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WINTER WHEAT STAND DENSITY DETERMINATION AND YIELD
ESTIMATES FROM HANDHELD AND AIRBORNE SCANNERS

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16. Abstract

Our objective was to relate radiance measurements from handheld (Exotech 100-A) and air-borne (Daedalus DEI 1260) radiometers to wheat (Triticum aestivum L.) stand densities (simulated winter wheat winterkill) and to grain yield. The field experiment was located 11 km north-west of Sidney, Montana, on a Williams loam soil (fine-loamy, mixed Typic Argiborolls). Three rates--67, 27, and 13 kg/ha-- of 'Len', a semidwarf hard red spring wheat cultivar, were seeded to stand.

Radiances were measured with the handheld radiometer on clear mornings throughout the grow-ing season. Aircraft overflight measurements were made thrice: at the end of tillering, the early stem extension period, and the mid-heading period.

The IR/red ratio and normalized-difference vegetation index were used in the anlysis. The aircraft measurements corroborated the ground measurements inasmuch as wheat stand densities were detected and could be evaluated at an early enough growth stage to make management decisions. The aircraft measurements also corroborated handheld measurements when related to yield prediction. The IR/red ratio, although there was some growth stage dependency, related well to yield when measured from just past tillering until about the watery-ripe stage. The results reinforce the potential of remote sensing for predicting grain yields.

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INTRODUCTION

Remote sensing of crop conditions and for potential yield forecasting is receiving continuing increased attention (Waldrop, 1982). Wheat has been the chief benefactor of remote sensing related research on preharvest information and yield prediction. Tucker et al. (1980) reviewed some of the various methods and approaches used. Positive relationships between spectrally measured data and various crop growth characteristics, including yield, have been reported for other crops as well (Kimes et al., 1981; Markham et al., 1981; Tucker et al., 1979, Holben et al., 1980).

Various combinations, referred to as vegetation indices (VI) of four wavebands corresponding to the four Landsat multispectral scanner (MSS) bands have been related to crop development and yield. The most commonly used spectral measurements have involved various combinations of red and near-infrared (IR) radiances, more or less corresponding to Landsat bands 5 and 7 (0.6 to 0.7, and 0.8 to $1.1 \mu m$, respectively). Tucker (1979), after reviewing the literature on IR/red ratio and some of the linear combinations of the IR and red radiances, concluded that they very similarly estimated the photosynthetically active phytomass.

Lautenschlager and Perry (1981) reviewed all vegetation indices (some four dozen) found in the literature, and based on a statistical analysis, concluded that many vegetative indices are closely similar.

Aase and Siddoway (1978, 1981a, 1981b), using a handheld radiometer, related the IR/red ratio and the normalized difference vegetation index [ND = (IR - Red)/(IR + Red)] of Rouse et al. (1973) and Deering et al. (1975) to wheat stand densities (simulated winter wheat winterkill) and to total dry

matter production and yield. They preferred to use the ND. Jackson et al. (1982) concluded that no one vegetation index will give all the information desired.

The objective of the study we report on presently was to extend and verify the earlier research of Aase and Siddoway. To do so, we used both handheld and air-borne radiometers to measure reflectances from large fields.

METHODS AND MATERIALS

The field experiment was located on a Williams loam soil (fine-loamy. mixed typic Argiborolls) 11 km northwest of Sidney, Montana. The 32 ha field with dimensions of 300 m north-to-south and 400 m east-to-west was summer fallowed in 1980. The coordinates at the southeast corner of the field are 47°44'47"N104°16'20"W. The field was divided into thirds with 6-m east-west summer fallowed alleys separating each third. On 15 April 1981, the north third was seeded with 67 kg/ha of 'Len," a semidwarf, hard red spring wheat (Triticum aestivum L.) cultivar; 121 kg/ha of diammonium phosphate (18-46-0) was broadcast with the drill. The wheat was seeded with a double disk opener drill in an east-west direction in 30.5-cm rows.

The middle and south thirds of the field were seeded in a similar fashion to the north third except the middle third was seeded on the 16th of April at a rate of 27 kg/ha and with 67 kg/ha of fertilizer broadcast; the south third was seeded on the 17th of April at the rate of 13 kg/ha with 34 kg/ha of fertilizer broadcast.

The resultant stand densities, as measured on 15 May from six 1 m^2 samples from each plot, were 104, 41, and 17 plants/m^2 on what will be designated the 100-, 40-, and 20-percent plots, respectively.

