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Monitoring Salt Accumulation Status and Saline Stress of Iceplant Leaves Using Hyperspectral Camera Imagery

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Abstract: Salinization in arid land regions is a major driver of desertification. One of the main causes of salinization is through capillary rise of saline groundwater often as a result of poor land management. According to the Soil Map of the World (FAO/ UNESCO, 1992), total area of ca. 323 Mha is believed to be salt-affected in the world. Halophytes in the iceplant family have potential to reduce the use of fresh-water irrigation, and improve soil health and food security when grown on saline soils as a bioremediation greening vegetable. In the following study, saline stress of the halophytic C3-CAM iceplant species, *Mesembryanthemum crystallinum*, was monitored at various growth stages using a Hyperspectral Camera NH-7 to measure surface reflectance of salt-accumulated leaves and calculate several narrow-band spectral indices. The iceplants received 12 treatments which included three soil water conditions (144.1%, 83.3% and 65.6% on dry basis), each with four salt concentration irrigation regimes (0%, 1%, 2% and 3%). Differences in hyperspectral reflectance imagery among treatments were not apparently obvious. The Plant Senescence Reflectance Index (PSRI), which uses reflectance in 500, 680, 750 nm, to monitor saline stress, was the best narrow-band spectral index for monitoring saline stress. It was also discovered that the relativeness in the reflectance between 680 and 500 nm shows some signal of saline stress index of the plant.

Key Words: Hyperspectral camera imagery, Iceplant, *Mesembryanthemum crystallinum*, Narrow-band spectral index, Saline stress

1. Introduction

Soil salinization is a major driver of desertification, which degrades land and limits agricultural production in arid regions. One of the main causes of this salinization is capillary rise of saline groundwater often as a result of poor land management (*e.g.* Banin and Fish, 1995). According to the Soil Map of the World (FAO/ UNESCO, 1992), global salt-affected land area is calculated to be ca. 323 Mha. Intensified use of halophytes is presumed to be necessary to deal with the limited fresh irrigation water resources due to the increase of recent world-wide desertification (Herppich *et al*., 2008).

Iceplant is a halophyte that is expected to be used for greening vegetable for salt-affected lands. Moreover, it has the potential for use in vegetative bioremediation to desalinize saline soils. Numerous studies on morphological (*e.g.* Barkla *et al*., 2012) or metabolic (*e.g.* Gabara *et al*., 2012) aspects of the saline effects on iceplant leaves have been done. However, there is not a full understanding of the spectral reflectance characteristics of the iceplant leaf in association with the status of salt uptake physiology. The techniques for monitoring salinity are important tools to address yield loss potential when deficit irrigating with poor water quality. In this study, we attempted to monitor the saline stress of iceplant using a Hyperspectral Camera to measure surface reflectance of salt-accumulated leaves.

2. Materials and Methods

In the current study, the saline stress of halophytic C3-CAM iceplant species, *Mesembryanthemum crystallinum* was monitored. The iceplants were planted into 9 cm diameter pots containing garden soil in September, 2012 and were grown. The plants received one of 12 treatments which included three soil water conditions, *i.e.*, Good, Fair and Poor (Soil water content on dry basis of 144.1%, 83.3% and 65.6%, respectively), each with four salt concentration irrigation regimes (0%, 1%, 2%, and 3% NaCl). The treatments were started after an iceplant grew six leaves on it. Salinized irrigation treatments were applied approximately every six days at treatment stages. The experiment had eight stages, with stage one beginning 28 October, 2012 on 0%, 1% and 3% salt concentration regimes for Fair and Poor irrigation soil conditions, and 20 November, 2012 on all regimes for Good irrigation condition and the 2% salt concentration regime for Fair

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Table 1. Treatment stages and schedule for salt concentration irrigation applications at different soil water conditions (cf. Hirokane *et al*., in press).

Soil Water Content $_{dry}$ (Irrigation Condition)	Salt Concentration	2012											2013
		28-Oct	1-Nov	7-Nov	13-Nov	20-Nov	27-Nov	2-Dec	8-Dec Image taken	14-Dec	20-Dec	26-Dec	1-Jan
144% (good)	0%					1	2	3	4	5	6	7	8
	1%					1	2	3	4	5	6	7	8
	2%					1	2	3	4	5	6	7	8
	3%					1	2	3	4	5	6	7	8
83.3% (fair)	0%	1	2	3	4	5	6	7	8				
	1%	1	2	3	4	5	6	7	8				
	2%					1	2	3	4	5	6	7	8
	3%	1	2	3	4	5	6	7	8				
65.6% (poor)	0%	1	2	3	4	5	6	7	8				
	1%	1	2	3	4	5	6	7	8				
	2%					1	2	3	4	5	6	7	8
	3%	1	2	3	4	5	6	7	8				

