



Strategy to Restore Abandoned Irrigated Land Using *Glycyrrhiza Glabra*: Case Study from Central Asia

Martin Kappas

Cartography, GIS and Remote Sensing Section,
Institute of Geography, University of
Göttingen, Goldschmidt Street 5, 37077
Göttingen, Germany, Corresponding Author
Email ID : mkappas@gwdg.de

Khabibjon H.Kushiev

Gulistan State University, Uzbekistan;
E-mail: kushiev@mail.ru

Aziz Kenjaev

Gulistan State University, Uzbekistan;
E-mail: kushiev@mail.ru

Sherzod Uzaydullaev

Gulistan State University, Uzbekistan;
E-mail: kushiev@mail.ru

Hayot Ibrakhimov

International Water Management
Institute, Central Asia Office, Tashkent
7000000, Uzbekistan

Tsolmon Renchin

Professor and Head of NUM-ITC-UNESCO
Laboratory for Space science and Remote
Sensing, National University of Mongolia,
Ulanbatar, Mongolia, E-mail:
tsolmonren@gmail.com

Abstract – Unsustainable agricultural practices have resulted in extensive salinization with the abandonment of large tracts of irrigated land in Central Asia. As conventional strategies to combat salinization are costly and are usually beyond the means of private farmers, alternative solutions, also offering potential income opportunities, are needed in order to ensure sustainable livelihoods. Moreover, such land rehabilitation measures need to be easy to upscale for wider adoption. In the context of Uzbekistan, interventions should also be tailored to fit the prevailing national agricultural policy priorities to be successful. A case study is presented that describes farmer adoption and up-scaling of field-scale bioremediation approach with help of licorice (*Glycyrrhiza glabra*) to restore 105 ha of abandoned land. Through a government-supported initiative, remediation has been scaled out to 640 ha in the Syrdarya province of Central Asia. A Knowledge Alliance was formed that served as a successful complement for relatively weak public extension services that enabled knowledge transfer and dialog among scientists, farming communities and state officials. Adjusting policies to encourage farmers to implement a bioremediation approach in combination with conventional practices has the potential of cost-affordable rehabilitation of abandoned salinized irrigated lands.

Keywords – Licorice (*Glycyrrhiza glabra*), Salinization, Abandoned Land, Irrigation, Degradation, Knowledge Alliance.

I. INTRODUCTION

More than half of the dryland resources globally have undergone anthropogenic degradation with a corresponding decline of agricultural productivity (FAO 2011). It is estimated that 20 % of all irrigated land suffers from human-induced secondary salinization (Ghassemi et al., 1995); these areas have progressively increase despite considerable remediation efforts. In the dryland areas of Central Asia, land salinization threatens sustainability of irrigated agriculture (Chen, J., Wan, S., Henebry, G., Qi, J., Gutman, G., Sun, G. & Kappas, M. (eds.), 2013, Bucknall et al, 2003) affecting ca. 12 % of the irrigated areas in Kyrgyzstan, 60 % in Uzbekistan and virtually all areas in Turkmenistan (Kappas, M., Kleinn, C., Sloboda, B., 2007; CAREC 2011). Salinization has led to a decline inland productivity and reduced net incomes, inevitably

requiring substantial investments to recover these areas (Bucknall et al, 2003) and in severe cases abandonment of land and are duction of the irrigated area (Kariyeva and van Leeuwen 2012).

Soil salinity and drought have implications for food security in Central Asia (Goldshtein et al, 2000, Aparin et al., 2006). Salinization processes in the region occur due to climatic aridity with an index of 0.12-0.3 (Chembarisov and Bakhriddinov, 1989), the over-application of irrigation water and associated rising saline groundwater tables beyond a minimum level of 2.5 m below surface due to dysfunctional field-level¹ drainage systems (Rakhimbaev and Gasnova 1986). According to internal reports of the Water Management Agency in the Syrdarya province, Uzbekistan, 2 % of the irrigated area in the province is taken out of production annually due to salinization.

The problems of land degradation and associated decline in water quality in the major river systems are well-recognized by the Central Asian land and water management authorities. Annually, allocations of 50 % of the state budget for water management have been committed to the maintenance of collector drains for remediation of ca. 15,000 ha of abandoned land. However, land reclamation strategies are narrow-focused and limited to technical rehabilitation of drainage infrastructure coupled with pre-season salt leaching. These strategies are capital intensive and often beyond the capacity of the national budgets (Bucknall et al 2003). At the same time, virtually no alternative amelioration methods are practiced.

Conventional rehabilitation options are often not suitable for private farmers (average area of farming enterprise is approximately 100ha) who are financially weak and resource-poor (Rudenko and Lamers 2006). In addition, the decision to invest an individual's limited resources within a centrally planned agricultural system with a fixed choice of crops, penalties for unmet production yields and other associated risks, must be accompanied by the assurance

¹ By law, inter-district and inter-farm conveyance irrigation canals and drainage collectors are maintained by the governmental water management agencies, whereas field-level canals and drain ditches must be maintained by farmers themselves.



that investments will yield 'quick and tangible' financial benefits (Noble et al., 2006). Hence, there is a need to provide an appropriate remediation approach, which is attractive to and adopted by farmers and creates an enabling environment whereby farmers can perceive direct positive benefits to themselves through their own investments in the rehabilitation of abandoned saline lands. Sufficient yields of the green biomass and marketable roots of halophytes can be viewed as the indicators of 'quick and tangible' outputs for farmers. Since halophytes can tolerate saline environments and potentially reduce salinity, subsequent cultivation of conventional crops such as wheat and cotton becomes possible due to restored land productivity.

Despite a 'vicious cycle' of deteriorating land and water quality, reduced productivity and declining incomes, there is evidence that there are farmers and farming communities performing at significantly higher levels in terms of productivity and farm incomes than the average, while curtailing environmental degradation or coping with prevailing constraints (Scherr, 2000). This paper presents a case study where individual farmers in the Syrdarya province, inspired by a field-scale soil remediation and economic profits from licorice cultivation combined their efforts to adopt remediation strategies to address salt-affected abandoned land on a large scale despite adverse policy settings and environmental conditions. The objectives of this study were twofold: to demonstrate the potential of a bioremediation approach to rehabilitate saline, long-abandoned irrigated lands using licorice (*Glycyrrhiza glabra*); and to present a successful implementation strategy for a wide scale use of bioremediation by combining the efforts of farmers in collaboration and support by local administration and scientists. In the absence of functional extension services bridging the knowledge gap between scientists and farmers was achieved through the establishment of a Knowledge Alliance.

II. CONVENTIONAL AND ALTERNATIVE LAND RECLAMATION STRATEGIES

Conventional soil salinity management practices are still based on the land reclamation principles developed in the 1960s, when pre-season soil leaching is conducted to dilute and remove salts through extensive drainage networks (Ikramov, 2004). However, performed without functional field-level drainage infrastructure, leaching is counter-productive (Akramkhanov et al, 2014; Forkutsa et al, 2009) and often causes unacceptable elevated groundwater tables that mobilize primary or fossil salinity that occurs naturally under arid conditions (Ibrakhimov et al, 2007). The annual water usage for leaching often exceeding 5,000 – 6,000 m³ ha⁻¹ is unsustainable due to frequent water shortages (Olimjanov and Mamarasulov, 2006).

In this regard, introduction of bioremediation technologies through the establishment of agro forestry patches (Khamzina et al, 2006) or salt-tolerant halophytes can assist in the remediation of salt-affected soils as well as provide an income to resource-poor farmers (Dagar et al.,

2004, Kushiev et al 2005, Toderich et al., 2006). Trees can be grown on marginal quality land while providing commercial timber and palatable foliage that can be fed to livestock (Khamzina et al 2012, Djumaeva et al 2009). Over the last decade, a number of plant species have been evaluated in Central Asia for their tolerance to salinity (Piankov and Mokronosov, 1991; Kurochkina and Makulbekova, 1984; Shamsutdinov and Shamsutdinov, 2005; Toderich et al., 2007, 2008, 2013a and b) and have shown to be highly productive under harsh saline conditions, digestible and palatable to animals. With appropriate screening and through socioeconomic and environmental evaluation, bioremediation can become an integral component of farm production systems of Central Asian countries that attempt to address productivity under saline environments.

