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ORIGINAL PAPER

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TOLERANCE OF *Berberis thunbergii* DC. TO GREYWATER IRRIGATION AND CHANGES IN SOIL QUALITY

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ABSTRACT

Climate changes that lead to an increasing shortage of drinking water (DW) dictate the use of alternative water sources for irrigation. Therefore the aim of this research was to determine the tolerance of plant growth and development of *Berberis thunbergii* DC. (Japanese barberry) to irrigation with greywater (GW) and to examine changes in chemical properties of soil. The two-year experiment, conducted during vegetation season, was comprised of the following treatments: K (control, 100% DW), T1 (diluted GW containing 50% DW and 50% GW), T2 (100% GW) and T3 (alternating watering with 100% DW and 100% GW). After statistical analyses, the results indicate the similarity between the K and T3 treatments in terms of the plant growth and development of new shoots. T1 treatment leads to slower plant growth, whereas T2 treatment leads to slower development of new shoots, but the vitality of the plants was not observed. Application of T1, T2 and T3 treatments resulted in slight salinisation of the soil. In general, the results of this research indicated that GW can be used for irrigation of *B. thunbergii*, preferably with the application of alternating watering T3 treatment.

Key words: greywater, irrigation, *Berberis thunbergii* DC., soil, salinisation, plant

INTRODUCTION

Demand for clean freshwater is growing. However, since freshwater is polluted in various ways under the influence of anthropogenic factors, it is considered that clean freshwater reserves represent a global problem [UN Water 2017]. The World Resources Institute [2015] estimates that 33 countries on all continents will be threatened by water shortages by 2040, and therefore there is an urgent need for an alternative water source. Recent research on the use of greywater (GW) in irrigation of ornamental and garden plants have provided encouraging results [Friedman et al. 2007, Casey 2010, Pedrero et al. 2010, Dabić et al. 2017].

There are different definitions of GW. In most cases, there is consent to the separation of GW and black water [WHO 2006], where GW refers to wastewater originating from a household excluding black water, which contains feaces. In this regard, GW does not contain an elevated level of pathogens in comparison to municipal wastewater [WHO 2006]. Bearing in mind that GW represents more than 2/3 of domestic wastewater and that at a global level over 70% of the consumption of freshwater is spent for agricultural purposes [FAO 2008], GW may represent an alternative source of water for irrigation during the dry season. GW potential is reflected in its content of nutri-

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ents [Siggins et al. 2016], while most of the detergents found in GW are relatively rapidly biodegradable (less than 1 hour) not posing a risk for the growth of ornamental plants [Al-Mashaqbeh et al. 2012]. However, to prevent infection with pathogenic microorganisms, which might be present in GW, it is necessary to apply safety measures [FAO 2017], such as wearing protective clothes, the application of underground irrigation systems, etc. Before application, it is necessary to analyse the physical and chemical characteristics of GW [Dabić et al. 2017]. An important limiting factor for determining the usefulness of GW is the content of salts because high salinity can negatively influence both soil and plants [Christova-Boal et al. 1996]. For these reasons, it is necessary to test chemical soil characteristics, as well as the influence of GW on the morphological characteristics of plants [Friedman et al. 2007, Pedrero et al. 2010].

The application of GW can provide significant economic and environmental benefits, such as increased availability of drinking water (DW) and the reduction of fertiliser application in plant production [Sanz et al. 2014]. Additionally, using GW for flushing toilets and irrigation, it is possible to reduce the consumption of DW by about 30–50% [Pinto et al. 2010]. Bearing in mind that there is a lack of knowledge on the effect of GW on specific plant species, in this study an impact of GW application on the morphological characteristics of the ornamental plant *B. thunbergii* DC was examined. This species originates from Japan and is characterised as very resistant, growing on different soil types and in a different illuminated habitat [USDA Forest Service 2005, Matson 2011]. The species has been chosen knowing that it is highly tolerable to a variety of environmental conditions, since in a case it is proven that the species cannot tolerate GW irrigation, it would be unlikely that other more sensitive, species would be capable of withstanding such a sort of irrigation. Although considered invasive in some parts of the world [Matson 2011], *B. thunbergii* DC. is a widely represented ornamental plant of urban greenery. Unfortunately, due to the climate changes, it also requires irrigation during drought periods. Therefore, the aim of this study is to assess the possibility of irrigation of *B. thunbergii* DC. with GW, monitoring plant growth and vitality, as well as properties of GW and soil, in order to assess if the application of GW might represent a possible solution for irrigation in terms of water savings.