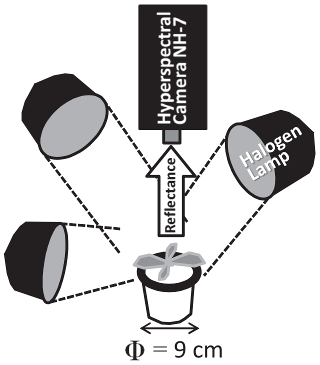

Fig. 1. Experimental setup of hyperspectral reflectance data acquisition.

and Poor irrigation conditions. Irrigation with salinized treatment was performed at every stage, *i.e.*, every 6 days after the first stage.

The electric conductivity (EC) of the soil, and a young and mature leaf for each sample at every stage by EC meter, DEC-2, Atago Co. Ltd. Soil EC and leaf EC were measured after diluted with 5 times and 20 times of water, respectively.

Hyperspectral reflectance images were taken from iceplant leaf surfaces 2 days after the fourth stages on all salt concentration regimes for Good irrigation soil water condition, and the 2% salt concentration regimes for Fair and Poor irrigation conditions. Images were taken again 2 days after the eighth stage on 0%, 1% and 3% salt concentration regimes for Fair and Poor irrigation conditions (**Table 1**).

A Hyperspectral Camera NH-7 (1280 × 1024 pixel resolution, 400 - 1000 nm range, 5 nm interval, Eba Japan Co., Ltd.) was used to predict the status of the halophytes by monitoring the leaves. Hyperspectral reflectance imagery measurements were collected on all iceplants used in the study. The hyperspectral reflectance data were measured on the illuminated iceplant leaf samples using 3 halogen lamp light sources (Caster, 250W CHP-250) (**Fig. 1**). Reflectance values were calculated using the white reference (ColorChecker White balance, X-Rite Inc.). The spectral reflectance data were normalized using the following equation to remove wavelength-independent magnitude differences between spectra and enhance wavelength-dependent effects (cf. Zhang *et al*., 2005).

$$R(\lambda) = R_o(\lambda) / R_T \quad (1)$$

Where, λ is wavelength, $R(\lambda)$ is normalized reflectance in λ, $R_o(\lambda)$ is original reflectance in λ, R_T is the total sum of $R_o(\lambda)$ over the defined spectral region (*i.e.*, 400 - 1000 nm). Since each hyperspectral image consists of 121 bands, we calculated the following narrow-band spectral indices: Normalized Difference Vegetation Index (NDVI) (Rouse *et al*., 1973), Photochemical Reflectance Index (PRI) (Gamon *et al*., 1997), Normalized Difference Index between 490 - 620 nm ($NDI_{(490, 620)}$) (Shimada *et al*., 2012), RENDVI (Gitelson *et al*., 1996), Plant Senescence Reflectance Index (PSRI) (Merzlyak *et al*., 1999), and Water Band Index (WBI) (Penuelas *et al*., 1997) to examine the iceplant saline stress indicator. Each narrow-band index can be expressed as follows:

$$NDVI = (R_{865} - R_{670}) / (R_{865} + R_{670}) \quad (2)$$
$$PRI = (R_{530} - R_{570}) / (R_{530} + R_{570}) \quad (3)$$
$$NDI_{(490, 620)} = (R_{490} - R_{620}) / (R_{490} + R_{620}) \quad (4)$$
$$RENDVI = (R_{750} - R_{700}) / (R_{750} + R_{700}) \quad (5)$$
$$PSRI = (R_{680} - R_{500}) / R_{750} \quad (6)$$
$$WBI = R_{905} / R_{973} \quad (7)$$

Where, R_n is the normalized reflectance in the wavelength of n nm. In this paper, the reflectance data at the central part of the leaves were used for analysis. Regression analysis was conducted between every narrow-band spectral index and the corresponding soil and leaf EC.

