	45	200	710		23.8	238
23.08.06	1	10:00	15	60	200	910	397.4	22.9	229
23.08.06	1	10:30	30	90	275	1185		19.9	199
23.08.06	1	11:00	30	120	300	1485		18.7	187
23.08.06	1	12:00	60	180	450	1935		16.2	162
23.08.06	1	13:00	60	240	550	2485		15.6	156
23.08.06	1	14:00	60	300	400	2885		14.5	145
23.08.06	1	15:00	60	360	350	3235		13.6	136
24.08.06	2	9:10							
24.08.06	2	9:15	5	5	50	50		15.1	151
24.08.06	2	9:20	5	10	25	75		11.3	113
24.08.06	2	9:30	10	20	50	125		9.4	94
24.08.06	2	9:40	10	30	0	125		6.3	63
24.08.06	2	9:55	15	45	40	165		5.5	55
24.08.06	2	10:10	15	60	25	190	397.4	4.8	48
24.08.06	2	10:40	30	90	40	230		3.9	39
24.08.06	2	11:10	30	120	20	250		3.1	31
24.08.06	2	12:10	60	180	50	300		2.5	25
24.08.06	2	13:10	60	240	60	360		2.3	23
24.08.06	2	14:10	60	300	70	430		2.2	22
24.08.06	2	15:10	60	360	50	480		2.0	20

Annex 9. Humus and nutrient content of soil in the study site in the Gurlan district

Date	Field №	Soil depth, cm	Humus		$N\text{-}NO_3$		P_2O_5		K_2O	
			[%]	Evaluation	[mg kg^{-1}]	Evaluation	[mg kg^{-1}]	Evaluation	[mg kg^{-1}]	Evaluation
05.09.06	1	0-10	0.817	moderate	10.30	very low	47.2	increased	140	low
05.09.06	1	10-20	0.752	poor	11.60	very low	41.6	moderate	140	low
05.09.06	1	20-30	0.666	poor	8.78	very low	37.2	moderate	120	low
05.09.06	1	30-40	0.580	poor	7.40	very low	30.0	low	120	low
05.09.06	1	40-50	0.494	poor	7.92	very low	25.2	low	100	low
07.09.06	2	0-10	0.709	poor	7.92	very low	43.0	moderate	80	very low
07.09.06	2	10-20	0.645	poor	9.08	very low	38.6	moderate	80	very low
07.09.06	2	20-30	0.559	poor	6.65	very low	31.6	moderate	60	very low
07.09.06	2	30-40	0.473	poor	5.65	very low	26.4	low	40	very low
07.09.06	2	40-50	0.408	poor	4.95	very low	21.4	low	40	very low
10.09.06	3	0-10	0.666	poor	6.65	very low	33.0	moderate	80	very low
10.09.06	3	10-20	0.602	poor	7.92	very low	30.0	low	60	very low
10.09.06	3	20-30	0.537	poor	5.90	very low	26.4	low	60	very low
10.09.06	3	30-40	0.451	poor	5.12	very low	24.0	low	60	very low
10.09.06	3	40-50	0.365	very poor	4.08	very low	20.0	low	40	very low

Annex 9. (cont.) Evaluation of soil fertility according to different authors

(a) Musaev (2001)

Evaluation	Available P_2O_5 [mg kg^{-1}]	Exchangeable K_2O [mg kg^{-1}]
Very low	0-15	0-100
Low	16-30	101-200
Moderate	31-45	201-300
Increased	46-60	301-400
High	>60	>400

Evaluation	N-NO_3 [mg kg^{-1}]
Very low	<20
Low	20-30
Moderate	30-50
Increase	50-60
High	>60

(b) Krasnouhova *et al.,* (1988)

Evaluation	Humus [%]
Very poor	<0.4
Poor	0.4-0.8
Moderate	0.8-1.2
Increased	1.2-1.6
Rich	1.6-2.0
Very rich	>2.0

Annex 10. Sodium Adsorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP) in the soil solutions of experimental sites

Field №	Plant species	Soil depth, cm	FAO classification ECe [dS m^{-1}]	SAR	ESP
1	*P.oleracea*	0-15	1.17	1.14	0.42
		15-30	1.02	1.09	0.35
		30-45	0.91	1.03	0.26
2	*P.oleracea*	0-15	4.24	3.05	3.14
		15-30	2.83	3.33	3.52
		30-45	1.81	3.66	3.97
3	*C.album*	0-15	10.58	2.39	2.21
		15-30	7.40	0.96	0.15
		30-45	4.16	0.75	-0.15
3	*K.caspia*	0-15	9.24	0.90	0.07
		15-30	8.02	0.53	-0.48
		30-45	6.02	0.41	-0.66
3	*A.lancifolium*	0-15	13.20	6.87	8.15
		15-30	11.40	6.71	7.95
		30-45	10.90	6.91	8.20
3	*T.hispida*	0-15	14.14	6.63	7.85
		15-30	13.18	7.01	8.32
		30-45	9.78	5.55	6.48
3	*G.glabra*	0-15	10.62	9.41	11.21
		15-30	6.30	5.76	6.75
		30-45	3.78	4.36	4.92

Annex 10 (a). Soil classification (Richards, 1954)

Soil classification	**FAO classification ECe [dS m^{-1}]**	**Exchangeable sodium percentage (ESP)**
Saline soil	> 4	< 15
Sodic saline soil	> 4	> 15
Sodic but not saline	< 4	> 15
No saline & no sodic	< 4	< 15

Annex 11(a). Area, plant density & biomass production, and ion extraction from the soil in the experimental sites of Khorezm Region, Uzbekistan **August**

