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# Physiological response of oat (*Avena sativa* L.) to the foliar application of silicon in conditions of increased soil salinity†

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**Abstract:** Plants are exposed in the environment to many unfavorable factors limiting their growth and yield. One of them is salt stress. The study was conducted to assess the effect of silicon foliar fertilization on the process of photosynthesis and the activity of oat plants (*Avena sativa* L.) under salt stress. Plants grown in a pot experiment were subjected to soil treatment with sodium chloride (NaCl) at a concentration of 200 mM. Three concentrations of Optysil (200 $g \cdot l^{-1}$ $SiO_2$) were used. Results of study indicated that the exogenous application of silicon improved tolerance of oat to salinity.

**Keywords:** chlorophyll fluorescence; gas exchange; plant stress

## 1. Introduction

Soil salinity has a negative impact on plant productivity and is one of the main environmental stressors that inhibit the growth and development of crops. Worldwide, soil salinity is thought to have a negative impact on approximately 800 million hectares of arable land [1]. The high concentration of salt in the soil causes osmotic stress and disturbances in ion homeostasis [2,3]. As a result of osmotic stress, the level of reactive oxygen species (ROS) increase in plants and consequently the occurrence of oxidative stress [4,5]. High salt levels inhibit the activity of enzymes involved in photosynthesis [6,7]. Many studies conducted on different species of crops prove the efficiency of micronutrients in creating plant resistance to environmental stresses [8,9,10]. One of the possibilities of limiting the negative influence of environmental factors on plants is foliar silicon supplementation. The beneficial role of silicon in salt stress tolerance has been described in various crops, such as rice [11], sorghum [12], wheat [13], and soybean [14].

Oats are now cultivated all over the world and are an important part of the diet of people in many countries because they are a rich source of nutrients [15]. This plant has phytosanitary properties, it can be grown in areas with less favorable farming conditions. New possibilities of using oats are currently related to the use of grain not only for fodder and consumption purposes, but as an industrial plant for energy production [16,17].

The global problem of saline soils, the positive role of silicon in mitigating the negative impact of the environment on plants and the beneficial features of oats make it necessary to conduct research on these issues. The target of the experiment was to assess the effect of silicon foliar application on the process of photosynthesis and gas exchange of oats (*Avena sativa* L.) under salt stress. A scientific hypothesis was adopted that silicon has a positive effect on photosynthesis and gas exchange in oat plants grown in conditions of increased soil salinity.

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## 2. Material and Methods

### *2.1. Material of plant and conditions of growth*

The pot experiment was carried out at the University of Rzeszow (Poland). In 10 dm diameter pots in which was placed 1.5 kg of soil with a grain size of clay sand and a slightly acidic pH were sown seeds of oat of the Bingo variety. The content of compounds in the soil was at an average level. The experiments were carried out in a growth chamber (Model GC-300/1000, JEIO Tech Co., Ltd., Seoul, South Korea) at a temperature of 22±2°C, 60±3% RH, and a photoperiod of 16:8 hours light:darkness.

An aqueous solution of NaCl with a concentration of 200 mM in a volume of 50 $cm^3$ was applied to the soil in each pot in the stage of the first pair of leaves. After 7 and 14 days from the application of the NaCl solution to the soil, applied foliar application of foliar fertilizer Optysil (contents 200 $g{\cdot}1^{-1}$ $SiO_2$). Preparation was given in three concentrations of 0.05, 0.1 and 0.2%. Plants in pots without addition of NaCl and Si were used as control. Spraying was performed with a laboratory hand sprayer. This was applied via a uniform spraying procedure and plants were sprayed until they were dripping. At the same time was applied deionised water to the control pots. Physiological measurements were made two and seven days after each application of Optysil.

