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**Application of Remote Sensing Technology to
Wheat Breeding**

E.T. Kanemasu, M. Fuchs, R. Sears, A. Blum

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1.0 Abstract

Spectral reflectance measurements were throughout the growing season on several genotypes of wheat in Kansas and Israel. The objective was to use remotely sensed data in selecting genotypes for disease and drought resistance. The results indicate that spectral reflectance (near infrared to red ratio) correlates well with leaf area and plant growth, but not with yield or yield components.

Because breeders use single rows, an experiment to compare results from large and small plots was conducted. Unfortunately, the genotype yields on small plots did not agree with yields on large plots. This is probably due to variability in soil and soil moisture across the field. Yield variance was greater in the small plots, indicating that plot size can be a limitation in predicting yield using reflectance data.

In Israel, canopy temperatures were correlated with percent disease coverage across variable germplasm, indicating that variation in resistance to *Septoria tritici* blotch among wheat cultivars can be assessed by variation in canopy temperatures under disease epiphytoticies.

2.0 Objectives of the Original Research Proposal

The objective of this research was to develop an operational package for the plant breeder which will allow him/her to rapidly screen genotypes in a quantitative manner using remotely sensed technology.

The general objective of this research is to explore the possibilities of replacing manual ground-level methods of data acquisition by computer-based remote sensing techniques for specific plant attributes.

Experiment 3 was deleted because of the reduced original budget. Its objective was to obtain detail measurements of photosynthetic and transperational rates which would have required purchase of additional equipment.

3.0 Chapter I

Experiment 1 & 2

(KANSAS)

ESTIMATING AGRONOMIC VARIABLES, GRAIN YIELD AND DISEASE SEVERITY
OF WINTER WHEAT GENOTYPES USING SPECTRAL REFLECTANCE DATA

R. B. Myneni and E. T. Kanemasu

I. Abstract

In this chapter we discuss the results of two experiments conducted to assess the feasibility of using spectral reflectance measurements to estimate agronomic variables, grain yield and disease severity of winter wheat genotypes. Twenty-five genotypes of winter wheat (*Triticum aestivum* L.) were selected as treatments in experiment 1 that was replicated four times and conducted during the seasons of 1984-85 and 1985-86. A subset (six) of these genotypes were selected as treatments for experiment 2. Each replication had 6 x 2 plots, one of each genotype was treated with the fungicide Bayleton to avoid leaf rust incidence. Spectral reflectance data were collected on clear sunny days during the growing season using a BARNES and an EXOTECH radiometer. Agronomic variables such as seedling vigor, plant height, above ground plant biomass at anthesis, grain yield and grain yield components were measured during the two years. Three spectral indices - Normalized Difference (ND), Near-infrared to Red reflectance ratio (NIR/R) and Greenness were computed from the spectral reflectance factors. Seedling vigor, quantified as seedling biomass at double ridge growth stage, was better correlated to NIR/R than ND. Plant height at anthesis was not correlated to any of three spectral indices. Above ground plant biomass at anthesis was better correlated with ND, although the slope of this relationship was weaker compared to the slope of NIR/R against above ground plant biomass at anthesis. The correlation between grain yield vs.. NIR/R and ND integrated over the whole growing season was poor and statistically insignificant. An analysis based on yield components and spectral indices to predict genotype grain yield was unsuccessful. We

conclude that predicting grain yield of winter wheat genotypes based only on spectral reflectance measurements requires further study. The results from experiment 2 indicate that although the effects of leaf rust on winter wheat genotypes can be seen as decreased spectral reflectance, these differences do not appear to be related to grain yield.

II. Introduction

As new varieties of wheat are developed, it becomes increasingly difficult to produce new and better genetic recombinations. This has a direct bearing on the size of the population that has to be processed by the plant breeder, since it relates exponentially to the number of genes that have to be recombined into one genotype.

Visual evaluation based on qualitative traits like plant height, maturity and disease resistance is the means of early generation selection used by most plant breeders. However, some important traits like grain yield and biomass are quantitative in nature and hence cannot be evaluated visually with consistent and accurate results. Generally, there is not enough seed available for replicated yield tests and the costs involved in yield testing of thousands of early generation lines is prohibitive.

Remote sensing technology is based on the spectral reflectance of leaves, vegetation and soil as influenced by plant growth and environment (Myers and Allen, 1968). The spectral reflectance of a crop canopy contains information within a wide range of wavelengths in the solar spectrum. Four main spectral regions are influenced by plants. These wavelength bands include the visible region of chlorophyll absorption, very near-infrared wavelengths, where leaf structure is of major

importance, the near and middle infrared wavelengths where water and CO₂ absorption predominate and the far-infrared region of thermal infrared emission. The spectral reflectance of wheat canopies has been related to intercepted solar radiation and green leaf area index by Asrar et al. (1984), and to plant biomass and grain yield by Aase and Siddoway (1981), Aase et al. (1984), and by Asrar et al. (1985). Leamer et al. (1980) related the physiological growth stages of wheat cultivars to their spectral reflectance properties. Emitted thermal radiation from the crop canopies has been used to predict plant water stress and irrigation requirements (Sumayao and Kanemasu, 1979; Jackson et al., 1980; amongst others). Crop signatures in the near infrared wavelengths has been used to evaluate various foliage diseases, root rots, etc. (Meyers and French, 1967; Story and Yapp. 1971; Ausmus and Hilty, 1972; Safir et al., 1972; Jackson et al., 1980; amongst others).

Remote sensing technology is well suited in reducing the amount of work involved in the manual data acquisition for individual nursery entries. The spectral reflectance of the crop can be translated into various parameters of agronomic significance that are of interest to the breeder. Further, remote sensing is inherently a rapid method of data acquisition that is directly compatible with computer data processing. Hence, the rapid remote sensing methodology may be used to replace the expensive and labor intensive ground-level data acquisition methods that are currently in used by the wheat breeder.

The general objective of this research endeavor is to explore the possibilities of replacing manual ground-level methods of data acquisition by computer based remote sensing techniques, for specific agronomic

variables such as seedling vigor, plant biomass, grain yield and the effects of leaf rust on grain yield.

III. Materials and methods

III. 1. Description of the experiments

Experiment 1: An experiment (Experiment 1 as outlined in the research proposal) was conducted at the Ashland Experiment Station south of Manhattan, KS on a Reading silt loam (fine, mixed, mesic, typic Argindolls) in 1984-85 and 1985-86 seasons. Twenty-five genotypes of winter wheat (*Triticum aestivum* L.) were selected as treatments for the two experiments (Table 1). Both experiments were planted to a randomized block design on October 3rd, 1984 and on October 7th, 1985 at the rate of 67.5 kg/h. Fertilization was limited to a preplant application of 198 kg of nitrogen (100 kg in 1985) and 66 kg of phosphorus (35 kg in 1985). In early spring of each year, 9.8 cc of Glean was applied to eradicate any weeds. Both experiments consisted of four rows spaced at 0.176 m apart. There was no moisture stress in both the experiments through out the growing period. The experiments were harvested on June 5th, 1985 and on June 20th, 1986.

Experiment 2: Experiment 2 (as outlined in the research proposal) was conducted at the Ashland Experiment Station during the 1984-85 and 1985-86 seasons. A subset (six) of the twenty-five genotypes of Experiment 1 were selected as treatments for this experiment. Of these six genotypes, two were disease (leaf rust) susceptible, two were disease tolerant and two were intermediate in response. The experiments were

planted to a randomized block design on October 3rd, 1984 and October 7th, 1985. The agronomic practices were similar to the ones used in Experiment 1 and are described above. In both years, Experiment 2 had four replications; each replication had 6 x 2 plots, one plot of each genotype was treated with fungicide Bayleton to protect from leaf rust and served as a control plot. There was no moisture stress during the growing periods and the experiments were harvested on June 5th, 1985 and on June 20th, 1986.

III. 2. Agronomic measurements

After seedling emergence, three plants of each genotype in the third replicate (arbitrarily chosen) were tagged in both experiment 1 & 2. Leaf emergence, length and width was recorded on these tagged plants at every 3-5 day intervals. For experiment 1, randomly selected plant samples of each genotype were periodically brought back to the laboratory to evaluate growth stages. Twenty plants in a one meter row transect of each genotype were harvested at single ridge growth stage and were oven dried at 70°C for a week. This plant biomass measurement was then recorded as an index of seedling vigor. Similar above ground plant biomass measurements of each genotype were made at anthesis. Plant height of all genotype in four replicates was measured periodically, on or around the day spectral measurements were collected. Lodging of all plots was visually scored. A one meter transect of each genotype was harvested separately to gather information of grain yield components. In Experiment 2, measurements of plant growth stage were

made, disease severity was visually scored and only plot grain yield was measured.

III.3. Spectral reflectance measurements

A metallic boom was specially constructed to mount the Modular Multispectral 8-channel radiometer ('Barnes') and the Exotech Model 100 radiometer. This boom was attached to the front of a garden tractor with approximately 150° freedom of rotation. Both radiometers had 15° field of view. The mounted radiometers were connected to a polycorder through a manual switch box. Starting from early April, on clear days spectral reflectance at nadir view angle was measured on all the genotypes in the four replicates in each experiment. At about every 15 minute intervals, the reflected radiance from a barium sulphate calibration panel was measured to compute the directional reflectance factors. The raw voltage values from the polycorder were dumped on the main computer at the laboratory and canopy reflectance factors were computed and checked for any measuremental errors.

III. 4. Spectral indices

In order to extract information pertinent to the crop canopy from remotely sensed spectral reflectance of crop canopy and soil background, it is essential to transform the spectral reflectance values in a manner that would minimize soil background contribution. Such minimization is provided by the preferential scattering behavior of the crop canopy and the soil in the near infrared and red wavelengths of the solar spectrum.

There are three spectral indices widely used which are essentially mathematical/statistical transformations of the crop+soil reflectance in the near infrared and the red wavelengths.

Normalized Difference (ND) is the ratio of difference in reflectance at near infrared (R_{ir}) and red (R_r) wavelengths, to the sum of the two reflectances,

$$ND = (R_{ir} - R_r) / (R_{ir} + R_r)$$

The other spectral index is simply the ratio of reflectance in near infrared to red, (NIR/R). The third index is called the Greenness. It is derived statistically using principal component analysis and is a linear combination of reflectances in the individual wavelength bands of the radiometer (Miller et al., 1984). The greenness was computed as,

$$\text{Greenness} = -0.4602 \times \text{MSS1} - 0.6770 \times \text{MSS2} + 0.3117 \times \text{MSS3} + 0.4331 \times \text{MSS4}$$

$$\begin{aligned} \text{Greenness} = & -0.1284 \times \text{MMR1} - 0.1578 \times \text{MMR2} - 0.3701 \times \text{MMR3} + 0.7532 \times \text{MMR4} \\ & + 0.2130 \times \text{MMR5} - 0.2469 \times \text{MMR6} - 0.3848 \times \text{MMR7} \end{aligned}$$

where MSS1 is the multi-spectral scanner band 1 and similarly, MMR is the modular multi-spectral radiometer band 1. The coefficients were taken from Miller et al., (1984), since they were developed for wheat grown at the same sites.

IV. Results And Discussion

IV. 1. Seasonal changes in the reflectance and spectral indices (Experiment 1)

One of the basic criterion in successfully applying remote sensing technology to wheat breeding is the quality of reflectance data and ability to find differences in spectral reflectance between the various

genotypes. A simple way to ascertain this is to plot the primary data and visually read it. If indeed there are differences, then the data may be subject to further analysis to quantify the differences.

The typical seasonal changes of the reflectance factor in the red wavelength for a genotype (Bounty 205) is plotted in Figs. 1a and b. The reflectance factor in this wavelength decreases as leaf area increases due to strong absorption by the chlorophyll pigments and increases as the plants die, reaching an asymptotic soil value. The reflectance factor in the near-infrared wavelength, however, increase as leaf area increases due to increased multiple scatterings reaching a peak value at anthesis and gradually decreases to the background value at the end of the plant growth (Figs. 2a and b).

The three spectral indices are plotted with Julian day number in Figs. 3 through 5. The plotted spectral indices were computed from both Barnes and Exotech radiometers. Both indices show a linear increase during the vegetative growth phase corresponding to the period of rapid leaf area increase and reach a peak value when the crop is flowering and subsequently decline as the crop senescences. The spectral indices computed from the Exotech data were slightly lower than the ones computed from Barnes data, which may be due to the difference in the wave bands of the corresponding channels in the two radiometers. The seasonal patterns reported here are consistent with the relationships published in the literature (Aase and Siddoway, 1981). The three spectral indices of all genotypes computed from Barnes data at flowering are plotted in Figs. 6 through 8. At this growth stage, the genotypes have achieved their maximal green leaf area, and it is crucial to find the differences among the various genotypes since their final productivity depends on

the growth and vigor at flowering. The simple NIR/R ratio better discriminates between the genotypes than ND and greenness, and hence seems more useful in further analysis.

The change in the ratio of NIR/R computed from Barnes data between terminal spikelet and booting, booting and flowering, and between flowering and senescence is plotted in Fig. 9a, b and c, respectively. The endpoints of the bar correspond to the value of the ratio at a growth stage, while the magnitude of change (increment or decrement) in the ratio is given by the size of the bar. It is interesting to note that between terminal spikelet and booting, the increment in the ratio is approximately constant (Fig. 9a), though the actual values of the ratio are different among the various genotypes. Between booting and flowering, however, the ratio increased in some genotypes, while in a majority of the genotypes it decreased. It is interesting to note that this magnitude of change is very small (Fig. 9b). The ratio decreased considerably from flowering to senescence (Fig. 9c). Though the ratio varied among the genotype at flowering, the value at senescence is contained between 5.0 to 7.5 for all the genotypes.

