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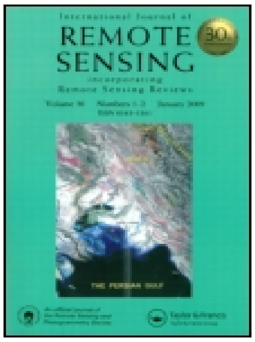

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Interpretation of salinity and irrigation effects on soybean canopy reflectance in visible and near-infrared spectrum domain

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Abstract. Soil and water salinity can reduce plant growth, affecting yield and quality of agricultural and horticultural crops. This study was designed to measure canopy spectral reflectance of soybean plants under different salinity and irrigation treatments (drip, sprinkler, and furrow), and to relate the reflectance characteristics to salinity-induced alterations in leaf chlorophyll, specific leaf mass, and above-ground biomass. Soybean canopy reflectance was measured with a hand-held Cropscan multispectral radiometer in the visible (460–710 nm) and near-infrared (NIR; 810–950 nm) spectrum domain. Canopy reflectance in the NIR was significantly and consistently reduced by the salinity treatment. The reduction was attributed to increases in specific leaf mass caused by salinity, and can be delineated with the simple ratio vegetation index (SRVI), with 660 and 830 nm as the most sensitive waveband combination. Reflectance in the visible domain did not show a salinity effect nor any correlation to leaf chlorophyll changes from salinity stress. Canopy reflectance in NIR showed the most salinity effect under furrow irrigation where the soybeans were subjected to the most cumulative salinity stress.

1. Introduction

Long-term mismanaged irrigation often leads to the salinization of soil and water, and concern is mounting about the sustainability of irrigated agriculture. Because the ability of plants to achieve maximum yield is strongly inhibited by salinity (Maas and Hoffman 1977), crop management techniques to avoid this stress are especially useful in cases where crops are produced in saline areas. However, in order to employ optimized management procedures such as variable-rate application of agricultural chemicals, highly detailed information on the spatial and temporal distribution of soil salinity and its effect on plant growth is sorely needed.

Field determination of soil salinity is often conducted by *in situ* soil core sampling. Unfortunately, soil sampling is very costly, time-consuming, and requires interpolation between sampling points in order to create a spatial assessment of apparent salinity distribution. To overcome these problems, mobilized units have been developed at the US Salinity Laboratory to measure soil salinity on the go, using

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either a four-probe electrical conductivity system or a non-invasive electromagnetic sensor (Rhoades 1993). These units are most useful for early-season measurements when plant height is low. Field access with this unit can be limited during the growing season, especially at later stages of vegetative growth when plant height exceeds the maximum clearance of the mobile units.

One possible alternative to the direct salinity measurement is to use plant responses to saline environments as an index of soil salinity. It is suggested that plant responses may provide a more comprehensive assessment of salinity because plant roots generally penetrate deep in the soil profile and measurements of growth characteristics at one point in time integrate the cumulative effect of substrate salinity. Remote sensing of the plant canopy is particularly useful in this respect. For example, Peñuelas *et al.* (1997) found that canopy reflectance of barley was lower in the near-infrared (NIR) and higher in the visible spectrum region with increasing salinity. To characterize salinity effects on cotton, Wiegand *et al.* (1992) found that the yield and plant cover were correlated to vegetation indices derived from remote sensing measurements using either multispectral video images or reflectance data from the SPOT satellite.

A more mechanistic approach of applying remote sensing to determine salinity effects on plant growth or eventual salinity assessment is to relate salinity-induced canopy reflectance characteristics to plant biophysical and biochemical properties that are also sensitive to salinity stress. One of the primary biochemical parameters that affects canopy reflectance in the visible domain is the concentration and total amount of leaf chlorophyll. Salinity has been shown to have some effects on leaf chlorophyll content of rice (Pandey and Saxena 1987), chickpea (Datta and Sharma 1990), and cowpea (Plaut *et al.* 1990). Remote sensing studies have also been conducted on developing algorithms of using vegetation indices to infer plant chlorophyll content (Chappelle *et al.* 1992, Gitelson and Merzlyak 1997, Blackburn 1998). However, no information can be found in the literature on interrelations between salinity, canopy reflectance, and leaf chlorophyll.

In the NIR spectrum domain, differences in canopy reflectance have been attributed to variations in leaf anatomical structure such as the number of palisade cell layers, cell sizes and orientation (Gausman 1974). A simple and indirect way of describing the leaf anatomical structure is to use the specific leaf mass (SLM) as a measure which includes both leaf thickness and density (Wiebold *et al.* 1981). Further, it has been found that the transmissivity-related leaf absorbance at 1000 nm is positively correlated to increases in SLM (Méthy *et al.* 1998). One may deduce that, with increasing absorbance, the reflectance in NIR would decrease with increasing SLM. Leaf morphology including SLM can be affected by salinity (Meiri and Poljakoff-Mayber 1967), therefore, canopy reflectance in NIR may be used as an index to infer the detrimental effects of salinity on plant growth. The ultimate goal of applying remote sensing techniques for salinity assessment is to provide an early estimation of the effect of salinity on plant growth and biomass production before final yield reduction occurs.

