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The effects of irrigation water salinity level on faba bean (*Vicia faba* L.) productivity

Učinci razine zaslanjenosti vode za navodnjavanje na produktivnost boba (*Vicia faba* L.)

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ABSTRACT

In Mediterranean region where seawater intrudes porous karst matrix and salinizes soil and water resources, water used for the irrigation of crops is frequently of inadequate quality. Measuring the productivity of horticultural crops under saline conditions helps to determine whether and when to irrigate crops if water is saline, thus balance between crop water and salt stress. A greenhouse pot experiment was set to study the effects of saline irrigation water on faba bean (*Vicia faba* L.) biomass and yield parameters. NaCl salinity was applied in a nutrient solution as follows: $NaCl_0$ as control (nutrient solution without added NaCl), $NaCl_{50}$ (control + 50 mM NaCl), and $NaCl_{100}$ (control + 100 mM NaCl). Five weeks after salinity treatment started, plant height (cm), number of lateral branches per plant, number of pods and seeds per plant, shoot weight (g), pod weight (g) and seed weight (g) were determined. Compared to control, increased irrigation water salinity statistically significantly decreased measured parameters ($P<0.01$), except for number of branches and pods. Faba bean productivity decreased proportionally to the irrigation water salinity level, suggesting that optimal saline agriculture management strategy can be to allow for the acceptable yield loss in order to avoid plant water stress.

Keywords: saline agriculture, drip irrigation, crop productivity, crop salt stress

SAŽETAK

Na području Mediterana, gdje dolazi do prodora morske vode kroz porozni krški materijal i zaslanjivanja tala i vodnih resursa, voda koja se koristi za navodnjavanje usjeva često nije odgovarajuće kakvoće. Mjerenje produktivnosti hortikulturnih usjeva u zaslanjenim uvjetima pomaže odrediti može li se navodnjavati zaslanjenom vodom i kada, kako bi se pronašla ravnoteža između vodnog stresa usjeva i stresa soli. Postavljen je pokus u loncima u plasteniku kako bi se istražili učinci zaslanjene vode za navodnjavanje na biomasu i parametre prinosa boba (*Vicia faba* L.). NaCl sol je primijenjena u hranjivoj otopini kako slijedi: $NaCl_0$ kao kontrola (hranjiva otopina bez dodanog NaCl), $NaCl_{50}$ (kontrola + 50 mM NaCl), i $NaCl_{100}$ (kontrola + 100 mM NaCl). Pet tjedana nakon početka tretmana zaslanjenom vodom, izmjerena je visina biljaka (cm), određen broj bočnih izdanaka, mahuna i sjemenki po biljci, masa nadzemnog dijela biljke (g), masa mahune (g) i masa sjemena (g). U usporedbi s kontrolom, povećana zaslanjenost vode za navodnjavanje statistički je značajno smanjila mjerene parametre ($P<0.01$), osim broja izdanaka i mahuna. Produktivnost boba smanjila se proporcionalno razini zaslanjenosti vode za navodnjavanje, sugerirajući da optimalna strategija poljoprivrednog gospodarenja u zaslanjenim uvjetima može biti dozvoljavanje prihvatljivog gubitka prinosa kako bi se izbjegao vodni stres usjeva.

Ključne riječi: poljoprivreda u zaslanjenim uvjetima, navodnjavanje kapanjem, produktivnost usjeva, stres soli usjeva

INTRODUCTION

High crop productivity is an unfeasible objective without the irrigation of crops. In Mediterranean coastal areas seawater frequently intrudes into rivers and aquifers (Zalidis et al, 2002), while surface and groundwater are used as the irrigation water supply. Because of the climatic conditions, agricultural production in these areas is unfeasible without the irrigation (Romic et al, 2008), therefore farmers often use water of poor quality (Ondrasek et al, 2006). Irrigation of crops with a low-quality water favors secondary salinization of soil, and contrary to its initial purpose, it is limiting the productivity of crops (e.g., Askari-Khorasgani et al., 2017). It is considered that 20 - 50% of the irrigated land worldwide is affected by the salinity (Pitman and Laüchli, 2002). Use of saline irrigation water changes soil physical, chemical, and biological properties (e.g., Filipović et al., 2018), which negatively affects crop development, growth and yield. Even though high productivity is the aim of crop irrigation, use of irrigation water of poor quality threatens the sustainability of crop production on the irrigated land (Matijević et al., 2014).

