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Intercepted Photosynthetically Active Radiation in Wheat Canopies Estimated by Spectral Reflectance

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Intercepted Photosynthetically Active Radiation Estimated by Spectral Reflectance a/

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ABSTRACT

Interception of photosynthetically active radiation (PAR) was evaluated relative to greenness and normalized difference ($\text{MSS}\ \frac{7-5}{7+5}$) for five planting dates of wheat for 1978-79 and 1979-80 in Phoenix. Intercepted PAR was calculated from a model driven by leaf area index and stage of growth. Linear relationships were found between greenness and normalized difference with a separate model representing growth and senescence of the crop. Normalized difference was a significantly better model and would be easier to apply than the empirically derived greenness parameter. For the leaf area growth portion of the season the model between PAR interception and normalized difference was the same over years, however, for the leaf senescence the models showed more variability due to the lack of data on measured interception in sparse canopies. Normalized difference could be used to estimate PAR interception directly for crop growth models.

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INTRODUCTION

Crop yield models require an estimate of the leaf area index or the interception of photosynthetically active radiation. Biscoe et al. (1975) showed that dry matter production by barley canopies could be driven by the intercepted radiation. Hodges and Kanemasu (1977) used a conversion factor from intercepted radiation to dry matter production in their wheat model. Daughtry et al. (1982) showed conceptually how remotely sensed data could be used to obtain an estimate of the solar radiation intercepted by canopies and then converted to dry matter. Thus, it would appear that an estimate of intercepted radiation by canopies from a remote sensing platform would be desirable.

Kollenkark et al. (1982) found that greenness and leaf area index were strongly related, however, they showed an even stronger relationship between soil cover and greenness for soybeans. They also showed that greenness reached a maximum although leaf area index continued to increase suggesting that at the upper values of leaf area index greenness may be saturating. Daughtry et al. (1982) also showed a similar relationship in their corn data, which suggests that greenness may not be directly related to leaf area index.

Pinter et al. (1981) found that an integrated approach using the normalized difference from heading until maturity of wheat was related to yield. They suggested that this integration would represent the duration of leaf area by a crop and thus directly transferable to yield.

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This approach was extended by Hatfield (1982) in which he used a thermal infrared measure of canopy temperature to evaluate the impact of stress on yield and a spectrally derived LAI at heading to determine the potential yield. Wiegand et al. (1979) showed how remotely derived leaf area indices could be used in evapotranspiration or crop yield models and suggested that these remotely obtained estimates would allow for the development of more regional crop models than presently exist.

Intercepted radiation by a canopy would be a desirable agronomic factor and this study was conducted to evaluate the role of spectral reflectance in the estimation of intercepted radiation.

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MATERIALS AND METHODS

Produra wheat (Triticum aestivum Desf. var. Produra) was grown at the U.S. Water Conservation Laboratory, Phoenix, Arizona during the 1978-79 and 1979-80 growing season. The treatments were five planting dates and typically four irrigation treatments within a planting date, Table 1. The plots were planted in north-south rows in an Avondale loam (a fine loamy, mixed (calcareous), hyperthermic Anthropic Torrifluvent).

Reflectance measurements were made over each plot on every non-rainy day with the sun at a normal elevation of 33°. These data were collected with a 4-band hand-held Exotech Model 100-A radiometer equipped with the four MSS bands. Data were collected with the radiometer held 2m above the soil surface. Each day was given a quality rating depending upon the cloud conditions, instrument operation, and general meteorological conditions, and only data of the highest quality were used in this study.

From the reflectance data greenness was calculated using the equation given by Rice et al. (1980) as:

$$\text{Greenness} = -0.4984\ MSS4 - 0.6125\ MSS5 + 0.1729\ MSS6 + 0.5854\ MSS7 \qquad [1]$$

where MSS4 is the reflectance in band 4 (0.5 - 0.6 μm), MSS5 the reflectance in band 5 (0.6-0.7 μm), MSS6 the reflectance in band 6 (0.7-0.8 μm), and MSS7 the reflectance in band 7 (0.8-1.1 μm). Normalized difference vegetation index was calculated as:

$$ND = \frac{MSS7 - MSS5}{MSS7 + MSS5} \qquad [2]$$

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The data for each day were adjusted to a constant sun angle of 39° before any transformations were made as suggested by Kauth et al. (1979).

