PROCEEDINGS OF THE YEREVAN STATE UNIVERSITY

Chemistry and Biology 2020, **54** (2), p. 159–167

Biology

SOIL SALINIZATION IN THE AGRICULTURAL AREAS OF ARMENIAN SEMI-ARID REGIONS: CASE STUDY OF MASIS REGION

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Soil salinization processes in the agricultural lands of Masis region, Armenia, were investigated. Soil samples collected from these areas at the beginning (April) and end (October) of irrigation season in 2019 were analyzed for electrical conductivity as an indication of salinity. The results of the study demonstrated that irrigation caused an intensive accumulation of soluble salts in the upper horizons of these agricultural soils posing a risk of a decline in soil productivity and of soil degradation. All of this calls for an urgent need for sustainable soil management in this region.

https://doi.org/10.46991/PYSU:B/2020.54.2.159

***Keywords*:** groundwater quality, soil salinization, electrical conductivity, irrigation, Masis region.

Introduction. Soil performs a regulator function in the hydrological and biogeochemical cycles of terrestrial ecosystems and provides important ecosystem services [1, 2]. Soil salinity is due to the presence of soluble salts, primarily alkali and alkaline earth metals and associated anions [3]. Large amount of arable land is abandoned every year due to salinization, which is the result of a combination of natural and anthropogenic factors [4] and is often associated with climates with low aridity index (<0.5) [5, 6], high groundwater levels, low quality of irrigation water [7], traditional irrigation methods practiced with poor drainage systems [8]. Soil salinization is an environmental worldwide problem that reduces soil quality [9] and restricts the sustainable development of regional economies and agriculture [10, 11]. Soil salinization primarily affects the ecological functions of soil, leading to a decrease in soil biodiversity and microorganism activity and influencing such processes in the soil as respiration, residue decomposition, nitrification, etc. [12]. In this case, the high osmotic pressure of soil solution complicates the process of water absorption by plants. Nutritional imbalances and toxicity caused by various ions can be noticed in plants, as well. Secondary salinization affects about 20% of irrigated

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land of the world [13]. Salinized areas are steadily growing and it has been estimated that more than 50% of croplands worldwide will be salinized by year 2050 [14]. Soil salinization can thus pose a serious threat to the biosphere and ecological security [15, 16] and hinders economic and general welfare. As a lot of agricultural lands and ecosystems are affected by soil salinization, greater focus is given to this issue, particularly within the scientific community [17–19].

Such an ecological issue also exists in Armenia, particularly Masis region. Masis region is characterized by such natural and climatic conditions (dry and hot summers, scarce precipitation, high groundwater level, etc.) that can cause soil salinization. These natural conditions are also combined with anthropogenic activities, namely agriculture, which intensifies the process of soil salinization. It should be noted that groundwater, which has mainly a high salt level and poor irrigation properties, is mostly used for irrigation purposes in this area [20]. Taking into consideration this fact, the monitoring of soil salinity in the area is an important basic work that is necessary to understand the distribution of saline soils and explore the mechanism of soil salinization [21, 22].

Materials and Methods.

Study Area. Masis region is located in the Ararat plain (northwest of Ararat Province). The climate in this region is strictly continental: summers are dry and hot, winters are cold. The average annual precipitation ranges from 200 to 300 *mm*, and the temperature from 12 to 13°C [23]. The relief of the study area is mainly flat, with the elevation of 826–851 *m* AMSL. The main soil types found in the study area are the following: irrigated meadow–gray, saline–alkaline, wet meadow–gray and irrigated residual–meadow–gray soils [24].

