Effect of soil salinization on the productivity of pasture in the arid land

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Abstract. This study compares the field data of the seasonal dynamics of halophytic plant productivity as dependent upon soil salinity level and soil type. The field study was carried out in the coastal area of Lake Kurinka (the Republic of Khakasia, south of Middle Siberia) between May and September of 2014 and 2016. Two plant communities with different soil salinity levels were studied. Results of the field investigation show that there is a correlation between plant growth and the soil salinity level. With high-salinity (3.72%) soils, the productivity of halophyte plants is lower than productivity with low-salinity (0.175%) soils.

1. Introduction
Natural pastures in arid regions are the main source of food for the cattle and horses [1]. In arid regions, natural pastures often have high salinity levels, and the vegetation growing on this land is usually represented by halophytic plants, which are physiologically adapted to high salt concentrations in the soil. Halophytes are ecologically, physiologically, and biochemically specialized plants capable of growth and production in the high-salinity environment and with saline irrigation [2]. Since halophytes form relatively tall, branched aboveground parts, large amounts of water are evaporated, the water table is lowered, evaporation from the soil surface is decreased, and salt concentrations in the upper soil horizons become lower [3]. It is very important to enhance productivity of saline lands, create high-yield grazing lands, and use them effectively in agriculture.

One of the issues that has always interested researchers studying halophytes is how the excess salt influences the growth and development of these salt-tolerant plants. Halophytes are found exclusively in habitats with high levels of soil salinity. It is generally assumed that salt stress is the most important limiting factor for plant growth in natural saline environments and that halophytes have developed specific adaptations to elevated salinity that make them unfit to grow in the absence of salt, thus explaining their distribution in nature [4].

In Khakasia (South Siberia, Russia), under arid climate conditions, there are about 300 lakes with different levels of mineralization. Meadow plants, mainly represented by halophytes, cover the shores of the salt lakes.

To evaluate the state of the pastureland, the productivity of plant communities should be regularly monitored throughout the growing season. This is, however, a labor-intensive and time-consuming process. Therefore, methods of mathematical modeling are a useful tool for forecasting plant productivity as dependent on the environmental factors. A mathematical model has been constructed to describe the growth dynamics of various plant communities of halophytic meadows depending on the

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temperature factor and degree of soil salinity [5]. The results of field investigations (2004 – 2006) and model studies show that there is a correlation between plant growth and air temperature for plant communities growing on soils with the lowest and medium salinity levels. It was proven in model studies that for the plant communities that grow on highly saline (3.58%) soils, not only air temperature but also the salinity level of the soil should be taken into account.

Halophytic plants are able to exist on soils with high salt concentrations [4]. Other researchers [6] observed beneficial effects of moderate salinization on life processes of halophytic plants such as an increase in enzyme quantity responsible for salt exchange, maximal growth, etc. However, high concentrations of soluble salts in the soils affect plants adversely. Soil salinity is a major abiotic stress in plant agriculture worldwide [7], [8]. In addition to that, the toxic effect of salts depends on the chemical composition of salts and the salt tolerance of the plant.

Numerous studies of salt marsh vegetation have shown strong relationships between zones of plant species distribution and physical gradients related to elevation and tidal flooding [9]. More recent studies have shown that plant species distributions are also correlated with the location and size of tidal channels since the tidal channel networks largely control the distribution of tidal flooding within the marsh [10].

It is very important to enhance productivity of saline lands, create high-yield grazing lands, and use them effectively in agriculture.

The purpose of this study was to investigate seasonal growth of halophytic plant communities taking into account the salinity level of the soil, based on the field study 2014 and 2016. Results of the present study can be used to predict productivity of different halophytic plant communities.

2. Materials and methods

Plants of halophytic meadows in the coastal area of Lake Kurinka, situated in the central part of South Siberia, the Republic of Khakassia (53°26’01’’N, 91°34’85’’E), were used in this study (figure 1).

