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Remote sensing canopy reflectance of salinized and deficit irrigated alfalfa and wheatgrass

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1 INTRODUCTION

Irrigation water management may address salinity stress indirectly by remote sensing of biomass reductions provided that beforehand knowledge of the relationship between crop salinity levels and crop reflectance is provided. Management options for reducing drainage water volumes on the west side of the San Joaquin Valley of California have the potential to adversely impact crop yields due to a build-up of soil salinity The ability to quickly adopt management practices that address productivity hinge on a timely and accurate assessment of factors that impede crop growth. Current methods for characterizing and monitoring salinity hazards in field situations have included soil electromagnetic induction techniques coupled with geographical information systems that estimate soil salinity patterns of fields between crop rotations (Corwin et al., 1999).

The objectives of this study were: (1) to applying remote sensing techniques to quantify the biomass production of two important forage crops subjected to simultaneous water and salinity stress and (2) to relate narrow-band hyperspectral plant reflectance to plant biophysical parameters including chlorophyll content, canopy leaf area index, and nitrogen and relative water content under these stress conditions.

2 MATERIALS AND METHODS

Six salinity treatments (EC_{iw}= 3, 8, 13, 18, 23, and 28 dSm^{-1}) were used to irrigate "Salado" alfalfa (*Medicago sativa,* L.) and "Jose" tall wheatgrass (*Agropyron elongatum*, L.) crops at differential percentages of baseline evapotranspiration (ET_0). Drought treatments based on ratios of cumulative ET_0 (ETR = 0.5, 0.75, 1.0, and 1.25 times ET_0) superimposed upon the salinity stress were established in a volumetric lysimeter system or VLS (Poss, et al., 2004). Of the 24 VLS units, half were used to grow alfalfa and half to grow tall wheatgrass. From the 24 potential treatment combinations for each species, a grid of treatments was selected to space salinity and water application treatments orthogonally over the desired ranges for each species using half of the combinations.

Plant reflectance of the forage canopy surface was measured at 350 to 2500 nm with a peak-to-peak bandwidth of about 1.5 nm with an ASD FieldSpec Pro spectroradiometer (Analytical Spectral Devices, Inc., Boulder, CO)[1]. Three scans were obtained from each plot under full canopy (81.5 cm wide x 202.5 cm long) on each of the three separate days. The spectroradiometer configured with an 8° foreoptic accessory. A distance of 35 cm was maintained from the foreoptic to the canopy surface at nadir view (perpendicular to canopy surface) and at a 45° angle from the canopy surface for a spot size of approximately 5 cm

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[1] Use of a company or product name is for the convenience of the reader and does not imply endorsement of the product by the USDA to the exclusion of others that may also be suitable.

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diameter (19 cm^2 area). Before each measurement, the instrument was optimized for integration time to allow for maximum allowable signal without saturation and calibrated to a white reference panel (Spectralon; Labsphere, North Sutton, NH) for percent reflectance through an automated optimization and white reflectance panel routine (RS^3, Analytical Spectral Devices, Inc). Pigment analysis used the method reported by Chappelle and Kim (1992). Leaf area index was measured indirectly with estimates from an LI-COR 2000 leaf canopy analyzer.

3 RESULTS AND DISCUSSION

Canopy reflectance was greater for alfalfa than for wheatgrass in the visible and near-infrared (NIR) portion of the spectrum. At longer wavelengths (> 1400 nm), the difference between the crops absolute reflectance was less obvious. The impact of drought stress and salinity stress appeared to be similar for both crops. The percentage of spectral reflectance of predominately salinity stressed forages was reduced to a greater degree in the visible and NIR than were primarily drought-stressed forages deficit irrigated with $8dSm^{-1}$ water at a rate of half the control volume of irrigation water (Figure 1).

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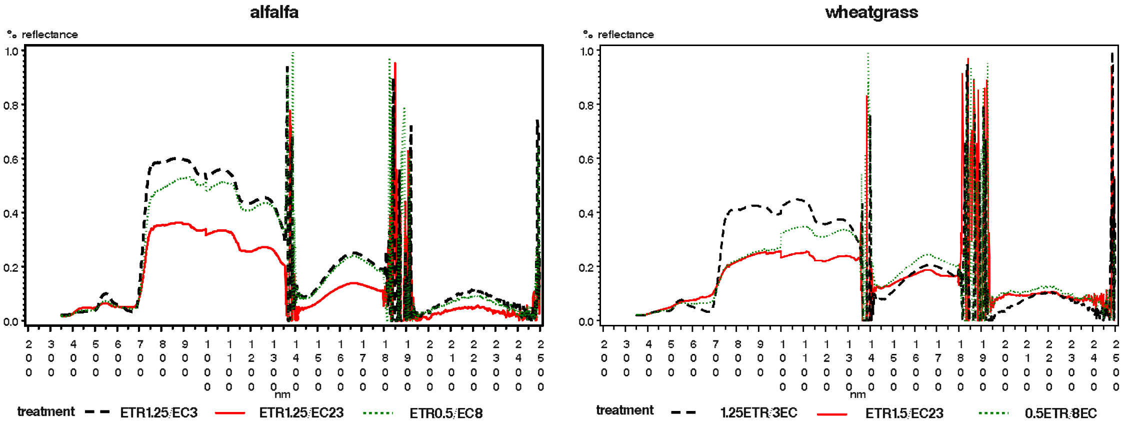