High concentration of soluble salts in the rhizosphere causes plant salt stress. Salt stress instigates water and nutrient imbalances, as well as triggers unspecific oxidation processes in plant cells. Growing in a saline environment is leading to morphological, physiological, biochemical, and molecular changes in plant cells, which negatively affects crop growth and productivity (Wang et al., 2003). Thus, plant salt stress is defined by the osmotic and ionic stress, accompanied with the oxidative stress. High soil salinity causes significant changes in soil water potentials, enabling the plant to uptake water from soil, causing the osmotic stress, which can disrupt cellular activities and cause cell death (Xiong and Zhu, 2002). Ionic stress triggers alterations in nutrient uptake and affects their transport and partitioning within the plant (Ondrasek et al, 2006), further causing changes in plant physiological processes, molecular damage, and growth retardation (Wang et al., 2008). Oxidative stress is characterized by the increased production of reactive oxygen species which leads to unspecific oxidation of proteins and membrane lipids, causing DNA injuries (Schützendübel and Polle, 2002). Plant salt stress has been frequently studied, usually focusing on certain plant physiological aspects affected by the salinity; however, from the agronomical perspective, it is especially important to conduct research addressing the issue of salinity effect on crop productivity, i.e., growth, development and yield (Sen and Mandal, 2016).

Faba bean (*Vicia faba* L.) is a legume crop produced worldwide, including the Mediterranean area. It is one of the major cool season grain legume crops produced worldwide, as its high yield makes it attractive to producers and its high protein content appealing to consumers (Merga et al., 2019). Legumes can support biological nitrogen fixation; thus, they offer an environmentally sustainable source of nitrogen to cropping systems (Crews and Peoples, 2004). Legumes are usually classified as either sensitive or moderately tolerant to salinity. *Vicia faba* (L.) is considered moderately tolerant to salinity, with a reduction of vegetative growth at irrigation water electrical conductivity of 6 dS m^{-1} or higher (Al-Tahir and Al- Abdulsalam, 1997). Furthermore, Katerji et al. (2000) identified faba bean as moderately sensitive to salinity, possibly less sensitive at later developmental stages (Al-Tahir and Al-Abdulsalam, 1997). Faba bean has been frequently studied under saline conditions for its nutrient removal, growth performance, water use efficiency and yield (e.g., Katerji et al, 2005; Abdelhamid et al., 2010; Qados et al, 2011; Katerji et al, 2011; Matijević et al., 2012).

It is necessary to determine how plants respond to high salinity with an aim to improve crop productivity under saline conditions. Biomass production and yield are considered valuable parameters when studying plant responses to salinity (Radwan et al., 2000). In this context, measuring the productivity parameters of horticultural crops under saline conditions is a useful tool for adjusting the saline agriculture management practices. The aim of this research was to study the effects of saline irrigation water on faba bean biomass and yield parameters.

The emphasis was on determining the plant response with respect to salinity level to which the plants were exposed. The final objective was to identify optimal agricultural management strategy for faba bean under saline conditions, i.e., whether and when to irrigate the crops with saline water, and thus balance between crop water and salt stress while considering the possible yield loss.

MATERIALS AND METHODS

Growing conditions

Greenhouse experiment was carried out from April 2nd - June 15th, 2012, at the experimental station of the University of Zagreb Faculty of Agriculture (Croatia). Faba bean (*Vicia faba* L. cv. Aguadulce) seedlings were grown from seeds in polystyrene cups containing peat soil (Potgrond P, Klasmann). After three weeks, uniform plants were selected and transplanted into pots (one plant per pot) filled with alluvial agricultural topsoil (5 - 25 cm soil depth). Soil was sampled from horticultural land at Croatian coastal region (i.e., Neretva river valley), with surficial organic deposit removed (0 - 5 cm). Soil was sieved through a 1 cm × 1 cm mesh before filing the pots to remove any rocks and visible impurities.

From the beginning of the experiment until the end of study, plants were irrigated daily using the automatic drip irrigation system. During the first three weeks after transplanting seedlings, pots were fertigated daily only with a basic nutrient solution (Poly-Feed Drip 20-20-20 with micronutrients; c = 2 g L^{-1}). Good drainage was ensured to provide soil aeration in pots and prevent waterlogging. The fertigation rate and frequency were the same for all the treatments and adjusted to the plant phenology and to the climatic conditions in a greenhouse in a way that drying of soil in the pots was avoided.