The overall objective of this study was to explain effects of soil and water salinity on soybean canopy spectral reflectance in the visible and NIR region using plant biophysical and biochemical parameters. Specifically, the study was designed to (1) relate canopy spectral reflectance in the visible and NIR to chlorophyll content and SLM, respectively, and (2) determine a simple and commonly used vegetation index to describe the salinity effects on soybean canopy reflectance. Since differences in irrigation method can create different processes by which salt is distributed in the soil and accumulated in plants (Bernstein and Francois 1973), drip, sprinkler, and furrow irrigation were used in the study. Therefore, this study was also designed to (3) compare the interactive effects of salinity and irrigation method on soybean growth using remote sensing. Soybean was selected as the test plant because previous studies have indicated that morphological features of soybean plants are highly responsive to changes in environmental conditions (Milton *et al.* 1989, 1991). Additionally, soybean has a uniform plant canopy, which would minimize the variability in canopy reflectance induced by factors other than salinity.

2. The field experiment

A field experiment was conducted between June and October 1998 in Riverside, California, USA (33°58′23″ N Lat.; 117°20′30″ W Long.). The soil at the study site is an Arlington fine sandy loam (coarse–loamy, mixed, thermic, Haplic Durixeralf) with an Ap horizon for the surface 10 cm. In this depth, the particle size distribution consists of 63% sand, 30% silt, and 7% clay. The initial soil salinity was low with an electrical conductivity of the saturated solution extract (EC_e) of 1.04 ± 0.12 dS m^{-1}, after correction for apparent soil water content.

Soybean variety 'Manokin' (*Glycine max* (L.) Merr.) was selected for investigating responses to salinity under different irrigation regimes. 'Manokin' is a late maturity group IV determinate variety developed for its superior yield and resistance to soybean cyst nematode (Kenworthy *et al.* 1996). No information was found in the literature on its potential salt tolerance. In the experiment, seeds were planted on 11 June 1998 or day of year (DOY) 162, at a rate of 32.8 seeds per metre and at depths between 3 and 5 cm from the soil surface. Three irrigation methods (drip, sprinkler, and furrow) were used to determine the effect of irrigation on soybean responses to salinity. For each method of irrigation, an adjacent plot was used as the control with no salt application. In drip and sprinkler treatments with salinity, the irrigation water was salinized with a NaCl and $CaCl_2$ mixture (at 1:1 mass ratio), to an electrical conductivity of water (EC_w) value of about 4 dS m^{-1} starting at 30 days after seedling emergence or DOY 204. To insure seedling establishment, non-salinized water was used in both irrigation treatments between DOY 162 and 204. Non-salinized water was also applied for about 30 min at the end of each irrigation event in the sprinkler–salinity treatment. This was done to wash off potential salt deposits on the soybean canopy that might create a biased reflectance measurement. A total of 3.2 and 5.7 Mg ha^{-1} mixed salts were applied in the drip– and sprinkler–salinity plot over the growing season. The cumulative amount of irrigation water applied was 208 and 681 mm for the drip and sprinkler plot, respectively. For the furrow-irrigated treatment with salinity, the soil was salinized with a NaCl and $CaCl_2$ mixture (at 1:1 mass ratio and 0.9 Mg ha^{-1} rate) prior to planting. Non-saline water ($EC_w \approx 0.5$ dS m^{-1}) was used for all subsequent furrow irrigations during the season. To schedule irrigation, a weather station was installed at the field site to monitor meteorological parameters such as air temperature and relative humidity.

3. Canopy spectral reflectance and vegetation indices

Soybean canopy reflectance was measured with a hand-held Cropscan Multi-Spectral Radiometer (MSR). Eight wavebands (460, 560, 660, 710, 810, 830, 900, and 950 nm; band width 10 nm) were selected to sample the visible and NIR region. Canopy reflectance was computed and recorded with a data logger controller for each band which consisted of a pair of sensors: a downward-facing sensor and an upward-facing sensor covered with a diffuser. To avoid the effect of bare soil surface, the first reflectance measurement was made on 14 August or DOY 226 when the soybeans were near the end of vegetative growth stage and 100% canopy closure had been reached. Remaining measurements were made on DOY 244, 257, 266, 279, and 289, respectively, to provide a temporal assessment of salinity and irrigation effects on soybean growth. During the measurements, the MSR unit was mounted at the end of a support pole and was held 50 cm above the canopy at an angle perpendicular to the horizontal plane (Nadir). The field-of-view of the MSR was 28°, therefore, a canopy area of about 30 cm in diameter was measured at the 50 cm height. Because the MSR unit was 8 × 8 × 10 cm in dimension and held 50 cm above the canopy, a minimum solar zenith angle of 22.3° was required to prevent shadowing the measured areas from the MSR unit itself. To avoid shadowing, solar zenith angle was calculated from the theoretical equation found in Campbell and Norman (1998):

$$\psi = \cos^{-1}\{\sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)\cos[15(t - t_o)]\} \tag{1}$$

where ψ is the solar zenith angle, ϕ is the latitude, δ is solar declination angle, t is time, and t_o is the time of solar noon. Based on computations from the equation, the reflectance measurements were made between the hours of 1300 and 1400 when the solar zenith angle ranged from a minimum of 24.5° at 1300 h on DOY 226 to a maximum of 54.8° at 1400 h on DOY 289.

Vegetation indices have been widely used in remote sensing to describe the degree of plant cover or biomass production. Although different methods can be used to derive the indices (Steven *et al.* 1990, Wiegand *et al.* 1991), the most commonly used are the normalized difference vegetation index (NDVI) and the simple ratio vegetation index (SRVI). The two indices are defined as $\mathrm{NDVI} = (R_{\mathrm{NIR}} - R_{\mathrm{RED}})/(R_{\mathrm{NIR}} + R_{\mathrm{RED}})$, and $\mathrm{SRVI} = R_{\mathrm{NIR}}/R_{\mathrm{RED}}$, where R_{RED} and R_{NIR} represent the canopy reflectance in the red and NIR spectral domain, respectively. To determine a R_{RED} and R_{NIR} combination that is most sensitive to salinity and irrigation method, R_{NIR} was sequentially selected at 810, 830, 900, and 950 nm, whereas R_{RED} was fixed at 660 nm waveband.