Sample Collection and Analysis. Soil samples were collected from 26 agricultural lands (which are almost evenly distributed in Masis region) at the beginning (April) and end (October) of the irrigation season in 2019 (Fig. 1). During the soil sampling, the geographical coordinates and elevations of sampling sites were determined by GPS. Samples were collected from 4 soil horizons: 0–10 *cm*, 10–30 *cm*, 30–60 *cm* and 60–100 *cm*. The sampling in all the sites was implemented according to the envelope sampling approach [25]. For each site, the samples taken from each corner and the center of square (side length of 5 *m*), all together 5 samples, were mixed, and about 3.5 *kg* of mixed soil was sampled. The soil samples were then placed in large plastic packages (zip-lock) and transferred to the laboratory for further studies.

Electrical conductivity (EC) of the soil extract is a conventional parameter for describing soil salinity [26, 27]. The standard laboratory method for determining the EC of soil is by using a saturated paste extract (EC_e). However, difficulties arise in preparing a saturated paste extract due to problematics of determining the appropriate water saturation point. This obstacle may be tided over using a 1 : n (n=1, 2, 2.5, 5, 10) soil to water extracts (1 part of soil to n parts of distilled water). This method has the advantage of simplicity, reduced time, and cost compared to saturation paste extracts.

We chose the 1:5 soil to water ratio, as this ratio was considered apt for assessing soil salinity in many studies (see [26] and references cited therein). A 1:5 extract was prepared from field soil samples using standard procedures. The electrical conductivity ($EC_{1:5}$) of the water extract of the soil was measured by a portable conductivity meter (MARK-603, CJSC “Ecological Sensors and Systems”, the Russian Federation). The analyses of the soil samples were implemented by three replicates.

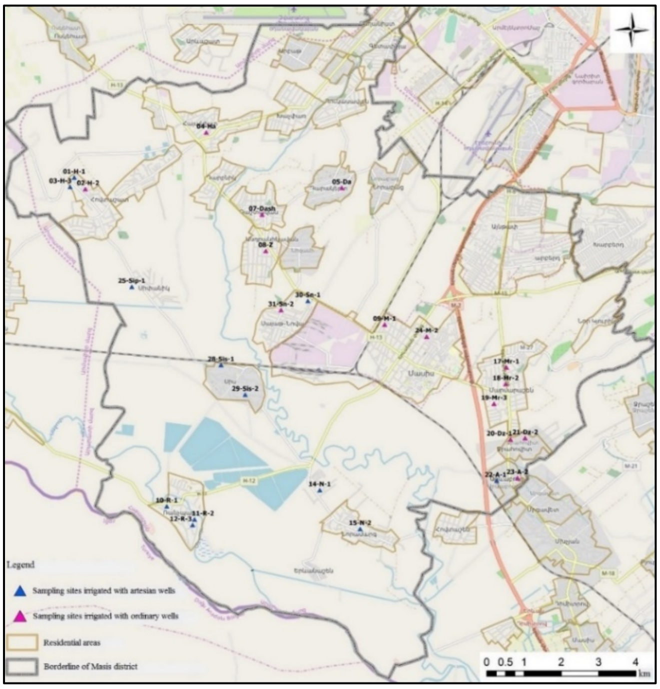

Fig. 1. Map of Masis region showing the soil sampling sites.

Soil salinity was assessed by EC of the saturated paste extract (EC_e), although it was not measured directly. The scale for the assessment of soil salinity degree according to EC_e is given in Tab. 1 [27]. $EC_{1:5}$ was re-calculated to EC_e according to the formulas certified in [28]: $EC_e = 7.36\ EC_{1:5} - 0.24$ for clay soil, $EC_e = 7.58\ EC_{1:5} + 0.06$ for loamy soil, and $EC_e = 8.22\ EC_{1:5} - 0.33$ for sandy soil.

Table 1

Classification of soil salinity degree according to EC_e

Salinity degree	Range of EC_e (*dS*/*m*)	Description
Non	0–2	Salinity effects are negligible for all plant types.
Slight	2–4	Yields of very sensitive crops may be restricted.
Moderate	4–8	Yields of many crops are restricted.
High	8–16	Only tolerant crops yield is satisfactory.
Extreme	>16	Only some extremely tolerant crops can survive.

Results and Discussion.

