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USE OF THERMAL INFRARED AND COLOUR INFRARED IMAGERY TO DETECT CROP MOISTURE STRESS

INTERIM REPORT

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1. INTRODUCTION

In southern Alberta, intensive agriculture is possible only on irrigated land. Irrigated crops must be provided with adequate amounts of water, but the periodic water shortages (such as in 1977 due to less-than-normal rainfall) and the expanding total area of irrigated land demand that water use be made more efficient. Thus, the 1978 Oldman River Report recommended that irrigation scheduling programs be enlarged and improved to increase water use efficiency. However, previous irrigation scheduling services have encountered difficulties because of the inability to adequately monitor moisture status of crops. Since crop water requirements may differ from one field to another as well as within fields, a complete soil moisture sampling program would be very expensive.

Preliminary studies conducted in the U.S. (e.g. Millard et al., 1977) have shown that crop moisture stress may be detected by using aircraft remote sensing data. The purpose of the project described here was to evaluate whether remote sensing data can provide information that would be useful to supplement ground observation in an irrigation scheduling program.

2. DATA ACQUISITION

Fifteen farm fields with different crops (irrigated corn, alfalfa, fall rye, potatoes, flax, and peas; unirrigated wheat, summerfallow, and native range) were chosen for the study. Five small experimental plots, each containing three water treatments and four replicates, were also included. They contained potatoes and carrots (at Cassils), cabbage and mustard (Duchess), and faba beans (Rockyford).

Two missions were undertaken by Canada Centre for Remote Sensing (CCRS) on June 21 and August 5, 1978. Each mission consisted of a day flight during which colour infrared and thermal infrared imagery were simultaneously obtained, and a night flight with only thermal imagery being collected. CCRS acquired photographs at 1:4,100 for the irrigation plots and 1:50,000 for all sites.

Two additional flights were made on July 24 and August 18 by Kenting Air Services on a contract from the Alberta Remote Sensing Centre. They obtained day colour infrared photographs on a 1:2,500 scale from the irrigation plots and 1:10,000 scale for all sites.

At the time of each flight, the irrigation plots were sampled to determine soil moisture gravimetrically. Twelve sites on each irrigation plot were sampled, one for each of the 3 water treatments and four replicates. Samples from four depths (30cm increments) were taken at each sample site. At the time of each CCRS flight, twelve to fifteen fields were sampled, while seven fields were sampled at the time of each Kenting flight. Six sites were sampled in each farm field and four depths (30cm increments) were taken per sample site. The above sampling procedure thus produced approximately 1,800 soil moisture samples during the experiment.

Soil texture was determined for each site, and both field capacity (FC) and permanent wilting point (PWP) were derived from the soil texture and available data (both published and unpublished). Using the above parameters and root depths obtained from the Alberta Agriculture irrigation scheduling program, the amount of available water (AW, in percent) was determined for each irrigation plot and each of the six sites within the farm fields as follows:

$$AW = \frac{WC - PWP}{FC - PWP} \times 100, \quad (\%)$$

where WC is the total water content in cm and all three variables refer to the root zone.

In addition to soil moisture samples, ground colour infrared photographs and normal colour photographs of the irrigation plots and farm fields were taken at the time of each flight. Measurements of crop canopy temperatures were also made with a portable radiation thermometer PRT-5 a number of times during the summer.

3. DATA ANALYSIS

Colour infrared aerial photographs processed as positive transparencies and thermal images in both analogue and level-sliced form were used for the analysis. Densitometric measurements of each sampled field site (on the small scale photography) and irrigation plot (large scale photography) were made using a Macbeth transmission densitometer TD-504, separately for each emulsion layer.

Thermogram analysis was carried out in three steps. First, analogue low altitude thermograms were displayed on a density slicer and the individual treatment/replicate combinations were ranked from coldest (=1) to warmest (=12), separately for day and night data. An average rank value was then computed for each treatment/plot (crop) /time (day or night) combination. Secondly, the apparent temperature "slice" was determined for each sampled site on the low altitude (irrigated plots) and high altitude (farm fields) level-sliced thermograms. This procedure was considered necessary because the level sliced thermograms contained relatively coarse temperature slices, particularly for the daytime images. As the third step, regression analysis was carried out using the farm fields data. For this analysis, average values were computed for all sites within one field which were located in the same temperature "slice"; emulsion densities and AW values were included in this averaging process. Results presented in the following section refer to data obtained on August 5, 1978. These data were given higher priority because moisture stress was more evident at that time.

