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Effects of mulching on evapotranspiration, yield and water use efficiency of Swiss chard (*Beta vulgaris* L. var. *flavescens*) irrigated with diluted seawater

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Abstract

Increasing scarcity of fresh water for agriculture in the drylands area is necessitating the use of the marginal quality water, including saline water. However, for sustainable agriculture it is necessary that the use of saline water is combined with suitable crop management practices to reduce salinity effect. This study investigated the effect of gravel mulch (GM) and rice-straw mulch (RM) on the soil salinity, crop evapotranspiration (ET) and fresh and dry weight yield and water use efficiency (WUE) of Swiss chard (*Beta vulgaris* L. var. *flavescens*) grown on Tohaku clay soil and irrigated with diluted seawater (6.86 dS m^{-1}). The experiment was conducted in a greenhouse using a weighing lysimeter system and irrigation was given from below to allow the water table to remain between 50 cm and 80 cm. The ET was determined every 15 minutes by weighing the lysimeter. Soil temperature was monitored at different depths. At the end of the experiment, the electrical conductivity of the soil was measured in four different layers (0-30 cm). The cumulative ET was higher with ‘no mulch’ control (292 mm) than under RM (254.7 mm) and GM (216.6 mm). Mulching generally increased the soil temperature slightly. RM treatment increased fresh matter yield by 76% and GM by 49% over control. Dry matter yield was also the highest under RM followed by that under GM and control. Salt accumulation in the top 25 cm soil layer was higher under control than under mulching and the differences were particularly conspicuous in the top 10 cm soil layer. This contributed to the yield reduction under control as compared to mulching treatments. RM treatment increased WUE by 143 and 10% as compared to control and GM treatment, respectively. Thus, RM is recommended for reducing salinity effect under shallow water table of saline water and improving WUE.

Kew words: Gravel mulch, rice-straw mulch, diluted seawater irrigation, shallow water table, evapotranspiration, water use efficiency.

Introduction

Drought and salinization represent serious threats to the sustainability of irrigated agriculture in arid and semi-arid regions [7]. Given current demographic trends and future growth projections, as much as 60% of the global population may suffer water scarcity by the year 2025 [14]. Because of the growing shortage of water resources of good quality, the water-scarce countries will have to use the available freshwater supplies more efficiently [12] and they will have to rely increasingly on the use of non-conventional water resources to partly alleviate the shortage of water [16, 18].

Direct evaporation from soil is often a major loss of available water because it is not contributing to biomass production. Reducing evaporation can help conserve soil moisture, save irrigation water, and reduce salt accumulation in surface layer of the soil [24]. Application of mulch is known to be effective in reducing soil evaporation [2]. Sun *et al.* [21] reported that organic mulch and tree-shelter treatments increased the survival of tree as compared to no mulching under saline condition. Mulching has also been reported to be effective in reducing leaching of nitrate fertilizer and thus reduce pollution [17].

Saline water was previously considered unusable for irrigation, but research during the past two decades has helped bring into practice its use for irrigation and some large saline water based irrigation schemes have been developed [1, 13]. Saline water can provide an interesting opportunity to meet increasing demand for irrigation water to produce food for rising population without competing with other pressing needs for fresh water such as domestic and industrial use in water scarce regions [6].

Sugar beet is known to be a salinity-tolerant species which can use its tap-root as a sink for accumulating large quantities of absorbed Na [3]. Swiss chard, a kind of beet (*Beta vulgaris* L.), is a highly nutritious crop frequently grown in rotation with other crops [20], particularly to break the disease cycle in mono-cropping systems [22]. It is expected that Swiss chard can also tolerate salinity like sugar beet and can be grown with saline water.

Ghadiri *et al.* [4] have shown that a 1:1 mixture of Caspian Sea and tap water can be used for irrigation without a significant reduction in the growth and yield of barley, when it is applied at the time of ear formation. However, saline water irrigation can lead to salt accumulation in the soil if the proper crop management is not followed. Salt accumulation in soil can be reduced by preventing evaporation on lands with shallow water tables. Only a few studies have been made about the effect of mulching on preventing salt accumulation [23] and information on relative effects of different types of mulches on reducing salt accumulation is lacking. Therefore, this experiment was conducted to assess the effect of two different kinds of mulches on the temperature of and the salt accumulation in the soil and the yield, evapotranspiration (ET), and water use efficiency (WUE) of Swiss chard grown with sub-irrigation with diluted seawater.