An Exotech[1] Model 100-A Radiometer with a 15° field of view (FOV) was used to measure spectral band radiances corresponding to the LANDSAT multi-spectral scanner (MSS) bands 4, 5, 6, and 7, representing 0.5 to 0.6, 0.6 to 0.7, 0.7 to 0.8, and 0.8 to $1.1-\mu m$ wavelengths, respectively. All channel outputs were read simultaneously and recorded on a portable, battery-operated digital printer, and later manually read and transferred for analysis. Because the morning is generally the clearest, scattered cumulus clouds commonly begin to move in from the west after about 1000 hours M.S.T., the sampling time was set for 0830 hours MST. Measurements were generally completed within 20 min. Readings were taken on clear days and on days when apparent haze or distant horizon cumulus clouds seemed not to interfere with the solar beam. Readings were obtained on 19 days during the growing season.

Sampling consisted of two dark level readings (background reading allowing no light to enter lenses), four readings from a pressed barium sulfate standard, six readings from each of the plots, and five from bare soil in the alleys in the following sequence: Dark level, standard, 20-percent plot, standard, bare soil, 40-percent plot, bare soil, standard, 100 percent plot, 100-percent plot, standard; bare soil, 40 percent plot, bare soil, standard, 20-percent plot, standard, and dark level.

The barium sulfate standard (30 cm x 30 cm) was transported during the course of the measurements to predetermined spots in the alleys separating the plots, and placed on prelevelled wooden stakes extending about 20 cm above ground level.

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[1]Trade and company names are included for the benefit of the reader and do not imply any endoresement or preferential treatment by the USDA of the product listed.

To facilitate the radiance measurements, planks (6 m) were placed in the middle of each plot, perpendicularly to the rows and supported 20 cm above ground by cement blocks. A worker standing on the planks took radiance readings from six locations on the east side of the planks. The radiometer reflectance readings subtended an area about 50 cm in diameter.

An Aerocommander 500B twin-engine airplane equipped with two down ports, one for a Daedalus DEI 1260 multispectral scanner and one for a RC-10, 23-cm format camera, was scheduled for four overflights during the season. The flights were scheduled to take place near the following growth stages as given by the Feekes scale (Large, 1954): 4 (leaf sheaths lengthen), 6 (first node of stem visible), 10 (ear swollen but not yet visible), and 10.5.4 (flowering over, kernel watery-ripe). The flights varied some from the schedule because of cloudy weather and, because of aircraft failure, the last flight was cancelled.

Two flights each took place on 29 May, 10 June, and 25 June near 0900 hrs and 1100 hrs, Mountain Standard Time, except cloud conditions prevented the 1100 hrs flight on 10 June.

The flights were at 610 m above ground level and were repeated twice, first in a west to east direction, then in a south to north direction.

Channels 6 and 10 (0.60 to 0.65 and 0.92 to 1.10-μm), respectively, of the DEI 1260 scanner were used for data analysis.

Weekly throughout the growing season, six 1 m^2 plant samples were clipped at ground level from each plot and growth components determined. Leaves, stems, and heads were separated, oven dried at 57°C and weighed to determine dry matter. Growth stage was determined according to the Feekes scale (Large, 1954).

RESULTS AND DISCUSSION

In Figs. 1 and 2, we illustrate the seasonal progression of the IR/red ratio and of the normalized difference vegetation index as calculated from data obtained with the handheld radiometer. The two figures are included for comparison purposes. The data are based on radiances rather than reflectances so as to be compatible with radiances obtained from aircraft overflights. As it turned out, there was not much difference between radiance and reflectance data. The curves in Figs. 1 and 2 verify earlier findings and conclusions of Aase and Siddoway (1980, 1981) that wheat stand densities, and thus winterkill of winter wheat, can be detected early enough in the spring to make reseeding decisions. The data points from the aircraft mounted sensor are superimposed on the figures. It is at once apparent that they fall below the data points obtained with the handheld radiometer, nevertheless, in all essentials, they supported the conclusion reached from the handheld radiometer measurements. In comparing Figs. 1 and 2, it appears that the normalized difference vegetation index is more sensitive in detecting vegetative cover during the early season than is the IR/red ratio. Later in the season, the IR/red ratio appears to be more sensitive. In Table 1, we have recorded the percent difference from bare soil readings of IR/red ratio and ND for each seeding rate plot and for the three dates where we also have aircraft data. The data in Table 1 agree with the observations based on Figs. 1 and 2 for the data obtained with the handheld radiometer. The ND remained more sensitive for all three observations using the airborne scanner.

A combination of digital data, as illustrated in Figs. 1 and 2 along with color images as shown in Fig. 3, may well enhance each other and facilitate interpretation. Details and variation in stand are readily discerned on the

color image, whereas the digital values only showed an average of the whole field.

There was a difference in the aircraft sensor data depending on whether or not they were obtained from a west-to-east flight or a south-to-north flight. As the aircraft passed in a west-to-east direction, parallel to the wheat rows, the scanner which scans orthogonally to the flight direction may have sensed less soil and more sunlit plants than on the south-to-north pass. On the south-to-north pass, the scanner may have "viewed" deeper into the canopy than it did on the west-to-east pass and sensed more shadows. That shadows may have had an effect agrees with the observation that the differences between south-to-north and west-to-east passes were greater on the fields with densest growth and increased as leaf area increased. The effect of shadows and view angle has been discussed in some detail by Jackson et al. (1979).

