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DETECTION OF WATER STRESS AND SALINITY AFFECTING SUMMER SQUASH AND CANTALOUPE USING REMOTE SENSING

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ABSTRACT

Summer squash-Early Yellow Crookneck (*Cucurbita pepo*) and Cantaloupe (*Cucumis melo*) were grown in the same concrete lysimeters. This study tested the ability of the two vegetation indices; normalized difference vegetation index and simple ratio vegetation index on the detection of water and salinity stress. Also, it assessed the capability of a new salinity stress index of recognizing salinity stress. Results showed that the salinity stress index indicated clear separation between the treatments for most of the data days; however, differences were not statistically significant. It appears that it was a more appropriate index for cantaloupe than for summer squash. Both vegetation indices separated between salinity treatments at most of the data days (60%) for both summer squash and cantaloupe. They clearly separated between water treatments in about 40-50% of the data days. It appears that their ability in showing water stress was not as theirs in showing the salinity stress. Simple ratio stress index was better than the normalized difference vegetation index in separating between salinity treatments because it gave clear separation between treatments in about 50-70% of the data days. Its capability of showing water stress was not as good as its in assessing salinity stress.

INTRODUCTION

The use of irrigation scheduling methods is constricted because they are expensive or time consuming to be set up for large scale (Ritchie *et al.*, 2004). With the introduction of variable rate irrigation systems, remote sensing offers a relatively low-cost method to explore large areas and water accordingly. Plant *et al.* (2001) mentioned that remote sensing can be a relatively inexpensive source of data for site-specific crop management and for addressing research issues concerning spatial variability of fields. Current remote sensing platforms include satellites, airplanes, and ground-based platforms. Of these, ground-based offer promise as a relatively cheaper method for monitoring crops in developing countries such as Egypt. Remote sensing in the form of reflectance indices can be used to monitor crop growth and health (Ball *et al.*, 1994). Reflectance indices such as the simple ratio vegetation index (SRVI) and the normalized vegetation index (NDVI) are commonly used to estimate crop growth and stress. Ritchie *et al.* (2004) stated that cotton NDVI decreased as plant water status decreased, which permitted the detection of water stress.

Summer squash is not a commercial crop; however, it is a popular crop for home owners. Some squash varieties such as the zucchini type are known as moderately tolerant to salts in the soils and irrigation water, but yellow summer squash is more subjected to salt problems (Clark *et al.*, 1998). Cantaloupe is another moderately tolerant crop that can be considered as a commercial crop. They are quite similar in their sensitive to salinity where both can be considered moderately sensitive to salinity (Graifenberg *et* al., 1996). Soil salts affect crops mostly by withholding moisture from plant tissues. They may also compete for uptake of nutrient ions. Salts will destroy soil structure and cause much-reduced water percolation rates.

Salinization is one of the main problems associated with semi-arid and arid regions. Salinity can be detected by conducting chemical analysis of soil water extracts or plant samples. But this process is very laborious and time consuming. Remote sensing techniques have been shown to be rapid, relatively inexpensive and useful tool in monitoring salinity related crop productivity problems (Rahman *et al.*, 1994; Alsaifi and Quari, 1996; White 1997). Satellite data have been used for detection and mapping of saline soils using different techniques such as principal component analysis (Marchanda, 1981), a combination of spectral classification and physiographic maps (Tricatsoula, 1988), and spectral correlation and classification (Abdel-Hamid and Shrestha, 1992). The objective of this research is to study the use of remote sensing for detection of water and salinity stresses affecting summer squash and cantaloupe. In particular, it evaluates the use of some vegetation and salinity indices for the detection of water and salinity stresses.