Different salt-accumulating halophyte species are able to significantly reduce soil salinization (Keiffer and Ungar, 2002). The halophytic plant licorice grows on saline soils of the north-west Caspian region with yields of dry matter ranging 3.2 – 4.5 t ha⁻¹ and roots that develop down to 1.82 m (Shamsutdinov 2002). The licorice develops extensive roots of high commercial value in the fourth year of cultivation, yielding 25 – 30 t ha⁻¹ and containing up to 23 % of glycyrrhizin acid. Glycyrrhizin acid is a mixture of potassium and calcium salts and is generated from the extracted salts in the soil profile during the development of licorice (Popov et al, 1990). This acid is 40 times sweeter than sugar beet and has medicinal properties (Popov et al 1990). Extracted from the roots, the glycyrrhizin acid is used in medicine as water-salt regulating substance, has hormonopoiesis and other functions and is used for treatment of even serious illnesses (Popov et al 1990). Moreover, the glycyrrhizin acid is largely used as a flavour in food, tobacco, alcohol and cosmetics. In addition to removal of salts by roots, the licorice creates macro-pores preventing capillary upward flow from groundwater and develops dense above-ground biomass, thus shading the ground and reducing evaporation from the soil surface. Harvesting of licorice roots enhances soil macro-porosity. Apart from the use of licorice to ameliorate soils, in pharmaceuticals and food industry, this plant is also used in the paint and varnish industry, metallurgy and textiles and many others. In addition, the green above ground biomass of licorice is fed to livestock.

The effective use of licorice to remediate saline soils encouraged a research activity to remediate long-term abandoned saline irrigated fields in the Syrdarya province, Uzbekistan. An experiment with licorice as a bioremediation species was established on a 13ha field in the Navbahor collective farm of the Syrdarya province over a 4-year period from 1999 through 2003 (Kushiev et al. 2005). The research focus was concentrated on analyzing the effects of licorice on biophysical attributes that included soil salinity, groundwater table and salinity, and soil fertility. This was compared to a neighboring abandoned 10-ha field, which served as a control treatment. The control treatment was left in its abandoned state throughout the duration of the study.



III. REMEDIATION EFFECTS OF SALT-AFFECTED FIELD WITH LICORICE

3.1 Yields of Licorice and Cultivation of Conventional Crops on Abandoned Field

Green biomass of licorice harvested in 2001 yielded $3.6 \pm 0.06 \text{ t ha}^{-1}$ of dry matter and contained 12 % of protein. Over the next years, forage yields progressively increased reaching a maximum of $5.11 \pm 0.17 \text{ t ha}^{-1}$ in 2003. The yields of licorice roots in 2002 and 2003 were 5.63 ± 1.19 and $8.55 \pm 0.82 \text{ t ha}^{-1}$, respectively. During this period, the plants were able to utilize groundwater as surface irrigations were reduced from initial four to two applications only.

The yields of conventional crops, winter wheat and cotton, planted in 2004 following the harvest and removal of licorice roots significantly differed in the both licorice-cultivated field and the control site. Comparison between the two fields demonstrated that germination of wheat seeds was 71 % and 30 %, and for cotton 67 % and 15 %, respectively. The yields were 2.42 t ha^{-1} and 0.87 t ha^{-1} for cotton, 1.89 t ha^{-1} and 0.31 t ha^{-1} for wheat, in the licorice amended field and the control field, respectively. Due to remediation effects of licorice, the yield of cotton was 2.8 times, and of wheat 6 times higher compared to the control site.

Thus, licorice has the potential to generate a net positive income for farmers through the production of green biomass and the sale of roots. After 4 years of licorice cultivation, conventional crops cotton and wheat were successfully grown on otherwise unproductive abandoned field.

3.2. The Reasons for the Restored Land Productivity Following Licorice.

There are three main factors that contributed to converting salt-affected land back into economically viable production:

3.2.1. Lowering Groundwater Tables to Favorable Levels and Reduced Groundwater Salinity

Over-irrigation and inadequate field-level drainage cause elevated ground water tables that result in mobilization of salts within the soil root zone. Measured prior to licorice cultivation, the average groundwater in both the control and licorice-grown sites was at $2.52 \pm 0.06 \text{ m}$ (control) and $2.43 \pm 0.04 \text{ m}$ (licorice), hence at the 2.5 m threshold of critically shallow and acceptable levels (Rakhimbaev and Gasnova 1986). The effect of groundwater abstraction by licorice is evident from the groundwater dynamics: in 2003, the average groundwater table rose up to $1.99 \pm 0.02 \text{ m}$ in the control site, thus contributing to more extensive soil salinization, whereas it became deeper at $2.62 \pm 0.06 \text{ m}$ in the field with licorice. Importantly, the groundwater salinity at the licorice field decreased from initial 6.35 in 1999 to 3.99 g l^{-1} in 2003 due to salts extraction by licorice roots or precipitation within the soil profile. At the same time, groundwater salinity remained unchanged in the control site fluctuating between 5.19 and 6.11 g l^{-1} , respectively.

3.2.2. Reduced Soil Salinity

Assessment of overall salinity in both licorice-grown and control sites within the 2 m soil profile indicated moderate to high salinity levels in the root zone. Over the period from 2000 to 2003, the initial total salt content of 215 t ha^{-1} decreased to 185 t ha^{-1} (14 %) under the licorice-grown plot. In contrast, the total salt content in the control site increased from 210 t ha^{-1} in 2000 to 305 t ha^{-1} in 2003 (31 %). Following licorice cultivation, the soil salinity was at the threshold of slight to moderate levels. Monitoring showed that the contents of harmful ions for crops (i.e. chloride and sulphate ions) slightly increased in the control site over the study period compared to the licorice-grown site, where these ions decreased. Chloride ions underwent marked decrease within 150 cm of the soil profile under the licorice-grown plot. These results indicate the ameliorative effect of licorice cultivation on the total salt balance for the research plot.

3.2.3. Increased Soil Fertility

Soil organic matter has an important role in maintaining the structural stability of soils thereby improving physical properties. It remained unchanged over the entire profile in the control site due to the absence of vegetation, whereas ca. 80 – 90 % increase of organic matter was observed on the licorice-amended field. Similarly, the contents of N, P and K also steadily increased at the licorice-cultivated site. This can be attributed to the prolific and extensive root system of the species and possibly organic exudates associated with root growth. The positive impact of higher organic matter on soil properties, including aggregate stability and hydraulic conductivity, would significantly enhance the amelioration process. In addition, high organic matter would also facilitate improvements in the biological component of these soils promoting the overall health of the soil.

IV. IDENTIFYING WAYS FOR KNOWLEDGE SHARING TO FACILITATE FARMERS-DRIVEN UPTAKE OF SUCCESSFUL REMEDIATION APPROACH

An example of the above-described research study clearly shows advantages of bioremediation as an efficient intervention to restore the productive capacity of abandoned irrigated lands in the Central Asia. If widely adopted, this option could be used as an important initial step of rehabilitation of large degraded areas in the region while significantly enhancing the livelihoods of rural communities. With proper screening and through socioeconomic and environmental evaluation, bioremediation can become an integral component of farm production systems of the Central Asian countries under saline environments. In this context, it is important to monitor and evaluate the performance of licorice-driven bioremediation of saline irrigated land over a larger area and longer period.

The major issue was to identify ways to disseminate the research-scale approach and knowledge to a wider agricultural community and to encourage farmers to adopt and apply it under current constraints such as the restrictive

state quota production system for wheat and cotton, difficulties in accessing financial credit outside wheat and cotton production, low investments by farmers into productivity improvement and other impediments. This knowledge sharing was a challenge since the existence of formal extension services as a conduit of research results and technologies is still at a fledgling stage in Central Asia.

It was therefore suggested to disseminate the idea of bioremediation among farmer communities through an innovative approach consisting of a formation of 'Knowledge Alliances'. This became possible within the frame of the Asian Development Bank (ADB)-funded project on enabling communities in the Aral Sea basin to combat land and water resource degradation through the creation of 'bright spots'. A Knowledge Alliance platform was established in the Galaba farming community of the Syrdarya province in 2005 and included farmers, who expressed their willingness to participate in the initiative and improve their farm performance; scientists from the Gulistan university, whose objectives were to transfer the concept and methodological guidelines through brochures and demonstrations to the farmers; and local authorities, who were interested in addressing degraded land and increased productivity of the agricultural sector. The acceptance of the bioremediation approach by, and active support from, the local governmental administration was of significant importance and contributed to the success in this endeavor. The process of dissemination was achieved through discussion group exercises and the distribution of leaflets outlining the successful remediation practices. To streamline activities of the Knowledge Alliance, strengthen relationships between all members and to create the common platform to discuss current and future plans, a round table meeting with all actors was organized. The major issues raised by farmer representatives during the meeting were the concern of present and future support to farmers' rehabilitation efforts from authorities and scientists, security of land tenure and agro-technical operations for the growing the licorice, among other issues.

In 2005, with the consent of the province authorities, 10 abandoned fields occupying 105 ha of salt-affected agricultural land were released by authorities to a group of eight farmers who expressed their willingness to cultivate licorice with their own financial investments. These farmers became active members of the newly established Knowledge Alliance in the Galaba community. In order to assess the effect of licorice cultivation on the remediation process and economic cost-benefit assessment of this approach, monitoring and analyses of soil salinity, groundwater table and salinity, soil fertility and yields were conducted on three selected sites with representative soil physical properties. In addition, an economic cost-benefit assessment of licorice cultivation was undertaken.