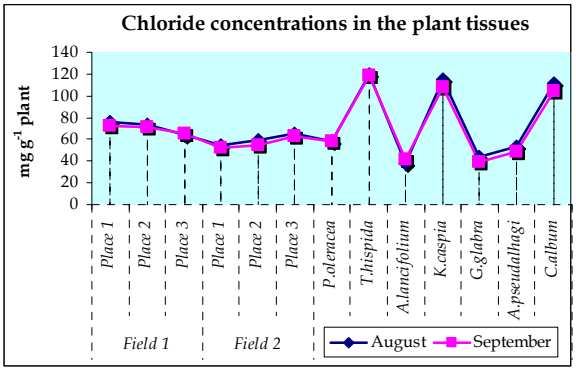
Field №	Soil plots №	Area (m^2)	Plant density	Fresh yield (gr)	Dry yield (gr)	Fresh yield kg ha^{-1}	Dry yield kg ha^{-1}	Ion concentr. mg g^{-1} plant (DM*)	Ion extraction (kg ha^{-1})	Ion extraction (mg $piece^{-1}$)
1	1	0.241	171	696	83.6	28880	3469	145.8	505.9	71.3
1	2	0.260	188	720	88.7	27692	3412	147.1	501.7	69.4
1	3	0.212	153	628	77.2	29623	3642	132.5	482.6	66.9
2	1	0.456	16	140	18.8	3070	412	104.6	43.1	122.9
2	2	0.395	15	131	15.9	3316	403	125.4	50.5	133.0
2	3	0.487	16	156	20.4	3203	419	131.5	55.1	167.7
3	Native *P.oleracea*	0.226	9	236	47	10442	2080	98.3	204.4	513.3
3	*T.hispida*	0.560	11	376	105.8	6714	1889	175.1	330.8	1684.1
3	*A.lancifolium*	0.225	3	172	37.4	7644	1662	64.2	106.7	800.4
3	*K.caspia*	0.483	15	190	70.2	3934	1453	186.8	271.5	874.2
3	*G.glabra*	0.542	6	232	77.6	4280	1432	78.3	112.1	1012.7
3	*A.pseudalhagi*	0.420	8	130	31.4	3095	748	107.8	80.6	423.1
3	*C.album*	0.772	25	772	207.6	10000	2689	200.2	538.4	1662.5

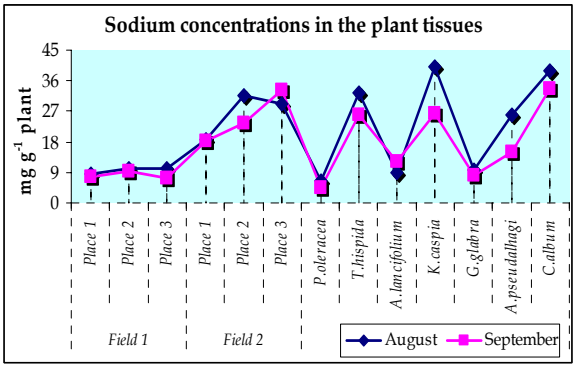
* **Dry matter**

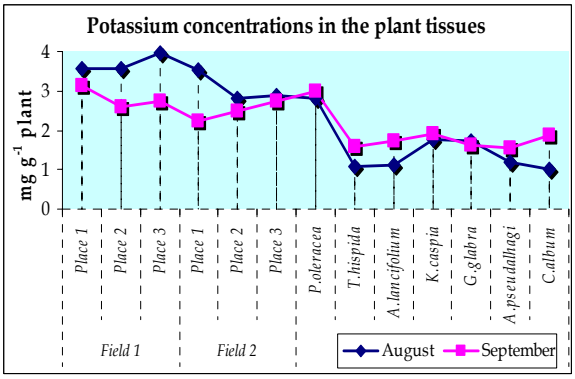
Annex 11(b). Area, plant density & biomass production, and ion extraction from the soil in the experimental sites of Khorezm Region, Uzbekistan **September**

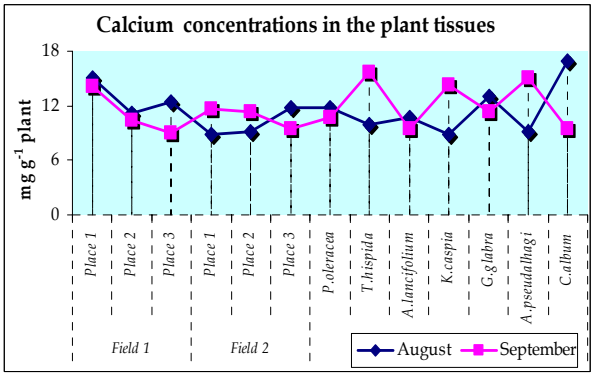
Field №	Soil plots №	Area (m^2)	Plant density	Fresh yield (gr)	Dry yield (gr)	Fresh yield kg ha^{-1}	Dry yield kg ha^{-1}	Ion concentr. mg g^{-1} plant (DM)	Ion extraction (kg ha^{-1})	Ion extraction (mg $piece^{-1}$)
1	1	0.311	160	905	121.7	29100	3913	132.8	519.5	101.0
1	2	0.292	160	891	117.6	30514	4027	135.2	544.3	99.3
1	3	0.280	160	880	109.3	31429	3904	120.4	469.9	82.2
2	1	2.156	65	687	92.4	3186	429	103.2	44.2	146.7
2	2	0.893	32	390	52.2	4367	585	109.8	64.2	179.2
2	3	1.821	50	583	82.5	3202	453	128.4	58.2	211.8
3	Native *P.oleracea*	0.743	23	827	148.1	11131	1993	100.8	200.8	648.8
3	*T.hispida*	0.890	19	586	183.5	6584	2062	179.9	370.9	1737.5
3	*A.lancifolium*	1.115	16	880	204.7	7892	1836	71.0	130.3	908.4
3	*K.caspia*	0.540	13	267	88.2	4944	1633	168.7	275.5	1144.6
3	*G.glabra*	1.10	10	478	146.2	4345	1329	68.9	91.6	1007.3
3	*A.pseudalhagi*	0.913	12	281	74.8	3078	819	94.2	77.2	587.2
3	*C.album*	0.345	12	403	111.9	11681	3243	175.6	569.6	1637.5