As the crop progresses from one phenophase to another, it undergoes a change in its morphology, which may be noted in its spectral signature. From a timely collection of spectral data it may be possible to relate the spectral reflectance of the canopy to the growth stage. As is documented here, though the actual values of the spectral indices may be different among the various genotypes, the differences between growth stages are possible identifiers. It should be possible to synthesize an index that perhaps accumulates means of differences and then map this index to crop growth stage. For instance, Leamer et al. (1980) have

related near infrared reflectance at 900 nm wavelength and Feekes growth stages in wheat. Knowledge of the stage of plant development through a crop season might improve the accuracy of yield predictions made prior to harvest.

IV.2. Relationships between spectral indices and agronomic variables (Experiment 1)

Seedling vigor is of interest in breeding materials as possible advantage for wheat seeded into difficult seedbed conditions. Also, under non-stress conditions it is of interest to develop an estimate of seedling vigor at an early growth stage. Seedling above ground biomass is plotted in Fig. 10 with MTR/R. There is scatter in the data, but both relationships were significant statistically at 99% probability level. The simple ratio NIR/R is better correlated to seedling vigor than ND.

The two spectral indices computed from Barnes data are plotted with plant height at anthesis in Figs. 11a and b. Though both the spectral indices were significantly correlated with plant height (probability of 99%), there is either considerable scatter or the relationship is weak. Plant height is not correlated with either of the spectral indices when the former exceeded 1.1 m. The weakness of these relationships and the scatter is understandable. The spectral reflectance of a crop is not directly related to its height. This relationship is physically meaningful only in the domain where plant height and green leaf area are correspondingly related.

The relationship between the spectral indices computed from Barnes data and the above ground plant biomass at anthesis is plotted in Figs. 12a and b. The spectral reflectance data used in the computation of the indices was collected at flowering. Both relationships were statistically significant at 99% probability level. In general, ND was better correlated with above ground plant biomass than the ratio NIR/R. However, the slope of this relationship is considerably weaker in case of ND, but there is considerable scatter in case of NIR/R.

IV.3. Relationship between grain yield and spectral indices (Experiment 1)

Analysis of variance of grain yield is presented in Table 2. The grain yields of the different genotypes were significantly different at a probability level of 99%.

We tried two different approaches to relate grain yield to spectral reflectance measurements. First, grain yield was correlated with seasonally integrated NIR/R ratio, which was computed as,

$$\int_{sg}^{sc} dt \text{ NIR/R}$$

where sg is spring regrowth and sc is senescence. The correlation was poor ($R^2=0.24$) and was statistically insignificant. Correlation of grain yield with EXOTECH data was also similarly poor ($R^2=0.29$).

Second, we hypothesized that since, "grain yield (g/m^2) number of spike per m^2 x grain number per spike x grain weight (g)" we tried to

relate the yield components to quantities derived from spectral reflectance, viz.,

- [a] number of spikes per m^2 as a function of the maximal value of the index during the season;
- [b] grain yield per spike as a function of spectral index integrated from terminal spikelet to anthesis;
- [c] grain weight (g) as a function of spectral index integrated from anthesis to senescence;

The simplest of such functional relationships is a linear one.

The relationship between grain weight (g) and the spectral index (NIR/R) integrated from anthesis to senescence was negatively correlated. So, we tried to relate grain yield per spike (g) with the spectral index integrated from terminal spikelet to senescence, where grain yield per spike was computed as grain number per spike times the grain weight (g). The relationship was again poor ($R^2=0.30$) and was statistically insignificant (Fig. 13a). However, by removing one outlayer (the encircled point in Fig. 13a), the R^2 was 0.43 which was statistically significant at the 95% level, but there was no justification in deleting the outlayer.

We then tried to relate the time rate of increase in spectral reflectance from double ridge growth stage to anthesis to the tiller number per m^2 ground area (Fig. 13b). The premise was that the spectral reflectance of genotypes with a higher number of tillers per unit ground area should be increasing rapidly (greater slope) than the spectral

reflectance of genotypes with fewer tillers. However, this relationship was statistically insignificant ($R^2=-0.07$).

Next, we tried to relate number of spike per m^2 ground area to the maximal value of the spectral index during the growing season. There was no relationship between the two variables ($R^2=-0.02$) and this relationship is plotted in Fig. 13c. This is possible because the spectral indices reach a peak value at an leaf area index of 2-3 and since all the genotypes had reached a threshold value at their peak growth, although they differ considerably in tiller number, their spectral reflectance values were almost similar.

The spectral reflectance of a vegetation canopy is related to its scattering surface - the green leaf area. The reflectance, however, reaches a peak value at a leaf area index of 2-3 and with further increase in leaf area, the spectral reflectances are invariant. The genotypes show differences in their spectral reflectances but this does not seem to be related to their yield potential - in general the leaf area is not directly related yield potential. Based on our analysis, we conclude that it is not possible to estimate grain yield of wheat genotypes based only on spectral reflectance measurements made remotely. However, it appears that by using spectral reflectance measurements in combination with agronomic variables it is possible to estimate grain yields of wheat genotypes (see experiment 6).

IV.4. Results from Experiment 2

The analysis of grain yield for the two years is given in Table 3. The differences in grain yield among the various genotypes during the

1984-85 growing season are not statistically significant. This was mainly due to the lack of a strong disease incidence. Visual scoring of the disease severity revealed that the incidence of leaf rust was moderate and occurred only after flowering when the spectral indices were decreasing as the genotypes senesced. On the other hand, the differences in grain yield among the various genotypes during the 1985-86 growing season were statistically significant. Further analysis was thus done only the second year data.

The near-infrared to red ratio computed from Barnes data for the various genotypes is plotted in Figs. 14 and 15. The indices from jointing onwards are plotted, because there were virtually no differences before this stage between the control and diseased plots. It is clear from Figs. 14 and 15, that diseased genotypes consistently had lower values of NIR/R than control plots. Tam 108, a disease susceptible genotype, showed most difference; while KS 80336, a disease tolerant genotype, showed the least difference between control and diseased plots. The lower spectral reflectance of diseased genotypes is not unexpected since the NIR/R ratio is proportional to green leaf area; the more the leaf rust, the lesser the value of the NIR/R ratio.

Grain yield of both the controlled and diseased genotypes are plotted with seasonally integrated NIR/R ratio in Fig. 16. The correlation between the two variables was not statistically significant. The differences in seasonally integrated NIR/R ratio and grain yield between the controlled and diseased genotypes is given in Table 4. The relationship between these two variables was also not statistically significant. It is apparent from this table that the diseased genotypes had consistently lower NIR/R ratios, but this does not seem to

correspond with a similar decrease in grain yield. For instance, Tam 108, a disease susceptible genotype, showed a 50.54 difference in its seasonally interpreted NIR/R ratio between the controlled and the diseased plots. The corresponding yield decrease was 104.25 g/m^2 . On the other hand, KS 80336, a disease tolerant genotype, shows a yield decrease of 100.21 g/m^2 for a difference in seasonally integrated NIR/R ratio of 22.67. Hence, we conclude that the effects of leaf rust on winter wheat genotypes can be seen by remote measurements of spectral reflectance; but such differences in reflectance do not appear to be related to their grain yield.

V. Conclusions

In this chapter we discussed the results of experiments conducted to assess the feasibility of using spectral reflectance measurements to estimate agronomic variables, grain yield and disease severity of winter wheat genotypes. Twenty-five genotypes of winter wheat (*Triticum aestivum* L.) were selected as treatments in an experiment that was replicated four times and conducted during the seasons of 1984-85 and 1985-86. A subset (six) of these genotypes were selected as treatments for experiment 2. Each replication had 6 x 2 plots, one of each genotype was treated with the fungicide Bayleton to avoid leaf rust incidence. Seedling vigor, quantified as seedling biomass at double ridge growth stage, was better correlated to NIR/R than ND. Plant height at anthesis was not correlated to any of three spectral indices. Above ground plant biomass at anthesis was better correlated with ND, although the slope of this relationship was weaker compared to the slope of NIR/R against above ground plant biomass at anthesis. The correlation between grain yield and NIR/R integrated over the whole growing season was poor and

statistically insignificant. An analysis based on yield components and spectral indices to predict genotypes grain yield was unsuccessful. We conclude that predicting grain yield of winter wheat genotypes based only on spectral reflectance measurements requires further study. The results from experiment 2 indicate that although the effects of leaf rust on winter wheat genotypes can be seen as decreased spectral reflectance, these differences do not appear to be related to grain yield.

IV. References

- ✓ Aase, J. K., and F. H. Siddoway. 1981. Assessing winter wheat dry matter production via spectral reflection measurements. *Remote Sens. Environ.* 11:267-277.
- ✓ Aase, J. K., F. H. Siddoway, and J. P. Millard. 1984. Spring wheat-leaf phytomass and yield estimates from airborne scanner and hand-held radiometer measurements. *Int. J. Remote Sens.* 5:771-781.
- ✓ Asrar, G., M. Fuchs, E. T. Kanemasu, and J. K. Hatfield. 1984. Estimating absorbed photosynthetic radiation and leaf area index from spectral reflectance in wheat. *Agron. J.* 76:300-306.
- ✓ Asrar, G., E. T. Kanemasu, R. D. Jackson, and P. J. Pinter, Jr. 1985. Estimation of total above-ground phytomass production using remotely sensed data. *Remote Sens. Environ.* 17:211-220.
- ✓ Ausmus, B. S., and J. W. Hilty. 1972. Reflectance studies of healthy, maize dwarf mosaic virus-infected, and *Helminthosporium maydis* - infected corn leaves. *Remote Sens. Environ.* 2:77-81.
- ✓ Jackson, R. D., S. B. Idso, R. J. Reginato, and P. J. Pinter, Jr. 1980. Remotely sensed crop temperatures as inputs to irrigation scheduling. *Irrigation and Drainage - Today's Challenges*. Boise, Idaho.
- ✓ Leamer, R. W., J. R. Noriega, and A. H. Gerbermann. 1980. Reflectance of wheat cultivars as related to physiological growth stages. *Agron. J.* 72:1029-1032.
- ✓ Meyers, V. I., and W. A. Allen. 1968. Electrooptical remote sensing methods as nondestructive testing and measuring techniques in agriculture. *Appl. Opt.* 7:1819-1837.
- ✓ Meyers, M. P., and D. W. Prench. 1967. Detection of disease trees. *Photog. Engs.* 33:1035-1040.
- ✓ Safir, G. R., G. H. Suits, and A. H. Ellingboe. 1972. Spectral reflectance and transmittance of corn leaves infected with *Helminthosporium maydis*. *Phytopathology* 62:1210-1213.
- ✓ Story, R., and G. A. Yapp. 1971. Variation in infrared reflectance of Eucalyptus radiation D. C. Aust. J. Bid. Sci. 24:945-953.
- ✓ Sumayao, C. R., and E. T. Kanemasu. 1979. Temperature and stomatal resistance of soybean leaves. *Can. J. Pl. Sci.* 49:153-162.

Table 1. List of Genotypes in Experiment I.

1. Newton
2. Hawk
3. Arkan
4. Mustang
5. Rocky
6. Bounty 205
7. Bounty 203
8. Bounty 310
9. PB 830
10. Colt
11. KS80336
12. Tam 107
13. Caldwell
14. Hart
15. Compton
16. Tam 108
17. Centura
18. Larned
19. Chisholm
20. Napb exp-283
21. Triumph
22. HW 3015
23. HR-64
24. Wranbler
25. KS1957

Table 2. Analysis of variance of grain yield
(Experiment 1)

Variation	D.F.	SS	MS	F
Total	99	6813.24		
Blocks	3	36.30	12.10	
Entry	24	4982.46	207.60	8.33*
Error	72	1794.48	24.92	

LSD for $t=1.98$ is 6.989

C.V. = 9.282%

Variation	D.F.	SS	MS	F
Total	103	15106.75		
Blocks	3	974.78	324.93	
Entry	25	10966.28	438.65	10.39*
Error	75	3165.69	42.21	

LSD for $t=1.96$ is 9.004

C.V. = 11.623%

* Significant at 0.01

Table 3. Analysis of Variance of Grain Yield (Experiment 2)

1984-85 season				
Variance	D.F.	SS	MS	F
Total	47	1525.65		
Blocks	3	95.30	31.77	
Entry	11	309.07	28.10	0.83
Error	33	1121.28	33.98	

LSD for $t = 1.96$ is 8.078

C.V. = 9.16%

1985-86 season				
Variance	D.F.	SS	MS	F
Total	47	5074.55		
Blocks	3	141.98	47.33	
Entry	11	4236.39	385.13	18.26*
Error	33	696.18	21.10	

LSD for $t = 1.96$ is 6.365

C.V. = 6.708%

* significant at 0.01

Table 4. Differences in seasonally integrated N/R/R ratio between diseased and control plots vs. grain yield; $R^2=0.196$

Genotype	Disease	NIR/R	Grain yield (g/m ²)
	Susceptibility	Control - Diseased	Control - Diseased
Newton	Susceptible	33.43	140.17
Tam 108	Susceptible	50.54	104.25
Brule	Intermediate	33.17	12.65
Victory	Intermediate	36.46	85.15
Arkan	Tolerant	29.78	39.95
KS 80336	Tolerant	22.67	100.21

Fig. 1: Seasonal changes of the reflectance factors in the red wavelength for the genotype Bounty 205. EXO and BRN refer to the radiometers EXOTECH and BARNES.