V. MATERIALS AND METHODS

5.1 Study Area

The Syrdarya province covers 428,000ha, of which 84% are considered to be potentially suitable for irrigated agriculture. According to provincial agricultural

management organizations, total irrigated area is currently approximately 293,000 ha, of which 54 % is considered to be affected with low salinity, 25% with moderate salinity and 7 % with high salinity (FAO2003).

The Galaba collective farm (N40°23', E68°49') is located in the central part of the Syrdarya province, next to the Navbakhor farm (Figure 1). The farm's irrigated area is 3,115 ha of which 1,149 ha is classified as highly and very highly saline (see Annex). Some of these highly saline areas have been abandoned for between 10 – 15 years. The territory is characterized by subtropical semi-desert climatic conditions with average annual temperature of +12.9°C ranging from –1.8°C in January to +26.7°C in July and precipitation of ca. 324 mm that falls almost entirely in winter-spring season. In contrast, potential evapotranspiration amounts to 1,600 mm indicating a high dependence of crop production on irrigation. The soils are silty loams, representative of large areas in the Hungry Steppe with bulk densities of 1.36-1.50 g cm⁻³ in the top 1 m depth. Yields of conventional crops such as cotton (*Gossypium hirsutum*) and wheat (*Triticum aestivum*) rarely exceed 1.6 and 2.6 t ha⁻¹, respectively. Average groundwater levels are 1.5 – 2.5 m below the surface, rising to 1.0 – 1.2 m during irrigation events having 3,000 – 5,000 mg l⁻¹ of salts.

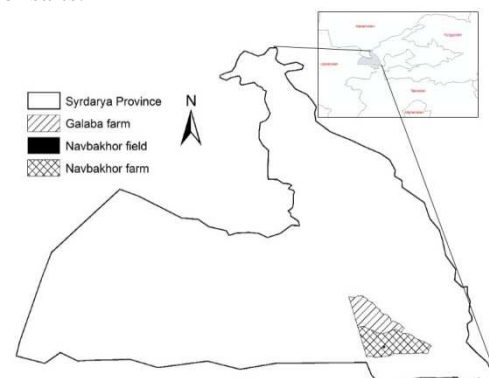


Fig. 1. Geographic location of the Syrdarya province, Navbakhor and Galaba farms

5.2 Field Data Collection and Statistical Analyses

Three out of ten fields representative of the area selected for licorice-assisted remediation were chosen for detailed data collection and analysis. The dynamics of the soil salinity and fertility, groundwater table and licorice yields in these three treatment plots of 10, 14.2 and 16 ha were analyzed and compared against three neighboring plots of 4.5, 5 and 7 ha, that served as control. The control plots were left in the abandoned state throughout the study period. The period of the data collection covered the licorice cultivation dates from planting to maturity (2005 – 2007) and beyond (until 2013) to analyze the changes in soil conditions.

Soil samples were collected from 0 – 15, 15–50 and 50–100 cm depths in three replicates for each of the treatment plots, air-dried and measured for the electrical conductivity (EC, dS m⁻¹), and total dry solids (TDS, ppm). When estimating soil salinity a major attention was paid to the Soviet salinity appraisal system; EC was measured during the first year with a purpose to establish a relationship



between EC and TDS. Soil fertility was assessed for organic matter, available nitrogen ($N-NH_4$) and phosphorus (P_2O_5) and exchangeable potassium.

Groundwater measurements for depth below surface and salinity (EC and total dissolved solids) were conducted each month during 2005 – 2013 in the three representative fields from three monitoring wells installed in each of the fields (total of 9) and one well in the control plot. The monitoring wells were constructed from polyethylene pipes with a diameter of 4 cm closed at bottom, perforated at the lower sides and filter-protected from clogging. All the wells were installed to a depth of 3 – 5 m thus always capturing groundwater table. Measurements in April through September were retained for further analyses to exclude natural decrease of groundwater levels.

An ANOVA test was employed to estimate differences between soil salinity, groundwater levels and salinity and soil fertility in the research fields and control sites prior to and after the harvest of licorice using SPSS statistical software. When necessary, a logarithm transformation was used for data normalization for ANOVA analyses. The significance of differences between tested variables was compared at $p < 0.05$ level.

5.3 Land Preparation and Agronomic Practices of Licorice Cultivation

Licorice planting activities started in the late 2005 – early 2006. These activities included cleaning from weeds, ploughing to a depth of 25 – 30 cm, harrowing, leveling and chiseling to 20 – 23 cm. Prior to planting of licorice, 90 cm spaced furrows were made and irrigation was applied to replenish soil moisture. The roots of licorice with lengths of 13 – 16 cm and diameter of 1 – 1.8 cm, having buds at 2 – 5 cm distance were used for planting to a depth of 18 – 20 cm at a rate of 70,000 cuttings per ha. Planting was conducted in September – December 2005.

Application of irrigation water for licorice is necessary especially during the first years of cultivation, until the established roots reach the groundwater pool. During the growing periods from 2005 to 2006, seven irrigations with the amounts of 66.5 ± 11 and 60.4 ± 6.6 mm, respectively were applied in each plot under licorice. In 2007, licorice was irrigated only three times with amounts of 61.4 ± 4.3 mm. It is necessary to mention that since the abandoned fields, which were released to the farmers for licorice cultivation were salinity-affected and hence, low-productive, the priority of the freshwater supply in the province is given to a more productive land under conventional crops. Hence, especially in water-short and moderate years and peak irrigation periods all the available freshwater is mainly directed for cotton and wheat crops. Although the water management officials supported the Alliance farmers by allocating water for irrigation of licorice plantations, some of the licorice fields received reduced water for irrigation.

5.4. Economic Assessment of Licorice Cultivation

The ex-ante economic analysis of licorice cultivation is based on general agronomic attributes of licorice as well as the on-farm results of the above mentioned research activities. The purpose of the economic evaluation is to analyze the profitability of licorice cultivation under

different prices, inflation rates, capital costs and yield scenarios. The data and assumptions used in the evaluation are based on cost benefit analysis using enterprise budgets. The production cost data, including variable (inputs) and fixed costs (taxes and depreciation), were collected through interviews with the farmers participating in the licorice out-scaling activities. As the licorice cultivation is undertaken in cycles corresponding to the maturing of licorice roots with required pharmaceutical properties, a long-term cost-benefit analysis was applied and indicators such as net present value (NPV) and internal rate of returns (IRR) were computed.

Taking into account the cyclic nature of licorice roots development, the agronomic results of the research scale experiment (Kushiev et al., 2005) and on-farm data collected through farmer interviews, the cost-benefit analysis model used the following five scenarios:

- Sc1. Licorice cultivated for 5 years (Scenario LC5yrs),
- Sc2. Licorice cultivated during 10 years (LC10yrs),
- Sc3. Licorice cultivated for 5 years, then farmer switches to cotton-wheat rotation for the following 5 years (Scenario LC5yrsCW5yrs),
- Sc4. Cotton-wheat rotation is practiced in the high saline area, without rehabilitation of land using licorice (Scenario No LC)
- Sc5. Current average profitability of cotton cultivation in the Syrdarya province, all levels of salinity combined. (Scenario No LC, Only Cotton).

Taking into account the difficulty to remove licorice roots before planting cotton and wheat after land rehabilitation with licorice, costs of cleaning the fields from licorice roots before planting cotton or wheat are incorporated into the costs of the Scenario LC5yrsCW5yrs.

The following main assumptions are made in the assessment:

1. Annual discount rate is equal to 10 %.
2. The yields of crops and amounts of applied irrigation water are obtained from the on-farm data provided by farmers through interviews and the earlier research as described in Kushiev et al.(2005).
3. For simplicity of comparison and better understanding, the data were converted on per hectare basis.
4. The prices and costs are kept unchanged over the years, their current levels are used, and they are expressed in \$ US Dollars (USD). The conversion rate from UZS to Dollar used in this study is equal to 1250 UZS per 1 USD, for 2006, when the data was collected on costs incurred on that year.
5. Licorice roots reach marketable quality at the fifth year of cultivation, and once harvested, the roots take another five years to regenerate to the appropriate quality requirements.
6. In addition to the roots, licorice provides biomass as fodder for livestock. Therefore, analysis takes into account both the economic benefits from the licorice roots, as well as benefits from its biomass as fodder.

VI. EFFECT OF LICORICE ON SOIL AND GROUNDWATER

6.1. Reduction of Soil Salinity at the Licorice-planted Research Sites

There was a strong relationship ($R^2 = 0.98$) between the sum of salts and measured EC of the saturated paste (Figure 2). The relationship was used to estimate EC values of salinity for the unmeasured years.