MATERIAL AND METHODS

The experiment was carried out in Irig, Vojvodina Province (Republic of Serbia), during vegetation seasons in 2017 and 2018, on the same plants. During the experimental period (June 3 – September 3, 2017 and June 6 – September 11, 2018) the mean daily air temperatures were in the range 22.4–24.1°C [RHMSS 2018, 2019]. The mean amount of rainfall for 2017 and 2018, was 31.7 and 98.5 mm/month respectively.

Japanese barberry plants were planted in pots of 17 cm diameter, as annual plants, in a pre-prepared substrate. The substrate consisted of a mixture of soil (bright and dark Baltic peat, earthworms-processed soil) and garden soil (loess soil covered with a humus layer) in a ratio of 2 : 1 in terms of volume. Then, all pots were irrigated with the same amount of appropriate water types according to the treatment. For each plant morphological features were monitored: height and canopy width (cm) and the number of new shoots. In addition, each plant was assessed on 1–3 scale, for phytopathological and entomological diseases, mechanical damage and rot, for which the phenomenon is: 1 – poorly expressed; 2 – medium expressed and 3 – highly expressed, in terms of disease and damage. Finally, vitality and assessment of decorativeness were implemented using a scale of 1–5; where 1 represents – the lowest and 5 – the highest grade. The monitoring of morphological features was conducted on a weekly basis.

GW was collected from one household, containing water from the kitchen and bathroom (after washing the dishes, showering, and washing hands). All variants of water (DW, diluted GW and GW) were stored in separate containers of 100 L. Experimental treatments are included in the following scheme: K (control) – irrigation with 100% DW; T1 – irrigation with diluted GW containing 50% GW and 50% DW; T2 – irrigation with 100% GW, and T3 – alternate irrigations with DW and then next time with GW. Each treatment consisted of eight pots with planted *B. thunbergii*, and two pots with just soil. For each 100 L amount of water, water quality analyses were performed. The biochemical analysis included sensory measurement of pH, conductivity – EC and biochemical oxygen demand – BOD_5, while photometric measurement was used to determine: suspended matter SS and nutrients parameters – ammonium (NH_4^+), nitrites (NO_2^-), nitrates (NO_3^-), orthophosphates (PO_4^{2-}), total nitrogen (total N) and total phosphorus (total P). Irrigation was carried out in accordance with weather conditions (rainfall) and the needs of plants for water.

To determine the influence of GW on soil characteristics, soil samples were collected and analysed before and after the experiment. The analyses included determination of parameters such as pH (sensory method – pH meter), electrical conductivity in the saturated soil paste extract – ECe (electrometric method – Conductometer), NH_4^+ and NO_3^- (Semimicro-Kjeldahl method – a Bremner modification (1960), easily accessible P (Al-method [Enger and Riehm, 1958]), Cl^- (Mohr method), CO_3^{2-} and HCO_3^- (HCl and methyl orange solution), and SO_4^{2-} (HCl, $BaCl_2$ and methyl orange solution). Soil salinity assessment was determined in 2 manners: by measuring the electrical resistance of the saturated soil paste, from which the % of total water-soluble salts was then calculated [Davis and Bryan 1910], and by the electrical conductivity of saturated aqueous extract (ECe dS/m) [Richards 1949]. According to a number of authors, the second method yields more objective results, because the concentration of saturated aqueous extract (obtained by extraction, vacuum filtration from saturated soil paste) is closest to the concentration of natural soil solutions, to which the root system of plants is most often exposed in the field.

Data related to soil characteristics and morphological characteristics of plants were statistically analysed using the R i386 3.5.1. software and included descriptive statistics, Tukey HSD test p = 0.05, and Duncan's Multiple Comparison test p = 0.05.

RESULTS

Results of the biochemical composition of the water used for irrigation (range for eight samples, during experimental period) are presented in Table 1. Since there are no limit values for irrigation of ornamental plants with GW, the limit values are extracted from literature sources related to the quality of water for irrigation, application of GW in agriculture and wastewater.

The basic chemical characteristics of the soil are given in Figure 1. Comparisons were made for each year separately.

