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Spectral indices for the detection of salinity effects in melon plants

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ABSTRACT: Water scarcity and soil salinization affect large semiarid agricultural areas throughout the world. The maintenance of agricultural productivity implies better agricultural practices and a careful selection of resistant crops. A proper monitoring of the physiological status of plants can lead to better knowledge of plant nutritional requirements. Visible and near-infrared (VNIR) radiometry provides a non-destructive and quantitative method to monitor vegetation status by quantifying chemical properties using spectroscopic techniques. In this study, the capability of VNIR spectral measurements to detect salinity effects on melon (*Cucumis melo* L.) plants was tested. Melon plants were cultivated under multiple soil salinity conditions (electrical conductivity, $(EC)_{1:5}$: 0.5, 1.0 and 2.5 dS m^{-1}). Spectral data of leaves were transformed into vegetation indices indicative of the physiological status of the plants. The results showed differences for N ($p < 0.05$), K and Na content ($p < 0.01$) due to salinity suggesting different degrees of salt stress on the plants. Specific leaf area increased with salinity levels ($p < 0.001$). The capabilities of VNIR radiometry to assess the influence of soil salinity on melon physiology using a non-destructive method were demonstrated. A normalized difference vegetation index ($NDVI_{750-705}$), and the ratio between water index (WI) and normalized difference vegetation index ($WI/NDVI_{750-705}$) showed significant relationships ($p < 0.01$) with the salinity. Therefore, this method could be used for *in-situ* early detection of salinity stress effects.
Keywords: VNIR radiometry, *Cucumis melo* L., saline soil

Introduction

Mediterranean ecosystems are characterized by the aridity of the climate and the persistent scarcity of water resources. Agriculture with high water requirements under increased occurrence of extreme drought events have forced irrigation with poor quality water from both irrigation drainage and groundwater sources, causing processes of degradation, reduction of the production capacity, and soil salinization (Pérez-Sirvent et al., 2003; Ashraf et al., 2007).

Salt stress is the most widespread abiotic stress that limits plant growth, physiology and productivity mainly affecting the ionic balance and plant water relations (Dogan et al., 2010). Salinity disturbs the mineral-nutrient relations in plants through their effects on nutrient availability, transport, and partitioning (Botía et al., 1998; Kaya et al., 2007; Cochard et al., 2010). Chlorophyll biosynthesis and nitrogen metabolism are also found to be affected due to high salinity (Ashraf, 2004). However, the effects of soil salinity depend on the plants' level of tolerance and the salinity level, since there are differences between species in terms of ability to maintain nutrient concentrations for growth under salt stress (Munns et al., 2002; Melgar et al., 2008).

Leaf traits play an important role in plant response to stress conditions (Hernández et. al, 2010, 2011; Tedeschi et al., 2011). Leaf pigment content is related to the physiological function of leaves, and provides valuable information about plant status. It has been suggested as one of the important indicators of salt tolerance in crop plants (Kaya et al., 2007). Traditional methods of pigment analysis through extraction with organic solvents and spectrophotometric determination in the obtained solution require destruction of the leaves measured. Recently, alternative optical methods have been developed for determining leaf pigment.

Spectral reflectance analysis is a fast nondestructive method, and allows for measurement of changes in the response over time for a single leaf. A number of vegetation indices have been developed using leaf reflectance spectrum. Some of these indices are first derivatives from the spectrum, such as reflectance simple ratio vegetation index (SR), normalized difference vegetation index (NDVI), stress index (SI), and water index (WI) (Gao and Li, 2012).

This study aimed to assess the visible and near-infrared (VNIR) radiometry to determine the influence of soil salinity stress on melon (*Cucumis melo* L.). Reflectance indices and leaf parameters in response to soil salinity were compared for early the detection of possible nutritional effects on the plants.