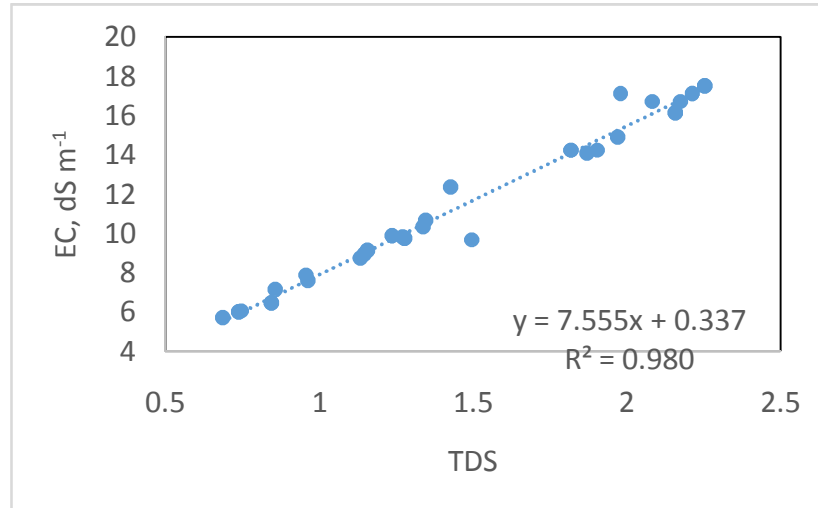


Fig. 2. Relationship between the sum of salts and electrical conductivity of the saturated paste.

The soil salinity assessment in the research sites before development of licorice roots and biomass (in 2005 – 2006) and in the control plots revealed that the top 0 – 15 cm soil layer was characterized as moderately saline, but highly saline at the depths 15 – 100 cm (Abrol et al., 1988, Table

1). Analysis of the individual anions and cations in soil of the treatment plots based on the Soviet appraisal system (see Annex) showed that the soil salinity is of sodium type, typical for the province.

Table 1. Descriptive statistics of soil salinity (EC, dS m⁻¹) from the three soils depths at the licorice-grown and control fields of the Galaba Farm in 2005 – 2013.

Depth	2005		2007		2009		2013	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Licorice								
0-15	7.41	1.62	6.73	1.72	5.65	1.53	4.64	1.27
15-50	9.69	0.95	9.93	1.9	8.15	1.14	7.27	1.16
50-100	15.23	1.36	15.62	0.04	13.9	0.58	12.31	0.54
Control								
0-15	7.44	1.98	7.57	1.99	7.7	1.89	7.73	1.95
15-50	11.06	2.66	11.33	2.88	11.18	2.55	11.37	2.87
50-100	17.02	0.36	17.31	0.43	17.16	0.3	17.28	0.42

Over the course of time, there were no changes in salinity in the 1 m soil profile in the control plots (Figure 3). However, there was a clear decrease of soil EC in the

licorice-cultivated plots. These changes were observed in each of the monitored soil layer over the cultivation period.

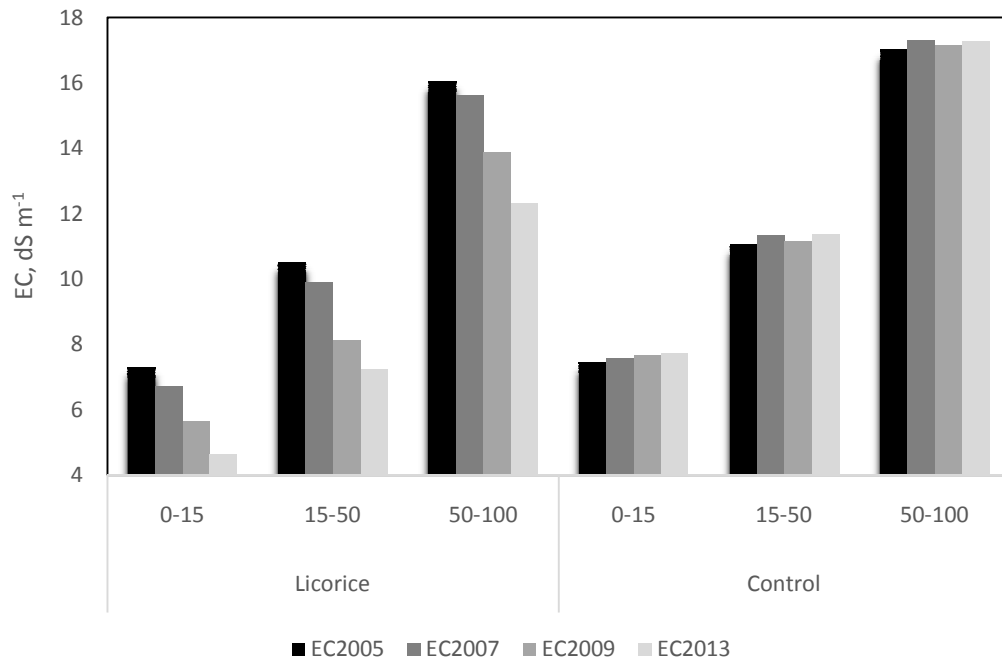


Fig. 3. Changes of the soil EC, dS m⁻¹ in the licorice cultivated and control plots during 2005 – 2013. Note: EC2005 through EC2013 – electrical conductivity of the soil extract in different years.

The ANOVA assessment revealed no statistical difference in soil salinity in the licorice-planted plots during the establishment period of licorice roots and biomass in 2005 through 2007 (Table 2). However, the statistically significant reductions (at $p < 0.05$) of soil salinity since 2009 through 2013 clearly indicate the desalination effect of licorice cultivation on soil over time.

At the same time, similarly, the statistical difference between the licorice and control treatments was significant only starting from 2009 onwards. The reduction of salinity may be attributed to the absorption of salts by the established roots of licorice in a process of synthesis of glycyrrhizin acid.

Table 2. Assessment of soil salinity (EC, dS m⁻¹) between measurement periods in licorice-grown plots with ANOVA

Measurement period	Mean difference	Std. Error	Sig.*	95% confidence Interval for Difference, bound		
				Lower	Upper	
2005	2007	0.016	0.366	0.966	-0.879	0.911
	2009	1.538*	0.360	0.005	0.657	2.420
	2013	2.703*	0.328	0.000	1.900	3.505
2007	2009	1.522*	0.184	0.000	1.073	1.972
	2013	2.687*	0.228	0.000	2.129	3.244
2009	2013	1.164*	0.135	0.000	0.835	1.494

*. The mean difference is significant at the .05 level.

6.2. Lowering of Groundwater Table

Average groundwater table measured prior to the establishment of licorice roots ranged between 0.97 and 1.22 m in 2006 and 0.82 – 1.13 m in 2007 (Table 3) indicating extremely shallow levels. The average

groundwater salinity was in the range of 4 to 6 g l⁻¹ indicating severe implications for crop development (Ayers and Westcot 1994). Such shallow saline groundwater is clearly a major source of salts in the soil profile.

Table 3. Descriptive statistics of groundwater table, m below surface in the representative research sites in Galaba farm in 2006, 2007, 2012 and 2013

Field	Statistics	Measurement period			
		2006	2007	2012	2013
1	Mean	1.22	1.12	1.22	1.75
	SD	0.18	0.29	0.23	0.32
2	Mean	1.14	0.82	1.47	2.01
	SD	0.15	0.54	0.3	0.41
3	Mean	0.97	1.13	1.69	2.32
	SD	0.31	0.32	0.22	0.39

The results of ANOVA analysis showed that the differences between the groundwater tables in the licorice grown plots in 2005 – 2006 and 2007 were insignificant as the licorice roots have not reached the groundwater (Table 4). However, in 2012 and 2013 these differences were

significant at $p < 0.05$, suggesting that the licorice was able to satisfy needs in evapotranspiration entirely from groundwater. This is also proved by the history of irrigations: the last irrigation conducted in 2008.

Table 4. Analysis of variance between groundwater tables, m in the licorice plantations during the monitoring period 2006 – 2013

Years	Mean Difference	Std. Error	Sig.	95% Confidence Interval		
				Lower Bound	Upper Bound	
2006	2007	0.088	0.139	0.529	-0.194	0.371
	2012	-0.353*	0.123	0.007	-0.605	-0.102
	2013	-0.916*	0.117	0.000	-1.156	-0.677
2007	2012	-0.442*	0.142	0.004	-0.730	-0.153
	2013	-1.005*	0.136	0.000	-1.283	-0.727
2012	2013	-0.563*	0.121	0.000	-0.809	-0.317

*. The mean difference is significant at the 0.05 level.

With the exception of groundwater levels in one of the plots, the effect of moisture extraction from groundwater by the licorice roots whereby licorice lowered groundwater levels can be observed (Table 5). Comparison of the groundwater table between the licorice treatment plots and the control plot expectedly revealed similar groundwater

levels during 2006 and 2007 and significantly different levels in 2012 and 2013. During the period 2012 – 2013, the deeper groundwater contributed least to soil salinity through capillarity, while at the same time provided sufficient moisture extraction for the development of the long-rooted licorice.

