Research article

An Attempt to Use High Salinity Water for Irrigating A Green-Roof Garden

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Abstract Though a green roof has been implemented mainly in city area due to the mitigation of heat island effect, it can also offer the benefit of energy saving to a building in rural area. A reuse of wastewater for irrigation may be an efficient practice for water conservation, especially in the water-scarce areas. In this study, we assessed the influence of frequent and intermittent saline irrigation on evapotranspiration (ET), dry matter yields (DM) and water-use efficiency (WUE) in crassulacean acid metabolism (CAM) plants used in the green roof program. The CAM plants Sedum kamtschaticum Fischer and Sedum oryzifolium were evaluated with turf grass, Cynodon dactylon. A sharp reduction in ET with an increase in soil salinity was found in CAM plants as compared to turf grass; however, the dry matter yield of CAM plants was higher than that of turf grass at the same amount of cumulative ET. Principle component analysis (PCA) was performed to group the treatments into fewer groups characterized by similar features. CAM plants were categorized by high DM and WUE. These features were expected to make green roof management sustainable because they have low water requirements with keeping the high-density vegetation.

Keywords CAM plants, saline irrigation, evapotranspiration, water-use efficiency

INTRODUCTION

As recent climate change has raised the inconsistency of seasonal pattern of rainfall and temperature, it may cause decreasing precipitation and increasing temperature in some area (Kiem and Austin, 2013). In case such severe condition for human health continues, an air-conditioning based on the heat pump would be spread more rapidly for cooling in residential buildings regardless of their urban or rural location.

The growing energy consumption for cooling could adverse effect on the household economy. For reducing the thermal load into buildings, green roof is being used due to their protection from the solar radiation (Kumar and Kaushik, 2005). Especially the soil used in this study has a greater effect on the thermal property of insulating because with the large value of for porosity, much of the pore space is filled with air (Radcliffe and Simunek, 2010). However in dry climate regions, green roofs are not widely adopted because irrigation water for green roof is scarce. The irrigation water availability could be enhanced through the use of saline water, the recycling of drainage water and the reuse of wastewater (FAO, 1992; Rhoades, 1998; Ould-Ahmed et al., 2007). A considerable amount of poor-quality water is available in many dryland countries (FAO, 2003). The idea of using poor-quality water for irrigation to increase food production has been reported successfully for more than five decades; however, little study has been conducted with poor-quality water with the aim of improving thermal performance and landscapes, such as developing green roofs (Moritani et al., 2013).

Succulent plants that have a Crassulacean acid metabolism (CAM) have fleshy leaves. CAM plants open their stomata during night so that CO_2 is fixed into organic acids and eventually stored in the vacuoles. These characteristics prevent water loss from CAM plants and decrease the uptake of salt into plant bodies (Gravatt and Martin, 1992). In this study, we tested two kinds of CAM plants - *Sedum kamtschaticum* and *Sedum oryzifolium* - both natives of coastal areas with turf grass (*Cynodon dactylon*) as the control (Fujita, 2007). The purpose of this study was to examine the possibility of using these plants for green roofs with saline water in terms of its dry matter yield and water-use efficiency (WUE).

METHODOLOGY

Table 1 Physical and chemical properties of the experimental soil

Fraction (%)				Bulk density	Saturated hydraulic conductivity	pH (H_2O)	EC	T-C	T-N	CEC
Gravel	Sand	Silt	Clay							
>2.0 mm	2.0–0.02	0.02–0.002	0.002>	g cm^{-3}	cm s^{-1}		dS m^{-1}	%	%	cmol$_{(+)}$ kg^{-1}
48.9	32.1	10.6	8.4	0.48	3.6×10^{-2}	6.7	0.70	12.0	0.96	40.4

Description of Soil, Plants and Irrigation Water

The experiment was performed in a glass greenhouse (glasshouse) at Arid Land Research Center (ALRC) of Tottori University in Japan. The soil shown in Table 1 was overlaid at a thickness of 10 cm, on a gravel layer for drainage, in a plastic pot with a diameter and height of 0.16 m and 0.20 m, respectively.

In this study, two CAM plants, *S. kamtschaticum* Fischer and *S. oryzifolium*, and a turf grass, *C. dactylon*, which is one of the primary turf grasses used for green roof in Japan, were used. The transpiration activity of *S. kamtschaticum* was relatively higher under normal condition than of *S. oryzifolium* because of higher leaf area index. 6 plants of *S. kamtschaticum* and 25 plants of *S. oryzifolium* plants were transplanted into each pot in the middle of June, and seeds of the *C. dactylon*, which is a C_4-type plant, were sown (Aires et al., 2008). Bare soil packed in same pot was also prepared for measuring the reference evaporation. All plants were grown for one month by watering well before starting the experiment on August 1. The experiment lasted for two months during summer.