MSS band 7 on the handheld radiometer encompasses 0.80 to 1.10 μm. Band 10 on the Daedalus scanner encompasses 0.92 to 1.10 μm. Band 5 on the handheld encompasses 0.6 to 0.7 μm, band 6 on the Daedalus scanner, 0.60 to 0.65 μm. Thus, portions of bands 5 and 7 of the handheld radiometer are included in each of bands 6 and 10 of the Daedalus scanner.

That leaf area or leaf phytomass can be related to spectral radiometric measurements has been shown in previous studies (i.e. Aase and Siddoway, 1981; Kimes et al., 1981; Holben et al., 1980; Wiegand et al., 1979). In Fig. 4, we illustrate the relationship from handheld measurements of IR/red versus leaf phytomass and air-borne scanner measurements of IR/red versus leaf phytomass. Because of differences in wavelengths in the handheld and airborne scanner measurements, the data points calculated from the air-borne scanner measure-

ments do not match those from handheld radiometer measurements; however, the relationships are similar. These types of relationships are potentially important for plant growth models requiring either leaf area or leaf phytomass as inputs.

Another potential use for seasonal spectral radiometric measurements is for grain yield prediction. There is a good linear relationship between grain yield and vegetation indices measured between approximately the end of tillering growth stage through the watery ripe growth stage (Aase and Siddoway, 1981, Tucker et al., 1980, Colwell et al., 1977). The relationship is somewhat growth stage dependent, and as Tucker et al. (1980) discussed, some type of normalizing factor must be found so that one relationship can be developed for use throughout the useful yield predictive period.

On Fig. 5, we have plotted data obtained with the handheld radiometer over three seasons. The data encompass two spring wheat cultivars, 'Olaf' in 1979 (Aase and Siddoway, 1981), 'Len' in 1981 (this paper), and one winter wheat cultivar, 'Roughrider' in 1980 (Aase, unpublished data). It was not possible to find data at the same growth stage for all years, therefore the nearest to the same was used: in 1979 at flowering complete, and in 1980 and 1981 at quarter of heading process complete. The data seem to be cultivar independent and reasonably uniform during the heading growth period.

It was encouraging that the data from 1980 fit so well with the rest. The data from 1980 came from a winter wheat experiment designed the same as the spring wheat experiment from which the 1979 data came (Aase and Siddoway, 1981). The difference was that a severe drought occurred in 1980 and yields were about half of those expected under more nearly "normal" conditions. The data from the 3 years were combined and one line drawn as shown in Fig. 5.

This line was drawn on Fig. 6 and there compared with 1981 data obtained from the air-borne scanner when flown in the west-to-east direction. The 1981 data obtained with the handheld radiometer is also repeated on Fig. 6. As expected from the earlier discussion, the 10/6 ratio data showed the same relationship as the 7/5 ratio data from the handheld radiometer, only that the slope was shifted over, but with almost identical slope.

CONCLUSION

Wheat stand density differences (simulated winterkill) were determined by handheld radiometer measurements. Air-borne scanner measurements verified the handheld radiometer measurements. Differences in wheat stands can be detected at an early growth stage by both handheld and airborne radiometers so timely decisions regarding possible reseeding can be made. Air-borne scanner measurements demonstrated similar sensitivity to that of handheld radiometer measurements for yield prediction. With proper calibration, the data from handheld and air-borne sensors would be almost identical. Care must be exercised when interpreting radiation yield relationships because disease, weeds, water stress, hail, etc. could reduce yield and not be accounted for. A combination of the radiation yield relationship and meteorological observation and disease detection could well work to an advantage.

Table 1. Air-borne and handheld radiometer readings over 0, 20, 40, and 100% wheat plots, expressed as IR/red rates and normalized difference vegetation index (ND) and percent difference from the 0% (bare soil) plot.

Plant stand density %	Air-borne IR/red	Diff. from bare soil %	Handheld IR/red	Diff. from bare soil %	Air-borne ND	Diff. from bare soil %	Handheld ND	Diff. from bare soil %
				28 May 1981				
0	0.817	--	1.58	--	-0.103	--	0.23	--
20	0.831	2	1.80	14	-0.096	7	0.28	22
40	0.917	12	2.47	56	-0.045	56	0.42	83
100	1.29	58	2.89	83	0.122	218	0.48	109
				10 June 1981				
0	0.843	--	1.66	--	-0.0891	--	0.25	--
20	1.09	29	2.21	33	0.029	132	0.37	48
40	1.45	72	2.68	61	0.173	294	0.45	80
100	2.21	162	4.84	192	0.371	516	0.66	164
				25 June 1981				
0	1.18	--	1.60	--	0.0769	--	0.23	--
20	2.56	117	2.91	82	0.422	449	0.48	109
40	3.02	156	4.09	156	0.492	540	0.60	161
100	4.33	267	5.34	234	0.621	708	0.58	196

FIGURE CAPTIONS

Fig. 1. IR/red radiance ratio vs. time for bare soil (0) and three spring wheat seeding rates: 20, 40, 100 percent (100 percent = 67 kg/ha) as measured by a handheld radiometer. The individual symbols represent values obtained from air-borne scanner in west-to-east and south-to-north flight patterns. Daily rainfall is included for reference.

