J. L. Hatfield
Department of Land, Air and Water Resources
University of California
Davis, CA 95616

Spectral Behavior of Wheat Yield Variety Trials

For 82 varieties, there was little spectral variation at jointing, but the variability increased during grain filling and declined again at maturity.

Abstract: *Spectral behavior of wheat canopies has been characterized by a number of researchers; however, most studies have concentrated on one or two varieties. This study was designed to evaluate the spectral behavior from jointing to maturity in International spring and hard red winter wheat* (Triticum aesitivum *L.) nurseries grown at Davis, California. Data were collected for 82 varieties entered in the nurseries using a Exotech model 100A to measure reflectance in four wave-bands. Measurements were taken about solar noon seven times from April to June of 1979; and were taken on clear days only.*

At jointing there was little variation between varieties, but the variability increased during grain filling and declined again at maturity. There was no relationship between spectral response and yield, and when yields were segregated into various classes the spectral response was the same. Spring and winter nurseries separated during the reproductive stage because of differences in dates of heading and maturity, but they exhibited similar spectral responses. The transformed normalized difference was at a minimum after the maximum grain weight occurred and the leaves began to brown and fall off. These data of 100 percent ground cover show that it is not possible to predict grain yield from only spectral data; this may not apply, however, when reduced yields are caused by less-than-full ground cover. Spectral responses may be used with confidence as supplementary data to detect growth stages between varieties, but additional data are needed if yields are to be predicted.

Introduction

Seasonal reflectance patterns of crops depend on crop species, soil background, and stress patterns. Leaves of crops are spectral filters, and when canopies cover the soil completely the visible wavelengths are highly attenuated, whereas the near-infrared are reflected. Hatfield and Carlson (1979) found that three maize canopies had different spectral albedos and that these differences were related to morphological characteristics. The leaf angle in the upper third of the canopy was the largest influence.

Kanemasu (1974) compared the seasonal reflectance patterns of wheat, soybean, and sorghum. He found that the differences were related to leaf area and morphological characteristics. For these three species he found that it was possible to estimate the leaf-area index with a ratio of MSS 4 and MSS 5 or MSS 4 and MSS 7; the MSS 4/5 ratio gave better results. Wiegand *et al.* (1978) examined the reflectance patterns of wheat and found it was possible to estimate leaf area from Landsat MSS data. Tucker *et al.* (1980) found that the spectral data in the 0.65- to 0.70- and 0.775- to 0.825-μm wavebands could be used to predict wheat yields. They found that the normalized difference method explained 64 percent of the yield variations within a field of winter wheat. Leamer *et al.* (1978) found that the seasonal variation between the two winter wheat varieties did not differ. Their study, how-

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ever, was designed to evaluate how spectral reflectance could be used to differentiate between bare soil and vegetation. These data suggest that spectral measurements may provide useful information for wheat yield models.

Idso *et al.* (1978) found for Produra wheat that the albedo declined during grain filling, reaching a minimum at maximum head weight and increasing rapidly as the crop matured. This original concept was extended to another variety of wheat and one of barley (Idso *et al.*, 1978). In these studies the minimum albedo just prior to maturity was significantly inversely correlated with the final yield. In a later study, Idso *et al.* (1980) found that the rate of senescence of a vegetative index using Landsat MSS bands 5 and 6 was positively related to the yield in wheat and barley. The higher yields were associated with faster senescence rates. These data suggest that it may be possible to develop spectral models to predict final grain yield.

Available data, however, are confined to only one or two varieties of wheat or stress treatments, and this study was designed to evaluate the variation that occurs between several varieties during the reproductive stage of growth. Data of this kind should be useful in determining spectral variability in wheat varieties commonly grown around the world.

Materials and Methods

During the spring of 1979, spectral reflectance in the International spring wheat and winter wheat nurseries was measured. There were 50 entries in the spring wheat nursery and 32 entries in the winter wheat nursery with each nursery replicated four times. These nurseries include entries from around the world and represent a large cross-section of the various wheat varieties. These trials were grown on the Campbell Tract of the University of California, Davis campus, in 1- by 3-m plots that were irrigated well throughout the growing season. These nurseries were planted in late November, 1978 at 114 kg ha^{-1} in 20 cm row spacings. Data were not collected until jointing, and all plots had achieved 100 percent ground cover by the time measuring commenced in early April. The primary purpose of these nurseries is to evaluate the yield of several varieties, both standard and new entries, at several locations throughout the world.

Spectral measurements were made in each variety using an Exotech model 100A* with four wavebands, 0.5-0.6, 0.6-0.7, 0.7-0.8, and 0.8-1.1 μm with a 15° field of view on all bands. Standard reflectance was measured using a 60-cm square barium sulfate plate in each of the eight plots. The reflectance standard was placed on a stand one metre above the soil and placed in an open area next to the nursery so that the standard was not influenced by the crop. Background was measured before and after each nursery. Four individual measurements within each plot were made with the unit held vertically 1 metre above the crop. These measurements were made at solar noon on clear days, seven times from jointing until maturity; the operator wore the same clothing each time. The data from the Exotech were recorded on a digital printer, which allowed the 82 plots to be measured in less than 40 minutes.