Leaf area measurements were made periodically throughout the study with data collected in each treatment almost daily and no more than six days between measurements. In each treatment six plants were randomly selected and the green and brown leaf area determined. These data were then used to compute the leaf area index (LAI) for each treatment.

Intercepted photosynthetically active radiation (PAR) was calculated for each day as described by Hipps et al. (1982). Their relationship was only applicable to the description of interception until maximum LAI was achieved (heading). Additional data collected in the manner described by Hipps et al. (1982) were analyzed to determine the interception - LAI relationship over the (post-heading) period of wheat. These relationships are given in Figure 1 and were used to calculate the amount of PAR intercepted by the Produra canopy for each treatment in this study.

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RESULTS AND DISCUSSION

<u>Greenness - interception relationships</u>. Interception of photosynthetically active radiation by a canopy is dependent upon the age of the plant as shown in Fig. 1. When leaves are being added to the plant (growth) the interception relationship rises very rapidly while under senescence the interception declines very slowly and only returns to values above 50%. The final point when all the leaves are gone would be dependent on the amount of biomass standing on a unit area of soil. The temporal behavior of greenness for the well-watered plots of 1978-79 also exhibits patterns similar to the interception of PAR (Fig. 2), starting at a value of bare soil but only returning to a value much above the bare soil value. The relationship of greenness with LAI and intercepted PAR for one irrigation treatment is shown in Figure 3 and shows that although LAI continued to increase above 4, greenness maintained a stable value much in line with PAR interception. Greenness declined when PAR interception decreased at the end of the season (Fig. 3). With the apparent differences between the preheading and postheading portion of the season the regression models between intercepted PAR and greenness were also divided between the two growth stages.

The fit between intercepted PAR and greenness were very good for all planting dates except planting date 5 in 1978-79 (Table 2). This planting date had very low PAR interception values and the lack of fit is due to a very limited range of values and these data did not detract from the overall fit for this year. The standard errors for the slope of the regression models were small and there was no statistical

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difference between the combined models for each year. The regression models between intercepted PAR and greenness for the senescence portion of growth did not fit as well and the greatest difference is seen in the intercept values (Table 3). Overall, there was more variation between planting dates, however, the combined models over years were not different (Table 3). The reason for the lack of fit on planting dates 5 of 1978-79 and 1 of 1979-80 can be attributed to a lack of fit of the PAR interception relationship given in Fig. 1. These data shown in Fig. 1 do not represent biomass values as low as those encountered in these planting dates. Other relationships more representative of this range of data would improve the greenness-PAR interception relationship.

The greenness values from the linear model fit for the growth and senescence phases are given in Figs. 4 and 5, respectively. There was no bias along any of the points for either portion of the curve and these relationships show that greenness values calculated by Eq. 1 are related to PAR interception by a canopy.

Normalized difference - Interception relationships. Trajectories of the normalized difference throughout the 1978-79 for the well-watered irrigation treatments of each planting date revealed that the normalized difference also behaved similarly to PAR interception (Fig. 6). This was more evident when the well-watered treatment of planting date of 1978-79 was examined and showed the PAR interception and normalized difference to be very closely related (Fig. 7). The relationship between normalized difference and intercepted PAR very closely followed the relationship given in Fig. 1 as shown in Fig. 8 which suggests that the values of normalized difference

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might be directly related to interception. When the regression coefficients were computed for each of the planting dates and growth phases the R^2 values showed a general improvement over those found for greenness. From emergence to maximum leaf area index only planting date 5 of 1978-79 did not show an improvement (Table 4). This discrepancy could be explained by the very low LAI values in this late planting. There was no statistically significant difference between the years when the planting dates were combined (Table 4).

There was more difference between years and planting dates in the relationships between normalized difference and PAR interception for the postheading phase (Table 5). This can be attributed to a lack of a more exact function describing the PAR interception - LAI relationship. Although the normalized difference values are responding to PAR interception, the values of LAI placed into the model do not estimate the correct interception value under sparce canopies. These data are promising and show that research is needed on the postheading phase of growth to further refine these relationships.