4. RESULTS AND DISCUSSION

Figure 1 shows the plot of apparent temperature rank as a function of available water. Each point is an average of four rank values (4 replicates/ treatment). The apparent temperature increased with decreasing available water in the range of 110 to 40%. The relative response to changing moisture availability was similar for all crops studied and for both day and night measurements, although its uniformity was lower for cabbage and mustard (Duchess site) than for other crops. It should be stressed, however, that neither absolute temperature values nor the slope (sensitivity) can be derived from Figure 1.

Apparent temperature ranges of the five irrigation plots are shown in Figure 2 for both day and night data. Night temperature values were lower and had a low or no sensitivity to available water deficiency than the daytime measurements. The absolute temperature ranges also differed between crops for similar available water (AW) amounts, even for adjacent crops at the Duchess and Cassils sites. Due to the coarseness of the daytime temperature "slices", no final conclusions concerning the magnitude of differences caused by crop cover and time of day can be drawn from the data. It is encouraging, however, that the daytime temperature decreased consistently with increasing AW content for all plots. It is also of interest to note that the irrigation plots apparent temperature levels were higher than those for large fields at comparable soil moisture conditions. This might be due to advection effects but the available data do not allow establishing the reason with certainty.

Only daytime temperature ranges of the farm fields were available for this interim report. In Figure 3, these values were plotted against corresponding available water contents for all fields. The data included irrigated and dryland crops, rangeland, and a fallow field. The apparent temperatures exhibited a general decrease with increasing water content, but a considerable scatter is evident as well. Energy balance considerations (Cihlar, 1976) as well as previous studies indicate that surface cover - particularly the relative proportions of green crop cover and bare ground - affects the surface temperature measured by an infrared remote sensor. Previous remote sensing studies established that the ratio of radiation reflected in near infrared and red portions of the electromagnetic spectrum increases with increasing crop cover. Therefore, we attempted to quantify the amounts of plant cover by using DRG which is defined as the difference between CIR transparency densities of the infrared - sensitive and the red - sensitive emulsion layers. A plot of DRG vs. apparent temperature (Figure 4) showed a close direct linear relationship between the two variables. Furthermore, the points were grouped into two clusters which coincided with irrigated (negative DRG) and dryland (positive DRG) sites. When the dryland sites were identified in Figure 3, they were found to be the highest apparent temperature values encountered. In other words, the lack of ground cover caused apparent temperature increase due to the increased exposure of bare soil. If only irrigated sites are considered in Figure 3, the relationship between temperature and available water is more closely defined. The goodness of fit of the temperature-water content relationship for irrigated fields (Figure 3) depends on the positions of three "outlier" data points (at AW = -11, 17 and 91%) which must be determined from more precise temperature data.

Relationships between remote sensing and ground variable were quantified using correlation analysis. Mid-values of the temperature "slices" were used in lieu of apparent temperatures. The following variables were included for all farm fields (a total of 18 data points):

DR = Density of the near IR - sensitive layer, dimensionless;
DG = Density of the red - sensitive layer, dimensionless;
DRG = Difference between DR and DG, dimensionless;
T_{ap} = Apparent temperature (day value), ^oC;
AW = Available water in the root zone, %.

The resulting correlation matrix (Table 1) shows that the apparent temperature was closely related to the difference DRG between red and green emulsion densities, which is in turn affected by the amount of green cover above the soil surface. The correlation between available water and T_{ap} was quite low (-0.41). Correlation coefficients between T_{ap} (dependent variable) and several independent variables were high when DRG was used, and fairly low otherwise (Table 2, data set DS1). The accuracy of predicting available water from T_{ap} did not improve significantly when DRG was also used, and increased partially after DR was added to the independent variables (r = 0.47, Table 2). The low improvement of the correlation coefficient suggests that DRG was only weakly related to the available water, and therefore did not improve the AW prediction. Since a definite relationship between soil water available at a given time and surface cover cannot be expected, variable surface cover would appear to be an intrinsic limitation of plant moisture stress determination through thermal infrared remote sensing.

