80-10099

AgRISTARS

SR-L0-00416
JSC-16309

NASA CR-160468

"Made available under NASA sponsorship in the interest of early and wide dissemination of Earth Resources Survey Program information and without liability for any use made thereof."

Supporting Research

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

January 1980

TECHNICAL REPORT

VARIABILITY OF CROP CALENDAR STAGE DATES

M. L. Sestak, T. Hodges, and J. A. Artley

(E80-10099) VARIABILITY OF CROP CALENDAR STAGE DATES (Lockheed Engineering and Management) 23 p HC A02/MF A01 CSCL 02C

N80-23726

Unclas
G3/43 00099

LOCKHEED ENGINEERING AND MANAGEMENT SERVICES COMPANY, INC.
1830 NASA Road 1, Houston, Texas 77058

SR-LO-00416
JSC-16309

TECHNICAL REPORT

VARIABILITY OF CROP CALENDAR STAGE DATES

Job Order 73-312

This report describes Vegetation/Soils/Field Research activities of the Supporting Research project of the AgRISTARS program.

PREPARED BY

M. L. Sestak, T. Hodges, and J. A. Artley

APPROVED BY

D. E. Phinney, Supervisor
Agricultural Technology Section

J. E. Wainwright, Manager
Development and Evaluation Department

LOCKHEED ENGINEERING AND MANAGEMENT SERVICES COMPANY, INC.

Under Contract NAS 9-15800

For

Earth Observations Division

Space and Life Sciences Directorate

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

January 1980

LEMSCO-14070

CONTENTS

TABLES

1. INTRODUCTION

The estimation of crop production involves determination of both acreage and yield. Techniques for estimating acreage from remotely sensed data require a knowledge of how crop growth progresses through the growing season. Separation of similar crops is largely dependent upon differences in their respective development cycles in at least a part of the season.

Yield models are dependent upon crop stage information in order to relate weather events to specific stages of the crop's growth. Whereas both agrometeorological and spectral crop calendar models may be used, the simplest form of growth stage information is the average date when a specified percentage of the crop is at each stage; e.g., 50-percent date for heading of wheat. However, for such information to be useful, the variability of each stage date about the mean is needed.

Described in this report is an analysis of historical crop stage data for determining the correlation and the covariance between stages of a specific crop and between crops.

2. METHOD

For 11 states, crop calendar stage dates were obtained from the U.S. Department of Agriculture (USDA) Statistical Reporting Service for 12 crops at the Crop Reporting District (CRD) level covering a 4- or 5-year period. Table 1 is a list of crops and the states where they occur as well as the number of years of data collected for each state.

For South Dakota, Minnesota, Nebraska, and Iowa, weekly stage dates were available and the 10-, 50-, and 90-percent stage dates were calculated. Extrapolation techniques were developed to recover data when the observation period did not include complete coverage of a stage. The data set does not always contain consecutive years due to deletion of unsuitable data.

TABLE 1.— YEARS OF CROP CALENDAR DATA COLLECTED BY STATE AND CROP

Crop	Arkansas	Iowa[a]	Kentucky	Louisiana	Michigan	Minnesota	Mississippi	Nebraska	Ohio	South Dakota	Wisconsin
Corn	5	5/4	5	5	5	5	5	5	4	5	5
Soybeans	5	5/4	5	5	5	5	5	5	4	5	5
Spring wheat						10				5	
Sorghum	5			5			5	5		5	
Oats		5/4			5	5				5	5
Barley			5			5				5	
Rye						5				5	
Winter wheat	5		5	5	5		5	5	4		
Rice	5			5			5				
Cotton	5			5			5				
Alfalfa		0/4	5						4		5
Other hay		0/4			5				4		

[a]For Iowa, first number indicates years in full season data set; second number is years in USDA-reported 50-percent stage date set.

For Kansas, Illinois, and Indiana, multiyear averages of stage data at 10-day intervals were obtained, therefore no deviations or correlations between dates could be calculated.

For all other states, historical average 50-percent dates were the only data available. Both historical average 50-percent dates and weekly data were available for Iowa.

The period of observation and also the specific stages observed varied by state. The observation usually included planting and harvest and sometimes flowering or maturity. Stage definitions also varied from state to state. Hence, an approximately uniform code was developed for the stages reported and is included in table 2. For states with 50-percent dates, data were available between 1978 and 1974. For the other states, 5 years of data were selected between 1975 and 1961, which were the latest years with complete seasonal data.

