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ESTIMATION OF GROWTH STAGES OF WHEAT FROM SPECTRAL DATA

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ABSTRACT

Growth stages of wheat subjected to different fertilizer treatments and sown on different dates have been estimated using spectral data. Greenness profiles were generated for different wheat plots. The profile parameters have been used to calculate growth stages at various times in the growing season. The model proposed by Badhwar (1981) has been used for this purpose. Results show that the model is capable of predicting growth stages accurately. There is a high correlation (r=0.97) between the observed and the predicted growth stages of wheat grown under various treatments.

INTRODUCTION

Estimation of growth stage of a crop is very useful in crop identification, crop yield modelling and crop condition assessment. Weather at different growth stages of the crop influences final yield differently. Hence, knowledge of the growth stage of the crop at the time of data acquisition is necessary. Moreover, many studies in the past (Tucker et al., 1980, Aase et al, 1981, Dubey et al, 1985) have shown that spectral data at a particular growth stage is highly correlated to its yield.

Normal crop calenders based on observations of many years do not take into account the wide fluctuations in weather which occur from one year to another. Agrometeorological models which compute the photothermal units required by a crop to proceed from one stage to another, require an extensive network of weather stations and they require daily meteorological data which become voluminous and tedious to handle.

Badhwar (1981) has suggested a new approach, that of estimating development stage of a crop from spectral data. This spectral approach has the advantage of integrating the effects of soil type, cultural factors, nutrient supply etc. on the crop growth and condition. These models can be easily extended to other geographical areas and can be applied to individual fields also.

In this study, results of an attempt made to determine growth stages of wheat using the model proposed by Badhwar (1981, 1984) are described.

THEORY AND MODEL USED

Kauth and Thomas (1976) carried out a tasselled - cap transformation of four-dimensional Landsat MSS vector space and defined the new vector space by 'Brightness;. 'Greenness'; 'Yellowness' and 'Non-Such'. Of these, the first two vectors namely the brightness and greenness contain most of the information of the original data. Brightness represents the soil vector and greenness which is orthogonal to it is a good measure of green vegetation.

Multidate greenness values have been used to develop a model for development stages. Prior to emergence of seedling and even for some days after physical emergence, greenness values correspond to soil background (soil greeness). Greenness starts rising above its soil value after the first leaf growth and this point in the profile is called spectral emergence date. In the early growing season crop canopy cover is sparse resulting in low values of greenness. As the season progresses, greeness rises, reaches

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a peak value and then declines during senescence period (fig. 1). This behaviour of greenness can be described by the mathematical form

where ρ (t) is greeness at any time t in the growing cycle of the crop $\rho_s(t_o)$ is the soil greenness at and before crop emergence data t_o and α and β are crop and condition specific constants.

$$\rho(t) = \rho_s(t_o)\left(\frac{t}{t_o}\right)^{\alpha} \exp[\beta(t_o^2 - t^2)] \ldots\ldots 1$$

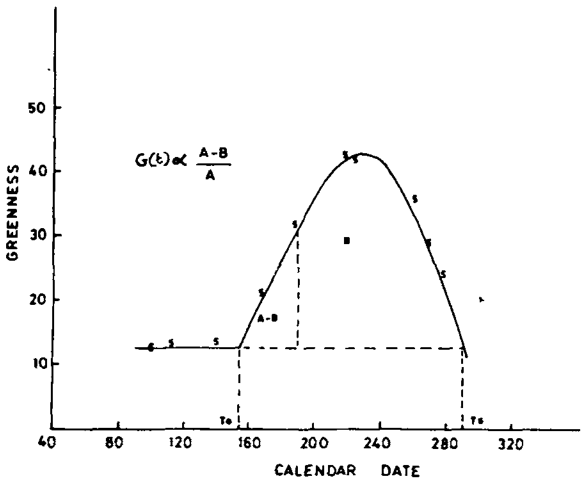

Fig. 1 A typical greeness profile of a crop
(Source: Badhwar 1981)

Badhwar suggested that the fractional area under this curve from t_o to t is linearly related to the crop development stage at time t. i.e.

$$G(t) \propto (A\text{-}B)/A$$

where A is the total area under the curve and B is the area under the curve from time t to t_s, the senescence date, when the profile returns to near soil value. This model has been used to predict the development stages of wheat.

Stages of development for cereals have been defined by Feekes, Large, Robertson and others (Large et al, 1954, Robertson, 1968). Robertson's developmental scale for spring wheat was used in Large Area Crop Inventory Experiment (LACIE) (Seeley et al, 1978). This scale has been adapted for use in this study (Table 1). Taking the emergence stage as 2.0 and the maturity as 6.0, proportionality constants are obtained and development stage is then given as:

$$G(t) = 6 - 4.B/A$$

$$= 6 - 4\left[\left(\frac{\alpha+1}{2}, \beta t^2\right) / \left(\frac{\alpha+1}{2}, \beta t_o^2\right)\right] \ldots 2$$

where (α,β) is the incomplete Gamma function (Abramowitz and Stegen, 1965). This model has been tested for different dates of sowing and different fertilizer treatments.