Materials and Methods

The experiment was carried out in a greenhouse at the Arid Land Research Center, Tottori University, Japan, using three weighing lysimeters. Each lysimeter was 1.2 m high and had a diameter of 0.798 m (surface area 0.5 m^2). The top 40 cm of lysimeter column was filled with the Tohaku clay soil (sand : silt : clay = 17.8% : 28.3% : 53.9%) to achieve a bulk density of 1.1 g/cm^3, and the rest of column was filled with a sandy soil with a bulk density 1.58 g/cm^3. The ET was estimated by measuring the weight changes of the lysimeter with an electronic balance, with a resolution of 50 g, which corresponds to 0.1 mm depth of water. Detailed description of the lysimeter is given by Inoue and Shimizu [5]. Soil temperature was monitored by 4-eletrode sensors at six depths (7, 17, 27, 47, 67 and 97 cm) in each column. A computer continuously recorded the weight of lysimeter and soil temperature data at 15 min time interval.

Swiss chard (*Beta vulgaris* L. var. *flavescens*) seeds were sown on October 1, 2005 in plastic tray containing potting soil to produce seedlings for the experiment. Fourteen seedlings were transplanted in each lysimeter on November 3, 2005. Just before transplanting, a compound NPK fertilizer (12-12-12) was applied at the rate of 1800 kg ha^{-1}. An irrigation tube, 70 cm in height with a small hole in the bottom, was inserted into the center of each lysimeter and used for sub-irrigation. The plants were irrigated with tap water in the first 20 days after transplanting. From November 23, 2005, they were irrigated with saline water (EC_w of 6.86 dS m^{-1}) prepared by diluting seawater with tap water. The ground water level was kept between 50 and 80 cm below the soil surface.

Three mulching treatments, control, rice-straw mulch (RM) and gravel mulch (GM) were compared. Based on the study of Sharma *et al.* [19], the thickness of mulch was kept 3 cm. During the whole experimental period, which lasted from November 2005 to June 2006 and covered the winter (November to February) and the spring (March to early June) seasons, the Swiss chard was harvested two times. First harvest was done at the end of the winter season, on March 1, 2006, when only the largest four leaves of each plant were cut at their base. Second harvest was done in spring, at the end of the experiment, when all of the above ground material (leaves and stem) were harvested and their fresh and oven-dry weights were determined.

Soil samples were taken from four layers (5, 10, 15 and 25 cm soil depth) at the end of experiment to measure electrical conductivity (1:5 soil extract, $EC_{1:5}$) using a conductivity meter B-173 (Horiba Co.).

Statistical analysis: The statistical analysis software SPSS v11.5 (SPSS Inc, Chicago, IL, USA) was used to analyze data. Means were compared by the *LSD* (least significant difference) at $p < 0.05$ level of significance.

Results and Discussion

Evapotranspiration: Fig. 1 shows the cumulative ET during the winter and spring parts of the total growth period. The ET was higher in spring than in winter under all treatments. This difference can be attributed to low evaporative demand of the atmosphere and smaller growth of the plants in winter than in spring. During winter both the mulching treatments reduced ET more or less equally as compared to control. In contrast, during spring the reduction in ET due to mulching was higher under GM than under RM. The RM gave higher ET compared to GM in spring because the crop grew better under RM and would have transpired more water than under the GM treatment. These results show reduction in ET because of mulching are consistent with the observations of several other workers [11, 15, 25].

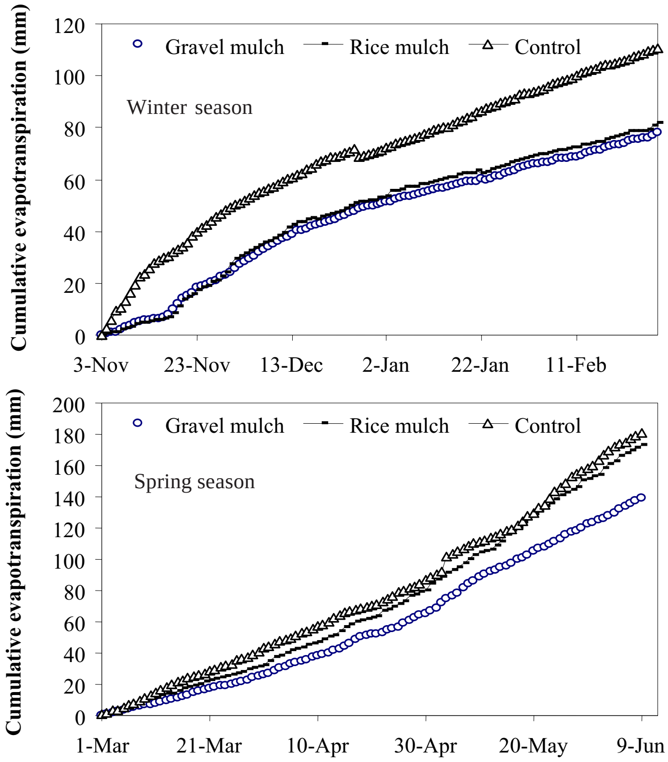

Figure 1. Cumulative evapotranspiration of Swiss chard measured in winter and spring as affected by mulching treatment under sub-drip irrigation with diluted seawater.

