Monitoring Cereal Rust Development With A Spectral Radiometer

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ABSTRACT

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Three wheat cultivars susceptible to either stem rust or stripe rust were evaluated to determine the association of stripe rust and radiometric leaf reflectance to rust development and yield. Four vegetative indices based on these measurements were used to detect differences between healthy and diseased plants. Vegetation index differences between inoculated and control plants became progressively greater as the rust infection developed. Thus, it would appear feasible to use remotely collected radiometric reflectance data to estimate disease incidence over large production areas. This information could also be used to estimate potential yield losses due to disease.

Additional key words: disease forecasting, *Puccinia graminis, Puccinia striiformis*, remote sensing.

Economic loss due to foliar pathogens has long been a worldwide threat to cereal producers. On a large land mass, the concern is with epidemics that develop over entire areas rather than with a single infection focus that develops on a few plants. The former situation may result from spore showers blanketing large areas. It often becomes difficult to describe and visually assess the amount of disease on a large scale and then to associate it with yield loss. Assessment of the severity of plant disease epidemics is essential for successful, timely, and cost-effective chemical control. Conventional methods of visual assessment are labor-intensive and results may vary with the experience of the individual. Remote-sensing techniques, including aerial photographs and high altitude satellite data, may provide an easily available permanent record of disease intensity for large crop areas without observer bias and error.

Aerial photography, ground-based sensor data, and Landsat multispectral scanner (MSS) data have been used to measure disease incidence in many agricultural systems. In 1933, Bawden (2) first used aerial photography for detecting plant virus diseases. Aerial photography was also used in 1956 by Colwell (5) to survey the cereal rusts and in 1962 by Brenchley and Dodd (4) and in 1967 by Manzer and Cooper (19) who investigated potato late blight. More recently, disease surveys have been done on a number of crop species (5,13,20,25,28). In addition, remote sensing has been used for crop recognition surveys (3,33), yield predictions (12,14,15,22), land-use mapping (32), soil erosion and water use surveys (6,9,12,15,21), smog damage assessment (8), and observation of crop canopy temperatures (9,11,15,17) and stand densities (1). There is, however, limited reference to use of hand-held radiometer or MSS data for the detection of disease and estimation of eventual crop loss . For the most effective control measure scheduling and accurate potential loss estimation, it is often imperative that disease be detected early in the infection process. Differences between the visible and near-infrared reflectance from healthy plants and those under stress are measurable with instruments before changes are detectable by eye (3,7,24,32,33). This may be the greatest advantage of using MSS data in disease surveys. Diseases profoundly decrease the infrared reflectance but increase the visible reflectance from plants (8,10,33,34). Healthy vegetation is highly reflective in the near-infrared but this quickly declines due to cellular changes caused by disease. Some investigators have reported that high reflectivity in a healthy crop is due to the leaf chlorophyll (8,23,33). The basis for most of these studies has been the observation that changes in the normal reflectivity pattern (signature) of a crop result from the loss of vigor in the diseased plants. Numerous formulae, such as vegetation indices (VIs), have been developed to reduce multi-spectral data to a single number for assessing vegetation characteristics. This provides a method of showing changes in crop canopies (3,27) that can later be verified by field observation.

The objective of this study was to investigate the use of VIs derived from data obtained with a hand held multi-spectral radiometer for detecting rust infections in winter and spring wheat and to compare these results with yield components and total grain yield. Assuming that rust pathogen activity is manifested in VI changes, efficient, rapid, and accurate quantification of infection and the study of its effect on yield should be possible.

MATERIALS AND METHODS

Itana (CI 12933), a winter wheat cultivar, and two spring wheat cultivars (Lemhi [CI 11415] and Federation [CI 4734]) were planted in 1.8 × 3.3-meter field plots on the Montana State University Experiment Station at Bozeman. Plots were separated into two treatments: protected with the systemic fungicide triadimefon (Bayleton, Mobay Chemical Co.); and inoculated (Itana and Lemhi) with *Puccinia striiformis* West. (the stripe rust pathogen) or (Federation) with *Puccinia graminis* Pers. f. sp. *tritici* Eriks. & E. Henn. (the stem rust pathogen).