As shown in Tab. 2, the mean values of $EC_{1:5}$ in April increased in parallel with the depth of soil layer. So, the lowest mean value of $EC_{1:5}$ (0.3772 *dS*/*m*) was observed for the depth range of 0–10 *cm*, and the highest value (0.4416 *dS*/*m*) for the depth range of 60–100 *cm*. In October, the opposite pattern was observed, namely

$EC_{1:5}$ values decreased in parallel with depth, and the highest average value (0.6696 *dS*/*m*) was recorded for the depth range of 0–10 *cm*, the lowest (0.4073 *dS*/*m*) for the depth range of 60–100 *cm*. Such changes in $EC_{1:5}$ values observed at the beginning and end of the irrigation season may have been conditioned by certain factors:

- chemical composition of groundwater used for irrigation purpose: the higher the content of soluble salts in this water, the more intense the accumulation of salts in the upper horizons of soil during the irrigation season and, consequently, the increase in $EC_{1:5}$ value;
- precipitation, most of which falls from the end of the irrigation season until the beginning of the next irrigation season: soluble salts are washed out by precipitation and moved from the upper to the lower layers of soil;
- groundwater level: the lower the groundwater level, the better the soil desalination process, and in the case of high groundwater level, due to the capillary forces, groundwater having relatively high salinity rises up through the soil profile transferring also soluble salts.

Nevertheless, in the case of a combination of low-level groundwater and intensive irrigation, the deep soil horizons can be washed during the irrigation season and soluble salts move deeper, even reaching groundwater.

Depending on the predominance of one or another of these processes, the salinization and desalination processes occurred in different ways. For example, during the irrigation season there was observed an intensive accumulation of soluble salts in the upper horizons of the observation site 13 R-3-2/1, which had no very high level (3 *m*) of groundwater and was irrigated with water having relatively high salinity [20], as well as desalination in the deep layers of this site. Whereas in the observation site 29 Sis-2/1, which was irrigated with water having good irrigation properties [20], and, theoretically, soil salinization processes should not have been observed, however, during the irrigation, not only the deep soil horizons were not washed due to the high level (0.6 *m*) of groundwater, but there was also an intensive accumulation of soluble salts due to the rise of groundwater with relatively high salinity into the upper horizons of soil, which was caused by capillary forces.

In order to more clearly reflect the dynamics of salinization process, the salinity of soils was also assessed (Tab. 3). The results of the study showed that in the spring 30.8%, 11.5%, 19.2% and 20% of the soil samples taken from the depth ranges of 0–10 *cm*, 10–30 *cm*, 30–60 *cm* and 60–100 *cm*, accordingly, belonged to non-saline, 61.5%, 80.8%, 65.4% and 60% to slightly saline, and 7.7%, 7.7%, 15.4% and 20% to moderately saline categories.

As shown in Tab. 3, the salinity degree in the studied soil samples in autumn was obviously changed, and the following pattern was observed: 38.5% of the soil samples taken from the depth range of 0–10 *cm* belonged to slightly saline, 53.8% to moderately saline, and 7.7% to highly saline categories; 3.8% of the samples taken from the depth range of 10–30 *cm* corresponded to non-saline, 46.2% to slightly saline, 46.2% to moderately saline, and 3.8% to highly saline categories; 15.4% of the samples gathered from the depth range of 30–60 *cm* were rated as appurtenant to non-saline, 53.9% to slightly saline, and 30.7% to moderately saline categories; 12% of the samples from the depth range of 60–100 *cm* were referred to non-saline, 80% to slightly saline, and 8% to moderately saline categories.