Due to various crop types and degrees of surface cover being present in the data set and since the T_{ap} values used were only approximate, an attempt was made to remove some of the uncertainties by reducing the data set in two ways. First, three seemingly anomalous points (at AW = -11, 17 and 91%) were ommitted to form a data set DS2 with 15 points. Secondly, irrigated fields from data set DS2 were put into data set DS3 which therefore contained 9 points. On the CIR transparencies, irrigated fields appeared to have a higher plant cover, were shown in deeper red colours, and soil was visible relatively seldom compared to the dryland fields. Correlation coefficients for various relationships were calculated for DS2 and DS3 in the same manner as for DS1.

The DS2 results were similar to those for DS1. Some improvements occurred, but were not very large even after including DRG and DR values (Table 2). In contrast, considerable improvement of AW prediction was found for DS3 (Table 3). In this case, DRG and T_{ap} together explained 70% of the total variability of the AW values encountered in the irrigated farm fields data (r = 0.84, Table 2).

The above results were derived from averages of several soil moisture samples per farm field and a relatively crude measure of the apparent temperature. Although additional data and a more thorough analysis will be required to arrive at definitive conclusions, findings to data are consistent with the following statement. In the presence of variable plant cover (primarily percent cover) and variable available water content, the remotely sensed apparent temperatures correlate closely with plant cover and poorly with soil water. To the extent that plant cover is not systematically related to available soil water, AW values may not be reliably predicted from the thermal infrared data. On the other hand, if plant cover is uniform and the soil surface is shown in a minor way, the thermal data indicate plant stress and consequently available water in the soil profile.

5. FUTURE WORK

To provide definitive analysis and interpretation of the above indicated trends, the following tasks will be carried out:

(i) Digitize daytime thermal infrared data for the 5 August 1978 flight

(ii) Extract apparent temperature values for individual sampled sites on both irrigation plots and farm fields.

(iii) Extract apparent temperatures for the nighttime data from level-sliced thermograms.

(iv) Calculate day-night temperature differentials for 5 August 1978.

(v) Analyze the relationships between field data, thermal data, and photographic density measurements.

(vi) Confirm the validity of the conclusions using data from 20 June 1978 over the same area.

6. REFERENCES

Cihlar, J. 1976. Soil moisture determination by thermal infrared remote sensing. Proceedings of the Workshop on Remote Sensing of Soil Moisture and Groundwater, 8-10 November 1976, Toronto, Ontario.

Millard, J.P., R.D. Jackson, R.G. Goettelman, R.J. Reginato, S.B. Idso, and R.L. LaPado. 1977. Airborne monitoring of crop canopy temperatures for irrigation scheduling and yield prediction. Proceedings of the 11th International Symposium on Remote Sensing of Environment, Ann Arbor, MI 1453-1461.

