E81-10197
FC-L1-04030 C-R-160977
JSC-16850

APR 0 6 1981

AgRISTARS

 NASA CR-160977

A Joint Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing

Foreign Commodity Production Forecasting

February 1981

EVALUATION OF SPRING WHEAT AND BARLEY CROP CALENDAR MODELS FOR THE 1979 CROP YEAR

C. V. Nazare and J. G. Carnes

(E81-10197) EVALUATION OF SPRING WHEAT AND BARLEY CROP CALENDER MODELS FOR THE 1979 CROP YEAR (Lockheed Engineering and Management) 35 p HC A03/MF A01 CSCL 02C
N81-29508
Unclas
G3/43 00197

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FC-L1-04030, JSC-16850		

4. Title and Subtitle
Evaluation of Spring Wheat and Barley Crop Calendar Models for the 1979 Crop Year

5. Report Date
February 1981

6. Performing Organization Code

7. Author(s)
C. V. Nazare and J. G. Carnes

8. Performing Organization Report No.
LEMSCO-15936

9. Performing Organization Name and Address
Lockheed Engineering and Management Services Company, Inc.
1830 NASA Road 1
Houston, Texas 77058

10. Work Unit No.

11. Contract or Grant No.
NAS 9-15800

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058 Technical Monitor: J. D. Erickson

13. Type of Report and Period Covered
Technical Report

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

During the Large Area Crop Inventory Experiment, spring wheat planting date and crop development stage estimates based on historical normals were improved by the use of the Feyerherm planting date and Robertson Spring Wheat Crop Calendar Models. The Supporting Research Crop Calendar Project element modified the Robertson model to reduce bias at cardinal growth stages within the growing season. These models were tested in 1980 along with a state-of-the-art barley model (Williams) against a ground-truth data set from 49 calendar year 1979 segments in the U.S. Great Plains spring wheat and barley region.

17. Key Words (Suggested by Author(s))
Agromet models
Labeling Procedures
Robertson Spring Wheat Model
Williams Barley Model
Feyerherm planting date model

18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	34	

*For sale by the National Technical Information Service, Springfield, Virginia 22161

FC-L1-04030
JSC-16850

EVALUATION OF SPRING WHEAT AND BARLEY CROP CALENDAR MODELS FOR THE 1979 CROP YEAR

Job Order 72-402

This report describes the Accuracy Assessment activities of the Foreign Commodity Production Forecasting project of the AgRISTARS Program.

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Under Contract NAS 9-15800

For

Earth Resources Applications Division

Space and Life Sciences Directorate

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

February 1981

LEMSCO-15936

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PREFACE

The Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing is a 6-year program of research, development, evaluation, and application of aerospace remote sensing for agricultural resources which began in fiscal year 1980. This program is a cooperative effort of the National Aeronautics and Space Administration, the U.S. Agency for International Development, and the U.S. Departments of Agriculture, Commerce, and the Interior.

The research which is the subject of this document was performed within the Earth Resources Applications, Space and Life Sciences Directorate, at the Lyndon B. Johnson Space Center, National Aeronautics and Space Administration. Under Contract NAS 9-15800, personnel of Lockheed Engineering and Management Services Company, Inc., performed the tasks which contributed to the completion of this research.

The following individuals contributed to this effort: Dr. A. G. Houston, NASA, helped with his interest and suggestions. M. L. Sestak, Lockheed, put together the original data set, and Dr. P. Doraiswamy, Lockheed, was responsible for the model improvements and much of the information on the inner workings of the models.

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1. BACKGROUND AND OBJECTIVES

This report describes the results of the evaluation of the performances of candidate agrometeorological crop calendar models. These models have been proposed by the Supporting Research Crop Calendar Project element for possible application to labeling procedures of the Agriculture and Resources Inventory through Aerospace Remote Sensing (AgRISTARS) program. This study is an addition to the 1980 U.S. and Canada Spring Wheat and Barley Exploratory Experiment.

During the Large Area Crop Inventory Experiment (LACIE), spring wheat planting date and crop development stage estimates based on historical normals were improved by the use of the Feyerherm planting date and Robertson Spring Wheat Crop Calendar Models. Modifications were subsequently made to the Robertson model to improve deficiencies identified in LACIE evaluations. These modifications were tested along with a state-of-the-art barley model (Williams, ref. 1) which became available for testing for the first time.

This study investigated two crop planting date (or starter) models, namely the Feyerherm (ref. 2) and the Normal models (ref. 3), and four crop growth stage models. These crop development stage models are designated the Original Robertson Model (R0), the Improved Robertson Version 1 Model (R1), the Improved Robertson Version 2 Model (R2), and the Williams Barley Model. The evaluation was based on 1979 ground-truth data consisting of 49 spring small grains blind-site segments in the U.S. Great Plains region and contains three crop categories of interest, spring wheat, durum wheat, and barley. For the purposes of this study, durum wheat is in the same category as spring wheat.

The primary objective of this study was to determine the combination of the crop planting date model and the crop development stage model which would most accurately predict the crop development stage as a function of time for spring wheat and barley. Other objectives were to determine if the Williams model predicts more accurately the barley development stages than do the Robertson models and to determine whether the models selected would produce results which are sufficiently accurate to be used in labeling and classification procedures.

2. APPROACH

The Feyerherm and the Normal planting date models were evaluated on their ability to accurately predict the median planting dates for the segments. The basis for comparison was the ground-truth median planting dates which yielded errors measured in units of days associated with the models. The ground-truth median planting dates for the spring wheat crop and for the barley crop were obtained by calculating the date at which 50 percent of the spring wheat or the barley fields in each of the segments were observed to be planted.

The performances of the three Robertson development stage models were evaluated using the ground-truth median development stages as the basis for comparison by use of the observed median planting dates to initiate the models. The ground-truth median development stages for the spring wheat crop and for the barley crop were obtained by calculating the observed median stage for the spring wheat or the barley fields within each of the segments for each of the dates on which the stages were observed. The comparison of the models' predictions versus the observed crop stage yielded errors in terms of crop stages associated with each of the models.

The barley development stage model was evaluated using the observed median planting dates for barley to initiate the models and subsequently to compare the model prediction of stage with the ground-truth median development stages for barley.

The planting date models and the development stage models were evaluated independently so as to minimize any adverse consequences to the performances of the crop development stage models as a result of inaccurate planting date input to the models.

Certain assumptions had to be made regarding the ground-truth data used for evaluation. The 49 segments contained from 15 to 30 special fields that were distributed through the segment and observed periodically. The locations and selections of these special fields were assumed to be random, and the periodically observed stages were assumed to be truly representative of crop development at those times.

3. DATA SET

The data set used in this study comprised 49 blind-site segments in the spring wheat areas of the U.S. Great Plains and 1979 periodic observations collected by enumerators at 9- to 18-day intervals corresponding to Landsat overpass dates (ref. 4). These periodic observations contained planting dates and crop development stages for each field in the segment. The number of fields within a segment varied from 15 to 30 spring wheat or barley fields. The planting date model contained the observed planting dates and predicted planting dates for spring wheat and barley. The crop stage model data contained observed crop stages and predicted crop stages for each of the models. The crop stages were given in terms of the Robertson Phenological Crop Scale.

Figure 1 is an illustration of the Robertson Phenological Crop Scale that was used in this study, superimposed on the Feekes Scale description of identifiable crop stages (refs. 5 and 6). Figure 2 shows the geographic location of the segments that contain the data set used in this study.