### *2.2. Chlorophyll content, physiological measurements, assessment of fresh mass and plant condition.*

Measurement of the relative content of chlorophyll (CCI), chlorophyll fluorescence - the maximum quantum yield of primary photochemistry ($F_v/F_0$), the maximal quantum yield of PSII photochemistry ($F_v/F_m$), the photosynthetic yield index (PI) and the total number of active reaction centers for absorption (RC/ABS); gas exchange - stomatal conductance ($g_s$), the net photosynthetic rate ($P_N$), transpiration rate (E) and intercellular $CO_2$ concentration ($C_i$); determination of fresh mass (FM) and assessment of plant condition conducted according to methods described in publication [18].

### *2.3. Statistical analysis*

Statistical analysis was made using TIBCO Statistica 13.3.0 (TIBCO Software Inc., Palo Alto, CA, USA). In order that of detect departures from a normal distribution at $p = 0.05$, the Shapiro-Wilk test was performed. The homogeneity of variance was checked. Two-way repeated measures ANOVA was then performed (with assessment of time as a factor). In order to verify the relationship, Tukey's post hoc test was per-formed with a significance level $p \leq 0.05$.

## 3. Results and discussion

The used experimental factors influenced of content of chlorophyll in oat leaves. Chlorophyll is one of the main characteristics of plant health [19]. Added NaCL decreased in CCI in oat plants (Figure 1). Similarly, in other studies conducted on oats [20,21,22,23], a decrease in chlorophyll content under salt stress was noted. The addition of silicon fertilizer improved the CCI value. The improvement in the content of chlorophyll due to the use of foliar silicon fertilizer under stress conditions was also noted in their research by other researchers [24,25].

The highest values were at doses of Optysil - 0.1% and 0.2%. Foliar spraying at the lowest concentration (0.05% Optysil) was more effective on the second day after the run compared to the seventh day (Figure 1). In plants treated with salt only and plants from the NaCl + Optysil 0.05% variant along with the duration of the experiment, significant decreases in the measured parameter were noted.

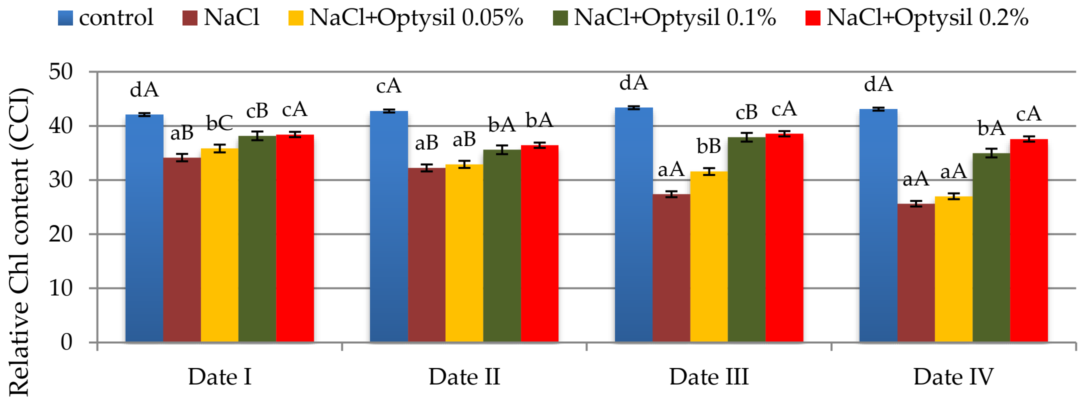


**Figure 1.** The effect of factors of experiment and measurement date on the chlorophyll content in the oat leaves (CCI); (Date I and Date II, 2 and 7 days after first Si application; Date III and Date IV, 2 and 7 days after second Si application) Statistical data are expressed as mean ± SD values. *Capital letters show significant differences between the means in the measurement dates, and lower case letters show significant differences between the means at next measurement dates ($p = 0.05$).

