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16. Sumário/Notas *The following three experiments were conducted on corn (Zea mays L.) plants using a calibrated Exotech Model 20C spectroradiometer under field conditions in the indium antimonide channel (InSb, 2.8 to 5.6 μm) and mercury cadmium telluride channel (HgCdTe, 7 to 14 μm): (1) ground cover experiment (2) experiment on non-systemic stressed corn plants and (3) experiment on systemic-stressed corn plants. In the first experiment, average spectral radiance temperature,* $\overline{T}_s(\lambda)$, *for the four healthy corn plant populations (15, 30, 60 and 90 thousand per hectare) were found to be statistically significantly different (level of significance 0.05). In the second experiment,* $\overline{T}_s(\lambda)$ *of the corn plants increased with increase in blight severity. In the third experiment,* $\overline{T}_s(\lambda)$ *of the corn having different rates of nitrogen applications (0 kg/hectare, 67 kg/hectare and 201 kg/hectare) were found to be statistically significantly different.*

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EFFECTS OF SYSTEMIC AND NON-SYSTEMIC STRESSES ON THE THERMAL CHARACTERISTICS OF CORN[1]

Ravindra Kumar, L.F. Silva, and M.F. Bauer[2]

ABSTRACT

Three experiments were conducted on corn (Zea mays L.) plants using an Exotech Model 20C spectroradiometer under field conditions: (1) ground cover experiment, (2) experiment on non-systemic stressed corn plants and (3) experiment on systemic-stressed corn plants. Wavelength and spectral radiance calibration of the spectroradiometer was done in the indium antimonide (InSb, 2.8 to 5.6 μm) and the mercury cadmium telluride channels (HgCdTe, 7 to 14 μm). A level of significance of 0.05 was taken throughout statistical analysis for all the experiments. The average of spectral radiance temperature was taken over certain selected wavelength regions in the indium antimonide and mercury cadmium telluride channels, and is denoted by $\overline{T}_s(\lambda)$. In the first experiment, average spectral radiance temperatures for the four healthy corn plant populations (15, 30 60 and 90 thousand per hectare) were found to be statistically significantly different in

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each of the selected wavelength regions of the indium antimonide channel. In the second experiment, $\overline{T}_s(\lambda)$ of the corn plants increased with the increase of blight severity in each of the selected wavelength regions of the InSb as well as the HgCdTe channel. The contact temperatures of the healthy and blighted spots of corn leaves were not found to be statistically significantly different. A tentative conclusion is that the percentage of the soil, especially sunlit soil, visible from the spectroradiometer is the predominant factor causing differences between $\overline{T}_s(\lambda)$ of the healthy and blighted corn plants. In the third experiment, $\overline{T}_s(\lambda)$ of the corn having different rates of nitrogen application (0 kg/hectare, 67 kg/hectare and 201 kg/hectare) - were found to be statistically significantly different in each of the selected wavelength regions of indium antimonide channel.

INTRODUCTION

Remote sensing is beginning to provide tools and techniques with which agronomists and plant pathologists can rapidly observe crop conditions. Detection of crop diseases is but one of many possible applications of remote sensing technology (Bauer, 1976). The interpretation of multispectral scanner data is enhanced by the use of spectral data taken under field conditions. The application of such field data to the analysis of multispectral information may allow the interpretation of second-order differences in the airborne observations (Silva et al., 1971; Hoffer, 1971).

The field van system of the Laboratory for Applications of Remote Sensing (LARS), of Purdue University, was used extensively in the 1968 growing season, to record the spectra from natural scenes with the Block 195 T Michelson Interferometer spectrometer in the region of 5 to 15 μm (LARS Annual Report, 1968).