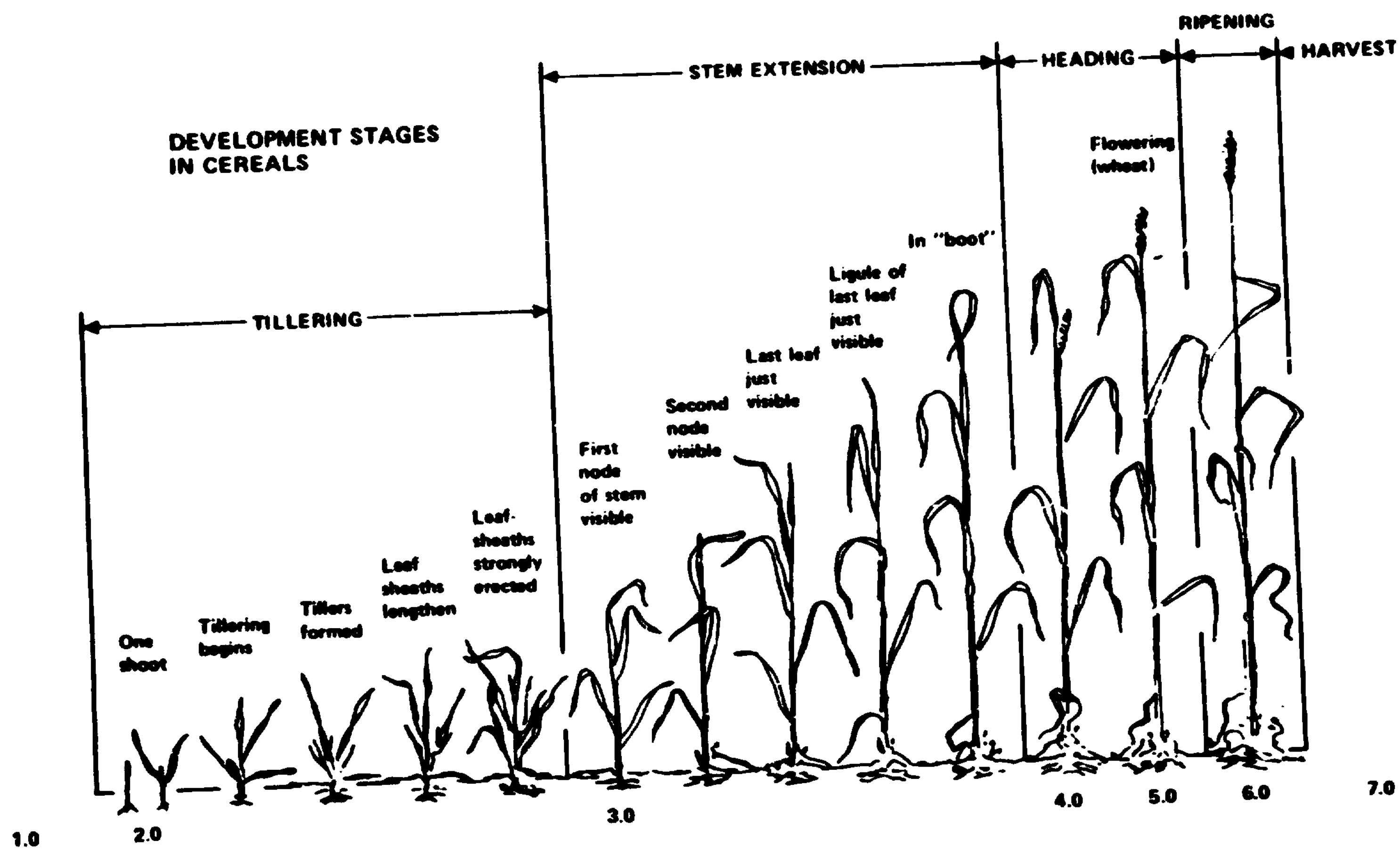

Figure 1.- Illustration of the Robertson Phenological Scale.

- FORTY-NINE SEGMENTS IN THE SPRING WHEAT AREAS OF THE U.S. GREAT PLAINS.
- 1979 PERIODIC OBSERVATIONS COLLECTED BY ENUMERATORS AT 9 TO 18 DAY INTERVALS CORRESPONDING TO LANDSAT OVERPASS DATES.

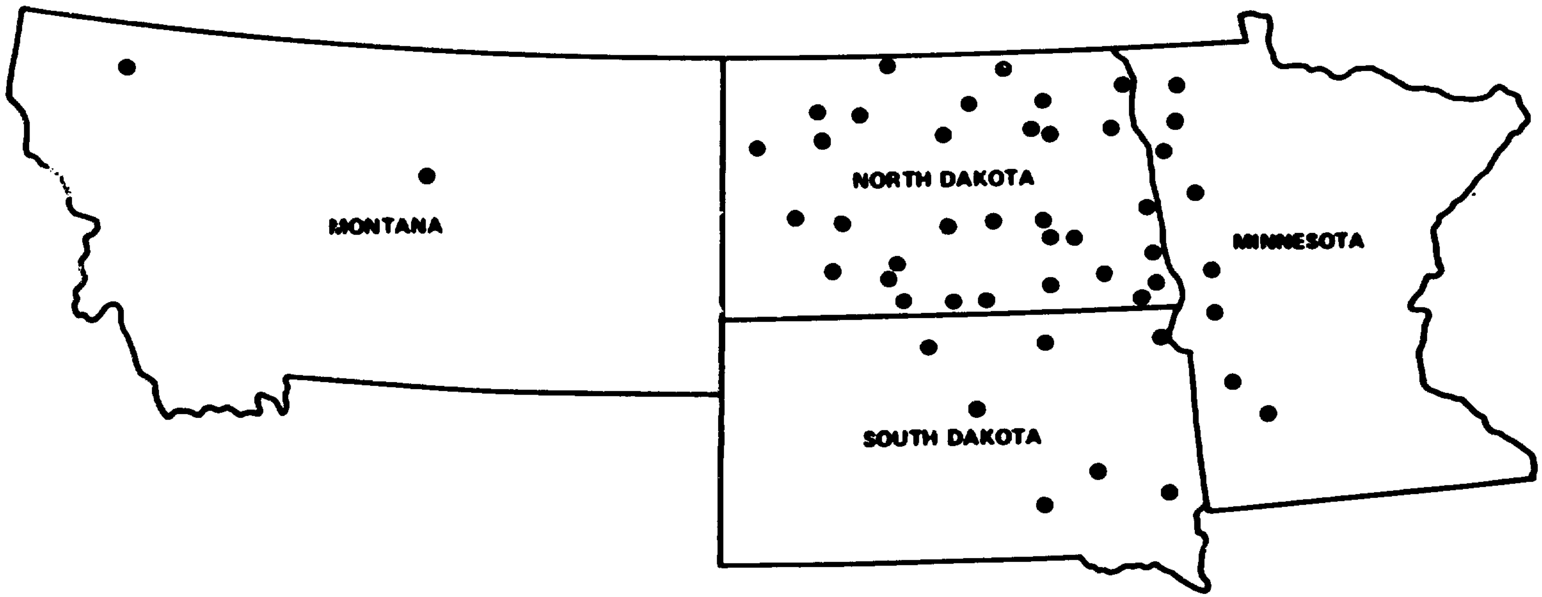

Figure 2.- Geographic locations of the segments.

4. DESCRIPTION OF THE MODELS

Robertson's concept (ref. 5) is based on certain physiological processes that are central to the development of spring wheat. Since temperature and photo-period are two primary environmental factors that influence the phenological development, a photothermal concept was used to compute the development of a crop over five fairly short and uniform physiological periods. The triquadratic responses of temperature and photo-period were estimated for each of the phenological stages by an interative regression technique.