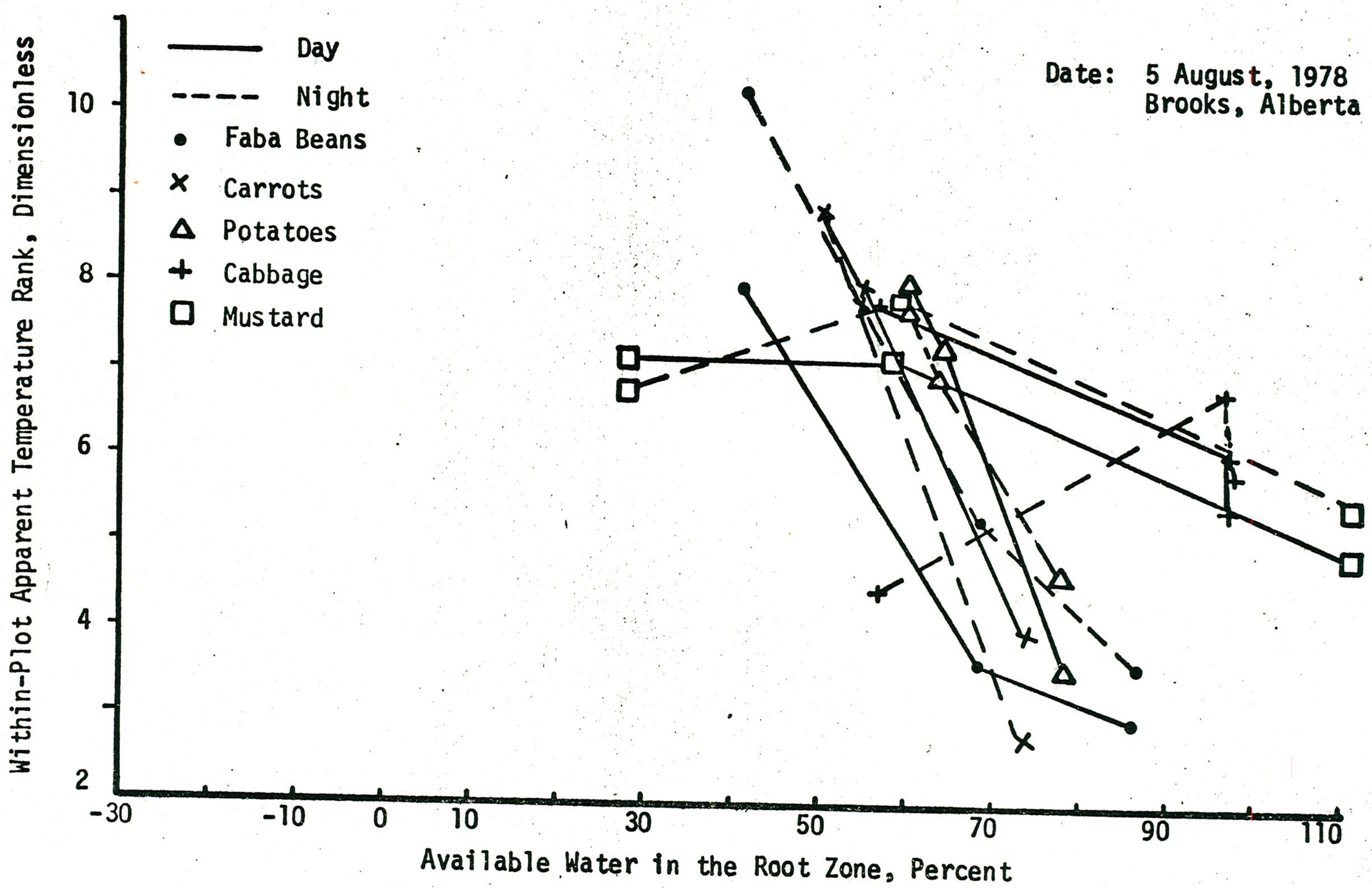


FIGURE 1. Within-Plot apparent temperature ranks plotted against the root zone water content. Ranks 1 through 12 were assigned to each treatment-replicate combination within a crop and time of flight.