MATERIALS AND METHODS

This research was performed in 10 concrete lysimeters in Tucson Arizona, latitude 33 23 N and longitude 111 58 W. They were irrigated using bubbler irrigation heads, three for each lysimeter at a rate of 2 GPM per bubbler head. The lysimeters had an average area of 0.6 by 2 m^2 with an average depth of 0.6 m. All lysimeters were filled with sandy loam soil that had 62.08%, 8.81% and 29.1% of sand, clay and silt, respectively. The soil field capacity and permanent wilting point were 0.2 and 0.09. A preplant application of 5-10-10 fertilizer at 150-g per square meter was made as recommended by the Clemson University Cooperative Extension Service, 2003. Summer squash-Early Yellow Crookneck (*Cucurbita pepo*) and Cantaloupe (*Cucumis melo*) were planted in July 1, 2005 in the same lysimeter. Then ammonium nitrate was sidedressed at 50-g per square meter every 2 weeks from planting. Three water treatments as well as three salinity treatments were evaluated. The salinity treatments were determined by applying a concentration that would result in 50%, 75%, and 100% of the excepted yield. Water treatments were achieved by applying irrigation water amounts equal to 50%, 75%, and 100% of the crop evapotranspiration (ET_c). Crop yield response function (Eq. 1) was used for calculation of the equivalent EC_e values for the 75% and 50% yield reduction (Cuenca, 1989). Calculations indicated that average soil salinity (EC_e) of 4.2 and 5.9 dSm^{-1} would result in 75% and 50% relative yield, respectively.

$$Yr = 100 - b(EC_e - a) \qquad \textbf{(Equation 1)}$$

where a = the salinity threshold expressed in dSm^{-1}; b = the slope expressed in percent per dSm^{-1}; and EC_e = the mean electrical conductivity of soil extract. The EC of irrigation water salinity (EC_{iw}) in relation to the soil salinity (EC_e) is difficult to predict because of the influences of texture, drainage, duration of saline irrigation and leaching fraction. However, assuming a leaching fraction of 10%, a reasonable estimate can be calculated through equation 2 (Ayers and Westcot, 1985).

Soil salinity (EC_e) = 1.0 x EC_{iw} **(Equation 2)**

Therefore based on this relationship, irrigation water at approximately 4.2 and 5.9 dSm^{-1} would result in relative yields of 75% and 50%, respectively. Table salt was mixed with water and kept in two 50-liter barrels, which were connected to two pumps, one for each treatment. The pumps would work automatically to inject the salt into the irrigation system at the time of irrigation. A simple excel work sheet was developed to give the speed of the pump that would result in the specified salt concentration using inputs such as salt concentration in the barrel (EC), desired concentration, and watering time.

Planters 5 and 8 corresponded to the 100% yield, while planters 1 and 2 represented the 75% salinity treatment. The 50% salinity treatment was in planters 7 and 9. On the other hand, 75% water treatment, which corresponded to the application of 75% of the estimated crop evapotranspiration, was in planters 4 and 10. Finally, Planters 3 and 6 were for the 50% water treatment (50% of the estimated crop evapotranspiration was applied). Before planting, all the planters were flooded with water for leaching purposes until the electrical conductivity of soil extract for all the planters were approximately 1 dSm^{-1}. Water and salinity treatments began on July 15 (DOY196) and ended on September 6 (DOY249). Irrigations versus day of year (DOY) were indicated in Figure 1. Irrigation water was collected from bubblers and the electrical conductivity, EC_w, was measured at a weekly basis, DOY 216, 223, 231, and 249, Table1. The table included the measurements for the 75% and 50% salinity treatments only; nonetheless, the rest of the planters had water EC values that ranged from 0.5 to 0.7.

Table 1: Irrigation water EC (dSm^{-1})

Planter	Treatment	DOY216	DOY223	DOY231	DOY249
1	75% yield	3.60	3.96	4.18	4.41
2	75% yield	3.50	3.37	4.24	4.49
7	50% yield	4.06	5.88	5.77	5.6
9	50% yield	4.32	6.37	5.86	5.96

Soil samples were collected from the upper part of the root zone; 10-cm. 1: 5 soil: water extract procedure was used for estimation of salinity content. Soil water extract EC, dSm^{-1}, was measured for different treatments and the results were summarized in Table 2.

Remote sensing data were collected using CROPSCAN, Inc, a multispectral radiometer (MSR16R) mounted on a stand. The MSR included both downward and upward looking sensors for measuring radiance and irradiance, respectively. The MSR included 16 upward and 16 downward looking sensors filtered at wavelengths: 510, 550, 560, 610, 660, 710, 750, 760, 810, 900, 1000, 1050, 1240, 1480, 1640, and 1680 nm. The upward looking sensors are covered with opal glass, which is a cosine transmitting diffuser that automatically correct for solar angle (CROPSCAN MANUAL, 2005).

