Chapter 12

Evapotranspiration of Succulent Plant *(Sedum aizoonvar.floibundum)*

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Additional information is available at the end of the chapter

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1. Introduction

Fresh water resources available for agriculture are declining quantitatively and qualitatively. Therefore, the use of less water or lower-quality supplies will inevitably be practiced for irrigation purposes to maintain economically viable agriculture. Globally arid and semiarid areas are facing salinization of soils along with the acute shortage of water resources. The utilization of marginal waters for agriculture is getting considerable importance in such regions. In hot and dry climate, one of the most successful ground covers is Sedum. It is perennial plant, which grows by natural moisture even if there is a little soil [1]. As their common name of stonecrop suggests, they do very well in rocky areas, surviving on little soil and storing water in their thick leaves. While some do well in very sunny areas, others thrive in shade and they all tend to like good drainage. Sedums are suitable plants for rock gardens and flower borders. They are very easy to propagate as almost any tiny leaf or piece of stem that touches the ground will root. Some types become rather invasive but are easy to control since the roots are never very deep [1].

Sedum is one of the promising plants in dry areas. It has the characteristics of fire prevention and dry resistance. It has low transpiration value in the daytime compared to other plants. It uses latent heat transmission to control water loss. Generally, succulents, such as Sedum, have been the most studied and used plants for green roofs [2-5]. Greenroofs are increasingly being used as a source control measure for urban storm water management as they detain and slowly release rainwater. Their implementation is also recognized as having other benefits, including: habitat creation for birds and insects [6] filtering of aerosols; energy conservation by providing thermal insulation [7, 8]; improvement of local microclimate through evaporation; reduction of rooftop temperatures [8]. One of the main reasons Sedums seem ideally suited to green roof cultivation is the fact that many possess Crassulacean acid metabolism (CAM). During periods of soil moisture deficit, CAM plants keep their stomata closed during the day when transpiration rates are normally high and open them at night when transpiration rates are significantly lower. This is in contrast to C3 and C4 plants, which do not keep their stomata closed during the day and therefore have higher water use rates than CAM plants.

Research that examines the growth obstruction moisture point in Sedum is little, and its growth is confirmed as for the amount of pF 3.0 or lower moisture content [9, 10]. Sedum has the characteristic of doing shutting transpiring control and when plant under water stress conditions, carbon dioxide is absorbed at nighttime which also common in some Crassulaceous plants that have Crassulaceous Acid Metabolism (CAM). For terrestrial plant species CAM is generally considered to be an adaptation to growth in dry environments [11, 12]. CAM species generally have high water use efficiencies and slow growth rates and are most abundant in arid regions and dry microhabitats. The degree of CAM expression (the proportion of nighttime CO_2 assimilation by PEP carboxylase) potentially may vary from CO_2 uptake only at night, to CO_2 uptake both at night and during daylight, to CO_2 uptake only during the day. A greater proportion of nighttime CO_2 uptake has been associated with greater water use efficiency. This phenomenon helps Sedum to save much water and keep it for longer time. Sedum is a drought tolerant plant and its growth and survival under very dry conditions, still not well known. Therefore, objective of this study was to evaluate the ability of Sedum plant to grow under different soils condition where evapotranspiration was the main indicator for plant interaction with dry conditions. In addition, the studies on the growth and survival of Sedum under saline water conditions are scanty and not well documented. Therefore, the other objective of the study was to evaluate Sedum growth under saline water irrigation either by surface or shower method.

2. Materials and methods

Glasshouse study

Plot experiment was carried out in a glasshouse at Arid Land Research Center of Tottori University, Japan. The plots were made in two directions (North & South) with a slope of 20 and 30 degree, respectively. Twelve plots were filled up to 10 cm thickness with five types of soils (Table 1). The used soils have different criteria in which four of them were artificial and the other two were sandy and clayey soils. Sedum (*Sedum aizoonvar.floibundum*) plants were transplanted uniformly in all types of soils. Plants were irrigated by sprinkler with intensity of 20 mm/h. Air temperature, relative humidity and solar radiation were measured continuously day and night by Hobo (Pro series, onset, USA) meter. Evaporation and evapotranspiration were measured by using micro-lysimeters and evaporation pan (class A) following pan evaporation method ($ET_o = E_{pan} * K_{pan}$, $ET_p = ET_o * K_c$) where ET_o: reference evapotranspiration, E_{pan}: pan evaporation, K_{pan}: pan coefficient, ET_p: potential evapotranspiration, K_c: crop factor [13].