NaCl treatments applied and experimental design

Three weeks after transplanting, treatment of faba bean seedlings with NaCl salinity started. NaCl salinity was applied in a nutrient solution, through the automated drip irrigation system as follows: $NaCl_0$ as control (nutrient solution without added NaCl; electrical conductivity (E.C.) of 2 dS m^{-1}), $NaCl_{50}$ (control + 50 mM NaCl; E.C. of 5 dS m^{-1}), and $NaCl_{100}$ (control + 100 mM NaCl; E.C. of 10 dS m^{-1}).

Randomized block design with three replicates was applied in the experiment: 6 plants per treatment × 3 NaCl levels × 3 replicates; total of 54 plants.

Measurement of biomass and yield parameters

Five weeks after the NaCl salinity treatment started, faba bean biomass and yield parameters were measured.

Shoots were separated from the roots by carefully cutting the plant above the soil. Lateral branches were counted and then plant was put on a straight surface for the height measurement (cm). Then, weight of the shoots (g) was measured using the technical balance. Pods were removed from plants, counted, and their weight was measured (g). After, seeds were separated from the pods, counted, and seed weight was measured separately from the pods (g).

Also, pictures of the "worst case scenario" leaf chlorosis (on low positioned older leaves) caused by the irrigation with saline water ($NaCl_{50}$ and $NaCl_{100}$) were taken (Figure 1).

Statistical analysis

Data were subjected to the analysis of variance using the One-way ANOVA procedure. The significance of differences between the means was determined using Tukey HSD (Honestly Significant Difference) test at $P<0.01$. Statistical analysis was done using the SAS statistical software package (SAS Institute, 2007).

RESULTS AND DISCUSSION

Biomass production and yield are important parameters when studying plant responses to salinity (Radwan et al., 2000), especially from the perspective of saline agriculture management strategies. The effect of saline irrigation water (50 and 100 mM NaCl) on faba bean biomass and yield parameters is presented in Table 1.

Table 1. The effect of saline irrigation water (50 and 100 mM NaCl), presented with control (basic nutrient solution, $NaCl_0$) on faba bean (*Vicia faba* L.) biomass and yield parameters

NaCl treatment	Plant height (cm)	Number of branches per plant	Number of pods per plant	Number of seeds per plant	Shoots weight (g)	Pod weight (g)	Seed weight (g)
$NaCl_0$	63.8 a	3	4	29 a	135 a	143.1 a	63.8 a
$NaCl_{50}$	59.8 b	3	4	24.4 b	134.1 b	124.2 b	49.2 b
$NaCl_{100}$	58.2 c	3.3	4	18.4 c	117.3 c	110.7 c	40.1 c

[1] Means with the different letter are significantly different at P<0.01

Although not very obvious, the differences in height of plants treated with two levels of salinity were noticed by visual inspection of plants during the experiment.

Furthermore, compared to the control plants, irrigation with saline water statistically significantly reduced plant height for 4 cm ($NaCl_{50}$) and 5.6 cm ($NaCl_{100}$), which is a reduction of 6.3 and 8.8%, respectively.

With the $NaCl_{50}$ irrigation treatment, number of seeds per plant was reduced by 4,6 (15.9%). Also, compared to the control plants, the weight of the shoots, pods and seeds decreased by 0.9, 18.9 and 14.6 g, respectively, which is 0.7, 13.2 and 22.9%, respectively (Table 1).

Compared to the control, with the $NaCl_{100}$ irrigation treatment number of seeds per plant was reduced by 10,6 (36.6%), and the weight of the shoots, pods and seeds by 17.7 g (13.1%), 32.4 g (22.6%) and 23.7 g (37.1%), respectively.

Number of branches per plant was not statistically significantly affected by the irrigation of plants with saline water ($NaCl_{50}$ and $NaCl_{100}$), although it was previously shown that the application of saline irrigation water can decrease number of faba bean branches (e.g., Eldardiry et al., 2017). Also, number of pods per plant was not statistically significantly affected by the saline irrigation water ($NaCl_{50}$ and $NaCl_{100}$).