Materials and Methods

Plants were grown in an experimental field at Carrizales, located in the municipality of Elche (Alicante) (38°9′ N, 0°43′ W), in the southeast of Spain from early Apr to end of Jul 2011. Carrizales is an agricultural area situated in the middle of two RAMSAR wetland sites ("Las Salinas de Santa Pola" Natural Park of "El Hondo" of Crevillente-Elche Natural Park) (Figure 1). The climate is arid to semiarid Mediterranean with an average annual rainfall of 250-300 mm and a thermal regime of warm temperatures with an average annual temperature of 19 °C. All through the experiment, rainfall was

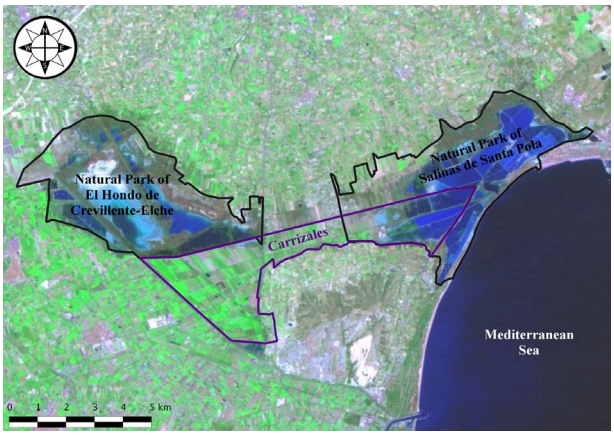

Figure 1 – Location map of *Carrizales* study area and surrounding Natural Parks.

36 mm and evapotranspiration obtained in accordance with the Penman-Monteith formula (Monteith, 1973) was 608 mm.

The soils in this experiment are classified as Calcaric Fluvisols (IUSS, 2006). The main characteristics of the soils (Table 1) were: texture based on the Bouyoucos method (Gee and Bauder, 1986); pH and electrical conductivity (EC) in deionized water 1:2.5 and 1:5 w/v, respectively; N-Kjeldahl (Bremmer and Mulvaney, 1982); exchangeable phosphorus (P) by the Burriel-Hernando method (Díez, 1982); exchangeable Ca, Mg, K and Na in ammonium acetate extraction 1N and Fe, Mn, Cu and Zn using Lindsay and Norwell extraction (Lindsay and Norwell, 1978), and measured by AAS-ES. Available boron (B) was measured in water extraction. These soils have a clay loam-texture, moderately basic pH and large content of carbonates. Soil nutrient composition was similar to a previous study by Pérez-Sirvent et al. (2003).

Irrigation water came from a drainage water channel, which is the source for the traditional irrigation system. The experimental plots were equally flood irrigated to field capacity (every 15 days). Water quality was analyzed five times throughout the experiment and parameters were determined in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA, 1989). Table 2 shows the main characteristics of the irrigation water (pH about 7.7 and high EC).

The plots in the study were selected on the basis of initial soil salinity (S1 = 0.5 ± 0.1, S2 = 1.0 ± 0.1 and S3 = 2.5 ± 0.1 dS m^{-1}). Each soil salinity level included two replicated plots. Melon plants (cultivar "piel de sapo") were grown in these field conditions and they were planted every 0.5 m, and the separation between crop lines was 1.5 m. Standard organic fertilization (20 t ha^{-1}) and inorganic fertilization (90 kg ha^{-1} N, 100 kg ha^{-1} P and 180 kg ha^{-1} K) for melon were applied at the beginning of the experiment.

Table 1 – Soil characteristics of the experimental site under differing salinity conditions (S1=0.5, S2=1.0 and S3=2.5 dS m–1). Data are the means ± standard deviation calculated on three replication basis.