Spreader rows of susceptible wheat cultivars were planted around the inoculated plots to ensure adequate and uniform infection levels. Plants in the spreader rows were inoculated by dusting them with a mixture of talc and lyophilized spores of the

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appropriate pathogen (30), either *P. striiformis* or *P. graminis*. Lemhi was inoculated with *P. striiformis* on 7 June and again on 18 June 1982. Itana was inoculated with *P. striiformis* once in early May. Federation was inoculated with *P. graminis* on 23 June. Plants were in the early-tiller to mid-tiller stage (stages 2 to 3) of growth (18). The spore concentration utilized for both pathogens was 1 g of spores per 30 m of spreader row. Inoculum of *P. graminis* consisted of race TNM (15B) as identified by the Cereal Rust Laboratory in St. Paul, MN. Inoculum of *P. striiformis* was a mixture of isolates endemic to the Bozeman area in 1981. Development of disease caused by the two pathogens was both severe and uniform in all inoculated plots. All control plots were sprayed with triadimefon at 90 g/ha (50WP) with a backpack sprayer on 25 June, when plants were in the late tiller to stem elongation stage (stages 4 to 5) of growth. Only a trace of rust developed in the control plots.

Growth stage estimates were made according to the Feekes scale (18). These assessments were made for 9 wk at 3- to 5-day intervals beginning on 16 June and ending on 19 August. Flecks that developed preceding pustule formation were considered to be the onset of initial infection. A modified Cobb scale and conventional visual procedures were used to assess several individual culms and the readings were averaged to give percent severity and infection type for each plot. In addition to the disease data, several other plant and meteorological parameters were recorded: time of day, cloud condition, amount of dew, precipitation, barometric pressure, solar radiation, wind speed, plant height, growth stage, and general crop condition. Color photographs of both the healthy and the diseased plots were taken at weekly intervals. All observations were assumed to be representative of the entire plot. Infection was uniform and the rust diseases developed well in environments favorable for spread (Table 1). An Exotech model 100A Spectrometer, which is a multispectral radiometer (MSR), was used to obtain spectral measurements which were recorded for each plot at 3- to 5-day intervals beginning on 15 June and ending on 20 August 1982. The Exotech MSR, a small hand-held instrument that can be carried and operated by one person, has the same band characteristics as the multispectral scanner (MSS) used on the land satellites (Landsat) (16). The spectral band widths covered by the Exotech radiometer correspond to MSS bands 4 through 7. Two of these bands are in the visible wavelength range: band 4 (0.5–0.6 μm) and band 5 (0.6–0.7 μm). The remaining two bands are in the near-infrared range: band 6 (0.7–0.8 μm) and band 7 (0.8–1.1 μm).

TABLE 1. Disease severities[a] following inoculation at different growth stages of three wheat cultivars with two cereal rust pathogens at Bozeman, MT, in 1982

Growth stage[b]	Federation Prot[c]	Federation Inoc[d]	Lemhi Prot[c]	Lemhi Inoc[e]	Itana Prot[c]	Itana Inoc[e]
One shoot	0	0	0	0	-	-
Tillers formed	0	0	0	5	-	-
Leaf sheaths lengthen	0	0	0	10	-	-
Leaf sheaths strongly erected	0	10	0	20	0	20
First stem node visible	0	20	0	20	0	70
Second stem node visible	0	20	0	20	0	70
Last leaf visible	0	20	0	40	0	80
Ligule of last leaf visible	0	30	5	50	0	80
In boot	1	40	5	50	0	80
Ripening	10	80	20	80	10	100

[a] Severity based on modified Cobb scale. Infection type was a uniform susceptible type "4" for all cultivars.
[b] According to the Feekes scale (18).
[c] Protected control treated with Bayleton at 90 g/ha.
[d] Federation wheat inoculated with uredospores of *P. graminis*.
[e] Lemhi and Itana wheat inoculated with uredospores of *P. striiformis*.

Various VIs have been used to interpret spectral data relative to crop condition and/or estimates for biomass, leaf area, percent ground cover etc. (1,3,7,10,16,17). The vegetative indices used in this study were a band ratio (R75), a normalized difference index (ND7), and two perpendicular vegetative indices (PVI6 and PVI7). The general form of these indices is described by Perry and Lautenschlager (27), but the coefficients in the indices used were custom fitted for this analysis by using local soils data.