Table 2

$EC_{1:5}$ values of the water extract of the investigated soil samples

Sampling site no.	Depth (*cm*)	$EC_{1:5}$ (*dS/m*)		Sampling site no.	Depth (*cm*)	$EC_{1:5}$ (*dS/m*)	
		April	October			April	October
01H/1	0–10	0.3094	0.4092	17 Mar-1/1	0–10	0.5478	0.6030
	10–30	0.2637	0.4095		10–30	0.4576	0.4919
	30–60	0.2601	0.2611		30–60	0.3890	0.4403
	60–100	0.7432	0.4035		60–100	0.3556	0.3320
02H/1	0–10	0.4966	0.4626	18 Mar-2/1	0–10	0.5020	0.6205
	10–30	0.3244	0.3021		10–30	0.4186	0.5355
	30–60	0.2064	0.2251		30–60	0.4019	0.4732
	60–100	0.1801	0.2482		60–100	0.4411	0.3940
03H/1	0–10	0.2482	0.3199	19 Mar-3/1	0–10	0.3441	0.4356
	10–30	0.2210	0.2466		10–30	0.3353	0.4018
	30–60	0.2303	0.2260		30–60	0.4692	0.3806
	60–100	0.2154	0.2155		60–100	–	–
04Ha/1	0–10	0.4300	0.6004	20 Dz-1/1	0–10	0.4119	0.9788
	10–30	0.4219	0.5930		10–30	0.3765	0.6391
	30–60	0.4764	0.4217		30–60	0.4528	0.4630
	60–100	0.4743	0.3476		60–100	0.4105	0.4700
05 Da/1	0–10	0.2906	0.5463	21 Dz-2/1	0–10	0.3793	0.9262
	10–30	0.2728	0.4026		10–30	0.3983	0.7552
	30–60	0.2957	0.3181		30–60	0.5397	0.6269
	60–100	0.2858	0.3126		60–100	0.4391	0.4749
07 Dash/1	0–10	0.2691	0.7991	22 A-1/1	0–10	0.3007	0.3675
	10–30	0.4074	0.7047		10–30	0.3917	0.3113
	30–60	0.4269	0.4612		30–60	0.3905	0.3153
	60–100	0.3488	0.3900		60–100	0.3910	0.3599
08 Z/1	0–10	0.2672	0.9560	23 A-2/1	0–10	0.3578	0.9196
	10–30	0.3556	0.8770		10–30	0.5310	0.6350
	30–60	0.3600	0.8428		30–60	0.8517	0.6765
	60–100	0.3937	0.4498		60–100	0.6018	0.5081
09 M/1	0–10	0.3132	0.6006	24 M-2/1	0–10	0.2574	0.9850
	10–30	0.4891	0.6172		10–30	0.3084	1.0220
	30–60	0.8087	0.4040		30–60	0.3972	0.6831
	60–100	1.0270	0.4254		60–100	0.4303	0.7195
10 R-1/1	0–10	0.4734	0.9859	26 Sip-2/1	0–10	0.2910	0.3479
	10–30	0.4445	0.8852		10–30	0.2881	0.3566
	30–60	0.7403	0.6931		30–60	0.2947	0.3078
	60–100	0.9806	0.4461		60–100	0.3984	0.3802
11 R-2/1	0–10	0.6484	1.1160	28 Sis-1/1	0–10	0.2416	0.3522
	10–30	0.7389	1.0040		10–30	0.3026	0.3206
	30–60	0.7191	0.8645		30–60	0.2162	0.2577
	60–100	0.2537	0.4901		60–100	0.2356	0.3583
13 R-3-2/1	0–10	0.3867	0.8183	29 Sis-2/1	0–10	0.6376	1.3260
	10–30	0.3356	0.7823		10–30	0.6602	1.4070
	30–60	0.3000	0.6681		30–60	0.4000	0.6913
	60–100	0.4080	0.3069		60–100	0.6160	0.6114
14 N-1/1	0–10	0.3210	0.3632	30 S-N-1/1	0–10	0.2500	0.5915
	10–30	0.3121	0.3726		10–30	0.3316	0.4803
	30–60	0.3533	0.4261		30–60	0.3512	0.2942
	60–100	0.3669	0.4364		60–100	0.3306	0.3369
15 N-2/1	0–10	0.4595	0.5238	31 S-N-2/1	0–10	0.3738	0.4556
	10–30	0.4110	0.5137		10–30	0.3440	0.4376
	30–60	0.3773	0.3548		30–60	0.3342	0.4251
	60–100	0.3355	0.2673		60–100	0.3769	0.4640

Table 3

Salinity categories of the soil samples.