However, much of the research on the reflective and thermal properties of plants and soils has been done in the laboratory (Kumar, 1972). Field studies have been hampered by the lack of suitable instrumentation for obtaining reliable spectral measurements (Silva et al., 1971). Consequently, there has been increased reliance on laboratory instruments and spectral measurements of individual leaves or small soil samples. Such techniques have been used effectively, but the resulting spectra lack the interrelationships between green leaves, dead leaves, the soil itself and shadows for the entire scene as measured by an airborne remote sensing system. Further, most previous researchers made multispectral measurements of the plants in the visible, near-and middle-infrared wavelength regions. This is due to the lack of suitable instrumentation for obtaining reliable spectral measurements in the thermal infrared wavelength region.

Gates (1970) pointed out that the chemical status of plants determines normality or abnormality of growth. A chemical excess or deficiency for a plant may cause chlorosis, premature yellowing and abscission of leaves, burning of leaf tips, bronzing, wilting, mottling, necrosis, water stress, cupping of leaves, flower-color changes or other abnormalities. A change in the spectral properties causes changes in the energy balance of the leaf and hence its temperature.

He found the temperatures of potassium-deficient sugarcane leaves to be 0.5° to $1.5^{\circ}C$ warmer than normal leaves exposed to sunlight. Silva et al. (1972) reported that a sulfur-deficient corn plant, in an ambient temperature of $24^{\circ}C$, and a nitrogen-deficient corn plant, in an ambient temperature of $23^{\circ}C$, were $1^{\circ}C$ *cooler* and $2^{\circ}C$ *cooler*, respectively, as compared to the healthy controlled plant, when the surface located immediately behind the plants, in both cases, was $16.5^{\circ}C$. The preliminary conclusion made was that nutritionally stressed plants are not always hotter than a controlled plant, but are apparently influenced more strongly by environment.

In the analysis of multispectral scanner data of the Corn Blight Watch Experiment, almost all the LARS analysts found the thermal channel (9.30 to 11.70 μm) to be one of the best four channels, out of twelve available channels, using a feature selection algorithm. This finding created interest among the staff members of LARS, to find the reasons for this and was an additional impetus for performing field experiments in the thermal infrared wavelength region using long wavelength spectroradiometer. Kumar and Silva (1974, 1977), analyzed multispectral scanner data in the twelve spectral channels for three flightlines. They found thermal channel to be one of the best ones in the subsets of four or more spectral channels for getting good overall statistical separability of agriculture cover types.

Cipra et al. (1971) measured the radiance characteristics of soil with an Exotech Field Spectroradiometer; the authors used a modified version of this spectroradiometer for the experiments described here.

The purpose of this study was to determine the effect of systemic and non systemic stresses on the spectral response of corn plants in the thermal infrared wavelength region, using the longwavelength head of the Exotech Model 20C spectroradiometer. This model has wavelength ranges of 2.8 to 5.6 μm and 7 to 14 μm. The specific objectives of the study were:

(1) To determine in what wavelength regions the spectral radiance temperature of the stressed

plants is statistically significantly different from the healthy ones;

(2) to try to determine predominant variables that cause the differences between the spectral radiance temperature of healthy and stressed plants, using statistical analysis of spectroradiometric data and ground observations; and

(3) to try to explain the results of these experiments on a physical basis.

METHODS AND MATERIALS

The Exotech Model 20C spectroradiometer was used to conduct three experiments: (1) ground-cover experiment, (2) experiment on non systemic stressed corn plants and (3) experiment on systemic stressed corn plants. The Exotech Model 20C spectroradiometer is a rugged field instrument that has four circular-variable-filters to provide spectral resolution of approximately 2%. This instrument is ideally suited to the rigors of a field environment, embodying sealed circuits for protection against dust and condensation, modular construction for simplified maintenance, and operational features designed to reduce data acquisition time. This instrument can be operated as two separate units. The short wavelength (SWL) unit is responsive to radiation in the wavelength range from 0.38 to 2.5 μm and the long wavelength unit (LWL) is responsive to radiation in the wavelength range 2.8 to 5.6 μm (indium antimonide channel) and 7 to 14 μm (mercury cadmium telluride channel). Further details of an earliar version of the instrument can be found in Leamer et al. (1973). In this paper, only the results with the long wavelength head are presented.