Chlorophyll fluorescence is an effective method to analyze the health and photosynthetic capacity of plants under normal or stressful conditions (such as e.g. salinity) [26]. The treatment of plants with NaCl at the level of 200 mM reduced the parameters of chlorophyll fluorescence (Figure 2). The obtained results confirm the research of other researchers on the negative effect of high salt concentration on the fluorescence of oat plants [27,28]. The lowest values of $F_v/F_0$, $F_v/F_m$, PI and RC/ABS were recorded in plants in the NaCl variant. The Optysil fertilizer in each of the applied concentrations had a positive effect on the measured parameters. In the research by Maghsoudi et al. [29] and Ghassemi-Golezani and Lotfi, [30] foliar application of silicon had also a beneficial effect on the parameters of chlorophyll fluorescence under salt stress. The highest results in comparison to the control were obtained in plants with the 0.1%Optysil and 0.2%Optysil variants. The positive effect of 0.05% concentration was observed primarily two days after used (Figure 2). This may indicate a short-term effect of a low dose of Si. In plants with only NaCl, a statistically significant decrease in PI was noted along with the exposure time of plants salinity (Figure 2C).

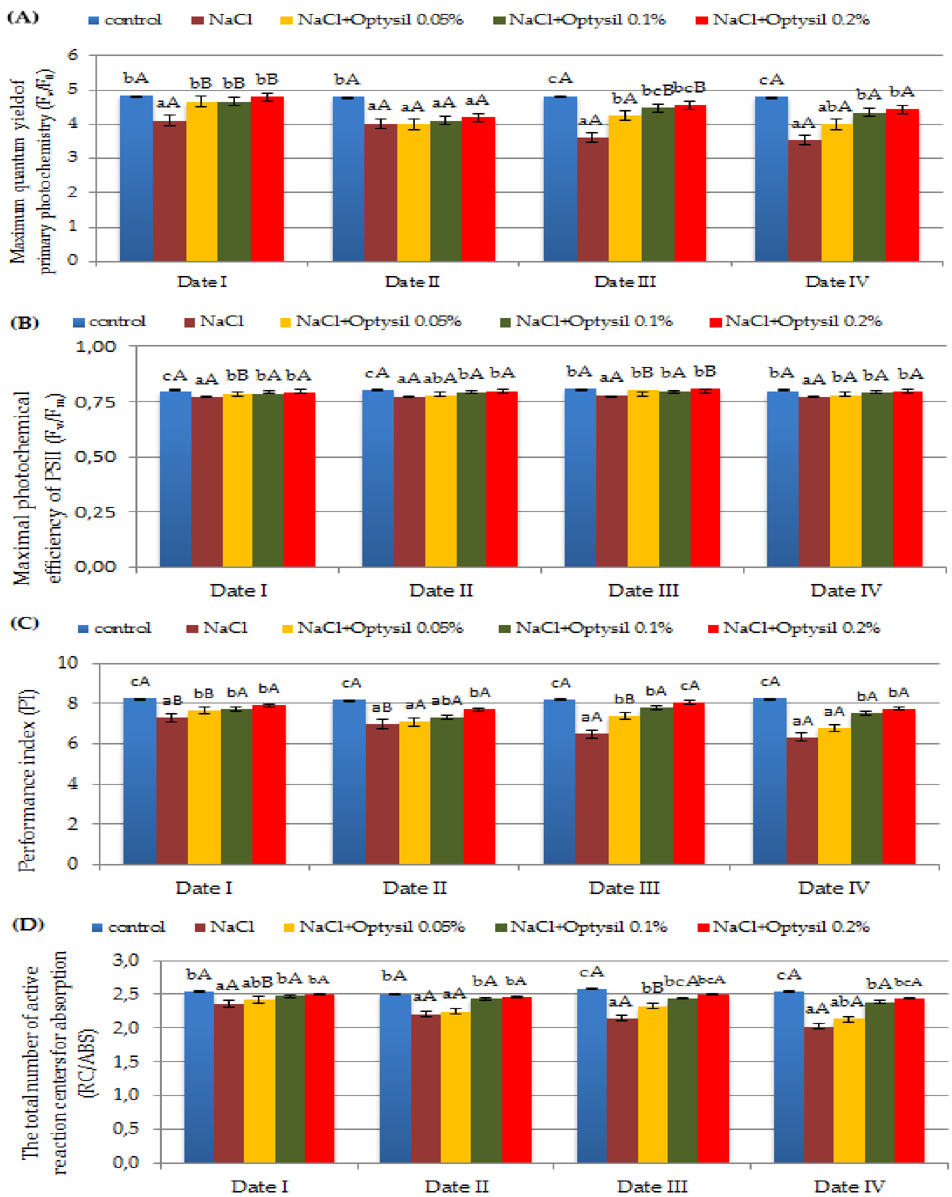


**Figure 2.** The effect of factors of experiment and measurement date on chlorophyll fluorescence parameters in oat plants (Date I and Date II, 2 and 7 days after first Si application; Date III and Date IV, 2 and 7 days after second Si application). Statistical data are expressed as mean ± SD values. *Capital letters show significant differences between the means in the measurement dates, and lower case letters show significant differences between the means at next measurement dates (p = 0.05).

In the experiment, the value of gas exchange parameters depended on NaCl and the concentration of Optysil. Treatment of the plants with NaCl significantly reduced the $g_s$, $P_N$, E and $C_i$ values (Figure 3). Also in the studies conducted on oats by Qin et al. [21] and Shah et al. [31] as a result of the action of salt, a decrease in gas exchange parameters was noted. Generally, plants close the stomata in stressful conditions arise in order to conserve water and in the sequel reduce stomatal conductance and photosynthesis [32]. The use of Optysil improved the value of the measured parameters (Figure 3). The positive effect of the action was demonstrated above all at the highest applied foliar fertilizer concentrations of 0.1% and 0.2%. The application of silicon fertilizer in conditions of salinity caused a significant increase in photosynthesis and transpiration index also in study Kutasy et al. [25].

