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PRELIMINARY EVALUATION OF THE ENVIRONMENTAL RESEARCH INSTITUTE OF MICHIGAN CROP CALENDAR SHIFT ALGORITHM FOR ESTIMATION OF SPRING WHEAT DEVELOPMENT STAGE

D. E. Phinney

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16. Abstract

An algorithm for estimating spectral crop calendar shifts of spring small grains was applied to 1978 spring wheat fields. The algorithm, developed by the Environmental Research Institute of Michigan, provides estimates of the date of peak spectral response by maximizing the cross-correlation between a reference profile and the observed multitemporal pattern of Kauth-Thomas greenness for a field. A methodology was developed for estimation of crop development stage from the date of peak spectral response.

Evaluation studies showed that the algorithm provided stable estimates with no geographical bias. Crop development stage estimates had a root mean square error near 10 days. The algorithm was recommended for comparative testing against other models which are candidates for use in AgRISTARS experiments.

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PRELIMINARY EVALUATION OF THE ENVIRONMENTAL RESEARCH INSTITUTE OF MICHIGAN CROP CALENDAR SHIFT ALGORITHM FOR ESTIMATION OF SPRING WHEAT DEVELOPMENT STAGE

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This report presents Crop Stage Estimation/Crop Calendar Activities of the Supporting Research project of the AgRISTARS program.

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ACRONYMS AND ABBREVIATIONS

ACQDAY	acquisition date of the field ground truth
AgRISTARS	Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing
AID	U.S. Agency for International Development
C/P	Conservation and Pollution
DC/LC	Domestic Crops and Land Cover
ERIM	Environmental Research Institute of Michigan
EW/CCA	Early Warning/Crop Condition Assessment
FCPF	Foreign Commodity Production Forecasting
Landsat	land observatory satellite
NASA	National Aeronautics and Space Administration
PKDAY	date of peak spectral response for the field
RMSE	root mean square error
RRI	Renewable Resources Inventory
SM	Soil Moisture
SR	Supporting Research
USDA	U.S. Department of Agriculture
USDC	U.S. Department of Commerce
USDI	U.S. Department of Interior
YMD	Yield Model Development

1. INTRODUCTION

The Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) is a 6-year program of research, development, evaluation, and application of aerospace remote sensing for monitoring agricultural resources beginning in fiscal year (FY) 1980. The AgRISTARS program is a cooperative effort of the National Aeronautics and Space Administration (NASA), the U.S. Agency for International Development (AID), and the U.S. Departments of Agriculture, Commerce, and the Interior (USDA, USDC, and USDI).

The goal of the program is to determine the usefulness, cost, and extent to which aerospace remote sensing data can be integrated into existing or future USDA systems to improve the objectivity, reliability, timeliness, and adequacy of information required to carry out USDA missions. The overall approach comprises a balanced program of remote sensing research, development, and testing which involves domestic resource management as well as commodity production information needs.

The technical program is structured into eight major projects as follows:

1. Early Warning/Crop Condition Assessment (EW/CCA)
2. Foreign Commodity Production Forecasting (FCPF)
3. Yield Model Development (YMD)
4. Supporting Research (SR)
5. Soil Moisture (SM)
6. Domestic Crops and Land Cover (DC/LC)
7. Renewable Resources Inventory (RRI)
8. Conservation and Pollution (C/P)

The majority of these projects will make direct use of information on crop phenology. Phenological information will be pertinent to these several areas of the projects including classification, acreage and yield estimation, and detection of episodal events.

Recent research at a number of locations has been directed toward developing techniques for correcting variations in Landsat spectral signals caused by local differences in growth stages. The general technique consists of fitting an exponential equation to multitemporal spectral data. One result of such fits is an estimate of the date on which the maximum spectral response would have been observed if there had been daily spectral observations.

The original algorithms of this type were developed by Badhwar (1979, ref. 1). Work conducted at the Environmental Research Institute of Michigan (ERIM) by Cicone et al. (1979, ref. 2) resulted in the use of a different functional form for the fitted equation. For crop stage estimation, a simplified algorithm was developed.