A LARS Hi-Ranger mobile aerial tower is used to lift the optical heads to the desired position relative to the target scene (Figure 1). The optical heads may be lifted to a height of 15.3 m above the ground and may be suspended as far as 6.4 m from the edge of the Hi-Ranger at a height of 9.15 m. The control electronics, recording equipment, and other data-recording instruments are located in the instrument van. A power unit towed behind the instrument van provides electrical power for both the instrument van and the spectroradiometer. Normally, a technician operates the equipment while the natural scientist directs the experiment. Further details of "The LARS Extended Wavelength Spectroradiometer" are available: Kumar & Silva (1973), Robinson et al. (In preparation).

The wavelength calibration for both the indium antimonide (InSb) and mercury cadmium telluride (HgCdTe) channels was done by finding the pulse number corresponding to the sharp and accurately known absorption bands of polystyrene, atmospheric carbon dioxide and methyl cyclohexane. A copper cone having an apex angle of 15° and a diameter of about 16.5 cm was painted with Parson's Optical Black Lacquer and fitted into a fiberglass covered foam box. This was used as a blackbody for calibration of spectral radiance of the spectroradiometer. Two such blackbodies were used in the field experiments; one kept well above the ambient temperature (called hot blackbody) and the other kept well below the ambient temperature (called cold blackbody). Spectral radiance calibration of the instrument was done in the field with the help of hot blackbody and cold blackbody before starting an experiment. Further details concerning the calibration of the instrument can be found in Kumar and Silva (1973) and Robinson et al. (In preparation).

In all of the experiments, spectroradiometric scan of each of the corn (Zea mays L.) plots was accomplished in the InSb and the HgCdTe channels on relatively cloud-free days (i.e., sky radiant temperature < $-5^{\circ}C$), from a height of about nine meters. Ground observations of sky radiant temperature, sunlit soil temperature, shaded soil temperature and air temperature etc., were generally made with each spectroradiometric scan. A portable radiation thermometer (PRT-5) was used to determine the radiant temperature of the sky. Calibrated probes types 709 and 705, manufactured by Yellow Springs Instruments, were used to measure the contact temperatures of soil and air respectively.

Data of spectral scans of the targets, hot blackbody and cold blackbody were stored on magnetic tapes. In addition, the ground observations were also stored on the same tapes. These tapes are digitized. A data processing software system has been developed at the LARS to calibrate the spectroradiometric scans for spectral radiance (L_λ) and spectral radiance temperature ($T_s(\lambda)$) of the target in InSb and HgCdTe channels at a wavelength interval of about 0.03 μm and 0.07 μm respectively.

The data in the wavelength regions 2.6 to 3.6 μm, 4.15 to 4.50 μm and 5.40 to 5.60 μm were not analyzed due to problems of low signal-to-noise ratio, of strong absorption by carbon dioxide, and of being close to the end of the circular variable filter wheel respectively. The spectral radiance temperature, calculated at wavelength interval of about 0.03 μm in InSb channel, was averaged over each of the wavelength regions mentioned above and is denoted by $\overline{T}_s(\lambda)$.

Similarly, HgCdTe channel (7 to 14 μm) was divided into the following seven wavelength regions for analyzing the data: 7.5 to 8.2 μm; 8.2 to 8.9 μm; 8.9 to 9.6 μm; 9.6 to 10.3 μm; 10.3 to 11.0 μm; 11.0 to 11.7 μm; and, 11.7 to 12.4 μm .

The data in the wavelength regions 7.0 to 7.5 μm and 12.40 to 14.00 μm were not analyzed because the signal-to-noise ratio can be low in these wavelength regions (as these correspond to near the start of and near the end of the circular variable filter wheel respectively). The spectral radiance and spectral radiance temperature of the target were calculated at a wavelength interval of about 0.07 μm in the HgCdTe channel. This calculated spectral radiance temperature was averaged over each of the wavelength regions mentioned above and is denoted by $\overline{T}_s(\lambda)$.