Effects of mulching on the hourly change in the cumulative ET during each day on three days in both winter (Feb. 27 to 29) and spring (May 20 to 22) are shown in Fig. 2. There was no irrigation given on these days, hence the hourly change in ET reflected the water balance (Δw) in the lysimeter as the system interacted with the ambient atmosphere. Results showed that for the control treatment, the Δw increased rapidly before 14:00, then the rate of increase slowed down. We attribute this to higher solar radiation before 14:00. For gravel mulch treatment, the Δw showed nearly the same trend as for the control. Under RM, however, the Δw value became negative during early morning on the first two days in spring and during afternoon on all the three days in winter, i.e. the weight of the lysimeter increased. The maximum weight increase for RM ranged from 0.2 to 1.4 mm/day. Since there was no irrigation given and the phenomenon occurred only during early morning

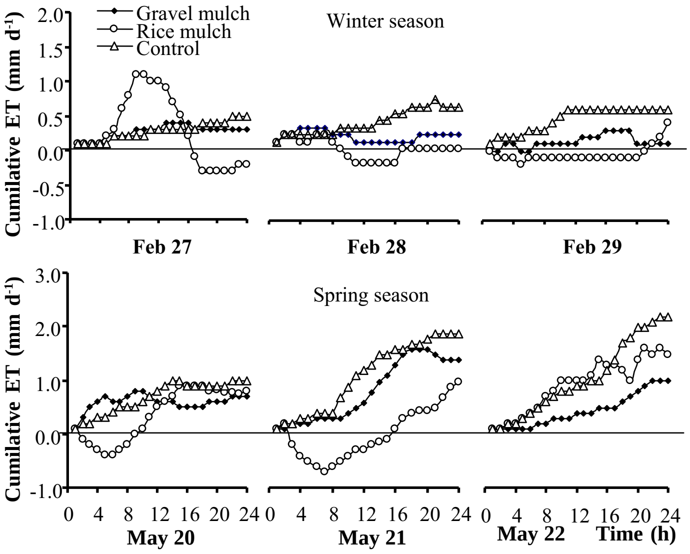

Figure 2. Effects of mulching on hourly change in cumulative ET of Swiss chard during each day on 3 consecutive days in winter and spring seasons.

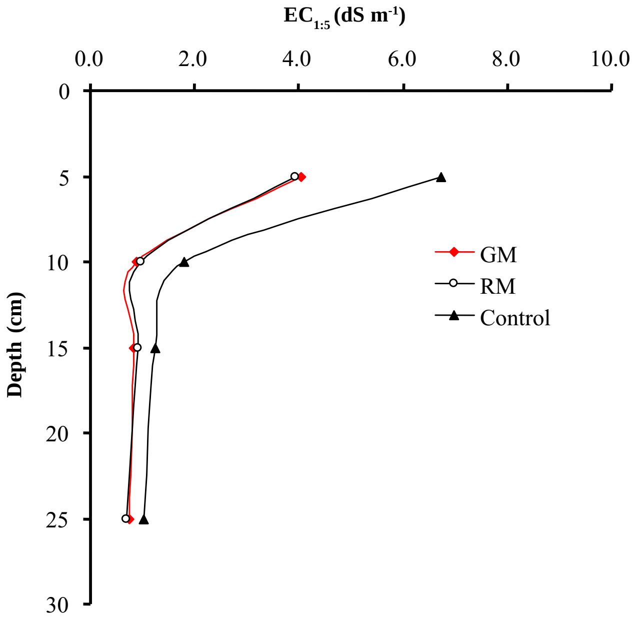

Figure 3. Salt distribution at the end of experiment under different mulching treatments as reflected by electrical conductivity of 1:5 soil extract.

in spring and during afternoon in winter, when humidity is high, we think that this reflects the capability of RM to adsorb water vapor from the air. This was also confirmed by visual observation of the rice straw mulch. As a result, RM not only prevented soil evaporation, but also could "catch" water from the air, which would be of benefit for crop growth in drylands. The ability of straw mulch to adsorb water vapor from the air has also been reported earlier [8, 9].

Electrical conductivity ($EC_{1:5}$): The electrical conductivity ($EC_{1:5}$) of soil at different depths for three treatments at the end of the experiment is shown in Fig. 3. There were significant differences between control and the two mulch treatments and the differences were particularly conspicuous in the top 10 cm soil layer, where most of the roots of the plant are located. This could be attributed to higher evaporation of water from the soil surface under control, which would have allowed greater upward movement of salt from the sub-irrigation with saline water. There were no differences in the $EC_{1:5}$ values between the RM and GM treatments.