Fig. 2. Normalized difference vegetation index vs. time for bare soil (0) and three spring wheat seeding rates: 20, 40, 100 percent (100 percent = 67 kg/ha) as measured by a handheld radiometer. The individual symbols represent values obtained from air-borne scanner in west-to-east and south-to-north flight patterns. Dail rainvall is included for reference.

Fig. 3. Color image of experimental area on three dates showing detail and contrast of the three fields with a fallow field on the west.

Fig. 4. IR/red ratio vs. leaf phytomass. Values determined from air-borne scanner measurements are shown separately (Symbols A, B. C).

Fig. 5. Grain yield vs. IR/red ratio at given growth stages as obtained by a handheld radiometer during three growing seasons, plus an average of the three.

Fig. 6. Grain yield versus IR/red ratio for average value in Fig. 4, readings from handheld radiometer in 1981, and air-borne radiometer values as indicated on figure.

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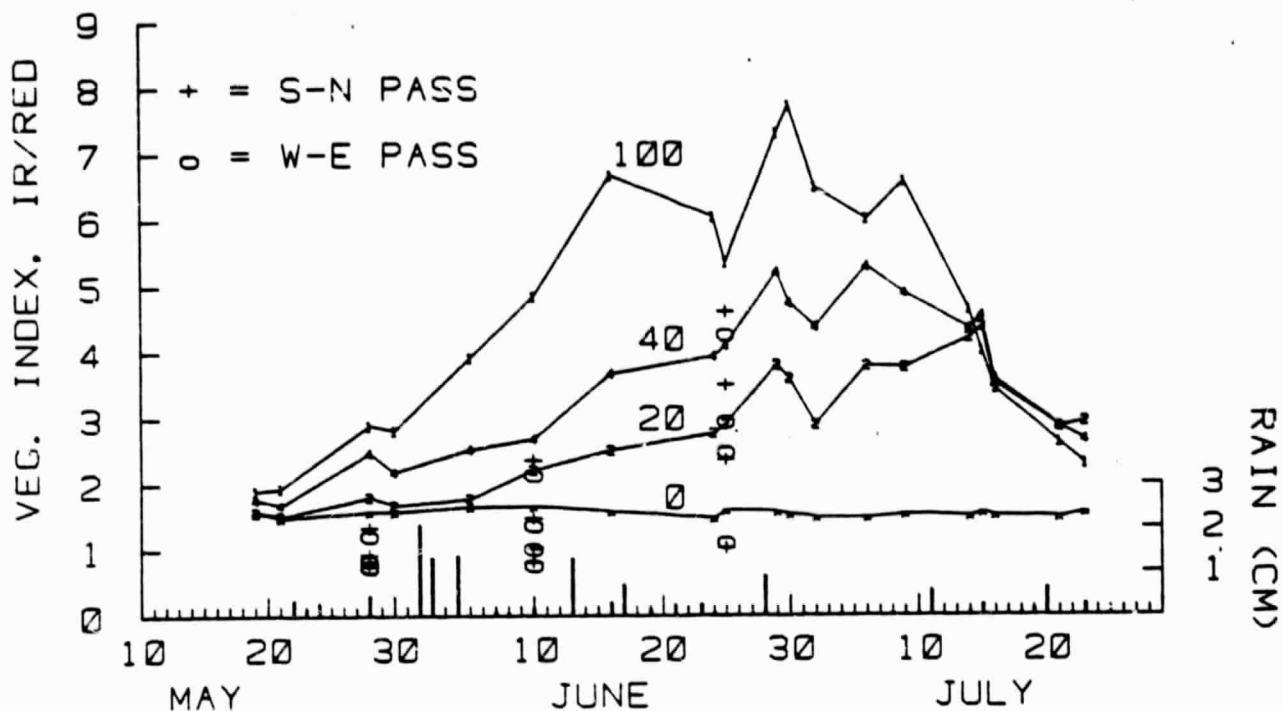