As pointed out above, three experiments were conducted. The method of these experiments is described briefly under their respective headings.

I. Ground-Cover Experiment

The experiment was conducted on the Purdue University Agronomy Farm in the summer of 1972. Corn (Zea mays L.) plants were grown in the plots in 6-76 cm rows, 4.6 meters long. Fertilizer and herbicides were applied prior to planting on 25 May 1972. The planting was done by hand in order to obtain uniform spacing between plants. Plots with varying amounts of ground cover were established by having five different plant populations: 0, 15, 30, 60 and 90 thousand plants per hectare, each plant population being replicated twice in a randomized completeblock design.

Spectroradiometric scan of each of the plot numbers one to ten was accomplished in the Indium Antimonide Channel (2.8 to 5.6 μm) with the Exotech Model 20C spectroradiometer on 18 August 1972, which was a relatively cloud-free day (sky radiant temperature was less than $-5^{o}C$).

II. Experiment on Non Systemic Stressed Corn Plants

This experiment was designed to study the effect of non systemic stresses on the spectral response of corn plants in the long wavelength thermal infrared wavelength region. The experiment was conducted for the southern corn leaf blight (Ullstrup et al., 1945) because corn blight is representative of the problems of non systemic stresses.

The field experiments were conducted on the Purdue University Agronomy Farm in the summer of 1972. Corn (Zea mays L.) plants of row width 76 cm, plant population 52500 plants per hectare, were planted 18 May on the silty clay loam chalmers soil.

Two hybrids, Pioneer 3306 and Pioneer 3571, were chosen for growing corn of normal (N) as well as Texas male-sterile cytoplasm. One of the objectives of the experiment was to determine if there was any statistically significant difference in the spectral radiance temperature of the Pioneer 3306 corn (healthy as well as blighted) and Pioneer 3571 corn. Helminthosporium maydis (H. maydis) causes relatively mild infection on corn of N cytoplasm, but it attacks corn in TMS cytoplasm with unusual virulence which causes southern corn leaf blight. Half of TMS corn plots were inoculated with H. maydis on 28 June; whereas, the other half were inoculated with H. maydis on 14 July. The whole experiment (N + TMS cytoplasm) was replicated twice on 9 August as well as 17 August 1972 under relatively clear-sky conditions.

III. <u>Experiment on Systemic Stressed Corn Plants</u>

The purpose of this experiment was to study the effect of systemic stresses on the spectral response of corn plants in the long wavelength thermal infrared wavelength region. Nitrogen deficient plants were used in the experiment because nitrogen deficiency is representative of the problems of systemic stresses.

The field experiments were conducted on the Purdue University Agronomy Farm where long-term fertility experiments are available. These are replicated experiments with varying rates of nutrient application. Corn plants of row width 71 cm, plant population 54,500 plants per hectare, were planted on 18 May 1972, on the chalmers soil having a smooth surface and a silty clay loam texture. The experiment was conducted on three rates of nitrogen application: (the nitrogen application was given in the form of ammonium nitrate in spring) 0 kg/hectare, 67 kg/hectare and 201 kg/hectare (healthy).

Two measurements (spectroradiometric scans) for each of the three nitrogen treatments were done in the Indium Antimonide Channel (2.8 to 5.6 μm) on 18 August, which was a relatively cloud-free day.

RESULTS AND DISCUSSION

A level of significance (α level) of 0.05 was used in all of the experiments for statistical analysis of data. Bartelett's Test (Ostle, 1969) was used individually in each of the wavelength regions of InSb and HgCdTe channels mentioned above, to test for the homogeneity of the variances of the average spectral radiance temperature $\overline{T}_s(\lambda)$ of: (A) four corn plant populations (15, 30, 60 and 90 thousands per hectare) in experiment (1); (B) healthy, early inoculated (28 June) with Southern corn leaf blight (SCLB), and late inoculated (14 July) with SCLB corn in experiment (2), and (C) corn plots with different rates of nitrogen application (0 kg/hectare, 67 kg/hectare and 201 kg/hectare-healthy) in experiment (3).