Table 5. Analysis of variance between groundwater table, m in the licorice plantations and a control plot during 2012 – 2013

Period	Treatments	Mean difference	Std. Error	Sig.	95% Confidence Interval		
					Lower Bound	Upper Bound	
2006	Control	Field 1	-0.010	0.208	0.962	-0.446	0.426
		Field 2	-0.307	0.208	0.157	-0.742	0.129
		Field 3	-0.585*	0.218	0.015	-1.042	-0.128
2007	Control	Field 1	0.297	0.208	0.170	-0.139	0.732
		Field 2	-0.278	0.218	0.218	-0.735	0.179
		Field 3	-0.221	0.109	0.053	-0.445	0.003
2012	Control	Field 1	-0.182	0.124	0.131	-0.947	-0.417
		Field 2	-0.929*	0.129	0.000	-1.194	-0.664
		Field 3	-1.150*	0.126	0.000	-1.415	-0.885
2013	Control	Field 1	-1.212*	0.140	0.000	-1.513	-0.910
		Field 2	-1.471*	0.143	0.000	-1.772	-1.169
		Field 3	-1.778*	0.148	0.000	-2.079	-1.476

6.3 Increased Soil Fertility

At the onset of the trial in 2005, the soil organic matter contents of both control and treatment sites were at the edge of poor to moderate levels (Krasnouhova et al. 1988, Table 6). In all fields, the initial contents of organic matter in the top 15 cm layer in 2005 – 2007 ranged 0.77 – 1.77 %, and in the 15 – 50 and 50 – 100 cm layers 0.69 –

0.87 %. According to Musaev (2001), the contents of plant-available N and P and exchangeable K are characterized as low in the top 15 cm, and expectedly reduce to very low category in the deeper horizons. Monitoring revealed the same status of SOM and N, P and K in the control plots (Table 6).

Table 6. Descriptive statistics of the soil organic matter, % and nutrients, mg kg⁻¹ in the licorice cultivated plots and control plots in selected years 2005, 2007, 2009 and 2013

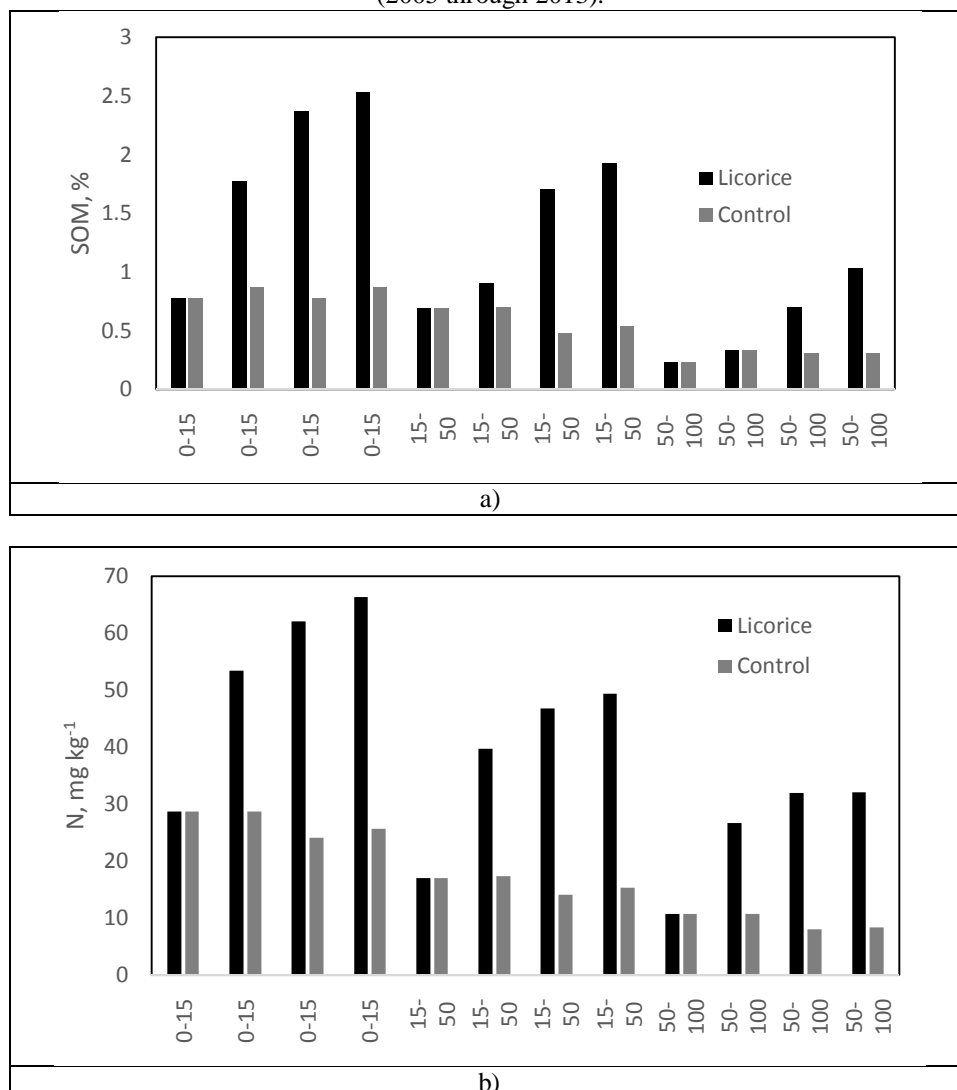
Year	Depth	SOM, %		N, mg kg ⁻¹		P, mg kg ⁻¹		K, mg kg ⁻¹	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Licorice									
2005	0-15	0.77	0.04	28.67	6.66	17	0.17	144.33	3.51
	15-50	0.69	0.01	17	4.36	14.4	0.8	133	4.58
	50-100	0.23	0.02	10.67	3.21	7.77	1.06	113.67	1.53
2007	0-15	1.77	0.23	53.33	9.29	20.07	4.9	131.33	7.09
	15-50	0.9	0.69	39.67	5.86	13.7	2.25	124.33	7.57
	50-100	0.33	0.15	26.67	2.52	9	2	111.33	4.16
2009	0-15	2.37	0.15	62	8.54	18	5.29	120.67	6.03
	15-50	1.7	0.2	46.7	6.51	11.67	2.08	109	6.56
	50-100	0.7	0.36	31.9	4.46	10	1	104	4.58
2013	0-15	2.53	0.12	66.33	7.02	21.33	7.37	104.33	5.51
	15-50	1.93	0.31	49.33	12.9	10.33	4.51	95	5.57
	50-100	1.03	0.51	32	4.36	11.67	6.66	88.33	1.53

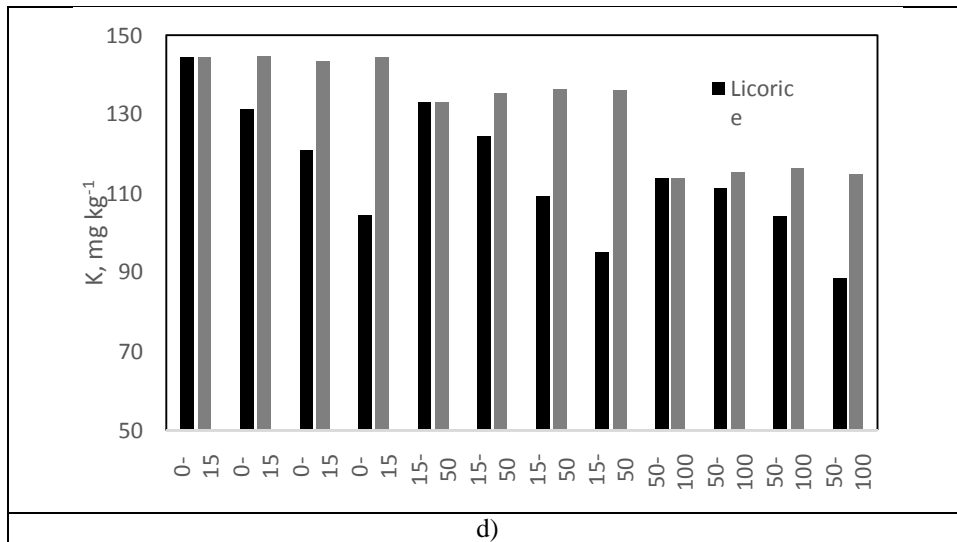
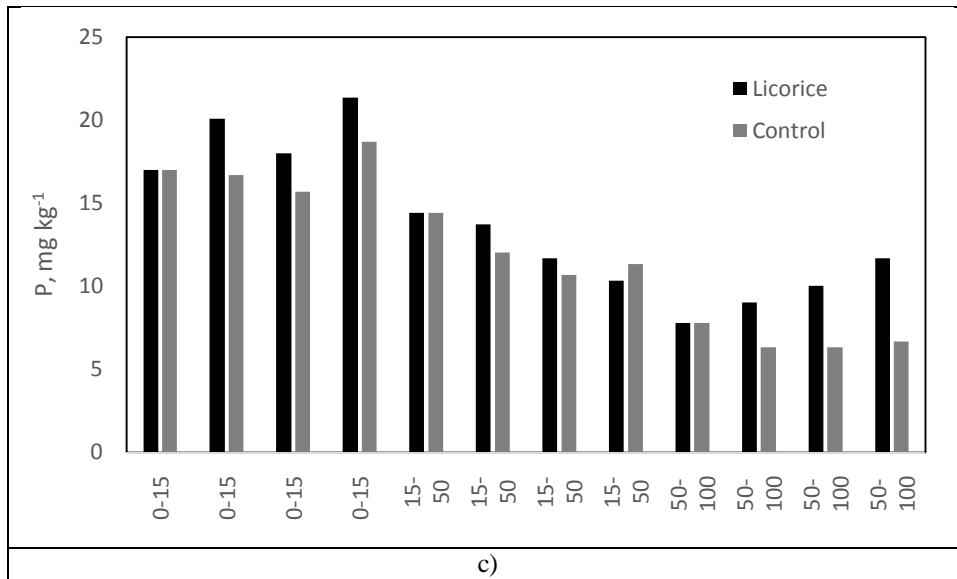
Control									
2005	0-15	0.77	0.04	28.67	6.66	17	0.17	144.33	3.51
	15-50	0.69	0.01	17	4.36	14.4	0.8	133	4.58
	50-100	0.23	0.02	10.67	3.21	7.77	1.06	113.67	1.53
2007	0-15	0.87	0.23	28.67	9.07	16.67	4.73	144.67	1.53
	15-50	0.7	0.1	17.33	5.03	12	3.46	135.33	4.04
	50-100	0.33	0.15	10.67	5.51	6.33	2.31	115.33	1.53
2009	0-15	0.77	0.25	24	8.72	15.67	2.89	143.33	2.52
	15-50	0.47	0.15	14	3.61	10.67	0.58	136.33	6.11
	50-100	0.3	0.1	8	1.73	6.33	1.53	116.33	0.58
2013	0-15	0.87	0.31	25.67	6.43	18.67	3.51	144.33	1.53
	15-50	0.53	0.06	15.33	2.08	11.33	1.53	136	5.57
	50-100	0.3	0.1	8.33	0.58	6.67	0.58	114.67	2.31