Table 1: Scale of wheat growth stages

Stages description	Stage No.
Planting	1.0
Emergence	2.0
2-5 leaves	2.3
Early tillering	2.5
Full tillering	2.8
First node of stem visible	3.0
Second node visible	3.2
Last leaf visible	3.4
Early-mid boot	3.6
Mid-late boot	3.8
Early heading	4.0
Heading complete	4.2
Flowering	4.4
Kernels formed, watery	4.6
Milking	4.8
Soft dough	5.0
Mid dough	5.5
Hard dough	5.8
Ripending	6.0

EXPERIMENTAL DETAILS

The experiment was carried out at Gujarat Agricultural Univesity Campus, Anand in the Rabi season of 1985-86 for wheat. Two agronomic treatments were considered in this experiment. They were :

i) Five dates of sowing (October 15, November 1, November 15, December 1, December 15, 1985).
ii) Six fertilizer treatments (varying amounts of N, P starting from zero fertilizer).

Each of the plot had two replicates and the plots were laid in a randomised complete block design.

Radiometric observations were taken weekly over all these plots with a seven-band handheld radiometer. Four of the bands are in visible region of the spectrum and three in the near infrared region. Irradiance measurements were taken using a barium sulphate coated plate. Development stages of wheat were also noted down concurrently with the spectral observations. Measurements of leaf-area index, green biomass and dry biomass at different stages for all plots and final grain yield of each plot were also carried out. Radiometric measurements were also carried out for different soil conditions like dry soil, wet soil, ploughed soil, unploughed soil etc. in the beginning of the experiment.

DATA ANALYSIS

Spectral radiance measurements obtained over each plot were converted to reflectance values and then converted to greenness using the following equation given by Rice et al. (1980).

$$\text{Greenness} = -0.4894\ \text{MSS4} - 0.6125\ \text{MSS5} + 0.1729\ \text{MSS6} + 0.5854\ \text{MSS7}.$$

Greenness was computed for different values of 't' in the growing season for each plot. For calculation of greenness, average of reflectance measured in the two replicates of a plot was used. These greenness values were fitted to equation 1 and the parameters α, β and t_0 were estimated. Growth stage at any point t was then estimated using equation 2. Observed growth stages were converted in the form of numbers according to the scale given in Table 1. Linear regression analysis was carried out between the observed and the estimated growth stages.

RESULTS AND DISCUSSIONS

The greenness profile parameters α, β and t_0 for different plots are given in Table 2. Figures 2 and 3 show the greeness profiles of some of the plots. It is clear that α is a growth related parameter and β is the decay parameter. The spectral emergence date t_0 varies from 8 days after sowing to 19 days after sowing. Normally one would expect the emergence date to be independent of the treatment condition of the plots but there is a variation as observed here. This is due to different weather and soil conditions encountered by the plant during germination phase. High correlation co-efficient obtained in all the cases suggests that the non linear form of the model taken for fitting the data is an appropriate one.

Growth stages predicted at five different times for each plot are given in Table 3 and Table 4 for different dates of sowing experiment and fertilizer experiment respectively. The difference between the observed and the predicted stages is less than 0.6 stage in all cases except for Early Heading (4.0) stage of D4 where the difference is high. Considering the fact that the ground observations of growth stages were carried out at the interval of 8-10 days (0.5 stage) the difference of 0.6 seen here can be considered within experimental error.

Predicted growth stage showed a good correlation to observed growth stage for each plot (Table 5). The slope and the intercept for each plot except D1 was not significantly different from one and zero respectively. The early sown plot D1 had slope different than one. All the data of fertilizer experiment and different planting dates when combined showed a high correlation between observed and prdicted growth statges. (Fig. 4). The slope and the intercept of this line are not significantly different from one and zero respectively indicating the applicability of this model in various conditions of sowing dates and