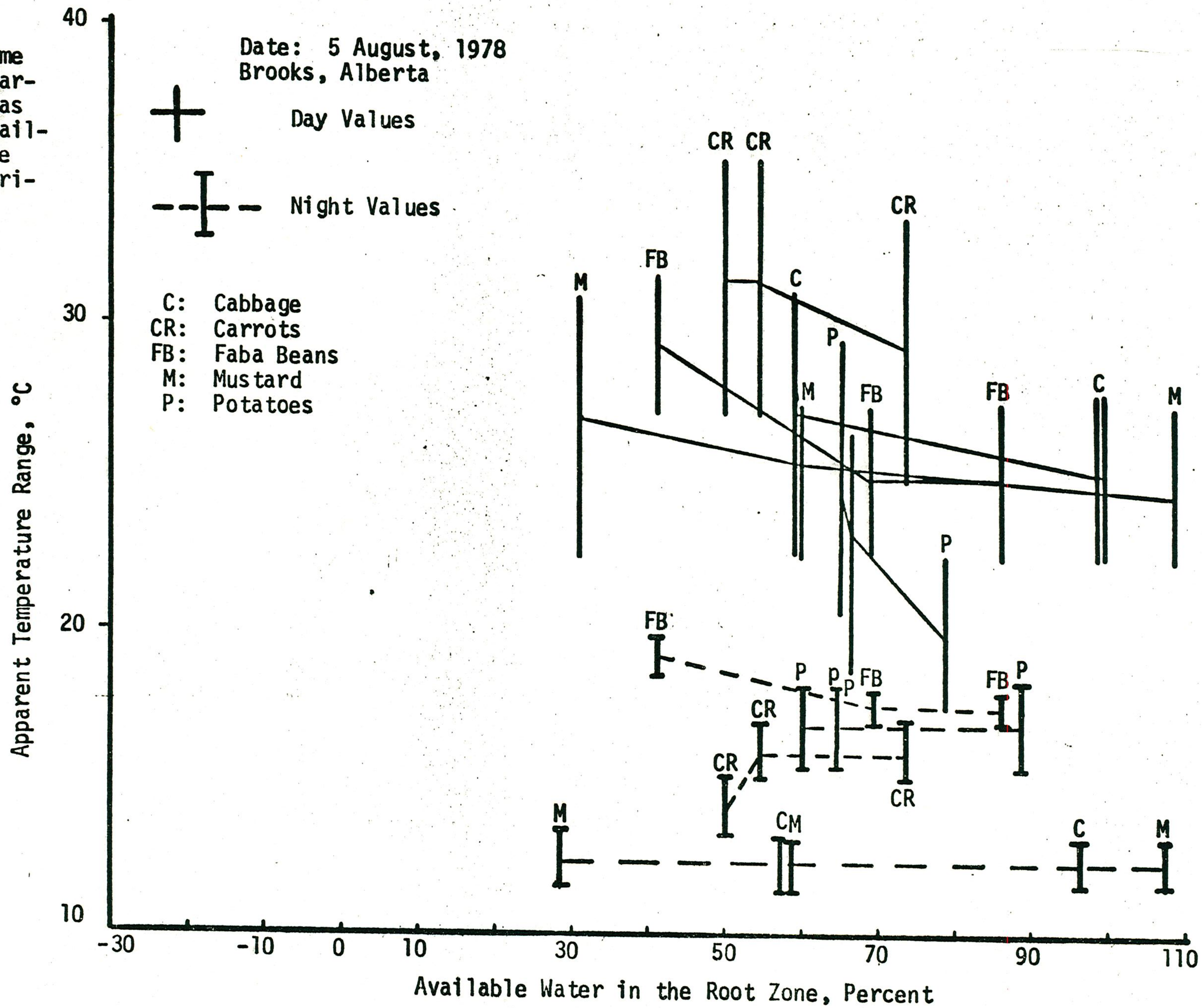
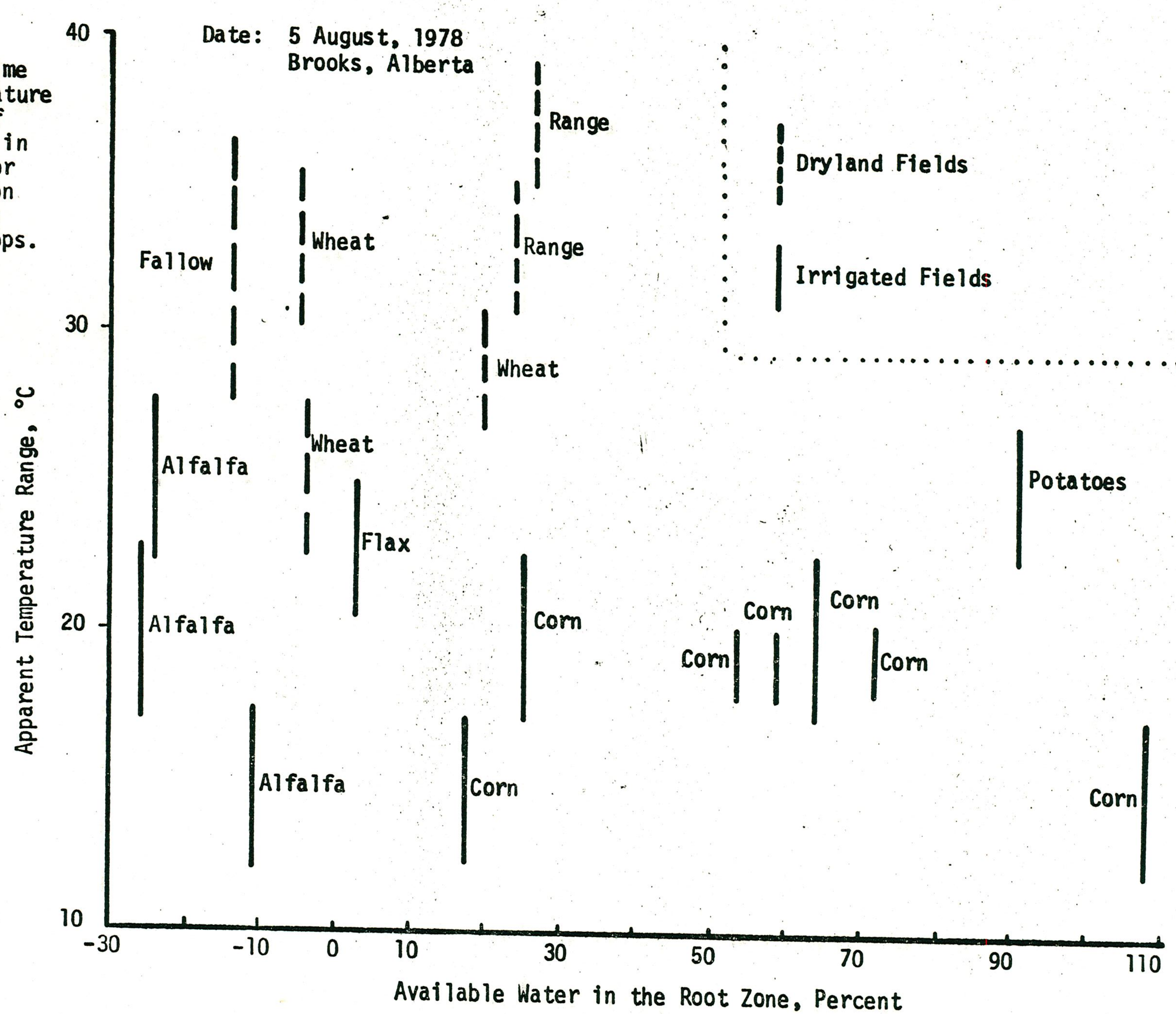