![Figure 1](https://example.com/figure1.png)

Figure 1. Halophytic plant communities on study plots: (A) - meadow fescue (*Festuca pratensis*) - couch grass (*Elytrigia repens*, *Elymus janceus*) – PC.1; (B) - sea blite (*Suaeda linifolia*, *Puccinellia tenuissima*) – PC.2.

The shore of this lake is a convenient environment for studying halophytic plants, as the level of soil salinity changes with the distance from the lake, and, thus, the plant canopy structure also changes. The lake is situated in the steppe region. The total mineral content of the lake water varies between 72 and 108 g/L. The size of the lake and water salinity change over a long-term time scale.

The climate is severe continental, with cold winters and hot summers. The frost-free season lasts 117-119 days. The climate is arid. The data on daily mean air temperatures were obtained from the “Khakasskaya” Meteorological Station. The total annual precipitation varies between 295 and 414 mm (the norm being 320 mm). During the study period, the amount of precipitation was within the normal...
range. In some of the years, however, the distribution of precipitation within one growing season was extremely non-uniform, and that had a certain influence on the productivity dynamics [11].

The field study was conducted in 2014 and 2016. We chose sample plots representing each plant community around the lake to conduct field studies. The geographic positions of the plots were determined with a Garmin 72 GPS navigation system. Plant samples were collected between May and September, on the same dates every month. Geobotanical descriptions were done taking into account the vertical and horizontal structures of plant communities.

Two plant communities were studied: meadow fescue - couch grass – PC.1 and sea blite – PC.2. Every plant community grew on the soil with a different level of salinity – the amount of the solid residue of the saline soil aqueous extract (table 1). The type of salinity was sulfate - sodic.

Table 1. Structure of plant communities and soil salinity levels.

| Plant community | Dominant species                  | Soil type               | Soil salinity, % |
|-----------------|----------------------------------|-------------------------|-----------------|
| PC. 1           | Elytrigia repens (L.) Nevski      | meadow loam             | 0.175           |
|                 | Elymus janceus Fisch.             |                         |                 |
|                 | Festuca pratensis Huds.           |                         |                 |
|                 | Puccinellia tenuissima Litv. ex V. Krecz. |               |                 |
| PC. 2           | Suaeda linifolia Pall.            | heavy loam - swamp saline soil | 3.720         |
|                 | Puccinellia tenuissima Litv. ex V. Krecz. |                |                 |
|                 | Lepidium cartilagineum (I. Mayer) Thell. |             |                 |

Plant productivity was determined during the growing seasons of 2014 and 2016. Three permanent sample plots (100 m² each) were located on the soils with different levels of salinity. Plant productivity calculations were based on the amount of live aboveground biomass collected from 1 m² area in the center of each plot in four replicates. All reproductive shoots were weighed, dried to air-dry state (at 80°C) and weighed again [12]. The field data were processed statistically using MS Office.

For determination of soil salinity level soil samples, 30 g each were scooped into 300-ml conical flasks. Then, 150 ml of distilled water was added to each flask. The soil samples and water were stirred for 3 min, and the suspension was allowed to settle for at least 5 min. After that, the extract was filtered, using double folded filters, and transferred into porcelain cups. Previously, the porcelain cups were dried and weighed, with a margin error no more than 0.001 g. Then, the porcelain cups were placed on a water-bath for evaporation of the filtrate. After that, the cups were weighed again (with a margin error no more than 0.001 g). The mass fraction of the solid residue of the saline soil aqueous extract (total dissolved solid (TDS)) was calculated using the following formula:

\[ TDS = \frac{(A-B)}{V} \times 1000, \]  

where A - weight of dried residue with dish, mg, and B - weight of dish, mg, V - sample volume, ml [13].