A set of standard statistics were calculated based on the data available. Mean 50-percent dates and standard deviations were calculated for all reported stages in each crop of each CRD using the International Mathematical and Statistical Library (IMSL) package on the Laboratory for Applications of Remote Sensing (LARS)/Purdue IBM 370/148. Similar programs were used to calculate mean and standard deviation for the stage-to-stage duration (50-percent date, stage Y minus 50-percent date, stage X) and the stage entry period (90-percent date, stage X minus 10-percent date, stage X) for appropriate stages. Since dates were collected by CRD, state averages (both yearly and for the entire period) were also calculated. This was done by averaging unweighted CRD values. Finally, variance/covariance and correlation matrices were calculated for various combinations of crops and stages where knowledge of a statistical relationship could be useful in separating crops for acreage estimation or for modeling of yields. An examination of preliminary results resulted in a decision that covariances would be calculated on a statewide basis only because of the high variability of CRD data.

TABLE 2.— CROP CALENDAR STAGES

Crop	Stage								
	1.0	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0
Corn	Planting	Floral initiation		Tasseling or silking		Dent	Maturity	Harvest	
Soybeans	Planting	Rapid nodal development	Bloom	Podding		Full seed	Maturity	Harvest	
Sorghum	Planting	Full fifth leaf		Half bloom		Dough	Maturity	Harvest	
Small grains	Planting	Emergence	Tillering	Jointing	Flag leaf	Heading	Dough	Maturity	Harvest
Spring wheat									
Winter wheat									
Oats									
Barley									
Rye									
Rice									
Alfalfa	First cutting	Second cutting							
Other hay	First cutting	Second cutting							
Cotton	Planting	First square		First bloom		Setting bolls	Open bolls	Harvest	

For states where stage percentages throughout the growing period were available, the 10-, 50-, and 90-percent stage dates were calculated by fitting to a linear transformation of the logistic curve as follows:

$$P = \frac{100}{1+be^{-at}} \quad \text{Logistic curve}$$

$$\text{or, } \ln \frac{100}{P} - 1 = \ln b + (-a)t \quad \text{Linear transform}$$

$$Y = B + At$$

where

P = percent at stage

t = Julian date of stage observation

A,B, and a,b = arbitrary coefficients to be fitted

e = base of the natural logarithm

$\ln$ = function of the natural logarithm

After fitting, the curve was reverse-substituted with 10 percent, 50 percent, and 90 percent in order to obtain the appropriate stage dates.

Since this study was expected to show how crop calendar stage dates vary from one section of the U.S. to another as well as between crops, isoline maps of stage dates and standard deviations were plotted by assuming that each data point fell in the center of a CRD. Because of the small number of points, isolines were approximated by hand. Due to high variability and lack of geographic consistency, individual CRD values were plotted only for some crop and stage combinations.

For purposes of yield modeling and remote detection, some stages of crops are more important than others. Statistical reporting services also have their priorities in record collection. Not only are different crops considered of sufficient economic importance to warrant recording of stage dates in each state but also each reporting service records a different subset of growth stages of these crops. Crop stages are expected to be most variable and have the highest standard deviations in states where a crop is of minor economic importance. For these reasons, analysis of results concentrated on planting, flowering or maturity, and harvest. These stages were most consistently reported (particularly planting and harvest) and are frequently critical for both yield modeling and remote monitoring. An early vegetative stage is also highly desirable, particularly for remote detection and differentiation of crops; however, such emergence-type stages are seldom recorded.

For covariance and correlation analyses, selected stages were analyzed for different crops that occurred in the same part of the year; i.e., flowering of corn, soybeans, and sorghum plus harvest of small grains. Knowledge of statistical relationships between stages of different crops may allow estimation of stages of one crop when stages of another crop can be seen in spectral data.

3. ANALYSIS OF RESULTS

The major map products constructed during this study are indicated in table 3. Due to the difficulty of reproducing the large quantities of map and tabular products created during this investigation, only a narrative interpretation will be given here. The basic data and data products will be retained by the Lockheed Engineering and Management Services Company, Inc., Agricultural Technology Section, for review and updating as additional data are received.

3.1 STANDARD DEVIATIONS, STAGE DATES, AND DURATION

Standard deviations vary substantially within and between states, also between crops and stages; overall, they range from 1.0 to 23.0. However, for planting and tasseling or flowering of corn, soybeans, and sorghum in the northern and central states, standard deviations are less than 9.0. Standard deviations of harvest dates of corn, soybeans, and sorghum everywhere and of planting and flowering or tasseling in the south are quite variable, ranging from very low to about 20.0.