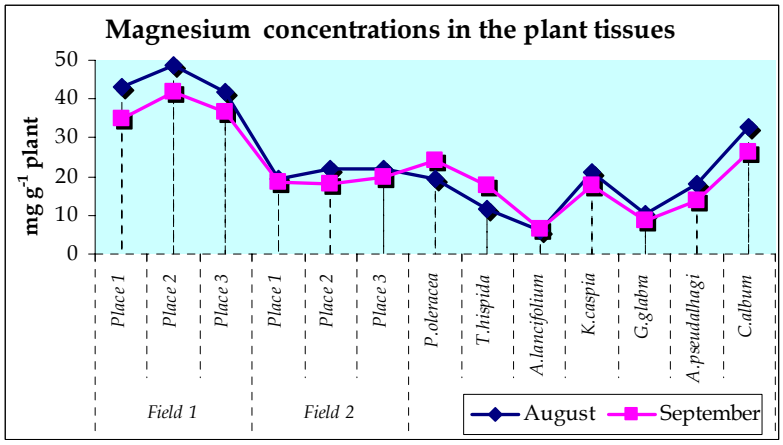
Annex 12. Salt (Cl^-, Na^+, K^+, Ca^{2+} and Mg^{2+}) contents in the tissues of investigated plants



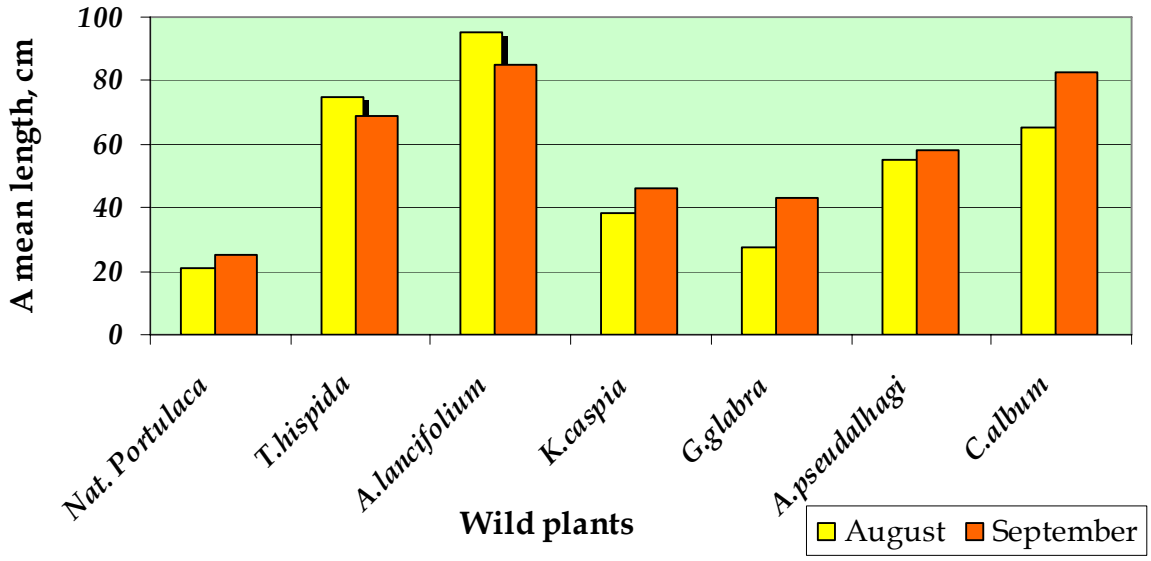








Annex 13. A mean stem length of wild naturally grown species at the harvest, Gurlan district, Khorezm Region



Annex 14. Chemical irrigation, drainage and groundwater content

Field №	Soil Pits №	Water	GWT [cm]	Date	*TDS* [g L^{-1}]	[g L^{-1}]		FAO classification EC_w [dS m^{-1}]
						HCO_3^-	Cl^-	
1		Irrigation		23.08.06	0.55	0.134	0.140	0.86
1		Drainage		23.08.06	1.40	0.244	0.350	2.19
1	1	Groundwater	115.0	23.08.06	3.60	0.586	0.350	5.63
1	2	Groundwater	108.0	23.08.06	3.68	0.586	0.490	5.75
1	3	Groundwater	110.5	23.08.06	4.60	0.549	0.560	7.19
2		Irrigation		26.0806	0.50	0.159	0.140	0.78
2		Drainage		26.0806	1.95	0.354	0.490	3.05
2	1	Groundwater	61.5	26.0806	6.35	0.512	0.770	9.92
2	2	Groundwater	60.5	26.0806	7.00	0.622	1.540	10.94
2	3	Groundwater	56.0	26.0806	8.30	0.732	1.820	12.97

Annex 14 (cont.). Water mineralization classification according to different authors

a) Priklonsky classification of water mineralization based on laboratory measurements [g L^{-1}]:

Salinity level	**Total dissolved solid (TDS)**
Non saline	< 1
Low saline	1 – 3
Moderately saline	3 – 10
High salinity	10 - 50
Severely saline	> 50

b) FAO (USDA) classification:

TDS [g L^{-1}]	**Electrical conductivity of water EC_w [dS m^{-1}]**
0.64	1

Annex 15. Statistical analysis of investigated plants in Khorezm Region, Uzbekistan

One-Way ANOVA

Cl^- concentration (mg g^{-1} dry plant) using potentiometric method[a]

Field №	Plant species	Mean	Std. Error of Mean	Minimum	Maximum	Variance	N
1	*P.oleracea*	75.6	2.17	71.4	78.6	14.16	3
		73.6	2.30	69.1	76.7	15.91	3
		64.2	2.44	61.2	69	17.82	3
2	*P.oleracea*	54.2	2.05	50.6	57.7	12.62	3
		59.8	3.15	54.2	65.1	29.80	3
		65.7	1.54	62.7	67.7	7.10	3
3	Nat. *Portulaca*	57.9	1.76	55.2	61.2	9.27	3
	T.hispida	120.0	1.39	118.5	122.8	5.76	3
	A.lancifolium	37.5	1.88	34.7	41.1	10.64	3
	K.caspia	115.0	2.52	110	117.8	19.06	3
	G.glabra	43.8	1.48	41.4	46.5	6.60	3
	A.pseudalhagi	53.4	2.23	50.6	57.8	14.88	3
	C.album	111.0	1.34	109.1	113.6	5.36	3

[a] Harvested months of the plants = August

Cl^- concentration (mg g^{-1} dry plant) using potentiometric method[a]