Parameters	Units (d.m.)	S1	S2	S3
pH		8.5 ± 0.3	8.5 ± 0.4	7.9 ± 0.1
EC	dS m^{-1}	0.5 ± 0.1	1.0 ± 0.1	2.5 ± 0.1
CO_3^{2-}	g kg^{-1}	511 ± 36	435 ± 46	474 ± 23
N	g kg^{-1}	1.3 ± 0.1	1.5 ± 0.2	1.7 ± 0.3
P	mg kg^{-1}	59.1 ± 7.0	53.5 ± 8.0	39.0 ± 5.1
Ca	g kg^{-1}	3.8 ± 0.3	4.3 ± 0.2	4.5 ± 1.1
Mg	g kg^{-1}	0.9 ± 0.1	1.2 ± 0.1	1.2 ± 0.1
Na	g kg^{-1}	0.3 ± 0.1	0.8 ± 0.1	1.3 ± 0.2
K	g kg^{-1}	0.5 ± 0.1	0.6 ± 0.1	0.6 ± 0.1
Fe	mg kg^{-1}	1.2 ± 0.3	1.3 ± 0.2	1.1 ± 0.1
Cu	mg kg^{-1}	1.1 ± 0.1	1.3 ± 0.1	1.8 ± 0.1
Mn	mg kg^{-1}	2.1 ± 0.6	3.0 ± 0.3	2.1 ± 1.0
Zn	mg kg^{-1}	1.4 ± 0.4	1.2 ± 0.3	1.3 ± 0.6
B	mg kg^{-1}	2.0 ± 1.1	1.2 ± 0.3	1.5 ± 0.1

Table 2 – Irrigation water characteristics: average, standard deviation, maximum and minimum.

Parameters	Units	Average	Standard deviation	Maximum	Minimum
pH		7.7	0.1	7.9	7.6
EC	dS m^{-1}	4.1	0.9	5.3	2.4
HCO_3	mg L^{-1}	526.8	18.1	559.5	506.1
NO_3^-	mg L^{-1}	17.6	8.4	30.7	10.0
P	mg L^{-1}	5.4	0.7	6.4	4.6
NH_4^+	mg L^{-1}	0.7	0.1	0.9	0.5
Ca	mg L^{-1}	189.9	10.5	206.0	179.9
Mg	mg L^{-1}	146.4	32.8	176.9	85.0
Na	mg L^{-1}	825.0	77.1	930.8	720.9
K	mg L^{-1}	12.4	0.9	14.2	11.6
Cl	mg L^{-1}	1318.7	246.1	1645.4	1032.4
B	mg L^{-1}	0.9	0.2	1.2	0.4

Twenty randomly selected plants per plot were chosen at the flowering stage (60 days after transplanting). Two fully mature leaves were taken from each plant for the measurements (40 leaves per plot). The collected leaves were immediately enclosed in plastic bags with wet filter paper and transported to the laboratory for further analyses. In the laboratory, leaf blades and petioles were separated. Five leaves were selected for spectral and pigment measurements from each experimental plot.

A FieldSpec HandHeld spectroradiometer (ASD Inc., Boulder CO, USA) was used to gather spectral data from melon leaf blades (Figure 2). The device records spectral reflectance measurements in the visible and near infrared (325 to 1075 nm). Reflectance measure-

ments were obtained after calibrating the device with a 99 % reflectance white reference panel (Labsphere, North Sutton NH, USA). A High Intensity Contact Probe was employed to minimize measurement errors associated with stray light. This accessory has a halogen bulb and a fiber optic cable connected to the spectroradiometer. The contact probe is placed on the sample that is illuminated and the reflectance radiation is conducted by the fiber optic to the spectroradiometer.

Melon leaf blades were placed over a stack of black cardboards with reflectance near to zero in order to avoid interaction of the background materials. The contact probe was placed at five points on each melon leaf (Figure 2). Spectral measurements were made at each of the five measured points, and then the five spectra were used to obtain an average spectrum per leaf. Due to some noise at the ends of the recorded spectra, only the data gathered between the 375 nm and 1025 nm were used. Melon leaf reflectance spectra were employed to compute selected spectral indices (Table 3).