FIGURE 2. Daytime and nighttime apparent temperature as a function of available water in the root zone for irrigation plots

FIGURE 3. Daytime apparent temperature as a function of available water in the root zone for irrigated and non irrigated fields with various crops.



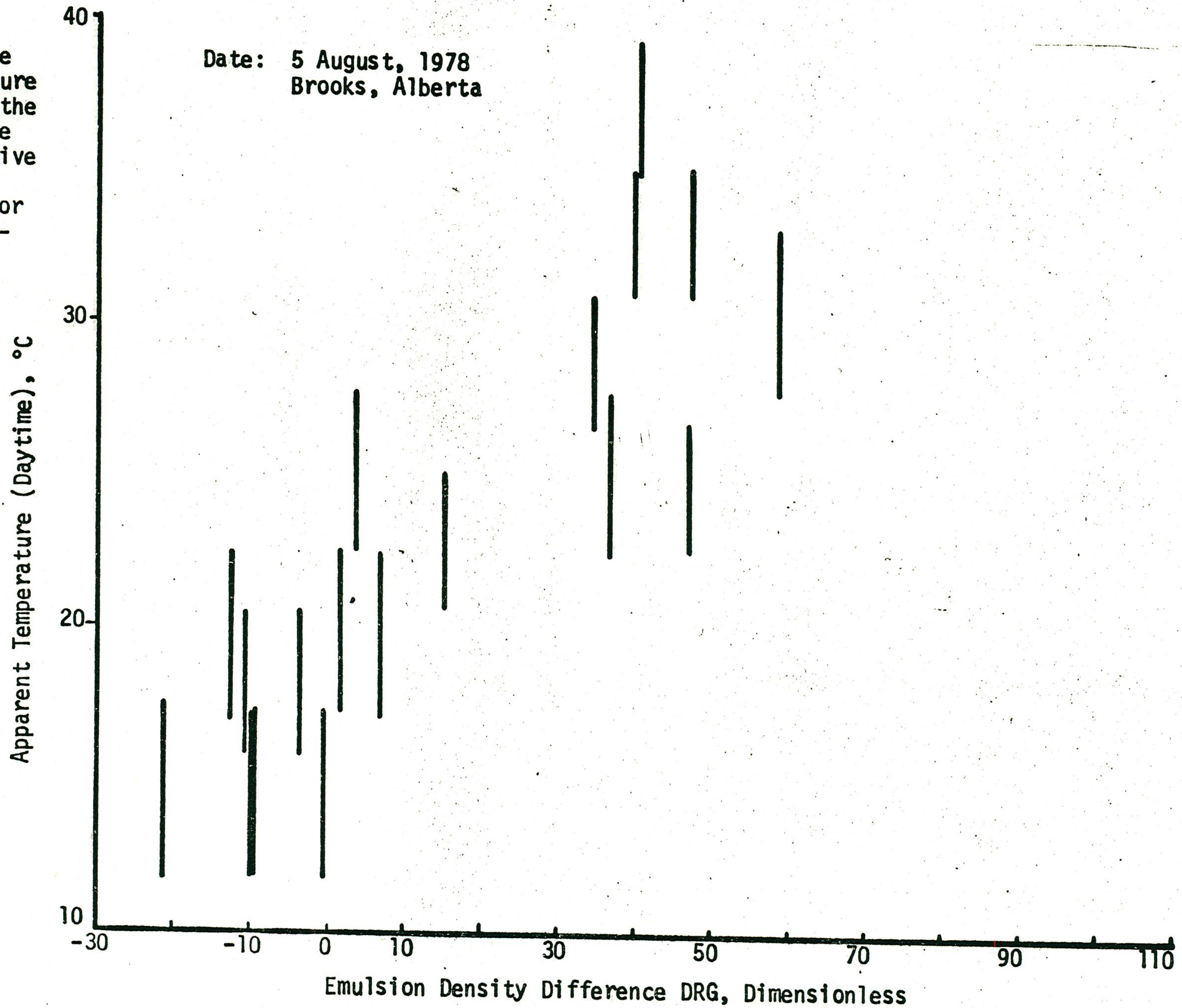


FIGURE 4. Daytime apparent temperature as a function of the density difference between IR-sensitive and red-sensitive layers of the color infrared transparencies.

Table 1. Correlation matrix for data set DS1 (all data, 18 points). **

	DR	DG	DRG	T_{ap}	AW
DR	1.00				
DG	0.31	1.00			
DRG	0.43	-0.72	1.00		
T_{ap}	-.27	-0.70	0.86	1.00	
AW	-0.33	-.14	-0.37	-0.41	1.00