3. Results and Discussion

Figures 2 and **3** show images (R:G:B = R_{845}:R_{695}:R_{595}) taken by the Hyperspectral Camera NH-7 on December 10 (cf. Table 1). No obvious differences are visible in iceplant leaf growth under different salinized irrigation regimes at Good irrigation condition (*i.e.*, pF 1.8) (Fig. 2). Good irrigation condition at stage four, the soil EC measurements were 1.6, 11.6, 17.3 and 31.1 mS cm^{-1}, mature leaf EC measurements were 0.09, 0.14, 0.21 and 0.50 mS cm^{-1}, and young leaf EC measurements were 0.22, 0.44, 0.38, 0.29 mS cm^{-1} for 0%, 1%, 2% and 3% salt concentration irrigation regimes, respectively. The prevention of the iceplant growth can be observed from the images by water stress (Fair and Poor irrigation) under the 2% salt concentration irrigated treatment (Fig. 3). The measured soil, mature leaf, and young leaf EC values in the Fair and Poor irrigation with 2% salt concentration conditions were 12.0 - 13.1, 1.22 - 1.62, 0.93-1.37 mS cm^{-1}, respectively.

Figure 4 shows the normalized reflectance curve for Good irrigation condition samples. According to the result,

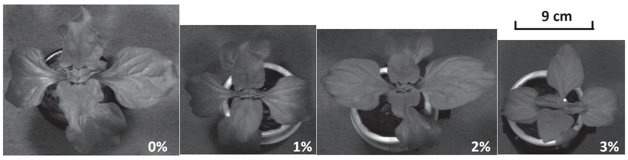

Fig. 2. Images of the iceplants in different salt concentration irrigated treatments (0%, 1%, 2%, 3%) under Good irrigation conditions at stage 4. NH-7 used.

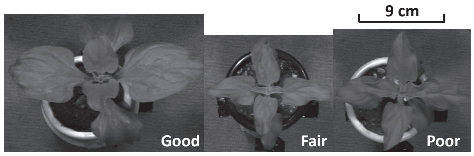

Fig. 3. Images of the iceplants in different soil water conditions (Good, Fair, Poor) under 2% salt concentration water irrigated treatment at stage 4. NH-7 used.

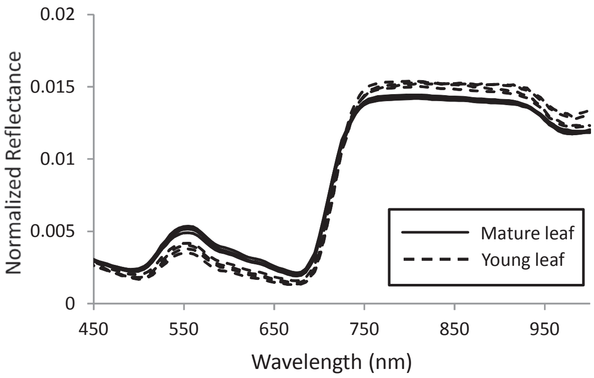

Fig. 4. Normalized reflectance curves for stage four mature and young iceplant leaves grown in Good irrigation soil water condition and four different salinized irrigation regimes.

differences in the normalized reflectance between near infrared (NIR: *ca*. 750 - 900 nm) and red (*ca*. 660 - 670 nm) regions was greater on young leaf than mature leaf, while difference between green (*ca*. 540 - 600 nm) and red regions was greater on mature leaf. This result indicates that, at this stage and soil water condition, differences in reflectance are more obvious between young and mature leaves than among different iceplant saline stress statuses.

Figure 5 shows images of all the calculated narrow-band spectral indices of iceplants under Good irrigation condition at stage four. The leaf veins had relatively lower values from NDVI, PRI, $NDI_{(490, 690)}$ and RENDVI, while relatively higher values were observed from PSRI and WBI.

Figure 6 shows the difference of narrow-band spectral indices in relation to the difference in salt concentration. As saline stress increases, NDVI, RENDVI and WBI tend to decrease, while the opposite trend can be seen for PRI and PSRI. Using the mature leaf reflectance and EC data, and the soil EC data, the strongest correlation was found between PSRI and soil EC, *i.e*., r = 0.88 (**Fig. 7 (A)**).

Other strong correlations (| r | > 0.6) were found between PRI-$NDI_{(490,620)}$ (0.83), PSRI-leaf EC (0.70), RENVID-

