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ASSESSMENT OF EVAPOTRANSPIRATION OF LICORICE UNDER SALINE ENVIRONMENTS: CASE STUDY FROM GALABA FARM, UZBEKISTAN

Land salinization is widespread in countries of the arid zone, including in the Aral Sea basin, where 4 million hectares of irrigated land are salt-affected, causing high economic losses. Current saline soil reclamation practices include soil leaching and deep drainage to remove excess water outside the irrigated zone. Growing pressure on limited water resources makes this practice ineffective. An alternative is biological methods of salinity control, which are not widely used in the region. In this study, the licorice plant was considered a potential crop for restoring the fertility of salt-affected soils. The study has two objectives: (1) to assess evapotranspiration from licorice fields, and; (2) to track changes in soil chemical properties as affected by the cultivation of licorice on irrigated land. The results of the study indicate high evapotranspiration from licorice fields under irrigation. The total amount of soluble salts may increase in the soil profile; however, after more than 10 years of cultivation of the crop, no accumulation of toxic salts has occurred and there was no deterioration in the chemical and water-physical properties of soils, while at the same time soil fertility has increased.

Key words: Soil salinization, Aral Sea basin, licorice, biological reclamation, soil fertility.

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Мия алқаптарында жер бетіндегі булану және өсімдіктердің транспирация кезінде болатын булануды бағалау: Ғалаба шаруа фермасының мысалында, Өзбекстан

Жердің тұздануы құрғақ шөлді елдерінде, оның ішінде Арал теңізі бассейнінде кең таралған, онда 4 миллион гектар жер тұзды, бұл үлкен экономикалық шығындарға әкеледі. Тұзды топырақты мелиорациялаудың қазіргі әдістері: топырақты терең дренаж аясында жуу және суармалы аймақтан тыс коллекторлық – дренаждар арқылы шығарып тастау. Су ресурстары тапшылығы өсуі жағдайында бұл әдіс тиімсіз болып тұр. Тұздануға қарсы қолайлы биологиялық әдіске өту қажет, бірақ бұл әдіс өкінішке орай аймақтарда кең таралмаған. Бұл зерттеуде мия тамыры тұзды топырақтың құнарлығын қалпына келтірудің ықтимал өсімдігі ретінде қарастырылады. Зерттеудің екі мақсаты бар: (1) мия алқаптарында эвапотранспирацияны бағалау және; (2) суармалы жерлерде мия тамырын өсірудің әсерінен топырақтың химиялық қасиеттерінің өзгеруін бақылау. Зерттеу нәтижелері мия алқаптарын суару жағдайында қарқынды эвапотранспирация процессін көрсетеді. Топырақ профилінде еритін тұздардың жалпы мөлшері баяу артуы мүмкін; алайда, дақылдарды өсірудің 10 жылдан астам уақытында улы тұздардың жиналуы және топырақтың химиялық және су-физикалық қасиеттерінің нашарлауы болған жоқ, сонымен бірге топырақтың жоғарғы қабатындағы қарашірік мөлшері артты.

Түйін сөздер: топырақтың тұздануы, Арал теңізі бассейні, мия тамыры, биологиялық мелиорация, топырақ құнарлылығы.

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Оценка эвапотранспирации с полей лакрицы: на примере Хозяйства Галаба, Узбекистан

Засоление земель широко распространено в странах аридной зоны, в том числе в бассейне Аральского моря, где 4 миллиона га орошаемых земель засолены, что ведёт к большим экономическим потерям. Текущие методы мелиорации засоленных почв включают промывку почв на фоне глубокого дренажа и отвод коллекторно-дренажного стока за пределы орошаемой зоны. В условиях нарастающего дефицита водных ресурсов эта практика становится неэффективной. Альтернативой являются биологические методы борьбы с засолением, которые к сожалению не получили пока широкого распространения в регионе. В этом исследовании лакрица рассматривалась как потенциальная культура для восстановления плодородия засоленных почв. Исследование преследует две цели: (1) оценить эвапотранспирацию с полей лакрицы, и; 2) проследить изменение химических свойств почвы под влиянием выращивания лакрицы на орошаемых землях. Результаты исследования свидетельствуют об интенсивной эвапотранспирации с полей лакрицы в условиях орошения. В почвенном профиле может медленно увеличиваться общее количество растворимых солей; однако за более чем 10 лет возделывания культуры не произошло накопления токсичных солей и ухудшения химических и водно-физических свойств почв, в то же время содержание гумуса в верхнем слое почвы увеличилось.