The data recorded in this study were analyzed to ascertain the relationships between the radiometric data and the conventional visual estimates of disease severity. The relationship between the radiometric data and test weight, number of heads per unit area, number of kernels per head, and kernel weight was assessed. This assessment was based on data collected after the harvest of all wheat heads within one square meter; these data were then converted to the number of heads per unit area.

RESULTS

All four VIs (R75, ND7, PVI6, and PVI7) were significantly lower in diseased plots than in the control plots. This observation is consistent with other reports that relate spectral data and plant vigor (8, 10, 33, 34). The VIs R75 and ND7, in that order, gave the best indication of disease incidence and subsequent yield loss regardless of the wheat cultivar or the rust pathogen. PVI6 and PVI7, in that order, were the next best indicators of disease (Figs. 1 to 3). The spectral differences observed between the stem rust-affected plots and their corresponding control plots were never as large as the corresponding differences observed for stripe rust.

All four VIs gave clear indications of both diseases, particularly stripe rust. Itana winter wheat was first to show stripe rust symptoms, both visually and in the spectral data (Fig. 3). For winter wheat cultivar Itana, VI differences were apparent by the early tillering stage (15 June) Feekes 4.0–5.0 (18). The largest differences in VIs occurred during grain ripening (10–15 July) Feekes 10.8–11.3. These differences narrowed when the high infection levels in both the control and inoculated plots eventually

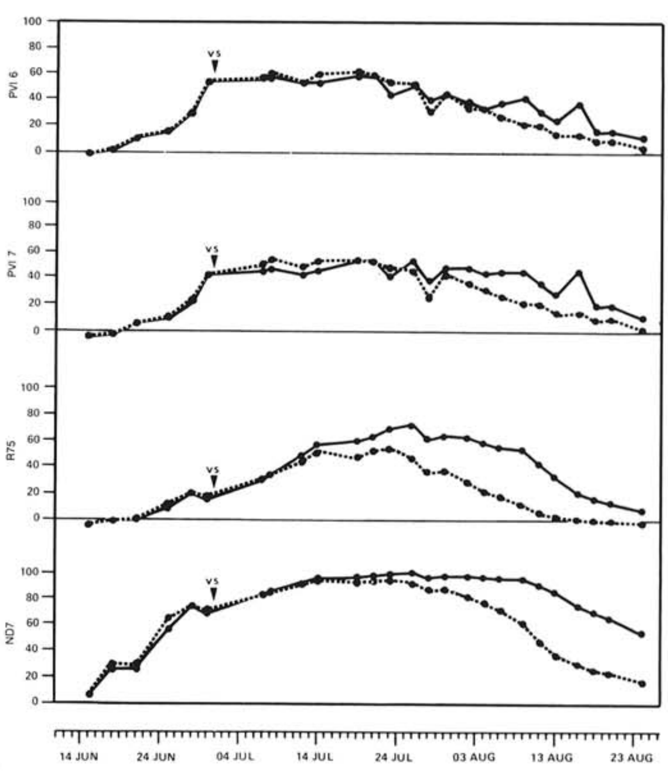

Fig. 1. Inoculated (------) versus control (——) comparison of four vegetation indices for wheat cultivar Federation and the wheat rust pathogen, *Puccinia graminis*. Arrow (vs) indicates date that flecks were first observed.

caused premature senescence of all plants (15–20 July) (Feekes 11.3–11.4). The two spring cultivars began showing spectral differences between control and inoculated plots during the late tillering to early stem elongation growth stage (28 June–1 July) Feekes 5.0–6.0; the largest spectral difference occurred during flowering and grain filling (25–30 July) Feekes 10.5–11.0.

The plot with the largest yield reduction (98%) was Federation spring wheat inoculated with stem rust. The infection began early and became severe later in the growing period, which contributed to the large yield reduction. These physical observations are correlated with changes observed in the spectral data. Using R75 or ND7, the largest spectral differences between control and inoculated plots occurred during flowering and grain filling. All yield components were drastically affected except the number of heads per unit area (Table 2). The yield component most affected was kernel weight which can be correlated with the early infection during stem elongation and floret formation.