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Soil properties	Sand (%)	Silt (%)	Clay (%)	Bulk density (gcm^{-3})	S. Hydraulic Conductivity (cm/s)	CEC ($cmol_{(+)}$/kg)	C (%)	N (%)	C/N
KS	89.6	5.8	4.6	0.48	3.6×10^{-2}	40.4	12.0	0.96	12.4
VS	92.9	1.7	5.4	0.67	9.2×10^{-1}	12.5	1.0	0.09	10.7
Powder Pearlite	98.6	1.4	0	0.19	3.2×10^{-1}	0.8	-	-	-
Coarse Pearlite	100	0	0	0.10	5.6×10^{-1}	-	-	-	-
Sand	96.1	0.4	3.5	1.42	3.4×10^{-2}	1.5	0.12	0.02	5.9
Touhaku	53.9	17.8	28.3	1.11	5.8×10^{-4}	9.5	0.50	0.09	5.4

Table 1. Soil physicochemical properties

Growth chamber study

Plastic containers of 15 cm height and 22 cm diameter were filled up to 10 cm height with different types of soils. The physicochemical properties of the used soils were same as the soils used in glasshouse study (Table 1). Sedum plant was transplanted in each pot with intensity of 30 plants/pot. All soils were irrigated until the field point of pF 1.8. After 24 hours, the evaporation process was inhibited by covering soil surface with plastic sheet. All pots were transferred to growth chamber with a day time temperature of 40 °C, 60 % relative humidity and light of 10000 Lux. Whereas, at the night time, the temperature and relative humidity were 20 °C and 60 %, respectively. All pots were placed in weighing balance scale so water lost by transpiration process was monitored (Figure 1).

Figure 1. Weighing balance for transpiration measurements

Physicochemical analysis

All used soils were air dried and passed through 2 mm sieve. Soil texture was determined by pipette method. Cation exchange capacity (CEC) was determined by atomic absorption spectrophotometer (Model Z-2300 Hitachi corp, Japan) after leaching with ammonium acetate solution and using sodium acetate as an index cation. Saturated hydrolyic conductivity was measured by constant head method. Whereas, percentage N and C were measured by C/N coda (MT700, Yanagimoto, Japan). The pF values for soil moisture characteristic curve were measured by suction and centrifuge methods for pF values of 0 - 4.2 and Saicromatar method for 4.2 - 6.0 (Figure 2). The selected properties of the soils are given in Table 1.

Salinity study

Pot experiment was carried out in same glasshouse at Arid Land Research Center, Tottori University, Japan. Sand dune soil was placed in 4 L pots. Sedum *(Sedum aizoon var. floibundum)* was planted in 24 pots at the planting density of 4 plants per pot. One group of the pots was irrigated with the saline water directly on the surface of the soil and the other group of pots was showered by the same water treatments. Irrigation with saline water was started after 14 days of planting. Saline water treatments were consisted of four levels:

i. fresh water (0.7 dS m^{-1}),

ii. saline (15 dS m^{-1}),

iii. highly saline (30 dS m^{-1}), and iv) sea water (46 dS m^{-1}).

Sea water was diluted by tap water to achieve these EC_w levels of irrigation water. Four saline water treatments were combined with two types of irrigation methods e. g., surface or normal irrigation (N) and shower or sprinkler irrigation (S). These treatments are denoted as 0.7(N), 0.7(S), 15(N), 15(S), 30(N), 30(S), 46(N), and 46(S) respectively. Plants were irrigated twice a week depending on the loss of evapotranspiration (ET_c) which was estimated by gravitational measurement. Extra water at the rate of 10% was added for leaching purpose. Evaporation was measured by using evaporation pan (class A). Air temperature and relative humidity were measured during the day as well as night by Hobo meter (Pro series, onset, USA). Prior to the harvesting of the plants for their fresh and dry weight, plant height and leaf area (by portable area meter LI-3000A) were also measured. Post-harvest soil samples were collected from each pot at a depth of 0-20 cm. Soil electrical conductivity (EC) was measured in the 1: 5 soil-water suspensions. Data were analyzed statistically for analysis of variance (ANOVA) and the means were compared at the probability level of 5% using least significant difference (LSD) test [14].

3. Results and discussion

Glasshouse study and Soil characteristics

Table 1 details the properties of the studied soils. All of them contain high percentage of sand particles with varied values of bulk density and saturated hydraulic conductivity. By checking cation exchange capacity (CEC) and C/N values, it seems that KS, VS and Touhaku soils are the most fertile soils. Generally, the physiochemical properties of these soils support plant growth but survival time or drought effect dependson how much moisture the

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soil can keep and the plant can take which usually related to soil water plant interactions. From Figure 2, it can be seen that Touhaku soil got the highest values for water content followed by K soil. That usually related to clay and silt contents in the soil. Moreover, as sand particles increase, volumetric water content decrease and that was the case with perlite and sand dune soils.