The irrigation water was prepared by mixing seawater and tap water shown in Table 2 (Al-Busaidi et al., 2007). The ratio of the Na ion content to the sum of Ca and Mg ions, expressed as the sodium adsorption ratio (SAR), is an important index to assess the quality of irrigation water. The definition of SAR is described in Eq. (1) below (US Salinity Laboratory, 1954):

$$SAR = Na^{+} / \sqrt{(Ca^{2+} + Mg^{2+})/2} \tag{1}$$

where Na^{+}, Ca^{2+} and Mg^{2+} are ion contents (mmeq L^{-1}) of sodium, calcium and magnesium, respectively. The quality of irrigation water used in this study was averaged to 12 dS m^{-1} with SAR of 50.4, which was classified as the most severe salinity condition (US Salinity Laboratory. 1954) with EC higher than 2.3 dS m^{-1} and SAR higher than 15.

Table 2 Chemical composition of irrigation water

Water type	pH	EC	Na^{+}	Ca^{2+}	Mg^{2+}	SAR
		dS m^{-1}	ppm			
Tap water	8.1	0.7	39.9	95.6	11.2	2.1
Saline irrigation water		12	2752	65	485	50.4
Sea water	7.5	38.5	11211	266	1976	104.0

Experimental Conditions

The humidity and temperature were measured every 15 minutes using a hobo logger (HOBO H8 PRO SERIES LOGGER). While the range of temperature was generally higher at averaged 32 ºC than that of an actual green roof setting Takebayashi et al. (2007), there was a slight wind blowing inside the glasshouse through open windows.

Two different irrigation intervals were used: frequent irrigation (FI) and intermittent irrigation (II) with averaged to 2 and 10 days interval, respectively. Evapotranspiration rate (ET) from the vegetation, evaporation rate from the bare soil (E), and pan evaporation rate were measured by weighing pots with and without plants and a small evaporation pan (internal diameter of 0.35 m). Daily ET ratio (ET_r) and E ratio (E_r) were calculated by dividing ET and E with pan evaporation rate, respectively. The amount of irrigation water (V_i) applied to each pot was 1.2 times the observed ET during each irrigation interval so that the excess of water V_d can be used to leach the salt from the soil by drainage (Yamamoto and Cho, 1987a,b ;Corwin et al., 2007). The EC of the drainage water (EC_d) was measured using a portable EC meter (HORIBA Compact Conductivity Meter/B-173). At the end of the experiment, the dry matter yield (DM) of each plant was observed by weighing the shoots after drying them at 80 ºC for 3 days. The water use efficiency (WUE) is defined as follows:

$$WUE = \frac{DM}{TotalET} \tag{2}$$

where total ET is the total ET during the irrigation experiment, which is measured by weighting pots. The soil water content and soil EC were calculated from the water and salt balances in pot soil, described in Moritani et al (2013).

Statistical Analyses

The experimental treatment under saline irrigation which was classified as the most severe salinity condition was replicated more than 3 times. These samples were subjected to a mean separation analysis using a one-way ANOVA with a significance level of P <0.05. (PCA) was used. Principal component analysis (PCA) was carried out under each irrigation method on the standardized data matrix for reducing the data complexity and extracting the latent patterns. The analysis of PCA can condense the variations in the treatments by loading in two orthogonal axes that summarize the main underlying gradients (Tamene et al., 2006). To analyze the direct impact of the parameters of EC_i, DM and WUE on the gradients, regression methods between the loadings of PC1 or PC2 and the correspondents of each parameter were calculated (Moritani et al., 2010; Singh et al., 2005). All of these statistical analyses were performed with SPSS software (Ver. 10.0).

RESULTS AND DISCUSSION

Influence of Evapotranspiration on Soil Salinity

ET for all plants decreased with time as EC_s increased, however ET of C.dactylon was observed with greatest amount. An average pan evaporation rate of 4.4 mm day^{-1} was observed during the experiment. Fig. 1 shows the decrease in evapotranspiration ratio (ET_r) and evaporation ratio (E_r) with increase in soil water EC (EC_s). The maximum ET_r for *S. kamtschaticum*, *C. dactylon* and *S. oryzifolium* was 2.0, 3.0 and 1.4, respectively. While the E_r exhibited a unit value of approximately 1.0, a decrease in the ET_r was observed for all of the plants caused by salt stress. The EC_s value when the ET_r became less than the E_r was at 10 dS m^{-1} for *S. kamtschaticum*, while at 2 dS m^{-1} for *S. oryzifolium*. In the case of *C. dactylon*, the ET_r moderately decreased, reaching a value > 0.8 at an EC_s value of 60 dS m^{-1}. The sharp reduction of the ET, particularly for *S. kamtschaticum* and *S. oryzifolium*, was assumed to be the result of the soil osmotic potential, which decreased the water uptake of the roots. Another reason for decreasing the ET might be the closure of the stomata during the day (preventing water loss from the plant) under the condition of salinity stress, alternating with the opening of the stomata during the night, when the evaporative demand was low.