Sampling site no.	Depth (*cm*)	Salinity degree	
		April	October
01H/1	0–10	slight	slight
	10–30	slight	slight
	30–60	slight	slight
	60–100	moderate	slight
02H/1	0–10	slight	slight
	10–30	slight	slight
	30–60	non	non
	60–100	non	non
03H/1	0–10	non	slight
	10–30	non	non
	30–60	non	non
	60–100	non	non
04Ha/1	0–10	slight	moderate
	10–30	slight	moderate
	30–60	slight	slight
	60–100	slight	slight
05 Da/1	0–10	slight	moderate
	10–30	slight	slight
	30–60	non	slight
	60–100	non	slight
07 Dash/1	0–10	non	moderate
	10–30	slight	moderate
	30–60	slight	slight
	60–100	slight	slight
08 Z/1	0–10	non	moderate
	10–30	slight	moderate
	30–60	slight	moderate
	60–100	slight	slight
09 M/1	0–10	slight	moderate
	10–30	slight	moderate
	30–60	moderate	slight
	60–100	moderate	slight
10 R-1/1	0–10	slight	moderate
	10–30	slight	moderate
	30–60	moderate	moderate
	60–100	moderate	slight
11 R-2/1	0–10	moderate	highly
	10–30	moderate	moderate
	30–60	moderate	moderate
	60–100	non	slight
13 R-3-2/1	0–10	slight	moderate
	10–30	slight	moderate
	30–60	slight	moderate
	60–100	slight	slight
14 N-1/1	0–10	slight	slight
	10–30	slight	slight
	30–60	slight	slight
	60–100	slight	slight
15 N-2/1	0–10	slight	slight
	10–30	slight	slight
	30–60	slight	slight
	60–100	slight	non
17 Mar-1/1	0–10	slight	moderate
	10–30	slight	slight
	30–60	slight	slight
	60–100	slight	slight
18 Mar-2/1	0–10	slight	moderate
	10–30	slight	moderate
	30–60	slight	slight
	60–100	slight	slight
19 Mar-3/1	0–10	slight	slight
	10–30	slight	slight
	30–60	slight	slight
	60–100	–	–
20 Dz-1/1	0–10	slight	moderate
	10–30	slight	moderate
	30–60	slight	slight
	60–100	slight	slight
21 Dz-2/1	0–10	slight	moderate
	10–30	slight	moderate
	30–60	slight	moderate
	60–100	slight	slight
22 A-1/1	0–10	non	slight
	10–30	slight	slight
	30–60	slight	slight
	60–100	slight	slight
23 A-2/1	0–10	slight	moderate
	10–30	slight	moderate
	30–60	moderate	moderate
	60–100	moderate	slight
24 M-2/1	0–10	non	moderate
	10–30	slight	moderate
	30–60	slight	moderate
	60–100	slight	moderate
26 Sip-2/1	0–10	non	slight
	10–30	non	slight
	30–60	non	slight
	60–100	slight	slight
28 Sis-1/1	0–10	non	slight
	10–30	non	slight
	30–60	non	non
	60–100	non	slight
29 Sis-2/1	0–10	moderate	highly
	10–30	moderate	highly
	30–60	slight	moderate
	60–100	moderate	moderate
30 S-N-1/1	0–10	non	moderate
	10–30	slight	slight
	30–60	slight	non
	60–100	slight	slight
31 S-N-2/1	0–10	slight	slight
	10–30	slight	slight
	30–60	slight	slight
	60–100	slight	slight

Comparing the dynamics of salinity degree in different soil horizons during the irrigation season, it can be stated that there was an intensive accumulation of readily soluble salts in the upper horizons (0–10 *cm* and 10–30 *cm*) of the soil and a slight accumulation in the middle horizon (30–60 *cm*), while an accumulation was practically absent in the deep horizon (60–100 *cm*), and there was even desalination, therefore, also an improvement in salinity degree in some observation sites.