4. Leaf chlorophyll, specific leaf mass, and biomass

Soybean leaf chlorophyll levels were measured with the Minolta hand-held SPAD-502 meter which has been found useful in estimating soybean chlorophyll content and its seasonal variations (Thompson *et al.* 1996). Calibration of the SPAD meter readings against actual leaf chlorophyll was made from replicated leaf punches (each 1.131 cm^2 in area), which were ground and digested in 80% (v:v) acetone solution saturated with $MgCO_3$, and analysed on a Beckman DU 7500 spectrophotometer. The relationship between the chlorophyll concentration (*CHL*; in μg cm^{-2}) and SPAD number (*SPAD*) was fitted with a three-parameter exponential equation ($r^2 = 0.661$):

$$CHL = -43.68 + 36.65\ \mathrm{e}^{0.0214(\mathrm{SPAD})} \tag{2}$$

This empirical calibration function compared well with calibrations reported by Monje and Bugbee (1992) and Markwell *et al.* (1995).

To determine specific leaf mass or SLM, nine soybean plants were randomly harvested on DOY 222, 243, and 264 from each treatment, right after the SPAD meter measurements, to compare with the reflectance measurements made on DOY

226, 244, and 266. No harvesting was made to compare with the reflectance measurements on DOY 279 or 289 since senescence had occurred. Total leaf area from each plant was measured in the laboratory by passing individual leaflets through a LICOR LI-3100 leaf area meter. The leaves were then dried at about 70° C in a forced-air oven to constant weights. SLM was calculated as the ratio of the dry weight over the total leaf area from each plant. Total above-ground biomass (AGB) was obtained by adding the dry weight of all above ground plant parts, including the leaves, stems, and pods (no pods for harvest made on DOY 226).

5. Results and discussion

5.1. *Characteristics of canopy reflectance*

Soybean canopy reflectance in the NIR was consistently lower under salinity than the control or non-salinity treatment for all three irrigation regimes (figures 1–3). No significant difference was found between the salinity and control

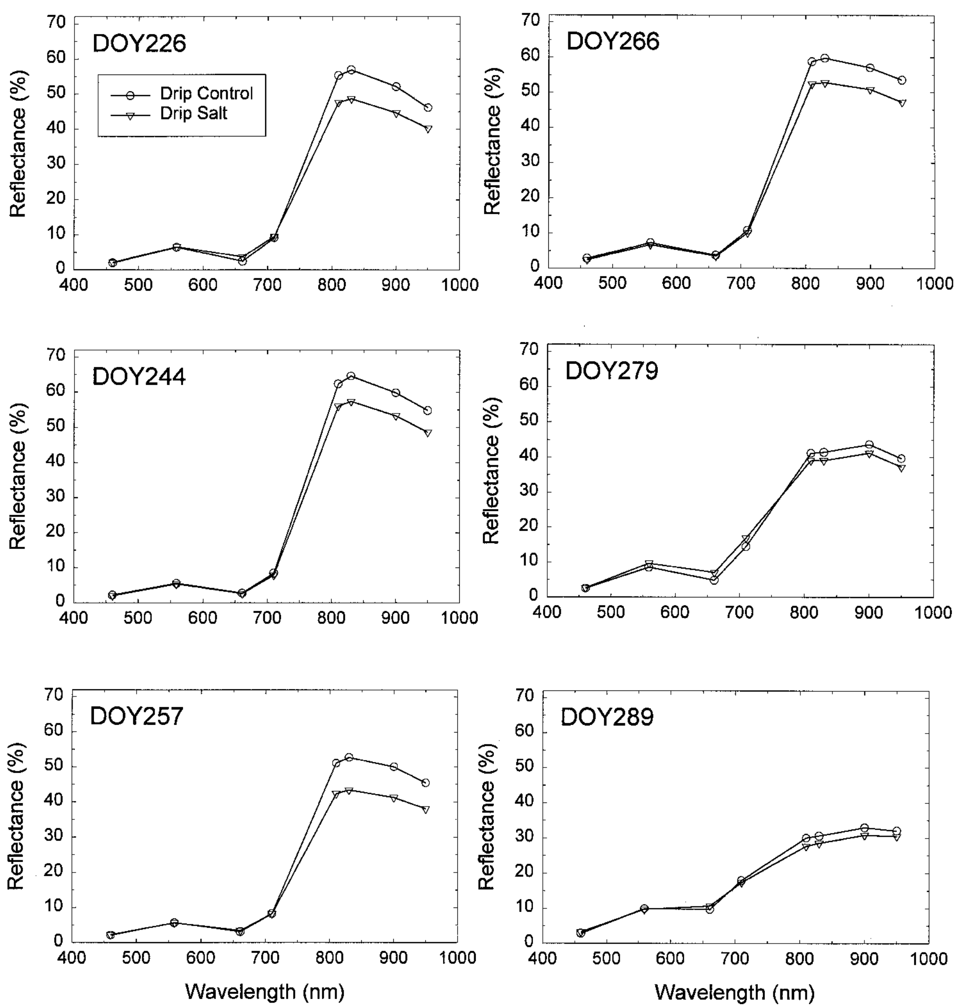

Figure 1. Canopy spectral reflectance of soybean plants under drip irrigation with saline and non-saline waters. Measurements were made from DOY 226 to 289 of 1998.