The shoots weight was significantly reduced with the application of saline irrigation water, especially with the highest ($NaCl_{100}$) salinity treatment (Table 1). The osmotic effect of plant salt stress is mostly induced by abscisic acid (ABA) released from the plant roots, causing stomatal closure (stomatal effect) and a consequent inhibition of gas exchange, i.e., transpiration (Koyro et al., 2010). Therefore, the water availability to plants is decreased, as well as the water content in plant tissue, which may be reflected on the shoots weight (Table 1). Also, chlorosis and drying of low positioned older leaves was noticed for plants irrigated with saline water (Figure 1).

The osmotic effect of salinity stress is considered to continue for the duration of exposure of plants to salinity (Carillo et al., 2011), and it is a part of plant response to maintain water relations and adapt to saline conditions. However, stomatal closure may also be reflected on plant photosynthesis and the ability to synthesize organic compounds, which has implications on number and weight of seeds. Although the irrigation with saline water ($NaCl_{50}$ and $NaCl_{100}$) statistically significantly decreased faba bean height, shoots and pod weight, the greatest reduction was observed for the number and weight of faba bean seeds (Table 1).

Therefore, even though the number of pods per plant was not affected by the irrigation of plants with saline water ($NaCl_{50}$ and $NaCl_{100}$, i.e., nutrient solution with 50 and 100 mM NaCl, respectively), measured pod weight and seed parameters (i.e., seed number and weight) still show that faba bean yield is significantly decreased by the salinity of irrigation water, proportionally to the salinity treatments (Table 1). From the yield perspective, the reduction of bean seed number per plant of 36.6% and seed weight of 37.1% with the highest ($NaCl_{100}$) salinity treatment, suggests that more than a third of total bean yield would be lost due to the use of irrigation water of extremely low quality, i.e. use of very saline irrigation water (i.e., 100 mM NaCl).

Figure 1. Low positioned older leaves of faba bean (*Vicia faba* L.) irrigated with: a) Nutrient solution without added NaCl ($NaCl_0$ as control); b) Control + 50 mM NaCl ($NaCl_{50}$); and c) Control + 100 mM NaCl ($NaCl_{100}$)

Furthermore, for all measured bean biomass and yield parameters which decreased with the application of saline irrigation water (plant height, number of seeds per plants, shoots, pod and seed weight), decrease was proportional to an increase in irrigation water salinity, i.e. greater decrease was recorded with a rise in irrigation water salinity level (Table 1). A linear relationship between salt stress and growth of four vegetable species differing in salt tolerance (sugar beet, cabbage, amaranth and pak-choi) was also found by Jamil et al. (2006). Data suggest that decrease of faba bean yield caused by the application of saline irrigation water will depend on the water salinity level. Therefore, the optimization of agricultural management strategy for growing faba beans in areas where irrigation water is affected by the salinity is possible if certain yield loss due to use of irrigation water of certain salinity level (i.e.,

<50 mM NaCl) is allowed, in order to avoid a greater one because of the drought conditions. Thus, optimal saline agriculture management strategy for faba bean can be to allow for the acceptable yield loss in order to avoid plant water stress. In this case, if possible, water of adequate quality can be mixed with water of low quality for the irrigation of crops, preferably after the initial growing period, in order to achieve this balance.

CONCLUSIONS

Saline irrigation water significantly decreased faba bean height, number of seeds per plant, shoots weight, pod weight, as well as the seed weight ($P<0.01$). However, number of lateral branches and number of pods per plant were not affected by the salinity treatments. Still, the reduction of bean seed number per plant of 36.6% and seed weight of 37.1% with the highest salinity treatment ($NaCl_{100}$), suggests that more than a third of total bean yield would be lost due to the use of irrigation water of extremely high salinity (i.e., 100 mM NaCl).

Furthermore, faba bean productivity decreased proportionally to the irrigation water salinity level, suggesting that the optimization of agricultural management strategy for growing beans in areas where irrigation water is affected by the salinity is possible in such way to allow for certain yield loss due to use of irrigation water of certain salinity level (i.e., < 50 mM NaCl), in order to avoid a greater one because of the drought conditions. Thus, the optimal saline agriculture management strategy can be to allow for the acceptable yield loss in order to avoid plant water stress.

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