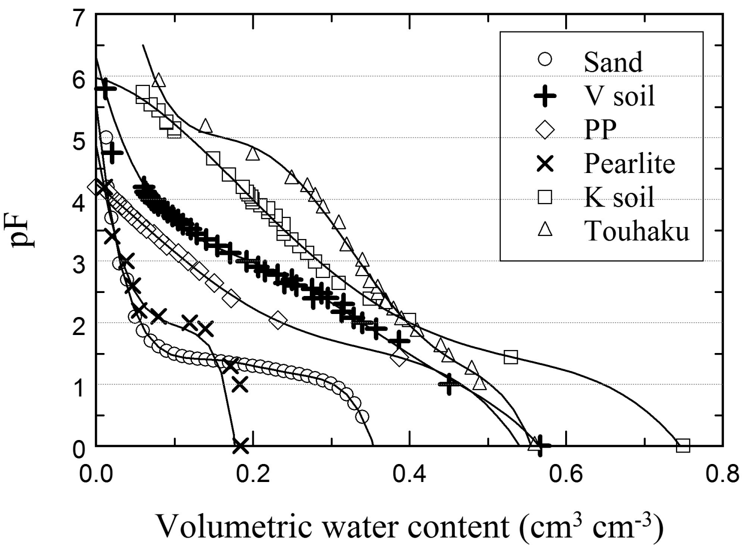

Figure 2. Soil water retention curve of studied soils

During the study period, the weather was changing with the average glasshouse temperature and humidity of 29 ^{o}C and 74 %, respectively. Average value of temperature seems to be suitable for Sedum growth but high value of 35 ^{o}C could enhance water loss through evapotranspiration (ET) process (Figure 3). Comparing ET values for both slopes of glasshouse study, it wasn't a big difference in the water lost between both slopes. However, there was a big difference between soil types (Figures 3-4) and that mainly related to the physiochemical properties of each soil. Generally, it can be noticed that after irrigation the water loss was high and gradually decreased with time. It is ranking in the following order: V soil > K soil > Sand >Touhaku> Pearlite. Moreover, it can be seen that Touhakusoil got the highest value for mean ET (Figure 4). Whereas, Pearlite soil got the lowest values. This can be related to the soil physical properties in which Touhakusoil has much clay content that can keep much water that could be subjected to ET losses. In same time, it was encouraging plant growth and plant lost much water through transpiration process compared to other soils. For Pearlite soil, since it has coarse particles so most water was lost through drainage and the rest of water was used for plant growing mechanisms. However, water lost from different slopes and directions (North and South) was inconsistence and was changing with time.

Since ET is one of the growth indicators, it seems that plant growing in K, V andTouhaku soils was growing very good by giving high values for ET. Whereas, plant growing in Pearlite soil was saving the water and reduce ET process (Figure 3 & 4).