TABLE 3.– DATA PRODUCTS IN MAP FORM

Crop	Duration, planting to harvest	Planting date and standard deviation	Planting duration and standard deviation	Flowering date and standard deviation	Harvest date and standard deviation
Corn	✓	✓	✓	Tasseling	✓
Soybeans	✓	✓	✓	Flowering	✓
Sorghum	✓	✓	✓	Half bloom	✓
Spring wheat	✓	✓	✓	Heading	✓
Oats	✓	✓	✓	Heading	✓
Barley	✓	✓	✓	Heading	✓
Winter rye	✓	✓	✓	Heading	✓
Winter wheat	✓	✓	✓	Heading	✓
Rice	✓	✓			✓
Cotton	✓	✓		Flowering	✓

For wheat, oats, barley, and rye, standard deviations are generally high for planting and low for heading and harvest. Exceptions are standard deviations for planting of spring barley and winter rye (only in South Dakota and Minnesota) and harvest of winter wheat in Michigan and Ohio. Also, standard deviations for winter wheat in Arkansas are high and variable. Except for the broad regional patterns noted above, there appears to be little geographical consistency to the standard deviations, though this may be due to the small samples used in each area.

Stages for winter rye in South Dakota are about the same as for winter wheat. Corresponding stage dates for spring small-grains are all very close in South Dakota.

Corn 50-percent planting dates occur about 10 days before soybean and sorghum 50-percent planting dates except in Louisiana and Mississippi where they are 35 to 50 days earlier than soybeans.

Soybeans and sorghum are planted approximately at the same time in South Dakota, Nebraska, Kansas, and Louisiana. Sorghum is planted 15 to 30 days earlier in Arkansas and about 10 days earlier in Mississippi.

Planting duration (90-percent date minus 10-percent date) of corn and soybeans varies greatly and shows no geographic trend across Nebraska, Iowa, South Dakota, and Minnesota.

In the states where data were available, corn tasseling occurs 5 to 15 days before bloom of soybeans and sorghum.

Winter wheat and winter rye are harvested 5 to 15 days earlier than the spring small-grains in South Dakota. Winter wheat is harvested about 10 days earlier than spring oats throughout the midwest.

The corn harvest occurs later from the south toward the north, which may be partly due to very early corn planting dates in the southern states. The corn harvest is 40 to 50 days before the soybean harvest in the southern states but occurs about 10 days after the soybean harvest in the central and northern states. The sorghum harvest comes between the corn and soybean harvests, except in Mississippi where sorghum is harvested about 10 days before corn.

The winter-wheat planting-to-harvest period is longer moving northward from the south due to early fall planting and late summer harvest in the northern states.

The planting-to-harvest period for spring oats is about 5 days shorter than for spring wheat and about 5 days longer than for spring barley in Minnesota.

The planting-to-harvest period for corn is longest in the central states and is shorter in Mississippi and Louisiana due to early harvest; in Minnesota, South Dakota, and Wisconsin, it is due to late planting. The soybean planting-to-harvest period is shorter than that for corn in the northern and central states and about the same in the southern states. The sorghum planting-to-harvest period is shorter than that for soybeans (or corn) in the southern states, about the same as that for soybeans in the central states, and longer than that for soybeans in the northern states.

Cotton is planted about 5 to 15 days after rice and is harvested about 20 days after rice, therefore the growth period is approximately 10 days longer than for rice.

3.2 COVARIANCE AND CORRELATION MATRICES

Covariance and correlation matrices between selected stages of different crops within a given state are shown in tables 4 through 10. The stages selected are those that occur at approximately the same time. Table 2 should be used as a key to the stages indicated in tables 4 through 10.

The diagonal elements of the covariance matrices give the variance of each crop at the specified stage. The off-diagonal elements indicate the degree

TABLE 4.— COVARIANCE AND CORRELATION MATRICES FOR IOWA

Crop	Stage 1.0, corn	Stage 1.0, soybeans	Stage 1.0, alfalfa	Stage 1.0, other hay	Stage 4.0, oats
Covariance matrix					
Stage 1.0, corn	42.53				
Stage 1.0, soybeans	34.96	-32.65			
Stage 1.0, alfalfa	29.33	24.16	46.71		
Stage 1.0, other hay	33.58	26.11	44.59	58.10	
Stage 4.0, oats	39.39	31.89	50.14	53.42	66.39
Correlation matrix					
Stage 1.0, corn	1.00				
Stage 1.0, soybeans	0.94	1.00			
Stage 1.0, alfalfa	0.66	0.62	1.00		
Stage 1.0, other hay	0.68	0.60	0.86	1.00	
Stage 4.0, oats	0.74	0.68	0.90	0.86	1.00