Table 2: Soil water extract (EC) in dSm^{-1}

Planter	Treatment	DOY216	DOY224	DOY231	DOY249
1	EC (75%)	3.09	3.57	3.93	4.00
2	EC (75%)	4.10	3.64	4.62	4.84
3	ETc (50%)	1.86	2.17	1.53	1.86
4	ETc (75%)	1.09	1.58	1.51	1.76
5	100% yield	1.05	1.11	1.27	1.47
6	ETc (50%)	1.20	1.23	1.33	1.37
7	EC (50%)	4.48	5.04	5.98	5.32
8	100% yield	1.05	1.51	1.90	1.54
9	EC (50%)	4.39	5.57	5.50	5.93
10	ETc (75%)	1.02	2.09	1.40	1.44

The downward looking sensors are covered with clear glass because of the assumption that it is lambertian. Filters at 1450-nm and 1950-nm along with other meteorological data might be better in showing water stress. However, neither the filters nor the meteorological data were available. Further more, the available filters were enough to calculate values for the tested vegetation indices. Since all the growth requirements except water were given sufficiently to the plants, the only factor that might limit vegetative growth would be water. Consequently, water would be the only factor affecting vegetation index values. The CROPSCAN included an acquisition program that convert the millivolts into percent reflectance at each of the selected wavelengths and sun angle and temperature effects were corrected as well. Measurements of either the summer squash or the cantaloupe consisted of three readings then their average was used. Data was taken with the sensor at nadir view, 2:30-3:00 pm daily, at an average height of 20-cm above the plant that resulted in a field of view diameter of 10-cm.

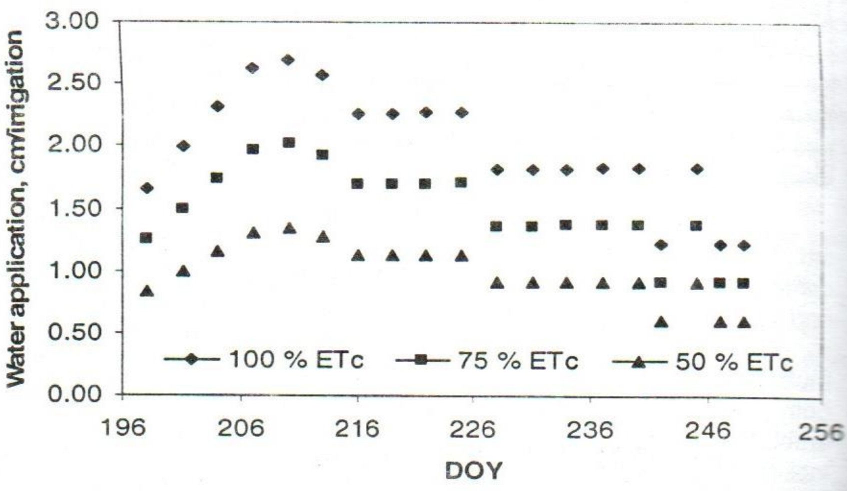

Figure 1: Water applications versus DOY for the different water treatments.

Three indices were used to indicate the water or salinity stress on the summer squash and cantaloupe. The first vegetation index was the normalized difference vegetation index, NDVI, Equation 1 (Rouse *et al.*, 1973) which is an index that is highly correlated with vegetation density. It incorporates the red and near infrared reflectance to mostly measure canopy density. NDVI is the difference between the near infrared (NIR) band and the red band divided by the sum of the NIR and red bands, and its values typically range from 0 (bare soils) to 1.0 (full canopy) over agricultural covers (Equation 1). The second index is the simple ratio vegetation index, SRVI, Equation 2 (Wang *et al.*, 2002). The last index is the salinity stress index (SSI) that was created to assess salinity stress in crops (Stong, 2003). It is calculated by dividing the summation of the reflectance at 1650 nm and 1450 nm, both shortwave infrared (SWIR), by the reflectance at 1000 nm (NIR), Equation 3. The limits of the last two indices changes from one crop to another and they are not defined for the investigated vegetables under study. However, higher values of NDVI and SSI reflect more vegetation and salinity, respectively.