There was a significant increase of the organic matter in the entire 1 m soil profile during the monitoring years (Figure 4, a). By 2013, the levels of SOM reached 2.53 ± 0.12 % classified as very rich (Krasnouhova et al. 1988). In contrast, the SOM levels remained unchanged or even decreased in the vegetation-free control fields. Similarly, the contents of nitrogen increased over the years in the licorice plots, while slightly decreasing in the control plots. The available P was increasing over years in the 0 – 15 cm and 50 – 100 cm, but decreasing in the 15 – 50 cm layer. In

contrast, the contents of exchangeable K were steadily decreasing overall years. ANOVA test of the mean differences (not shown) indicate that the changes of all four soil fertility factors in the control plots were insignificant. At the same time, the positively significant differences of the dynamics of SOM and N, negatively significant changes in K and no difference in P between the licorice cultivated and control plots over years could be attributed to the effect of licorice on soil fertility.

Fig. 4. (a, b, c, d) Changes of soil organic matter and NPK in the licorice cultivated and control plots over the study period (2005 through 2013).





VII. ECONOMICS OF LICORICE CULTIVATION

7.1. Scenarios of Licorice Cultivation.

The economic analysis demonstrated that under Scenario LC5yrs the NPV of the net benefit is 112 USD ha⁻¹, or 22 USD ha⁻¹ annually over 5 years. The cost benefit ratio is equal to 1.2 at the end of the fifth year. Similarly, under Scenario LC10yrs the NPV of the net benefit is 252 USD ha⁻¹, or 25 USD ha⁻¹ annually over 10 years. The cost benefit ratio is equal to 1.3 at the end of the tenth year. To analyze the profitability of switching to cotton-wheat rotation after 5 years of licorice cultivation under Scenario LC5yrs CW5yrs, the data on licorice profitably from the Scenario LC5yrs with average costs and benefits of the

cotton-wheat cultivation were combined. The NPV of this scenario is 222 USD ha⁻¹, or 22 USD ha⁻¹ annually over 10 years. The cost benefit ratio is equal to 1.1. Under Scenario NO LC, the net profitability is negative with losses of USD 258 ha⁻¹ for the 10-year period, i.e. USD 25.8 ha⁻¹ annually. Thus, the analysis clearly demonstrates that these highly saline fields, which are now abandoned, cannot be cultivated profitably under cotton or wheat at this level of salinity. The NPV of the net benefit makes up 169 USD ha⁻¹ for the 10-year period, i.e. 16.9 USD ha⁻¹ annually. Table 7 summarizes the results of the analysis.

Table 7. Profitability of licorice cultivation under different scenarios in the Syrdarya province

Indicators	LC5yrs	LC10yrs	LC5yrsCW5yrs	NO LC	No LC Only Cotton
Revenues	689	1,132	1,829	1,217	3,380
Costs	587	880	1,607	3,800	3,548
Net benefit	112	252	222	-2,583	169
BCR	1.2	1.3	1.1	negative	
Annual Net benefit	22	25	22	negative	17

The scenario LC10yrs comes out slightly more profitable than scenario LC5yrs, scenario No LC, scenario Only Cotton Model (all salinity levels) and scenario LC5 yrs CW5 yrs, and much more profitable than cultivating either cotton or wheat in highly saline areas.

7.2. Business Evaluation of Licorice Cultivation

Since the licorice has positive effects on soil salinity and fertility, the business evaluation was undertaken with the purpose to assess the profitability of licorice cultivation for farmers' incomes. With the hypothesis that cultivating licorice is a low-cost option of managing saline lands and at the same time a livelihood enhancing strategy for farmers in these areas, the production costs of, and benefits from,

licorice cultivation were assessed based on cost-benefit analysis of on-farm enterprise budgets.

The cost benefit analysis included farmers' expenditure items of input costs such as weeding, soil processing, irrigations, etc. and yields and prices of licorice roots. The analysis demonstrates that, at 10 % of annual price growth both for licorice roots and input costs, the final cost benefit ratio (BCR) for growing licorice would be 1.9, i.e. per each Uzbeksoum invested in licorice cultivation, the farmer will be able to generate 1.9 soums in total revenues (Table 8). The net accumulated benefit at the 5th year is 596,014 soumha⁻¹, at 18 % of commercial interest rate, the Net Present Value of that net benefit would be 139,349 UZS ha⁻¹, or about 110 USDha⁻¹.

Table 8. Estimated cost benefit analysis of licorice cultivation for 1 ha in UZS

Designation	2006	2007	2008	2009	2010
Yield licorice root, t/ha	0	0	0	0	10
Dried licorice weight	0	0	0	0	7
Price 1 t/root dried/uzs	120,000	132,000	145,200	1,597,200	175,692
Total sales	0	0	0	0	1,229,844
Net profit	-173,000	-96,800	-106,480	-59,895	1,032,189
Accumulated net profit	-173,000	-269,800	-376,280	-436,175	596,014
BCR at the end of the period					1.9
Discounted value of the net accumulated benefit					139,349

Worldwide production and trade of licorice products is considerable being on average 30,000 – 40,000 t year⁻¹; the import of licorice in various forms into UK and USA is ca. 16,000-17,000 t year⁻¹ and into Japan about 6,000 t of roots and 1,400 t of extract². In Uzbekistan, exports of licorice are regulated through licensing procedures. In recent years, there has been a significant expansion in the internal licorice processing capacities. The exact volume of exports and of internal processing in Uzbekistan are difficult to evaluate due to lack of available data. However, it is noteworthy to mention that a private company OZUQA LLC, one of the leading players in the licorice processing sector in Uzbekistan, has the processing capacities of more than 100 t month⁻¹, and communications with company's management revealed that currently the company is experiencing significant shortages of raw material.

The average price paid by the OZUQA LLC for 1 ton of dried licorice roots of required quality standards is ca. 100 USD. The company bears transportation costs of licorice roots from the farmers' fields to its processing facilities. Consequently, the licorice-producing farmers would be much better off to sell the raw licorice materials directly to the processing plant instead of middlemen who offer about 50,000 UZSt⁻¹ (ca. 40 USD t⁻¹), as it was indicated by the experts during the Round Table Meeting. Therefore, in addition to the beneficial effect of licorice cultivation on soil, the value and thus, economic benefits of licorice are encouraging for increased production in the near future.

VIII. GOVERNMENT-SUPPORTED UPTAKE OF BIOREMEDIATION AND INDUSTRY DEVELOPMENT

Possibilities of potentially higher benefits from local processing of licorice roots encouraged the scientists from the Gulistan university to address these issues to the provincial and country's authorities. In 2012, the project on local processing of licorice was developed, approved by the Syrdarya Khokimiat (local authority) and submitted to the Cabinet of Ministers of Uzbekistan. Implementation of this project was in line with the general strategy of the industrial development and utilization of marginal lands in the province. Moreover, the international trade of the products of licorice processing will increase national revenues. As a result, in the same year the government of Uzbekistan has approved this strategy and released ca. 640 ha of abandoned irrigated areas to the farmers majority of which were the members of Knowledge Alliance. A licorice-processing "Syrdarya Licorice Extract" plant has been established in 2013 to process the roots of licorice into a powder for export purposes. The plant with a capacity of more than 9,000 t year⁻¹ of roots contracted the licorice-producing farmers with extra payment for delivery of the roots. Currently, the plant has developed a business-plan and signed contracts with international companies from China, Thailand, Germany and Japan to deliver dry extract.

