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REMOTE SENSING OF CROP CANOPY TEMPERATURES FOR SCHEDULING IRRIGATIONS AND ESTIMATING YIELDS

R. D. Jackson, S. B. Idso, and R. J. Reginato

ABSTRACT

Emitted thermal radiation in the 8 to 14μ waveband was used to infer surface temperatures of bare soils and crop canopies. The maximum-minimum soil surface temperature differences were related to soil water content. This procedure provides a means of remotely estimating soil water content over large areas. The difference between the crop canopy temperature, and the air temperature measured just above the crop 1 to 1 1/2 hours after solar noon was found to be an indicator of crop water stress. The difference was defined as a stress degree day. The sum of the stress degree days from heading to harvest for wheat was well correlated with final yields. The sum of the positive values of stress degree days after an irrigation can be used as an indicator of when the next irrigation is required.

The utilization of remote sensing technology by agricultural interests is rapidly increasing. Reflected radiation in the visible region routinely is being measured by ground, aircraft, and satellite-based instruments. Color photographs produced from Landsat data have been widely distributed and have appeared in many popular magazines. The use of the thermal infrared (8-14μ) region has not developed as rapidly as the use of reflected visible radiation because the data gathering and processing equipment is more complex and more expensive. Thermal IR channels are not on the present Landsat satellites, but are planned for the follow-on satellites. Thermal IR may become a major agricultural tool because of its potential usefulness to estimate soil water content and crop water stress.

Our first efforts in remote sensing were to develop means of estimating soil water content. Conventional methods of measuring soil water content are essentially point samples, but may be taken to any desired depth. Remote sensing methods are restricted to the upper few centimeters of soil, but can be made over large areas. The basis for using remotely sensed thermal IR is that soils containing water have a higher heat capacity and a higher thermal conductivity than dry soils. In addition, evaporation of water cools the soil surface of moist soils, further increasing the temperature difference between wet and dry soils under the same environmental conditions.

Using portable ground-based IR thermometers and some aircraft data, we found that the difference between the maximum soil surface temperatures (at about 1 to 1 1/2 hours after solar noon) and the minimum soil surface temperatures (just prior to sunrise) were closely related to the soil water content in the upper few centimeters of soil (Idso et al. 1975, Reginato et al. 1976). The maximum-minimum temperature difference is affected by environmental factors such as changes in the precipitable water in the atmosphere, clouds, etc. We developed a method of minimizing these variations by normalizing the soil temperature difference with the maximum-minimum air temperature difference (Idso et al. 1976).

The basis for crop water stress measurements lies in the relationship between evaporation of water from plant leaves and their resultant temperature. When a plant has an ample supply of soil moisture, water is readily absorbed by the roots, transported to the leaves, and evaporated at the rate dictated by atmospheric conditions. The cooling effect of this evaporation generally reduces leaf temperatures below air temperature. As water becomes more limiting, however, it becomes more and more difficult for absorption by roots and translocation through the plant to meet the atmospheric demand for evaporation. Thus, less water is lost from the leaves, and the reduced cooling results in leaf temperatures rising above air temperature.

Although these concepts have been known for years, it was not until thermal infrared thermometers and airborne infrared scanners became available to infer surface temperatures that a practical management tool for crop water stress assessment could be developed. The key factors in such operations are essentially the same as for estimating soil water content, the canopy-air temperature differential at the time of maximum temperature (about 1 to 1.5 hours after solar noon) and the maximum-minimum canopy temperature differential (the minimum occurring about 30 minutes before sunrise). The first factor is most useful in ground-based assessment of plant water stress with hand-held infrared thermometers, when the air temperature above the crop as well as the canopy temperature may also easily be obtained. The second factor is most useful for aircraft and satellite operations utilizing thermal scanners, where both presunrise and early afternoon fly-overs are made. In these cases, air temperatures above the crop are not needed, but local Weather Service daily maximum and minimum air temperatures are required for the flight days to normalize the canopy temperature differences to reduce the effects of environmental factors such as clouds and water vapor on the canopy temperatures (Idso et al. 1976).

We have called the temperature difference for a day a "stress degree day," somewhat analogous to the centuries-old concept of the "growing degree day." Summing daily values of the stress degree day has promise of being a reliable index of crop water stress (Idso et al. 1977, Jackson et al. 1977). Detailed experiments were conducted in which we related the stress degree day to plant water stress as measured by the Scholander pressure technique (Ehrler et al. 1977). These comparisons were made during the growing season of a durum wheat crop (Triticum durum Desf. var. Produra) at Phoenix, Arizona in the spring of 1976. We measured predawn and early afternoon wheat canopy temperatures every day during the season on six plots of wheat, each of which was irrigated at different times in order to create several water stress conditions. Beginning at heading, we summed the stress degree days (SDD's) for each irrigation treatment. We found that the final yield was linearly correlated with the accumulated SDD's at the time of maturity. That is, the higher the canopy temperature rose above the air temperature, and the more often it did so, the lower was the final yield of grain (Idso et al. 1977). We found the same principle to hold with alfalfa when the SDD summation was made over the period of vegetative growth (Reginato et al. 1977).

If the accumulated SDD's have been increasing for some time, indicating a stress period, and the plants are watered, the SDD's will level off if the stress has not been severe, but will continue to increase if the water arrived too late to help the plant. Thus, the recurrent monitoring of SDD's following a stress period can be used to evaluate the effects of rain or irrigation on the final yield.

If crop temperatures are monitored in irrigated areas, accumulated SDD's provide an index to determine the optimum time for water application. We found that wheat plants had ample water as long as the SDD's remained negative. Thus, it is necessary to accumulate only the positive values of SDD's to determine when to irrigate. Our first results, obtained by comparison with measured water use, indicated that a value of 10 is a good index (Jackson et al. 1977). We are currently conducting an experiment to fine-tune this value for wheat, and will soon work with cotton to determine its index value.

Small infrared thermometers, about twice the size, but one-half the weight of a standard 35 mm camera, should soon be available. If they prove reliable for field use, it would be relatively simple for a farmer to walk into his field after lunch, read the canopy-air temperature difference, record it, and add only the positive values to date to determine when to irrigate. Taking it one step further, remote infrared thermometers in air or spacecraft could scan fields and report to a computer that would actuate an automatic irrigation system. We have successfully used an airborne thermal scanner to evaluate plant water stress (Millard et al. 1977a, b).

To date, we have considered only agricultural applications of thermal IR. Remote sensing of rangelands with thermal IR should be a very productive endeavor. The relatively sparse vegetation on rangelands (compared to agricultural fields) is a complicating factor. We have worked with bare soil and crops with essentially a full canopy. The intermediate region - sparse vegetation, row crops, etc. - where both bare soil (which may be hot) and vegetation (which would be cooler than soil) are observed by the radiometer, is difficult to interpret and is certainly a prime target for future research.

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