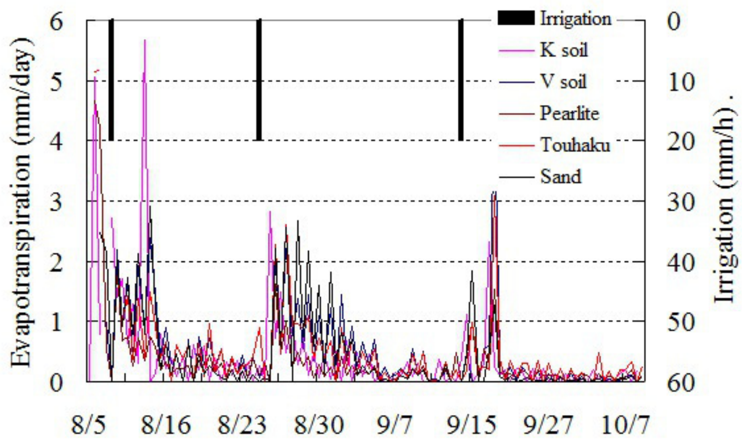

Figure 3. Irrigation and evapotranspiration values of Sedum in glasshouse study

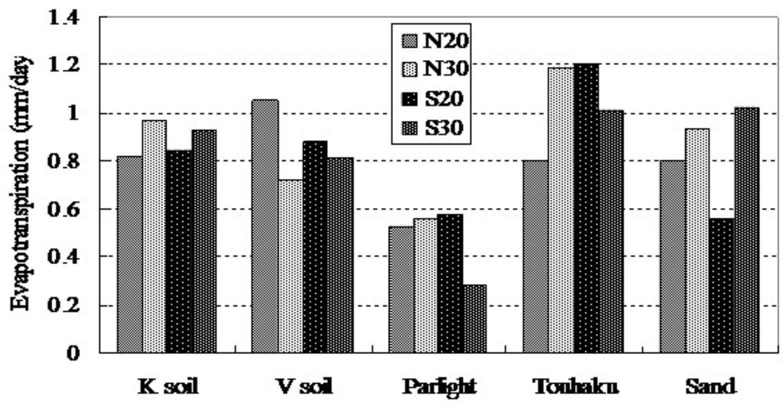

Figure 4. Mean values for Sedum evapotranspiration in glasshouse study

Growth chamber study

Growth chamber is a controlled environment and what happened inside the chamber can be more understandable than outside environment. In this study, Sedum transpiration ratio was continuously monitored by weighing scale (Figures 5-6). Day time was considered from 0-12 o'clock and night time from 12-24 o'clock. Figure 5 represent transpiration ratio at the first day of study. It can be seen that plants grown in V, K and sand soils got the highest transpiration values among others. Whereas, plants in Pearlite and PP soils got the lowest values in both intervals. This can be related to the soil physical properties which supply water to plants. Pearlite and PP are coarse soils with particle size of 3 and 1 mm, respectively, in which most water in the soil was in vapor form and not directly available for the plant. Whereas, K and V soils have high values of clay and silt contents and that increasedwater holding capacity compared to others.

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In this study, plants were irrigated at the beginning of the study and soil surface was sealed so the only way to loss water was through transpiration process. Amount of transpiration water usually depend on plant growth and available soil moisture content. In CAM plants the transpiration process usually increase with day time and decrease at night. In this study the plant was under water stress condition so soil water content was decreasing with time. In the first day, since there was much water, plant was losing much water in the day time compared to night time (Figure 5). Whereas, at the last day of the study (Figure 6), plant was under stress and was losing less water in the day compared to the night time. This phenomenon usually happen in CAM plants when they are under stress condition. Under heat and water stress condition plants were trying to save much water by closing their stomata and opening them at normal conditions. This phenomenon can be seen very clear in Figure 6.

Generally Sedum plant is keeping much water in their leaves and since the plant was getting much water in the first day so it was losing much water in the day and night time (Figure 5) but in the last day (Figure 6) water lost was low and transpiration rate was almost constant in which the plant was keeping constant water potential value [10].

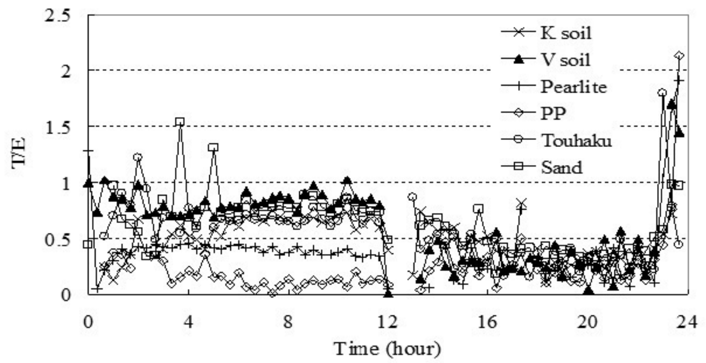

Figure 5. Transpiration ratio at early stage of study

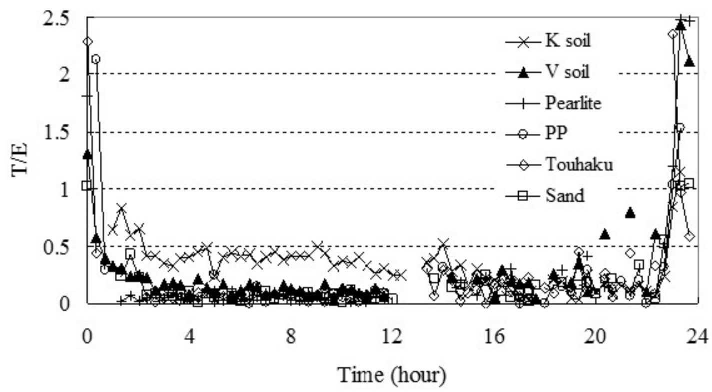

Figure 6. Transpiration ratio at late stage of study

Transpiration ratio assumption

In case of water stress, evapotranspiration could be a good indicator for plant survival. In this study cumulative transpiration and ET were related to square roots of elapse time (Figure 7). Both studies in glasshouse and growth chamber were agreed with starting point but with the time, each study gave different patterns especially in the last days of measurements. This can be related to the environmental conditions of both studies. Glasshouse conditions were varied and both evaporation and transpiration were counted. In same time plant was growing under normal condition without any heat or drought stresses. Whereas, in growth chamber, the growth conditions were almost constant and transpiration was the main factor that was measured. In addition plant was growing under stress condition in which transpiration was decreasing with time. However, all values in growth chamber were highly correlated with R^2 value of 0.99. This finding was also confirmed by Moritaniet al. [9] and Iijima [10].