Pinter et al. (1981) showed that the normalized difference could be integrated with time and related to the yield of wheat. They postulated that this would represent a measure of the leaf area duration, however, these data would suggest that an integration of the normalized difference would represent a measure of the ability of a canopy to intercept PAR and thus would be directly related to plant productivity. Daughtry et al. (1982) also showed that solar radiation interception by corn could be approximated by greenness and then they proposed how this could be integrated to arrive at final yield of the crop. It would appear that the normalized difference, which

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has no empirically derived coefficients, would be more applicable than greeness to the evaluation of intercepted PAR.

Evaluation of the Model. The model of normalized difference was used to estimate the interception measured on wheat by Hipps et al. (1982) and on soybean data extracted from Kollenkark et al. (1982). The data given by Hipps et al. were matched to spectral reflectance measurements made over the plots with MSS bands 5 and 7, and Thematic Mapper bands 3 and 4. In all cases the agreement was within 10%. The model would then appear to work for TM bands as well as MSS bands. However, these comparative data sets were collected only in the later stages of growth and the interception values were above 80%. We extracted MSS 5 and 7 data from published data by Kollenkark et al. (1982) and computed the normalized and the PAR interception. For their data on percent soil cover our model agreed within 10% for the range from 10 to over 90% soil cover.

When bare soil reflectance values from Manhattan, Kansas and Davis, California were placed in the model, the predicted interception was almost zero suggesting that the model as defined is not sensitive to different soil types. The model needs further evaluation on different soil types and cultural practices to fully test its sensitivity to these parameters.

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SUMMARY AND CONCLUSIONS

Calculated values of PAR interception and greenness or normalized difference were related throughout the growing season on wheat. Both of these spectral models were sensitive to PAR interception although two different relationships are required to represent preheading and postheading phases of the plant. The greenness and normalized difference both follow the PAR interception very closely and begin at the bare soil value but do not return to that value when the crop is mature. The value at maturity of either spectral model is a function of the canopy density or biomass at the end of the season. Pinter et al. (1981) related this behavior to the grain yield of wheat and the model presented in this paper suggests that the normalized difference would provide a direct measure of PAR interception and duration of this interception.

Improvements in the relationship of the spectral model with PAR interception were found with the normalized difference over greenness. This would suggest that normalized difference that has no empirical coefficients attached would be preferable over a calculation of greenness. It is also possible that Thematic Mapper bands could be utilized in this model without loss of sensitivity. This aspect would need further evaluation over different crops and locations throughout a growing season. PAR interception, however, can be estimated reliably and accurately with remotely sensed data.

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LITERATURE CITED

Biscoe, P.V., Gallagher, J.N., Littlejon, E.J., Monteith, J.L., and Scott, R.K. (1975), Barley and its environment. IV. Sources of assimilate for the grain. J. Appl. Ecol. 12: 295-318.

Daughtry, C.S.T., Gallo, K.P., and Bauer, M.E. (1982), Spectral estimates of solar radiation intercepted by corn canopies. Agristars Technical Report. SR-P2-04236. 14 p.

Hatfield, J.L. (1982), Remote sensing estimators of potential and actual crop yield. Remote Sensing Environ. (In press).

Hipps, L.E., Asrar, G., and Kanemasu, E.T. (1982), Assessing the interception of photosynthetically active radiation in winter wheat. Agristars Technical Report SR-M2-04270. 16 p.

Hodges, T. and Kanemasu, E.T., (1977), Modeling daily dry matter production of winter wheat. Agron. J. 69: 974-978.

Kauth, R., Lambeck, P., Richardson, W., Thomas G., and Pentland, A. (1979), Feature extraction applied to agricultural crops as seen by Landsat. LACIE Symposium, pp. 705-721.

Kollenkark, J.C., Daughtry, C.S.T., Bauer, M.E., and Housley, T.L., (1982), Effects of cultural practices on agronomic and reflectance characteristics of soybean canopies. Agron. J. 74: 751-758.

Pinter, P.J. Jr., Jackson, R.D., Idso, S.B., and Reginato, R.J. (1981), Multidate spectral reflectance as predictors of yield in water stressed wheat and barley. Int. J. Remote Sensing. 2: 43-48.

Rice, D.P., Crist, E.P., and Malila, W.A. (1980), Application of selected wheat remote sensing technology to corn and soybeans. Final Report NAS 9-15082. ERIM 32 p.

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OF POOR QUALITY

Wiegand, C.L., Richardson, A.J., and Kanemasu, E.T. (1979), Leaf area index estimates for wheat from LANDSAT and their implications for evapotranspiration and crop modeling. Agron. J. 71: 336-342.