Ключевые слова: Засоление почв, бассейн Аральского моря, лакрица, биологическая мелиорация, плодородие почв.

Introduction

One of the main reasons for the low productivity of 424 million (mln) hectares (ha) of topsoil in the world is soil salinization (FAO, 2005; UN General Assembly, 2015). Soil salinization is widespread in India, Pakistan, Egypt, the western states of the USA, and in the Aral Sea basin (Stavi et al., 2021). The area of the irrigated land in the Aral Sea basin is 7.9 million ha, of which 28.5%, or 2.25 million ha, are subject to moderate or severe salinity. Pankova E.I. (2016) summarized previous studies in the basin and made several important conclusions about causes of land salinization. She noted that before the intensive irrigation of lands in the middle of the 20th century, automorphic soils did not experience the active modern salt accumulation, although the soils had easily soluble salts in their profile. Under natural conditions, only hydromorphic soils experienced the process of salt accumulation. After developing the virgin land in mid-20th century, because of low efficiency of water distribution and use in conditions of insufficient natural drainage, automorphic soils pass into the rank of irrigated-hydromorphic soils, subject to soil secondary salinization. According to Karlykhanov and Toktaganova (2016), soil salinity is a major cause of unsustainability in farming in the lower reaches of the Amudarya River. Reclamation of secondary saline lands under irrigation has required their artificial drainage and intensive leaching practices using extra water resources. Increasing the water resources shortages makes it difficult to supply the additional water for leaching salts.

Another strategy is to adopt advanced irrigation technologies, such as sprinkler or drip irrigation. This measure intended to improve on-farm irrigation and off-farm water distribution efficiencies, can reduce groundwater recharge and gradually lower the groundwater table. This long-term strategy is not enough alone to deal with salinity issue and it has significant barriers to be solved. For example, it requires significant investments from the countries of Central Asia to make wide-scale irrigation modernization possible. This approach to salinity management is itself a big issue and as shows the experience of Spain and other European states, implemented such projects, the intended objectives may not be delivered (Berbel et al., 2019).

The third strategy discussed in this paper is the use of bio-reclamation methods. Salt-tolerant crops with a deep root system are able to intensively transpire the available soil moisture and groundwater, thereby reducing the level of groundwater, as well as improving the water-physical and chemical properties of soils. One of such crops is licorice. Despite the great interest in this crop due to the numerous products that can be obtained from it, its water regime on irrigated lands has not been studied enough, which is the main objective of this study.

There is 4 million (mln) hectares (ha) of salt-affected land in the Aral Sea basin. Salinity management practices on these lands include intensive soil leaching and deep drainage to remove excess water outside the irrigated area. Growing pressure on limited water resources makes these practices inefficient. An alternative is biological methods to combat land salinization, which have not been widely applied in the region. At the same time, many studies indicate that biological methods can reduce soil salinity levels and improve land productivity.

Licorice is one of the native perennial plants that grow in the salt-affected environments. Long-term studies have shown that the introduction of this plant into the agricultural land can contribute to obtaining a crop from abandoned unproductive lands, improve soil's physical properties and increase the biological activities of soils. On irrigated lands with shallow 1.5—2.5 m groundwater table, deep roots of the plant reaches the groundwater, intensively pump out water and transpire it to form big biomass, and at the same time lower the groundwater level and perform the biological drainage. Of particular interest are the studies that took place in the farm Galaba, Bayaut district, Uzbekistan.

In 2007, an alliance of farmers in cooperation with the Gulistan State University and the International Water Management Institute established on a 100 ha licorice site on abandoned lands of the farm. This was preceded by the experiment of the farmer who grew licorice on abandoned lands on an area of 4 ha. The farmer started growing the native plant on the abandoned land and after three years has found, that the groundwater table went down and soil salinity is reduced. After harvesting the roots of licorice in the 4th year, he sowed cotton seeds and received more than 2 t/ha of raw cotton (Kushiev et al., 2015). Following this experiment, the group of the farmers planted the licorice roots on 100 ha area which allowed them to lower the groundwater level and arrest soil salinization. The outcome of these efforts was establishing a joint venture near the farm for the production of a primary extract from the licorice roots for the subsequent extraction of glycyrrhizin acid.