Fig. 2: Seasonal changes of the reflectance factors in the near-infrared wavelength for the genotype BOUNTY 205.

Fig. 3: Plot of NIR/R ratio and ND with time for the genotype Bounty 203.

Fig. 4: Plot of NIR/R ratio and Normalized Difference for the genotype PB 830.

Fig. 5: Plot of Greenness for the genotype Newton.

Fig. 6: Near-infrared to red ratio of all genotypes at flowering.

Fig. 7: Normalized difference of all genotypes at flowering.

Fig. 8: Greenness of all genotypes at flowering.

Fig. 9: Plot of NIR/R ratio (Barnes data) for different genotypes between terminal spikelet and booting (a), booting and flowering (b), and between flowering and senescence (c).

Seedling vigor = $-0.14 + 0.096 \text{ NIR/R}$
 $R^2 = 0.84$

Fig. 10: Plot of seedling vigor with near-infrared to red ratio (Barnes data).

Fig. 11: Plot of NIR/R ratio and ND (Barnes data) with plant height at anthesis. The data points circled are not included in the

Fig. 12: Plot of NIR/R ratio (Barnes data) and Normalized difference (Exotech data) with total above ground biomass per plant at anthesis.

Fig. 13: Plot of yield components with spectral data.

Fig. 15: Plot of Near-infrared to Red ratio (Barnes data) of control (ND) and diseased (D) genotypes in Experiment 2, with time.

Fig. 14: Plot of Near-infrared to Red ratio (Barnes data) of control (ND) and diseased (D) genotypes in Experiment 2, with time.

Fig. 16: Plot of grain yield of genotypes in Experiment 2 (both diseased and control) with seasonally integrated NIR/R ratio (Barnes data).

4.0 Chapter II

Experiment 6

(KANSAS)

ESTIMATING GRAIN YIELD ACROSS WINTER WHEAT
GENOTYPES USING SPECTRAL REFLECTANCE DATA

P. Shields and R. Sears

I. ABSTRACT

An experiment was conducted to determine if a relationship exists between spectral reflectance and grain yield across many winter wheat genotypes grown in small plots typical of a breeding program. The experiment contained 52 genotypes and was conducted in Manhattan and Hutchinson during the 1985-86 growing season. Spectral reflectance data were collected with an EXOTECH radiometer on clear days during the growing season. When all genotypes were pooled, there was no relationship between single day Normalized Difference (ND) and genotype grain yield. When analyzed by family, the best model contained the five variables ND101, ND1039, ND151, heading date and plant height ($R^2=0.81$). When analyzed by entry, the same model was significantly related to grain yield but not as strongly as on a family basis ($R^2=0.40$). The coefficients from the model developed at Manhattan were used to predict yield using Hutchinson data. When analyzed by entry R^2 values were 0.38 and 0.65 when analyzed by family. This indicates that it may be possible to predict yield using models developed in previous seasons, even when conditions vary from one season to the next.

II. INTRODUCTION

As wheat is systematically improved it becomes increasingly difficult to identify new and improved genotypes. Selection of genotypes requires large populations, and considerably more time and effort. Promising genotypes are identified in early generations by visual selection. Visual selection can be used to select for qualitative traits such as plant height, maturity, and disease resistance. Quantitative traits however, such as yield are much more difficult to visually evaluate with consistent and accurate results, especially under stress conditions (Briggs and Shebesk, 1970; Shuthman and Steidl, 1976).

Remote sensing may provide a means by which estimates of yield could be obtained rapidly and accurately without the cost of early generation yield testing. Remote sensing is the measurement of spectral reflectance from the crop canopy in the near-infrared and visible regions of the electro-magnetic spectrum. As green leaf biomass increases during crop development, red radiance decreases due to increased chlorophyll absorption (Gates et al., 1965) and infrared radiance increases due to an increased number of hydrated cell walls to air space interfaces (Mestre, 1935).

Spectral reflectance measurements have been shown to be related to leaf area index (LAI) across planting dates (Hatfield et al., 1985) and irrigation levels of wheat (Asrar et al., 1985), sorghum and soybean (Kanemasu, 1974). Aase and Siddoway (1981) found that spectral data could predict total dry matter accumulation in wheat. Using data from 24 separate studies their results showed that a strong relationship existed between total dry matter and grain yield over a wide range of

environments, cultivars, and time ($R^2=0.95$). This suggests that it may be possible to predict grain yield in wheat using spectral reflectance data.

Using spectral data Tucker et al. (1980) was able to explain 64 percent of the variation in grain yield between plots of a single variety of wheat. A 40 day time frame existed when spectral data was correlated to grain yield with the highest correlations occurring at heading. Aase et al. (1984) combined three years of data for two spring wheats and one winter wheat. A significant relationship was found between spectral data and grain yield ($R^2=0.84$). Pinter et al. (1981) used a method based on the spectral reflectance trend over a critical period, grain filling, rather than single-date observations. The integration of spectral data with time measures the duration and amount of photosynthetic active tissue present. For two wheats and one barley variety, grain yield was predicted with an $R^2=0.88$.

Hatfield (1981) evaluated the use of spectral data in estimating yield across a range of wheat genotypes. Very little variation in spectral data was observed between genotypes prior to heading. When genotypes were grouped according to yield no differences in spectral reflectance were observed between the 3000-4000 kg/ha and 5000-6000 kg/ha groups. Differences were found only when specific comparisons were made among the highest and lowest yielding genotypes. He concluded that spectral data alone could not predict wheat yields.

Most previous studies contained only one or a few genotypes and results were directed towards the potential use of LANDSAT in predicting global crop production. Our objective was to use many genotypes, some of them related which is typically seen in a wheat breeding program

and determine 1) if a relationship exists between spectral reflectance data and grain yield across many genotypes and 2) if spectral data can detect yield differences between similar genotypes.

III. MATERIALS AND METHODS

The experiment was conducted at the Ashland Experiment Station south of Manhattan, KS on a Reading silt loam soil (fine, mixed, mesic, typic Argindolls) and the Hutchinson Experiment Station south of Hutchinson, KS on a Clark-Ost complex loam soil (Clark: fine-loamy, mixed, thermic, typic Calciustolls; Ost: fine-loamy, mixed, thermic, typic Argiustolls). Plots of winter wheat (*Triticum aestivum* L.), 4.6 m long, containing 3 rows 0.176 m apart were planted Oct. 17 and Oct. 23, 1985 at Manhattan and Hutchinson, respectively, at a rate of 72 kg/ha. Plots were later trimmed to a final length of 3 meters at harvest. Preplant fertilizer was applied at a rate of 114 kg N/ha and 40 kg P/ha. Glean was applied (23.4 g/ha) during the winter to prevent the emergence of any broadleaf weeds. The following spring, April 8, 1986, plots at Hutchinson were topdressed with 61.4 kg N/ha at growth stage Feekes 7. Tilt was applied to plots at Manhattan May 19, 1986, growth stage Feekes 10.5.3-11.1. Plots were harvested June 16 and June 25, 1986 at Hutchinson and Manhattan respectively.

The experiment consisted of two replications of 60 plots at each location. The experimental design was a randomized complete block augmented design. Each replication consisted of four blocks of 15 plots per block. Two plots in each block were checks, Arkan and KS-831374. The experiment contained 52 genotypes, 14 released varieties or

advanced experimental lines and sister lines from 5 different families (Table 1). The five families represented different plant architecture, differing in leaf angle, plant height, tillering and head size.

A short-row non-replicated test was included at Manhattan. Plots were 1 m long, containing 3 rows 17.6 cm apart. The test included the same genotypes as the replicated test. The test consisted of five blocks of 15 plots per block. Four plots in each block were checks. Seeding, fertilizer, herbicide, and fungicide rates were identical to rates for the replicated test at Manhattan.

Canopy spectral radiance measurements were made with a 15° field-of-view Exotech radiometer, Model 100A, which has four multispectral (MSS) bands, MSS4, 0.5-0.6 μm ; MSS5, 0.6-0.7 μm ; MSS 6, 0.7-0.8 μm ; and MSS7, 0.8-1.1 μm . The radiometer was held at a height of 2.3 meters above the surface of the soil using a hand-held boom while measurements were taken. Three measurements within each plot were made with a polycorder used to record the data. Spectral radiance measurements were obtained nine times throughout the growing season at Manhattan beginning at second node formation (Feekes 7) and ending at maturity (Feekes 11.2) (Table 2), seven measurements were taken in the short-row test. Measurements were taken twice at Hutchinson, one at heading to beginning flowering (Feekes 10.1-10.5.1) the other at kernel milky ripe (Feekes 11.1-11.2). Standard reflectance was measured using a barium sulfate panel every 30 plots. Normalized difference vegetative index (ND) was used to relate spectral reflectance data with grain yield. Prior to harvest 0.5 m of the middle row was cut at the soil line. Total biomass, number of spikes, spikelets/spike, and kernel weight was

measured. Additional data collected from each plot included heading date, height, disease ratings and grain yield.

All data collected from the plots were adjusted before analysis. The plots within each block were compared to the checks within that same block. Differences in a check across blocks was assumed to be caused environmentally and would affect all plots the same within a block. An adjusted value for each plot was obtained using the equation:

$$\text{adj. value} = \text{entry value} - \text{check(block) mean} + \text{overall check mean}$$

The checks within a block were averaged together and then subtracted from each plot within that same block. This causes the check average to equal zero so any plot with a value less than the check average will have a negative adjusted value. Negative values were eliminated by adding the check mean of the analysis.

Data from the experiment were analyzed by entry and by family. When analyzed by entry each genotype was considered separately for a total of 52. When analyzed by family the sister lines within each of the five families were averaged to obtain one value. Each of the 14 released or advanced experimental lines was considered as a separate family, for a total of 19 families.

A multiple regression model containing ND values from the nine days, along with heading date and plant height was used to determine if reflectance data from multiple days or additional variables could provide a method of predicting yield. A stepwise procedure was used to determine the best model.

IV. RESULTS AND DISCUSSION

Analysis began by using data from the replicated test at Manhattan. When a single genotype, KS831374, was analyzed reflectance data was significantly related to yield on several days, the highest occurring at day 139 ($R^2=0.77$). This supports previous work (Aase and Siddoway, 1981; Tucker et al., 1980; Aase et al., 1984). When all genotypes were considered no relationship between single day ND values and actual grain yield was found for any of the nine days (Table 3). This agrees with Hatfield (1981) in that across genotypes, spectral reflectance data alone could not predict grain yield.

When analyzed by family, the best model contained the five variables ND101, ND139, ND151, heading date, and plant height (Table 4). All were significant at the 0.01 level. The model was strongly related to actual grain yield, $R^2=0.81$ (Figure 1). The three days of reflectance data coincided with stages of growth that appear critical in determining grain yield. We theorize that the reflectance data from day 101 gave some measure of stand establishment. Plots were planted in wet soil and stand density was not uniform for all plots. Reflectance readings at early stages of growth may have detected differences in stand density. Measurements at day 139 occurred close to anthesis when maximum leaf area is present. Reflectance readings at this stage should be able to differentiate between genotypes for amount of photosynthetic active biomass present which is basic to production of grain. The coefficient for ND139 was negative which we were unable to explain. When ND131 was substituted for ND139 the coefficient for ND131 was positive and the

model remained significantly related to grain but with a lower R^2 value, $R^2=0.63$. Since ND131 is closer to anthesis than ND139 further studies may indicate that a reading coinciding with anthesis may be the most beneficial. Day 151 occurred when leaves were beginning to senesce. Measurements at this stage may estimate leaf area duration which has been shown to be related to grain yield (Barojeciv and Williams, 1982). Even though the range in yield was only 104 g/m^2 the model ranked the families correctly except for reversing the top two entries (Table 5).

When analyzed by entry the same variables were used in the model (Table 4). The model was significantly related to actual grain yield, $R^2=0.40$ (Figure 2) but not as strongly as on a family basis. The coefficients for the model were not the same as for the model based on families.

In early generation testing many genotypes are tested and often selections with identical pedigrees are included, similar to the families in this experiment. These tests are not normally harvested for yield, therefore yield is visually selected. At this stage of testing the determination of the highest yielding genotype is not as important as the selection of a group of genotypes with a high yield potential that can be advanced for further testing. Table 6 shows the top 30% yielding entries and their ranking based on predicted yield. The model correctly identified 7 out of 15 genotypes. To compare this to visual selection a wheat breeder and four graduate students from the wheat breeding program visually selected what they thought to be the top 30% yielding entries. The number of entries correctly selected by visual evaluation ranged from 6 to 8. A yield component study showed that high yielding entries not selected by the model generally had a high seed

weight, which the radiometer is unable to detect (Table 7). Entries incorrectly predicted to be high yielding were normally genotypes with a high number of heads per area (Table 8). This resulted in higher ND values than expected.

Integration of ND with time, a method similar to that suggested by Tucker et al., 1980 was not found to be effective at predicting yield.

Stepwise regression was also used to analyze data from the non-replicated short rows. The full model included 7 days of spectral reflectance data, heading date, and plant height. Analyzed by family the fit best contained the four variables ND121, ND125, ND131, and ND159, $R^2=0.64$. Analyzed by entry using the same model $R^2=0.36$. Using data that was taken at approximately the same time as the replicated test, ND106, ND131, ND151, heading date, and plant height the model was unable to predict yield, $R^2=0.18$ when analyzed by family. When six entries were eliminated based on thin stands, R^2 increased to 0.30 but still was not significant. Variance in yield was significantly greater for the short-row test when compared to the replicated test. In addition, rank correlations for yield were poorly correlated between the two tests, $r=-0.17$. This indicates that for this experiment there are limitations on plot size in predicting grain yield using spectral reflectance data.