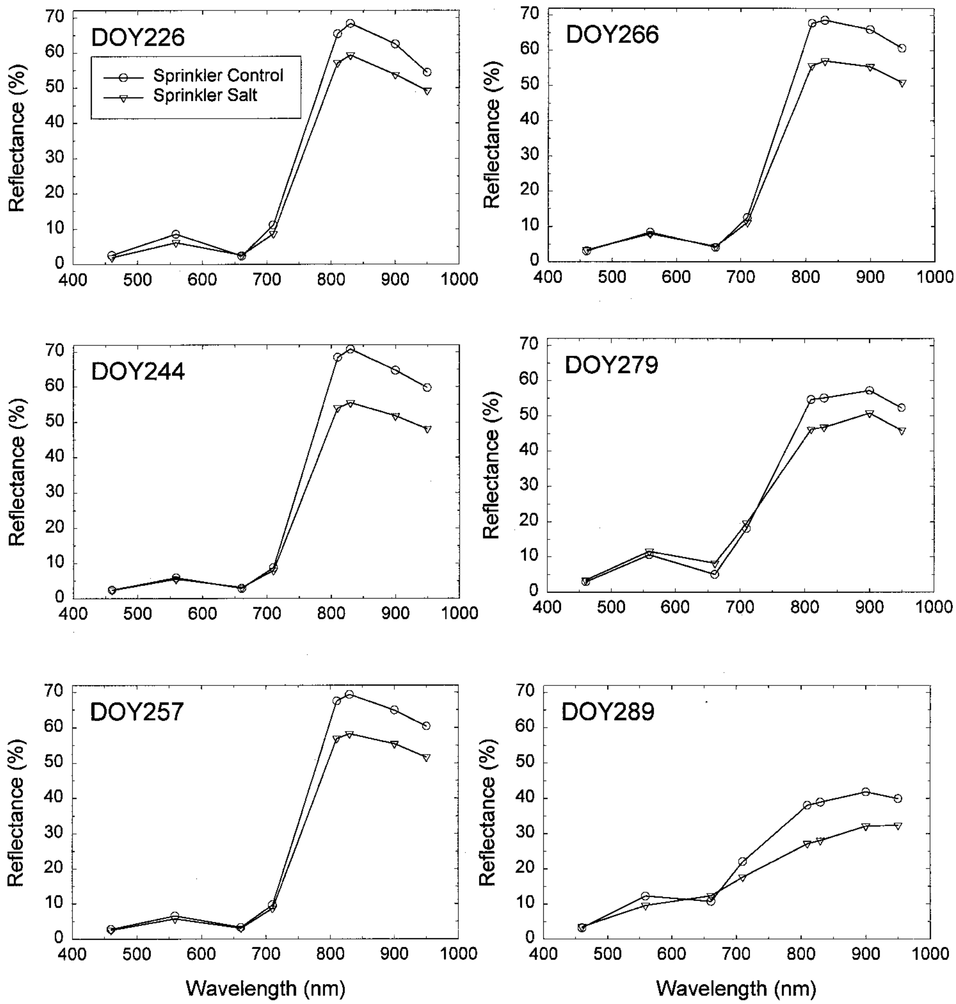

Figure 2. Canopy spectral reflectance of soybean plants under sprinkler irrigation with saline and non-saline waters. Measurements were made from DOY 226 to 289 of 1998.

plots in the visible (460–710 nm) domain. The reflectance measurements also clearly showed plant senescence on DOY 279 and 289, with a characteristic reflectance reduction in the NIR and an increase in the red spectra. Tukey's Honestly Significant Difference (HSD) tests among means further confirmed that differences in canopy reflectance between the salinity and control plots were not significantly different from zero at the 460 and 660 nm band (table 1). In the NIR, however, the difference was all significantly less than zero for the three irrigation methods. Reflectance data from DOY 279 and 289 was not included in the statistical test due to the possibility that senescence could confound the salinity effect on canopy reflectance. In fact, differences in canopy reflectance in NIR became significantly smaller after senescence, especially with drip irrigation (figure 1).

The reflectance spectra prior to senescence appeared to be very similar among irrigation treatments, and showed very little temporal changes (from DOY 226 to 266). This is likely attributed to the saturation effect on canopy development (Guyot