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ACKNOWLEDGEMENTS

We sincerely appreciate the unselfish use of the data set from the U.S. Water Conservation Laboratory, Phoenix, Arizona, and specifically thank Drs. R.D. Jackson, R.J. Reginato, P.J. Pinter, Jr., and S.B. Idso.

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Table 1. Irrigation and planting dates for the 1978-79 and 1979-80 experiment on Produra wheat at Phoenix, Arizona.

Treatment	Planting date	Irrigation dates (Julian date)	Treatment	Planting date	Irrigation dates (Julian date)
1A	31 Oct 1978	307, 094	1A	28 Sept 1979	271, 278, 289, 334
1B	31 Oct 1978	307	1B	28 Sept 1979	271, 278, 290, 313, 345
1C	31 Oct 1978	307, 047	1C	28 Sept 1979	272, 278, 290, 324
1D	31 Oct 1979	307, 047, 074, 106			
2A	13 Dec 1978	349	2A	22 Oct 1979	295, 302, 334
2B	13 Dec 1978	349, 095	2B	22 Oct 1979	296, 302, 324
2C	13 Dec 1978	349, 075, 109	2C	22 Oct 1979	296, 302, 317, 345
2D	13 Dec 1978	349, 047, 094, 106, 124			
3A	13 Feb 1979	047, 095, 128	3A	14 Nov 1979	319, 351
3B	13 Feb 1979	047, 075, 103, 120, 134	3B	14 Nov 1979	319, 079
3C	13 Feb 1979	047, 096	3C	14 Nov 1979	320, 351
3D	13 Feb 1979	047			
4A	15 Mar 1979	078, 107, 129	4A	18 Dec 1979	353
4B	15 Mar 1979	079, 096, 110, 129, 149	4B	18 Dec 1979	353, 079, 099
4C	15 Mar 1979	079, 107, 130	4C	18 Dec 1979	354, 098
4D	15 Mar 1979	078, 103, 113, 135	4D	18 Dec 1979	354, 091
5A	01 May 1979	123, 127, 131, 135, 150, 162, 176	5A	06 Feb 1980	039, 100
5B	01 May 1979	123, 127, 131, 135, 146, 157, 166, 173, 179, 186, 193	5B	06 Feb 1980	039, 079, 106, 123, 134
5C	01 May 1979	124, 128, 131, 135, 146, 159, 173, 184	5C	06 Feb 1980	039, 093, 114
5D	01 May 1979	124, 128, 131, 135, 149, 162, 176, 191	5D	06 Feb 1980	039, 098, 119

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Table 2. Regression coefficients for the linear model of greenness and PAR interception from planting until maximum leaf area index for the 1978-79 and 1979-80 planting dates of Produra wheat at Phoenix.

Year	Planting date	n	R^2	Intercept	b	s.e. b
78-79	1.	116	.975	-2.537	2.172	0.033
	2.	80	.954	-1.160	2.339	0.058
	3.	64	.961	-2.873	2.584	0.066
	4.	30	.833	-1.428	2.221	0.187
	5.	32	.468	-0.023	1.588	0.309
	Combined	322	.959	-1.462	2.241	0.026
79-80	1.	63	.810	-3.987	3.035	0.188
	2.	69	.942	-1.441	2.132	0.064
	3.	45	.963	-3.270	2.079	0.062
	4.	28	.983	1.546	1.912	0.049
	5.	24	.988	-0.360	2.104	0.048
	Combined	229	.885	3.025	2.063	0.049

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Table 3. Regression coefficients for the linear model of greenness and PAR interception from maximum leaf area index until maturity for the 1978-79 and 1979-80 planting dates of Produra wheat at Phoenix.

	Planting date	n	R^2	Intercept	b	s.e. b
1978-79	1.	76	.879	67.406	0.615	0.026
	2.	60	.926	65.054	0.770	0.028
	3.	48	.890	68.861	0.672	0.035
	4.	42	.764	70.400	0.617	0.054
	5.	64	.410	75.214	0.214	0.033
	Combined	290	.853	71.551	0.525	0.013
1979-80	1.	21	.330	78.268	0.364	0.119
	2.	21	.963	65.049	0.741	0.033
	3.	24	.900	66.871	0.578	0.041
	4.	32	.827	66.774	0.625	0.052
	5.	40	.922	65.823	0.658	0.031
	Combined	138	.800	67.927	0.610	0.026

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Table 4. Regression coefficients for the linear model of the normalized difference and PAR interception from emergence until maximum leaf area index for the 1978-79 and 1979-80 planting dates of Produra wheat at Phoenix.