Field №	Plant species	Mean	Std. Error of Mean	Minimum	Maximum	Variance	N
1	*P.oleracea*	72.7	1.51	70.5	75.6	6.80	3
		70.8	2.25	66.6	74.3	15.19	3
		64.7	2.33	61.0	69.0	16.27	3
2	*P.oleracea*	52.7	2.54	48.2	57.0	19.41	3
		54.4	2.23	50.0	57.2	14.88	3
		63.1	1.27	60.6	64.7	4.81	3
3	Nat. *Portulaca*	58.4	2.20	54.8	62.4	14.52	3
	T.hispida	119.1	1.71	115.9	121.7	8.74	3
	A.lancifolium	41.3	1.43	38.5	43.2	6.13	3
	K.caspia	108.3	1.92	105.2	111.8	11.01	3
	G.glabra	39.4	2.59	34.4	43.1	20.06	3
	A.pseudalhagi	48.9	1.03	46.8	49.9	3.20	3
	C.album	104.5	2.31	101.1	108.9	15.96	3

[a] Harvested months of the plants = September

Post Hoc Tests - Homogeneous Subsets

Cl^- concentration (mg g^{-1} dry plant) using potentiometric method[b]

Duncan[a]

Field №	Plant species	N	Subset for alpha = .05							
			1	2	3	4	5	6	7	8
3	*A.lancifolium*	3	37.533							
3	*G.glabra*	3		43.767						
3	*A.pseudalhagi*	3			53.400					
2	*P.oleracea*	3			54.233					
3	Nat. *Portulaca*	3			57.900	57.900				
2	*P.oleracea*	3			59.833	59.833	59.833			
1	*P.oleracea*	3				64.167	64.167			
2	*P.oleracea*	3					65.733			
1	*P.oleracea*	3						73.600		
1	*P.oleracea*	3						75.633		
3	*C.album*	3							111.033	
3	*K.caspia*	3							115.033	115.033
3	*T.hispida*	3								120.033
Sig.			1.000	1.000	0.054	0.053	0.068	0.496	0.186	0.101

Means for groups in homogeneous subsets are displayed.

[a] Uses Harmonic Mean Sample Size = 3.000.

[b] Harvested months of the plants = August

Cl^- concentration (mg g^{-1} dry plant) using potentiometric method[b]

Duncan[a]

Field №	Plant species	N	Subset for alpha = .05							
			1	2	3	4	5	6	7	8
3	*G.glabra*	3	39.367							
3	*A.lancifolium*	3	41.300							
3	*A.pseudalhagi*	3		48.867						
2	*P.oleracea*	3		52.733	52.733					
2	*P.oleracea*	3		54.400	54.400					
3	Nat. *Portulaca*	3			58.433	58.433				
2	*P.oleracea*	3				63.100	63.100			
1	*P.oleracea*	3					64.700			
1	*P.oleracea*	3						70.800		
1	*P.oleracea*	3						72.733		
3	*C.album*	3							104.500	
3	*K.caspia*	3							108.300	
3	*T.hispida*	3								119.133
Sig.				0.502	0.075	0.067	0.112	0.578	0.502	0.192

Means for groups in homogeneous subsets are displayed.

[a] Uses Harmonic Mean Sample Size = 3.000.

[b] Harvested months of the plants = September

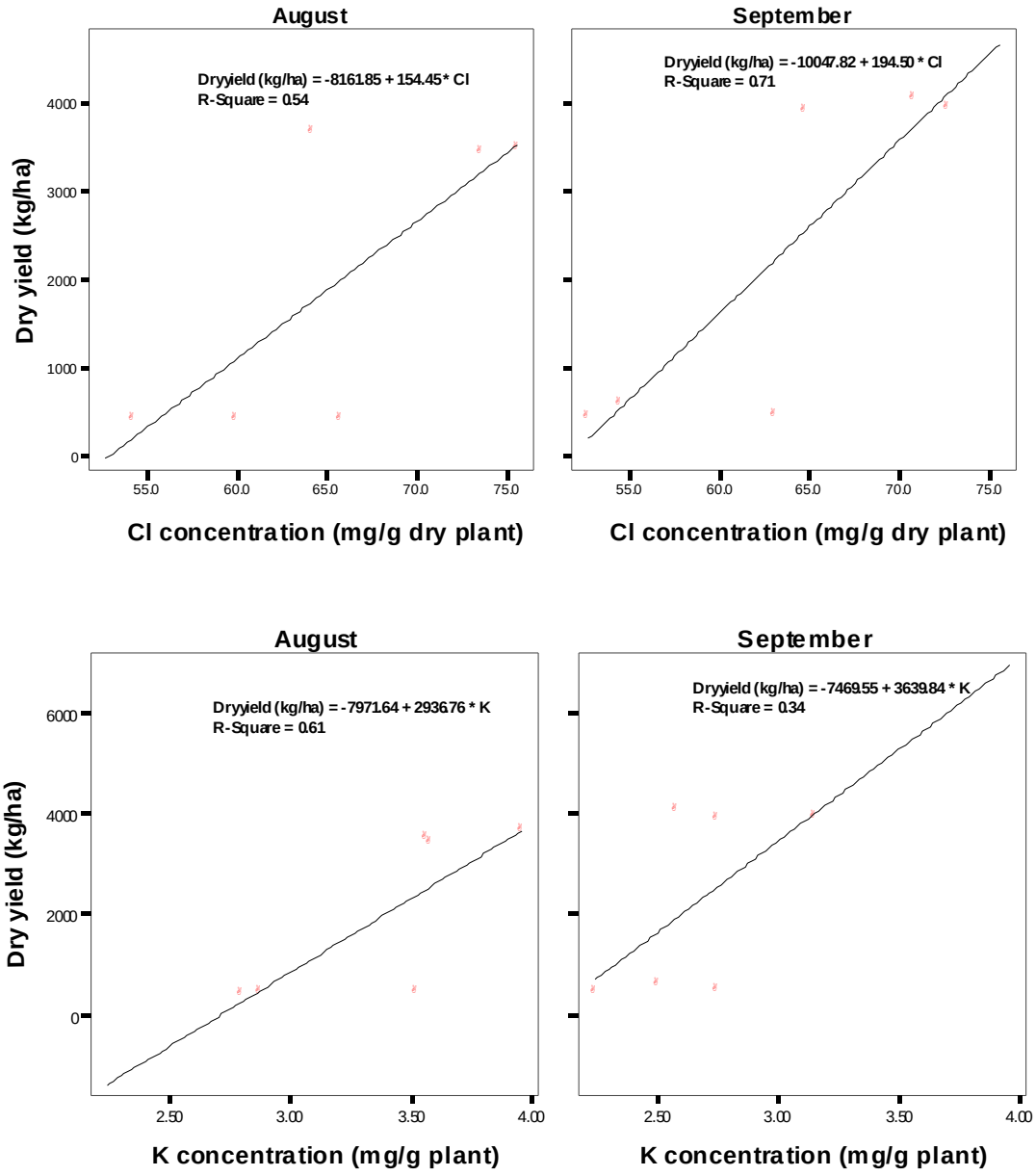
Linear Regression

A crop production system is characterized by the link between the production and the factors involved in it. Mathematically it is given by:

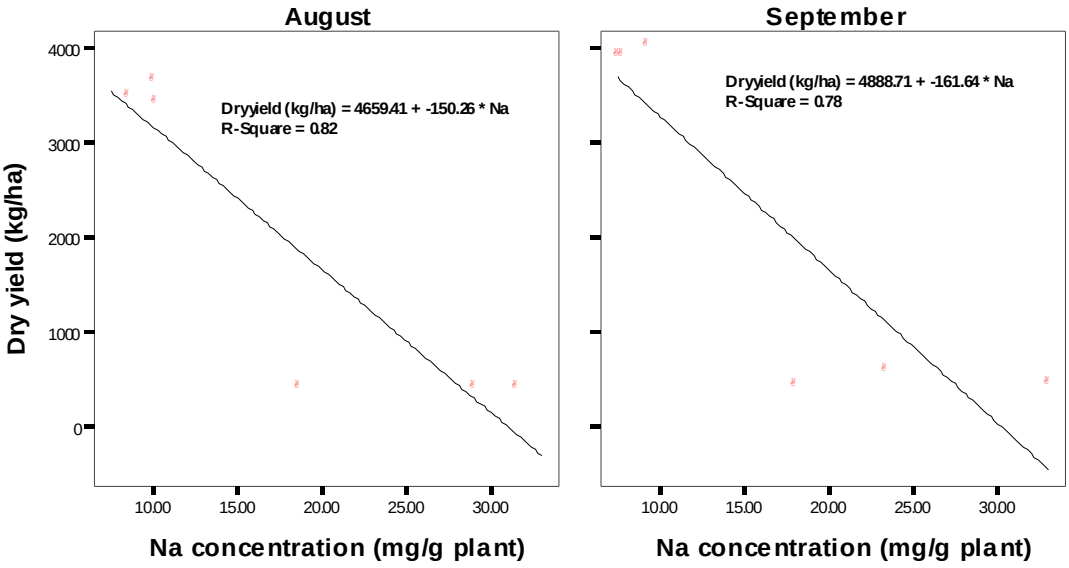
$$Y = F(X_i) = F\ (X_1, X_2, \ldots\ldots X_n)$$

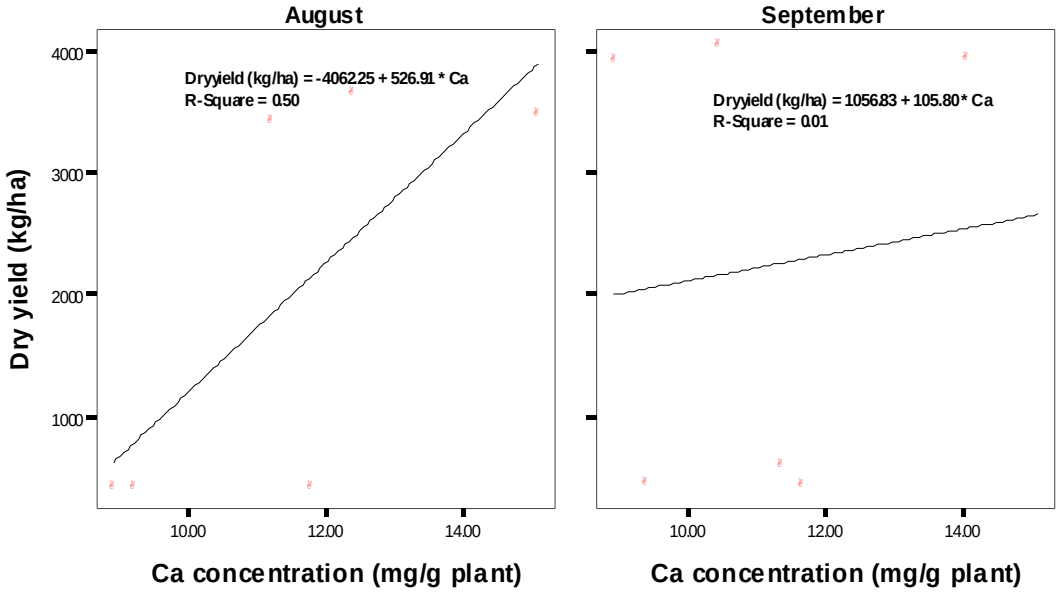
where: Y is the dry matter crop production (kg ha^{-1}) and X_i is the factor (mg g^{-1}) affecting it (i.e. Cl^-, Mg^{2+}, etc). The findings of the regression output are provided below.