This paper presents the results of a preliminary study of the characteristics of the ERIM algorithm. A methodology for using the calculated date of peak response to estimate growth stage was used to evaluate the algorithm and to provide a comparison with the Badhwar approach.

2. BACKGROUND

The ERIM crop calendar shift algorithm operates on the greenness component of the Kauth-Thomas transformation (Kauth et al., 1976, ref. 3). The day of peak response is determined by examining the cross-correlation between the observed values and the corresponding values of a reference profile. The program requires that three spectral acquisitions separated by at least 15 days in the emergence to preharvest period be available. The existing algorithm checks for these conditions and does not require manual selection of acquisitions. The data should be preprocessed to remove the effects of satellite calibration, Sun angle, and atmospheric haze. ERIM recommends the use of its spatially varying XSTAR algorithm and associated correction factors for preprocessing.

The basic algorithm was provided in the form of a Fortran subroutine (Horvath, 1980, ref. 4). Complete documentation of the program along with a user's guide and a series of test cases for program verification is given by Crist and Malila (1980, ref. 5).

For this study, a data set was constructed using spectral data collected over spring wheat test sites during the 1978 crop year in the U.S. northern Great Plains. Periodic ground-truth observations were available for selected fields on actual growth stages. Table 1 shows a summary of the data set. From 1 to 13 fields were available in each of 22 locations. A total of 681 growth stage observations were available. This data set was used previously (Cate et al., 1980, ref. 6) to evaluate the Badhwar crop calendar shift algorithm. Manual quality assurance had already been performed on the data. As a result, the only preprocessing employed in this evaluation was satellite calibration and Sun-angle correction.

3. ESTIMATION OF PEAK SPECTRAL RESPONSE DATE

The ERIM algorithm provides estimates of the date of peak spectral response. The program provides the value of the cross-correlation coefficient for those fields which have satisfactory acquisition histories. Table 2 summarizes the results of initial model runs. Estimates were made for approximately 65 percent of the fields in the original data set. The number of fields, number of Landsat acquisitions, and the average and range of observed R^2 values for the cross-correlation associated with the estimated peak response date are shown. Most fields had R^2 values in excess of 0.9, indicating that the profile fits were of a high quality. No geographical pattern was found in the distribution of the goodness of fit as measured by the R^2 values.

4. ESTIMATION OF DEVELOPMENT STAGE

Since the basic algorithm only provides estimates of the date of peak spectral response, an attempt was made to develop a technique for the estimation of individual growth stages. The ground-truth observations were taken on the

TABLE 1.- SUMMARY OF DATA FOR EVALUATION OF THE ERIM CROP CALENDAR SHIFT ALGORITHM

Segment	State	Number of fields
1392	N. Dak.	6
1394	N. Dak.	4
1457	N. Dak.	5
1461	N. Dak.	11
1473	N. Dak.	4
1518	Mont.	11
1537	Mont.	2
1542	Mont.	6
1544	Mont	4
1553	Mont.	3
1566	Minn.	6
1584	N. Dak.	4
1612	N. Dak.	5
1619	N. Dak.	8
1636	N. Dak.	9
1664	N. Dak.	1
1668	S. Dak.	6
1811	S. Dak.	12
1825	Minn.	13
1918	N. Dak.	2
1920	N. Dak.	7
1924	N. Dak.	3

TABLE 2.- SUMMARY OF MODEL PERFORMANCES BY FIELD

Segment	Number of fields	Number of acquisitions	Cross-correlation, R^2	
			Average	Range
1392	5	3	0.944	0.873-0.995
1394	4	4-5	.978	.974- .984
1457	5	3-4	.982	.938- .999
1461	11	5-6	.935	.916- .963
1518	11	4	.858	.599- .990
1537	1	5	.970	.970
1542	6	3-5	.932	.824- .984
1544	2	4	.863	.752- .973
1553	2	5	.798	.753- .842
1566	2	3	.748	.649- .846
1584	4	3	.986	.980- .990
1636	5	3-5	.940	.870- .980
1668	2	3	.992	.992
1811	10	3-4	.911	.757- .980
1825	13	4	.979	.932- .998
1920	5	3-4	.919	.894- .944
1924	2	5	.967	.948- .985

Feekes scale (Large, 1941, ref. 7). In previous work, Cate et al. (1980, ref. 6) developed a relationship between the Feekes scale and the percent of the normal growing season which had elapsed at each stage. Table 3 gives a recent revision of this relationship (Hodges, 1980, ref. 8). This table provides a vehicle for transforming the Feekes observations into a quantity which is linear in time. The table shows the percent of the plant growth which had elapsed at the midpoint of each Feekes stage as well as the stage duration.