Even though the beneficial properties of licorice have been well studied, the amount of evapotranspiration of this crop on irrigated lands remains uncertain, which complicates the planning of its irrigation. The goal of this study is to promote licorice-based bioremediation of salt-affected soils. The research objective is two-fold: (1) assessment of evapotranspiration from licorice fields, and; (2) to track changes in soil chemical properties as affected by the cultivation of licorice on irrigated land.

Materials and research methods

The studies were carried out in the Galaba farm, Bayaut district, Syrdarya region. Climatic conditions are typical for arid environments with hot summers when the air temperature rises to 40°C, and warm winters, when the air temperature is in the range of (-5°C)...(+5°C). The amount of the annual effective precipitation in some years drops below 100 mm. There is a strong wind in the spring season from east to west and in the autumn from west to east. The soils of the farm are compacted heavy and medium loams by texture with medium and high degrees of topsoil salinity. The soil has a high content of coarse silt fraction (particles 0.05-0.01 mm), varying from 24 to 50% in the upper soil layer of 0-50 cm. Groundwater is 2.5-3.0 m deep and has total dissolved solids above 5000 mg/l.

The main objective of the study was to estimate the evapotranspiration (ET) of licorice plants under irrigation as affected by the age of the plants. Crop ET was studied at the representative plot (N – 40°22'38.8''; E – 68°50'54.7''). From 1 March to 1 November 2020 soil samples were collected twice per month to determine soil moisture content. Soil samples were collected from soil intervals of 0-15, 15-30, 30-45, 45-60, 60-75, 75-90, 90-120, 120-160 cm and 160 -200 cm and below after each 50 cm. Soil moisture content was determined by the drying method. From the same depths, soil samples were collected for chemical analyses including total soluble solids (TSS) and organic matter (humus). Soil texture is determined in laboratory conditions. Soil bulk density is determined using the cylinder method. Chemical analyses of soil samples included: determining electro-conductivity of soil water solution of 1:5; anions of HCO_3^-, Cl^-, SO_4^{-2}, and cations of Na^+, Ca^{+2}, and Mg^{+2}; exchangeable cations of Na^+, Ca^{+2}, Mg^{+2}, and; humus content. The humus content is determined using the Tyurin method. Soil properties are compared with data for 2014 (Kurbantaev et al., 2014), given for the same site.

Crop ET is calculated using FAO method (Allen et al., 1998). Reference ET is estimated using

Penman-Montheith method. Crop ET adjusted is calculated using formula as follows:

$$ETa = (Ks * Kcb + Ke) * ETo$$

ETa – crop ET adjusted, *ETo* – reference ET, *Ks* – stress coefficient, *Kcb* – crop coefficient, *Ke* – evaporation coefficient from wet soil.

FAO Irrigation and Drainage Paper 56 (Allen et al., 1998), a standard procedure is applied to compute actual crop evapotranspiration under standard and non-standard (stressed) conditions. Crop ET is estimated using the excel-sheet developed by Allen et al. (1998). In the spreadsheet, the root zone is treated as a single layer from which water is depleted by the crop. Since crop coefficient was not available for licorice, in this study, the crop coefficient for licorice is taken to be equal to the crop coefficient for alfalfa, the other widespread legume crop. Soil crop cover, crop height, and root depth are taken from the field studies for different phases of the crop development. Following indicators, expressing the impact of soil alkalinity on soil physical properties are calculated using results of chemical analyses of soil water solution 1:5:

1) Sodium adsorption ratio (Wascom et al., 2010):

$$SAR = Na^{+} / (Ca^{+2} + Mg^{+2})^{0.5}$$

This indicator accounts for changes in soil filtration properties. If SAR exceeds 13 this indicates poor filtration properties of the soil and potentially, soil physical properties may affect crop evapotranspiration and biomass.

2) Ratio of concentration of Mg^{+2} to Ca^{+2}. If $Mg^{+2}/ Ca^{+2} > 1$ then the soil has excessive Mg^{+2} -ion that also can affect soil filtration properties and reduce crop ET and biomass.