Year	Planting date	n	R^2	Intercept	b	s.e. b
1978-79	1.	116	.985	-23.565	127.414	1.490
	2.	80	.980	-17.986	117.634	1.883
	3.	64	.949	-17.403	121.516	3.589
	4.	30	.871	-13.472	105.562	7.663
	5.	32	.291	- 6.878	68.097	19.417
	Combined	322	.974	-18.398	120.032	1.109
1979-80	1.	63	.867	-14.062	122.300	6.141
	2.	69	.958	-20.429	121.103	3.116
	3.	45	.985	-19.944	120.345	2.271
	4.	28	.994	-33.006	136.853	2.092
	5.	24	.981	-27.864	127.310	3.760
	Combined	229	.947	-19.739	122.353	1.917

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Table 5. Regression coefficients for the linear model of the normalized difference and PAR interception from maximum leaf area index until maturity for the 1978-79 and 1979-80 planting dates of Produra wheat at Phoenix.

Year	Planting date	n	R^2	Intercept	b	s.e. b
1978-79	1.	76	.935	59.774	36.445	1.118
	2.	60	.961	61.236	34.332	0.908
	3.	48	.905	67.021	28.421	1.357
	4.	42	.821	68.687	24.998	1.847
	5.	64	.388	74.247	9.738	1.552
	Combined	290	.869	68.414	25.707	0.587
	1.	21	.873	60.937	36.381	3.185
	2.	21	.971	60.347	36.047	1.437
	3.	24	.919	59.585	35.961	2.273
	4.	32	.887	59.288	37.528	2.439
	5.	40	.949	58.830	36.946	1.394
	Combined	138	.925	59.499	36.890	0.898

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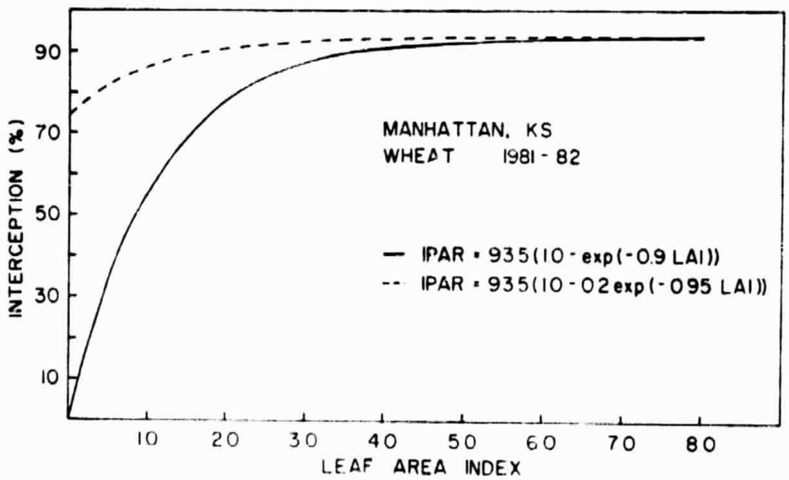

Figure 1. Interception of photosynthetically active radiation for preheading phase (——) and postheading phase (----) of wheat as a function of leaf area index. Derived from Hipps et al. (1982).

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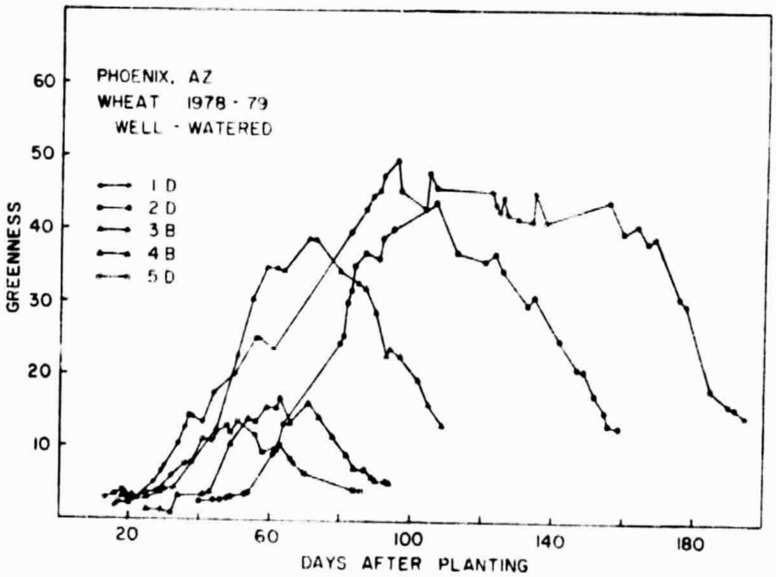