IX. DISCUSSION

The alarming speed of agricultural land salinization in Central Asia and high costs of conventional recovery

²Mana Kai Rangahau. Growing licorice. New Zealand Institute for Crop and Research Institute, A Crown Research Institute, www.crop.cri.nz

options call for alternative measures to combat this degradation. Since farmers are the main decision makers regarding the land they work on, the success or failure of rehabilitation measures depend to a large extent on their attractiveness to and hence, adoption by farmers. The efforts of individual farmers and especially their collective action, in salinity remediation is an important precondition to addressing this issue. However, current agricultural policies create disincentives for investments. E.g., state quota system retained from the past dictates cropping patterns and yield targets leaving little room for alternative crops; improved actual yields of conventional crops cause immediate reassessment of planned areal productivity followed by increased quota without offering any benefits to farmers in return. Obtaining financial credits for agricultural activities is very difficult despite official announcements of their availability to farmers. Currently, there are no effective strategies, instruments and incentive-inducing policies to encourage farming communities to rehabilitate their land. Moreover, if these existed, there is no official structure such as extension services, to deliver the required knowledge from science to the farm level and among farm communities.

This case study is an example of how a simple cost-effective approach involving licorice could be used to rehabilitate abandoned irrigated lands. Apart from land rehabilitation, bioremediation also offers additional income for individual farmers with relatively modest investments thus rendering it attractive for implementation. It also demonstrates the existence of superior farmers in the Galaba community, who are willing to improve their land and produce higher crop yields even under unfavorable environments or policy impediments. However, how to achieve out-scaling of such approaches in a wider area? Conventional extension services as commonly used to disseminate knowledge among farming communities are non-existent in the Central Asian countries and it is unlikely that such services will be established as knowledge based platforms in the centrally managed agricultural systems within the foreseeable future.

Hence, innovative approaches in addressing this knowledge gap that links the products of research with the farmers as main actors and other beneficiaries are required. This may take the form of creating linkages between farmers, researchers, management authorities and markets. It was shown that the creation of the Knowledge Alliance was the key strategy of exposing the potential of these superior farmers in an extension role that bypasses non-existent extension services. It was also evident that in implementing this collaboration the support of local authorities is important. However, the scientific and institutional support for such incentives needs to be put in place.

The advantage of building functional Knowledge Alliance groups is to deploy farmers themselves in the land rehabilitation process and linking them to neighboring farmers to facilitate the transfer of information between the two groups. The groups will remain active and will play a role of major dissemination agents among farming community. Unique to these established Knowledge

Alliance groups is that they do not only represent farmers but also representatives of provincial government and local businesspersons (i.e. licorice traders). The Knowledge Alliance group held meetings, in which information and discussions related to the cultivation of licorice was highlighted, work plans prepared and responsibilities of different parties agreed upon. The formation of the group can be seen as an attempt to institutionalize land rehabilitation efforts within local communities.

This study suggests that if a greater number of farmers in the region would adopt this strategy, it would result in significant positive benefits to all actors and the environment. Reverting adverse salinity effects and restoring productivity would enable enhanced production of both strategic and alternative crops in a much wider area that otherwise remained unproductive.

Bioremediation with *Glycyrrhiza glabra* can be regarded as one of the potentially successful options, which should not be conducted outside of, but on the contrary coupled with, the resource-saving irrigation and functional drainage infrastructure. There is however a need for more in-depth study of the other suitable varieties of halophytes and their effects on land. For instance, there are potential negative impacts associated with the introduction of plant species in the process of bioremediation that need to be considered. In the case of licorice it has all the attributes common to an invasive weedy species. Its extensive root system with the ability to sucker makes this species difficult to control without the use of herbicides.

X. CONCLUSION

Among the most effective ways to combat extensive land salinization in Central Asia and beneficially utilize marginal resources is to equip individual farmers and farming communities with efficient, affordable and profitable solutions. Bioremediation offers such an efficient alternative solution, however, no structures such as extension services exist to transfer the required knowledge to the farmers and initiate dialog between all actors including governmental authorities. Innovative approach, the formation of Knowledge Alliances including farming and scientific community and officials, offers an alternative. A case study in the Syrdarya province of Central Asia demonstrated a successful out-scaling of research-scale rehabilitation of 105 ha of abandoned irrigated land. Importantly, it offers not only farmer-supported remediation of degraded land, but also benefits to all actors by promoting the development of the local processing industry and international trade. This approach to out-scaling innovations may be an appropriate mechanism that could be promoted by the government.

REFERENCES

- [1] Abrol, I.P.; Yadav, J.S.P. and Massoud, F.I. 1988. Salt-affected soils and their management, FAO Soils Bulletin, vol. 39. Italy, Rome, 93 pp.
- [2] Akramkhanov, A., B. Tischbein, U. K. Awan. 2014. Effective management of soil salinity - revising leaching norms. In: JPA Lamers, A. Khamzina, I. Rudenko, PLG Vlek