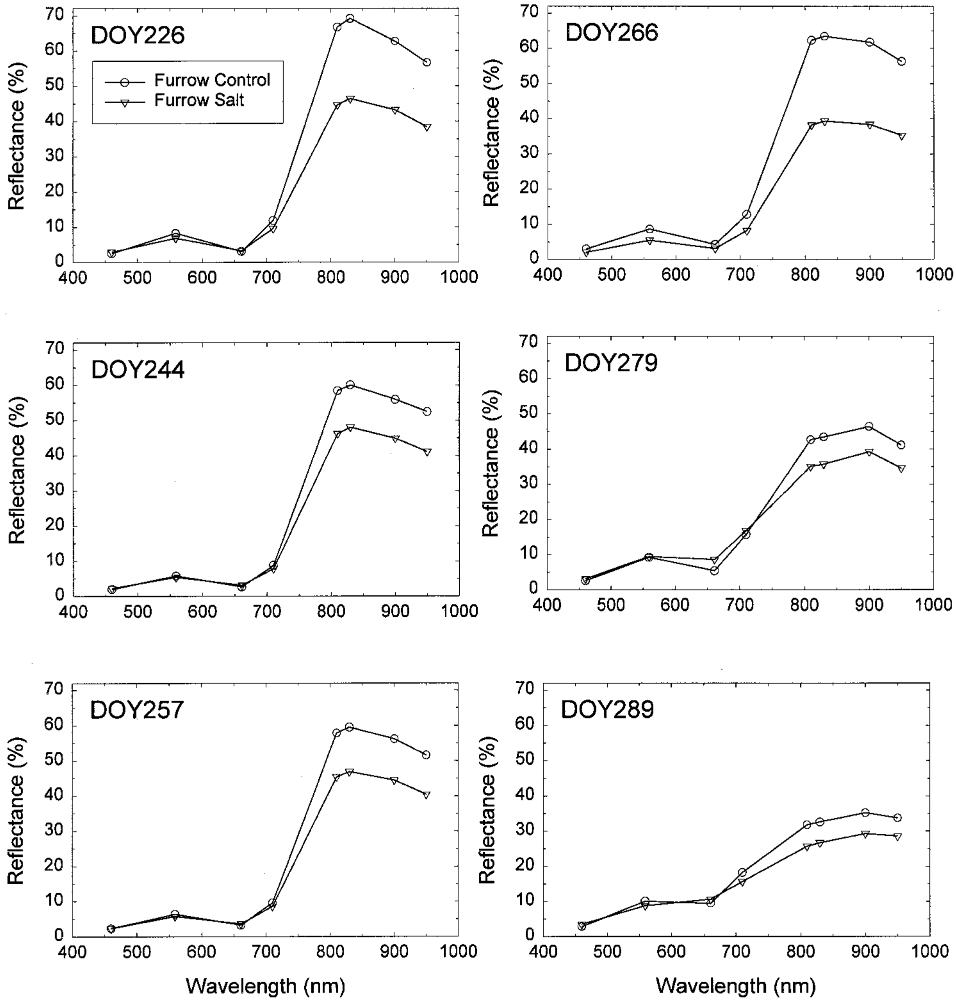

Figure 3. Canopy spectral reflectance of soybean plants under furrow irrigation in pre-salinized field plots with non-saline water. Measurements were made from DOY 226–289 of 1998.

1990) since by DOY 226 plant leaf area index (LAI) had reached about 3 in both the salinity and control plots. The most interesting or useful aspect of the reflectance spectra is the relatively constant difference in NIR between the salinity and non-salinity treatment. From a salinity assessment perspective, this would provide a temporal window of about 30 days to conduct field measurement or surveillance. The timing is also of practical importance in that it may be early enough to employ management measures necessary to alleviate the salinity stress.

5.2. *Effects of leaf chlorophyll, specific leaf mass, and above-ground biomass*

A temporal increase in leaf chlorophyll from about 35 $\mu g\,cm^{-2}$ on DOY 226 to about 50 $\mu g\,cm^{-2}$ on DOY 266 was found among all the salinity or irrigation treatments (figure 4). Although the temporal increase was significant, it was not reflected in the canopy reflectance measurement at the two chlorophyll bands,

Table 1. Effect of salinity and irrigation on biophysical parameters of soybean growth.

Difference† (Salt—Control)	Unit	Drip	Sprinkler	Furrow
		(averages between DOY 226 and 266)‡		
Reflectance in				
460 nm	%	-0.08^{a}	-0.19^{a}	-0.09^{a}
560 nm	%	-0.16^{a}	-1.01^{ab}	-1.40^{ab}
660 nm	%	0.29^{a}	0.10^{a}	-0.03^{a}
710 nm	%	-0.21^{a}	-1.41^{ab}	-2.19^{b}
810–950 nm	%	-7.21^{b}	-10.59^{b}	-16.85^{c}
Chlorophyll	$\mu g\ cm^{-2}$	1.15^{a}	2.85^{ab}	7.78^{b}
	%	3	7	19
SLM	$mg\ cm^{-2}$	0.97^{b}	0.59^{b}	0.93^{b}
	%	21	13	19
AGB	$g\ plant^{-1}$	-3.90^{ab}	-19.62^{b}	-21.11^{b}
	%	17	42	58

†SLM = specific leaf mass, AGB = above-ground biomass, and % difference for chlorophyll, SLM, and AGB was referenced to the pertinent control values.

‡Different letters indicate significant difference at $P = 0.05$ between irrigation treatments according to Tukey's HSD test.

i.e. 460 and 660 nm (figures 1–3, table 1). The canopy-level reflectance between DOY 226 and 266 remained at about 2.7 and 3.9% for the 460 and 660 nm band, respectively. Further, differences in chlorophyll between the salinity and control treatment were not significantly different from zero for the drip and sprinkler irrigation (1.15 and 2.85 $\mu g\ cm^{-2}$), but were greater than zero for furrow irrigation (i.e. 7.78 $\mu g\ cm^{-2}$, table 1). The effect of salinity among different irrigation methods on chlorophyll was reflected in the 560 and 710 nm bands, which were less efficient in absorbing chlorophyll or relatively sensitive to small changes in chlorophyll content (table 1). Overall, it appears that the salinity treatment imposed in this experiment did not lead to a significant increase in leaf chlorophyll and the canopy level reflectance measurement in the visible domain was not very sensitive to the salinity effect.