Figure 2. Temporal behavior of greenness for the well-watered plots of Produra wheat grown in 1978-79 planting dates in Phoenix.

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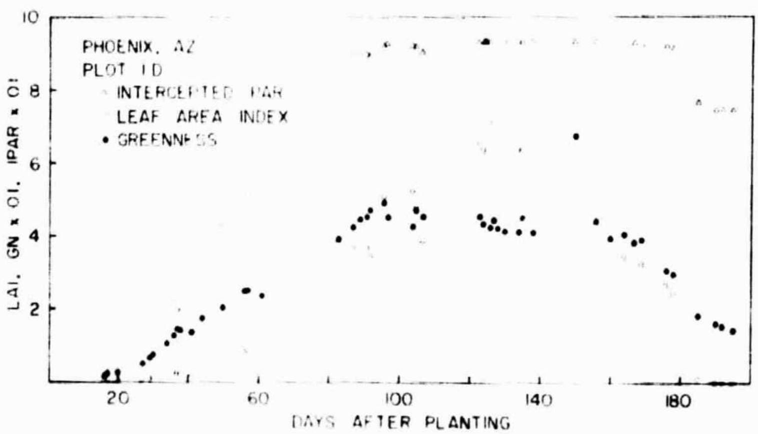

Figure 3. Intercepted PAR, leaf area index, and greenness for the October 31, 1978 planting date of Produra wheat maintained in a well-watered condition.

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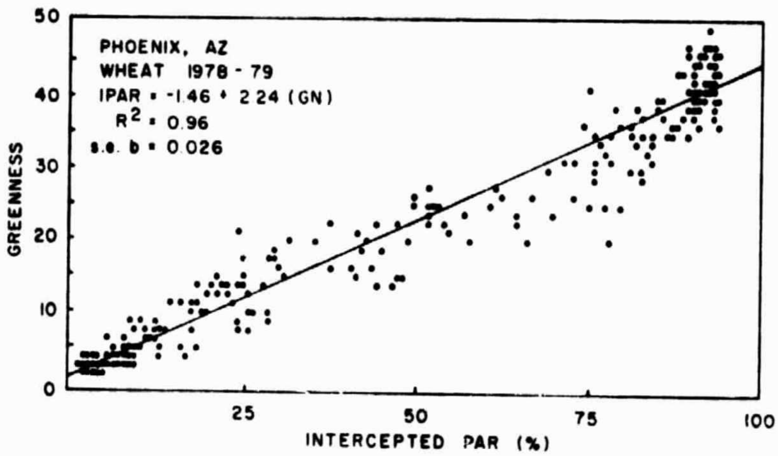

Figure 4. Linear fit between intercepted PAR and greenness for the preheading phase of Produra wheat 1978-79.

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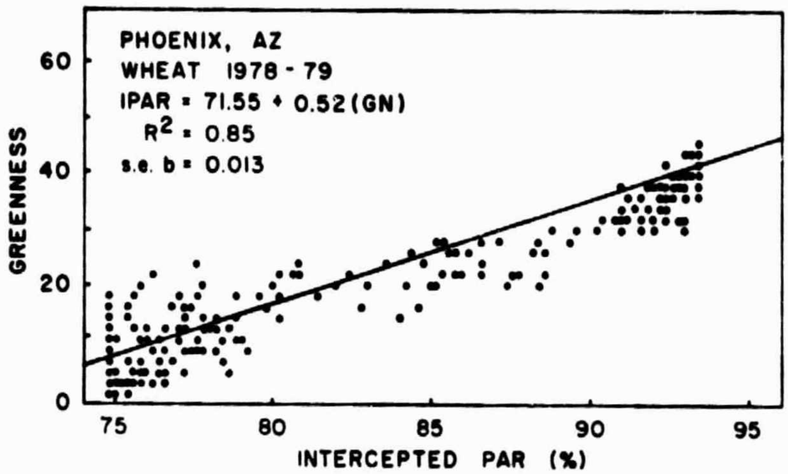

Figure 5. Linear fit between intercepted PAR and greenness for the senescence phase (postheading) of Produra wheat 1978-79.