Pigment contents were determined in 80 % acetone extract. Total chlorophyll (Total Chl) as well as chlorophyll *a* (Chl-*a*), chlorophyll *b* (Chl-*b*), and carotenoid (Car) concentrations were calculated according to Lichtenthaler (1987). The Car/Chl-*a* ratio was also determined.

Specific leaf area (SLA; leaf area per leaf biomass) was calculated as described by Jones (1971). Previously, leaf area had been measured using image analysis software. Nutrients were analyzed in leaf samples that were pre-heated in an oven at 65 °C for at least 48 h to constant weight (dry matter, d.m.) and the moisture content determined (%). Leaves were grounded and nitrogen was determined using the Kjeldahl method (Bremmer, 1965). After that, leaf samples were mineralized by dry ashing at 450 ºC for five hours and redissolved in HCl 1:1. After that, K and Na were determined by inductively coupled plasma mass spectrometry (ICP-MS; VG PQ Excell, Thermo Elemental, Winsford, UK).

Statistical analysis was carried out using the SPSS v.20 (IBM Corp., Armonk, NY, USA) software. Normal distribution of the variables was assessed by the Kolmogorov-Smirnov test. Data were subjected to one-way

Table 3 – Spectral indices selected for the assessment of plant status.

Indices	Formulation	References
$NDVI_{750\text{-}705}$	$NDVI = \frac{\rho_{750\ nm} - \rho_{705\ nm}}{\rho_{750\ nm} + \rho_{705\ nm}}$	Gitelson and Merzlyak, 1998
$NDVI_{800\text{-}680}$	$NDVI = \frac{\rho_{800\ nm} - \rho_{680\ nm}}{\rho_{800\ nm} + \rho_{680\ nm}}$	Peñuelas et al., 1997b
CRI_{550}	$CRI_{550} = (\rho_{510\ nm})^{-1} - (\rho_{550\ nm})^{-1}$	Gitelson et al., 2002
SIPI	$SIPI = \frac{\rho_{800\ nm} - \rho_{445\ nm}}{\rho_{800\ nm} + \rho_{445\ nm}}$	Peñuelas et al., 1995
WI	$WI = \frac{\rho_{900\ nm}}{\rho_{970\ nm}}$	Peñuelas et al., 1997b
WI/NDVI	$WI_{corrected} = \frac{WI}{NDVI}$	Peñuelas et al., 1997b

NDVI: Normalized Difference Vegetation Index; CRI: Carotenoid Reflectance Index; SIPI: Structure Intensive Pigment Index; WI: Water Index; ρ: Reflectance.