- (Eds.): Restructuring land and water use in the lower Amudarya region: Policies and practices.
- [3] Aparin, V., Kawabata Y., Ko S., Shiraishi K., Nagai M., Yamamoto M., Katayama Y. 2006. Evaluation of Geoeological Status and Anthropogenic Impact on the Central Kyzylkum Desert (Uzbekistan). *J. Arid Land Studies*: 15-4: 129-133.
- [4] Ayers, R.S. and Westcot D.W. 1994. Water quality for Agriculture, FAO Irrig. and Drain. Paper 29, FAO, Rome
- [5] Bazilevich, N. I., and Pankova, E. I. 1972. Experience in classification of soils by toxic salts and ions. Genesis and amelioration of irrigated soils, Bulletin of the soil institute after Dokuchaev. Ed.4, M., p36-40.
- [6] Bucknall, J., I. Klytchnikova, J. Lampietti, M. Lundell, M. Scatasta, M. Thurman. 2003. Irrigation in Central Asia: Social, Economic and Environmental Considerations. Europe and Central Asia Region. Environmentally and Socially Sustainable Development Division. World Bank. Washington DC. Also available at www.worldbank.org/eca/environment
- [7] Chen, J., Wan, S., Henebry, G., Qi, J., Gutman, G., Sun, G. & Kappas, M. (eds.): *Dryland East Asia: Land Dynamics Amid Social and Climate Change*. 415 p., De Gruyter. 2013
- [8] CAREC, 2011. Gap analysis on adaptation to climate change in Central Asia. Priorities, recommendations, practices. Regional Environmental Centre for Central Asia, Almaty.
- [9] Chembarisov, E.I. and Bakhrudinov, B.A. 1989. Hydro-chemistry of river and drainage waters of Central Asia. Tashkent, Ukituvchi, 132pp.
- [10] Dagar, J.C., Tomar, O.S., Kumar, Y. and Yadav, R.K. 2004. Growing three aromatic grasses in different alkali soils in semi-arid regions of northern India. *Land Degradation and Development* 15, 143–151.
- [11] Djumaeva, D., N. Djanibekov, P.L.G. Vlek, C. Martius, C., J.P.A. Lamers. 2009. Options for optimizing dairy feed rations with foliage of trees grown in the irrigated drylands of Central Asia. *Research Journal of Agricultural and Biological Sciences*. *Research Journal of Agricultural and Biological Sciences*, 5 (5): 698-708.
- [12] FAO. 2003. Soil Resources, Land Degradation Assessment in drylands (LADA) Report, Land and Plant Nutrition Management Service (AGLL) of the Land and Water Development Division.
- [13] FAO. 2011. The state of the world's land and water resources for food and agriculture (SOLAW) – Managing systems at risk. Food and Agriculture Organization of the United Nations, Rome and Earthscan, London.
- [14] Forkutsa, I., Sommer R., Shirokova Y.I., Lamers J.P.A., Kienzler K., Tischbein B., Martius C., Vlek P.L.G. (2009) Modeling irrigated cotton with shallow groundwater in the Aral Sea Basin of Uzbekistan: II. Soil salinity dynamics. *Irrigation Science* 27 (4): 319-330
- [15] Ghassemi, F., Jakeman, A. J. and Nix, H. 1995. Salinization of land and water resources: Human causes, extent, management, and case studies. Univ. New South Wales Press, Sydney, Australia.
- [16] Goldshtein, R.I, Tsukatani T., Toderich K.N., Aparin V.B., Ashurmetov A. A. 2000. Ecological state and conservation of arid salt /affected lands using Asiatic *Salsola* species. Abstracts of International Seminar, Prospects for Saline Agriculture, Islamabad, p. 68.
- [17] Ibrakhimov, M. A. Khamzina, I. Forkutsa, G. Paluasheva, J. P. A. Lamers, B. Tischbein, P. L. G. Vlek, C. Martius. 2007. Groundwater table and salinity: Spatial and temporal distribution and influence on soil salinization in Khorezm region (Uzbekistan, Aral Sea Basin). *Irrig Drainage Syst* (2007) 21:219–236
- [18] Ikramov, R. 2004. Present salinity and drainage condition, and salinity control measures in Uzbekistan. Proceedings of the IWMI conference “Materials for meeting on development of the salinity, Land degradation and Drainage- Waste Water Reuse. Research program for Central Asia”. May 11-17, Tashkent, 2004.
- [19] Kappas, M., Kleinn, C., Sloboda, B. (Hrsg.), 2007 *Global Change Issues in Developing and Emerging Countries*. Universitätsdrucke Göttingen, 401 S.
- [20] Kariyeva, J. and van Leeuwen, W.J.D., 2012. Phenological dynamics of irrigated and natural drylands in Central Asia before and after the USSR collapse. *Agriculture, Ecosystems & Environment* 162, 77-89.
- [21] Keiffer, C. H. and Ungar, I. A. 2002. Germination and establishment of halophytes on brine-affected soils. *Journal of Applied Ecology*, 39, pp. 402–415. British Ecological Society
- [22] Khamzina, A., J.P.A. Lamers, M. Worbes, E. Botman, and P.L.G. Vlek, 2006. Assessing the potential of trees for afforestation of degraded landscapes in the Aral Sea Basin of Uzbekistan. *Agrofor. Syst.* 66 (2), 129-141.
- [23] Khamzina, A., Lamers J.P.A., Vlek P.L.G. 2012. Conversion of degraded cropland to tree plantations for ecosystem and livelihood benefits. In: Martius C., Rudenko I., Lamers J.P.A., Vlek P.L.G. (eds.), *Cotton, Water, Salts and Sooms-Economic and Ecological Restructuring in Khorezm, Uzbekistan*. Springer Science+Business Media, B.V., pp 235-248
- [24] Krasnouhova, R.A., E.G. Bessonov and etc. 1988. Methodical instructions on humus mapping for soils of Uzbek SSR (in Russian). pp.7. Gosagroprom UzSSR, Tashkent.
- [25] Kurochkina, L. Ya. and Makulbekova, G. B. 1984. Issues of phyto amelioration of denuded shores of Aral Sea. *Problems of development of deserts*. № 4.
- [26] Kushiev, H., Noble, A.D., Abdullaev, I., and Toshbekov, U. 2005. Remediation of abandoned saline soils using *Glycyrrhiza glabra*: A study from the Hungry Steppes of Central Asia. *International Journal of Agricultural Sustainability* 3: 103-113.
- [27] Musaev, B.S. 2001. *Agrochemistry (in Uzbek)*. pp.81. Shark, Tashkent.
- [28] Noble, A.D.; Bossio, D.A.; Penning de Vries, F.W.T.; Pretty, J.; Thiyagarajan, T.M. 2006. Intensifying agricultural sustainability: an analysis of impacts and drivers in the development of ‘brightspots’. Colombo, Sri Lanka: Comprehensive Assessment Secretariat 42 p. Comprehensive Assessment Research Report 13.
- [29] Olimjanov, O., and K. Mamarasulov. 2006. Economic and Social Context of the Vegetable System in Uzbekistan. Pages 91-95, in: Kuo, C.G., R.F. Mavlyanova, and T.J. Kalb (eds.).
- [30] Piankov, V. I., and Mokronosov, A. T. 1991. Physic-biochemical basis of ecological differentiation of desert plants and problems of phyto-amelioration of arid systems (in Russian). *Problems of development of deserts*. № 3–4. Pp. 161–170.
- Popov, V., Shapiro, D., and Danusevich, I. 1990. Medicinal plants (in Russian). Minsk, Polimya. 2nd edition.
- [31] Rakhimbaev, F.M. and Gasanova, G.K. 1986. Calculation of the Ameliorative Parameters of Irrigation Systems. Tashkent: Mehnat.
- [32] Rudenko, I., and Lamers, J.P.A., 2006. The comparative advantages of the present and future payment structures for agricultural producers in Uzbekistan. *Central Asian Journal of Management, Economics and Social Research* 5 (1/2), 106–125.
- [33] Scherr, S J. 2000. A downward spiral? Research evidence on the relationship between poverty and natural resource degradation. *Food Policy*, 25: 479-498
- [34] Shamsutdinov, N. Z. 2002. Cropping of *Glycyrrhiza Glabra* on the secondary salinity soils. In: Ahmad, R., Malik, K. A. (Eds.) *Prospects for saline agriculture*. Kluwer Academic Publishers, the Netherlands. Pp. 411-414.
- [35] Shamsutdinov, Z.Sh. and Shamsutdinov N.Z. 2005. *Galofitnoerastenievodstvo (jekologo-biologicheskiesnovy)*. M.: Publisher «Sovetskij sport». 404 p.
- [36] Toderich, K.N., Li V.V., Clanton C. Black, Yunusov T., Suiskeya E.V., Mardanova G.K. and Gismatullina L.G., 2006. Linkage studies of structure, isoenzymatic diversity and some biotechnological procedures for *Salsola* species under desert saline environments. *Biosaline Agriculture and salinity Tolerance in plants* (Munir Ozturk, Y. Waisel & A. Khan eds), Birkhauser Publisher: 73-83
- [37] Toderich, K.N., Shoaib, I., Juylova E.A., Bekchanov B., Rabbimov A.R. and Radjabov T. 2007. New approaches for Biosaline Agriculture Development, management and conservation of Kyzylkum Desert Ecosystems. Proceedings of the International Conference on Biosaline Agriculture & High Salinity Tolerance 3-8, Tunisia.
- [38] Toderich, K.N., Shuyskaya E.V., Rajabov T.F., Shoaib Ismail, Shaumarov M., Kawabata Yoshiko, and Li E.V. 2013. Uzbekistan: Rehabilitation of Desert Rangelands Affected by Salinity, to Improve Food Security, Combat Desertification and Maintain the



Natural Resource Base. In book: «Combating Desertification in Asia, Africa and Middle East» Editors: A. Heshmati, V.R. Squires, Chapter 13, 249-278.

marginal soil and water resources in irrigated agriculture. Editor: S.A. Shahid et al. Dordrecht: Springer, 579-602

[39] Toderich, K.N., Shuyskaya E. V., Taha F.K., Matsuo N., Ismail Sh., Aralova D.B., Radjabov T.F. 2013. Integrating agroforestry and pastures for soil salinity management in dryland ecosystems in Aral Sea Basin. In book: Developments in Soil Salinity Assessment and Reclamation: Innovative Thinking and Use of

Annex. Soil salinity assessment in Central Asia
Currently, soil salinity is assessed based on both Soviet system of appraisal and standard measurements of electrical conductivity (EC). To assess salinity based on the Soviet system, the various types of salinity are classified (Table 9, Bazilevich and Pankova 1972)

Table 9. Classification of salinity types in Central Asia

Type of salinity	Anions	Ratio of anions		
		Cl - SO ₄	HCO ₃ -Cl	HCO ₃ - SO ₄
Chloride	Cl	≥ 2.5		
Chloride-sulphate	SO ₄ -Cl	1.0 – 2.5		
Chloride sodic	HCO ₃ -Cl	> 1	> 1	
Sodic chloride	Cl-HCO ₃		< 1	
Sulphate sodic	HCO ₃ - SO ₄			> 1
Sodic sulphate	SO ₄ - HCO ₃			< 1
Sulphate chloride	Cl - SO ₄	0.3 - 1		
Sulphate	SO ₄	≤ 0.3		
Hydrocarbonate sulphate or hydrocarbonate chloride	HCO ₃ - SO ₄ - Cl		> 1	< 1

Soil salinity is further classified as non-saline, slightly, moderately, strongly and very strongly saline based on these soil salinity types (Table 10).

Table 10. Degree of soil salinity from toxic salt ions (g l⁻¹)

Salinity degree	Cl	SO ₄ -Cl	HCO ₃ -Cl, Cl-HCO ₃	HCO ₃ - SO ₄ , SO ₄ -HCO ₃	Cl - SO ₄	SO ₄	HCO ₃ - SO ₄ - Cl
Non-saline	<0.3	<0.5	< 1.0	< 1500	< 1000	< 1500	< 1500
Slightly	0.3 – 1.0	0.5 – 1.2	1.0 – 5.0	1.5 – 2.5	1.0 – 2.5	1.5 – 3.0	1.5 – 3.0
Moderate	1.0 – 3.0	1.2 – 3.5	1.5 – 3.0	2.5 – 3.5	2.5 – 5.0	3.0 – 6.0	3.0 – 5.0
Strongly	3.0 – 6.0	3.5 – 7.0	3.0 – 5.0	3.5 – 6.0	5.0 – 9.0	6.0 – 14.0	
Very strongly	> 6.0	> 7.0	> 5.0	> 6.0	> 9.0	> 14.0	