Crop	Stage 2.0, alfalfa	Stage 2.0, other hay	Stage 3.0, corn	Stage 3.0, soybeans	Stage 7.0, oats
Covariance matrix					
Stage 2.0, alfalfa	41.86				
Stage 2.0, other hay	7.21	38.42			
Stage 3.0, corn	26.60	2.19	26.09		
Stage 3.0, soybeans	27.64	8.16	25.61	30.82	
Stage 7.0, oats	37.88	1.38	29.39	27.96	45.44
Correlation matrix					
Stage 2.0, alfalfa	1.00				
Stage 2.0, other hay	0.18	1.00			
Stage 2.0, corn	0.80	0.07	1.00		
Stage 2.0, soybeans	0.77	0.24	0.90	1.00	
Stage 7.0, oats	0.87	0.03	0.85	0.75	1.00

Crop[a]	Stage 4.0, corn	Stage 4.0, soybeans	Stage 6.0, corn	Stage 6.0, soybeans
Covariance matrix				
Stage 4.0, corn	32.96			
Stage 4.0, soybeans	18.76	19.91		
Stage 6.0, corn			40.76	
Stage 6.0, soybeans			17.91	56.41
Correlation matrix				
Stage 4.0, corn	1.00			
Stage 4.0, soybeans	0.73	1.00		
Stage 6.0, corn			1.00	
Stage 6.0, soybeans			0.37	1.00

[a]Some small tables have been combined.

TABLE 5.— COVARIANCE AND CORRELATION MATRICES FOR MINNESOTA

Crop	Stage 3.0, corn	Stage 3.0, soybeans	Stage 4.0, corn	Stage 4.0, soybeans	Stage 7.0, spring wheat	Stage 7.0, oats	Stage 7.0, barley	Stage 7.0 rye
Covariance matrix								
Stage 3.0, corn	13.84							
Stage 3.0, soybeans	8.98	33.17						
Stage 4.0, corn	8.39	8.14	12.26					
Stage 4,0, soybeans	10.46	15.84	11.43	27.29				
Stage 7.0, spring wheat	26.74	8.66	18.64	8.30	141.36			
Stage 7.0, oats	27.29	19.61	24.56	20.38	57.46	136.46		
Stage 7.0, barley	20.58	15.40	18.29	19.14	33.06	104.35	87.84	
Stage 7.0, rye	14.97	11.16	11.45	9.66	20.79	62.42	49.39	37.63
Correlation matrix								
Stage 3.0, corn	1.00							
Stage 3.0, soybeans	0.42	1.00						
Stage 4.0, corn	0.64	0.40	1.00					
Stage 4.0, soybeans	0.54	0.53	0.62	1.00				
Stage 7.0, spring wheat	0.60	0.13	0.45	0.13	1.00			
Stage 7.0, oats	0.63	0.29	0.60	0.33	0.41	1.00		
Stage 7.0, barley	0.59	0.29	0.56	0.39	0.30	0.95	1.00	
Stage 7.0, rye	0.66	0.32	0.53	0.30	0.29	0.87	0.86	1.00

Crop	Stage 1.0, corn	Stage 1.0, soybeans	Stage 4.0, spring wheat	Stage 4.0, oats	Stage 4.0, barley	Stage 4.0, rye
Covariance matrix						
Stage 1.0, corn	86.62					
Stage 1.0, soybeans	54.71	41.69				
Stage 4.0, spring wheat	40.61	27.88	43.59			
Stage 4.0, oats	47.71	32.41	22.59	47.42		
Stage 4.0, barley	50.23	36.75	28.67	34.06	36.91	
Stage 4.0, rye	8.68	1.76	8.08	11.09	9.63	21.36
Correlation matrix						
Stage 1.0, corn	1.00					
Stage 1.0, soybeans	0.92	1.00				
Stage 4.0, spring wheat	0.66	0.65	1.00			
Stage 4.0, oats	0.75	0.73	0.50	1.00		
Stage 4.0, barley	0.89	0.94	0.71	0.81	1.00	
Stage 4.0, rye	0.20	0.06	0.26	0.35	0.34	1.00

Crop	Stage 1.0, rye	Stage 6.0, corn	Stage 6.0, soybeans
Covariance matrix			
Stage 1.0, rye	8.62		
Stage 6.0, corn	1.63	53.42	
Stage 6.0, soybeans	5.58	54.99	83.96
Correlation matrix			
Stage 1.0, rye	1.00		
Stage 6.0, corn	0.08	1.00	
Stage 6.0, soybeans	0.21	0.82	1.00