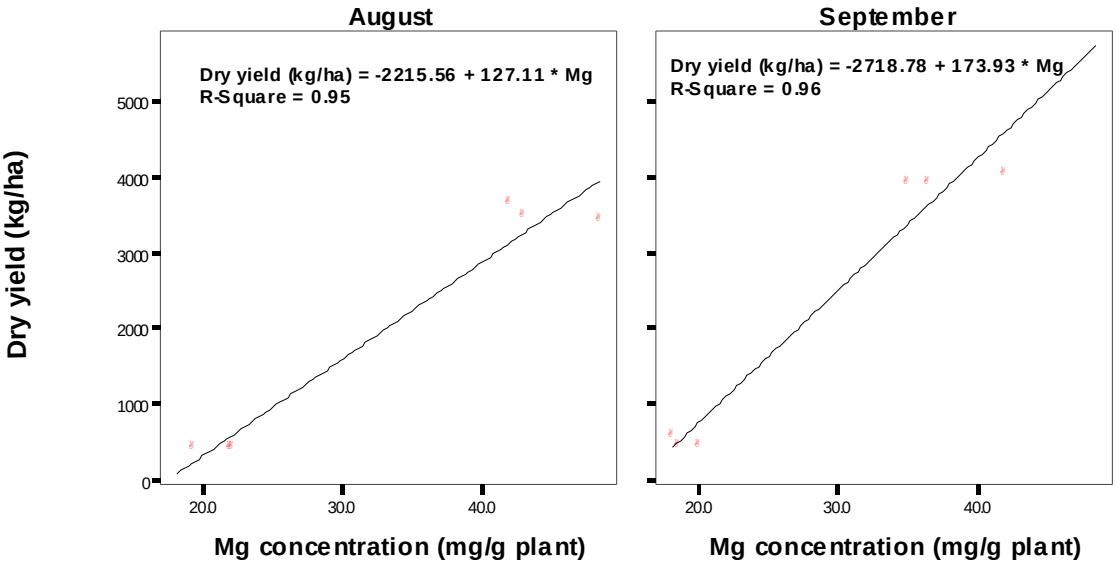
Annex 15 (a). Relationship between dry yield of *P.oleracea* golden purslane, examined in field 1 and field 2 of Khorezm Region, and ion (Cl^-, Na^+, K^+, Ca^{2+}, Mg^{2+}) concentrations.

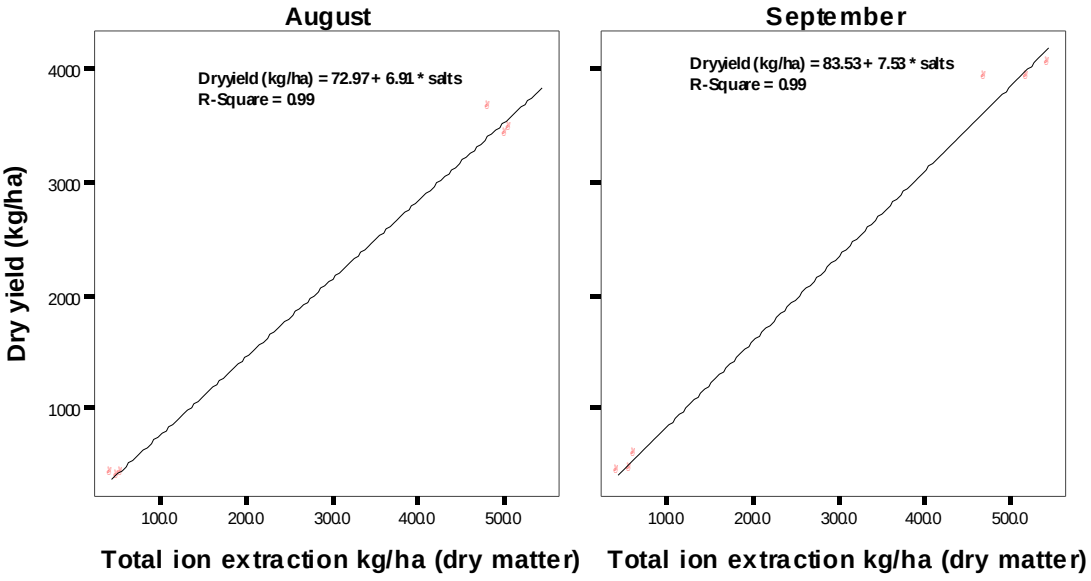


The below graph indicates that there is no linear relationship between the plant dry yield of *P.oleracea* golden purslane and Na^+ concentration.