3) Percentage of exchangeable sodium in cation exchange capacity (Corwin и др., 2007)

$$ESP = Na^{+} / CEC * 100\%$$

where Na^{+} – exchangeable sodium in mg-equ/100g of dry soil, CEC – cation exchange capacity, in mg-equ/100g d.s.

If ESP > 15% it indicates poor filtration properties of soils.

Results and their discussion

1. *Evapotranspiration from licorice fields*

For the period of 1.03.2020 through 31.10.2020, reference ETo amounted to 1109 mm, crop standard ETc 1272 mm, and crop adjusted ETca 1009 mm (figure 1). Crop ETca was 20% less than optimal ETc, which indicates a negligible influence of soil salinity levels on crop evapotranspiration.

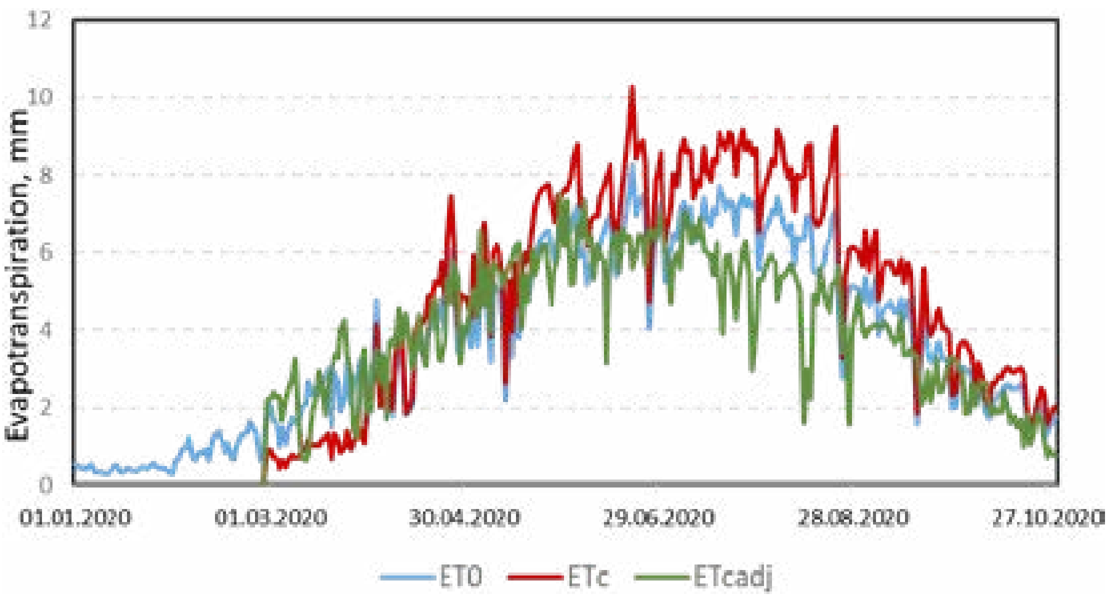

Figure 1 – Reference ETo, crop standard ETc and crop adjusted ETca for licorice estimated for the period of 1.03.2020 through 31.10.2020. Galaba farm

2. *Changes of soil chemical properties under licorice plants*

Changes in soil chemical properties under licorice plants of different ages studied in 2014 are given in Table 1 (modified from Kurbantaev et al, 2015).

The field data presented in Table 1 indicated reducing soil salinity levels, low risk of soil alkalinity increase, and improved soil organic matter content under licorice plantations. Soil SAR under the licorice plantations was less than under the cotton field and significantly below the threshold level, when occurs degradation of soil physical properties. The EC value showed that the soil salinity level reduced from low-saline to non-saline under the licorice. At the same time, abandoned soils were moderate saline in the top 0-15 cm layer. Ratio Mg^{2+}/ Ca^{2+} was less than 1 which indicated no negative impacts of Mg^{2+} ions on soil filtration properties. These results showed that soil physical properties were favorable for growing licorice, and had no negative impact on licorice crop ET and biomass. These findings were confirmed by the field studies in 2020 (Table 2).