Soil plots (plant population = 0) were not included in the statistical analysis because the spectral radiance temperature of the soil throughout 3.60 to 5.40 μm was considerably higher than the spectral radiance temperature of any of the other plant populations (Table 1).

No evidence was found to reject the hypothesis of homogeneous variances in *each* of the wavelength regions of InSb and HgCdTe channels mentioned above in *each* of the three experiments.

For each of the three experiments, the analysis of variance was used individually in each of the wavelength regions of InSb and HgCdTe channels mentioned above to test for the homogeneity of the means of $\overline{T}_s(\lambda)$. The results and discussion of the three experiments are given below under their respective headings.

In all of the three experiments, $\overline{T}_s(\lambda)$ in 3.6 to 3.9 µm and 3.9 to 4.15 µm was significantly higher than $\overline{T}_s(\lambda)$ in 4.50 to 4.80 µm and beyond. The reason for this result is that there was a significant amount of solar radiation reflected from the target in 3.6 to 3.9 µm and 3.9 to 4.15 µm. This result also shows that the plants were not perfect blackbodies in these wavelength intervals, because $\overline{T}_s(\lambda)$ for a blackbody is constant with respect to wavelength. The details of this explanation are given in the ground-cover experiment.

I. Ground-Cover Experiment

The means of $\overline{T}_s(\lambda)$ for the four plant populations were found to be statistically significantly different for each of the five wavelength regions of InSb channel and are given in Table 1.

The spectral radiance temperature of a plant depends upon its spectral emittance and temperature. Table 1 shows that $\overline{T}_s(\lambda)$ of the soil is considerably higher than $\overline{T}_s(\lambda)$ of any of the plant populations. This resulted because contact temperature of the sunlit bare soil was found to be 8 to 12°C higher than the temperature of the shaded soil under the plant. The temperature of the sunlit bare soil was also considerably higher than the temperature of the leaves. Sunlit soils have generally higher temperatures than plants because of their greater absorption of the solar energy. Thus, percentage of sunlit soil visible from the spectroradiometer is an important factor determining its spectral radiance temperature. Table 1 shows that $\overline{T}_s(\lambda)$ of the plants decreases significantly as we go from plant population zero (soil) to the plant population 30,000 plants per hectare in all wavelength regions shown in the table. This decrease is probably due to a significant decrease in the percentage of sunlit soil between plant population 0 to 15,000 and 15,000 to 30,000. The differences between $\overline{T}_s(\lambda)$ in plant populations of 30,000, 60,000 and 90,000 plants per hectare are rather small. These small differences probably occurred, because there were relatively small differences in the percentage of sunlit soil of plant populations 30,000, 60,000 and 90,000 plants per hectare. Most of the soil under the plants of population 30,000 and 60,000 plants per hectare was shaded. There was no sunlit soil under the plants of population 90,000 plants per hectare.

Table 1 shows that $\overline{T}_s(\lambda)$ of the plants and soil decreases significantly with the increase in wavelength from 3.6 to 4.80 μm. This is because the solar irradiance reflected from the target decreases with increasing wavelength.

Calibrated spectroradiometer data of Exotech Model 20C spectroradiometer, on Russell Silt Loam Soil, in the Purdue University Agronomy Farm, W. Lafayette, Indiana were available for comparing experimental results with theoretical calculations. Using the emittance and contact temperature of the soil and the calculated value of solar irradiance, calculations of radiant flux density, reflected as well as emitted from the soil, were done using Kirchhoff's law and assuming the target to be lambertian in both reflecting and emitting modes. Table 2 is a comparison of the experimental results with the theoretical calculations. It indicates that the radiant flux density reflected from the target from 3.6 to 4.5 μm cannot be neglected, as compared to the radiant flux density emitted by it. The table also shows that experimental results agree reasonably well with the theoretical calculations, except in 4.8 to 5.1 μm and 5.1 to 5.4 μm. This is because atmospheric (emitted) exitance reflected from the target is not likely to be negligible in these wavelength regions (Kumar, 1976, 1977).