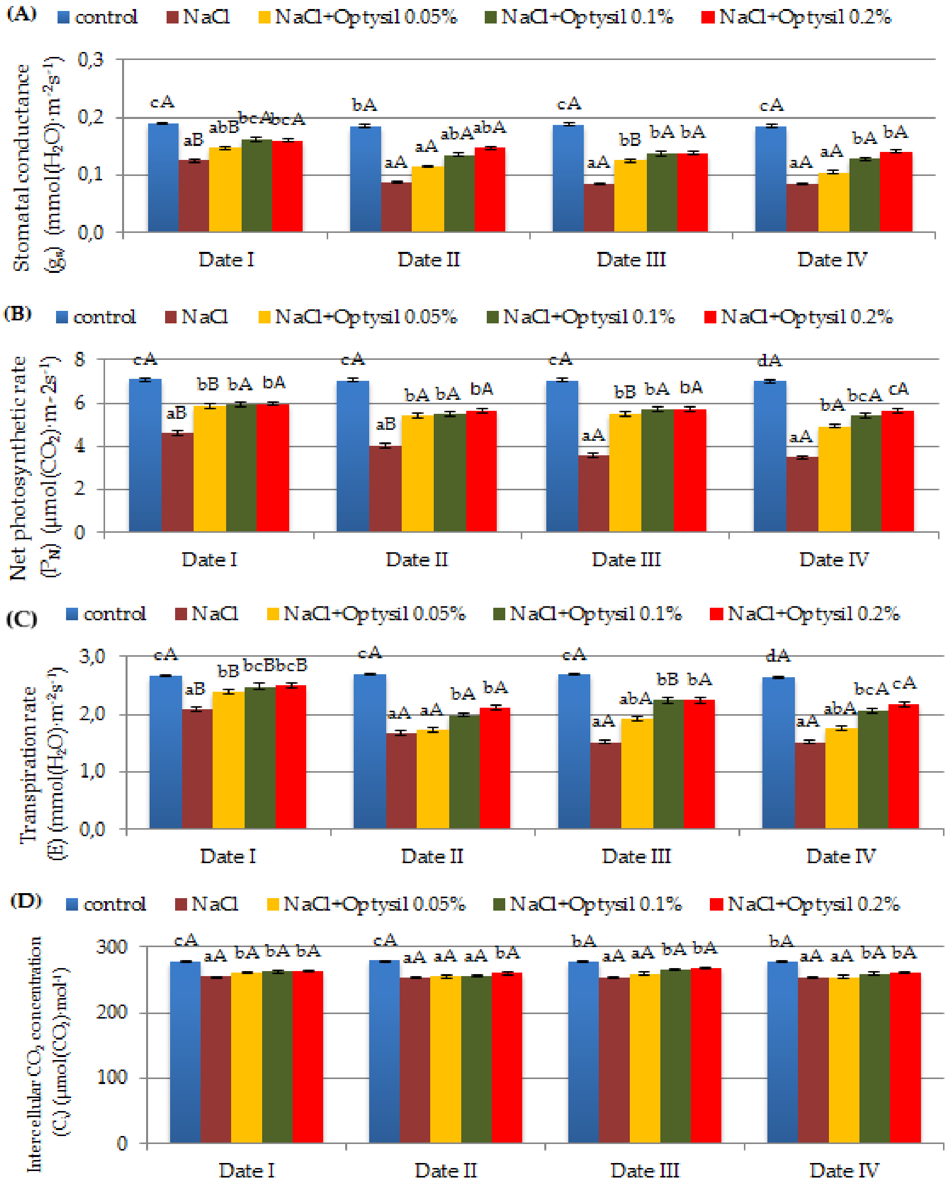


**Figure 3.** The effect of factors of experiment and measurement date on gas exchange parameters in oat plants (Date I and Date II, 2 and 7 days after first Si application; Date III and Date IV, 2 and 7 days after second Si application). Statistical data are expressed as mean ± SD values. *Capital letters show significant differences between the means in the measurement dates, and lower case letters show significant differences between the means at next measurement dates (p = 0.05).

In the final stage of the experiment, the fresh mass of plants (FM) was estimated and the general condition of the plants was assessed. 200 mM NaCl had a negative effect on plant growth. Plants treated with salt showed a lower content of FM and were characterized by a worse visual condition [Figure 4]. In plants treated with NaCl only, FM was lower by 31.7% compared to control plants. The obtained results are consistent with the reports of other