Soil temperature: The average soil temperature (Table 1) at every depth was higher under GM and RM than under control but the difference did not generally reach the level of significance. Only at 17 and 47 cm depths the average temperatures during winter were significantly higher under GM than under control. During spring again, significantly higher average temperatures were recorded for 17 cm depth under mulching treatments than under control. Mao [11], Li [10] and Rahman *et al.* [15] also reported increase in soil temperature due to mulching in winter cropping season.

Yield and water use efficiency: The effect of mulching on total ET, fresh and dry matter yield, and WUE of Swiss chard, for winter, spring and the whole crop duration is shown in Table 2. The total seasonal fresh matter yield under RM was 76% higher as compared to control and under GM it was 49% higher than control. The dry matter yield results showed similar trends. This improvement in the yield because of mulching over control can be attributed to the reduction in salinization of the surface layer of soil (Fig. 3) and improved moisture availability to the plants because of lesser ET (Fig. 1).

The relative increases in the yield because of mulching were higher in the spring part of the growing season than in the winter. This can be attributed to higher evaporative demand of the atmosphere in spring, which would have subjected the plants under control to more stress than the mulched plants. As already indicated, the total seasonal ET was highest under control and it was reduced by 26 and 13% by GM and RM treatments, respectively. Thus, GM was more effective in reducing ET as compared to RM. As both GM and RM would have provided nearly the same ground cover to prevent evaporation, the higher ET under RM should have been because of more transpiration under this treatment, which should have improved photosynthesis and ultimately benefited crop growth and yield (Table 2).

Table 1. Average soil temperature at different layers measured during the entire winter and spring seasons of the experimental period.

Depth (cm)	7	17	27	47	67	97
			Winter season (°C)			
Control	8.30a	8.05b	8.61a	8.97b	7.51a	7.23a
GM	9.98a	10.25a	8.82a	9.67a	7.89a	7.82a
RM	9.59a	9.87ab	8.23a	9.54ab	8.03a	7.82a
			Spring season (°C)			
Control	22.80a	19.53b	19.26a	18.03a	18.03a	18.06a
GM	23.18a	23.11a	20.04a	19.74a	18.74a	18.47a
RM	23.14a	23.14a	20.01a	18.92a	18.24a	18.73a

Different letters in a column denote significant differences between treatments at $p < 0.05$.

Table 2. Evapotranspiration (ET), fresh yield, dry yield and water use efficiency (WUE) of Swiss chard as affected by mulching treatment.

Treatment	ET (mm)	Fresh matter yield (g per plant)	Dry matter yield (g per plant)	WUE (kg m^{-3})
Winter season				
Control	110.8	14.8±3.1	1.6±0.9	0.23
GM	77.9	16.6±2.5	1.9±0.5	0.39
RM	81.6	19.2±2.1	2.3±0.9	0.45
Spring season				
Control	181.2	33.6±6.3	9.5±2.5	0.84
GM	138.7	55.5±5.6	16.3±1.8	1.88
RM	173.1	66.1±5.9	21.3±4.1	1.97
Total				
Control	292	48.4±11.3	11.1±3.6	0.61
GM	216.6	72.1±14	18.2±2.9	1.34
RM	254.7	85.3±13	23.6±4.2	1.48

WUE was improved by mulching treatment (Table 2) because of reduced ET and higher yield than under control and the highest value was recorded under RM. WUE increased by 143% under RM treatment over control and by 10% over GM treatment. Although both ET and yield were higher under RM than GM, the relative increase in yield under RM was higher than in GM. Therefore, the WUE was the highest under RM.

Conclusions

Both gravel mulch (GM) and rice-straw mulch (RM) could reduce salt accumulation when diluted seawater irrigation was used for irrigation. Compared with control, the $EC_{1:5}$ of soil under mulches was nearly 38% lesser. The ET was 26% lesser under GM and 13% lesser under RM than under control. On the other hand, the fresh and dry yields were, respectively, 64% and 113% higher under RM and 49% and 64% higher under GM than under control. Therefore, the WUE increased by 143% under RM and 120% under GM as compared with control treatment. Monitoring of hourly change of cumulative ET over three days period, when no irrigation was given, indicated that there was small adsorption of water from the atmosphere by the RM during the relatively cooler hours of the day, and this could be very useful for crop growth in the arid and semi-arid regions. It can be concluded from this study that mulching was a good strategy for getting good yield and water use efficiency for Swiss chard when grown with saline shallow ground water. Compared with gravel mulch, rice-straw mulch showed a measure of superiority, and given the additional advantage of convenience in managing the material used, therefore, rice straw mulch was a better option than gravel mulch.

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