DISCUSSION

The stage of plant development at which rust first appears can have great influence on subsequent losses. If rust symptoms do not appear until the soft dough stage of kernel development, losses will be minimal. Early detection of infection can be very useful for chemical control and can lead to more reliable estimates of disease loss over large areas that may not be accessible except by remote sensing.

In these trials, a uniform infection was established at an early stage of plant development and losses incurred are believed to be near maximum for the respective host-pathogen combinations. Significant reductions occurred not only in all yield components measured but also in total yield.

VI differences between healthy and diseased plants could easily be detected. One can speculate that early detection of stripe rust by VI differences as compared to visual inspection is related to the vegetative growth habit of the causal fungus. The stripe rust fungus is semi-systemic and, even before visual symptoms and signs of the disease appear, there is abundant vegetative growth of the pathogen extending several millimeters from each initial infection site (29,31). In stem rust, on the other hand, the initial fungal development is localized to the immediate area of the single rust pustule, and only belatedly forms secondary and tertiary areas of vegetative growth with concomitant pustule development.

In speculating about the extension of techniques described in this paper to a satellite-based wheat rust-monitoring system, it is important to remember that MSS data acquired from a satellite are different from the spectral data used in this study in two respects: the Landsat MSS observes a relatively large ground area and the accuracy of its MSS data can be severely affected by atmospheric conditions. With these considerations in mind, the advantage of a satellite-based wheat rust-monitoring system over the traditional ground-based assessment techniques presently employed are many: timeliness, large area coverage, remote area coverage, and possible computer automation. For example, one can visualize using satellite-based VI measurements to detect the presence of disease and monitor its spread in remote areas that may not be easily or feasibly accessible. In the future, as we obtain more spectral data, including more narrow-band data, and consequently the signatures of more diseases and the signatures of other plant stress factors, we may be better able to forecast disease epidemics and to implement

TABLE 2. Effect of stem rust and stripe rust on wheat yield components and total yield expressed as percent of control

Cultivar	Disease	Heads/ unit area (%)	Kernels/ head (%)	Kernel wt. (%)	Total grain yield (%)
Federation	Stem rust	92	7	22	1.4
Lemhi	Stripe rust	60	68	56	23
Itana	Stripe rust	82	70	67	40

[a]Control was treated with Bayleton at 90 g/ha at the tillering stage (Federation and Lemhi) and at the rapid-elongation stage (Itana).

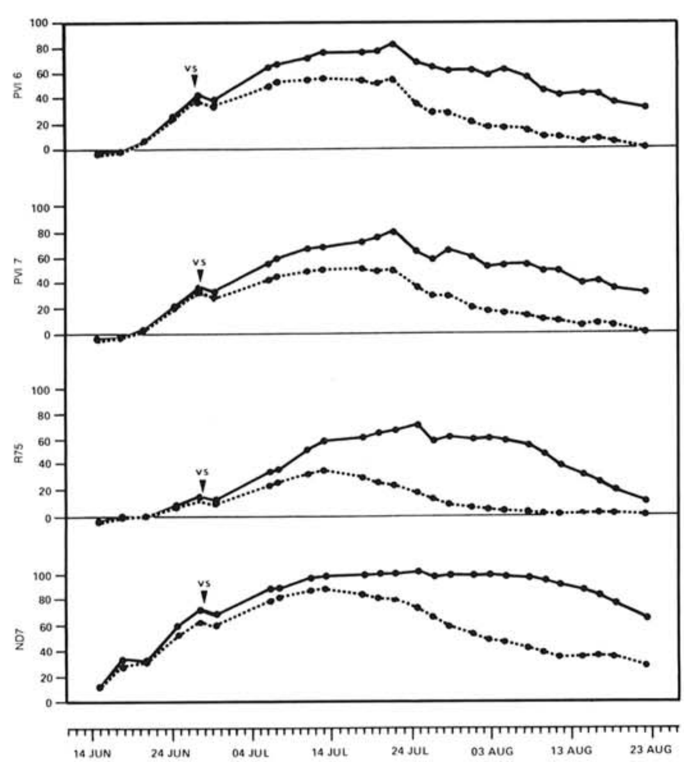

Fig. 2. Inoculated (------) versus control (——) comparison of four vegetation indices for wheat cultivar Lemhi and the wheat rust pathogen, *Puccinia striiformis*. Arrow (vs) indicates date that flecks were first observed.