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$$ **Equation 1**

$$SRVI = \frac{\rho_{NIR}}{\rho_{RED}}$$ **Equation 2**

$$SSI = \frac{\rho_{1650} - \rho_{1450}}{\rho_{1000}}$$ **Equation 3**

Where:

- ρ_{NIR} = Reflectance in the near infrared (850-nm)
- ρ_{RED} = Reflectance in the red (660-nm)
- ρ_{1640}, ρ_{1450}, and ρ_{1000} are reflectance at 1640-nm, 1450-nm, and 1000-nm, respectively

RESULTS

Ten successful data days were plotted versus day of year (DOY) and results were statistically analyzed using student's paired t-Test, with a two-tailed distribution to test the significance of the difference between treatments.

Salinity stress index versus DOY for summer squash and cantaloupe were plotted in figures 2 and 3, respectively. In general, the highest values of the index were associated with the EC50 treatment, which was the salinity treatment that would give 50% yield. Though, the lowest values were associated with the EC100 treatment (100 on the figure), which was the treatment that had no salt addition. On DOY 249, the EC50 and 100 had SSI values of 0.11 and 1.0, respectively, for summer squash that were considered as extremes. For the cantaloupe, the highest SSI value was observed at the same day, DOY 249, Fig. 3, which might be justified by the high salinity dose that was applied by the morning of that day. Although most of the differences between salinity treatments were not significant, it was believed that the differences were clearer for the cantaloupe than the summer squash. The EC75 treatment had lower values than that of the EC100 treatment before DOY225, therefore it can be stated that the SSI did start to work properly until DOY225. That might be the result of lower salinity concentration of leaves at early stages.

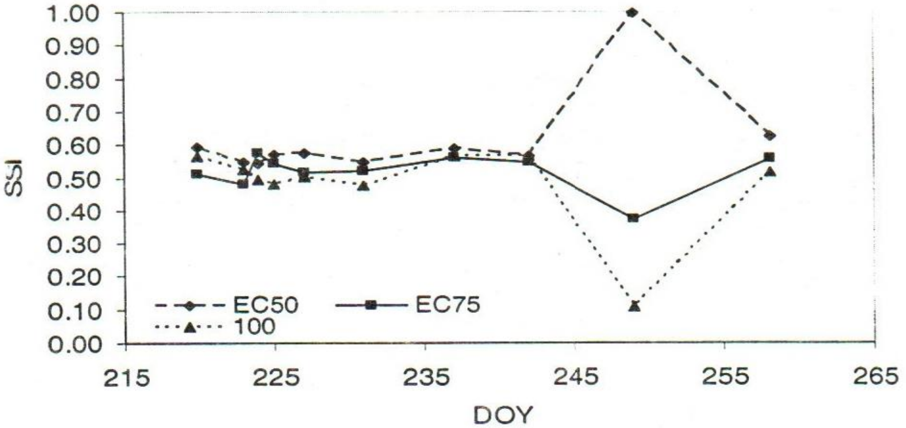

Figure 2: Salinity stress index vs. DOY for summer squash.

The normalized difference vegetation index (NDVI) did not indicate the difference between the salinity treatments for summer squash until DOY242, Figure 4. However, for cantaloupe, it worked better early in the season (DOY223 to 227), Figure 5. Again similar to the SSI, most of the differences were not significant. Excluding DOY 231 and DOY 237, the difference between salinity treatments was clearer for cantaloupe than that for the summer squash. Apparently, the EC50 treatment had low NDVI values at DOY 249 and DOY258 which might be due to a high salinity dose that was applied in the morning of DOY249. Its effect was obvious in the SSI figures too, Figures 1 and 2. However, the cantaloupe recovered its effect at DOY 258, on the contrary, the squash did not.