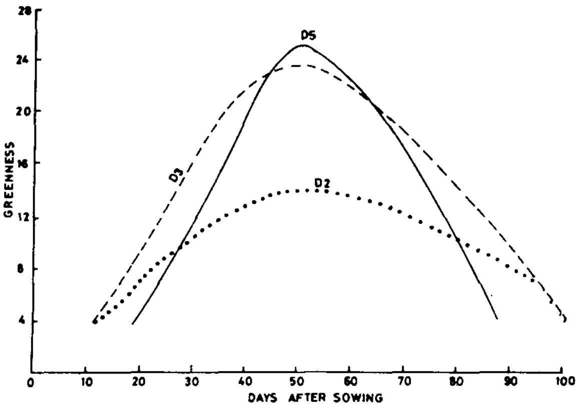

Fig.2. Greenness profiles for different dates of sowing treatment

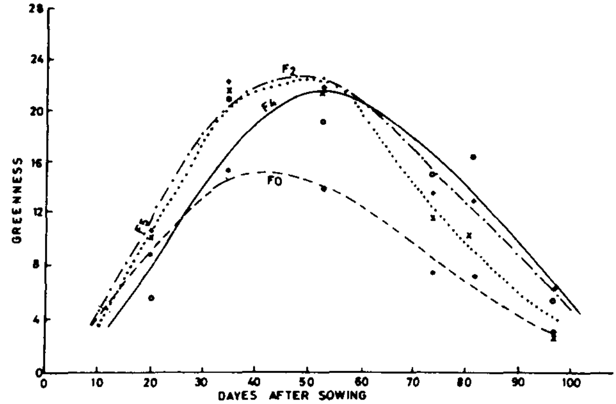

Fig.3. Greenness profiles for different fertilizer treatment

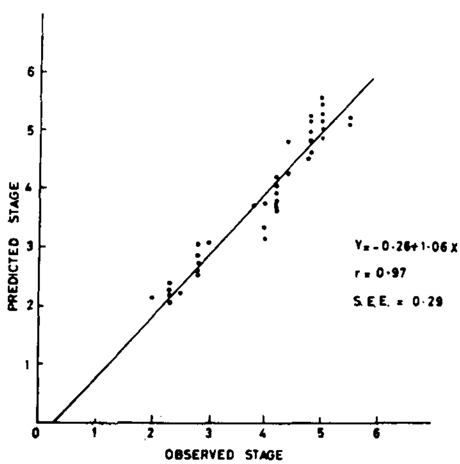

Fig.5. Mean predicted stage vs observed stage

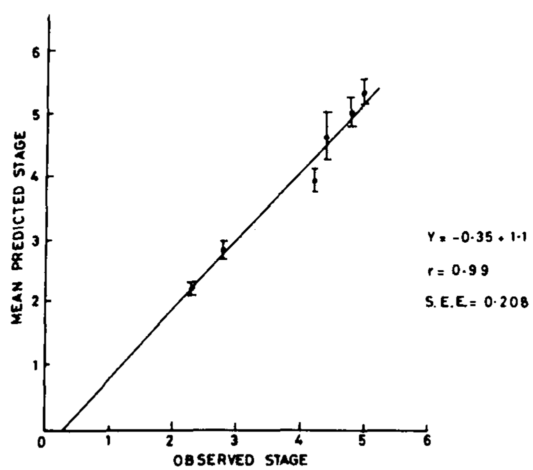

Fig.4. Predicted growth stage vs observed growth stage for all plots

Table 2: Parameters obtained by non-linear fitting of greenness

Plot	α	β	t_o	r
F0	1.31	0.00036	8	0.99
F1	1.97	0.00045	10	0.99
F2	1.77	0.00041	10	0.98
F3	1.68	0.00032	9	0.88
F4	1.87	0.00034	12	0.84
F5	1.52	0.00033	8	0.97
D1	1.25	0.00017	17	0.96
D2	1.30	0.00024	11	0.95
D3	1.86	0.00036	11	0.95
D4	1.90	0.00023	15	0.94
D5	3.42	0.00063	19	0.99

Table 3: Predicted growth stages for plots sown on different dates

Plot	Obs. stage	Pred. stage	Difference
D1	2.3	2.34	0.04
	3.0	3.11	0.11
	4.2	3.79	-0.41
	4.8	4.56	-0.24
	5.5	5.15	-0.35
D2	2.5	2.20	-0.30
	2.8	2.67	-0.13
	4.0	3.41	-0.59
	4.4	4.33	-0.07
	5.0	5.08	0.08
D3	2.0	2.14	0.14
	2.8	2.73	-0.07
	4.0	3.82	-0.18
	4.8	4.86	0.06
	5.5	5.32	-0.18
D4	2.8	2.55	-0.25
	4.0	3.21	-0.79
	4.2	3.77	-0.43
	4.8	4.63	-0.17
	5.0	4.93	-0.07
D5	2.3	2.06	-0.24
	2.8	2.88	0.08
	3.8	3.75	-0.05
	4.4	4.89	0.49
	5.0	5.27	0.27