Reflectance readings were taken at Hutchinson on day 122 and 140, closely matching the growth stage of wheat at Manhattan on day 131 and 151 respectively. A model containing ND122, ND140, heading date, and plant height was used to predict yield. Analyzed by family $R^2=0.67$ and by entry $R^2=0.42$ (Table 9).

To determine the contribution of reflectance data to the prediction of grain yield a model containing only heading date and plant height was used. For Manhattan data R^2 values were 0.25 analyzed by entry and 0.43 by family (Table 4). Approximately half of values obtained from the model contained reflectance data. These values are significant but are too low to provide a reliable method of predicting yield. For Hutchinson data R^2 values for the models containing heading date and plant height were only slightly lower than values from the models containing reflectance data; 0.41 for entries and 0.65 for families (Table 7). Plots at Hutchinson were not sprayed with a fungicide therefore, a great deal of leaf rust was present. This caused premature loss of leaves reducing the effectiveness of spectral reflectance data. Using six genotypes which had some level of resistance to leaf rust, the model containing reflectance data was almost twice as effective as the model containing heading date and plant height, R^2 value of 0.64 versus 0.38. A difference similar to that found for the Manhattan data. In a breeding program leaf rust susceptible genotypes would be eliminated by visual evaluation and reflectance data would select high yielding genotypes from those with a desirable level of foliar disease resistance.

A main objective of the Hutchinson test was to determine if the model developed at Manhattan could be used in a different environment. This would give an indication of whether the model would be stable across years. The coefficients from the model developed at Manhattan containing the variables ND131, ND151, heading date, and plant height were used to predict yield using Hutchinson data. Using this method R^2 values were 0.38 analyzed by entry and 0.65 when analyzed by family.

These values indicate that it may be possible to predict yield using models developed in previous seasons, even when conditions vary from one seasons to the next. However, because heading date and plant height had such a strong influence, the heading date and plant height model from Manhattan predicted grain yield at Hutchinson nearly as well as the model containing reflectance data. If leaf rust had not been present at Hutchinson, we conclude that the model containing reflectance data would have been more effective than the model containing heading date and plant height.

Reflectance data combined with heading date and plant height are related to yield. Identification of high yielding families which have the greatest chance of containing high yielding genotypes could benefit plant breeders. A large number of families could be eliminated well before harvest enabling the plant breeder to concentrate his efforts on the high yielding families. Individual lines can be selected but not as effectively as families, but perhaps equally as well as visual selection. Although the model was not accurate enough to justify the use of remote sensing in a breeding program at the current time, it did show enough promise to continue further studies. Further studies need to be undertaken to determine stability across environments and genotypes.

V. CONCLUSIONS

There was no relationship between single day ND and grain yield of all the genotypes. The best model contained spectral data collected at 3 critical stages and heading data and plant height. When analyzed by family, this model was better ($R^2=0.81$) than when analyzed by entry

($R^2=0.40$). Integration of ND with time was not found to be effective at predicting yield. Variance in grain yield was significantly greater for the non-replicated short rows indicating that for this experiment there are limitations on plot size in predicting grain yield using spectral reflectance data. Also, the coefficients from the model developed at Manhattan were used to predict yield using data collected at Hutchinson. When analyzed by entry, R^2 values were 0.38 and 0.65 when analyzed by family. This indicates that it may be possible to predict yield using models developed in previous seasons, even when conditions vary from one season to the next.

VI. REFERENCES

- ✓ Aase, J. K. and F. B. Siddoway. 1981. Spring wheat yield estimates from spectral reflectance measurements. *IEEE Trans. Geosci. Remote Sens.* 19:78-84.
- ✓ Aase, J. K., F. B. Siddoway, and J. P. Millard. 1984. Spring wheat-leaf phytomass and yield estimates from airborne scanner and hand-held radiometer measurements. *Int. J. Remote Sens.* 5:771-781.
- ✓ Asrar, G., E. T. Kanemasu, and M. Yoshida. 1985. Estimates of leaf area index from spectral reflectance of wheat under different cultural practices and solar angle. *Remote Sens. Environ.* 17:1-11.
- Borojevic, Slavko and William A. Williams. 1982. Genotype X environment interactions for leaf area parameters and yield components and their effects on wheat yields. *Crop Sci.* 22:1020-1025.
- Briggs, K. G. and L. H. Shebeski. 1970. Visual selection for yielding ability of F_3 lines in a hard red spring wheat breeding program. *Crop Sci.* 10:400-402.
- ✓ Hatfield, J. L. 1981. Spectral behavior of wheat yield variety trails. photogram. *Eng. Remote Sens.* 47:1487-1491.
- Hatfield, J. L., E. T. Kanemasu, G. Asrar, R. D. Jackson, P. J. Printer, Jr., R. J. Reginato, and S. G. Idso. 1985. Leaf-area estimates from spectral measurements over various planting dates of Wheat. *Int. J. Remote Sens.* 6:167-175.
- ✓ Idso, S. B., P. J. Printer, Jr., R. D. Jackson, and R. J. Reginato. 1980. Estimation of grain yield by remote sensing of crop
- ✓ Kanemasu, E. T. 1974. Seasonal canopy reflectance patterns of wheat, sorghum, and soybean. *Remote Sens. Environ.* 3:43-47.
- Large, E. C. 1954. Growth stages in cereals. Illustration of the Feekes scale. *Plant Pathol.* 3:128-129.
- Mestre, H. 1935. The absorption of radiation by leaves and algae. *Cold Springs Harbor Symp. Quant. Biol.* 3:181-209.
- ✓ Pinter, Jr., P. J., R. D. Jackson, S. B. Idso, and R. J. Reginato. 1981. Multidate spectral reflectance as predictors of yield in water stressed wheat and barley. *Int. J. Remote Sens.* 2:43-48.
- Stuthman, D. D. and R. P. Steidl. 1976. Observed gain from visual selection for yield in diverse oat populations. *Crop Sci.*
- Tucker, C. J., B. N. Holben, J. H. Elgin, Jr., and J. E. McMurtrey III. 1980. Relationship of spectral data to grain yield variation. *Photogram. Eng. Remote Sens.* 46:657-666.

TABLES AND FIGURES

Table 1. Entries from each family and number of released or advanced experimental lines grown at Manhattan and Hutchinson, KS in 1985.

SELECTION	PEDIGREE	ENTRIES
XGH80167	TX71A916/KS79468	11
X81125	KS79468/NEWTON//ND7735/TX71A916	9
X7878	NEWTON/DAVID	7
X789-16	PLAINSMAN V/TAM 105	6
X7866	NEWTON/NE76698	5
RELEASED OR ADVANCED EXP. LINES		14
	TOTAL	52

Table 2. Days and growth stage when radiometer data were collected from the replicated test at Manhattan.

Day of Year	GROWTH STAGE
	----- FEEKES
101	7
110	7-8
112	8-9
121	9-10.1
125	10.2-10.5
131	10.5.1-10.5.4
139	10.5.3-11.1
151	11.1-11.2
159	11.2

Table 3. Coefficient of Determination values for ND and grain yield for each of the 9 days spectral reflectance data were collected when analyzed by family and by entry.

Date of Reflectance Measurement	ND R ² VALUES	
	FAMILY	ENTRY
101	.14	.13**
110	.001	.003
112	.02	.000
121	.13	.002
125	.06	.06**
131	.01	.01
139	.000	.000
151	.04	.03
159	.09	.01

** means significant at 1% level

Table 4. Regression coefficients and coefficient of determination values for models from replicated test at Manhattan analyzed by family and by entry.

REGRESSION COEFFICIENTS							
	B _O	ND101	ND139	ND151	PLANT HEIGHT	HEADING DATE	R ²
FAMILY	2450.8	2635.2	-1137.5	752.9	9.6	-37.8	0.81**
FAMILY	2757.0				10.9	-26.0	0.43**
ENTRY	421.2	1693.9	-103.6	188.0	5.9	-16.2	0.40**
ENTRY	1861.5				6.7	-15.9	0.25**

** means significant at 1% level

Figure 1. Actual grain yield from Manhattan replicated test versus predicted grain yield from model containing ND101, ND139, ND151, heading date, and plant height for the 19 families.

Figure 2. Actual grain yield from Manhattan replicated test versus predicted grain yield from model containing ND101, ND139, ND151, heading date, and plant height for the 52 entries.

Table 5. List of families and ranking based on actual harvested grain yield and rank based on predicted yield.

FAMILY	RANK BY YIELD	
	ACTUAL	PREDICTED
X7866	1	2
X81125	2	1
XGH80167	3	3
X789-16	4	4
X7878	5	5

Table 6. List of 15 highest yielding entries based on actual harvested grain yield and rank based on predicted yield from model.

ENTRY	RANK BY YIELD	
	ACTUAL	PREDICTED
BOUNTY 301	1 *	1
X81125-25	2 *	14
BOUNTY 122	3 *	9
X7866-11-8	4 *	8
KS8312Q3	5 *	6
KS82H144	6	25
VICTORY	7	18
X7878-3-7	8	17
X81125-26	9 *	5
KS79238-2	10 *	13
X7866-11-4	11	39
XGH80167-2-18	12	28
X7866-11-7	13	20
KS831936	14	27
CHISHOLM	15	29

* entries model correctly selected

Table 7. Rank by actual yield, predicted yield, and kernel weight of high yielding entries model underestimated for yield grown at Manhattan, KS.

	RANK		
	ACTUAL YIELD	PREDICTED YIELD	200 KERNEL WEIGHT
X81125-25	2	14	5
KS82H144	6	25	3
VICTORY	7	18	2
X7878-3-7	8	17	26
X7866-11-4	11	39	20
XGH80167-2-18	12	28	6
X7866-11-7	13	20	8
KS831936	14	27	10
CHISHOLM	15	29	15

Table 8. Rank by actual yield, predicted yield, and heads/0.5 m row of entries model overestimated for yield grown at Manhattan, KS.

	RANK		
	ACTUAL YIELD	PREDICTED YIELD	HEADS/0.5 m ROW
XGH80167-23	32	2	3
X81125-60	31	3	8
PONY	16	4	7
X81125-30	25	7	14
KS82H4	19	10	2
KS831957	34	11	11
NEWTON	30	12	20

Table 9. Regression coefficients and coefficient of determination determination values for models from replicated test at Hutchinson analyzed by family and by entry.

REGRESSION COEFFICIENTS						
	B _O	ND122	ND140	PLANT HEIGHT	HEADING DATE	R ²
FAMILY	2334.0	112.2	167.1	5.9	-21.3	0.67**
FAMILY	2536.2			7.0	-21.9	0.65**
ENTRY	1816.7	22.5	68.4	1.9	-13.3	0.42**
ENTRY	1898.0			2.3	-13.6	0.41**

** means significant at 1% level

5.0 Chapter III

Experiment 2 and 6

(ISRAEL)

CANOPY TEMPERATURE AS A CORRELATIVE MEASURE FOR ASSESSING HOST RESPONSE
TO SEPTOREA TRITICI BLOTCH OF WHEAT

Z. Eyal and A. Blum

I. ABSTRACT

The utility of canopy temperature sensing by the infrared thermometer for assessing wheat resistance to *Septoria tritici* blotch was evaluated for three years. Forty three, 31 and 33 cultivars of common spring wheat (*Triticum aestivum*), durum wheat (*T. durum*) and triticale (*x triticosecale*) were field-tested from 1985 through 1987, respectively. Canopy temperatures were measured on several dates after anthesis, in disease infected plots and in disease-protected and non-infected plots of the same cultivars. Canopy temperatures were evaluated against percent disease coverage and percent green leaf area in each date and the integrated reaction to the disease as measured by the area under the septoria progress curve (AUSPC) and percent kernel weight loss due to the disease.

Canopy temperatures increased with the increase in percent disease coverage and decreased with the increase in percent green leaf area of cultivars. These associations tended to weaken with time after anthesis, as all materials senesced due to either complete disease coverage or to natural plant senescence. When canopy temperatures were recorded before maturity and when cultivars varied for disease coverage, the correlations between the two variables ranged from $r=0.48^{**}$ to $r=0.71^{**}$, depending on year and date of measurement. On a given date, disease coverage and canopy temperatures were reduced in the later flowering cultivars. The association between canopy temperatures and disease coverage was generally improved when evaluated within cultivars of similar phenology. In all years, canopy temperatures were positively associated with AUSPC and percent kernel weight loss, and correlation

coefficients differed according to year and date of temperature measurement. These results showed that infrared thermometry of diseased canopies of wheat was useful for predicting differences in plant resistance to *Septoria tritici* blotch, whether resistance resulted from reduced disease coverage on cultivars of similar phenology or whether it was a result of a longer growth duration of a cultivar. Infrared thermometry could not differentiate between these two reactions.

II. INTRODUCTION

Septoria tritici blotch, which is caused in wheat by the fungus *Mycosphaella graminicola* (Fuckel) Schroeter (anamorph: *Septoria tritici* Rob. ex Desm.), may impose severe limitations on wheat yields in several parts of the world (3). Under severe epidemics some vulnerable wheat cultivars may suffer 30 to 50% losses in yield, resulting in shriveled grain (3).