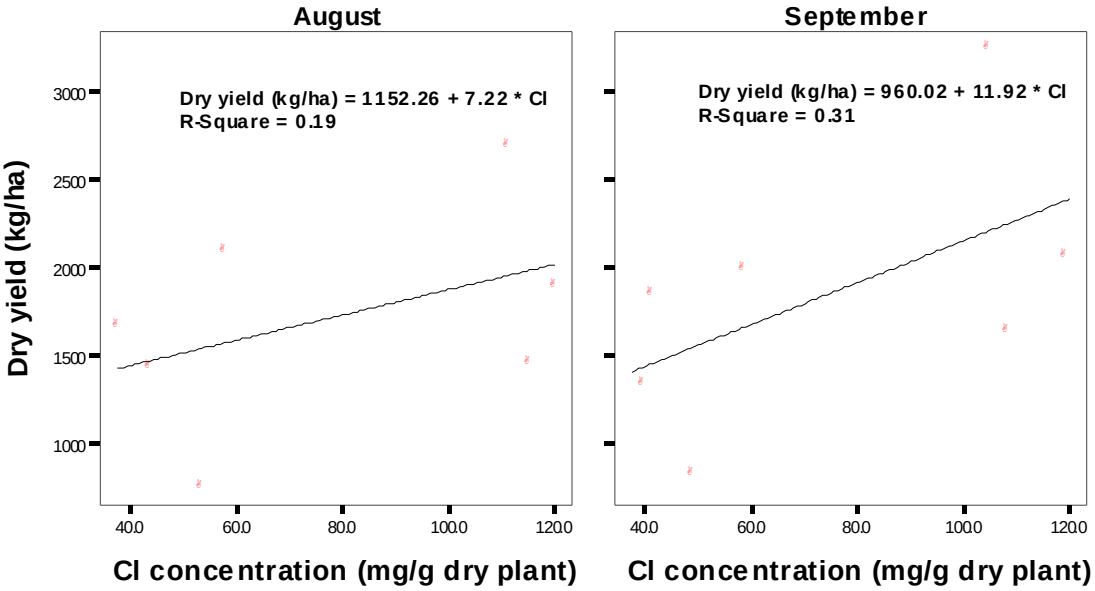


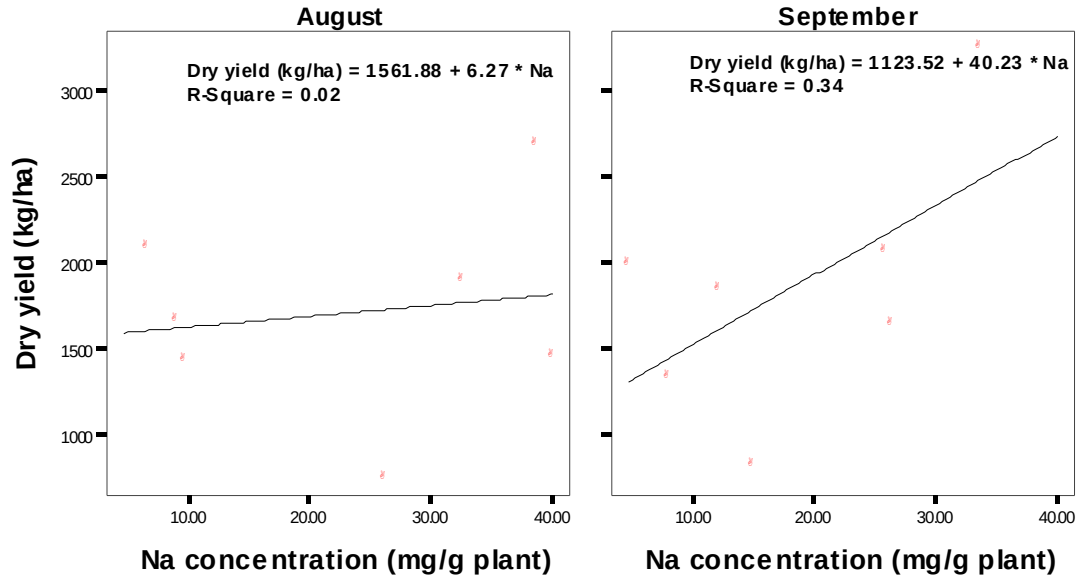


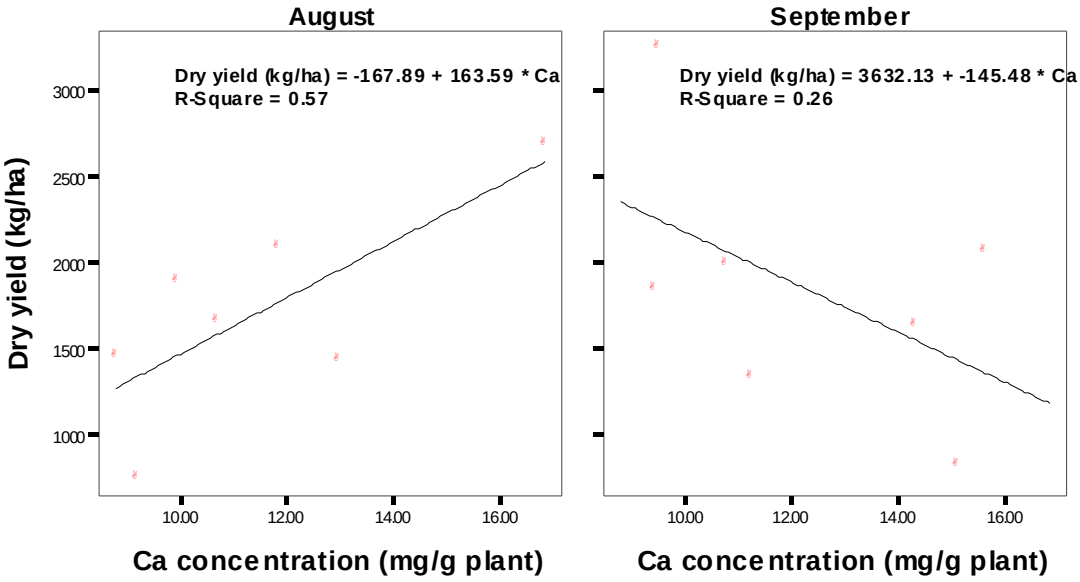

August
Dry yield (kg/ha) = -2215.56 + 127.11 * Mg
R-Square = 0.95
September
Dry yield (kg/ha) = -2718.78 + 173.93 * Mg
R-Square = 0.96
Dry yield (kg/ha)
5000
4000
3000
2000
1000
0
20.0
30.0
40.0
Mg concentration (mg/g plant)
Mg concentration (mg/g plant)

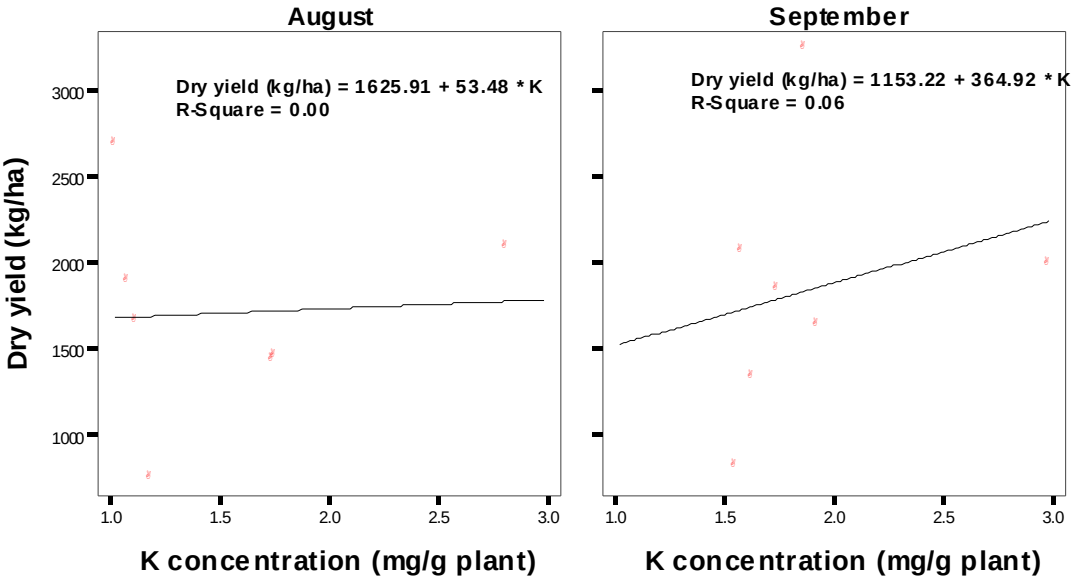

August
Dryyield (kg/ha) = 72.97 + 6.91 * salts
R-Square = 0.99
September
Dryyield (kg/ha) = 83.53 + 7.53 * salts
R-Square = 0.99
Dry yield (kg/ha)
4000
3000
2000
1000
100.0
200.0
300.0
400.0
500.0
Total ion extraction kg/ha (dry matter)
Total ion extraction kg/ha (dry matter)