** 0.01 significance level: 0.58

Table 3. Correlation matrix for data set DS3 (irrigated fields only, DS3)**

	DR	DG	DRG	T_{ap}	AW
DR	1.00				
DG	0.81	1.00			
DRG	0.08	-0.08	1.00		
T_{ap}	0.22	-0.05	0.52	1.00	
AW	-0.06	-0.01	-0.28	-0.80	1.00

** 0.01 significance level: 0.62

Table 2. Correlation coefficients between available soil water and remote sensing variables for three data sets.

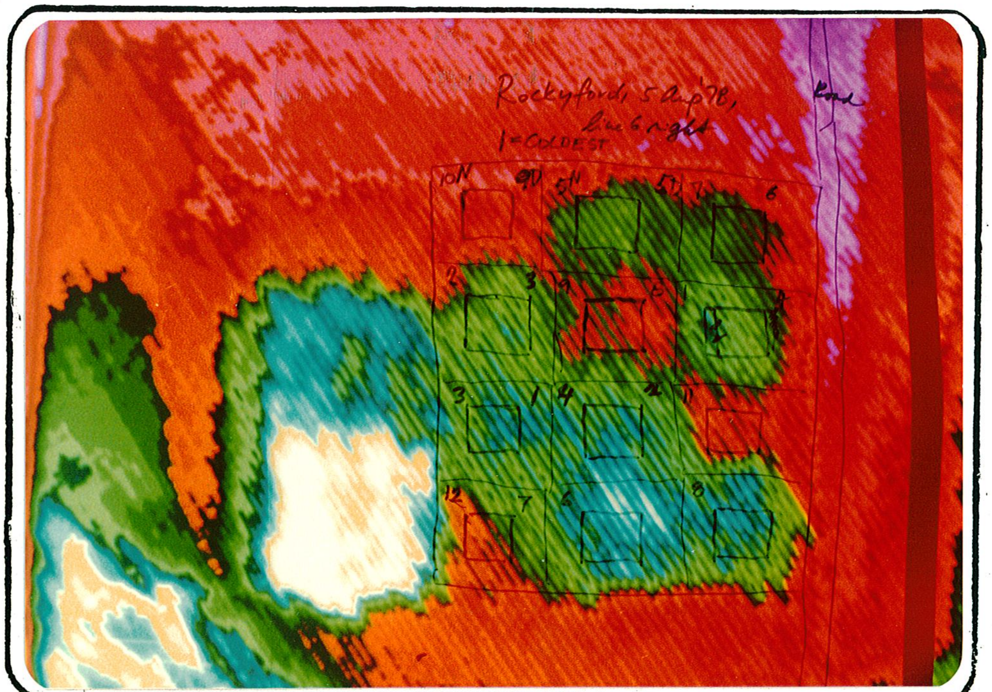
VARIABLES		CORRELATION COEFFICIENT FOR DATA SET +		
DEPENDENT	INDEPENDENT	DS1	DS2	DS3
T_{ap}	AW	0.41	0.54	0.80
T_{ap}	DRG	0.86	0.82	0.40
T_{ap}	AW,DRG	0.86	0.89	0.87
T_{ap}	AW,DRG,DR	0.88	0.89	0.88
AW	T_{ap},DRG	0.41	0.55	0.84
AW	T_{ap},DRG,DR	0.47	0.57	0.85
		N = 18	N = 15	N = 9