Conclusion. Summarizing the results of the study, it can be concluded that the continuous use of irrigation systems and irrigation water of the quality that are actually used can lead to the salinization of agricultural soils in Masis region and, consequently, to a decline in productivity and, ultimately, soil degradation. Depending on the specific area, the identification of sources of better-quality irrigation water, switching to a drip irrigation system (less amount of salts will accumulate during the irrigation season and the natural washing of soils by precipitation will be more complete) and groundwater level lowering (at least 3–4 *m*) depending on soil texture, in order to prevent the salinization of soils by groundwater with a high degree of salinity and to make the process of the natural washing of soils more efficient, have to be considered as urgent measures to stop soil salinization process and improve soil state.

This work was supported by the Science Committee of the Ministry of Education, Science, Culture and Sport of RA under Grant No. 18T-4C345 and by Food and Agriculture Organization of the United Nations under Grant No. GCP/GLO/853/RUS.

Received 17.06.2020
Reviewed 17.07.2020
Accepted 27.07.2020

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ՀՈՂԵՐԻ ԱՂԱԿԱԼՈՒՄԸ ՀԱՅԱՍՏԱՆԻ ԿԻՍԱՉՈՐԱՅԻՆ ՇՐՋԱՆՆԵՐԻ ԳՅՈՒՂԱՏՆՏԵՍԱԿԱՆ ՀԱՆԴԱԿՆԵՐՈՒՄ. ՀԻՄՆԱԽՆԴՐԻ ՈՒՍՈՒՄՆԱՍԻՐՈՒՄ ՄԱՍԻՍԻ ՏԱՐԱԾԱՇՐՋԱՆՈՒՄ

Ուսումնասիրվել են հողի աղակալման գործընթացները Մասիսի տարածաշրջանի գյուղատնտեսական հանդակներում: Այս տարածքում 2019 թվականին ոռոգման սեզոնի սկզբին (ապրիլ) և վերջին (հոկտեմբեր) վերցված հողերի նմուշներում որոշվել է էլեկտրահաղորդականությունը՝ որպես աղակալվածության ցուցանիշ: Ուսումնասիրության արդյունքները ցույց են տվել, որ ոռոգումն առաջացրել է լուծելի աղերի ինտենսիվ կուտակում այդ գյուղատնտեսական հողերի վերին հորիզոններում, ինչը կարող է հողի արտադրողականության անկման և դեգրադացիայի պատճառ հանդիսանալ: Ուստի, այս տարածաշրջանում կա հողային պաշարների կայուն կառավարման հրատապ անհրաժեշտություն:

К. А. КАЗАРЯН, Г. А. ГЕВОРГЯН, А. С. МОВСЕСЯН, Г. Э. ХАЧАТРЯН

ЗАСОЛЕНИЕ ПОЧВ В СЕЛЬСКОХОЗЯЙСТВЕННЫХ УГОДЬЯХ ПОЛУЗАСУШЛИВЫХ РАЙОНОВ АРМЕНИИ: ИЗУЧЕНИЕ ПРОБЛЕМЫ В МАСИССКОМ РЕГИОНЕ

Изучены процессы засоления почв сельскохозяйственных угодий Масисского региона Армении. В пробах почвы, взятых на этих участках в начале (апрель) и конце (октябрь) ирригационного сезона в 2019 г., была определена электропроводность как показатель засоленности. Результаты исследования показали, что орошение приводит к интенсивному накоплению растворимых солей в верхних горизонтах этих сельскохозяйственных земель, что создает риск снижения продуктивности почвы и ее деградации. Все это свидетельствует о насущной необходимости устойчивого управления почвенными ресурсами в этом регионе.