The estimate of day of peak greenness was calculated for each available field. A regression between the ground-truth stage in percent and the days from date of peak greenness was run for the entire data set. A similar analysis was carried out using peak date estimates obtained from the Badhwar algorithm. Table 4 gives the regression results. Plots for each algorithm are shown in figures 1 and 2.

The estimated growth stage for a given field on a particular acquisition was calculated using the following equation.

$$\text{Stage } (\%) = a_0 + a_1 (\text{PKDAY} - \text{ACQDAY})$$

where

Stage (%) = percent of the growing season

a_0, a_1 = intercept and slope, respectively, of the regression

PKDAY = date of peak spectral response for the field

ACQDAY = acquisition date of the field ground truth

Table 4 indicates that the models are estimating substantially different dates of peak spectral response. The ERIM algorithm peaks when 55 percent of the growing season has elapsed as opposed to 63 percent for the Badhwar algorithm. Table 3 shows that the peaks of the two algorithms are roughly a week apart; the peak of the ERIM algorithm occurs near the beginning of heading, and the peak of the Badhwar algorithm occurs near the end of heading.

TABLE 3.- RELATIONSHIP BETWEEN FEEKES DEVELOPMENT STAGE AND PERCENT OF NORMAL SEASON GROWTH FOR SPRING WHEAT

Feekes stage	Normal % of season		Description
	Stage midpoint	Stage duration	
0.0	0.0	8.33	Planted
1.0	13.88	11.11	Emergence
2.0	20.83	2.78	Beginning tillering
3.0	23.61	2.78	Tillers formed
4.0	26.85	3.70	Begin pseudostem erection
5.0	30.55	3.71	Pseudostem strongly erect
6.0	33.80	2.78	Jointing
7.0	37.04	3.70	Second node formed
8.0	40.28	2.78	Last leaf visible
9.0	43.52	3.70	Last leaf ligule visible
10.0	50.00	9.26	Boot
10.1	55.32	1.37	First heads visible
10.2	56.75	1.50	1/4 headed
10.3	57.90	.80	1/2 headed
10.4	59.15	1.70	3/4 headed
10.5	67.35	14.70	Headed
11.1	78.00	6.60	Milky ripe
11.2	84.65	6.70	Soft dough
11.3	91.22	6.44	Hard dough
11.4	97.22	5.56	Ripe
11.5	100.00		Harvest