The consistent reduction in canopy reflectance in NIR (figures 1–3) is most likely explained by increases in SLM induced by the salinity treatment (figure 5). Soybean SLM in the salinity treatment was about 20% higher than in the control plot for drip and furrow irrigation, and 13% higher for sprinkler irrigation (table 1). The differences were all significantly greater than zero. Although the absolute values of SLM increased over time from about 4.5 $mg\ cm^{-2}$ on DOY 226 to about 5.5 $mg\ cm^{-2}$ on DOY 266, the difference between the salinity and control plot remained relatively constant (figure 5), which is also consistent with the canopy reflectance measurement (figures 1–3). Therefore, SLM and canopy reflectance in NIR are significantly correlated ($r = -0.49$) at $P = 0.05$. The underlying mechanism may be that increasing SLM leads to a relative increase in light absorption by soybean leaves in the low absorbing NIR region. The result would also automatically lead to a reduction in reflectance in NIR. For salinity assessment, if remote sensing can use reflectance reductions in NIR as an index to determine plant salinity stress, ground sampling of plant SLM may provide another measure of plant response to salinity. The obvious advantage with remote sensing is the ability to acquire large-scale frequent field measurements. Interestingly, a correlation analysis showed that SLM was significantly correlated

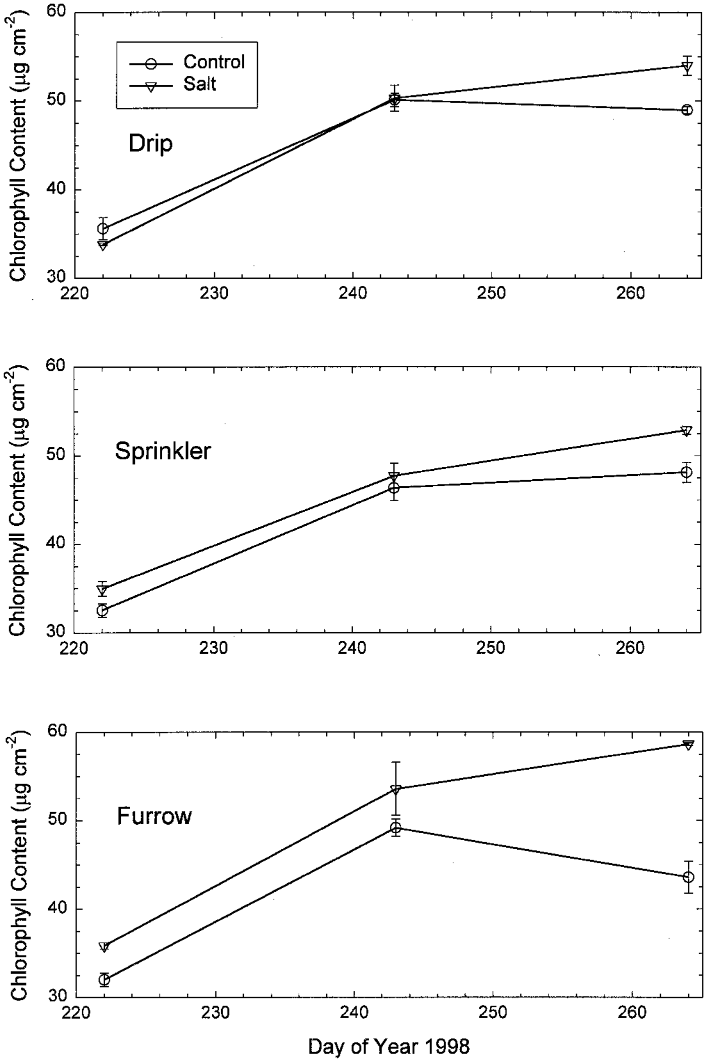

Figure 4. Soybean leaf chlorophyll content between salt and control treatment and under drip, sprinkler, and furrow irrigation. Error bars are standard errors ($n=9$).

to leaf chlorophyll content at $P=0.01$ (Pearson's correlation coefficient $r=0.68$), yet canopy reflectances in the visible were not sensitive to salinity effect.

Soybean above-ground biomass, or AGB, was not significantly different between the salinity and control treatment on DOY 226 for drip and sprinkler irrigation (figure 6). This indifference may be a result of insufficient time for salt accumulation because the salinity treatment was initiated on DOY 204. The control plot appeared to gain more biomass starting from DOY 244, especially in sprinkler plot, which was attributed primarily to pod formation and salinity stress suppressed soybean seed filling. Soybean average AGB in the salinity treatment was significantly less than that in the control plot for sprinkler and furrow irrigation (table 1). However, the average AGB values were not significantly correlated with either leaf chlorophyll ($r=0.44$) or SLM ($r=0.31$) at $P<0.05$. Interrelations between SLM and AGB or

