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SHORT COMMUNICATION

Remote Detection of Nutrient and Water Deficiencies in Sugarcane Under Variable Cloudiness

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Spectral measurements were made in a red (0.63-0.69 um) and an infrared (0.76-0.90 um) band over sugarcane using a radiometer mounted on a 4-m aluminum pole. Infrared/red ratios measured over a plot with adequate nitrogen, potassium, and water were significantly higher than those measured over a nitrogen-deficient plot at the 1% level, and higher than those over a potassium deficient plot at the 10% level. In a second experiment, the infrared/red ratios of water-deficient plots were significantly lower than those for plots receiving adequate water. The measurements were made under conditions of variable cloudiness, ranging from full shade to direct sunlight. Although radiance values changed by a factor of 5 from one measurement to the next, changes in the infrared/red ratio were minimal, indicating that this ratio can be adequately measured under variable irradiance conditions for sugarcane when the plants form complete ground cover.

Introduction

Sugarcane is the most economically important agricultural crop in the State of Hawaii. About 100,000 ha are grown on four islands under annual rainfall conditions varying from less than 50 to greater than 500 cm. About 50% of the hectarage is irrigated, all of which requires fertilization during the 20- to 24-month growing season. Irrigation requirements are determined by a water budget method that uses pan evaporation and rainfall as inputs. Visual symptoms of water stress and the rate of internode elongation are used as checks of irrigation adequacy. Fertilizers are applied periodically as soil tests, plant tissue tests, and experience dictate.

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If an accurate, rapid method can be developed to monitor entire fields to detect nutrient and water deficiencies at an early stage, fertilizer and irrigation schedules can be adjusted to more adequately satisfy crop needs. This report presents the results of an experiment designed to determine if remotely-sensed ratios of infrared to red radiance data are useful in evaluating nitrogen (N), potassium (K), and water deficiencies in sugarcane, and to determine if such measurements can be made during rapidly changing irradiance) conditions caused by clouds.

Experimental

Our experiments were conducted at the Hawaiian Sugar Planters' Association's Kunia substation, Oahu, on a soil described as clayey, kaolinitic, and isohyperthermic of the family of Typic Torrox, Molakai series. Two sugarcane fields were used. One field consisted of plots having different nutrient levels and uniform irrigation (approximately equal to pan evap oration); and a second field consisted of plots that received equal fertilization at the recommended rates, but were irrigated with different amounts of water. The fertility plots contained 5-month-old ratoon-cycle cane. When 2 months old, two plots received **112** kg/ha of both N and K; one received N but no K; and one received K but no N. The plots were irrigated 5 days per week through a drip irrigation system at a rate approximately equal to the daily rate of water loss from a standard Class A ground-level U.S. Weather Service evaporation pan. One of the two plots that received both N and K was kept as a control and the second was not irrigated (no rain occurred) for 3 weeks before to the date that the measurements were made.

In the irrigation experiment, the plant-cycle cane was 6 months old and had received irrigations 5 days' per week through the drip irrigation system at four rates: 35, 45, 60, and 75% of pan evaporation, adjusted for rainfall.

In both fields the sugarcane was 2.5-3.5 m high and formed a complete canopy. The N-deficient plot showed visual symptoms of chlorosis and growth depression. The K-deficient plot showed no foliar symptoms, but a slight growth depression was observed. In the irrigation experiment, water-deficient plots showed some growth depression and browning of the lower leaves.

Radiance measurements in the red (0.63-0.69 um) and the infrared (0.76-0.90 um) bands were made between **1000** and **1100** hours local time using a portable radiometer described by Tucker et al. (1980). The radiometer's sensing element (set to a nominal 15 field-of-view angle) was mounted on an arm at the top of a 4-m aluminum pole. The arm was counter balanced so that the entire apparatus could be easily leveled during measurements and readily moved, while holding the sensing element about 1.5 m from the center pole.

Although the sugarcane was of sufficient height and width that rows were nearly indistinguishable from above, the measurement sequence was first over, and then between, rows to minimize the effects of differences in plant density due to row structure. Four readings (two bands per reading) were taken per site (two over rows, two between rows) by rotating the pole about 150. The apparatus was sequentially moved about 1 m four times within each plot to yield four sites, or 16 measurements, per plot.

Results and Discussion

Detection of N and K deficiencies

Results of measurements over the fertilized plots are presented in Table 1. Means of the infrared/red ratios and their standard deviations are given. The t statistic was used to determine if the means were significantly different from one another. The levels of significance (in percent) are given in the lower part of the table.

The data indicated that N deficiency can be readily detected and could probably have been detected earlier when visual symptoms of deficiency were less evident. The K-deficient plot had a ratio only slightly less than that for the control, with the t test significant at the 10% level. Withholding irrigation for 3 weeks before the measurements had a slightly greater effect on the infrared/red ratio than a lack of K, but these differences were not significant. The water-deficient plot differed significantly from the control at the 5% level.