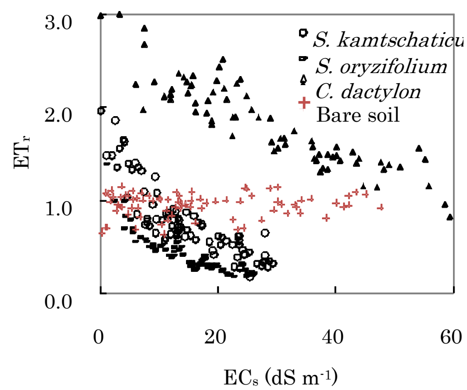

Fig. 1 The relationships between the EC of soil water (EC_s) and the evapotranspiration ratio (ET_r) of *S. kamtschaticum*, *S. oryzifolium* and *C. dactylon* and the evaporation ratio of the bare soil (E_r)

Dry Matter Yields and Water-use Efficiency

The total ET of *S. kamtschaticum*, *S. oryzifolium*, and *C. dactylon* in the control pots were 381, 192 and 574 mm, respectively. The 24 % reduction in total ET by soil drought condition under II was observed in *S. oryzifolium* compared to the control while those in *S. kamtschaticum* and *C. dactylon* were averaged to 64 %. Table 3 shows the total ET, DM, and WUE for all three types of plants under both saline irrigation methods. The total ET of *C. dactylon* under FI was the highest among others. However, this ET decreased by 48.2% under II that is statistically significant. The DM of all plants under the control showed similar values averaged to 15.7 (±0.8) t ha^{-1}. The DM of *S. oryzifolium* was the highest, although the ET was lowest; this led to the highest WUE (Table 3). While the WUE was not affected significantly by the irrigation method, the order of the WUE among these plants was as follows: *S. oryzifolium* > *S. kamtschaticum* > *C. dactylon*.

As mentioned above, CAM plants consume water efficiently when the stress is given however, the plant biomass decreases. The reduction of biomass is unfortunately not appropriate for improving the thermal performance and landscaping. A combination of high WUE and high DM are thus required for the high-quality green roof management. The quantification of this combination given as follows was undertaken as a factor of vegetated condition (FVC):

$$FVC = WUE \times DM \tag{3}$$

The FVC in Table 3 shows the relative value against the control in percentage. While the difference in the FVC between the FI and II conditions in each plant was insignificant (P <0.05), the FVC can be grouped depending significantly on the plant status. The FVC value was highest in *S. oryzifolium*, followed by *S. kamtschaticum* and *C. dactylon*.