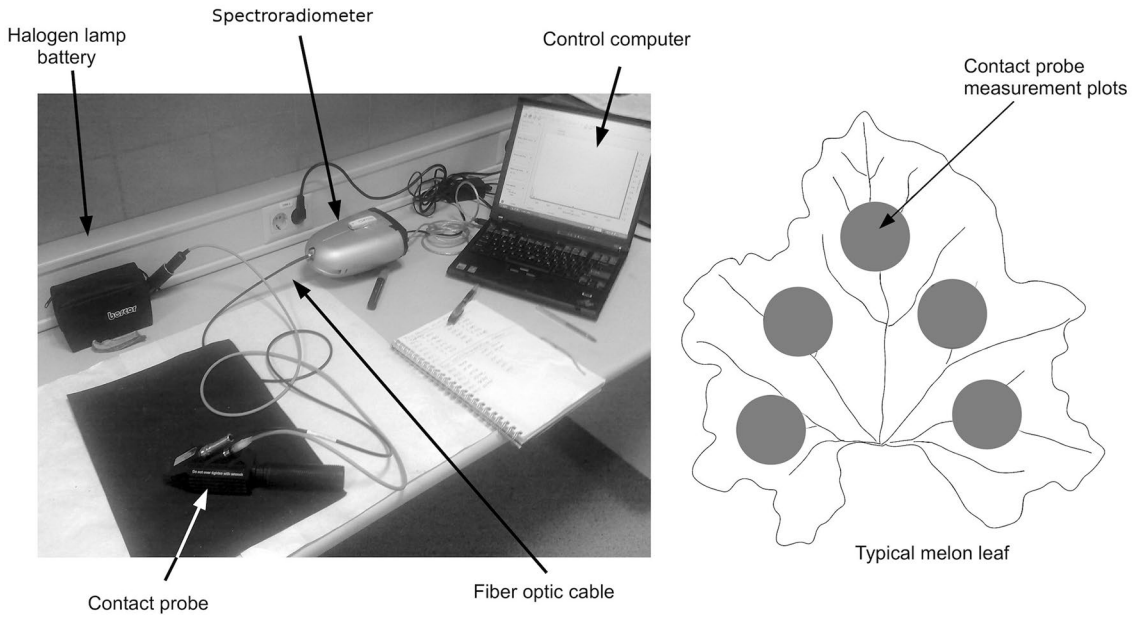

Figure 2 – Melon leaves spectral measurement system.

analysis of variance (ANOVA) test to find the differences in the parameters analyzed and spectral indices due to soil salinity levels. Means were compared using Duncan's Multiple Range test ($p < 0.05$). Relationships between spectral indices and the parameters measured in the leaf blades were calculated using Pearson Correlation Coefficients.

Results and Discussion

The spectra obtained from melon leaves showed changes when salinity treatments were applied, although the plants did not manifest visual symptoms (Figure 3). An increment in the soil salinity generally tends to induce a decrease in leaf reflectance in the near infrared spectral region (Leone et al., 2007; Peñuelas et al., 1997b), but an increase in near infrared reflectance with salinity was observed in this study. Previous studies reported the same pattern found in the near infrared reflectance when salt-tolerant species were irrigated with moderately saline water (Poss et al., 2006, Tilley et al., 2007). Similarly, Zhang et al. (2011) observed a rise in near infrared reflectance for salt-tolerant species growing on moderately saline soils in a wetland environment.

Higher near infrared reflectance values are associated with proper development of the plants (Jensen, 1983). The general pattern of near infrared reflectance reduction results was adequate for describing the effect of salt stress on salt-sensitive species, but not good enough for salt-tolerant species that grow better on moderately saline soils than on non-saline and highly saline soils (Läuchli, 2002; Zhang et al., 2011). Another spectral change associated with higher salinity conditions that was observed was the narrowing of the red absorption band and a shift of the red edge to shorter wavelengths (Horler et al., 1983; Peñuelas et al., 1994).

The salinity effects on the spectral indices were different depending on the index selected (Table 4). Differences ($p < 0.001$) were obtained for the $NDVI_{750-705}$, values decreasing as soil salinity increased; but differences found for the $NDVI_{800-680}$ were insignificant. Spectral index values were much higher for the $NDVI_{800-680}$ (about 0.7) than for the $NDVI_{750-705}$ (about 0.4), suggesting that the $NDVI_{800-680}$ had a tendency to saturate. $NDVI_{800-680}$ employs a wider range of spectral bands far from the red edge position. The employment of the $NDVI_{800-680}$ is well justified because it is highly correlated with the NDVI as calculated from broadband satellite sensors (Peñuelas et al., 1997a). NDVI spectral indices, from broadband satellite sensors, play a very important role in monitoring large areas, but with less spectral resolution than field radiometers or hyperspectral remote sensors. The $NDVI_{750-705}$ exploits the sensitivity of the red edge. Leaf reflectance at 700 nm is related to chlorophyll concentration and reflectance at 750 nm virtually does not depend on chlorophyll concentration, thus allowing for formulation of the index (Gitelson and Merzlyak, 1998).

The water related indices used in this study provided insightful information. The $WI/NDVI_{750-705}$ ratio showed changes in soil salinity levels (Table 4). Differences ($p < 0.001$) in this ratio were observed values decreasing as soil salinity increased, and may therefore become a useful tool in the evaluation of the effects of salinity.