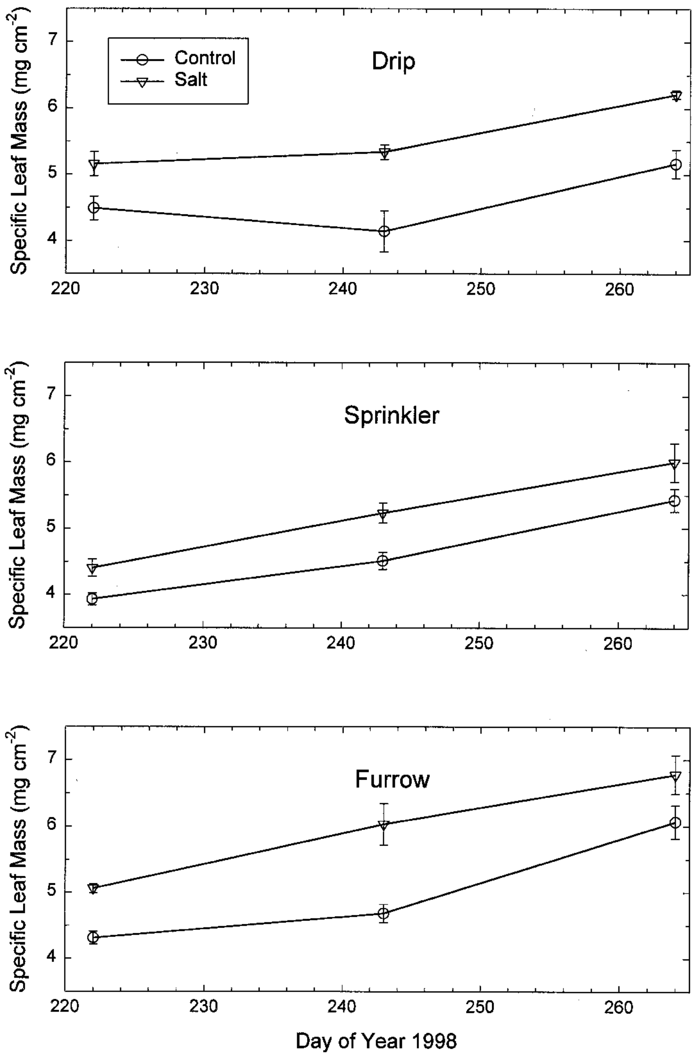

Figure 5. Soybean specific leaf mass between salt and control treatment and under drip, sprinkler, and furrow irrigation. Error bars are standard errors ($n=9$).

yield may be determined but would require more detailed studies emphasizing the physiological processes that control plant growth and photosynthate allocation to yield components.

5.3. *Vegetation indices*

Both NDVI and SRVI appeared to be higher in the control than in the salinity plot (table 2). This was attributed to the reduced reflectance in NIR by salinity since the reflectance in the visible did not respond to the treatment. Because of the vegetation saturation effect, the difference in NDVI between the salinity and control treatment was very small (0.005–0.070), not significantly different from zero at $P=0.05$, and it did not seem to change over time. Therefore, NDVI was not a sensitive indicator to describe salinity stress on soybean canopy reflectance. Fortunately, SRVI

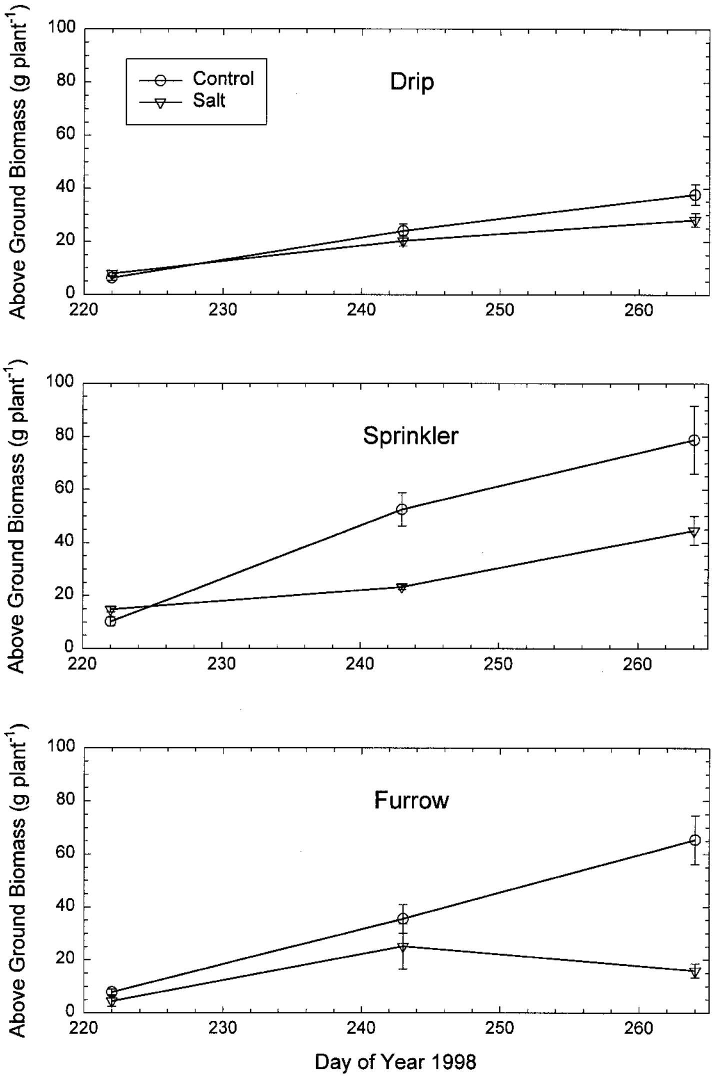

Figure 6. Soybean above-ground total biomass between salt and control treatment and under drip, sprinkler, and furrow irrigation. Error bars are standard errors ($n=9$).

showed significant differences ($P=0.05$) between the salinity and control treatment (0.6–10). SRVI also appeared to change over time and a better time for detection was early in the growing season. This would make the remote sensing measurement more meaningful since corrective management measures can be taken to reduce the salinity effect on plant growth. Combinations of the red (660 nm) and the four NIR bands (810, 830, 900, and 950 nm) all produced similar SRVI values. Therefore, SRVI was also relatively robust in terms of selecting a sensitive NIR band for depicting the salinity stress on soybean canopy reflectance. Nonetheless, the bandwidth at 830 nm appeared to provide the largest difference in SRVI, therefore, the highest detection.