TABLE 4.- RESULTS OF REGRESSION BETWEEN STAGE AND DAYS FROM ESTIMATED TIME OF PEAK SPECTRAL RESPONSE

Algorithm	R^2	Intercept	Slope
ERIM	0.91	55.01	0.927
Badhwar	.88	62.99	.920

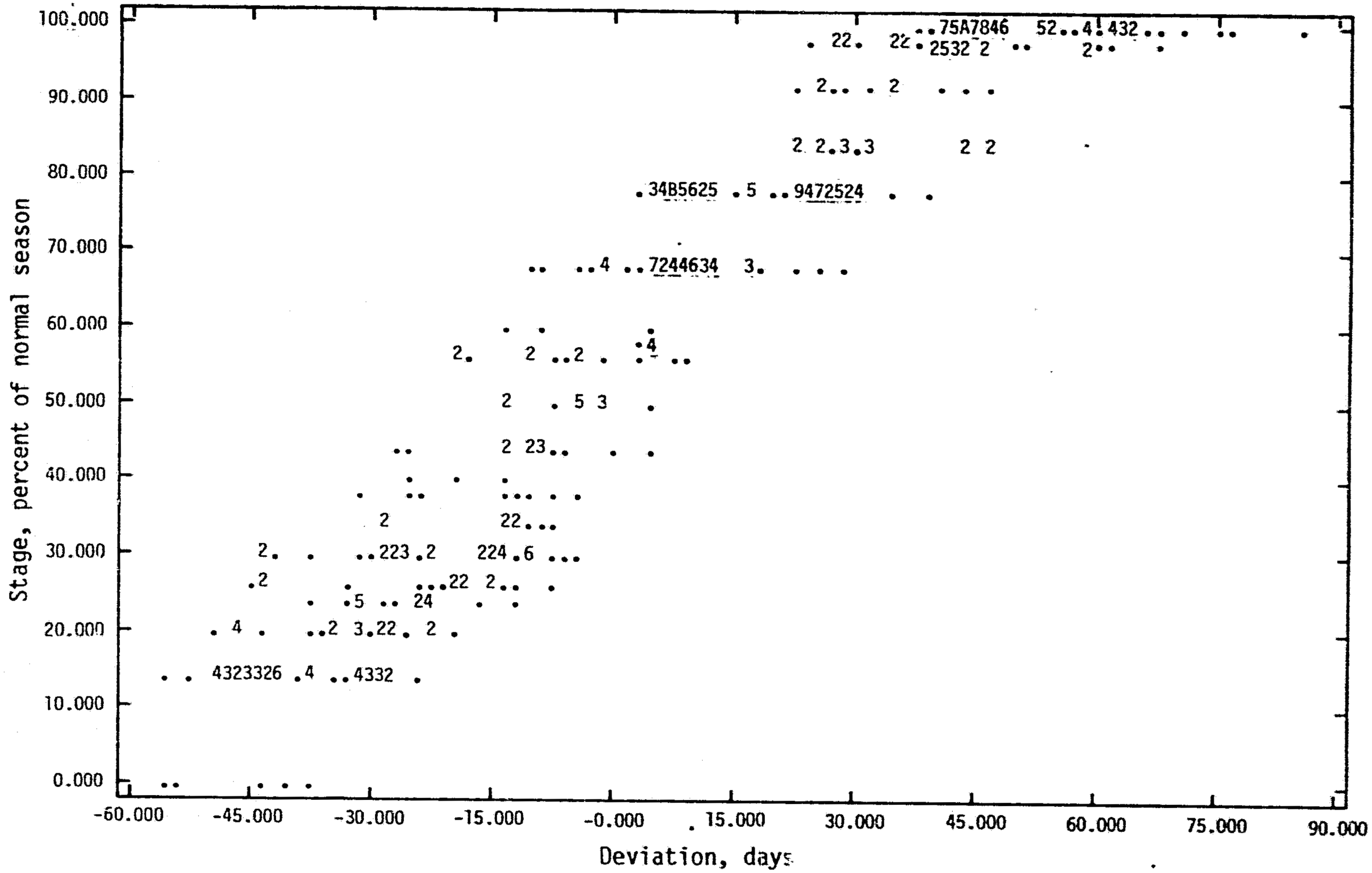

Figure 1.- Plot of development stage versus days from time of peak spectral response for the ERIM crop calendar shift algorithm.