It should be noted that due to significant contributions of radiant flux density reflected from the target, average spectral radiance temperature in the wavelength ranges 3.6 to 3.9 μm and 3.9 to 4.15 μm is higher than the contact temperature of the target. This illustration (Table 2) is created because Table 1 might give misleading indication to many readers that emittance of the targets decreases with increasing wavelengths.

II. Experiment on Non Systemic Stressed Corn Plants

From the analysis of variance for factorial design, the following conclusions were obtained: (1) $\overline{T}_s(\lambda)$ of the corn Pioneer 3306 was not found to be statistically significantly different from $\overline{T}_s(\lambda)$ of the corn Pioneer 3571. This means that although the experiment was conducted for only two hybrids of corn-Pioneer 3306 and

Pioneer 3571--the results obtained from this analysis may well be applicable to many other corn hybrids. (2) $\overline{T}_s(\lambda)$ of the healthy corn, blighted corn inoculated on 14 July (average blight level[3] = 1.40) and blighted corn inoculated on 28 June (average blight level[3] = 3.4) were found to be statistically significantly different (3) $\overline{T}_s(\lambda)$ of the corn (healthy and blighted), on 9 August, was found to be statistically significantly different from $\overline{T}_s(\lambda)$ of the corn on 17 August.

Values of $\overline{T}_s(\lambda)$ of the healthy, late inoculated blighted corn and early inoculated blighted corn are given in Table 3.

The variables which can cause differences in the average spectral radiance temperature of the healthy and blighted corn are given by Kumar & Silva (1973, p. 161). Based on limited measurement of the emittance of the healthy and blighted leaves, it was concluded that there was no significant difference in the emittance of healthy and blighted leaves. From fifty readings of the temperature of the healthy spots of leaves, blighted spots of leaves and air temperature near leaves, no statistical significant difference between the temperatures of healthy spots and the blighted spots of leaves was found.

From these experiments, it seems that neither the difference in contact temperature nor the difference in emittance is a

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[3] *Average blight level of the blighted corn inoculated on July 14 is defined as the average of the blight levels of four plots, inoculated on July 14, from which the spectroradiometric data was taken. The average blight level of the blighted corn inoculated on June 28 is defined similarly.*

predominant factor causing the differences in the spectral response of the healthy and blighted plants. The percentage of ground cover of a corn plant decreases as the blight level increases. It was found during the ground observations that the temperature of the shaded as well as sunlit soil decreases as the percentage of ground cover increases. The preliminary conclusion, yet to be confirmed by further experiments, is that the percentage of soil visible from the spectroradiometer, especially the sunlit soil is the predominant factor causing the differences in the average spectral radiance temperature of the healthy and blighted corn plants. The results of the ground-cover experiment support this conclusion. $\overline{T}_s(\lambda)$ of the blighted corn plants was found to be higher than $\overline{T}_s(\lambda)$ of the healthy corn plants because there was relatively more percentage of soil visible from the spectroradiometer under the blighted plants than under the healthy plants and the average spectral radiance temperature of the soil was higher than that of the leaves. Kumar and Silva (1973) found, from a detailed analysis of aircraft twelve channel MSS data in the 0.46 to 11.7 μm of ten flightlines , that the spectral classes of healthy and blighted corn are most separable in the wavelength range 1.00 to 1.40 μm. Again, the reason for this is probably that the percentage of soil visible from multispectral scanner is a predominant factor causing differences in spectral response of healthy and blighted plants and there is much contrast between the reflectance of the soil and the plant leaves in this wavelength region (Myers et al. 1964).