Table 4: Predicted growth stages for different fertiliser treatment plot

Plot	Obs. stage	Pred. stage	Difference
F0	2.3	2.32	0.02
	2.8	3.11	0.31
	4.2	4.26	0.06
	4.8	5.29	0.49
	5.0	5.57	0.57
F1	2.3	2.18	-0.12
	2.8	2.89	0.09
	4.2		-0.08
	4.8	5.3	0.50
	5.0	5.57	0.57
F2	2.3	2.20	-0.10
	2.8	2.92	0.12
	4.2	4.12	-0.08
	4.8	5.27	0.47
	5.0	5.55	0.55
F3	2.3	2.17	-0.13
	2.8	2.75	-0.05
	4.2	3.77	-0.43
	4.8	4.91	0.11
	5.0	5.10	0.10
F4	2.3	2.13	-0.17
	2.8	2.67	-0.13
	4.2	3.71	-0.49
	4.8	4.89	0.09
	5.0	5.23	0.23
F5	2.3	2.21	-0.09
	2.8	2.88	0.08
	4.2	3.95	-0.07
	4.8	5.05	0.25
	5.0	5.35	0.35

Table 5: Correlation coefficients between observed and calculated growth stages

Plot	Intercept	Slope	R	S.E.E.
D1	0.42	0.85	0.99	0.15
D2	-0.53	1.09	0.98	0.275
D3	0.17	0.94	0.99	0.137
D4	-0.69	1.07	0.95	0.352
D5	-0.61	1.19	0.99	0.206
F0	-0.25	1.14	0.99	0.206
F1	-0.61	1.21	0.99	0.234
F2	-0.53	1.19	0.99	0.231
F3	-0.28	1.05	0.99	0.243
F4	-0.46	1.10	0.98	0.288
F5	-0.33	1.10	0.99	0.241
Combined data	-0.26	1.07	0.97	0.294

Table 6: Accuracy of prediction of different stages

Stages	Obs. stage	Mean	S.D.	Error
Early Tillering	2.3	2.20	0.09	-0.10
Tillering	2.8	2.82	0.15	0.02
Heading	4.2	3.91	0.21	-0.29
Flowering	4.4	4.61	0.39	0.21
Milking	4.8	4.97	0.28	0.17

fertilizer amounts.

The real test of this model lies in its ability to predict a particular stage accurately. Statistics of the predicted growth stages showed that the mean predicted stage compared well with the observed stage (Table 6). Percent coefficient of variation is highest for the flowering stage suggesting large variation in the individual values of predicted stages and consequently would mean that flowering stage prediction maynot be very accurate always. The correlation coefficient between the observed stage and mean predicted stage was found to be very high (Fig. 5). The slope of the fitted line was not significantly different from one but the intercept showed some bias in the observations. This bias can probably be removed by taking large number of observations for each point and then calculating the mean stage.

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REFERENCES

Abramovitz, M. and I.A. Stegen, 1965. Handbook of mathematical functions. Dover Publications, Inc., New York.

Aase, J.K. and Siddoway, F.H. 1981. Assessing winter wheat dry matter production via spectral reflectance measurements. Rem. Sens. Environ. 11:267-277.

Badhwar, G.D., Henderson, K.E. 1981. Estimating development stages of corn from spectral data - An initial model. Agronomy Journal, Vol. 73, July - Aug. 1981, pp. 748-755.

Dubey, R.P. Sharma Tara, Garg, J.K., Mallick, K.D. and Patel, J.R. 1985. Relationship of wheat yield with spectral and agrometeorological data. Proc. Sixth Asian Conf. on Rem. Sens., Hyderabad, Nov. 21 - 26, pp. 406 - 411.

Henderson, K.E. and Badhwar, G.D., 1984. An initial model for estimating soyabean development stages from spectral data. Rem. Sens. Environ. 14:55-63.

Kauth, R.J. and Thomas, G.S., 1976. The tasselled cap graphic description of the spectral - temporal development of agricultural crops as seen by Landsat. Proc. Symp. on Machine Processing of Remote Sensing data, pp. 46-41-51.

Large, E.C., 1954. Growth stages in cereals - Illustrations of the Feekes scale. Plant Path., vol. 3, pp. 128-129.

Rice, D.P., Crist, E.P. and Malila, W.A., 1980. Applicability of selected wheat remote sensing technology to corn and soyabeans, Final Report, Contract NAS9-15082, ERIM, Ann Arber, M.I.

Robertson, G.W., 1968. A biometeorological time scale for a cereal crop involving day and night temperatures and photoperiod. Int. J. Biometeorol. vol. 12, pp 191-223.

Tucker, C.J., Holben, B.N., Eligin, J.H. and McMurtrey, J.E., 1980. Relationship of spectral data to grain yie"d variations. Photogram. Engg. Rem. Sens. 46, 5, pp. 657 - 666.