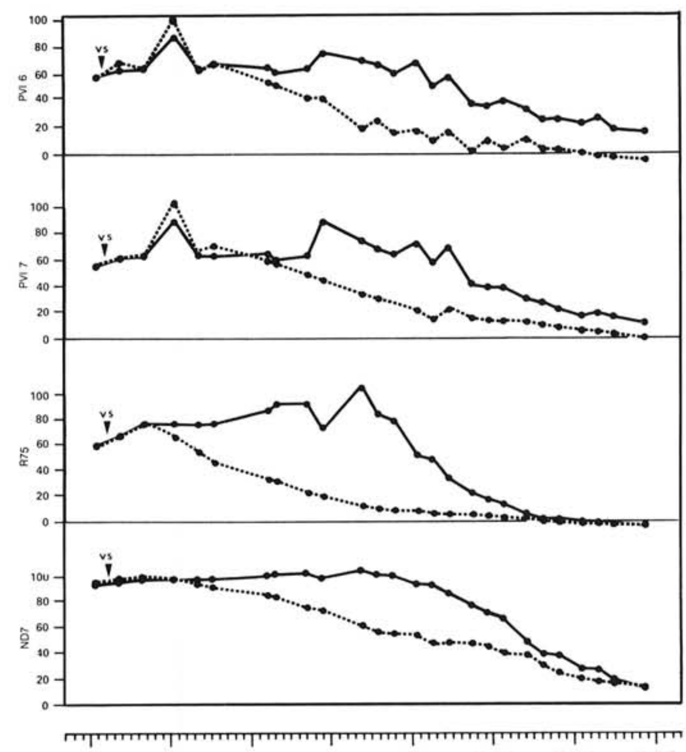

Fig. 3. Inoculated (------) versus control (——) comparison of four vegetation indices for the wheat cultivar Itana and the wheat rust pathogen, *Puccinia striiformis*. Arrow (vs) indicates date that flecks were first observed.

desirable control measures more effectively. Future investigations are planned to further delineate spectral differences among various plant diseases and to determine the possibility of estimating disease losses at early growth stages.