Figure 1. Representative canopy reflectance spectra for wheatgrass and alfalfa crops under three different combinations of applied water (ETR, % control) and salinity (EC, dSm^{-1})

A multiple linear regression model with four remotely-sensed indices was developed to relate total fresh weight biomass to canopy spectral reflectance for each species. A red region NDVI (NDVIred $=R_{710nm} - R_{670nm} / R_{710nm} + R_{670nm}$) and green region NDVI (NDVIgreen $=R_{550nm} - R_{670nm}/ R_{550nm} + R_{670nm}$) were developed based on wavelength sensitivities reported by Carter (1993) where increased reflectance at both these wavelengths (710 nm and 550 nm) were reported to respond to stress regardless of the stress agent or species measured with a sensitivity minimum observed at 670nm. Another NDVI index, ($NDVI_{NIR} = R_{913nm} – R_{711nm}/ R_{913nm} + R_{711nm}$), based on reflectance measurements at longer wavelengths in the NIR was also incorporated (Luther and Carroll, 1999) into the regression model as was a derivative-based red-edge position pseudo-absorbance (REPA) index modified from Rinehart et al. (2002). In the latter case, instead of reporting the wavenumber or wavelength where the slope is the greatest (visable-Red Edge = Log(1/R), Rinehart, et al., 2002), our method reported the value of the steepest slope of the function in the region between 600nm and 800 nm.

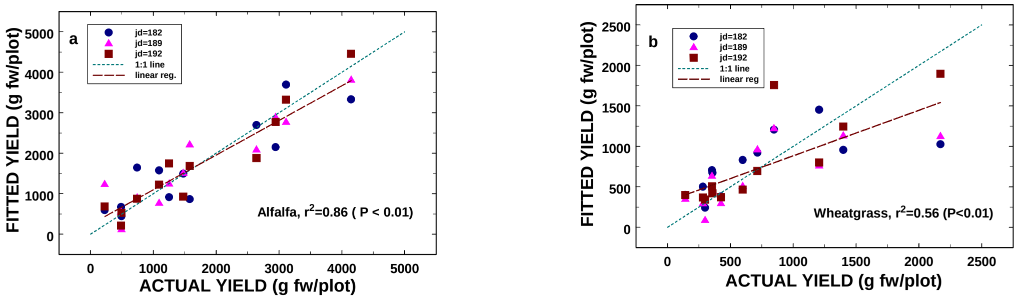

Figure 2. Multiple linear regression model fitted yield as a function of measured yield for alfalfa (a) and wheatgrass (b).

The model fitted the yield data significantly for both crops (Figure 2) with a greater adherence to a one-to-one relationship for alfalfa. Subsequent yields predicted with the coefficients developed with the above fitted relationships were similarly significant for biomass harvests before and after those employed in model development (r^2= 0.41 before and r^2= 0.51 after for alfalfa, and r^2= 0.40 before and r^2= 0.95 after for wheatgrass).

Physiological variables including chlorophyll a and b concentrations (mg Chla/bdm^{-2}), leaf tissue relative water content (RWC), plant nitrogen (%N), and leaf area index (LAI) were measured as ground truths and correlated with a large number of vegetative indices (>60) from the literature and some developed here. The greatest correlations of those significantly related to ground truth measurements measured ranged from r^2 = 0.45 for alfalfa chlorophyll a&b and r^2 = 0.94 for leaf area index (Table 1).

Table 1. Relationships between measured physiological variables (Chlorophyll a&b, Relative Water Content (RWC), Plant N, leaf area index (LAI)) and vegetative indices for each crop based on coupled measurements with spectral analysis. In all cases a P>F was <0.01.