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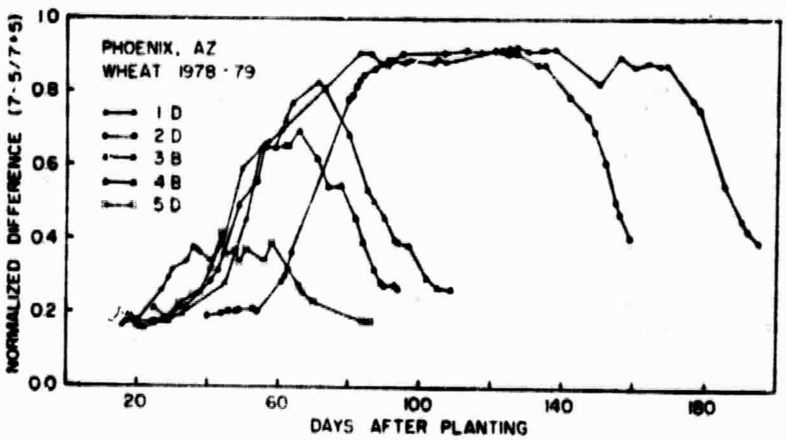

Figure 6. Temporal behavior of normalized difference for the well-watered plots of the 1978-79 planting dates of Produra wheat in Phoenix.

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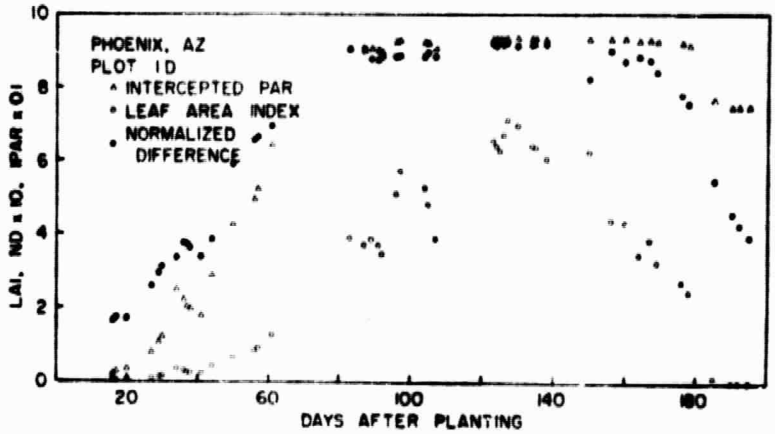

Figure 7. Intercepted PAR, leaf area index, and normalized differences for the October 31, 1978 planting date of Produra wheat maintained in a well-watered condition.

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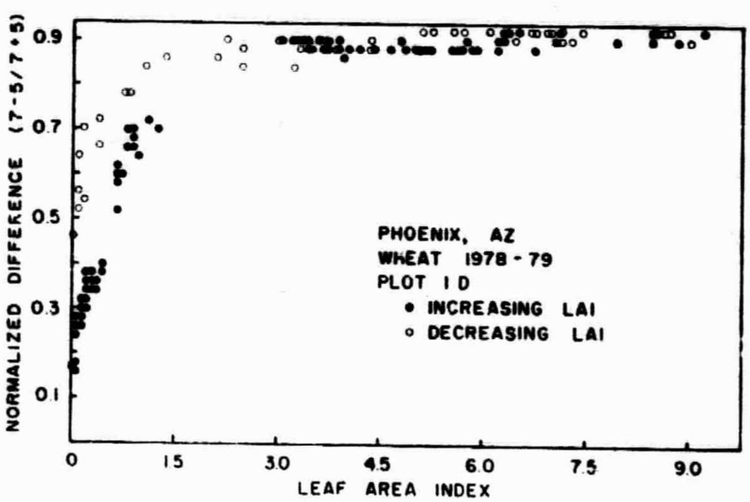

Figure 8. Normalized difference as a function of leaf area index for the 1978-79 Produra wheat treatment 1D.