LITERATURE CITED

1. Aase, J. K., and Siddoway, F. H. 1980. Determining winter wheat stand densities using spectral reflectance measurements. Agron. J. 72:149-152.
2. Bawden, F. C., 1933. Infrared photography and plant virus diseases. Nature 132:168.
3. Blair, B. D., and Baumgardner, M. F. 1977. Detection of the green and brown wave in hardwood canopy covers using multispectral data from LANDSAT-1. Agron. J. 69:808-811.
4. Brenchley, G. H., and Dodd, C. V. 1962. Potato blight recording by aerial photography, N.A.A.S. (Nat. Agric. Advis. Serv.) Q. Rev. 57:21-25.
5. Colwell, R. N., 1956. Determining the prevalence of certain cereal diseases by means of aerial photoghraphy. Hilgardia 26:223-286.
6. Daughtry, C. S. T., Bauer, M. E., Crecelius, D. W., and Hixon, M. M. 1980. Effects of management practices on reflectance of spring wheat canopies —Technical Report. Purdue University-LARS (Large Area Remote Sensing), West Lafayette, IN. 20 pp.
7. Duggin, M. J., 1977. Likely effects of solar elevation on the quantification of changes in vegetation with maturity using sequential Landsat images. Appl. Optics 16:521-523.
8. Flowerday, D. A., 1982. Low-altitude infrared photography as a crop management tool. Pages 379-386 in: Remote Sensing for Resource Management. C. J. Johannsen and J. L. Saunders, eds. Soil Conservation Society of America, Ankeny, IA.
9. Gausman, H. W., Leamer, R. W., Noriega, J. R., Rodriquez, R. R., and Weigand, C. L. 1977. Field-measured spectroradiometric reflectances of disked and nondisked soil with and without wheat straw. Soil Sci. Soc. Am. J. 41:793796.
10. Harper, D. 1976. Eye in the Sky. Multiscience Publications Ltd., Montreal, Canada.
11. Hatfield, J. L., 1979. Canopy temperatures: The usefulness and reliability of remote measurements. Agron. J. 71:889-892.
12. Heilman, J. L., and Kanemasu, E. T., Bagley, J. O., and Rasmussen, V. P. 1977. Evaluating soil moisture and yield of winter wheat in the Great Plains using LANDSAT data. Remote Sens. Environ. 6:315-326.
13. Heller, R. C., 1973. Large-scale photo assessment of smog-damaged pines. Pages 138-143 in: The Surveillant Science: Remote Sensing of the Environment. R. K. Holz, ed. Houghton-Mifflin Co., Boston.
14. Idso, S. B., Hatfield, J. L., Jackson, R. D., and Reginato, R. J. 1979. Grain yield predictions: Extending the stress degree-day approach to accomodate climatic variability. Remote Sensi Environ. 8:267-272.
15. Idso, S. B., Jackson, R. D., and Reginato, R. J. 1977. Remote-sensing of crop yields. Science 196:19-25.
16. Jackson, R. D., Pinter, P. J., Reginato, R. J., and Idso, S. B. 1980. Hand-Held Radiometry. USDA-ARS, Agricultural Reviews and Manuals, ARM-W-19. 66 pp.
17. Kanemasu, E. T., 1974. Seasonal canopy reflectance patterns of wheat, sorghum and soybean. Remote Sens. Environ. 3:43-47.
18. Large, E. C., 1954. Growth stages in cereals. Plant Pathology 3:4:128-129.
19. Manzer, F. E., and Cooper, G. R. 1967. Aerial photographic methods of potato disease detection. Maine Agric. Exp. Stn. Bull. 646.
20. Meyer, M. P., and Calpouzos, L. 1968. Detection of crop diseases, Photogramm. Eng. Rem. Sens. 34:554-556.
21. Millard, J. P., Jackson, R. D., Goettelman R. C., Reginato, R. J. and S. B. Idso, 1978. Crop water-stress assessment using an airborne thermal scanner. Photogramm. Eng. Rem. Sens. 44:1:77-85.
22. Morain, S. A., and Williams, D. L. 1975. Wheat production estimates using satellite images. Agron. J. 67:361-364.
23. Murtha, D. A., 1982. Detection and analysis of vegetation stress. Pages 141-158 in: Remote Sensing for Resource Management. C. J. Johannsen and J. L. Saunders, eds. Soil Conservation Society of America, Ankeny, IA.
24. National Academy of Sciences. 1970. Remote Sensing with Special Reference to Agriculture and Forestry. National Academy of Sciences, Washington, DC. 423 pp.
25. Norman, G. G., and Fritz, N. L. 1973. Infrared photography as an indicator of disease and decline in citrus trees. Pages 198-201 in: The Surveillant Science: Remote Sensing of the Environment. Houghton-Mifflin Co., Boston.
26. Pennypacker, S. P., Scharen, A. L., Sharp, E. L., and Sands, D. C. 1982. Spectral classification of wheat infected with barley yellow dwarf and stripe rust. (Abstr.) Phytopathology 72:1006.
27. Perry, C. R., and Lautenschlager, L. F. 1984. Functional equivalence and spectral vegetation indices. Rem. Sens. Environ. 14:169-172.
28. Philpotts, L. E., and Wallen, V. R. 1969. IR color for crop disease identification. Photogramm. Eng. Rem. Sens. 35:1116 1125.
29. Pope, W. K., Sharp, E. L., and Fenwick, H. S. 1963. Stripe rust of wheat in the Pacific Northwest in 1962. Plant Dis. Rep. 47:554-555.
30. Sharp, E. L., and Smith, F. G. 1952. Preservation of Puccinia uredospores by lyophilization. Phytopathology 42:263-264.
31. Sharp, E. L., 1965. Prepenetration and postpenetration environment and development of *Puccinia striiformis* on wheat. Phytopathology 55:198-203.
32. Swain, P. H., and Davis, S. M. 1978. Remote Sensing—The Quantitative Approach. McGraw-Hill, New York. 396 pp.
33. Thaman, R. R., 1974. Remote sensing of agricultural resources. Pages 189-216 in: Remote Sensing Techniques for Environmental Analysis. J. E. Estes & L. W. Senger, eds., John Wiley & Sons, Santa Barbara, CA.
34. Thomas, J. R., and Oerther, G. F. 1972. Estimating nitrogen content of sweet pepper leaves by reflectance measurements. Agron. J. 64:11-13.