Ground Truth (y)	Crop	Vegetative Index	Linear Equation	r^2	Author
Chlorophyll a&b	grass	Bder717	y = 76.48*Bder717+9.27	0.60	Blackburn, 1998
Chlorophyll a&b	alfalfa	Bder664	y = -247*Bder664+4.01	0.45	Blackburn, 1998
RWC	grass	ARIlf	y=-0.20*ARILF+0.923	0.59	Steddom et al., 2003
RWC	alfalfa	CRILF	y=0.0068*CRILF+0.723	0.81	Steddom et al, 2003
Plant N(%)	grass	RFrat	y=1.2x10^{-6}*RFrat+3.82	0.54	This publication
Plant N(%)	alfalfa	CRILF	y=-0.082*CRILF+4.99	0.76	Steddom et al., 2003
LAI	grass	REPA	y=-27.41*REPA-0.14	0.87	This publication
LAI	alfalfa	SRVI	y=0.082*SRVI-0.169	0.94	Wang et al., 2002

Strong relationships were found for both crops for SRVI (Wang, et al., 2002) and REPA indices with LAI. However, it is noteworthy that for other cases, the same index did not work equally well for both crops with respect to a particular variable (RWC and Chlorophyll a&b, for example). In some cases no significant relationship existed for alfalfa when it was significant for wheatgrass and vice-versa. Additionally, indices reported to target carotenoids and anthocyanins in sugar beets (Steddom et al., 2003) were related significantly to relative water content and plant nitrogen content in this study. The derivative of pseudo-absorbance (Log 1/R) appears to be a useful tool to relate remote indices to pigments content in plants in addition to LAI. As proposed by Blackburn (1998), however, the index represented by the second derivative of Log(1/R) at 664 nm (Bder664) was significantly correlated to chlorophyll a&b for alfalfa but not for wheatgrass. Similarly, Blackburn (1998), noted the index represented by the first derivative of Log(1/R) 717nm region (Bder717) was sensitive to carotenoid concentrations, but was significant here for chlorophyll a&b for wheatgrass only. In this study, REPA behaved similarly to the index Bder717.

4 CONCLUSIONS

The ability to characterize the production of salinity and water stressed forage crops with ground-based remote sensing is quite strong. It is clear from this study that LAI and indices that accurately predict LAI (REPA and SRVI) are very useful in assessing final production potential. Additional information gathered with remote sensing, however, includes crop relative nitrogen nutrition and water content, and pigment development in the canopy. It is important to substantially improve our ability to remotely characterize certain physical or biological processes important in crop production because of the inter-related nature of these processes independent of plant type (the change in water content and pigment concentrations with varying levels of nitrogen, for example, should be independent of canopy architecture). Ground truth experimental control is very important when examining how plant variables are related to remotely–sensed vegetation reflectance information.

5 REFERENCES

Blackburn. G. A. 1998. Quantifying chlorophylls and carotenoids at leaf and canopy scales: an evaluation of some hyperspectral approaches.

Carter. 1993. Responses of leaf spectral reflectance to plant stress. American J. Botany. 80: 239-243.

Chappelle, E. W., M. S. Kim. 1992. Ratio analysis of reflectance spectra (IARS): an algorithm for the remote estimation of the concentrations of chlorophyll A , chlorophyll B, and carotenoids in soybean leaves. Remote sensing of Env. 39: 239-247.

Corwin, D.L., M.L.K. Carrillo, P.J. Vaughan, J.D. Rhoades and D.G. Cone. 1999. Evaluation of a GIS-linked model of salt loading to groundwater. J. Environ. Qual. 28:471-480.

Luther, J. E. and A. L. Carroll. 1999. Development of an index of balsam fir vigor by foliar spectral reflectance. Remote Sens. Environ. 69: 241-252

Poss, J. A., W. B. Russell, P. J. Shouse, R. S. Austin, S. R. Grattan, C. M. Grieve, J. H. Leith, and L. Zeng. 2004. A volumetric lysimeter system (VLS): and alternative to weighing lysimeters for plant-water relations studies. Comput. Electronics Agric. 43:55-68.

Rinehart. G. J., J. H. Baird, R. N. Calhoun, and O. Schabbenberger. 2002. Remote sensing of brown patch and dollar spot on creeping bentgrass and annual bluegrass turf using visible and near-infrared spectroscopy. Australian Turfgrass Management. Vol. 4.2 (April-May 2002): 7pps

Steddom, K, G. Heidel, D. Jones, and C. M Rush. 2003. Remote detection of Rhizomania in sugar beets Phytopathology. 93(6). 720-726.

Wang, D., C. Wilson, and M. C. Shannon. 2002. Interpretation of salinity and irrigation effects on soybean canopy reflectance in visible and near-infrared spectrum domain. Int. J. Remote Sensing. 23:811-824.