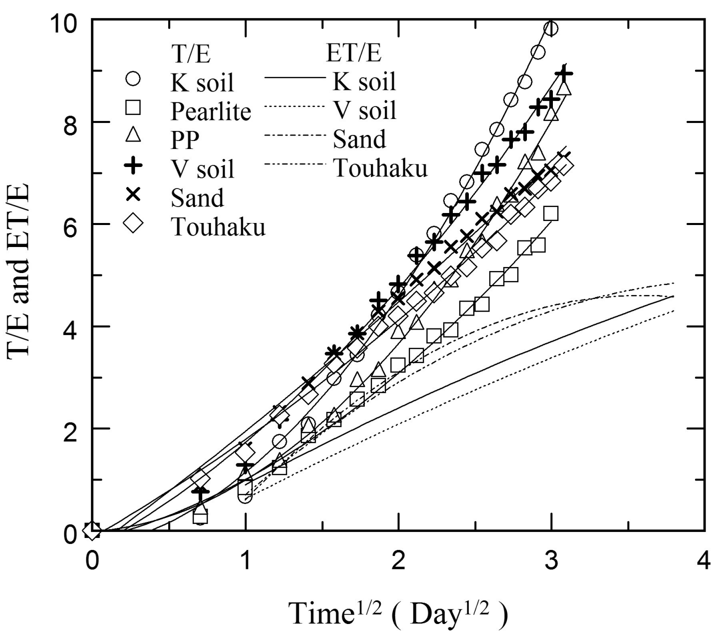

Figure 7. Relationship between cumulative transpiration ratio and square root elapse time

Transpiration ratio and soil water potential

Figure 8 shows soil water potential with transpiration ratio. The transpiring ratio for the study period decreased gradually with the increase in soil water potential (pF). The dotes shown in Figure 8 are the observation points. Whereas, the line was the predicted values found by equation 1.

$$y = \alpha / \{1 + \beta * \exp(-\gamma * x)\} + \delta \quad (1)$$

whereα, β, γ, and δ are fitting parameters. Root mean square error (RMSE) was calculated between dotes and plotted line using equation 2.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} d_i^2}{N}} \tag{2}$$

where d is the difference between observed and calculated values and N is the total number of the data. The average value for RMSE is 0.0097 which mean there is a good fit between observed and calculated data. It can be seen that K and V soils were giving different graphs depending on physicochemical properties of each soil. Point 1 and point 2 are the changing points. A decrease of 10 % from highest point in the graph is a representation of point 1 and an increase by 10 % from lowest point is a representation for point 2. Many points were checked and 10 % of increase or decrease was giving the best data and matching with value of changing point. The best values for point 1 were found in K soil followed by Touhaku > V > Pearlite > Sand > PP soils. For point 2 the order is Touhaku > K > V > Pearlite > Sand > PP soils (Table 2). Soils of K, V, and Touhaku types gave the highest values for point 1 and 2. The starting point for V, Touhaku and Sand soils is 0.8 and 1.6 for K soil. Whereas, Pearlite and PP soils got 0.3. From table 2 and within evapotranspiration ratio, it can be seen that K, V and Touhaku soils had almost similar values for point 1 and 2. Whereas, Sand, Pearlite and PP soils got the lowest values for transpiration. This reflects the poor structure of the soils and disability of the soil to hold water. It is also mean that soil was losing much water in short time and plant got stressed within short period. Since different soil has different properties of sand, silt and clay so each one was storing different amount of water and that was reflected in plant growth.

Sedum evapotranspiration ratio showed same results as found by many researchers [9, 10]. However, using different soil with different properties will give different values for point 1 and 2 (Table 2).

	T/E		ET/E	
	Point 1	**Point 2**	**Point 1**	**Point 2**
K soil	3.1	4.6	3.0	4.2
V soil	2.2	3.2	3.0	4.2
Sand	1.2	1.5	2.2	4.2
Touhaku	2.6	4.7	3.0	4.2
Pearlite	2.0	2.7	-	-
PP	0.8	1.3	-	-