Ideally, a remote sensing-based salinity index may be developed to more

Table 2. Differences of vegetation indices between the control and salinity treatment.

Irrigation	Vegetation index†	Wavelength in NIR (nm)	Day of Year 1998			
			226	244	257	266
Drip	NDVI	810	0.060	0.005	0.033	0.005
	NDVI	830	0.059	0.006	0.033	0.006
	NDVI	900	0.064	0.006	0.035	0.005
	NDVI	950	0.068	0.007	0.035	0.006
	SRVI	810	9.693	1.386	3.887	0.620
	SRVI	830	10.057	1.663	4.091	0.766
	SRVI	900	9.214	1.465	3.869	0.598
	SRVI	950	7.941	1.417	3.321	0.695
Sprinkler	NDVI	810	0.017	0.027	0.010	0.029
	NDVI	830	0.017	0.027	0.010	0.027
	NDVI	900	0.019	0.027	0.009	0.027
	NDVI	950	0.016	0.029	0.010	0.029
	SRVI	810	5.304	6.155	2.153	3.510
	SRVI	830	5.689	6.479	2.289	3.401
	SRVI	900	5.382	5.592	1.855	3.134
	SRVI	950	3.765	5.066	1.697	2.903
Furrow	NDVI	810	0.049	0.038	0.041	0.025
	NDVI	830	0.047	0.036	0.039	0.023
	NDVI	900	0.048	0.038	0.040	0.023
	NDVI	950	0.055	0.043	0.045	0.024
	SRVI	810	7.984	7.105	5.295	2.539
	SRVI	830	8.243	7.106	5.410	2.447
	SRVI	900	7.112	6.583	5.028	2.356
	SRVI	950	6.611	6.484	4.737	2.047

†NDVI = normalized difference vegetation index = $(R_{NIR} - R_{RED})/(R_{NIR} + R_{RED})$; SRVI = simple ratio vegetation index = R_{NIR}/R_{RED}, where R_{RED} is from 660 nm, R_{NIR} from 810 to 950 nm, respectively.

specifically address the salinity effect on plant growth by relating to individual plant biophysical and biochemical parameters. Although this study was not specifically designed for that purpose, correlation analysis was performed between chlorophyll, SLM, AGB and reflectance in each band. On the average, SLM and AGB were significantly correlated with the reflectance measurements in the NIR ($r = -0.49$ and 0.54 for SLM and AGB, respectively) at $P = 0.05$, but no significant correlation was found in the visible range. Leaf chlorophyll was not significantly correlated to reflectance in all the wavebands measured.

5.4. *Interaction with irrigation method*

Observations of the reflectance spectra before senescence indicated that the highest NIR reflectance (at 830 nm) for the control plot averaged about 60, 70, and 60% for drip, sprinkler, and furrow irrigation, respectively (figures 1–3). Under salinity, it was reduced to about 50, 55, and 45% for the three irrigation methods. Therefore, sprinkler irrigation appeared to favour soybean vegetative growth. The increased plant growth under sprinkler irrigation was also evident from the biomass measurement. According to figure 6, the AGB on DOY 266 was 78.8 and 44.6 g plant^{-1} for the control and salinity treatment, respectively. It was only 37.7 and 28.3 g plant^{-1} for drip, and 65.4 and 15.9 g plant^{-1} for furrow irrigation. Therefore, canopy reflectance measurement was able to detect variations in AGB caused by irrigation method.

The significant reflectance reduction by salinity in furrow irrigation, 16.85% as compared to 10.59% in sprinkler and 7.21% in drip (table 1), may be attributed to the method of salinization. Growing soybeans under natural conditions in a saline soil would inevitably subject the plants to more cumulative salinity stress than starting the salinity treatment in the middle of the season. In furrow irrigation, soybean seeds were sown in the salinized soil, whereas the drip and sprinkler plot did not receive salinity treatment until 42 days after planting. The prolonged salinity stress in furrow–salinity treatment also induced significant changes in leaf chlorophyll content, though not detectable by the remote sensing measurement. Therefore, it is clear that measuring plants to indicate environmental stresses such as salinity can integrate the temporal cumulative effect. It is also more direct because in most agricultural applications, the eventual goal for salinity assessment is to optimize plant growth for yield or biomass production.

6. Conclusions

Soybean canopy reflectance in the NIR (810–950 nm) was significantly and consistently lower under salinity than control treatment after the plant reaching 100% canopy closure but before senescence. No significant difference was found between the salinity and control treatment in the visible domain (460–710 nm). The reflectance reduction in NIR was attributed to increases in specific leaf mass caused by salinity, which can be detected with SRVI, and with 660 and 830 nm as the most sensitive waveband combination. Because of the vegetation saturation effect, the difference in NDVI between the salinity and control treatment was very small, therefore, it was not a sensitive indicator to describe salinity stress on soybean canopy reflectance. Sprinkler irrigation appeared to be more favourable for soybean growth, compared to drip or furrow irrigation. Canopy reflectance measurement can be used to detect variations in plant biomass production caused by irrigation method. Remote sensing of plant canopy can provide a comprehensive assessment of plant salinity stress because measurements of growth characteristics at one point in time integrate the cumulative effect of substrate salinity on canopy development. The timing of detection may also be early enough to employ management measures necessary to alleviate the salinity stress before final yield reduction occurs.

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