The Improved Robertson Version 1 and the Improved Robertson Version 2 Models are improvements over the Original Robertson Model with respect to the photo-period and temperature responses. The photo-period response is limited to stages between emergence and flowering. The thermal responses for subsequent stages are adjusted to represent realistic physiological responses. The development rates of spring wheat immediately before and after flowering are responsive primarily to the daily maximum temperature.

The Williams Barley Model is based on approximately the same concept as the Robertson model, the difference being that the coefficients were developed specifically for barley.

Figure 3 is a schematic of the models' input requirements and resulting output data. The Normal model, although not an agrometeorological model, is included in figure 3 for the sake of completeness. It is based on historical data averaged for the crop reporting district. The daily minimum and maximum temperatures are obtained from reports of weather stations nearest the segments.

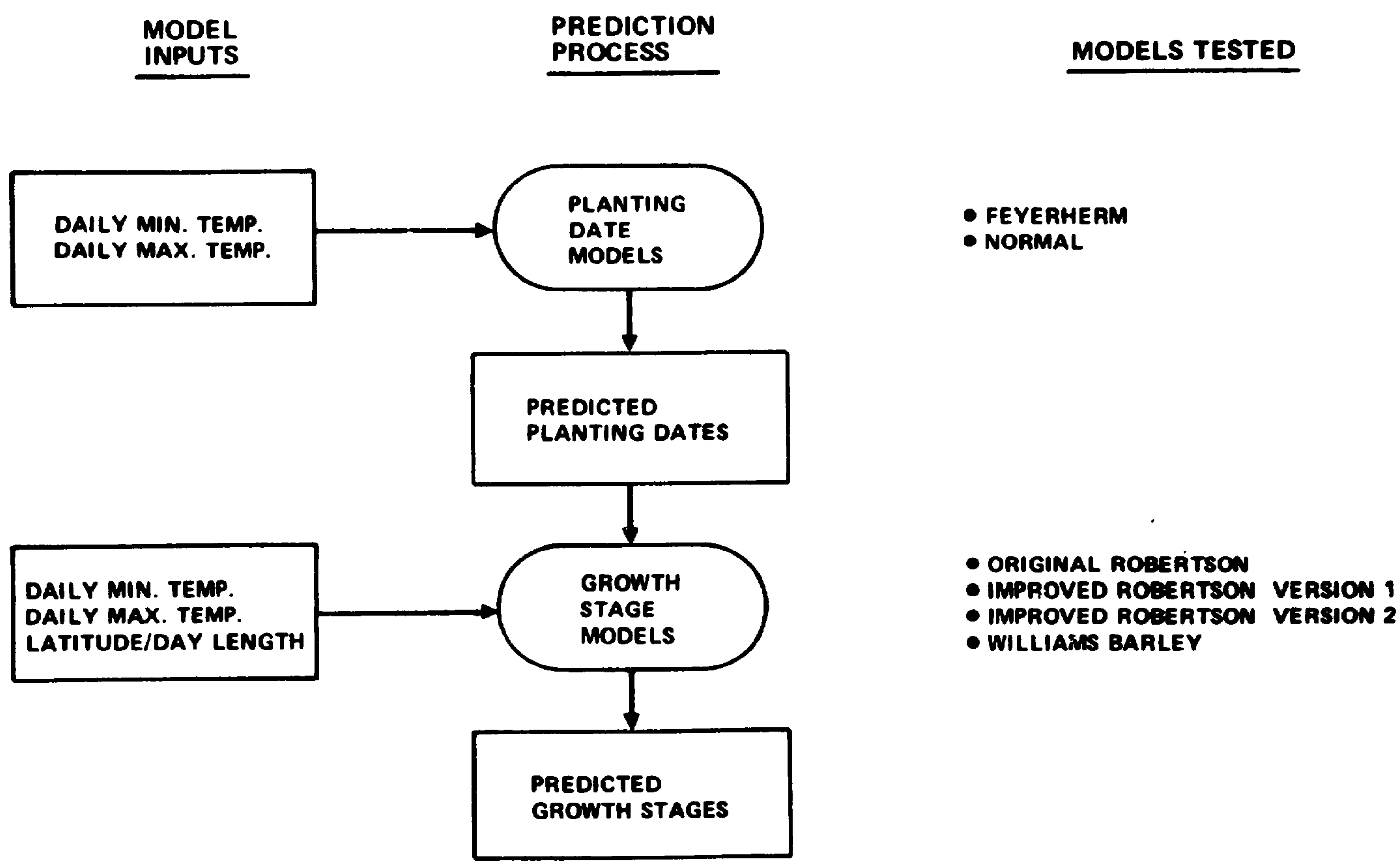

Figure 3.- Schematic of the evaluation process.

5. RESULTS FOR PLANTING DATE MODELS

Both the Feyerherm and the Normal models produce median planting date estimates at the segment level. The performances of the models for the spring wheat fields and the barley fields were evaluated separately.

Figure 4 is a histogram showing the distribution of errors measured in days for the Feyerherm versus the Normal planting date models applied to spring wheat fields. The error is the difference between the median ground-truth planting dates and the model-predicted planting dates, and the distribution of these errors should give an indication of the bias associated with the models. As can be seen from figure 4, both distributions appear normal, the differences being the locations of the midpoints of these distributions. The Feyerherm model has a positive displacement, whereas the Normal model has a negative displacement. This indicates that the Normal model is very early compared to the ground-truth median planting dates, while the Feyerherm model is slightly late. Based on reports jointly published by the U.S. Department of Agriculture and the National Oceanic and Atmospheric Administration in the Weekly Weather and Crop Bulletin, the 50 percent planting date of spring wheat in North Dakota for 1979 was 13 days late. Thus, the Normal model performed as expected.

Table 1 summarizes the statistics on the errors measured in days for the Feyerherm versus the Normal model applied to spring wheat. The sign test shown in table 1 is based on the absolute magnitude of the error and gives the percent of times one model is closer to the ground-truth than the other model.

TABLE 1.- COMPARISON OF ERRORS IN PLANTING DATE MODELS
APPLIED TO SPRING WHEAT FIELDS

	Feyerherm model	Normal model
Number of segments (n)	49	49
Mean error (in days)	+3.9	-10.4
Standard deviation (in days)	7.0	7.50
Median error (in days)	+4.0	-11.0
Sign test (%)	75.5	22.4
(2% tied)		