The increasing versus the decreasing trends of NDVI for the summer squash and cantaloupe, respectively, might be owed to the fact that at the time remote sensing data started, squash was almost at the end of the crop development period, however, the cantaloupe was at the beginning of the crop development period. The length of the crop development period of the cantaloupe was two times that of the summer squash. Therefore, most of the data was taken during crop development and mid season for the cantaloupe, however, the data time covered mostly mid season and late season for the summer squash. Consequently, the NDVI had a decreasing trend for the squash and decreasing trend for the cantaloupe. Also, the summer squash might be more sensitive to salinity than the cantaloupe. Therefore, vegetative growth was better for cantaloupe compared to summer squash.

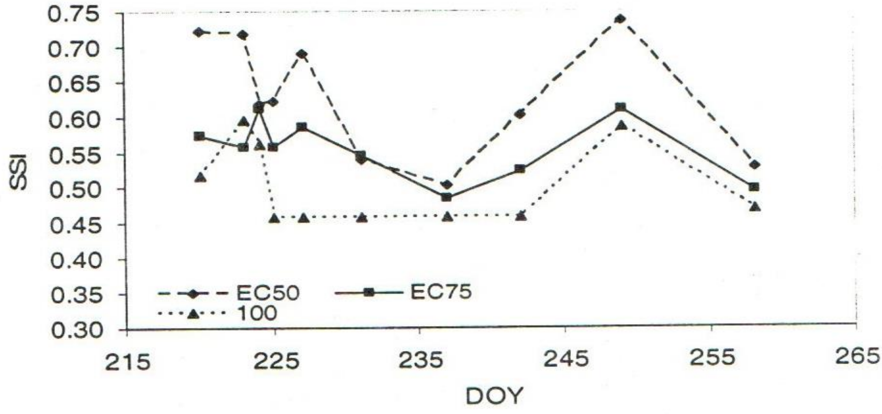

Figure 3: Salinity stress index vs. DOY for cantaloupe.

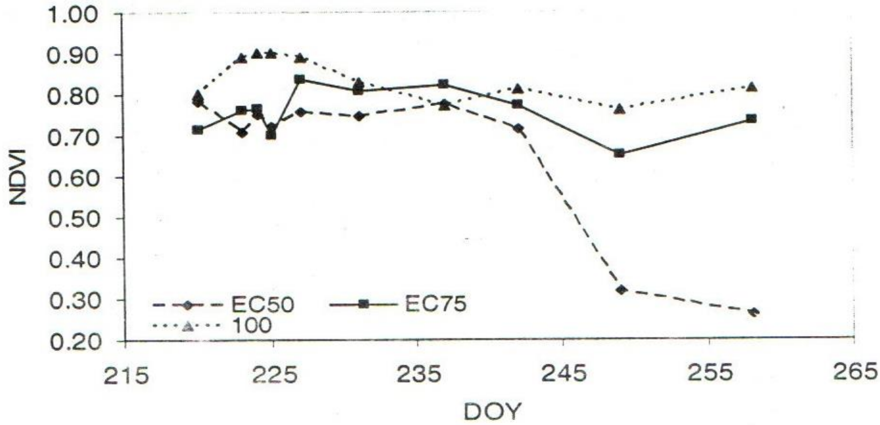

Figure 4: The ability of normalized difference vegetation index to show salinity stress of summer squash.

NDVI was not very successful in showing the difference between water treatments, Figures 6 and 7. For the summer squash, it was successful in differentiating between the water treatments only from DOY 223 to DOY227. During that period, the NDVI was positively correlated with the amount of water applied. Similar to the summer squash, NDVI showed some difference between the water treatments for cantaloupe but during a short period of time, from DOY237 to DOY242.

For Cantaloupe, the difference between the W100 (100 on the figure) and W50 treatments was clear along the whole season, however, the W75 treatment was not following a consistent trend. In other words, W100 treatment had higher NDVI values than that of the W50 treatment during the whole season. Once more, the NDVI had a decreasing trend with the summer squash and increasing trend with the cantaloupe for the same reason mentioned above.