The calculation of the specific growth rate was carried out according to the formula 2:

\[ \mu(I) = \mu_{max} \left[ \frac{k_l}{k_l+I} \right] \]  

where I - soil salinity level, %;  
k_l = 1.5% – inhibition constant numerically equal to the soil salinity level at which specific growth rate of the plant community is equal to half maximum specific growth rate.
3. Results

Temperature is one of the main ecological factors determining whether a plant species can grow in a certain climate zone and perform its primary biological production. Variations in temperature conditions (and, of course, all other weather parameters) cause interseasonal variations in plant growth rates. A study of the temperature dependence of the crop yield can give valid results only if the moisture content of the soil is sufficiently high [14].

In 2014, plant growth conditions (temperature and moisture) were optimal – it was warm and humid; 2016 was cold and humid. The mean daily air temperature of the first three months of active plant growth in 2014 was 5°С higher than in 2016.

Meadow plants, mainly represented by halophytes, cover the shores of the salt lakes. The major habitat-forming species of plant communities of saline soils are representatives of Chenopodiaceae, with Asteraceae occurring more seldom and Poaceae species being even rarer. On the saline soils of Khakasia, Puccinellia, Elytrigia, and Suaeda species mainly represent these families.

Plant community PC. 1. grew on the medium loam meadow soil with a low salinity level (0.175%), pH varied between 7.7 and 8.9 along the soil profile. Vertical stratification of this plant community had three layers. The first layer was 85 – 90 cm high; it was occupied by the dominant species Elytrigia repens and subdominant Festuca pratensis. The second layer was represented by Artemisia nitrosa and rarely Potentilla inclinata and Limonium gmelinii. The third layer was occupied by Suaeda linifolia (the coverage lower than 2%).

Plant community PC.2. had a specific two-layered structure due to the high level of salinity, which reached 3.720%. The value of pH was the highest in the near-surface zone (0 – 5 cm) and reached 9.2. The first layer was 25 cm high; the dominant species Suaeda linifolia and the second layer - subdominant Suaeda corniculata, represented it.

The graphs in figures 2 show the crop productivity of PC.1 and PC.2 in 2014 and 2016. For PC.1 there is correlation between the crop productivity and climate conditions (temperature and humidity). The crop productivity of PC.1 on the soil with the lowest salinity level (0.175%) was 12-14% higher during the first three months of active plant growth in 2014 than in 2016 (figure 2). The only parameter in which they differed was the maximum crop productivity.

![Figure 2](image)

Figure 2. Seasonal plant productivity of PC.1 (A) and PC. 2. (B) in 2014 and 2016.

However, no correlation was found between the crop productivity of PC.2, growing on the high-salinity soil (3.720%), and the air temperature. Moreover, the crop productivity of PC.2 during the active plant growth was much lower than the crop productivity of PC.1 and PC.2, reaching just 140 g/m² in 2014 and 2016.

Further, we used our field results to calculate the dependence of the maximum specific growth rate of Puccinellia tenuissima, the main plant of plant communities, on soil salinity. It had a shape of a classical curve showing inhibitor dependence of specific growth rate (figure 3).
Figure 3. *Puccinellia tenuissima* growth depending upon soil salinity level (based on field data).

*Puccinellia tenuissima* is a major halophytic species of the family Poaceae, which is typically found in the haylands and pasturelands of Khakasia. In plant communities, *P. tenuissima* is often a monodominant species. Before it enters the flowering stage, *P. tenuissima* is a very useful pasture plant, an early source of nutritious, mineral-rich feed. Physiologically speaking, *P. tenuissima* is a glycohalophyte (its cell protoplasm is nearly impenetrable to salts) [15].

### 4. Conclusion

Thus, results of our study suggest that both climate conditions (temperature and humidity) and ecological factors of the plant habitat (soil salinity level) affect halophyte plant productivity. However, depending on the degree of salinization of the soil, the limiting factor for the growth of plants of halophyte communities changes. With a low degree of salinization of the soil, climatic conditions (low temperature and humidity) can be a limiting factor. With a high degree of soil salinization, the limiting factor is soil salinization. Under any climatic conditions, the productivity of halophytes in soils with high salinity does not change.

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