Morphological traits (plant height and canopy architecture), physiological traits (photoperiod and vernalization requirements) and growth habit all influence the expression of symptoms and signs (chlorosis, necrosis and pycnidial production). Differentiation of cultivar response to the pathogen is usually based on quantitative assessment of symptoms. The pathogen affects leaf tissue causing large coalescing necrotic lesions, which in many cases harbor pycnidia. Pycnidia can often be found also on leaf sheath, spike peduncle, glumes and awns, depending on cultivar susceptibility and plant architecture (3).

Leaf tissue necrosis and pycnidia coverage were linearly correlated with losses in yield components (3,5). Gaunt (5) argued that green

leaf area, rather than diseased leaf tissues should be used to estimate yield losses. Wheat cultivars of similar phenology may express differential yield responses under similar apparent disease severity and progress (15). Wheat cultivars may differ in the ability to endure (tolerate) severe epidemics without sustaining significant losses in yield, when compared with vulnerable (non-tolerant) cultivars (15).

The better understanding in recent years of the leaf and leaf-canopy energy balance brought about the use of canopy temperature measurements as a simple probe of plant water-relations. The measurement of transpirational cooling of leaves by remote infrared thermal sensing of crop canopies allowed to develop methodologies for assessing crop water stress for irrigation scheduling (8,9). Recently, the infrared thermometer has been proposed as a tool in screening plant breeding materials for drought resistance (1,2,4,6,12).

Infrared canopy temperature measurement was also suggested for assessing biotic stresses (9,11,13,14). Canopy temperature was initially reduced in diseased as compared with non-diseased plants, as a consequence of an increase in transpiration in the diseased (e.g. rust) plants. However, this trend was reversed with the progression of infection (11,13), when canopy temperatures rose as a consequence of progressive leaf death. It was therefore hypothesized that the variation among wheat breeding germplasm differing in response to *Septoria tritici* blotch could be assessed by the measurement of canopy temperature under disease epiphytotics.

III. MATERIALS AND METHODS

Experiments were performed under normal wheat growing practices aimed at optimizing the growing conditions. These practices included ample fertilization, chemical weed control and supplemental irrigation when needed. Forty three and 31 cultivars of common spring wheat (*Triticum aestivum*), durum wheat (*T. durum*) and triticale (x triticosecale Wittmark) were tested at Bet Dagan in 1985 and 1986, respectively. Thirty three common spring wheat and durum wheat cultivars were tested at Saad in 1987 (Table 1). Cultivars were chosen for their receptivity to *Septorea tritici* and their response in yield components to the disease. A split-plot design was adopted in all experiments. Infection by *S. tritici* was compared with non-infected and fungicide-protected (three applications of tilt) conditions in main plots. Cultivars were planted as sub-treatments in two replicates (blocks). Each plot was 5 m long and 2 m wide, planted by drill at 15 cm row spacing. *Septorea tritici* blotch epidemics were incited by a weekly sprays of the canopy with a suspension of 1×10^7 spores per ml of a mixture of five virulent isolates of *S. tritici*. Sprays were applied from emergence of flag minus-2-leaf until the end of the milk stage of grain ripening. Each isolate of *S. tritici* was grown separately in a liquid sucrose (3%) and yeast extract (0.5%) medium and rotated for 5 to 6 days at 18C prior to application. The suspension of each isolate was adjusted and mixed in the field prior to application. Application was performed with a low-volume low-pressure Ulva 8 sprayer (Micron Co., Bromyard, England) during rainy days and/or dewy nights. Assessments of percent pycnidia coverage on the four uppermost leaves and percent

residual green leaf area were performed at about weekly intervals. Green leaf area was assessed also in the non-diseased plots on the same dates. The final estimate of the severity of infection was the area under the Septoria progress curve (AUSPC) for the 30 days past anthesis for each plot.

Canopy temperature measurements were performed within 0 to 4 days of the date of disease measurement. Two, 4 and 1 temperature measurements were made in 1985, 1986, and 1987, respectively (Table 2). Temperature was measured from the ground at midday in all diseased and control plots with a hand-held Everest infrared thermometer aimed at the center of the plot. Target area diameter was 55 to 65 cm. Extreme care was taken to avoid the viewing of the ground surface in the target area. Temperature readings were standardized by calculating the temperature of each plot in a block as the percent of the mean temperature of all plots in that block. Air temperatures on all dates of measurement in the three years ranged from 19.1 to 26.3C.

All plots were harvested and kernel weight was determined for evaluating the effect of the disease on this yield component.

IV. RESULTS AND DISCUSSION

High pycnidia coverages were recorded on the susceptible wheat cultivars in all years. Up to 95% of the leaf area was necrotic and desiccated in the most susceptible cultivars (e.g. 'Barkaee') by the last date of measurement in each of the three years. AUSPC (Table 1) as a final integrated measure of disease development and intensity differed greatly among cultivars. For the most susceptible (e.g. 'Barkaee') and

the most resistant (e.g. 'KVZ-4500 A.L.U.') cultivars differences in AUSPC were consistent over years.

IV. 1. 1985 trial

Regressions between percent disease coverage and canopy temperature in infected plots across all cultivars were computed for the two dates when canopy temperature was measured (Fig. 1). The association was significant and slightly better in the second ($r=0.57^{**}$) than in the first ($r=0.48^{**}$) date of measurement. It was non-linear on the second date. This association was by no means perfect. Undoubtedly it was affected by factors additional to percent disease coverage. The use of the temperature difference between inoculated and control plots instead of canopy temperature in inoculated plots did not improve the regressions. Percent disease was negatively correlated with days to anthesis (DTA) ($r=-0.68^{**}$ and $r=-0.73^{**}$ for the two dates, respectively). The greater resistance of late flowering cultivars is well documented (3). Data were therefore partitioned into early (85 to 105 DAE) and late (106 to 120 DAE) flowering cultivars. Within-group correlations between canopy temperature and disease coverage were relatively improved. For example, the respective correlation coefficients for the early flowering group on the first date of measurement was $r=0.73^{**}$, as compared with 0.48^{**} for the pooled data (Fig. 1). Undoubtedly, canopy temperatures taken on a given date after anthesis were affected by the amount of green leaf area at that date, irrespective whether plants highly infected or not (Table 2). Therefore, on a given date canopy temperatures were negatively correlated with DTA (Table 2), partly

because of the greater disease coverage and partly because of the greater senescence in earlier cultivars.

Although temperature measurement represented a transient situation for a given date, canopy temperature on on both dates was found to be correlated ($r=0.48^{**}$ and $r=0.53^{**}$, respectively) across cultivars with AUSPC (Table 2), which represents an integrated an integrated response to the disease over a period of about a month. Loss of kernel weight under septoria leaf blotch infection, which ranged across cultivars from 0 to 41.5%, is a complex response. It involves the effect of the reduced viable leaf area by the disease during grain filling as well as tolerance to the disease in terms of stem reserve mobilization for grain filling (15). Still, a significant positive association was revealed across all cultivars on both dates between canopy temperature and percent kernel weight loss measured at maturity ($r=0.39^{**}$ and $r=0.54^{**}$, respectively) (Table 2).

IV. 2. 1986 trial

Canopy temperatures in infected plots were significantly associated with percent disease across all cultivars in the first three dates of measurement (Table 2). This association tended to weaken with time of measurement (Table 2, Fig. 2). Canopy temperature was negatively correlated with percent green leaf area in infected plots on the first three dates (Table 2). The correlation coefficient was reduced from $r=-0.71^{**}$ in the first date to $r=-0.41^{**}$ in the third date. The correlation did not hold for the fourth date ($r=-0.05$). Mean percent green leaf area of all cultivars in the control plots decreased from 72.7% on

the first date to 19.4% on the fourth date. Canopy temperatures in infected plots were negatively correlated also with percent green leaf area in control plots (Table 2, Fig. 2). Canopy temperatures were therefore affected by the canopy greenness, which in turn was influenced by either the rate of senescence or by the disease coverage of the given variety. Apparently, the lack of correlation between canopy temperature and percent disease coverage or percent green leaf area in infected plots in the last date and the overwhole tendency of these correlations to weaken with time resulted, at least partly, from the progression of leaf senescence in all cultivars. Fig. 2 and the associations between canopy temperature and percent green leaf area in infected and in control plots therefore demonstrate that canopy temperatures may estimate variations in disease coverage among cultivars largely by way of sensing differences in green leaf area (or canopy greenness). Thus, differences among cultivars in age and natural leaf senescence seem to be a major intervening factor in assessing plant resistance by infrared thermometry, as based on disease coverage only. As in 1985, the association between canopy temperature and percent disease coverage became stronger when evaluated within a group of cultivars of similar phenology. Thus, for example, the correlation coefficient between canopy temperature and percent disease coverage across early cultivars only (anthesis at 95 to 115 DAE) was 0.81^{**} , as compared with 0.71^{**} for all cultivars, on the first date. However, as shown for 1985, days to anthesis was significantly and negatively correlated with percent disease ($r=-0.73^{**}$, $r=-0.64^{**}$ and $r=-0.55^{**}$ for the first three dates, respectively). Late cultivars that were greener than earlier cultivars on a given date after anthesis also tended to be less susceptible to the

disease. Thus lower canopy temperatures on a given date were sensed in later flowering cultivars which were inherently greener but were also more resistant.

As in 1985, canopy temperature measured on all four dates was significantly associated with AUSPC (Table 2). Only on the last date of measurement was canopy temperature correlated with percent kernel weight loss (Table 2).

IV. 3. 1987 trial

The third year experiment was performed on the basis of the accumulated information in the previous years. Only one temperature measurement was planned. An effort was made to optimize the date of temperature measurement by observing the progress of leaf desiccation with time due to disease progress and natural senescence. At 130 DAE (Table 2) leaves of the most susceptible and early variety ('Barkaee') were nearly totally desiccated, while all other cultivars varied in the amount of green leaves, as estimated visually. This date was therefore considered suitable for infrared thermometry.

The correlation across all cultivars between canopy temperature and percent disease coverage at 130 DAE ($r=0.74^{**}$, Table 2) was as good as or better than the similar correlations obtained in 1985 and 1986. The correlation between canopy temperature and days to anthesis was comparatively high ($r=0.83^{**}$) in this year (Table 2). Data were partitioned into two groups of cultivars according to their heading date. For the late cultivars the correlation between canopy temperature and percent disease was improved to $r=0.91^{**}$ (Fig. 3). The correlation did not

improve for the early cultivars, largely because of four cultivars that had the highest canopy temperatures while they differed for percent disease coverage (Fig. 3, right of dashed line).

The correlations between canopy temperature and AUSPC ($r=0.62^{**}$) or percent kernel weight loss ($r=0.59^{**}$) were better than any of those obtained in the previous years.

V. CONCLUSIONS

In all years of study canopy temperatures were correlated with percent disease coverage across variable germplasm, indicating that variation in resistance to *Septoria tritici* blotch among wheat cultivars can be assessed by variation in canopy temperatures under disease epiphytotics. The inclusion of non-diseased controls for temperature measurements did not improve the method and evaluations can therefore be performed with disease-infected plots only.

Natural senescence intervenes with this association, to the extent that canopy temperatures obtained closer to plant maturity were not predictive of resistance because all materials entered an advanced stage of leaf desiccation, either due to disease coverage or due to natural senescence. It is therefore essential, for this method, that sufficient disease development will be established before materials enter advanced stages of senescence and that temperatures will be monitored before all materials senesce.

Plant phenology has an important effect on both plant resistance and the association between resistance and canopy temperature. However, this effect does not pose a serious problem. Later flowering cultivars

are usually more resistant and have a longer leaf area duration after anthesis. Both attributes affect canopy temperature in the same direction, i.e. reduction in temperature. The infrared thermometer is apparently sensitive to canopy greenness (10), irrespective whether greenness results from reduced disease coverage or lateness of maturity. The subdivision of the materials tested into two groups of plant phenology often improved the prediction of disease coverage by infrared thermometry within a group. The associations between canopy temperature and disease coverage were supported by the significant associations seen in all years between canopy temperature on a given date and AUSPC or percent kernel weight loss at maturity. Both parameters expressed an integrated response to the disease over a period of about a month.

In conclusion, infrared thermometry of disease-infected canopies of wheat is useful for predicting plant resistance to *Septoria tritici* blotch, whether resistance results from reduced disease coverage on cultivars of similar phenology or whether it is a result of a longer growth duration of a cultivar. Infrared thermometry can not differentiate between these two reactions.