The leaf blade analyses supplied a physiological basis to explain the behavior of spectral indices. Nitro-

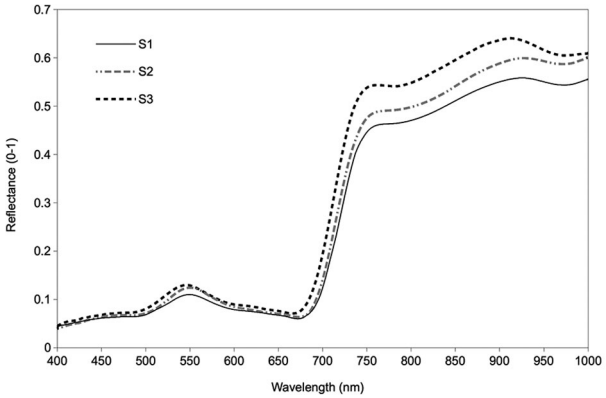

Figure 3 – Leaf spectra of melon plants grown at three different soil salinity levels (S1 = 0.5 dS m^{-1}; S2 = 1 dS m^{-1}; S3 = 2.5 dS m^{-1}).

Table 4 – Descriptive statistics (mean ± s.d) and ANOVA results for spectral indices of melon leaves under different soil salinity conditions (S1=0.5, S2=1.0 and S3=2.5 dS m^{-1}). Duncan's test on homogeneous subgroups are denoted with letters.

Spectral indices	S1	S2	S3	Sig.
$NDVI_{750-705}$	0.469 ± 0.022 a	0.443 ± 0.029 a	0.406 ± 0.021 b	***
$NDVI_{800-680}$	0.754 ± 0.032 a	0.779 ± 0.017 a	0.757 ± 0.030 a	ns
CRI_{550}	3.981 ± 0.941 a	4.802 ± 0.698 a	3.925 ± 0.774 a	*
SIPI	0.762 ± 0.028 b	0.802 ± 0.023 a	0.790 ± 0.012 a	**
WI	1.020 ± 0.008 a	1.029 ± 0.024 a	1.032 ± 0.020 a	ns
$WI / NDVI_{750-705}$	0.460 ± 0.023 a	0.431 ± 0.038 a	0.394 ± 0.026 b	***
$WI / NDVI_{800-680}$	0.740 ± 0.035 a	0.758 ± 0.019 a	0.734 ± 0.041 a	ns

Significance levels: [ns] not significant; [*] < 0.05; [**] < 0.01; [***] < 0.001. NDVI: Normalized Difference Vegetation Index; CRI: Carotenoid Reflectance Index; SIPI: Structure Intensive Pigment Index; WI: Water Index.

gen content decreased ($p < 0.05$) in leaves in response to soil salinity (Table 5). Salt stress affected N nutrition in plants and in this sense, Carvajal et al. (1998) suggested that once the older leaves start to die due to long-term exposure to salt, melon plants can no longer support continued growth. A positive correlation between $NDVI_{750-705}$ and N ($r = 0.742$, $p < 0.01$) was found. The salt stress effect on N nutrition was endorsed by the leaf spectral measurements. N-limited leaves are proper to a red-edge shift to shorter wavelengths (Peñuelas et al., 1994). The red-edge position of high salinity melon plant was clearly shifted to shorter wavelengths.

Soil salinity favored the increment of K and Na ($p < 0.01$) and SLA ($p < 0.001$) in leaves. Salt-tolerant cultivars have a mechanism to select high K contents under salt stress, since maintenance of adequate levels of K is essential for plant survival in saline habitats (Grattan and Grieve, 1999). In this sense, K is related to osmotic adjustment in many species because it is one of the primary osmotic solutes (Iannucci et al., 2002). Furthermore, K is also associated with stomatal regulation, which is a principal mechanism that controls water balance in plants (Tuna et al., 2010).