Table 2. The pF value of point 1and 2

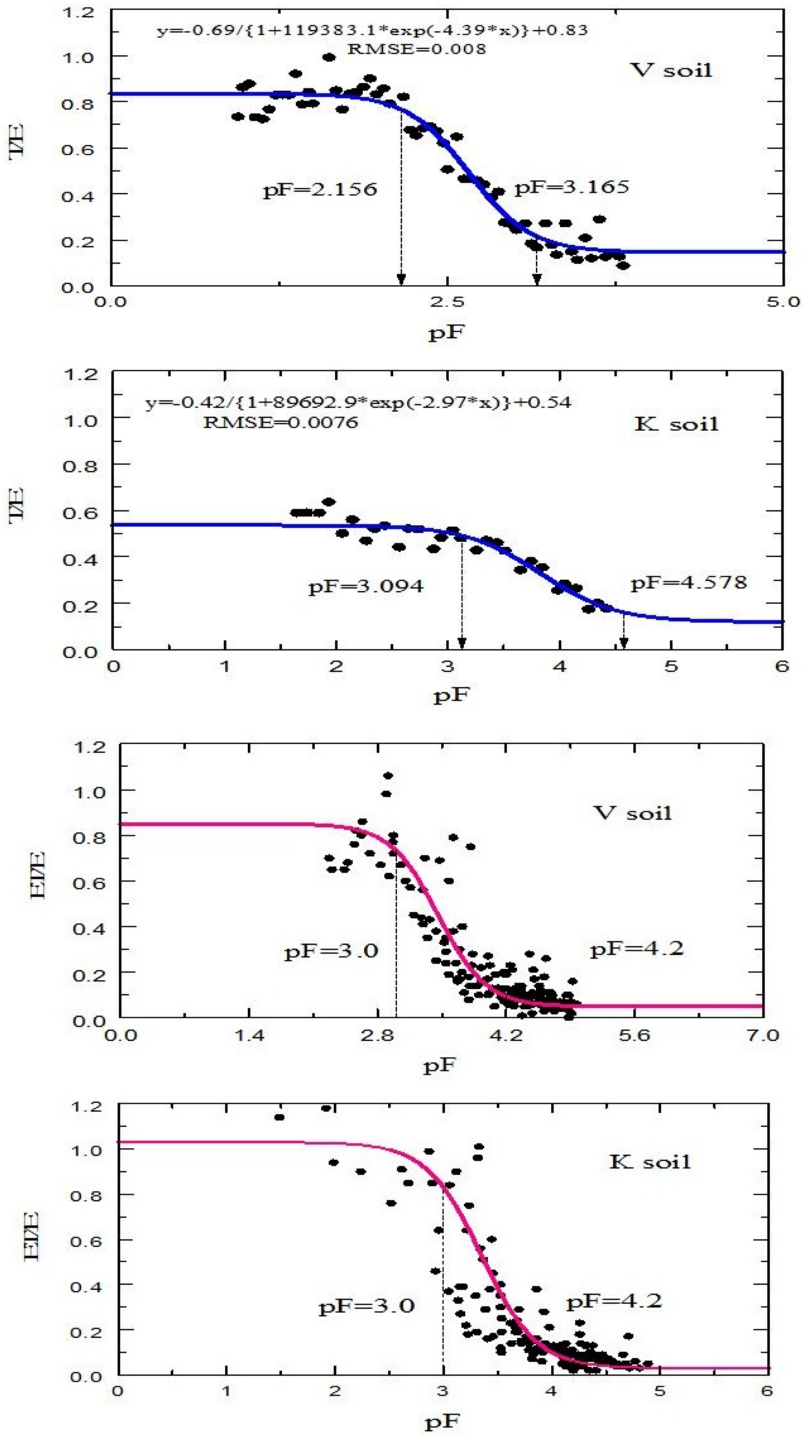

Figure 8. Relationship between transpiration ratio, evapotranspiration ratio and water potential

Salinity study

During the experiment, weather fluctuated with the average glasshouse temperature of 29 °C and humidity of 74 %. Changes in the temperature and humidity during the experiment are shown in Figure 9. Under fresh water treatment the plants exhibited the highest values of evapotranspiration as compared to saline water treatments (Figure 10). In general the higher level of evapotranspiration and accumulation of salts on the soil surface was caused by the variations in the temperature over time.

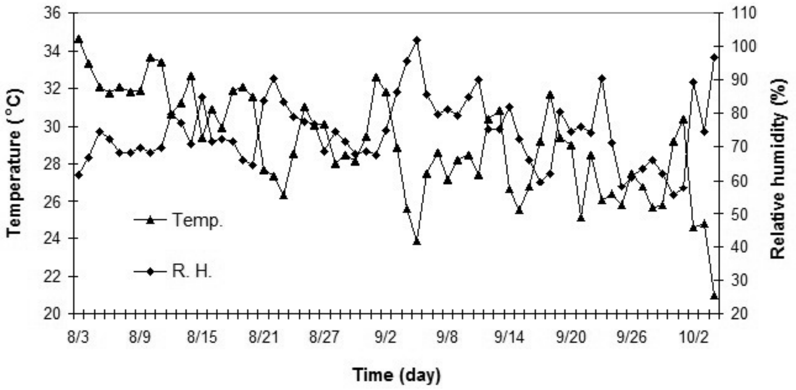

Figure 9. Variations in temperature and humidity during study period

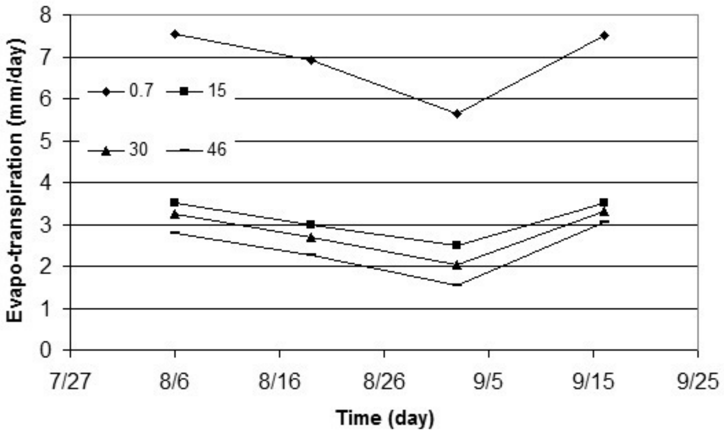

Figure 10. Variability in the evapotranspiration as affected by saline treatments