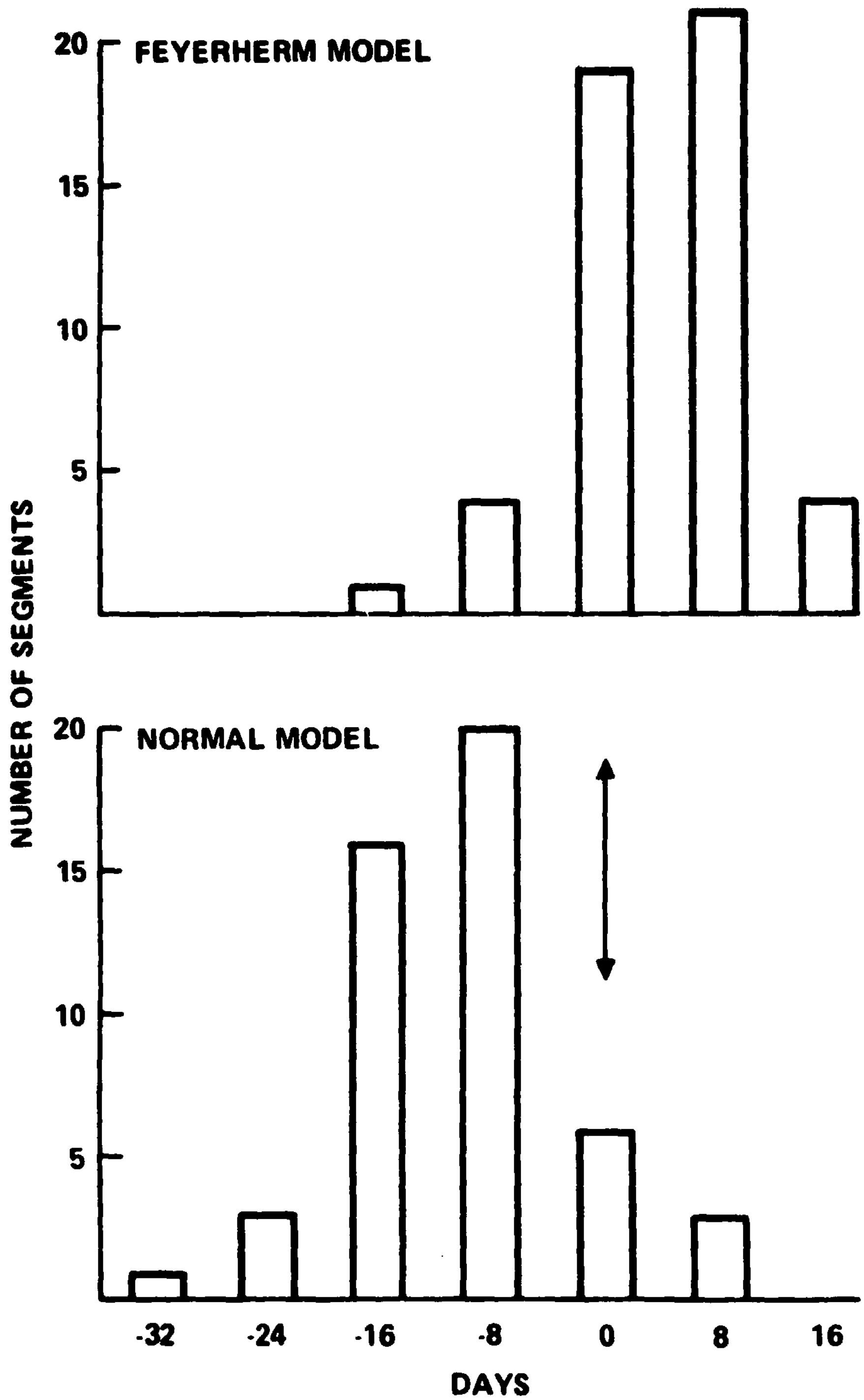

Figure 4.- Distribution of errors (in days) for the Feyerherm versus the Normal planting date models applied to barley.

From table 1 it can be seen that, on the average, the Feyerherm model is 3.9 days late compared to the observed planting date, whereas the Normal is on the average 10.4 days early compared to the observed planting date. Statistically, the sign test indicates that the Feyerherm model is significantly better than the Normal model at the 6-percent level of significance. The overall statistics indicate that the Feyerherm model is closer to the ground-truth than the Normal model in predicting spring wheat planting dates for this year.

Figure 5 is a histogram showing the distribution of error measured in days for the Feyerherm versus the Normal planting date models applied to barley fields. As can be seen from figure 5, both distributions appear normal. However, the Feyerherm model midpoint has a positive displacement, whereas the Normal model has a negative displacement. This indicates that the two models are, on the average, late and early compared to the ground-truth median planting dates as seen for barley fields.

Table 2 summarizes the statistics on the error measured in days from the Feyerherm versus the Normal model applied to barley fields. From table 2, it can be seen that, on the average, the Feyerherm model is 2.9 days later than the observed planting date, whereas the Normal is, on the average, 10.9 days earlier than the observed planting date. The sign test indicates that the Feyerherm model is better than the Normal model, though not statistically significant at the 5-percent level of significance. The overall statistics indicate that the Feyerherm model is better for this year than the Normal model is for predicting barley planting dates.

TABLE 2.- COMPARISON OF ERRORS IN PLANTING DATE MODELS
APPLIED TO BARLEY FIELDS

	Feyerherm model	Normal model
Number of segments (n)	44.0	44.0
Mean error (in days)	+2.9	-10.9
Standard Deviation (in days)	11.48	9.55
Median error (in days)	+4.5	-11.5
Sign test	63.6	36.4

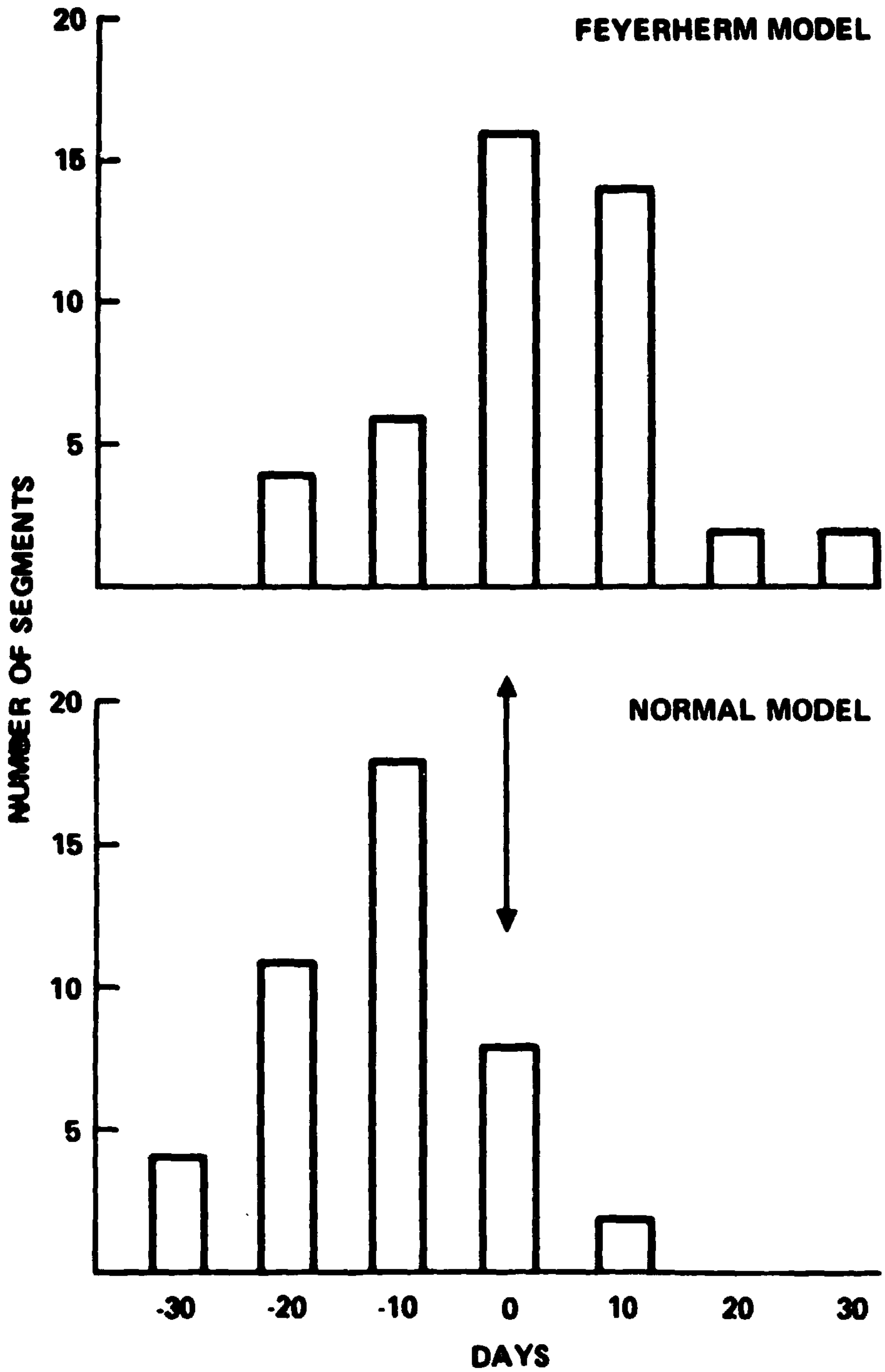

Figure 5.- Distribution of errors (in days) for the Feyerherm versus the Normal planting date models applied to barley.