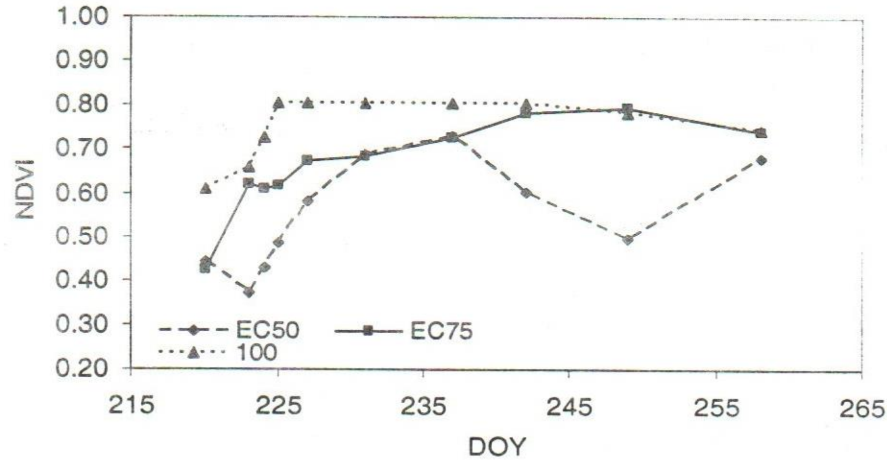

Figure 5: The ability of normalized difference vegetation index to show salinity stress of cantaloupe.

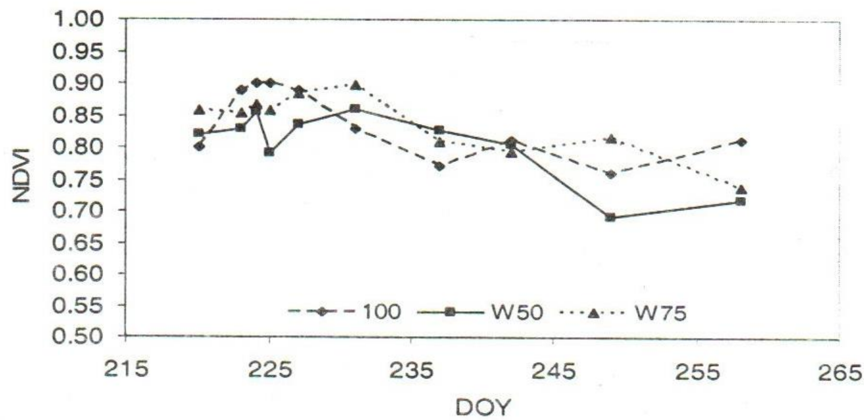

Figure 6: The ability of normalized difference vegetation index to indicate the water stress of summer squash.

Excluding DOY237, simple ratio vegetation index (SRVI) indicated clear differentiation between salinity treatments for the summer squash as early as DOY227 until the end of the season, Figure 8. Comparatively, the SRVI was not clear in differentiating between salinity treatments for cantaloupe as for the summer squash, Figure 9. It separated between salinity treatments from the first data day until DOY227. After DOY227, the difference between the high (EC50) and no salinity (EC100) treatments was clear where the EC 100 treatment was mostly on top. Nevertheless, the EC75 treatment did not have a steady trend. Similar to the NDVI, SRVI had a decreasing trend with the summer squash and increasing trend with the cantaloupe.

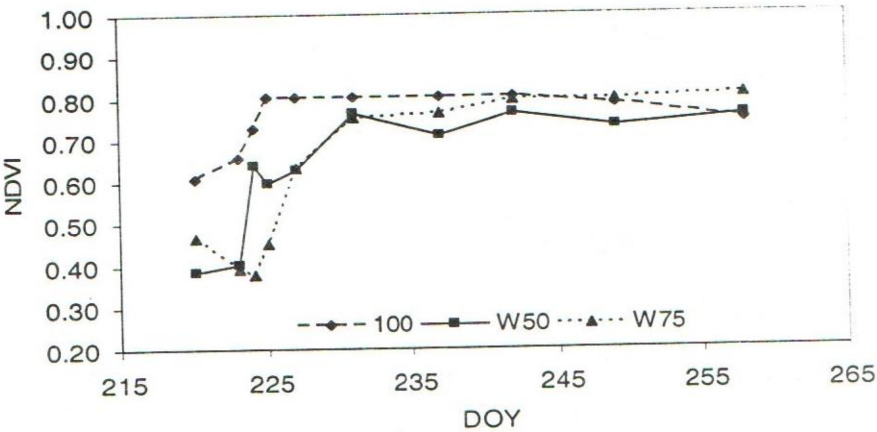

Figure 7: The ability of normalized difference vegetation index to indicate the water stress of cantaloupe.