VI. REFERENCES

- ✓ Blum, A., Mayer, J. and Golan G. 1982. Infrared thermal sensing of plant canopies as a screening technique for dehydration avoidance in wheat. *Field Crops Res.* 5:137-146.
- ✓ Chaudhuri, U.N., Deaton, M. L., Kanemasu, E.T., Wall, G. W., Marcarian, V., and Dobrenz, A.K. 1986. A procedure to select drought-tolerant sorghum and millet genotypes using canopy temperature and vapor pressure deficit. *Agron. J.* 78:490-494.
- Eyal, Z. 1981. Integrated control of Septoria diseases of wheat. *Plant Disease* 65:763-768.
- Fischer, K.S., Johnson, E.C. and Edmeades, G.O. 1983. Breeding and selection for drought resistance in tropical maize. *International Maize and Wheat Improvement Center, Mexico*, pp. 21.
- Gaunt, R.E. 1985. Reduced green leaf area and yield loss caused by *Septoria tritici*. pp. 77-79. In: *Septoria of cereals*. ed. A.L. Scharen. *Proc. Workshop, August 2-4, 1983, Bozeman, MT, USDA-ARS Publ. no. 12.*
- ✓ Harris, D.S., Schapaugh, W.T. and Kanemasu, E.T. 1984. Genetic diversity in soybeans for leaf canopy temperature and the association of leaf canopy temperature and yield. *Crop Sci.* 24:839-842.
- ✓ Idso, S.B. 1982. Non-water-stressed baselines: a key to measuring and interpreting plant water stress. *Agric. Meteorol.* 27:59-70.
- ✓ Idso, S.B., Reginato, R.J., Jackson, R.D. and Pinter Jr., P.J. 1981. Measuring yield-reducing plant water potential depressions in wheat by infrared thermometry. *Irr. Sci.* 2:205-212.
- ✓ Pinter Jr., P.J., Stanghellini, M.E., Reginato, R.J., Idso, S.B., Jenkins, A.D. and Jackson, R.D. 1979. Remote detection of biological stresses in plants with infrared thermometry. *Science* 205:585-587.
- ✓ Redelfs, M.S., Stone, L.R., Kanemasu, E.T. and Kirkham, M.B. 1987. Greenness-leaf area index relationship of seven row crops. *Agron. J.* 79:254-259.
- ✓ Sharp, E.L., Perry, C.R., Scharen, A.L., Boatwright, G.O., Sands, D.C., Lautenschlager, L.F., Yahyaoui, C.M. and Rauet, F.W. 1985. Monitoring cereal rust development with a spectral radiometer. *Phytopathology* 75:936-939.
- ✓ Singh, D.P., Singh, P., Kumar, A. and Sharma, H.C. 1985. Transpirational cooling as a screening technique for drought tolerance in oil seed brassicas. *Ann. Bot.* 56:815-820.
- ✓ Smith, R.C.G., Heritage, A.D., Stapper, M. and Barrs, H.D. 1986. Effect of stripe rust (*puccinia striiformis* West.) and irrigation on the yield and foliage temperature of wheat. *Field Crops Res.* 14:39-52.
- Tu, J.C. and Tan, C.S. 1985. Infrared thermometer for determination of root rot severity in beans. *Phytopathology* 75:840-844.
- Zilberstein, M., Blum, A. and Eyal, Z. 1985. Chemical desiccation as a simulator of post-anthesis speckled leaf blotch stress. *Phytopathology* 75:226-230.

Table 1. Cultivars tested in 1985, 1986 and 1987, their origin, days from emergence to anthesis (DTA) and the final integrated reaction to septoria leaf blotch in terms of AUSPC.*** In each year, differences among cultivars in days to anthesis and in AUSPC were significant at $p \leq 0.01$.

Cultivar*	Origin**	1985		1986		1987	
		DTA	AUSPC***	DTA	AUSPC***	DTA	AUSPC***
AIX "S" (D)	CIMMYT	-	-	105	513	-	-
ALTAR 84 (D)	CIMMYT	104	322	-	-	-	-
BARKAEE	Volcani	89	1394	95	1328	73	1783
BEAGLE (T)	CIMMYT	100	223	107	195	-	-
BET-HASHITA	Volcani	-	-	98	891	75	1144
BETHLEHEM	Volcani	88	699	95	650	74	1061
BOBWHITE "S"	CIMMYT	108	654	107	265	92	415
CEEON	Hazera	88	930	101	1560	75	1443
CIANO	CIMMYT	108	1835	-	-	-	-
COLOTANA	CIMMYT	122	552	-	-	-	-
DEGANIT	Weizmann	106	1966	-	-	78	1059
ETIT 38 (D)	Volcani	112	540	-	-	-	-
FORTALEZA-1	Brazil	124	505	-	-	-	-
GENARO 81	CIMMYT	108	1706	110	896	91	1260
GIA "S" (D)	CIMMYT	-	-	107	380	-	-
GIORGIO331 (D)	Italy	113	1302	125	1200	112	547
GLENNSON	CIMMYT	94	940	-	-	-	-
H-2230	Hazera	95	1333	-	-	-	-
H-337	Hazera	89	1141	101	1553	74	1348
H-870 (D)	Hazera	100	1081	102	765	78	667
IAS 20=IASSUL	Brazil	113	894	115	433	94	594
INBAR (D)	Volcani	108	931	104	442	89	374
KVZ/7C	CIMMYT	110	667	-	-	-	-
KVZ-4500 ALU	CIMMYT	106	436	110	171	96	404
LACHISH	Volcani	108	1966	103	982	83	1353
LI-217 (T)	Australia	102	379	107	165	-	-
MAPACHE (T)	CIMMYT	101	661	107	309	-	-
Med-Kif/Sapi	CIMMYT	-	-	111	365	-	-
MEXI 75 (D)	CIMMYT	-	-	101	790	-	-
MIRIAM	Volcani	89	1069	96	1286	73	1175

MJI	CIMMYT	100	1341	104	800	88	1097
MUSALA"S"	CIMMYT	109	860	112	741	95	1206
OLAF	USA	122	903	-	-	-	-
PAVON 76	CIMMYT	109	1660	107	1065	91	1015
POLK/WALDRON	USA	120	634	-	-	-	-
SERI 82	CIMMYT	104	1375	107	856	88	1239
SHAFIR	Hazera	-	-	95	986	74	1356
TITAN	Argentina	120	319	128	316	115	306
TOROPI	Brazil	118	638	-	-	-	-
KVZ-UP301	CIMMYT	110	1208	-	-	-	-
V392-304	Volcani	86	915	-	-	-	-
V447 (D)	Volcani	110	665	104	279	-	-
YAV 79 (D)	CIMMYT	-	-	104	266	-	-
V858-1	Volcani	95	1316	-	-	-	-
V8828-233	Volcani	95	1381	98	1137	85	1574
V977	Volcani	98	1420	-	-	-	-
V979-28	Volcani	104	1322	-	-	-	-
VERANOPOLIS	Brazil	113	835	113	332	105	520
ZB (D)	N.Africa	112	376	-	-	-	-
ZT-7751	Landrace	112	535	-	-	-	-
TAU57-16	TAU	-	-	-	-	85	767
TAU60-10	TAU	-	-	-	-	80	1298
TAU16-13	TAU	-	-	-	-	80	724
TAU57-37	TAU	-	-	-	-	84	1126
TAU54-18	TAU	-	-	-	-	79	864
TAU60-2	TAU	-	-	-	-	78	1209
TAU54-50	TAU	-	-	-	-	77	950
TAU54-32	TAU	-	-	-	-	76	1033
V748-74-1	Volcani	-	-	-	-	78	704
H8240	Hazera	-	-	-	-	90	706

Total Tested Cultivars	43	31	33

(*) D: Durum wheat, T: Triticale; all others are common wheats.

(**) Abbreviations:

CIMMYT: Centro International de Mejoramiento de Maiz y Trigo, Mexico.

Volcani: The Volcani Centre, Bet Dagan, Israel.

Hazera: Hazera Seed Co., Mivhor, Israel.

Weizmann: Weizmann Institute of Science, Rehovot, Israel.

TAU: Tel Aviv University, Tel Aviv, Israel.

(***) AUSPC: Area under the Septoria progress curve.

Table 2: Simple correlations (r) across cultivars between canopy temperature (as percent of the block mean) in Septoria-infected plots and percent disease coverage, percent green leaf area in infected and in control plots, days to anthesis, area under the Septoria progress curve (AUSPC) and percent kernel weight loss due to disease, on several dates in three years.

Year	Date Measured (DAE)	% Disease Coverage	% Green Leaf Area (infected)	% Green Leaf Area (control)	Days to Anthesis	AUSPC	% Kernel Weight Loss
1985	107	0.48**	-0.51**	-0.42**	-0.49**	0.48**	0.39*
	145	0.57**	-0.39*	-0.26 ns	-0.39*	0.53**	0.54**
1986	107	0.71**	-0.71**	-0.56**	-0.52**	0.53**	0.35 ns
	115	0.65**	-0.63**	-0.51**	-0.32*	0.52**	0.23 ns
	132	0.51**	-0.41*	-0.43*	-0.43*	0.40*	0.03 ns
	145	-0.05 ns	-0.28 ns	-0.38*	-0.51**	0.51**	0.40*
1987	130	0.74**	-	-	0.83**	0.62**	0.59**

(*, **) Significant at p=0.05 and p=0.01, respectively.

Figure 1: The association across 43 cultivars between percent disease coverage and canopy temperature (as percent of the block mean) in infected plots, on two dates in 1985. Top: 107 DAE; bottom: 145 DAE.

Figure 2: The association across 31 cultivars between percent disease coverage (n), percent green leaf area in control plots () and canopy temperature (as percent of the block mean) in infected plots on two dates in 1986. Top: 107 DAE; bottom: 115 DAE.

Figure 3: The association across 33 cultivars between percent disease coverage and canopy temperature (as percent of the block mean) in infected plots at 130 DAE in 1987. n- late cultivars (anthesis at 86-115 DAE); X- early cultivars (anthesis at 73-85 DAE). For vertical dashed line - see text.

FIGURE 1

FIGURE 2

FIGURE 3

6.0 Chapter IV

Experiment 4

(ISRAEL)

SPECTRAL REFLECTANCE ASSESSMENTS OF WATER STRESS
IN WHEAT VARIETAL TRIALS

M. Fuchs

INTRODUCTION

The application of spectral reflectance data to diagnose the developmental status of wheat has received considerable attention (Mohiuddin and Kanemasu, 1982). It has been shown that various indices derived from spectral reflectance can be used to follow the developmental stages of wheat and other grain crops and be used to predict their yield (Stanhill, Kafkafi, Fuchs and Kagan, 1972; Idso, Jackson and Reginato, 1977; Tucker, Holben, Elgin and McMurtry, 1980; Hatfield, 1982). Reflectances as measured or combined in vegetation indices produced fair to good correlations with final yield. However, more encouragingly, they followed very closely the seasonal green biomass development of the crops; and, therefore, it seemed possible to refine their application to detect the physical crop factors responsible for high productivity. This optimism was confirmed by the results of a research made on a large number of small grain species and genotypes (Miller, Fuchs, Hall, Asrar, Kanemasu and Johnson, 1983) which showed that it was possible to lessen the effect of soil reflectance on the variability of vegetation indices and improve their sensitivity to green area. The need to improve the screening method in genotype selection trials seemed to be answered by the promises of spectral measurements. The present report examines the possible application of this technique to predict yield of wheat genotypes with and without water stress.

METHODS

The measurements were made during three years from 1985 to 1987 in comparative yield test plots of selected wheat genotypes listed in Tables 2, 3, 4, and 5, at the Gilat Experiment Station in the Northern

Negev (latitude 31:20; longitude 34:42; 150 m above mean sea level). The average rainfall is 250 mm but extremely variable. This rainfall is much below the normal water requirement of wheat; and, consequently, the crop is grown in water stress conditions, if it is not irrigated. The soil is a sandy loam of loessial origin. Its available water holding in the root zone of wheat is approximately 120 mm.

In 1985 and 1986, 25 genotypes of wheat were included in the investigation. They were sown in 30 m² plots grouped in three replicate randomized blocks and submitted to two treatments: non irrigated and fully irrigated. In 1987, the investigation was done on 17 genotypes in four replicate blocks. Irrigation was times on the basis of time elapsed from the previous irrigation or significant rainfall. The framework for scheduling is an average daily evapotranspiration of 2 mm and a 50% depletion of the available soil water (i.e. a 30-day interval between irrigation). The amount was in excess of the loss to provide as much as possible uniform conditions to all genotypes. In 1985 the winter was unusually droughty; and, therefore, supplemental irrigation had to be given to the dry treatment to allow it to reach maturity. This irrigation was applied to simulate the average annual rainfall. The low amount caused large variability between replicate plots. Consequently, it was decided to associate agronomic and spectral measurements on a plot and not on a genotype basis.

The spectral reflectances were measured with an Exotech 100 radiometer (Exotech, Gaithersburg, MD, USA) in four Thematic Mapper wavebands used in LANDSAT satellites (Table 1). Measurements were only possible on days with cloudless sky. This limited considerably the number of sampling days; because the winter season, even when rainless,

is often overcast. The field of view was set at 10° with nadir sighting of the plot from 2.5 m above the ground. Signals were digitally recorded on a Polycorder 512B (OmniData, Logan, UT, USA). A calibrated barium sulfate panel served as reference surface. In 1987 it was replaced by a synthetic reference surface. Comparative measurements of both reference surfaces show minor differences between them (Table 1).

Spectral reflectance data were combined into three vegetation indices. The most commonly used indices (Tucker et al., 1980) is the near infrared to red reflectance ratio (NIR/RED), which takes advantage of the sharp contrast between the spectral properties of soil and green foliage. The second index is the normalized difference (ND), which is the ratio of near infrared minus red over near infrared plus red reflectance. This index has the theoretical advantage of being proportional to intercepted light (Asrar, Fuchs, Kanemasu and Hatfield, 1984). The third index is greenness (GR), a linear combination of the four wavebands (Kauth and Thomas, 1976). The coefficients used here are those derived by Dusek et al. (1985) with Jackson's N-space orthogonal algorithm (Jackson, 1983).

Average row spacing was 13.5 cm. Plots were sown every year during the week which includes 15 November, except for the irrigated treatment during the 1986-1987 season which was delayed for ten days by a rainfall period.