6. APPROACH: CROP DEVELOPMENT STAGE MODELS

The three Robertson models and the Williams Barley Model were started using the ground-truth median planting dates for spring wheat and barley fields as input to the models. They were evaluated on their ability to accurately predict median crop development stages for spring wheat and barley between stages 2.0 and 6.0, which are the emergence through ripe stages.

In an attempt to determine if the models performed differently during different parts of the growing season, the models were evaluated at five ranges of stages as shown below.

1. Stage 2.0 to 2.9: emergence to prejointing
2. Stage 3.0 to 3.9: jointing to preheading
3. Stage 4.0 to 4.9: heading to presoft dough
4. Stage 5.0 to 5.9: soft-dough to preripening
5. Stage 6.0: ripe

In addition, the overall performance was tested for the entire growing season from stage 2.0 to stage 6.0.

7. CROP DEVELOPMENT STAGE MODEL RESULTS APPLIED TO SPRING WHEAT FIELDS

Figure 6 contains scatter plots of the median predicted development stages versus the observed median development stages for models R0, R1, and R2. The letters represent the number of data points falling on the character (A = 1, B = 2, etc.). The common trend on all three plots is for the predicted growth stage to converge on the 1-1 line, indicating that the performance of all three models is improving with time through the growing season. It can also be seen from figure 6 that model R0 is progressing faster than models R1 and R2 by noting that 13 ground truth observations are off scale and greater than stage 6.0 (i.e., swathed and harvested).

Table 3 summarizes the statistics on the errors between the observed stages and the predicted stages that were applied to spring wheat at various intervals throughout the growing season. The errors are the differences between the predicted stages and the observed stages and should give an indication of the amount of bias associated with each of the models. An average positive error would indicate that the model is ahead of the ground-truth, while an average negative error would indicate that the model was behind the ground-truth. In addition, the absolute value of the error was ranked on a scale of 1 to k, where k is the number of models being compared with each other (in table 3, k = 3). The sum of the various ranks associated with each model was then utilized in a Friedman nonparametric test of ranks (ref. 7) to determine if any one model produced better results consistently.

Table 3 shows that there were no significant differences between any of the three models when evaluating the overall performance from ground-truth stages 2.0 to 6.0. The range of the mean error for the three models was two-tenths of a stage, and the Friedman T-statistic also indicates that there is no significant difference between the models at the 95-percent confidence level.

For stages 2.0 to 2.9, there was a marginal difference between the three models. It is apparent that R1 is the worst performer of the three models at this stage interval, as indicated by the statistics on the errors and the

TABLE 3.- COMPARISON OF ROBERTSON MODELS APPLIED TO SPRING WHEAT

Ground-truth range	Statistic	Robertson 0	Robertson 1	Robertson 2
2.0 - 6.0 Entire growing season	Mean error	0.0	0.2	0.2
	STD	0.53	0.48	0.46
	Median error	0.0	0.1	0.2
	ΣRank observed	100.21	97.08	96.71
	Friedman's T-statistic: 0.15 (not significant)			
2.0 - 2.9	Mean error	0.9	1.0	0.9
	STD	0.25	0.28	0.25
	Median error	0.9	1.0	0.9
	ΣRank observed	25.00	37.75	27.25
	Friedman's T-statistic: 6.17 (significant)			
3.0 - 3.9	Mean error	0.3	0.7	0.4
	STD	0.26	0.32	0.26
	Median error	0.3	0.7	0.4
	ΣRank observed	42.42	95.25	66.33
	Friedman's T-statistic: 41.17 (significant)			
4.0 - 4.9	Mean error	-0.2	0.1	0.1
	STD	0.26	0.27	0.31
	Median error	-0.2	0.1	0.0
	ΣRank observed	89.67	70.75	79.58
	Friedman's T-statistic: 4.48 (not significant)			
5.0 - 5.9	Mean error	-9.2	0.0	0.1
	STD	0.42	0.27	0.33
	Median error	-0.2	0.0	0.2
	ΣRank observed	109.45	66.60	93.95
	Friedman's T-statistic: 20.92 (significant)			
6.0	Mean error	--	--	--
	STD	--	--	--
	Median error	-0.5	-0.4	-0.3
	ΣRank observed	50.0	48.4	33.5
	Friedman's T-statistic: 24.07 (significant)			

At 95-percent confidence level, Friedman's T-statistic critical value = 5.99.
At 99-percent confidence level, Friedman's T-statistic critical value = 9.21.

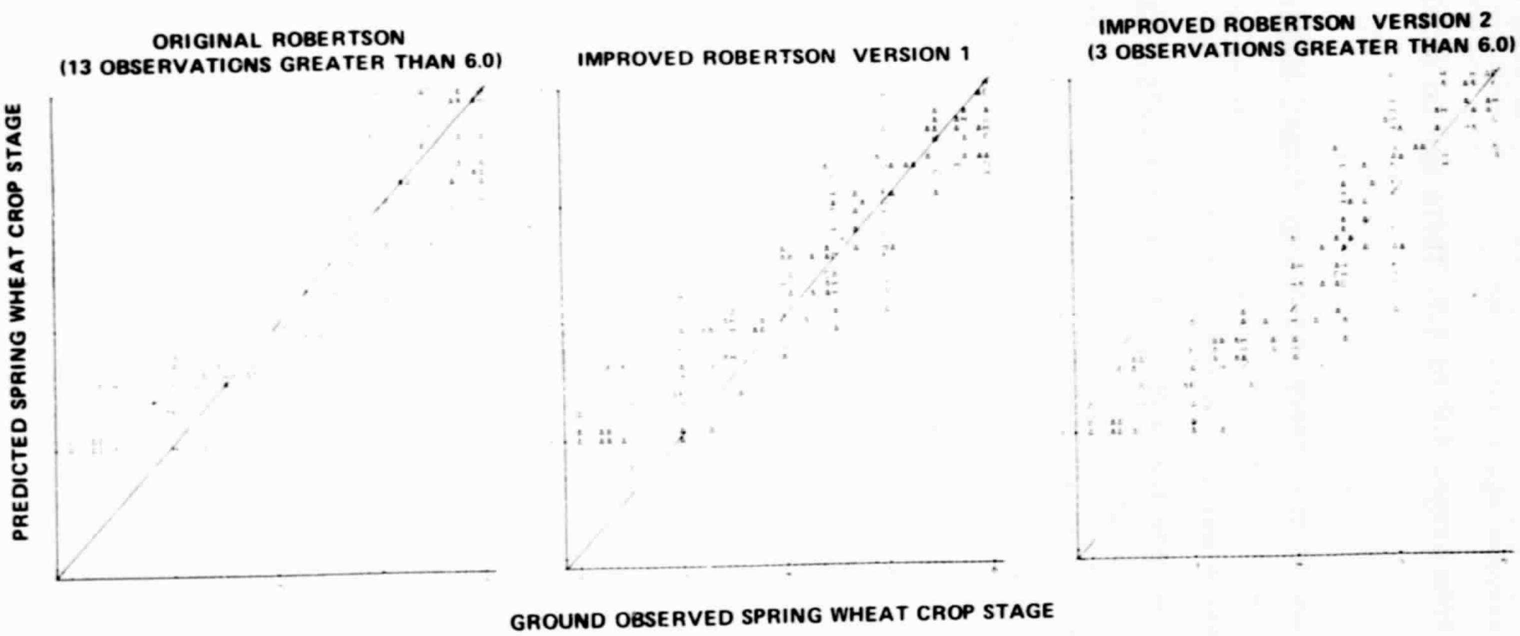

Figure 6.- Scatter plots of predicted versus ground-observed spring wheat crop stages for the three spring wheat crop stage models.