DISCUSSION

The values of pH in water used in the treatments ranged from a mildly acidic to a moderate alkaline reaction, which was slightly below the permissible limit

Table 1. Biochemical characteristics of waters used in the research

Water quality parameters	Units	K	T1	T2	Limit values
pH		6.69–7.87	6.60–7.59	6.28–7.61	6.5–8.4[1]
EC	dS/cm	0.73–0.83	0.78–0.86	0.83–0.93	<0.7[1]
BOD_5	mg O_2/L	0.0–1.70	22.40–52.00	52.00–101.60	≤240[2]
NH_4^+	mg N/L	<0.02–4.2	<0.02–10.9	0.10–26.30	–
NO_2^-	mg N/L	<0.01	<0.01–0.04	<0.01–0.05	–
NO_3^-	mg N/L	<1.0–1.9	<1.0	<1.0	<5[1]
Suspended matter	mg/L	0.0–6.0	13–114	122–206	–
Total N	mg/L	<0.50–2.00	1.30–9.00	0.17–20.40	–
PO_4^{2-}	mg P/L	0.04–0.15	0.05–0.77	<0.02–>1.10	–
Total P	mg P/L	0.15–0.51	0.20–0.71	0.38–>1.10	<2[3]

[1]Ayers and Westcot [1985]; [2]WHO [2006]; [3]Silva et al. [2016]

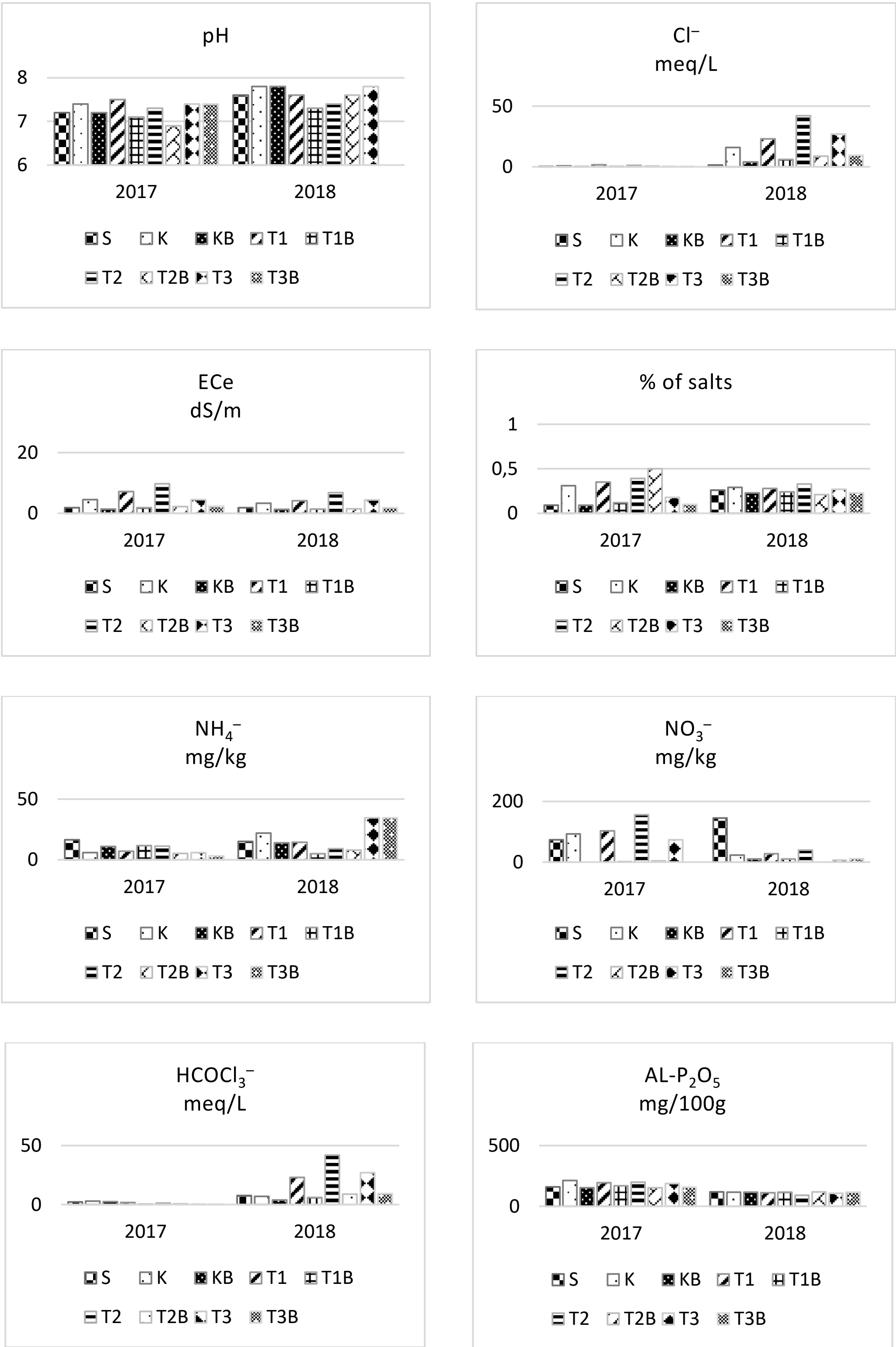

Fig. 1. Basic chemical characteristics of the soil. S – substrate: garden soil + purchase soil at the beginning of the experiment); K – 100% DW; T1 – 50% DW + 50% GW; T2 – 100% GW; T3 – alternating watering with 100% DW and 100% GW; B – pots without plants