The development of the biomass was monitored by harvesting at each sampling date all the above ground plant material over a 1 m length of row. Leaf area of the fresh sample was measured with an optical area meter (Licor, Lincoln, NE, USA) and its dry matter content after 72 hours in a 60°C oven. Because of the destructive nature of this

Table 1. Technical specification of spectral reflectance measurements.

Color	Waveband nanometers	Barium sulfate (1)	Halon (2)	N-space Coefficients (3)
blue	450-520	0.975	0.993	-2.232
green	520-600	0.975	0.998	-0.316
red	630-690	0.971	0.971	-0.549
near infrared	760-900	0.963	0.963	+0.737

(1) Absolute reflectance

(2) Relative to barium sulfate

(3) Dusek, Jackson and Musick (1985)

measurement, it was made in one replicate block only. Sampling blocks were successively alternated for one measurement date to the next. After analysis of the first year's data, it was judged necessary to extend the measurement of leaf area index (LAI) to all plots. This called for a non-destructive method, based on light ray penetration assuming a random spherical leaf distribution. This measurement was made by placing a 1 m long ruler permanently in each plot and recording the total length of sunflecks on the ruler as a function of the sun's zenith angle. Final yield of each plot was recorded.

The plots of second year's experiment were invaded by weeds, which did not respond to the usual herbicide treatment. It was impossible to separate wheat and weed biomass. Analysis of the data produced meaningless results.

RESULTS

Yield 1985

The analysis of the data needs to be considered in view of the final yield obtained in the varietal trial of the 1985 season. Table 2 shows the production of the 25 genotypes included in the water stress experiment. They are listed in decreasing mean yield order. The range of yield is large, but so is the variability between replicate plots. Table 3 reports the same information for the fully irrigated treatment. The comparison between the two tables indicates that water stress was a severe limiting factor of the wheat productivity. However, it is important to note that full irrigation also diminished variability. These two observations lead to the conclusion that the soil moisture

Table 2. Yield and yield variability of water stressed wheat genotypes (Gilat 1985).

Genotype	Blk 1	Blk 2	Blk 3	Mean	Coefficient of Variation %
	g/square meter				
V969-28	342	374	556	424	22.2
Miriam	256	363	492	370	25.9
C59/83	310	310	449	356	18.4
V977-3-3	321	182	545	349	42.9
V652-79	235	128	662	342	67.5
Bethlehem	279	342	353	324	10.2
V991-7	267	353	288	303	12.0
V1353-3	192	363	342	299	25.4
V1074-17	342	192	342	292	24.1
V1335-63-3	288	256	214	253	12.1
V1375-1	288	288	150	242	27.0
747-16-1	171	246	299	239	22.0
V1431-24	256	288	160	235	23.2
Lakhish	235	235	224	232	2.2
C835/80-6	214	256	192	221	12.1
V1156-30	235	203	214	217	6.1
V1439-12	192	139	321	217	35.1
C86/83	224	107	278	203	35.2
V940-41	235	203	160	199	15.4
V140817-2	171	171	214	185	10.9
H895	256	150	150	185	27.2
V938-19-1	256	85	171	171	40.8
V1069-51	182	171	85	146	29.5
V763-17	107	107	192	135	29.8
Barkay	85	128	150	121	22.0
			MEAN	250	24.0

Table 3. Yield and yield variability of fully irrigated wheat genotypes (Gilat 1985).

Genotype	BLK1	BLK2 g/square meter	BLK3	Mean	Coefficient of Variation %
V1156-30	641	695	684	673	3.4
Bethlehem	662	716	641	673	4.7
C59/83	641	662	598	634	4.2
V1074-17	673	588	598	620	6.1
V977-3-3	545	759	534	613	16.9
V1335-63-3	598	737	470	602	18.1
V1375-1	620	598	577	598	2.9
V1408-17-2	470	620	513	534	11.8
H895	662	620	321	534	28.5
Lakhish	588	470	524	527	9.1
V652-79	609	363	545	506	20.6
V938-19-1	513	620	299	477	27.9
V1431-24	481	492	427	467	6.0
V979-28	427	481	459	456	4.8
V1439-12	492	534	342	456	18.1
V991-7	449	459	406	438	5.3
V763-17	299	492	502	431	21.6
C86/83	299	449	524	424	22.0
Barkay	395	375	449	406	7.7
V940-41	363	427	324	378	9.6
V1069-51	256	513	288	353	32.4
Miriam	513	235	278	342	35.7
747-16-1	321	299	192	271	20.7
C835/80-6	288	192	246	242	16.2
V1353-3	299	267	128	232	32.1
			MEAN	475	15.5

distribution in the water stressed blocks was non-uniform. As variability is a function of the water amount, field trials using differential irrigation treatment are not suitable for detecting drought resistance traits in wheat genotypes.

In view of the variability between replicate blocks, the only possible evaluation of yield prediction performance of the spectral reflectance data is on a plot by plot basis. Figures 1 through 24 show the relationship existing between final yield and NIR/RED, ND, and GR. They cover the period of foliage development to the early signs of maturation.

NIR/RED (Fig. 1 to 8).

This index is well correlated to final yield of the water stressed treatment. The linear regression fit starts very near the origin of axes for all four sampling dates. NIR/RED of bare soil is between 1 and 2 and is close to the statistical linear extrapolation. The slope of the relation is the same for the three sampling periods corresponding to the growing phase of the canopy are very similar. The onset of maturation and foliage yellowing is associated with a smaller slope. Correlation on the other hand improves slightly as the season progresses. These observations are very similar to results obtained by other workers (e.g. Tucker et al., 1980). However, the practical value of the correlation for yield prediction is low as same high yielding plots have low NIR/RED, and mediocre yields are associated with high ratios.

In the irrigated plots the general level of the NIR/RED ratio is higher than in the stressed treatment. The index increases with canopy

development and decreases at maturation. But there is no correlation between yield and the index.

ND (Fig. 9 to 16).

Normalized difference correlates with final yield of the stressed treatment in the same general fashion as NIR/RED. The linear relation has a large zero offset, but its value is nearly constant through the growing season. It is much larger than $ND = 0.1$ found for the bare soil. The slope of the line is nearly constant during the developing phase of the canopy and drops with maturation. Correlation are statistically significant, but do not have sufficient precision to single out the high yielding varieties. In the irrigated plots, ND is uniformly high and appears completely unrelated to the yield.

GR (Fig. 17 to 24).

Greenness correlates with yield of the stressed plots like the two other indices. Its predictive performance stands between that of the ND and the NIR/RED. As for ND, it has a significant zero offset of 0.07 in contrast with the near zero value obtained for bare soil. Again, the irrigated treatment produces a range of GR which is not correlated to yield. In both treatment GR is a little more sensitive to the growth stage than the other two indices. It already senses maturation on the 4 March, whereas the two other indices perceived it only 10 days later.

The positive offset found for ND and GR indicates that the linear model is not appropriate for their relation to yield. A curve with

negative second derivative would produce a better fit to data. However, these relationships have very low sensitivity at the higher range of the potential yield of wheat genotypes. Even if the problem of variability is overcome, their yield prediction ability is limited to the low end of the yield range.

Biomass 1985

The ability to predict yield from spectral reflectance stems from the possible relation between green biomass accumulating in the canopy, which is converted in harvestable production. The differential reflectance between green biomass and soil appears in all indices which are sensitive to the low reflectance of green vegetation in the visible spectrum and its very high reflectance in the near infrared. Two objective measurements of biomass were considered LAI and total above ground dry matter. Their relation to NIR/RED, ND, and GR are examined in Fig. 25 through 30.

ND (Fig. 27 and 28).

The relation between LAI and ND is described by an asymptotic exponential fit which saturates at an LAI of approximately 2. As high yielding crops have LAIs superior to 2, this index is not very useful for detecting productive traits. The link with dry matter is similar to that observed for LAI.

GR (Fig. 29 and 30).

The relation between greenness and LAI can be fitted by an asymptotic exponential which, like in the previous case, saturates for an LAI around 2. A similar function was also fitted to dry matter, but its superiority over a linear fit is not very significant.

Of the three vegetation indices NIR/RED presents the widest range of response to biomass parameters. Although its use as a measure of LAI or dry matter has a large error component, it can provide a first order evaluation of biomass development. The usefulness of ND and GR is in their good sensitivity at low biomass density, allowing them to screen out wheat genotypes with slow vegetative development.

As the correlation between vegetation indices and biomass parameters is better than their prediction of yield, the research plan was modified to investigate if the LAI which directly affects spectral reflectance is related to the productivity of the genotypes included in the study. Because of the variability among replicates blocks, it is necessary to consider individual plots. The massive data and the small size of the plots imposes a non-destructive method of LAI sampling based on ray interception measurements.

Yield 1987

The yield of 1987 reflects the performance of the wheat genotypes for an average rainfall year. The mean yield of the non-irrigated plots is higher than in 1985 (Table 4). Only three genotypes are common to both years (Bethlehem, Lakhish, Barkay). In each of them the 1987 yields are higher. The irrigated treatment is also better yielding in 1987, but the differences are smaller (Table 5). The variability is lower than in 1985, but the number of replicates in 1987 is larger. The water stressed treatment has more variability than the irrigated

treatment, confirming the high sensitivity of wheat to water availability and the heterogeneity of the growing conditions of the field.

NIR/RED (Fig. 31 to 38).

The predictions of yield by NIR/RED are similar to the 1985 findings. The slope and offset of the linear fit are identical to those found at corresponding growth stage in 1985. Correlations are of the same order. The index follows the phenological development of the crop. In the stressed treatment NIR/RED decreases from the period of active vegetative development on 18 January to harvest ready state on 28 April. The irrigated treatment on 18 January was slightly behind the developmental stage of the stressed treatment as a result of the delay in planting data. The duration of vegetative development was considerably longer, and maturation occurred later. It is worthwhile noting that this difference is picked up by NIR/RED.

ND (Fig. 39 to 46).

The results for ND are reported to illustrate that this index is not correlated with final yield. The blind application of correlation statistics may lead to believe that the correlation is good. For example, in Fig. 45 the R square is 0.73, but this result is caused by the bare soil data included in the analysis.

Table 4. Yield and yield variability of water stressed wheat genotypes (Gilat 1987).

Genotype	BLK1	BLK2	BLK3	BLK4	Mean	Coefficient of Variation %
	g/square meter					
IB143/84	465	267	517	493	436	22.7
Beth Hashita	306	410	486	524	431	19.4
Ruth	420	420	434	424	424	1.3
Bethlehem	347	406	500	413	417	13.1
Lakhish	319	365	483	490	414	17.8
V763-1311	378	340	465	417	400	11.6
Deganit	288	361	528	410	397	22.0
H-895	295	347	510	424	394	20.6
Barkay	290	382	490	365	382	18.7
IB124/84	417	240	431	427	378	21.2
C58/83	472	313	420	288	373	20.3
IB125/84	413	295	427	351	372	14.2
V748-74-1	323	330	458	365	369	14.6
IB119/84	389	264	413	392	365	16.1
V1353-5	420	167	465	354	352	32.4
V940-41	368	278	361	313	330	11.2
V353-1	267	170	441	306	296	32.8
				MEAN	384	18.2

Table 5. Yield and yield variability of irrigated wheat genotypes
(Gilat 1987).

Genotype	BLK1	BLK2	BLK3	BLK4	Mean	Coefficient of Variation %
g/square meter						
Beth Hashita	646	878	610	731	716	14.4
Deganit	644	658	724	718	686	5.2
CD189/80	749	695	689	595	682	8.2
C58/83	643	683	715	660	675	4.0
Barkay	629	671	660	720	670	4.9
V763-1311	603	621	668	704	650	6.0
H-895	611	695	658	541	626	9.2
Bethlehem	654	616	601	529	600	7.5
V748-74-1	576	640	587	546	587	5.8
V1353-5	579	580	591	519	567	5.0
Lakhish	477	481	646	664	567	15.6
Inbar	592	507	563	590	563	6.2
D350/79-4-2	699	645	534	358	559	23.3
CD29/77	677	626	485	444	558	17.3
V940-41	477	611	611	433	533	14.9
V1353-1	545	587	60	372	391	53.1
				MEAN	602	12.5

GR (Fig. 47 to 54).

The correlation of GR with yield is slightly better than that with ND, particularly during the vegetative developmental stage of the wheat. The data also confirm its capability to detect early the maturation phase.

LAI 1987

The simultaneous measurement of LAI and spectral reflectances on a large number of samples permits a statistical analysis of their interrelations. This investigation confirmed the results obtained in 1985. For NIR/RED a linear relation fits well the data (Fig. 55). The range of values of this index was approximately half of that obtained in 1985. We have not been able to explain this difference. The correlation, although lower than in 1985, is still significant. The extrapolation to zero LAI is close to value found for bare soil, and the slope is about half of 1985 value.

The ND was fitted with an exponential curve (Fig. 56). The correlation is high, but the function has little usefulness. In its high sensitivity range (for $LAI < 2$), the scatter of data point is extremely broad. For $LAI > 2$ the sensitivity is too low for having a practical meaning. The same comments apply to the comparison with GR (Fig. 57). The result of this analysis is that NIR/RED is the only index of the three to bear information about the green biomass on the ground. Its correlation with LAI is better than that with the yield.

Fig. 58 examines the relation between yield and LSI taken at the peak of foliage development. The spread of data is very considerable,

indicating That the link between green leaves and the final yield is weak. The linear regression has a positive slope, but the correlation is poor. The larger offset at zero LAI shows that the linear fit is not adequate and that a curvilinear with negative second derivative would be more suitable. However, test of an asymptotic exponential curve produced larger estimator errors.