observed sum of the ranks. From stages 3.0 to 3.9, there was a significant difference between the models. RO appeared to be the best at this stage interval. From stages 4.0 to 4.9, there was no significant difference between the models.

For stages 5.0 to 5.9, there was a significant difference between the models, and R1 appeared to perform the best within this stage interval. Finally, at stage 6.0, there was a significant difference between the three models, and R2 appeared to perform the best of the three models. At ground-truth stage 6.0, the mean and standard deviation have not been displayed, as they are not valid. The observations obtained beyond stage 6.0 were beyond the range of the model's abilities of prediction and, therefore, were not valid.

8. CROP DEVELOPMENT STAGE MODEL RESULTS APPLIED TO BARLEY FIELDS

Figure 7 contains scatter plots of the median predicted development stage for model R2 and the Williams Barley Model versus the observed median development stage. The letters represent the number of data points falling on that character. At first glance, there is no apparent difference between the two models, although the barley model appears to be more dispersed about the 1-1 line than R2 (figure 10). More significant is the fact that 33 observations are beyond 6.0, indicating that the barley model is progressing faster than the spring wheat model.

Table 4 gives the statistics on the errors between the median ground-truth stage and the model predicted median stage applied to barley at various stage intervals through the growing season. It can be seen from table 4 that there was a significant difference between the models for the overall performances from stages 2.0 to 6.0. The barley model is significantly worse than at least one of the spring wheat models.

From stage 2.0 to 2.9, there were marginal differences between the models. R0 appeared to perform the best of the four models as indicated by the error statistics and the observed sum of the ranks. For stages 3.0 to 3.9, there was a significant difference between the models. R0 appeared to be the best of the four models. From stages 4.0 to 4.9, there were no significant differences between the models. They appeared to be nearly identical at this stage interval. For stages 5.0 to 5.9, there was a significant difference between the models. Model R1 appeared to perform the best. At stage 6.0, there were no significant differences between the models, and R2 appeared to perform the best.

TABLE 4.- COMPARISON OF ROBERTSON AND WILLIAMS MODELS APPLIED TO BARLEY

Ground-truth range	Statistic	Robertson 0	Robertson 1	Robertson 2	Williams barley
2.0 - 6.0 Entire growing season	Mean error	-0.2	0.0	0.0	0.4
	STD	0.67	0.60	0.61	0.60
	Median error	-0.2	0.0	0.0	0.0
	ΣRank observed	117.67	96.96	98.58	126.79
	Friedman's T-statistic: 8.74 (significant)				
2.0 - 2.9	Mean error	1.0	1.1	1.0	1.2
	STD	0.32	0.37	0.33	0.35
	Median error	1.1	1.2	1.1	1.2
	ΣRank observed	22.33	33.50	24.67	39.50
	Friedman's T-statistic: 9.49 (significant)				
3.0 - 3.9	Mean error	0.3	0.4	0.4	0.6
	STD	0.32	0.38	0.36	0.42
	Median error	0.2	0.4	0.3	0.5
	ΣRank observed	50.58	90.67	65.08	113.67
	Friedman's T-statistic: 43.79 (significant)				
4.0 - 4.9	Mean error	-0.3	-0.1	-0.2	0.1
	STD	0.32	0.34	0.38	0.52
	Median error	-0.3	0.0	-0.1	0.2
	ΣRank observed	89.42	62.67	74.92	79.0
	Friedman's T-statistic: 7.18 (not significant)				
5.0 - 5.9	Mean error	-0.5	-0.3	-0.2	0.1
	STD	0.57	0.45	0.54	0.59
	Median error	-0.6	-0.2	-0.2	0.3
	ΣRank observed	129.93	70.67	95.10	114.30
	Friedman's T-statistic: 28.68 (significant)				
6.0	Mean error	--	--	--	--
	STD	--	--	--	--
	Median error	-0.9	-0.7	-0.6	>0.0
	ΣRank observed	48.0	35.0	26.5	50.5
	Friedman's T-statistic: 14.31 (significant)				

At 95-percent confidence level, Friedman's T-statistic critical value = 7.82.
At 99-percent confidence level, Friedman's T-statistic critical value = 11.34.