Detection of water deficiency

The infrared/red ratios for four irrigation treatments are shown in Fig. 1. The increase in the infrared/red ratio that occurred when irrigation was increased from 45% to 75% of pan evaporation indicated that the ratio is a useful indicator of water deficiency in sugarcane. The ratio would not be expected to continue to increase exponentially with increasing irrigation as indicated by the four data points, but would level off to form a sigmoid curve.

The data in Table 1 and Fig. 1 show that the infrared/red ratio is sensitive to both N and water deficiencies. However, the ratio will not differentiate between the two. When a low value for-the ratio is found, other methods must be used to determine whether a nutrient or a water deficiency exists. If the ratio were to be determined by periodic monitoring of sugarcane fields, the records should indicate which deficiency to expect. The measurements would show the location and the extent of the deficiency.

Effects of cloud cover

Sugarcane is grown in warm, subhumid-to-humid areas of the world. In these areas, clouds are usually present, causing variable conditions of irradiance. For a remote sensing technique to be useful as a management tool, it must perform well under these variable conditions. Table 2

TABLE 1 The Infrared/Red Ratios for Sugarcane Plots Having Adequate Nitrogen, Potassium, and Water (Control); Deficient Potassium (K), Deficient Nitrogen (N), and Deficient Water (By Withholding Irrigation for 3 Weeks Prior to Measurement).

		Deficiency		
	Control	K	N	Water
Infrared/red ratios				
Mean	17.4	16.2	9.3	15.1
Standard deviation	0.44	0.33	0.61	0.60
t test %				
Control	—	10	1	5
K		—	1	NSa
N				1

a Not significant

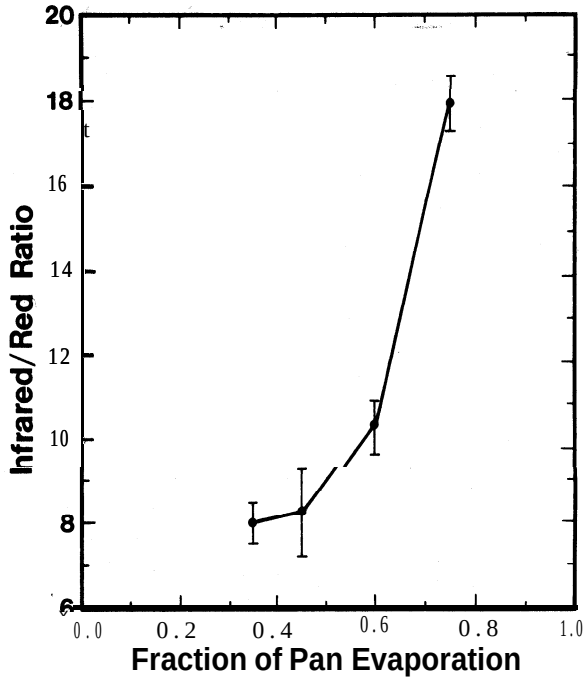

FIGURE 1. Infrared/red ratios for four sugarcane plots that were irrigated daily with an amount of water equivalent to the fraction of pan evaporation shown. Nutrients were not limiting.

TABLE 2 The Effect of Variable Irradiance on the IR/R Ratio Measured over Sugarcane.

RADIANCE		
RED	IR	IR/R RATIO
1.03	17.0	16.5
0.284	4.50	15.8
0.326	5.24	16.1
1.22	20.0	16.5

shows radiance values for the red and infrared bands at four sites on the K-deficient plot in the fertility experiment. Rapidly changing cloud conditions during the 5-min measurement period caused radiance values to vary up to a factor of 5 in both bands. However, the ratio remained essentially constant, indicating that it is a useful parameter, even under conditions of variable irradiance. We believe that the ratio would not necessarily remain constant under variable irradiance conditions if the crop did not cover the soil. Row crops, in which soil is exposed, yield infrared/red ratios that are time-of-day (solar elevation and azimuth) dependent, even under clear sky conditions (Jackson et al. 1979).

Concluding Remarks

Sugarcane is planted in rows (usually about 1.5 m apart), and grows rapidly to cover the soil within 3 to 4 months. Since it has full ground cover during about 20 of its 24-month growing season, measurements over sugarcane should yield useful infrared/red ratios during the period that the detection of nutrient and water deficiencies is most critical. The data reported here indicated that a remote

sensing technique, using the ratio of infrared-to-red radiance data, would be a useful tool for detecting nutrient and water deficiencies in sugarcane. Additional research is needed to establish expected values of the ratio for a "normal" crop and to solve problems related to the development of an operational monitoring system, based on remote sensing, such as the effects of lodging as the cane ages.

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