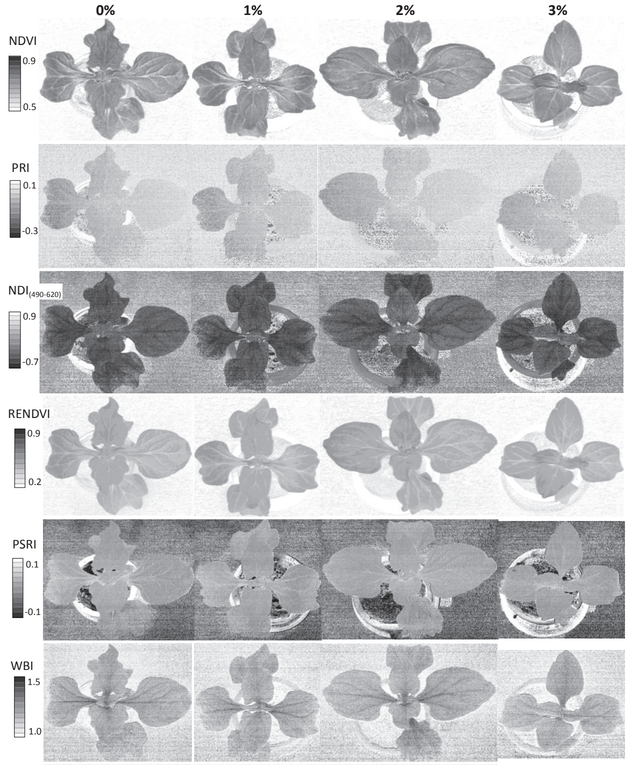

Fig. 5. Images of narrow-band spectral indices (NDVI, PRI, $NDI_{(490, 690)}$, RENDVI, PSRI, WBI) for each salt concentration (0%, 1%, 2%, 3%) under Good irrigation condition at stage 4.

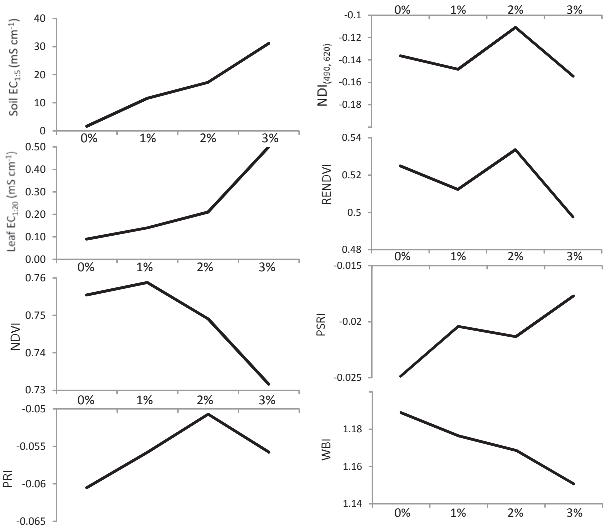

Fig. 6. Difference of narrow band spectral indices (NDVI, PRI, $NDI_{(490, 620)}$, RENVID, PSRI, WBI) with soil and leaf EC in the degree of irrigated salt concentration 0%, 1%, 2% and 3%.

$NDI_{(490,620)}$ (0.68), soil EC-leaf EC (0.66), RENDVI-WBI (0.66) and PRI-soil EC (0.61). These results suggest that PSRI is the best narrow-band spectral index for monitoring soil EC and the saline stress status of iceplant. These results also indicate that spectral reflectance information from leaf surface reflects more sensitively on soil salinity than on leaf salinity.

Since PSRI uses the reflectance values 500, 680, and 750 nm (eq (6)), we checked each part (R_{500}, R_{680}, R_{750}, R_{680} - R_{500}, R_{680}/R_{750} and R_{500}/R_{750}) of the index that contributes the most

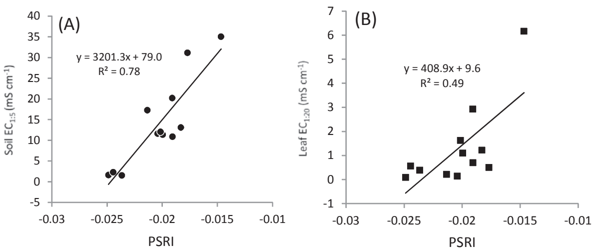

Fig. 7. Correlation of (A) PSRI–soil $EC_{1:5}$ and (B) PSRI-leaf $EC_{1:20}$.