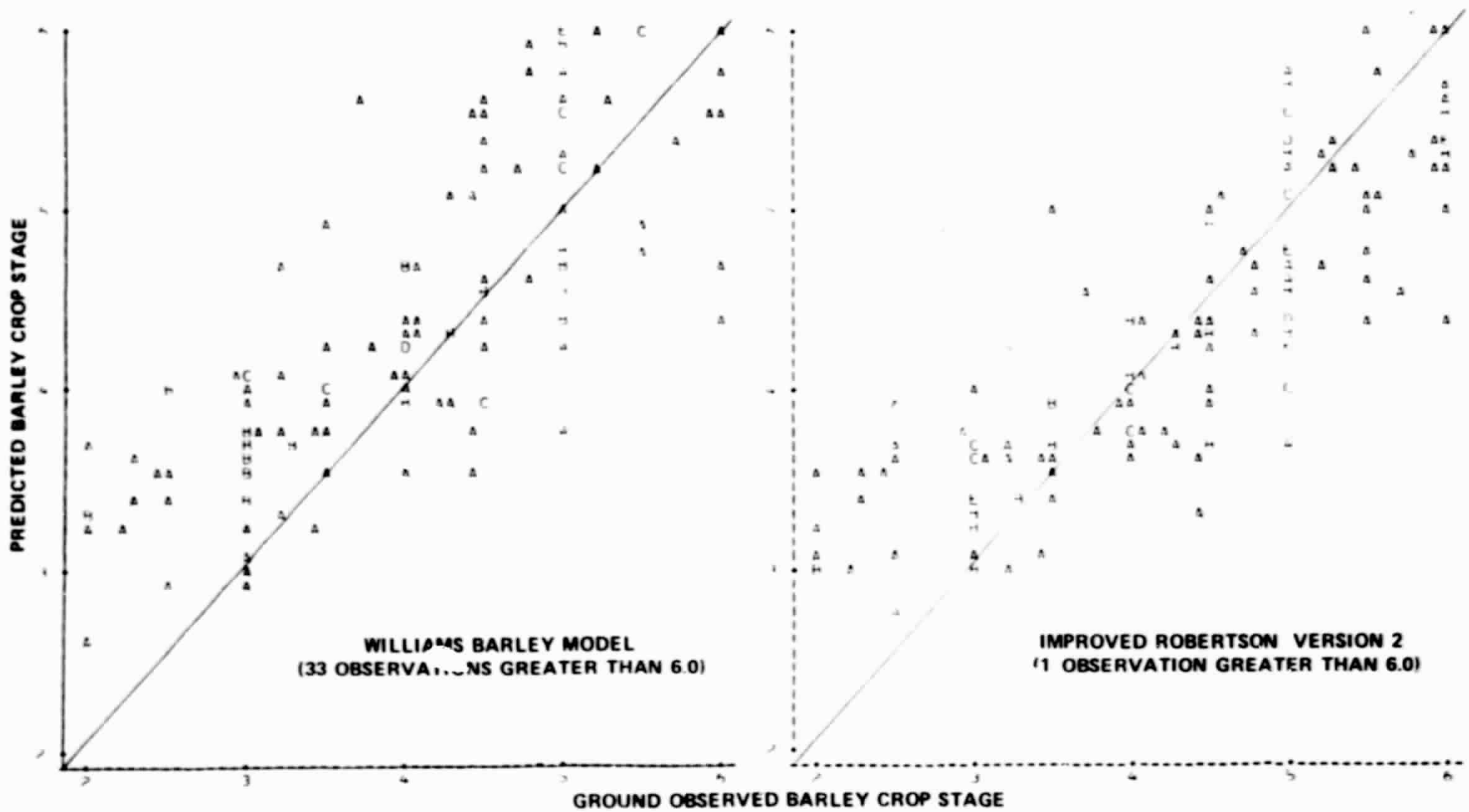

Figure 7.- Scatter plots of predicted versus ground-observed barley crop stages for the Williams Barley Model and the Improved Robertson Version 2 Spring Wheat Model.

9. APPLICATION TO LABELING PROCEDURES

The results shown in the preceding discussion indicate that the Feyerherm planting date model is more accurate than the Normal model. However, with respect to the growth-stage models, it is not readily apparent that any one model produces consistently better results through the growing season. The Improved Robertson Version 2 Model was selected on the basis of its being the most physiologically realistic model for application to the labeling procedures in AgRISTARS (ref. 8). In order that the models be useful for the spring small grains labeling procedure, it is necessary that they be able to predict crop growth stages at particular points of time with reasonable accuracy. The Reformatted procedure (ref. 9) prescribes and identifies four Landsat acquisition biowindows that are necessary for accurate labeling as shown in table 5.

TABLE 5.- BIOWINDOWS FOR REFORMATTED PROCEDURE

Window	Open	Close
1	Spring wheat 50% Planted minus 5 days	Spring wheat 50% Planted plus 18 days
2	Spring wheat 50% Headed minus 10 days	Spring wheat 50% Headed plus 10 days
3	Spring barley 50% Turning to ripe minus 5 days	Spring barley 50% Turning to ripe plus 6 days
4	Spring wheat 50% Harvested plus 15 days	Spring wheat 50% Harvested plus 30 days

Using the criteria described in table 5, the predicted growth stages for the Improved Robertson Version 2 Model were converted to days of development to reach each of three crop stages described in the Reformatted procedure. Biowindow 4 was not calculated because it was out of the ranges of stages in which the models are effective.

Table 6 lists the median ground-truth dates and the median predicted dates for three biowindows. Biowindow 1 used the Feyerherm planting date model and biowindows 2 and 3 used the Improved Robertson Version 2 model for spring wheat and barley with the Feyerherm planting date model as the starter model.

TABLE 6.- OBSERVED VERSUS PREDICTED BIOWINDOWS ACCORDING TO THE REFORMATTED PROCEDURE

OBS	STATE	APU	CRD	County	Seg. no.	Biowindow 1 (SW) OBSPLT	Biowindow 1 (SW) FPLT	Biowindow 2 (SW) OBSHEAD	Biowindow 2 (SW) R2HEAD	Biowindow 3 (Barley) OBSRIPE	Biowindow 3 (Barley) R2RIPE
1	27	15	70	Redwood	1380	126	136	183	190	.	.
2	27	13	40	Grant	1566	138	140	188	191	232	236
3	27	19	40	Otter Tail	1835	139	145	194	196	221	240
4	27	19	40	Yellow Medicine	1842	123	134	191	184	.	.
5	27	20	10	Marshall	1514	158	148	211	198	236	239
6	27	20	10	Roseau	1518	148	148	201	197	246	246
7	27	20	10	Norman	1825	142	144	196	197	219	246
8	27	20	10	Polk	1987	133	145	191	196	214	238
9	30	23	50	Fergus	1948	136	123	188	188	219	220
10	30	104	10	Flathead	1725	120	115	192	175	223	223
11	38	19	20	Benson	1392	153	148	198	197	226	239
12	38	19	20	Pierce	1461	147	155	204	202	226	249
13	38	19	20	Bottineau	1611	155	155	204	202	223	241
14	38	19	20	McHenry	1612	146	150	195	196	.	.
15	38	19	30	Ramsey	1387	152	153	202	202	220	242
16	38	19	30	Towner	1467	155	159	197	209	223	257
17	38	19	30	Cavalier	1617	155	154	214	202	247	242
18	38	19	50	Stutsman	1636	143	144	202	193	229	237
19	38	19	60	Barnes	1472	145	148	196	200	212	241
20	38	19	90	Dickey	1658	133	142	193	195	217	233
21	38	19	90	Sargent	1664	141	145	191	194	207	236
22	38	19	90	La Moure	1924	143	144	196	194	226	238
23	38	20	30	Pembina	1584	159	147	213	197	226	240
24	38	20	30	Grand Fork	1619	135	146	201	196	219	238
25	38	20	60	Cass	1473	141	142	200	192	229	237
26	38	20	60	Traill	1645	143	142	196	192	228	237
27	38	20	90	Richland	1399	136	144	183	196	205	.
28	38	20	90	Ransom	1974	140	145	198	197	220	.
29	38	21	10	Burke	1394	154	156	201	199	225	241
30	38	21	10	Ward	1457	156	159	202	209	232	246
31	38	21	10	Mountrail	1602	152	158	204	207	247	246
32	38	21	40	Dunn	1571	136	145	187	193	232	241
33	38	21	40	McKenzie	1627	141	138	187	185	.	.
34	38	21	40	Mercer	1630	149	145	198	188	240	226
35	38	21	50	Kidder	1909	140	148	198	198	214	240
36	38	21	70	Hettinger	1650	136	141	186	190	.	.
37	38	21	80	Burleigh	1653	142	152	197	201	.	.
38	38	21	60	Morton	1656	143	149	195	199	204	242
39	38	21	80	Emmons	1917	138	136	186	188	222	226
40	38	21	80	Grant	1918	131	149	191	199	217	.
41	38	21	80	Sioux	1920	134	136	186	188	.	.
42	38	21	90	McIntosh	1661	137	147	193	199	220	238
43	46	15	60	Minnehaha	1784	123	134	173	189	210	228
44	46	16	50	Brule	1676	118	121	183	.	201	219
45	46	16	50	Sully	1689	110	127	180	184	220	222
46	46	16	50	Jerauld	1755	109	128	175	183	198	223
47	46	17	10	Dewey	1485	123	134	185	187	212	230
48	46	19	20	Edmunds	1599	140	136	184	189	214	226
49	46	19	30	Roberts	1960	132	140	188	189	209	236

OBSPLT = Observed planting date (ground-truth).

FPLT = Feyerherm planting date (predicted).

OBSHEAD = Observed heading date (predicted).

R2HEAD = Improved Robertson Version 2 Model heading date (predicted).

OBSRIPE = Observed ripening date (ground-truth).

R2RIPE = Improved Robertson Version 2 Model ripening date (predicted).