Specific leaf area (SLA) increased from 150.0 to 229.9 $cm^2\ g^{-1}$ in response to salinity, which indicates the formation of thinner leaves and a higher area per unit of dry weight. Tedeschi et al. (2011) observed similar results in SLA with salinity treatment on the melon cultivar 'Tendral'. These results suggest a reduction in the activity of the leaves under higher saline conditions.

Differences ($p < 0.05$) were obtained for Chl-a and total chlorophylls, values decreasing when soil salinity content increases, but no differences in the Chl-*b* content were found. Previous studies also reported that Chl-*b* was less sensitive to salt stress than Chl-*a* (Naumann et al., 2008; Qin et al., 2010). However, no correlation was found between chlorophylls and the NDVI indices used in this work thus indicating that levels of chlorophyll were not the only parameter affecting NDVI indices.

Although differences ($p < 0.05$) between the carotenoid related indices, CRI_{550} and SIPI ($p < 0.05$ and $p < 0.01$, respectively), were observed for the saline treatments, CRI_{550} and SIPI did not show a clear tendency related to soil salinity (Table 4). Carotenoid content and the Car/Chl-*a* ratio were not affected ($p > 0.05$) by soil salinity in field conditions (Table 5). Similar results were observed for two co-occurring shrubs by Zinnert et al. (2012). The Car/Chl-*a* ratio generally increases in senescing and unhealthy plant conditions (Peñuelas et al., 1995) so salinity tolerance of melon plants may be associated with this response. CRI_{550} exhibits a direct linear correlation with carotenoid content (Gitelson et al., 2002), but the carotenoid content values are quite low and could affect the robustness of the relationship. The relationship between Car/Chl-*a* and SIPI is not linear and SIPI has low sensitivity to the low Car/Chl-*a* values obtained (Peñuelas et al., 1994). Thus, both indices had poor correlation with the carotenoid content (Table 6).

Leaf water content did not show differences between individual salinity levels, although a reduction from S1 to S3 was observed. Also differences were not found for the WI and $WI/NDVI_{800-680}$ in response to higher soil salinity levels. In this sense, Sohan et al. (1999) reported that the plants grown under salt stress have to maintain a favorable water status to ensure water loss is minimal. Thus, plants withstand salt stress through osmotic adjustment by maintaining cell water content (Kramer and Boyer, 1995). This could be the reason for the insightful information provided by the water relation indices used in this study. WI values of the leaves were consistent with previous studies (Peñuelas et al., 1997a) and a light decrease in leaf water content due to salinity was observed. Indeed, correlations between WI and plant water content have more robustness under controlled experimental conditions than in field experiments (Peñuelas et al., 1997a). Greater differences between treatments may be expected but the plants were frequently flood irrigated to avoid water deficit and maximize yield under field conditions.

Table 5 – Descriptive statistics (mean ± s.d) and ANOVA results for nutrients and pigments in leaf blades of melon under different soil salinity conditions (S1=0.5, S2=1.0 and S3=2.5 dS m^{-1}). Duncan's test on homogeneous subgroups are denoted with letters.

Parameters	S1	S2	S3	Sig.
N (g kg^{-1})	39.5 ± 0.4 a	32.9 ± 5.1 ab	30.9 ± 0.8 b	*
K (g kg^{-1})	21.3 ± 1.4 c	26.6 ± 0.5 b	30.0 ± 1.8 a	**
Na (g kg^{-1})	2.7 ± 0.1 b	3.6 ± 0.3 a	3.9 ± 0.1 a	**
Chl a (µg cm^{-2})	1.46 ± 0.18 a	1.29 ± 0.17 b	1.23 ± 0.17 b	*
Chl b (µg cm^{-2})	0.45 ± 0.07 a	0.39 ± 0.07 a	0.43 ± 0.07 a	ns
Total Chl (µg cm^{-2})	1.95 ± 0.24 a	1.72 ± 0.24 b	1.70 ± 0.24 b	*
Car (µg cm^{-2})	0.31 ± 0.06 a	0.25 ± 0.06 a	0.24 ± 0.06 a	ns
Car/Chl a	0.21 ± 0.03 a	0.20 ± 0.03 a	0.19 ± 0.03 a	ns
SLA ($cm^2\ g^{-1}$)	150.0 ± 25.2 c	182.0 ± 24.4 b	229.9 ± 23.4 a	***
Water content (%)	84.4 ± 0.1 a	82.3 ± 2.5 a	82.7 ± 0.4 a	ns