Fig. 1. IR/red radiance ratio vs. time for bare soil (0) and three spring wheat seeding rates: 20, 40, 100 percent (100 percent = 67 kg/ha) as measured by a handheld radiometer. The individual symbols represent values obtained from air-borne scanner in west-to-east and south-to-north flight patterns. Daily rainfall is included for reference.
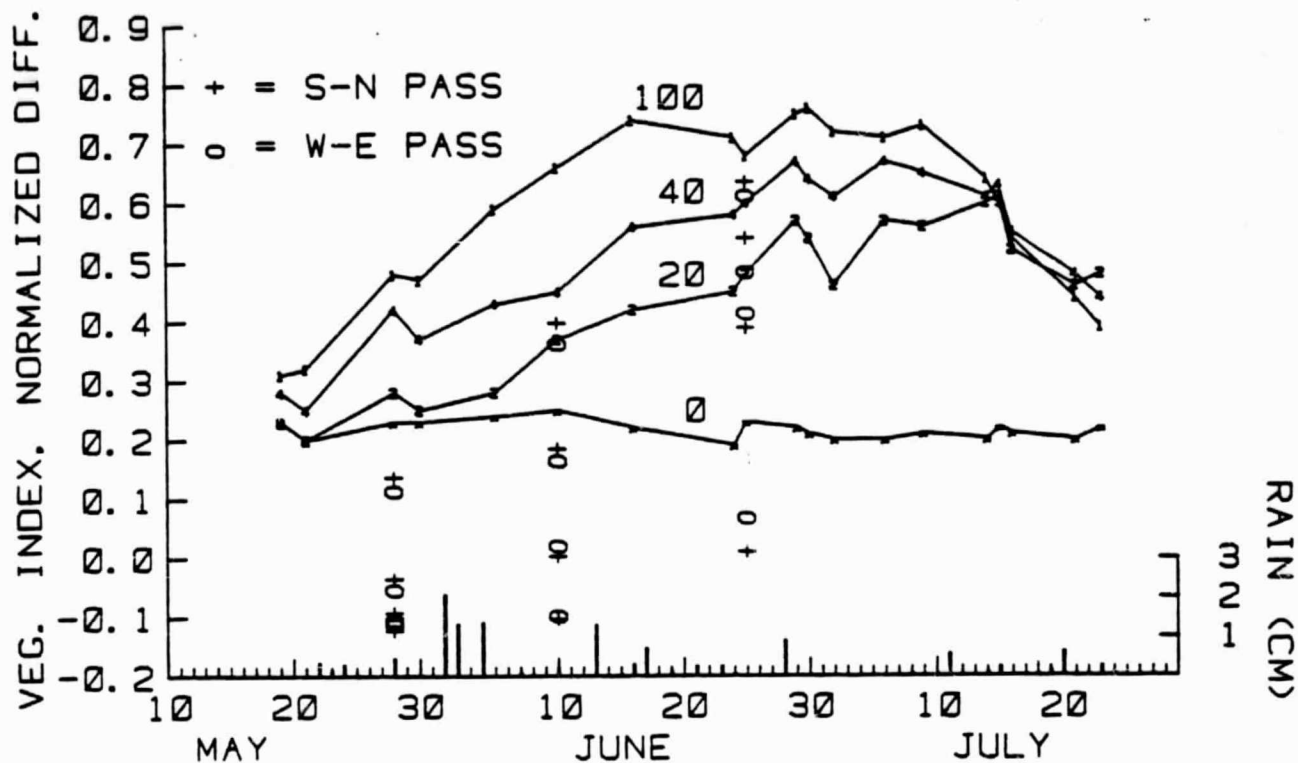
Fig. 2. Normalized difference vegetation index vs. time for bare soil (0) and three spring wheat seeding rates: 20, 40, 100 percent (100 percent = 67 kg/ha) as measured by a handheld radiometer. The