II. Experiment on Systemic Stressed Corn Plants

The means of $\overline{T}_s(\lambda)$ of the three corn plots with different nitrogen application, (0,67 and 201 kg/hectare), were found to be statistically significantly different and are given in Table 4.

It shows that $\overline{T}_s(\lambda)$ of nitrogen deficient plants (0 and 67 kg/hectare) was significantly higher than $\overline{T}_s(\lambda)$ of healthy plants. In the wavelength ranges 3.6 to 3.9 μm and 3.9 to 4.15 μm, $\overline{T}_s(\lambda)$ of the plants having nitrogen application of 67 kg/hectare was higher than the $\overline{T}_s(\lambda)$ of plants having nitrogen application of 0 kg/hectare. However, this difference is small and is of the order of experimental errors involved in determining $\overline{T}_s(\lambda)$. Although no detailed measurements of emittance and contact temperature of the leaves were made, based on the results of experiments nºs 1 and 2, the percentage of soil, especially the sunlit soil, is an important factor causing the differences between the spectral response of the healthy and nutritionally stressed plants. The higher $\overline{T}_s(\lambda)$ of the nutritionally stressed plants can be explained by the fact that they had a significantly greater percentage of soil visible from the spectroradiometer, as compared to the healthy plants.

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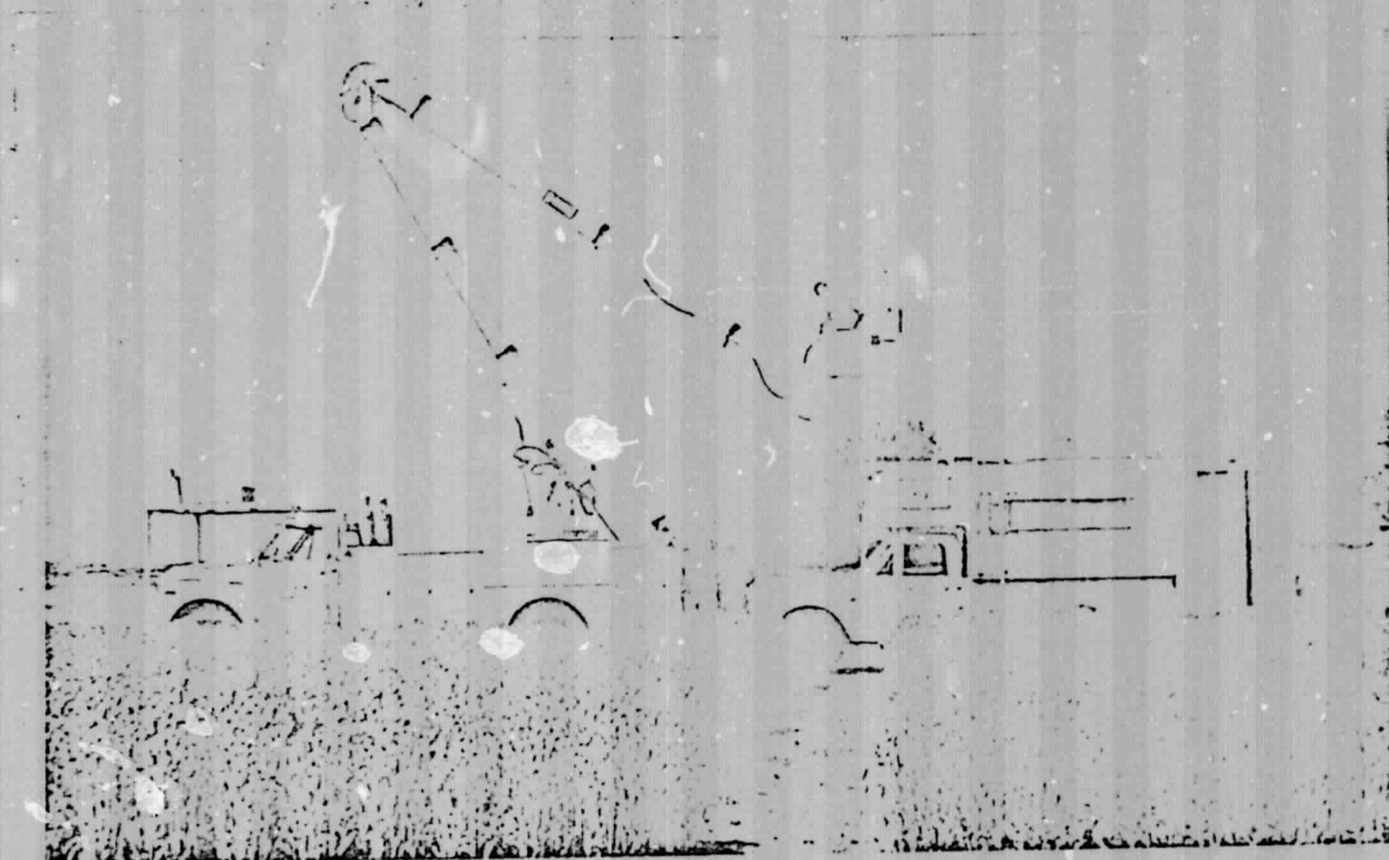