Figures 10, 11 illustrated the ability of SRVI in showing water stress for summer squash and cantaloupe, respectively. It showed the difference between water treatments only for DOY224 and DOY225. Therefore, it was pointed out that it did not work very well for the summer squash. It was successful in illustrating the differences between water treatments for cantaloupe from DOY237 until the end of the season excluding DOY258. In regards to the separation between the W100 and the W50 treatments it was successful in separating between these two treatments during the whole season. The W75 treatment did not have a steady trend. Likewise, SRVI had a decreasing trend with the summer squash and increasing trend with the cantaloupe.

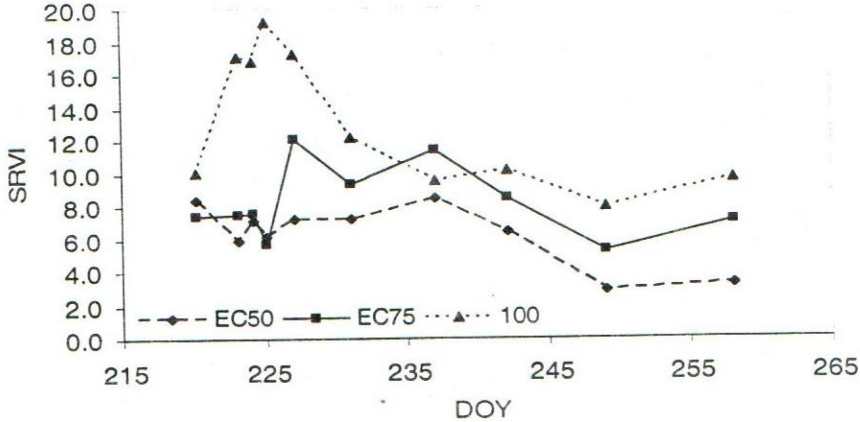

Figure 8: The ability of simple ratio vegetation index to show salinity stress of summer squash.

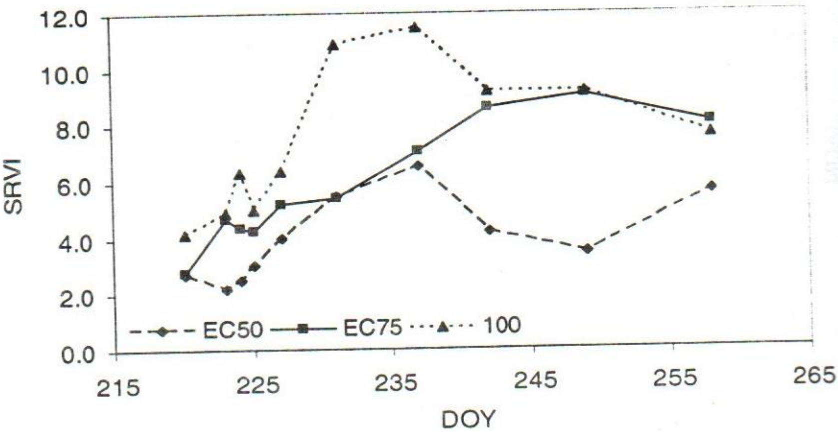

Figure 9: The ability of simple ratio vegetation index to show salinity stress of cantaloupe.

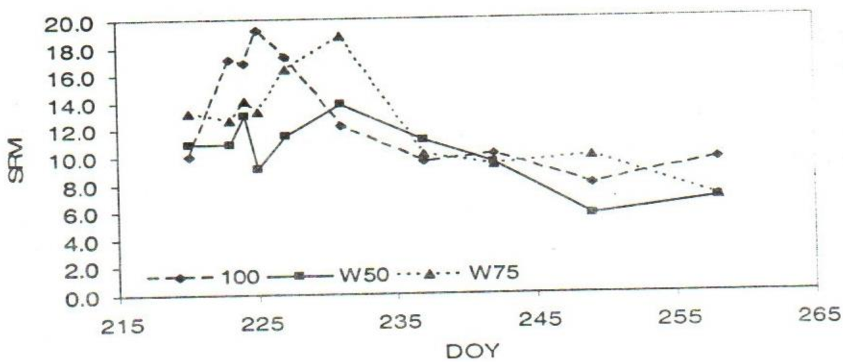

Figure 10: The ability of simple ratio vegetation index to show water stress of summer squash.