individual symbols represent values obtained from air-borne scanner in west-to-east and south-to-north flight patterns. Dail rainvall is included for reference.
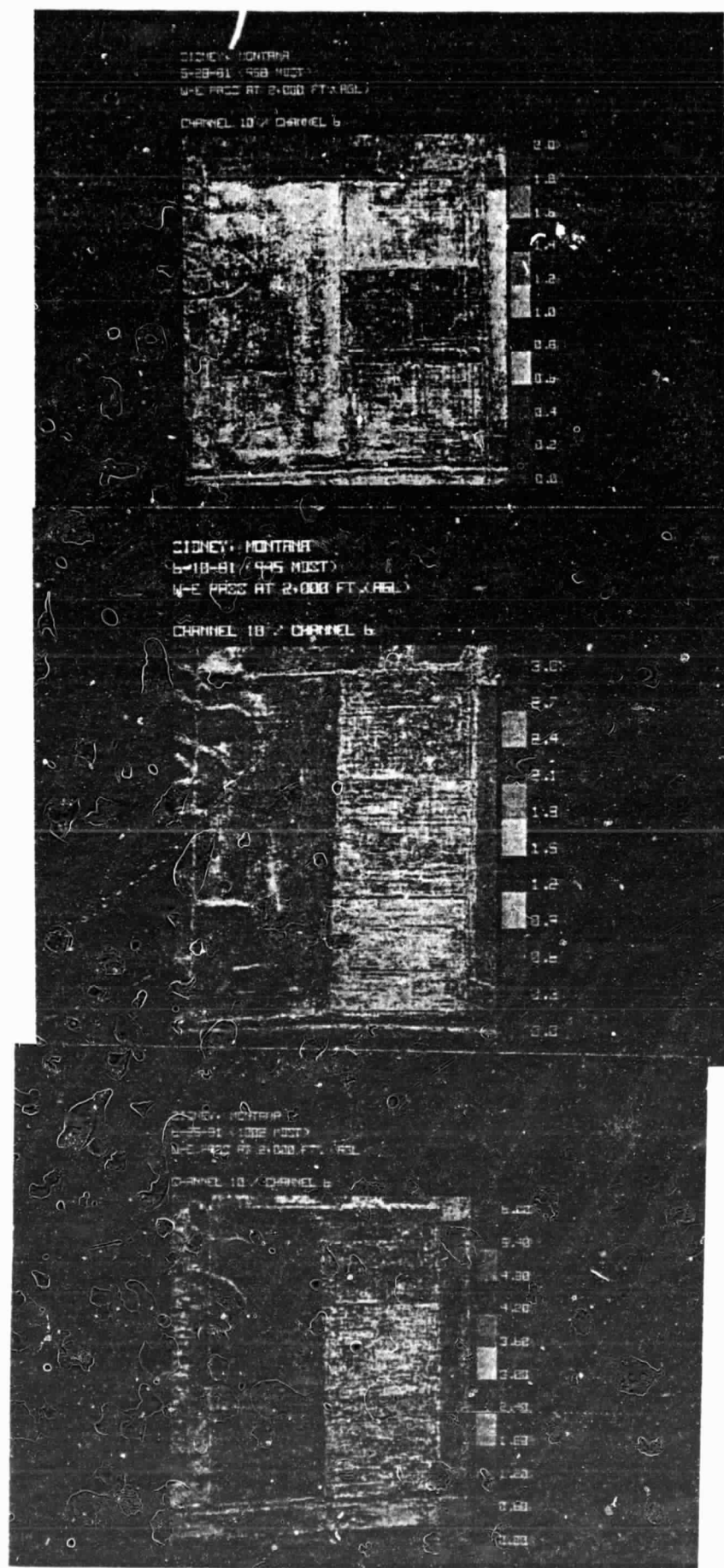
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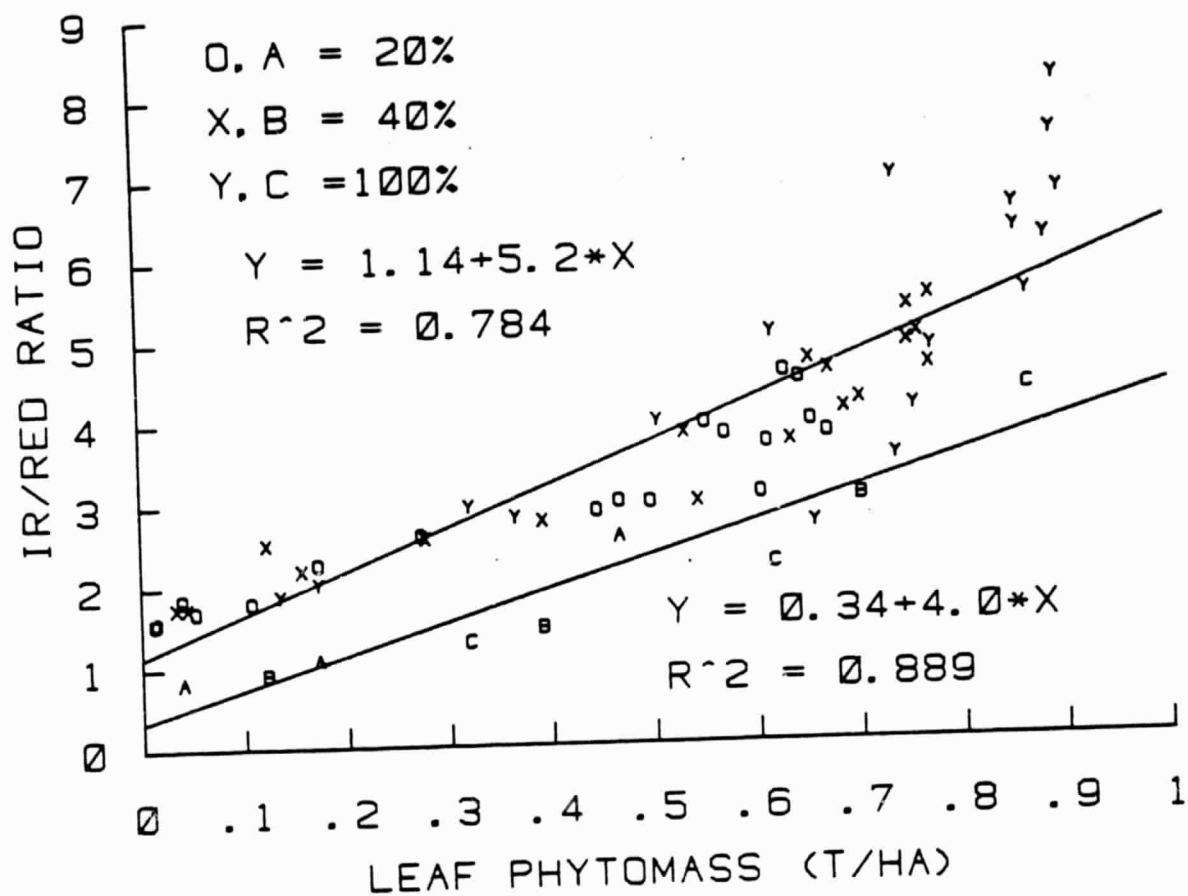
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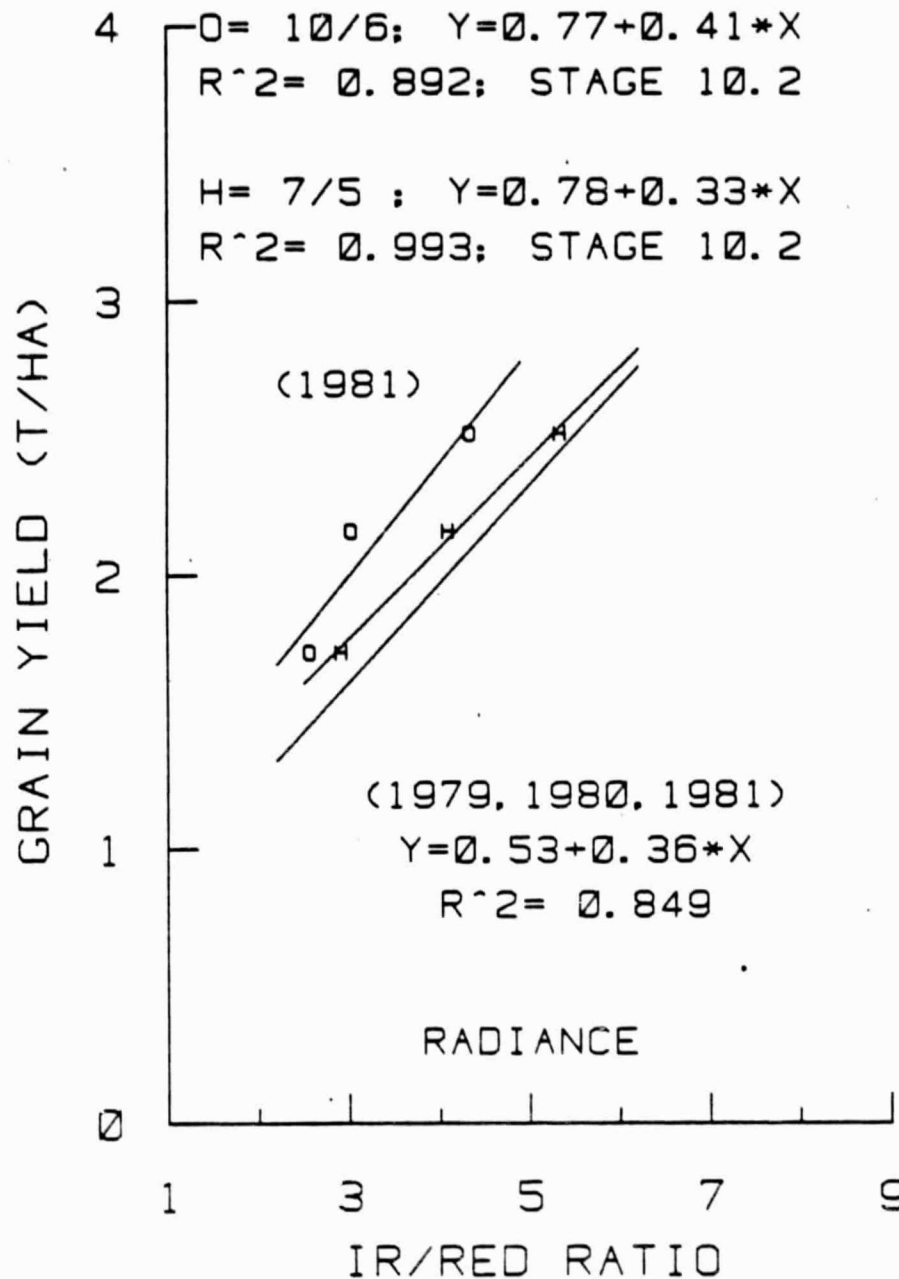
Fig. 5. Grain yield vs. IR/red ratio at given growth stages as obtained by a handheld radiometer during three growing seasons, plus an average of the three.