Fresh water encouraged evaporation process more than saline water. Maximum evapotranspiration occurred with good quality water. Since the plants absorb water in saline conditions with higher pressure therefore the water losses through transpiration were retarded. Thus the magnitude of the evapotranspiration was inversely related to the amount of salts in the irrigation water. Reduced bioavailability of water and retarded plant growth under saline irrigation produced poor evapotranspiration in the system. On the other hand presence of salts in the saline irrigation inhibits evapotranspiration and reduces water consumption. Water density, viscosity and formation of salt crust are factors that could reduce evaporation and maintain higher water in the soils. Al-Busaidi and Cookson [15] reported salt crust formation on the soil surface due to saline irrigation inhibited evaporation and reduced leaching efficiency. It has been reported elsewhere that salt accumulation in root zone causes the development of osmotic stress and reduces plant development [16, 17].

Application of irrigation water with certain level of salts results the deposition of soluble salts in the soils. Evaporation and transpiration of irrigation water eventually accumulate excessive amounts of salts in the soils unless an adequate leaching and drainage systems are not practiced [18]. During the study, a low electrical conductivity of soil was noted under normal water whereas sea water irrigation largely increased the salinity level of soil (Figure 11). The saline water accumulated salts in the soil in spite of the leaching process. Petersen [19] reported that the accumulation and release of salts could depend on the quality and quantity of irrigation water, soil type and plant response. Abu-Awwad [20] reported high salt concentration on the soil surface due to evaporation.

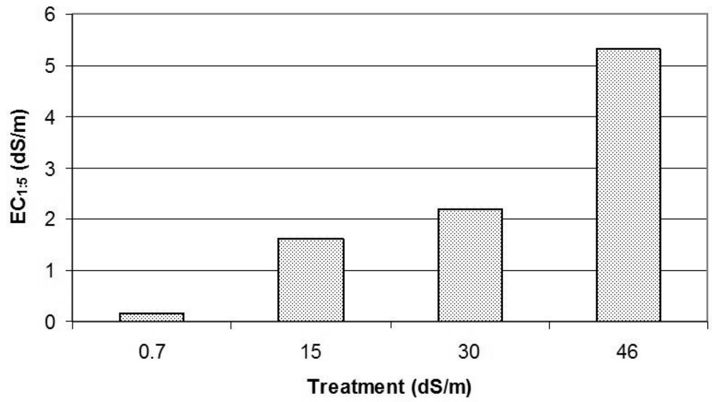

Figure 11. Soil salinity under different saline irrigation treatments

Plant growth

Plant parameters were the function of irrigation water treatments. Sedum plant grew well under non-saline conditions. Highest plant fresh and dry biomass, plant height and leaf area were noticed with normal irrigation water. While, sea water treatment gave the lowest values of the plant parameters (Table 3). Soil salinity was the main reason behind the lower plant growth whereas the effects of irrigation methods were statistically found insignificant. Sedum plants accumulated more salts and leaf injuries were seen especially under high saline treatments. The physiological thickness of the Sedum leaves with higher water absorbing potential could possibly facilitate Sedum plants to survive under high saline conditions. Usually, CAM plants are capable of transporting water very effectively to those tissues necessary for survival. This also happened in Sedum when the plants were dry, water was transported from the older leaflets to the younger parts of the shoots, which were thus kept turgescent, whereas the older leaflets died. Closure of the stomata helped further to maintain a sufficiently high water potential [21].

There is a general consensus that higher salinity profoundly impaired plant growth parameters. The response of crops to salinity could depend upon plant species, soil texture, water holding capacity and composition of the salts. Abu-Awwad [20] reported that saline soils with considerable soluble salts interfered the growth of crop species. Heakal et al. [16] reported that dry matter yield of plants decreased with increasing salinity of irrigation water.

Treatment	Plant height (cm)	Leaf area (cm^2)	Fresh weight (g)	Dry weight (g)
0.7 (N)	31	11	355	44
0.7 (S)	25	10	314	39
15 (N)	20	5	69	22
15 (S)	20	4	57	16
30 (N)	17	3	39	17
30 (S)	16	3	43	18
46 (N)	14	2	42	17
46 (S)	14	2	35	20

Table 3. Plant parameters as affected by saline water irrigation

In general the plant biomass is dependent absolutely on the growth of plants. Differences were found in the fresh and dry weights among the irrigation treatments. Water deficit level increased with the increasing salinity (Figure12). The ratio of dry weight to fresh plant weight increased significantly with the increasing level of salinity treatments. The stress caused by the ion concentrations allows the water gradient to decrease, making it more difficult for water and nutrients to move through the root membrane [22]. Accumulation of salts in the root zone affects plant performance through creation of water deficit and disruption of ion homeostasis [23] which in turn cause metabolic dysfunctions. The differences in the water content of the plants between the irrigation methods could reflect the efficiency of surface irrigation which can provide enough water to the plant without physically touching the leaves. Sprinkler or shower irrigation adds salts directly on the leaves and may disturb its normal functions.