Thus, the poor ability of vegetation indices, derived from spectral reflectance, to detect the potential yield of genotypes in test plots is primarily due to the low correlation between yield and green biomass. This is a direct consequence of the dwarfing traits selected by breeders. The second cause is the poor accuracy of the relation between indices and green biomass. NIR/RED which correlates best with green biomass is also the best yield predictor. The correlation found in this study is of the same order as that quoted in the literature. The accuracy, however, is insufficient for genotype screening trials.

SUMMARY AND CONCLUSIONS

The detection by spectral reflectance measurements of wheat genotype productivity was investigated in plots used to observe the effect of water stress. Forth varieties of wheat were compared. The differential treatment consisted of supplemental irrigation applied in similar fashion to all genotypes. The reflectance measurements were made in the three visible and the shortest near infrared waveband used in LANDSAT's thematic mapper. The reflectance data were used to compute three vegetation indices which are known to be related to biomass: near infrared over red ratio (NIR/RED), normalized difference (ND), and

greenness (GR). Their ability to predict the final grain yield and their response to irrigation was investigated during the first year of the experiment. But, whereas all indices recognized the more favorable water status of the irrigated treatment, the correlation with final yield was weak. A surprising finding was the total lack of correlation with final yield for the irrigated treatment.

Measurements of the biomass (DM) and the leaf area index (LAI) were carried out to assess the spectral reflectance related physical characteristics of the genotypes which have an incidence on the productivity of the plant. For this purpose a small number of plots were selected at each sampling date. The measurement is destructive, therefore it could not be made on all plots. They showed that NIR/RED correlated much better with LAI than with DM. But both correlations were by far superior to that obtained for the final yield. The data for ND and GR confirmed earlier findings that these indices are very sensitive to change of DM and LAI at the low end of the scale. However, exponential curves fitted to their response functions showed that the saturation values are reached at DM and LAI too low for allowing practical discrimination between genotypes. We concluded that NIR/RED is the most suitable index.

The good sensitivity of the spectral reflectances response to LAI and DM confirms the initial hypothesis on which the proposal had been formulated, but contradicts its poor performance as a yield predictor. In order to investigate this contradiction, the measurement program of the second and third year were modified to include a non-destructive method of LAI measurement, based on sunfleck distribution theory. This allowed to include all the genotypes and replicate plots in the

investigation. As the result of an unusual growth of weeds in the experimental plots in 1986, reflectance data could not be related in any meaningful way with LAI or yield. The experiment was repeated in 1987. The measurements confirmed the correlations found in 1985 between LAI and NIR/RED, ND, and GR, respectively. The numerical values are somewhat different, because the indirect measure of LAI has a low sensitivity at large LAIs. However, the seasonal peak LAI of all genotypes, both with and without irrigation is poorly correlated with final yield of genotypes. It is concluded that the spectral reflectance derived vegetation indices, and NIR/RED in particular, give information on the foliar developmental stages of wheat. However, their use as final yield predictors in genotype screening test is not supported by the results of this research.

REFERENCES

- ✓ Asrar, G., M. Fuchs, E.T. Kanemasu and J.L. Hatfield. 1984. Light interception and leaf area estimated from spectral reflectance in wheat. *Agron. J.* 76:300-306.
- ✓ Dusek, D.A., R.D. Jackson and J.T. Musick. 1985. Winter wheat vegetation indices calculated from combinations of seven spectral bands. *Rem. Sens. Environ.* 18:255-267.
- Hatfield, J.L. 1983. Remote sensing estimators of potential and actual yield. *Rem. Sens. Environ.* 13:301-311.
- Idso, S.B., R.D. Jackson and R.J. Reginato. 1977. Remote-sensing of crop yields. *Sci.* 196:19-25.
- ✓ Jackson, R.D. 1983. Spectral indices in N-space. *Rem. Sens. Environ.* 13:409-421.
- ✓ Kauth, R.J. and G.S. Thomas. 1976. The tasseled cap - a graphic description of the temporal development of agricultural crops as seen by Landsat. *Proc. Symp. Machine Processing of Remote Sensing Data.* LARS, Purdue Univ. West Lafayette, IN. USA.
- ✓ Miller, G.P., M. Fuchs, M.J. Hall, G. Asrar, E.T. Kanemasu and E.E. Johnson. 1984. Analysis of multispectral reflectances of small grains. *Rem. Sens. Environ.* 14:153-167.
- ✓ Mohiuddin, S. and E.T. Kanemasu. 1982. A review of biophysical and cultural characteristics of small grain crops that are potentially observable from remotely sensed data. *Agristars* SR-M2-04265, 65p.
- ✓ Stanhill, G., U. Kafkafi, M. Fuchs and Y. Kogan. 1972. The effect of fertilizer application on solar reflectance from a wheat crop. *Israel J. Agric. Res.* 22:109-118.
- ✓ Tucker, C.J., B.N. Holben, J.H. Elgin and J.E. McMurtrey. 1980. Relationship of spectral data to grain yield variation. *Photogram. Engr. and Rem. Sens.* 46:657-666.

YIELD PREDICTOR, GILAT 24 JAN 1985
WATER STRESSED

Fig. 1

YIELD PREDICTOR, GILAT 10 FEB 1985

Fig. 2

YIELD PREDICTOR, GILAT 04 MAR 1985

Fig. 3

YIELD PREDICTOR, GILAT 14 MAR 1985

Fig. 4

YIELD PREDICTOR, GILAT 24 JAN 1985

Fig. 5

YIELD PREDICTOR, GILAT 10 FEB 1985

Fig. 6

YIELD PREDICTOR, GILAT 04 MAR 1985

Fig. 7

YIELD PREDICTOR, GILAT 14 MAR 1985

Fig. 8

YIELD PREDICTOR, GILAT 24 JAN 1985

Fig. 9

YIELD PREDICTOR, GILAT 10 FEB 1985

Fig. 10

YIELD PREDICTOR, GILAT 04 MAR 1985

Fig. 11

YIELD PREDICTOR, GILAT 14 MAR 1985

Fig. 12

YIELD PREDICTOR, GILAT 24 JAN 1985

Fig. 13

YIELD PREDICTOR, GILAT 10 FEB 85

Fig. 14

YIELD PREDICTOR, GILAT 04 MAR 1985

Fig. 15

YIELD PREDICTOR, GILAT 14 MAR 1985

Fig. 16

YIELD PREDICTOR, GILAT 24 JAN 1985

Fig. 17

YIELD PREDICTOR, GILAT 10 FEB 1985

Fig. 18

YIELD PREDICTOR, GILAT 04 MAR 1985

Fig. 19

YIELD PREDICTOR, GILAT 14 MAR 1985

Fig. 20

YIELD PREDICTOR, GILAT 24 JAN 1985

Fig. 21

YIELD PREDICTOR, GILAT 10 FEB 1985

Fig. 22

YIELD PREDICTOR, GILAT 04 MAR 1985

Fig. 23

YIELD PREDICTOR, GILAT 14 MAR 1985

Fig. 24

GILAT 1985

Fig. 25

GILAT 1985

Fig. 26

GILAT 1985

Fig. 27

GILAT 1985

Fig. 28

GILAT 1985

Fig. 29

GILAT 1985

Fig. 30

YIELD PREDICTOR, GILAT 18 JAN 87

WATER STRESSED

Fig. 31

YIELD PREDICTOR, GILAT 31 MAR 1987

Fig. 32

YIELD PREDICTOR, GILAT 06 APR 1987

Fig. 33

YIELD PREDICTOR, GILAT 28 APR 1987

Fig. 34

YIELD PREDICTOR, GILAT 18 JAN 87

Fig. 35

YIELD PREDICTOR, GILAT 31 MAR 1987

Fig. 36

YIELD PREDICTOR, GILAT 06 APR 1987

Fig. 37

YIELD PREDICTOR, GILAT 28 APR 1987

Fig. 38

WATER STRESSED

YIELD PREDICTOR, GILAT 31 MAR 1987

Fig. 40

YIELD PREDICTOR, GILAT 06 APR 1987

Fig. 41

YIELD PREDICTOR, GILAT 28 APR 1987

Fig. 42

YIELD PREDICTOR, GILAT 18 JAN 87

Fig. 43

YIELD PREDICTOR, GILAT 31 MAR 1987

Fig. 44

YIELD PREDICTOR, GILAT 06 APR 1987

Fig. 45

YIELD PREDICTOR, GILAT 28 APR 1987

Fig. 46

YIELD PREDICTOR, GILAT 18 JAN 87

Fig. 47

YIELD PREDICTOR, GILAT 31 MAR 1987

Fig. 48

YIELD PREDICTOR, GILAT 06 APR 1987

Fig. 49

YIELD PREDICTOR, GILAT 28 APR 1987

Fig. 50

YIELD PREDICTOR, GILAT 18 JAN 87

Fig. 51

YIELD PREDICTOR, GILAT 31 MAR 1987

Fig. 52

YIELD PREDICTOR, GILAT 06 APR 1987

Fig. 53

Fig. 54

GILAT 1987

Fig. 55

GILAT 1987

Fig. 56

GILAT 1987

Fig. 57

GILAT 1987

Fig. 58

7.0 Description of Cooperation

The co-investigators enjoyed a close cooperation. Dr. Fuchs visited Kansas State University on two occasions. Dr. Kanemasu visited Israel in April 1987. Presently, Dr. Blum is spending his sabbatical leave at Kansas State University. There has been considerable exchange of information throughout the project. This was made possible, in part, by electronic mail (Bitnet). Bitnet was used on a weekly basis to compare notes. Frequently there were equipment problems which were solved collectively. Kansas State University loaned some equipment items to Dr. Fuchs and vice versa. In 1986 Drs. Fuchs and Kanemasu met at international meetings in England to exchange results and developed the format for the final report.

8.0 Evaluation of the Research Achievements

The application of spectral reflectance data to diagnose the developmental status of wheat has received considerable attention (Mohiuddin and Kanemasu, 1982). It has been shown that various indices derived from spectral reflectance can be used to follow the developmental stages of wheat and other grain crops and be used to predict their yield (Stanhill, Kafkafi, Fuchs and Kagan, 1976; Idso, Jackson and Reginato, 1977; Tucker, Holben, Elgin and McMurtry, 1980; Hatfield, 1982). Reflectances as measured or combined in vegetation indices produced fair to good correlations with final yield. However, more encouragingly, they followed very closely the seasonal green biomass development of the crops, and, therefore, it seemed possible to refine

their application to detect the physical crop factors responsible for high productivity. This optimism was confirmed by the results of a research made on a large number of small grain species and genotypes (Miller, Fuchs, Hall, Asrar, Kanemasu and Johnson, 1983), which showed that it was possible to lessen the effect of soil reflectance on the variability of vegetation indices and improve their sensitivity to green area. The need to improve the screening method in genotype selection trials seemed to be answered by the promises of spectral measurements. The present report examines the possible application of this technique to predict yield of wheat genotypes with and without water stress and disease.

In order for remotely sensed measurements to be useful to the breeding selection process, the measurements must be capable of detecting plant attributes in small plots (head rows). Poor plant establishment due to soil microrelief could result in misleading interpretation by the radiometer but not by the seasoned plant breeder upon personal visual inspection. Our results indicate that spectral reflectance measurements are limited by small plots where the variability is great.

Our study confirmed that spectral reflectance is closely correlated with leaf area index and green biomass. However, spectral reflectance was not highly correlated with yield or yield components. The near infrared to red ratio is more closely correlated with leaf area index than the other spectral indices. The normalized difference indice, which we have found to be correlated with intercepted light, was integrated between different phenological events and correlated with the yield component being developed during that period. However, while being physiologically logical, the correlations were poor. The

genotypes being studied were not from a widely diverse background, which could have affected our results. Under conditions where leaf area and biomass strongly affect the yield, spectral reflectance offers a means of estimating yield potential. However, under conditions of a breeding trial where growth difference and plant attributes are small and spatially variable, spectral reflectance has limited utility. It can identify the poor yielders, but these are readily identified by the plant breeder.

The spectral reflectance measurements did monitor disease severity (leaf rust) among genotypes; however, the differences in reflectance did not relate to their grain yield. The lower reflectance ratio was associated with disease and, hence, susceptible and resistant genotypes can be identified. Canopy temperature measurements also correlated well with disease severity (*Septoria tritici*) among wheat cultivars.

We believe that image-remote sensing could offer a better technology than radiometry for the plant breeder. Video systems with spectral capability are available; thus, the analyses could be done on the individual plants, whereas the radiometer gives an average analog signal for the entire field of view.

9.0 List of Publications

- ✓ Asrar, G., E.T. Kanemasu, R.D. Jackson and P.J. Pinter, Jr. 1985.
Estimation of total above ground phytomass production using
remotely sensed data. Rem. Sens. of Env. 17:211-220.
- ✓ Kanemasu, E.T., J. Ranson, D. Saunders, J. Killeen and M. Yoshida.
1985. Use of spectral data to assess wheat response to soil water.
Field Crop Res. 12:105-113.
- ✓ Myneni, R.B., G. Asrar, E.T. Kanemasu, D.J. Lawlor, and I. Impens.
1986. Canopy architecture, irradiance distribution on leaf
surfaces and consequent photosynthetic efficiencies in
heterogeneous plant canopies. I. Theoretical Considerations.
Agric. and Forest. Meteor. 37:189-204.
- Shields, P. 1986. Estimating grain yield using spectral reflectance
data in winter wheat genotypes. M.Sc. Thesis, Kansas State
University.