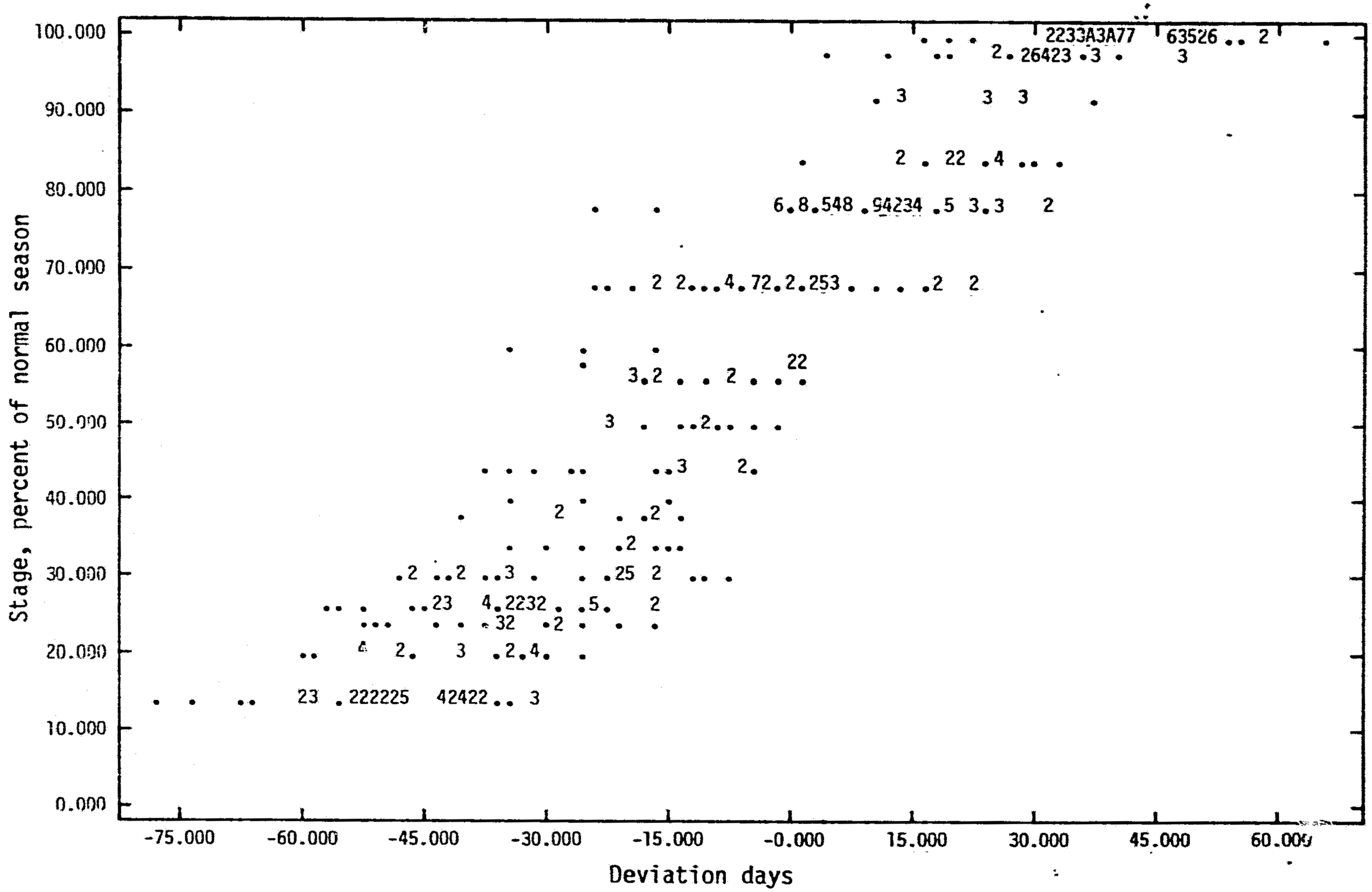

Figure 2.- Plot of development sta versus days from time of peak spectral response for the Badhwar crop calendar shift algorithm.

During preliminary review of these results, it has been suggested that this variation may have been the result of differences in the data preprocessing employed with the two algorithms. Spectral greenness values often are negative during part of the growing season. The usual procedure is to add a constant value to greenness to ensure positive numbers. A constant value of 32 has been adopted. The ERIM algorithm subtracts 25 from the greenness, resulting in an effective offset of 7. The Badhwar algorithm was run with an offset equal to 32. This difference may partly explain the discrepancy between the two models.

5. EVALUATION OF DEVELOPMENT STAGE ESTIMATES

The ERIM algorithm calculated peak response dates for 92 of the 139 fields listed in table 1. A total of 489 of the possible 681 growth stage estimates were made. The Badhwar algorithm estimates were summarized for the same field-date combinations. The ground truth was converted to percent of season and the error of each estimate was calculated in percent. Table 5 compares the results obtained from the two algorithms summarizing the bias and root mean square error (RMSE) by growth stage. In general, the algorithm's performances were similar with the Badhwar algorithm showing higher RMSE for most stages.