of water quality required for irrigation in agriculture of 6.5–8.4 pH [Ayers and Westcot 1985]. This pH range not only sustains the growth of cultivated plants, but it is also important for maintaining soil fertility and functionality of equipment for irrigation. Therefore, for the mentioned reasons, it can be applied for the cultivation of decorative plants, as well as for urban greenery. The highest pH value was recorded in K treatment. However, in the relevant literature, it is stated that pH values for DW are generally lower than the pH of GW [Friedman et al. 2007, Travis et al. 2010, Rodda et al. 2011]. The reason for this phenomenon may be the presence of organic matter in GW, the decomposition of which leads to a decrease in pH. In the waters used for irrigation the values of EC, ranged from 0.73 dS/m in treatment K, to 0.93 dS/m in treatment T2, which indicates slightly saline water [Ayers and Westcot 1985]. Bearing in mind that DW used in this research was already slightly saline, the components that are part of the GW additionally contribute to the salinity. The values of BOD_5 in treatment T2 of 52–101.60 mgO_2/L and in treatment T1 of 22.40–52 mgO_2/L might indicate the presence of a large number of bacteria and their activity. The reason for this was probably the fact that GW originated from the kitchen [Maimon et al. 2014].

The analysis of the obtained results showed that the values of the parameters in the pots with plants were generally higher than those of the pots without plants. Also, there was an increase in salt content in pots without plants, compared to the first year of the study. pH values measured in the saturated soil paste were in the range of neutral to slightly alkaline reaction [USDA 1993]. The reason for an increased pH value in pots with plants was probably already a noted phenomenon related to *Berberis* sp., i.e. its ability to increase the pH of the soil, making it more alkaline [Ehrenfeld et al. 2001]. However, according to Duncan's multiple comparison test results, there was no statistically significant difference between treatments of pH value. The content of water-soluble salts (%) ranged from slightly saline to mean saline soil [Kátai 2013]. Most treatments showed an elevated salt content in the second year. According to the USDA [1993], the values of the ECe in the tested samples were below the limit value of salinity, except in T1 (4.12 dS/m), T2 (6.78 dS/m) and T3 (4.41 dS/m) treatments, where the soil was slightly saline. This phenomenon can be monitored by the application of T2 in the presence of plants, which needs to be further investigated. Since T1, T2 and T3 treatments contain a certain percentage of greywater, it can be said that irrigation with greywater leads to an increase in ECe soil, which was confirmed by already conducted research [Friedman et al. 2007, Rodda et al. 2011]. The Duncan's Multiple Comparison test indicates a statistically significant difference between the treatments T2, and other treatments, as well as the similarities of T3 treatments with all treatments. It is interesting to note that the substrate properties, from the beginning of the experiments, and treatments without plants were not statistically different. Although recommended ECe value, in the range 0–1.5 dS/m [De Clerck et al. 2003], and an elevated level of soil salinity in this research did not significantly affect the growth and the number of developed new shoots of *B. thunbergii* DC. Similarly, the higher level of salinity in GW did not affect the growth and yield of other plants and crops. In addition, the authors point out the great resistance of these plant species to the increased level of salinity in GW, as well as the increased content of Na^+ in the soil, as a consequence of GW used for irrigation [Friedman et al. 2007, Rodda et al. 2011]. The results of the examined soil samples indicate the absence of carbonate soils, with the toxic content of Al-P_2O_5, except in T2 treatment (91.05 mg/100 g) where the high to noxious content of this element was present. The content of NH_4^+, NO_3^-, HCO_3^-, SO_4^{2-}, and Cl^- were generally elevated in pots with plants, in relation to pots without plants. The phenomenon of elevated NO_3 – has already been recorded for B. thunbergii DC. This species affects the change in the microbiological community in the soil and nitrogen mineralisation, which leads to a change in the pH and nitrogen content of the soil and the amount of nitrate to favour its growth [Matson, 2011]. This also was confirmed by our research when comparing pots with plants, to the ones without them, where NO_3– concentration in the first case was higher (Tab. 1).