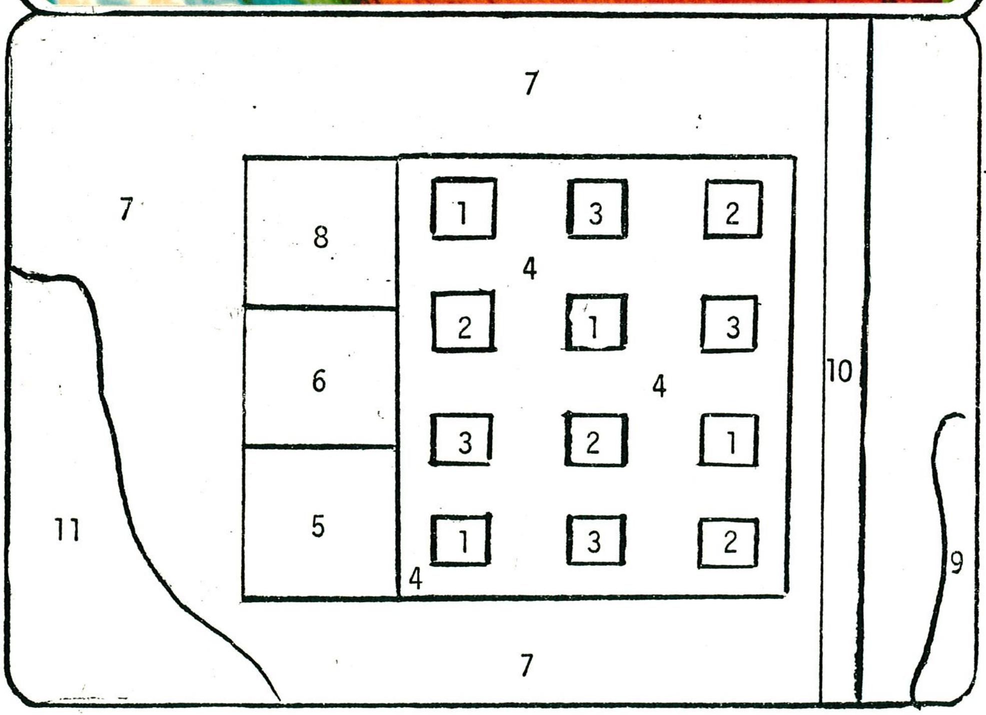
+ Data set DS1: All data (18 points)

+ Data set DS2: Outlier points excluded (15 points)

+ Data set DS3: Only irrigated fields of data set 2 (9 points)

A Night Infrared Thermal Analogue Image (As Seen Under A Density Slicer) of A Faba Bean Irrigation Plot and Surrounding Area





1. Water 1 faba bean treatment under moisture stress. 2. Water 2 under slight moisture stress. 3. Water 3 under no moisture stress. 4. Border area of faba bean plots. 5. Plots of beans - soybeans, mung beans, faba beans, lentils which were recently irrigated to excess at the same rate as #6 which had a higher water use. 6. Plot of corn, forage sorghum, sorghum-sudangrass, and sorghum which was recently irrigated. 7. Wheat not irrigated severe stress. 8. Wild oats and weeds severe stress. 9. Summerfallow. 10. Roadway. 11. Grassland next to irrigation ditch moderate to no stress.

White, yellow, blue, green, red, mauve.
Coolest ⟶ hottest.