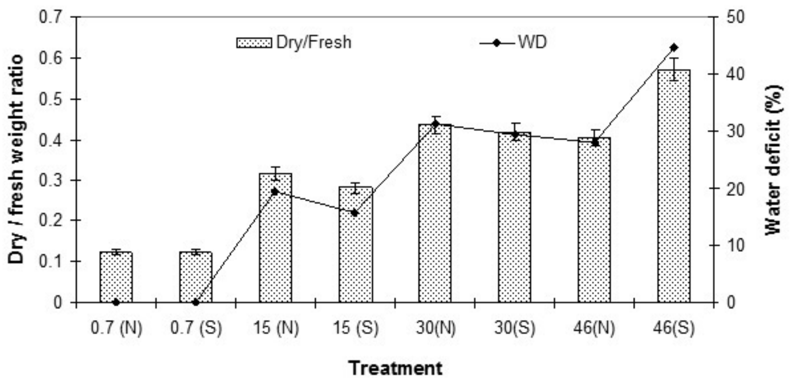

Figure 12. The ratio of dry to fresh weight and water deficit (WD) as affected by the saline treatments

Water salinity and irrigation method can affect plant growth. Moreover, the interaction effect of both independent parameters was affecting plant height and biomass (Table 4). However, it can be seen that all dependent parameters were significantly affected by applied treatments. Volkmar et al. [22] reported that plants grown in saline soils have diverse ionic compositions and concentrations of salts. The fluctuations in the salts concentrations could be related to the changes in the water source, drainage, evapotranspiration, and solute availability. The two major environmental factors that currently reduce plant productivity are drought and salinity and these stresses cause similar reactions in plants due to water stress [24].

Parameter	Saline water (S)	Irrigation method (I)	S x I
		P-value	
Plant height	0.0001*	0.0001*	0.0002*
Leaf area	0.0001*	NS	NS
Fresh weight	0.0001*	0.0001*	0.0001*
Dry weight	0.0001*	0.0006*	0.0001*

Table 4. Summary of two-way analysis of variance on the effects of saline water and irrigation method on plant parameters* denotes the level of significance at P value < 0.05 and NS denotes non-significance.

Most studies of CAM plants have focused on the physiology and ecology of individual plant performance. It has generally been assumed that the expression of CAM is associated with adaptive success in arid environments because traits related to water use efficiency and tolerance of low water availability are genetically correlated with CAM. Water loss in CAM plants is reduced as a result of low stomatal frequency and high cuticular resistance [11, 25-27].

It is known that malate accumulation in at least some CAM plants can result in a substantial level of osmotic adjustment [28]. The maintenance of negative leaf potential during drought appears to be related to the continued ability of the Amistad plants to take up CO_2 and to accumulate dry weight. Both Troughton et al. [29] and Mooney et al. [30] have found that reproductive tissue in a variety of leaf succulents may have carbon isotope ratios that are considerably less negative than those of vegetative tissue from the same plant. While this may relate to the concurrence of drought and reproduction, it does illustrate that CAM activity may make an important contribution to reproductive carbon sinks.

4. Conclusion

All plants are subjected to a multitude of stresses throughout their life cycle. Depending on the plant species and stress source, the plant will respond in different ways. Sedum is a drought tolerant plant. Its ability to grow with different soil types and under water stress condition was investigated. The main reason for the difference in water loss between treatments was differences in soil types. At the end of growth chamber study, it was found that transpiring ratio at the day and night was almost equal. However, transpiration value can be predicted from the relationship of the square root time and measured values for plant transpiration. Low transpiration values in the day time were related to the photosynthesis characteristic of Sedum with leaf water potential. In the night time where low temperature was observed, the stomata was open and plant was exchanging CO_2 with more transpiration rate compared to the day time. In salinity study, the experiment could confirm that Sedum plants can tolerate salinity stress and can survive with water deficit conditions, which was related to its ability to store water for long time. However, the saline waters remarkably affected the evapotranspiration rate, salts accumulation in the soils and plant biomass production. Water deficit increased with the increase in salinity level. The salinity of the soil significantly increased with higher saline water. The plant growth was not affected by surface or sprinkler irrigation methods. The use of sea water up to certain dilution could be an option for Sedum production in water scarce areas.

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