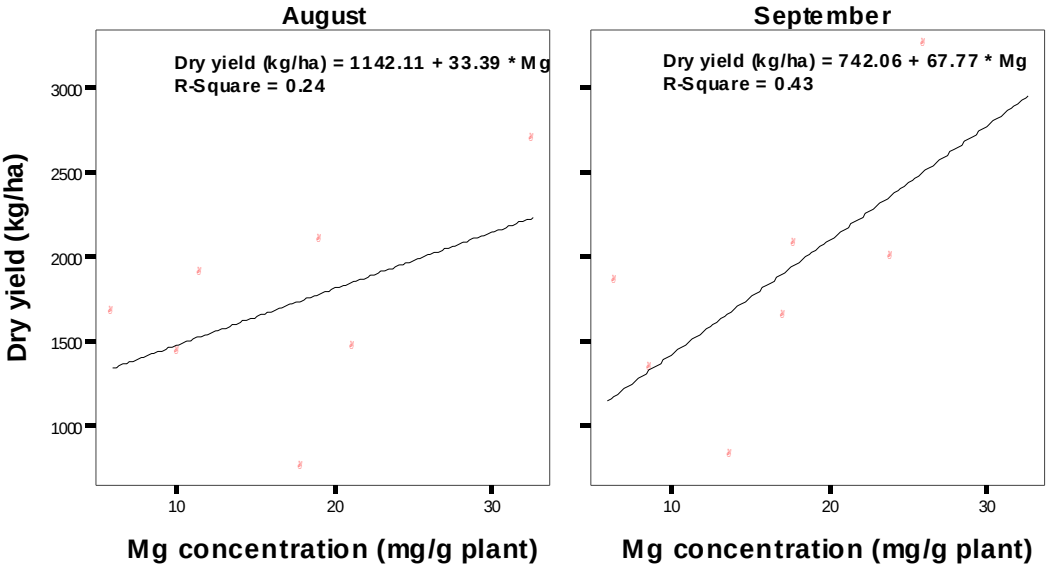
Annex 15 (b). Relationship between dry yield of naturally grown wild species, examined in field 3 of Khorezm Region, and ion (Cl^-, Na^+, K^+, Ca^{2+}, Mg^{2+}) concentrations

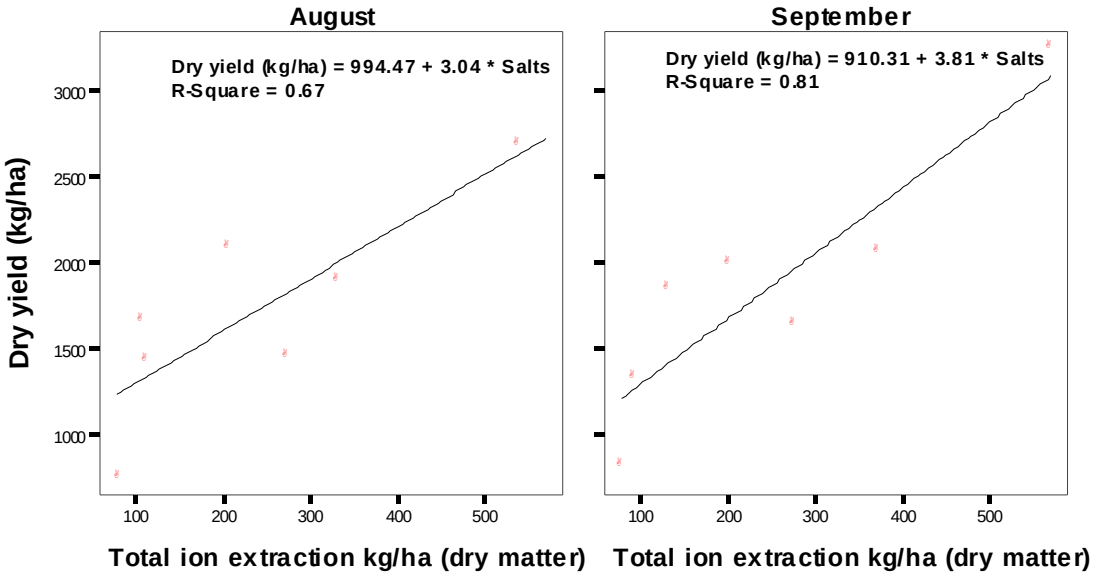





August
Dry yield (kg/ha) = -167.89 + 163.59 * Ca
R-Square = 0.57
Dry yield (kg/ha)
3000
2500
2000
1500
1000
10.00
12.00
14.00
16.00
Ca concentration (mg/g plant)
September
Dry yield (kg/ha) = 3632.13 + -145.48 * Ca
R-Square = 0.26
10.00
12.00
14.00
16.00
Ca concentration (mg/g plant)


August
Dry yield (kg/ha) = 1625.91 + 53.48 * K
R-Square = 0.00
Dry yield (kg/ha)
3000
2500
2000
1500
1000
1.0
1.5
2.0
2.5
3.0
K concentration (mg/g plant)
September
Dry yield (kg/ha) = 1153.22 + 364.92 * K
R-Square = 0.06
1.0
1.5
2.0
2.5
3.0
K concentration (mg/g plant)


August
Dry yield (kg/ha) = 1142.11 + 33.39 * Mg
R-Square = 0.24
Dry yield (kg/ha)
3000
2500
2000
1500
1000
10
20
30
Mg concentration (mg/g plant)
September
Dry yield (kg/ha) = 742.06 + 67.77 * Mg
R-Square = 0.43
10
20
30
Mg concentration (mg/g plant)


August
Dry yield (kg/ha) = 994.47 + 3.04 * Salts
R-Square = 0.67
Dry yield (kg/ha)
3000
2500
2000
1500
1000
100
200
300
400
500
Total ion extraction kg/ha (dry matter)
September
Dry yield (kg/ha) = 910.31 + 3.81 * Salts
R-Square = 0.81
100
200
300
400
500
Total ion extraction kg/ha (dry matter)