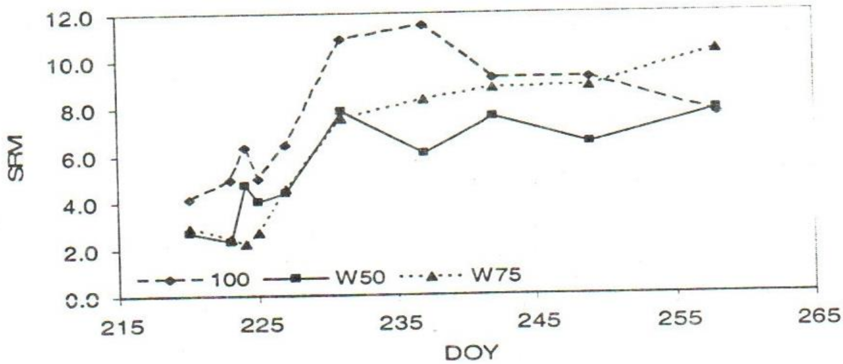

Figure 11: The ability of simple ratio vegetation index to show water stress of cantaloupe.

CONCLUSION

The salinity stress index differentiated between salinity treatments at most of the data days but it did not work properly at early stages. Nevertheless the differences were mostly not significant. It appears that it was a more appropriate index for cantaloupe than for summer squash. Normalized difference vegetation index was better in showing the difference between salinity treatments early season for the summer squash and late in the season for the cantaloupe. Its ability in showing water stress was not as good as its ability in showing salinity stress. The ability of simple ratio vegetation index in showing salinity stress was better for summer squash than for cantaloupe. The SRVI ability in illustrating the differences between water treatments was relatively better early in the season for summer squash and late in the season for cantaloupe. Due to the fact that most of differences between treatments were not significant, more salinity and water levels should be used in future studies to determine the extent of the tested indices in showing the water and salinity stress.

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إستخدام الإستشعار عن بعد لإكتشاف الملوحة و نقص الميـاه لنباتـات الكوسـة الصيفية و الكنتلوب

ضياء الدين محمد الشيخة
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تم إجراء هذا البحث لدراسة إستخدام الإشعاع المنعكس من الكوسة و الكنتالوب في المنطقة المرئية و غير المرئية من الفيض الكهرومغناطيسي بالإضافة إلي معايير الخضرة مثل معيار النسبة البسيطة، معيار الفرق المعدل و معيار الملوحة لإكتشاف التأثر بالملوحة و نقص المياه. و إشملت التجربة ثلاث معاملات ري بما يكافئ ٠،٥ ، ٠،٧٥و ١،٠٠ من البخرنتح و ثلاث معاملات ملوحة تكافئ الحصول علي ٠،٥ ،٠،٧٥ و ١،٠٠ من المحصول. و بينت النتائج ان كل المعايير كانت ذات علاقة طردية مع كمية مياه الري للكوسة الصيفية و الكنتالوب. كما إتضح أن معيار الملوحة كان أكفأ في تقدير التأثر بالملوحة للكانتلوب عن الكوسة الصيفية. و بينت النتائج أيضا أن معايير الخضرة المدروسة كانت أقدر في تقدير الملوحة عن تقدير نقص المياه لكلا من الكوسة الصيفية و الكنتالوب. و أثبتت النتائج بصفة عامة تفوق معيار النسبة البسيطة عن معيار الفرق المعدل في تتبع الملوحة و نقص المياه. و يمكن القول ان نتائج هذه التجربة تدعم إمكانية إستخدام الإستشعار عن بعد لتقدير محتوي المياه و التأثر بالملوحة لكلا من الكوسة الصيفية و الكنتالوب.