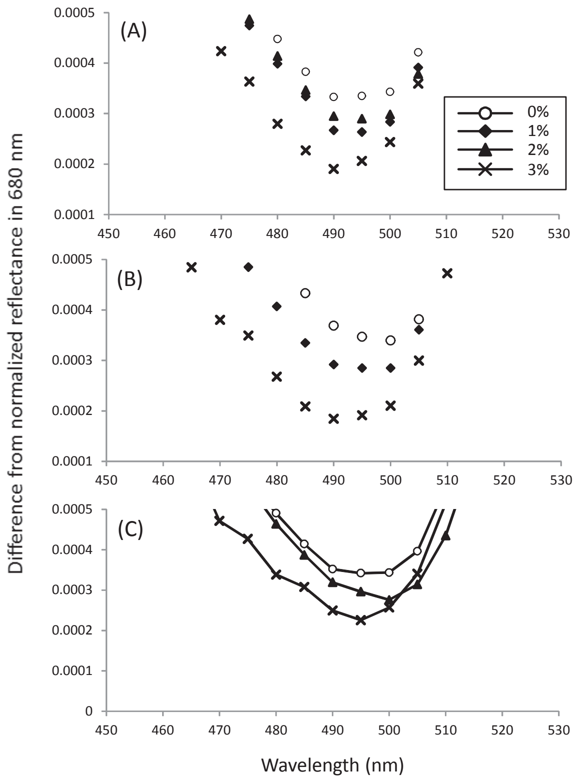

Fig. 8. Difference values of normalized reflectance for iceplant between the wavelengths of 680 nm and around 500 nm under different irrigation conditions, (A) Good, (B) Fair and (C) Poor, with various salt concentration patterns.

to the estimation. Results show that the (R_{680} - R_{500}) had the strongest correlation with soil EC (r = 0.92), which was higher than the correlation between PSRI and soil EC (cf. Fig. 7). This result led the authors to determine the difference values of normalized reflectance between the wavelengths of 680 nm and 500 nm (**Fig. 8**). Results show an obvious decline as the saline stress increased in response to the growing environment. This trend was more obvious when the soil water condition was good (*i.e.*, Good and Fair irrigation conditions).

We can conclude that detection of iceplant saline stress is possible by narrow-band spectral information and that the PSRI and the difference value between normalized reflectance in 680 nm and 500 nm are good indicators for monitoring saline stress.

References

Banin A., Fish A. (1995): Secondary desertification due to salinization of intensively irrigated lands. *The Israeli experience Environmental Monitoring and Assessment*, **37**(1-3): 17-37.

Barkla B.J., Vera-Estrella R., Pantoja O. (2012): Protein profiling of epidermal bladder cells from the halophyte *Mesembryanthemum crystallinum*. *Proteomics*, **12**(18): 2862-2865.

FAO/ UNESCO (1992): *The Digitized Soil Map of the World*.

Gabara B., Kuzniak E., Sklodowska M., Surowka E., Miszalski Z. (2012): Ultrastructural and metabolic modifications at the plant-pathogen interface in *Mesembryanthemum crystallinum* leaves infected by *Botrytis cinerea*. *Environmental and Experimental Botany*, **77**: 33-43.

Gamon J.A., Serrano L., Filella I. (1995): The photochemical reflectance index: An optical indicator of photosynthetic radiation use efficiency across species, functional types and nutrient levels. *Oecologia*, **112**: 492-501.

Gitelson A.A., Merzlyak M.N., Lichtenthaler H.K. (1996): Detection of red edge position and chlorophyll content by reflectance measurements near 700 nm. *J. Plant Physiology*, **148**: 501-508.

Herppich W.B., Huyskens-Keil S., Schreiner M. (2008): Effects of saline irrigation on growth, physiology and quality of *Mesembryanthemum crystallinum* L., a rare vegetable crop. *Journal of Applied Botany and Food Quality*, **82**: 47-54.

Hirokane T., Ooba M., Shimada S., Toyoda H. (2014): Effect of water stress, salinity stress on the growth of iceplant. *J. Arid Land Studies*, **24**(1) (In Press).

Merzlyak M.N., Gitelson A.A., Chivkunova O.B., Rakitin V.Y. (1999): Non-destructive optical detection of pigment changes during leaf senescence and fruit ripening. *Physiologia Plantarum*, **106**: 135-141.

Penuelas J., Pinol J., Ogaya R., Filella I. (1997): Estimation of plant water concentration by the reflectance water index WI (R900/R970). *Int. J. Remote Sensing*, **18**: 2869-2875.

Rouse J.W., Haas R.H., Schell J.A., Deering D.W. (1973): Monitoring vegetation systems in the Great Plains with ERTS. *Proceedings of 3rd ERTS-1 Symposium*. Washington, DC, December 10-14, NASA, SP-351, 1, pp: 309-317.

Shimada S., Funatsuka E., Ooba M., Takyu M., Fujikawa T., Toyoda H. (2012): Developing the monitoring method for plant water stress using spectral reflectance measurement. *Journal of Arid Land Studies*, **22**(1): 251-254.

Zhang J.K., Rivard B., Sanchez-Azofeifa A. (2005): Spectral unmixing of normalized reflectance data for the deconvolution of lichen and rock mixtures. *Remote Sens. Environ.*, **95**(1): 57-66.