Additional variables collected on each plot included dates of heading and maturity, height, lodging, disease ratings, and yield. These data were included to evaluate differences in the spectral reflectance.

Results and Discussion

In both nurseries the variability in yield for winter wheat and spring wheat was large. Yield, heading dates, and maturity dates are given in Table 1. There was a large range in the yield and a relatively small deviation in the dates of heading and maturity; there was more scatter in the winter wheat than in the spring wheat nursery. With this variation in yield there may be an accompanying variation in the spectral response.

Transformed normalized differences were calculated using reflectance values as

$$TND = \left[\frac{MSS7 - MSS5}{MSS7 + MSS5} + 0.5\right]^{1/2} . \qquad (1)$$

Results from jointing to after maturity are shown in Figure 1, along with the standard error about the mean. Three points are evident from these data: (1) before heading there is very little variation in the transformed normalized differences; (2) the trend during grain filling is similar between the two trials; and (3) the value attained by each trial at maturity was the same; however, the standard error was larger at maturity than before heading. The last data collected were after maximum grain weight had been attained and the leaves began to brown and fall off, and the soil background was beginning to influence reflectance. The variability was the largest before maturity, which suggests that the differences in head weight were most evident. These data suggest that spectral models alone should not be able to predict wheat yields.

To determine why yield differences did not segregate in more detail, the plots were divided into yield categories of 1000-kg ha^{-1} increments. For both trials the plots grouped in the 3000- to 4000- and 5000- to 6000-kg ha^{-1} increments were evaluated for their spectral response. Figures 2 and 3, respectively, give data for the spring and winter wheat nurseries. There are no differences in the spectral behavior of these two categories,

* Mention of a specific tradename does not imply endorsement by the University of California or the California Agricultural Experiment Station.

TABLE 1. AGRONOMIC CHARACTERISTICS OF THE INTERNATIONAL SPRING AND WINTER WHEAT NURSERIES GROWN AT DAVIS, CALIFORNIA, IN 1979

Trial	Entries	Yield (kg ha^{-1})			Heading*		Maturity	
		Mean	S.D.	Range	Mean	S.D.	Mean	S.D.
Spring	50	4809	1271	2070-7585	103	5.62	149	3.94
Winter	32	4209	1083	1968-7822	122	8.61	155	4.97

* Julian date.
S.D. = standard deviation.

and these values were not different from the overall mean value and had similar standard errors.

To determine if any differences in spectral behavior were related to yield, the lowest and highest yielding plots in each nursery were analyzed. Figures 4 and 5, respectively, show data for the spring and winter wheat nurseries. In this separation there were differences between plots. In both nurseries there was no difference at the jointing stage; the plots separated during grain filling. The lowest-yielding plot had a larger TND index than did the highest yielding plot; this was evident in both spring and winter wheat nurseries. The reason for this segregation was not evident in the agronomic characteristics. However, two parameters routinely noted in the field trials may explain the variation. In both trials the lower yielding varieties had a larger amount of grain shattering, which caused some grain to be lost on the ground, and a greater percentage of stripe rust. These results are not conclusive, however, because other plots that had higher shatter and stripe ratings were closer to the mean yield. The trend was for the lower-yielding plots to have a higher rating in these parameters. This suggests that these aspects need further investigation. For the winter wheat nursery, the lower-yielding variety also had a shorter grain-filling period (Figure 5). This fact was evident in both nurseries and the longer grain-filling period was significantly related to yield.

The fact that all plots had 100 percent ground cover contributes to the small differences between varieties during grain filling. As shown in Figure 1, there was very little variation once the plots had achieved 100 percent ground cover, with a large increase in the variability just before maximum head weight. Because the area of the heads do not cover the vegetative material completely, changes in spectral reflectance due to differences in head size or morphology were not evident early in grain filling. The decrease in the variability after maturity is because all varieties turn yellow late in senescence.

Other combinations of spectral bands were assembled to determine if any relationship to yield could be determined. When band 7/6 ratios were computed, there was little change throughout the season; there was an increase at maturity only. Throughout the season, however, the coefficient of the variation for all dates was less than 5 percent, indicating that this approach would not distinguish between yield levels. Bare soil data were not taken to determine whether a perpendicular vegetation index would be more indicative of yield level.