Figure 8 shows how the models would perform in biowindow 1 (planting stage), 2 (heading stage), and 3 (ripening stage for barley) if the criteria described in table 5 for the reformatted procedure were applied to the Feyerherm and Improved Robertson Version 2 Models. For example, in figure 8 the vertical lines are the limits of the biowindow prescribed in the procedure. The vertical distance between these two lines is the width of the window in days for the biowindow (in this case, the window is 23 days). Each horizontal bar represents the location of the biowindow predicted by the model for each of the 49 segments.

In figure 8 for biowindow 1, it can be seen that there is a fair amount of overlap with the prescribed biowindow with a bias towards the positive side (i.e., the model is progressing faster than the observed stage). For biowindow 2, there is a fair amount of overlap with little apparent bias. For biowindow 3, there is poor overlap with a bias on the positive side. Table 7 gives the probability that the model prediction will be within the prescribed biowindow. This was achieved by dividing the total number of days predicted inside the ground-truth window by the total number of days within the window for all the segments. It can be seen from table 7 that the Feyerherm model is accurate in predicting the planting data for biowindow 1 (spring wheat planting) 73 percent of the time, the Improved Robertson Version 2 Model selects days in biowindow 2 (spring wheat heading) 73 percent of the time and in biowindow 3 (barley ripening) only 21 percent of the time.

TABLE 7.- REFORMATTED PROCEDURE BIOWINDOW SELECTION RESULTS

	Biowindow 1 (spring wheat, plant)	Biowindow 2 (spring wheat, head)	Biowindow 3 (barley, ripe)
Total percent outside window	27.0	27.0	79.0
Percent days past the window (model late)	22.0	15.0	75.0
Percent days before the window (model early)	5.0	12.0	4.0
Probability of being inside window	73.0	73.0	21.0

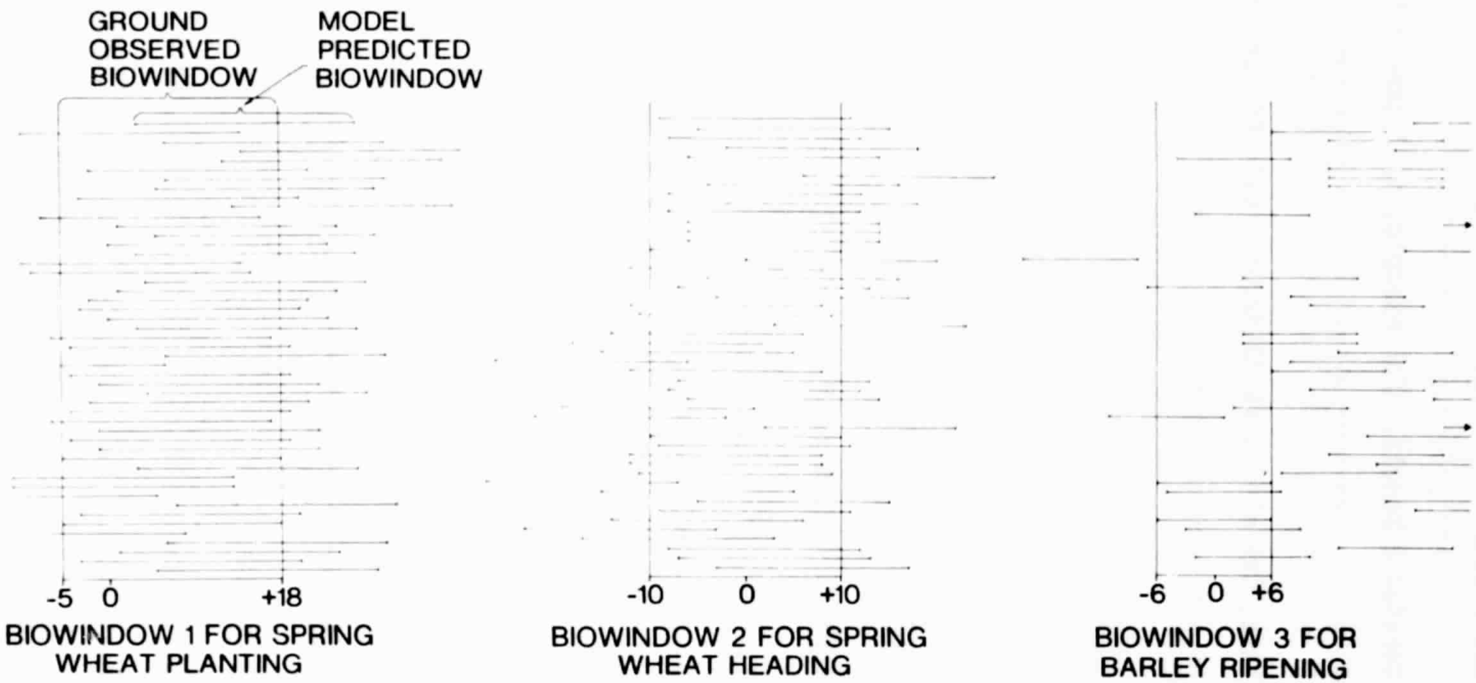

Figure 8.- Comparison of predicted biowindows versus the ground-observed biowindows for the Reformatted procedure.

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10. DISCUSSION OF RESULTS AND CONCLUSIONS

It should be noted that the analysis described is based on only 1 year of ground-truth data. It is possible that the scale utilized for the ground-truth data may be too coarse (± half a stage) to be used in this type of analysis. This is evident from tables 3 and 4 where the errors are, on the average, one-tenth to seven-tenths of a stage off. A small shift in the ground truth could conceivably shift the results to yield a different set of conclusions.

As far as the Feyerherm and Normal planting date models are concerned, the Feyerherm model is closer to the true planting date, as can be seen from the results. It is the more realistic of the two models because it compensates for unusual spring planting conditions whereas the Normal model does not. The 1979 crop year was unusual in that both spring wheat and barley were planted later than usual (ref. 7).

There appeared to be no difference between any of the spring wheat models (i.e., R0, R1, and R2) applied to spring wheat, based on the ground-truth data available for evaluation. The differences in the magnitudes of the errors between the three models are so small as to be insignificant from a physical standpoint, as can be seen from tables 3 and 4. This is true for almost all the stage intervals within which the models were evaluated. Since the ground-truth data are no more accurate than a one-half stage, any differences in the models could probably be attributed to "noise." The same may be said of the Robertson and Williams models when they are applied to barley so far as the magnitudes of the errors are concerned. It can be seen from figure 7 that the Williams model is progressing too fast for barley.

So far as application to the Reformatted procedure is concerned, the Feyerherm model performs adequately for the planting stage while the Improved Robertson Version 2 Model performs adequately for the heading stage but not for the ripening stage.

Modifications to the Original Robertson Model yielded more accurate results at the later stages of spring wheat growth than the earlier stages. An example of the improvement in performance can be seen in figure 9 which shows the distribution of the errors for stages 5.0 to 5.9. Both the improved versions show a smaller amount of variability than the Original Robertson Model.

Figure 9.- Distribution of crop stage prediction errors for spring wheat stages 5.0 - 5.9.

11. RECOMMENDATIONS

Based on the results to date, it is recommended that the Feyerherm planting date model be utilized for both spring wheat and barley. It appears that the Improved Robertson Version 2 Model is the more useful for predicting spring wheat and barley development stages. However, the model is not adequate to determine window 3 of the Reformatted procedure, which is used to separate barley from spring wheat. Further research on biowindow 3 is required if accurate results are to be obtained for identifying this window.

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U.S. GOVERNMENT PRINTING OFFICE 1981 771-014/875