researchers [20,22,33]. Optysil foliar application improved FM. The best effects were noted at 0.1% and 0.2%. In these variants, the FM content was 18.9% and 22.1% higher, respectively, compared to the plants without the addition of Optysil.

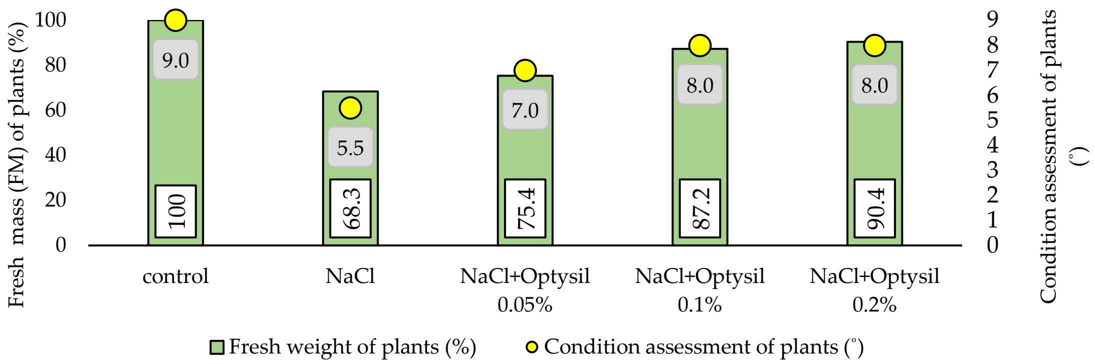


**Figure 4.** The effect of experiment factors on the fresh mass and the state of the oat plants.

## 4. Conclusions

The target of conducted research was to assess the effect of silicon foliar fertilizer application on oat (*Avena sativa* L.) plants under salt stress. Results confirmed hypothesis that silicon has a positive effect on alleviation salinity stress in oat plants. Outcome of conducted research are indicative of positive effect of silicon on the chlorophyll content in leaves, selected parameters of chlorophyll fluorescence, gas exchange, fresh mass and condition of plants. The doses of Optysil 0.1% and 0.2% were the most beneficial.

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