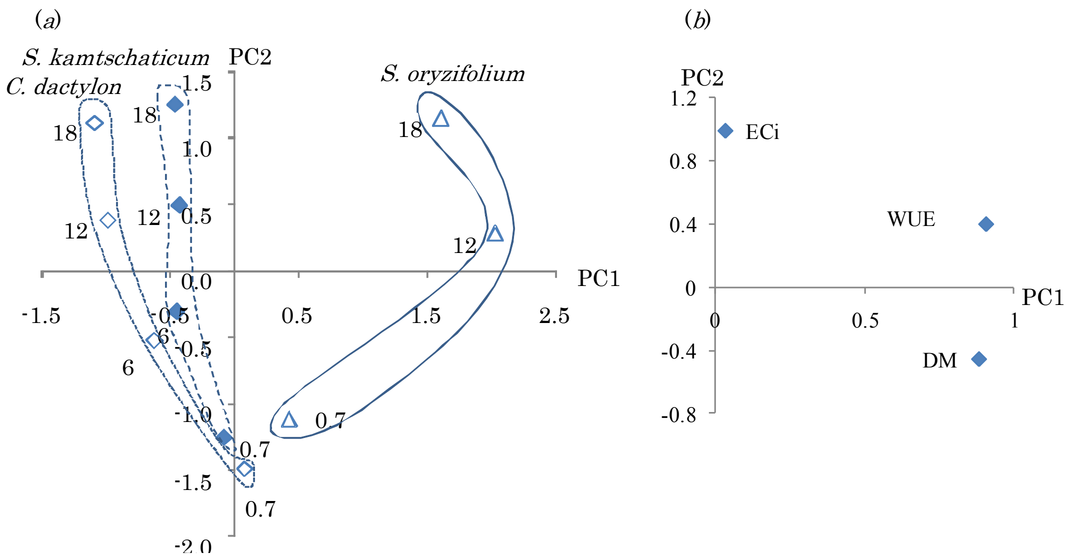

Fig. 3 Results of the principal component analysis under the frequent irrigation method. (*a*) Loadings: the enclosed lines indicate the group characterized the by underlying component associated with the factor scores. Numerical values indicate the EC of the irrigation water. (*b*) Factor scores: EC_i, DM and WUE indicate the EC of the irrigation water, dry matter yield and water use efficiency, respectively

Multivariate Analysis

The PCA resulted in two significant principal components (PC), PC1 and PC2, with eigenvalues > 0.8, which explained approximately 98% of the total variance in the dataset. The PCs provide information on the most meaningful parameters, which describe a whole dataset, affording a data reduction with a minimal loss of the original information. PC1 and PC2 therefore explain the most significant part of the variance within the variables (Pardini et al., 2003). Figs. 3 (a) and (b) show the loadings and factor scores from the results of the PCA, respectively, under FI. The treatments for each plant tended to be divided into same group, as shown by the enclosed lines in the figure. The factor scores indicate that the higher EC_i, for example, decreased the DM but increased the WUE. In the loadings, group of *S. oryzifolium* was distributed in the range of a high positive x-axis. From the factor scores, DM and WUE were gathered in the positive x-axes. This indicates *S. oryzifolium* meets the requirement of a high DM with a high WUE. *C. dactylon* tended to be in the lower DM and WUE ranges, while *S. kamtschaticum* was distributed between these two plants. These tendencies were also observed under II. One of the different results in PCA between two irrigation methods was that the y-axis of EC_i was closer to the DM and WUE under II. This indicates the influence of the EC_i on the DM and WUE decreased, as compared with that under FI. This is because the drought stress was added under II, which in turn decreased the influence of the salt stress expressed as EC_i, relatively.

Table 3 Total ET or E, DM, WUE and FVC of *S. kamtschaticum*, *S. oryzifolium* and *C. dactylon* in the two different of irrigation of frequent (FI) and intermittent (II) with saline irrigation

	S. kamtschaticum		*S. oryzifolium*		*C. dactylon*		Bare soil	
	FI	II	FI	II	FI	II	FI	II
ET or E (mm)	157.3 b	91.8 a	93.3 a	93.2 a	366.2 c	189.0 b	184.2 b	163.9 b
DM (t ha^{-1})	10.3 a	9.0 a	17.0 b	15.5 b	10.4 a	8.2 a		
WUE (kg m^{-3})	6.7 bc	9.9 c	18.3 d	16.9 d	2.9 a	4.4 ab		
FVC (%)	133.7 b	151.3 b	241.8 c	207.7 c	62.7 a	75.5 a		

Letters indicate significance level at 0.05

The higher WUE observed in the CAM plants, with a little reduction of the DM, highlights the benefit of using them as green roof vegetation, in terms of low water management requirements and a high quality of landscape. This study did not account for the leaf fall that is characteristic of *S. oryzifolium* during the winter season that may change the WUE and may damage the green roof landscape. Therefore, a year-round study needs to be performed in future to evaluate the WUE during the dormant season.

CONCLUSION

In this study, the performance of two CAM plant species, *S. kamtschaticum* and *S. oryzifolium*, were evaluated under frequent and intermittent irrigation conditions with saline water. A prompt decrease in ET with increasing EC_s was found under *S. kamtschaticum* and *S. oryzifolium* compared to that of turf grass, *C. dactylon*. As a consequence, the dry matter yield showed the following order: *S. oryzifolium* > *S. kamtschaticum* > *C. dactylon*. This is evidence that saline irrigation reduced the dry matter yield but increased the WUE in CAM plants, resulting in a decrease in the amount of irrigation water required. In other words, saline irrigation to CAM plants saves water. The paradox is that maximum plant growth would imply maximum dry matter yield, which would contribute to carbon sequestration, but would also require maximum irrigation water. However, the higher WUE seen in CAM plants with a little reduction of DM makes them suitable for green roofs in terms of low water management requirements with keeping high quality of landscape. This knowledge of CAM plants' response to saline irrigation, dry matter yield and WUE could help in selecting suitable plants and in designing optimal saline irrigation systems and scheduling for green roofs.

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