Figure 1 - Typical set up of the field spectroradiometer system.

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Table 1 - Results of the ground-cover experiment

Plant population (plants per hectare)	Percentage ground cover	Average spectral radiance temperature in °C				
		3.6 to 3.9μm	3.9 to 4.15μm	4.5 to 4.8μm	4.8 to 5.1μm	5.1 to 5.4 μm
0 (soil)	0 (soil)	43.8	39.6	36.2	36.3	36.0
15,000	30	37.1	35.5	34.2	34.2	34.0
30,000	50	34.9	33.8	33.1	33.0	33.0
60,000	75	34.5	33.1	32.9	33.0	33.0
90,000	90	35.0	33.8	32.9	32.9	33.5

Table 2 - Comparison of theoretical and experimental results

Wavelength range (µm)	Theoretical values of radiant flux density from the target($wcm^{-2}x\ 10^{-4}$)			Experimental Results
	Emitted	Reflected	Emitted + Reflected	
3.6 to 3.9	0.620	0.215	0.835	0.857
3.9 to 4.15	0.835	0.133	0.968	0.981
4.5 to 4.8	2.280	0.055	2.335	2.374
4.8 to 5.1	3.040	0.022	3.062	3.200
5.1 to 5.4	3.867	0.001	3.868	4.036

Table 3 - Average spectral radiance temperature of healthy and blighted corn

Wavelength range (μm)	Average spectral radiance temperature in °C		
	Healthy corn	Blighted corn inoculated 14 July average blight level† 1.4	Blighted corn inoculated 28 June average blight level† 3.4
3.6 to 3.9	30.4	31.6	32.7
3.9 " 4.15	29.3	30.5	31.5
4.5 " 4.8	28.6	29.8	30.5
4.8 " 5.1	28.3	29.6	30.3
5.1 " 5.4	28.2	29.3	30.1
7.5 " 8.2	28.9	30.2	31.2
8.2 " 8.9	28.7	30.2	31.3
8.9 " 9.6	28.4	29.9	31.0
9.6 " 10.3	28.2	29.7	30.9
10.3 " 11.0	28.3	29.7	30.7
11.0 " 11.7	28.2	29.9	30.9
11.7 " 12.4	28.5	30.0	31.0

† Average blight level is defined in the text.

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Table 4 - Results of the nitrogen deficiency experiment

Nitrogen Application (kg/hectare)	Percent ground cover	Average spectral radiance temperature $\overline{T}_s(\lambda)$ 3.6 to 3.9µm	3.9 to 4.15µm	4.5 to 4.8µm	4.8 to 5.1µm
0	40	36.7	35.4	34.7	34.6
67	50	36.9	35.9	34.8	34.7
201 (healthy)	80	35.4	34.5	33.6	33.5

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