Although there are evident differences in the growth of plants and the number of developed new shoots (Fig. 2), according to Duncan's Multiple Comparison test, GW does not have a statistically significant influence on the growth of plants. According to the number of developed new shoots, there is also no

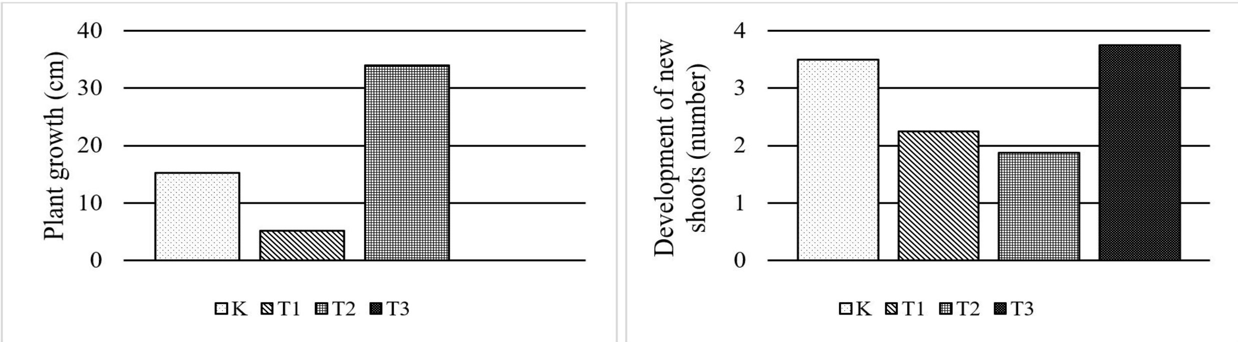

Fig. 2. Average plant growth (left) and development of new shoots (right) under different treatments during the 2-years experimental period

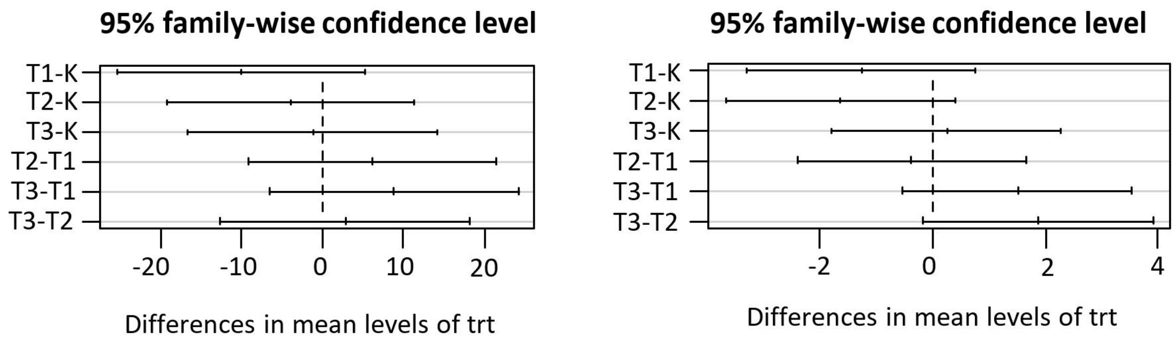

Fig. 3. Tukey HSD test for plant growth in cm (left) and development of new shoots (right)

statistically significant difference between the K and T3 treatments, from which the T2 treatment is statistically significantly different. T1 treatment has similarities to other treatments. The results of the Tukey test indicate the greatest similarities between K and T3 treatments in terms of plant growth and development of new shoots (Fig. 3). According to the evaluation of vitality, all treatments were rated with the highest score.

CONCLUSIONS

The results of this study indicate similar results when applying K and T3 treatments, which did not endanger the morphological characteristics of plants and their vitality. Also, by applying T2 and T3 irrigation treatments, it is possible to reduce the use of DW to a major extent (about 50%), and at the same time not decrease the aesthetic quality of plants. In general, the results of this research indicate the possibility of using GW for irrigation of the *B. thunbergii*, best with the application of T3 treatment. Since irrigation with GW can lead to the salinity of soil, this should be considered when selecting plants less sensitive to salts. Also, long-term application of GW can impair the quality of irrigation equipment and lead to the spread of harmful bacteria that can be found in GW. For this reason, it is very important to follow the guidelines for the application of GW, issued by the competent services, i.e. to perform quality control of GW, as well as the application of GW through underground irrigation systems. In general, irrigation with GW can be an alternative solution for irrigation of *B. thunbergii*, which is very important during the summer season when usually atmospheric precipitation is not sufficient for maintaining vitality and decorativeness of plants.

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