Significance levels: [ns] not significant ; [*] < 0.05 ; [**] < 0.01; [***] < 0.001

Table 6 – Pearson correlations between spectral indices and parameters measured in the leaf blades.

Variables																	
1. $NDVI_{750-705}$	1																
2. $NDVI_{800-680}$	0.274	1															
3. CRI_{550}	0.153	0.918**	1														
4. SIPI	-0.231	0.806**	0.821**	1													
5. WI	-0.655**	-0.221	-0.129	0.248	1												
6. WI / $NDVI_{750-705}$	0.990**	0.275	0.154	-0.248	-0.756**	1											
7. WI / $NDVI_{800-680}$	0.491**	0.917**	0.812**	0.567**	-0.591**	0.534**	1										
8. N	0.742**	0.178	0.016	-0.064	0.399*	0.845**	0.065	1									
9. K	0.549**	-0.040	-0.229	-0.328	0.282	0.607**	-0.346	0.655**	1								
10. Na	-0.121	-0.541**	-0.493**	-0.451*	-0.138	-0.085	-0.639**	-0.054	0.445*	1							
11. Chl a	0.224	-0.283	-0.348	-0.337	0.058	0.183	-0.259	0.141	0.515**	0.465*	1						
12. Chl b	0.048	-0.270	-0.355	-0.193	0.122	0.022	-0.270	-0.096	0.297	0.469*	0.902**	1					
13. Total Chl	0.180	-0.285	-0.357	-0.304	0.077	0.142	-0.267	0.085	0.469*	0.473**	0.993**	0.947**	1				
14. Car	0.343	-0.286	-0.300	-0.361	0.040	0.290	-0.257	0.247	0.611**	0.306	0.734**	0.585**	0.707**	1			
15. Car/Chl a	0.300	-0.188	-0.157	-0.227	0.038	0.253	-0.176	0.285	0.542**	0.073	0.190	0.079	0.163	0.798**	1		
16. SLA	-0.289	0.296	0.207	0.394*	0.106	-0.275	0.203	-0.565**	-0.679**	-0.203	-0.339	-0.177	-0.300	-0.352	-0.220	1	
17. Water content	0.629**	-0.385*	-0.401*	-0.362	0.244	0.706**	-0.318	0.823**	0.505**	0.226	0.378*	0.208	0.343	0.244	-0.076	-0.576	

Significance levels: *$p < 0.05$ (2-tailed); **$p < 0.01$ (2-tailed). NDVI: Normalized Difference Vegetation Index; CRI: Carotenoid Reflectance Index; SIPI: Structure Intensive Pigment Index; WI: Water Index; N: Nitrogen; K: Potassium; Na: Sodium; Chl: Chlorophyll; Car: Carotenoids; SLA: Specific Leaf Area.

Conclusions

An early knowledge base to apply radiometric techniques to field diagnosis could be used for the early detection of salinity effects in plants, before they manifested visual damage and also irreversible injury. $NDVI_{750-705}$ and $WI/NDVI_{750-705}$ indices showed significant relations with the salinity and were the most effective spectral indices for discriminating the effects of soil salinity on melon plants. Thus, $NDVI_{750-705}$ and $WI/NDVI_{750-705}$ may be used for detecting early signs of increasing salinity exposure in crops like the melon, and VNIR radiometry could be an interesting tool to check plant responses whilst avoiding possible damage due to salinity that can lead to irreversible injury.

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