CONCLUSIONS

Data collected for over 82 varieties of wheat suggest that spectral yield models will require additional inputs. The Transformed Normalized

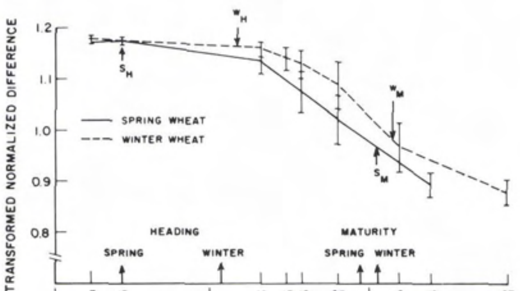

FIG. 1. Transformed normalized difference calculated from jointing to maturity for the International spring and winter wheat nurseries at Davis, California in 1979. Lines indicate standard error about the mean.

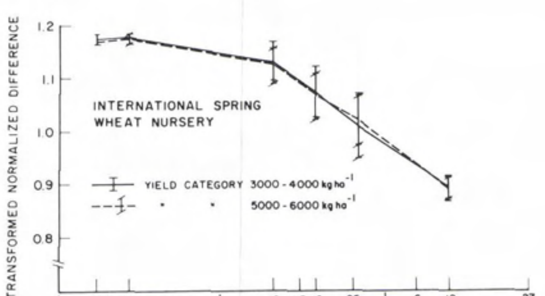

FIG. 2. Transformed normalized difference for the 3000- to 4000- and 5000- to 6000-kg ha^{-1} yield categories for the International spring wheat nursery.

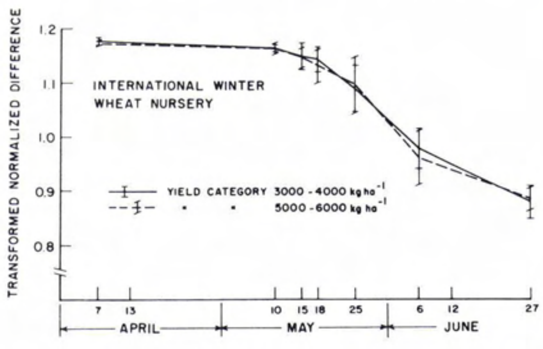

FIG. 3. Transformed normalized difference for the 3000- to 4000- and 5000- to 6000-kg ha^{-1} yield categories for the International winter wheat nursery.

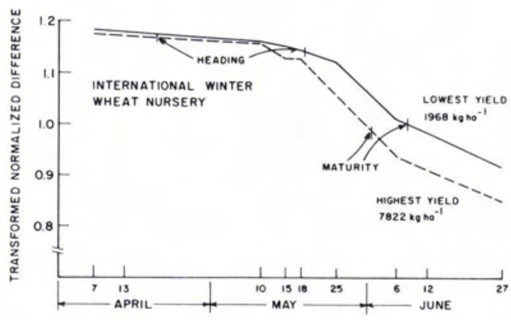

FIG. 5. Transformed normalized differences for the lowest- and highest-yielding variety in the International winter wheat trials.

Difference exhibited no differences when all varieties were at the vegetative stage, but the variability increased during the reproductive stage. These trends suggest that, although there were greater spectral differences between varieties during the reproductive stage, these spectral differences were not related to yield. These results would appear to be in conflict with those reported by Tucker *et al.* (1980); however, in reality they represent an extension of their data set. In their study, the ground cover was never greater than 68 percent and the relationship between spectral estimators and yield was only 64 percent. These data suggest that, when the vegetative material completely covers the soil, the relationship between yield and spectral estimator would need further refinement. In this study, there is no green-up period in the spring because growth is continuous and would represent areas with no dormant period during the winter. Calculation of senescence rates as suggested by Idso *et al.* (1980) did not relate to final yield. Again in their study, there was a range of ground covers, and final yield could be related to total biomass. These data suggest that research be continued to evaluate spectral models when there is complete ground cover during the grain-filling stage.

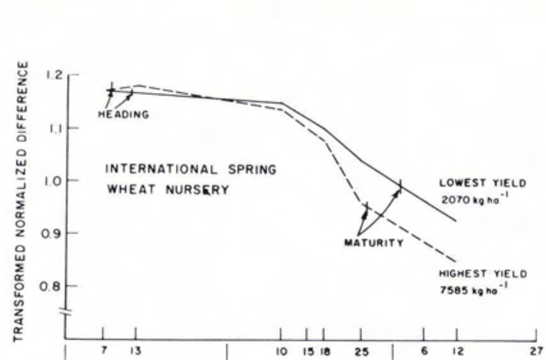

FIG. 4. Transformed normalized differences for the lowest- and highest-yielding variety in the International spring wheat trials.

Attempts to use other combinations of wavebands, such as normalized difference or band ratio of MSS 7/6, did not relate to yield. Only when the spectral patterns of the highest-yielding and lowest-yielding varieties were compared for both the spring and winter wheat nurseries was there any detectable difference. Between these yields there was more stripe rust and shattering of grain to the ground present in the lower-yielding variety; however, the stripe-rust ratings were also high in varieties that had yield close to the mean. Although it is encouraging that a large range of wheat varieties assembled from around the world exhibit such close spectral relationships, yield differences were not detectable.

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