O= 1979; Y=0.30+0.39*X
R^2= 0.811; STAGE 10.5.2

X= 1980; Y=0.35+0.44*X
R^2= 0.894; STAGE 10.2

H= 1981; Y=0.78+0.33*X
R^2= 0.993; STAGE 10.2

(1979, 1980, 1981)
Y=0.53+0.36*X
R^2= 0.849

RADIANCE

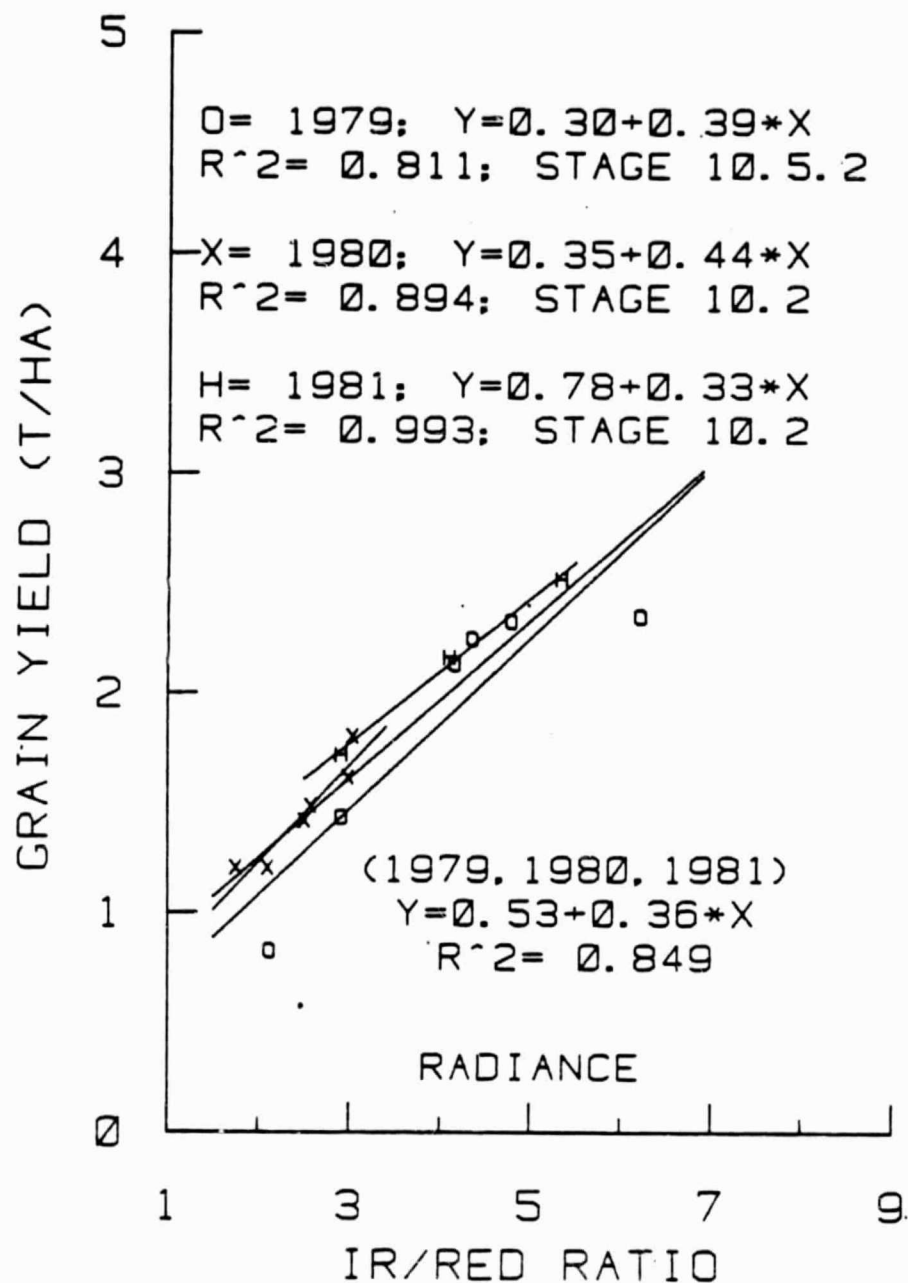GRAIN YIELD (T/HA)

IR/RED RATIO

Fig. 6. Grain yield versus IR/red ratio for average value in Fig. 4, readings
from handheld radiometer in 1981, and air-borne radiometer values as
indicated on figure.