The overall results were summarized in table 6 to provide a better measure of model performance. Two methods of summarization are shown. In the first case, the errors were weighted by the number of observations in each stage. All growth stages were used. The second method examined only the period between emergence and ripe. In this case, the errors were weighted by the duration of the stage as given in table 3. The ERIM algorithm again shows the best results, particularly in the second case. Since spring wheat has approximately a 100-day growing season, these errors may be interpreted broadly as errors in days. Thus, the ERIM algorithm results in a 1- to 1.5-day reduction in error for estimating the date of a given growth stage when compared with the Badhwar algorithm.

TABLE 5.- COMPARISON OF RESULTS FOR THE ERIM AND BADHWAR CROP CALENDAR SHIFT ALGORITHMS BY FEEKES DEVELOPMENT STAGE

Feekes stage	Number of observations	ERIM		Badhwar	
		Bias	RMSE	Bias	RMSE
0.0	7	-3.6	7.02	-3.3	8.57
1.0	45	1.2	7.95	2.8	11.04
2.0	22	[illegible].3	9.16	2.6	10.49
3.0	17	-2.6	6.84	-1.0	9.74
4.0	34	- .4	8.50	1.2	9.98
5.0	34	-2.2	10.94	-1.4	10.91
6.0	9	-4.8	8.63	-5.4	8.56
7.0	8	- .4	9.05	-1.0	8.31
8.0	3	5.7	7.52	3.8	8.62
9.0	13	- .1	8.52	.8	10.89
10.0	12	.4	4.91	1.0	7.13
10.1	9	6.2	12.23	3.2	8.23
10.2	4	9.1	9.62	9.0	10.11
10.3	5	-1.3	1.45	- .5	10.45
10.4	3	9.8	12.23	22.1	23.32
10.5	47	3.4	8.50	5.2	12.16
11.1	80	3.9	9.88	5.2	11.38
11.2	16	-4.6	9.18	-1.6	7.60
11.3	11	1.0	7.61	3.5	8.96
11.4	32	-2.6	10.94	.3	9.08
11.5	78	-9.1	13.36	-8.5	11.89

TABLE 6.- SUMMARY OF RESULTS FOR THE ERIM AND BADHWAR CROP CALENDAR SHIFT ALGORITHMS WEIGHTED BY NUMBER OF OBSERVATIONS AND BY DURATION OF STAGE

Algorithm	Feekes stages	Weighting technique	Bias	RMSE
ERIM	All	Number of observations	-0.7	9.92
Badhwar	All	Number of observations	.5	10.79
ERIM	1.0 to 11.4	Stage duration	.9	8.63
Badhwar	1.0 to 11.4	Stage duration	2.3	10.42

Additional runs were made to determine the effect of relaxing the acquisition restrictions in the software. When a 9-day separation in acquisitions was allowed, a bias of 0.3 and an RMSE of 10.22 was observed, and the number of estimates increased to 590. When the definition of the growing season was increased to 110 days, as opposed to 90 days in the basic algorithms, the bias was -0.1, the RMSE was 10.38, and the number of estimates was 613. When a 110-day season and 9-day acquisitions were allowed, the bias was 0.3 days, the RMSE was 10.59 and the number of estimates was 681. Comparing these results to the baseline results — which showed a bias of -0.7, an RMSE of 9.92, and 489 estimates — indicates that, while some deterioration in performance occurs when the restrictions are relaxed, the increase in the number of estimates probably justifies the loss in accuracy.

6. RECOMMENDATIONS

The ERIM algorithm is recommended for testing with independent 1979 crop year data. The model should be tested in both the original configuration and with the relaxed restrictions, allowing 9-day acquisitions and an expanded definition of the growing season.

The performance of models of this type can probably be enhanced by using meteorological data from the date of peak spectral response to estimate the dates of other stages. It is recommended that the use of accumulated degree days be investigated for this purpose. One simple approach along these lines would be to develop an equation analogous to the one presented in the methodology section, which relates stage to the difference between the estimated peak day and the acquisition date.

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