Table 1 – Selected soil chemical properties in top 0-50 cm soil layer as affected by the age of licorice plants. 2014. Galab farm

Age of licorice, years	Soil layer, cm	EC dS/m	Cl^-/SO_4^{-2} [–]	Mg^{+2}/Ca^{+2} [–]	SAR [–]	Humus %
1	0-30	1.91	0.15	0.63	0.60	0.6
1	30-53	3.02	0.33	0.72	1.11	0.4
4	0-30	1.55	0.35	0.99	4.24	1.64
4	30-50	2.20	0.56	0.34	2.19	0.4
6	0-20	1.61	0.11	0.71	0.80	0.74
6	20-40	1.48	0.10	0.43	0.70	0.34
10	0-30	0.81	0.08	0.33	0.06	1.5
10	30-50	0.85	0.09	0.25	0.48	0.81
Cotton	0-35	0.65	0.18	0.49	1.13	0.93
Cotton	35-56	0.34	0.17	0.66	0.74	0.38
Abandoned soils	0-35	5.70	0.26	0.33	1.63	0.72
Abandoned soils	35-60	3.20	0.29	0.35	1.08	0.25

Notes: EC – electrical conductivity; SAR –sodium adsorption ratio

The field data from 2020 indicate minor increasing total soluble solids in the topsoil; however, none of the indicators considered show negative impacts of soil chemical properties on soil physical properties. For example, there are reductions in Cl^-/SO_4^{2-} and Mg^{2+}/Ca^{2+} ratios, and SAR. Moreover, the humus content in the top 0-15 cm soil profile is increased from 1.03% under 3-years old plants to 1.58% under 5-years old and 1.86% under over 10-years old plants. The data presented for two consequent periods indicates no degradation of soil chemical properties and negative effect of soil chemical properties on licorice ET and biomass in long run.

Table 2 – Selected soil chemical properties in top 0-50 cm soil layer as affected by the age of licorice plants. 2020. Galaba farm

Age of licorice, years	Soil layer cm	EC dS/m	$Cl^-/SO4^{-2}$ [–]	Mg^{+2}/Ca^{+2} [–]	SAR [–]	Humus %
3	0-15	1.61	0.36	0.79	1.59	1.03
3	15-30	1.67	0.24	0.80	1.29	0.70
3	30-50	1.26	0.25	0.76	0.97	0.53
5	0-15	2.19	0.34	0.66	1.95	1.58

Continuation of the table

Age of licorice, years	Soil layer cm	EC dS/m	$Cl^{-}/SO4^{-2}$ [–]	Mg^{+2}/Ca^{+2} [–]	SAR [–]	Humus %
5	15-30	2.33	0.12	0.43	0.96	0.91
5	30-50	2.07	0.10	0.42	0.82	0.30
10	0-15	3.20	0.15	0.52	1.59	1.86
10	15-30	2.70	0.09	0.31	0.79	0.70
10	30-50	3.20	0.06	0.28	0.61	0.38

A comparison of the soil chemical properties for 2014 and 2020 showed a bioremediation effect of licorice. There were no signs of degrading soil's physical properties, and the redistribution of soluble solids in the soil profile was compensated by increasing the organic matter content in the topsoil.

Conclusions

Licorice can contribute to the bioremediation of salt-affected soils. This legume crop accumulates a significant amount of nitrogen in the top 0-50 cm soil layer, which is a base for forming high biomass and gradual increase humus content in the soil profile. High biomass and the deep-rooting system indicate a high transpiration rate. Crop evapotranspiration under optimal conditions amounts to 12,000 m^3/ha, while crop adjusted evapotranspiration exceeds 10,000 m^3/ha. There is indicated a gradual increase of total soluble solids in the topsoil profile; however, the content of the toxic solids is reduced. There were no degradation of soil physical or chemical properties and no negative impacts of soil salinity on crop evapotranspiration and formation of biomass. The results of this study show that licorice, with its bioremediation and bio-drainage capabilities, is a suitable crop for creating a fully circular water use system on irrigated lands prone to salinity. The estimates of crop evapotranspiration were based on the assumption that the crop coefficient for licorice is the same as for alfalfa. Further studies are needed to refine the crop coefficient for licorice. It is expected that the actual crop coefficient for licorice is higher than accepted in this study.

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