TABLE 6.— COVARIANCE AND CORRELATION MATRICES FOR MISSISSIPPI

Crop	Stage 1.0, corn	Stage 1.0, soybeans	Stage 1.0, sorghum	Stage 1.0, cotton
Covariance matrix				
Stage 1.0, corn	150.41			
Stage 1.0, soybeans	38.20	108.14		
Stage 1.0, sorghum	39.93	18.81	101.62	
Stage 1.0, cotton	74.49	26.15	31.28	81.60
Correlation matrix				
Stage 1.0, corn	1.00			
Stage 1.0, soybeans	0.30	1.00		
Stage 1.0, sorghum	0.32	0.18	1.00	
Stage 1.0, cotton	0.67	0.28	0.34	1.00

Crop	Stage 4.0, corn	Stage 4.0, soybeans	Stage 4.0, cotton
Covariance matrix			
Stage 4.0, corn	79.57		
Stage 4.0, soybeans	18.92	33.51	
Stage 4.0, cotton	41.69	21.54	98.43
Correlation matrix			
Stage 4.0, corn	1.00		
Stage 4.0, soybeans	0.37	1.00	
Stage 4.0, cotton	0.47	0.38	1.00

Crop	Stage 6.0, corn	Stage 6.0, soybeans	Stage 6.0, sorghum	Stage 6.0, cotton
Covariance matrix				
Stage 6.0, corn	165.65			
Stage 6.0, soybeans	55.64	55.13		
Stage 6.0, sorghum	29.63	25.79	118.29	
Stage 6.0, cotton	90.92	60.07	54.38	163.34
Correlation matrix				
Stage 6.0, corn	1.00			
Stage 6.0, soybeans	0.58	1.00		
Stage 6.0, sorghum	0.21	0.32	1.00	
Stage 6.0, cotton	0.55	0.63	0.39	1.00

TABLE 7.— COVARIANCE AND CORRELATION MATRICES FOR NEBRASKA

Crop	Stage 1.0, corn	Stage 1.0, sorghum	Stage 4.0, winter wheat
Covariance matrix			
Stage 1.0, corn	17.17		
Stage 1.0, sorghum	5.41	14.25	
Stage 4.0, winter wheat	9.66	1.61	35.53
Correlation matrix			
Stage 1.0, corn	1.00		
Stage 1.0, sorghum	0.35	1.00	
Stage 4.0, winter wheat	0.39	0.07	1.00

Crop	Stage 3.0, corn	Stage 4.0, winter wheat	Stage 7.0, winter wheat
Covariance matrix			
Stage 3.0, corn	31.54		
Stage 4.0, winter wheat	8.49	35.53	
Stage 7.0, winter wheat	2.03	22.35	53.94
Correlation matrix			
Stage 3.0, corn	1.00		
Stage 4.0, winter wheat	0.25	1.00	
Stage 7.0, winter wheat	0.05	0.51	1.00

TABLE 8.— COVARIANCE AND CORRELATION MATRICES FOR OHIO

Crop	Stage 1.0, corn	Stage 1.0, soybeans	Stage 4.0, winter wheat
Covariance matrix			
Stage 1.0, corn	68.63		
Stage 1.0, soybeans	48.51	46.41	
Stage 4.0, winter wheat	39.91	32.40	41.17
Correlation matrix			
Stage 1.0, corn	1.00		
Stage 1.0, soybeans	0.86	1.00	
Stage 4.0, winter wheat	0.75	0.74	1.00

Crop	Stage 3.0, corn	Stage 3.0, soybeans	Stage 7.0, winter wheat
Covariance matrix			
Stage 3.0, corn	14.24		
Stage 3.0, soybeans	7.86	26.58	
Stage 7.0, winter wheat	14.42	17.77	36.39
Correlation matrix			
Stage 3.0, corn	1.00		
Stage 3.0, soybeans	0.40	1.00	
Stage 7.0, winter wheat	0.63	0.57	1.00

Crop[a]	Stage 4.0, corn	Stage 4.0, soybeans	Stage 1.0, winter wheat	Stage 6.0, corn	Stage 6.0, soybeans
Covariance matrix					
Stage 4.0, corn	49.70				
Stage 4.0, soybeans	15.97	17.94			
Stage 1.0, winter wheat			31.26		
Stage 6.0, corn			3.23	21.38	
Stage 6.0, soybeans			4.96	2.79	15.88
Correlation matrix					
Stage 4.0, corn	1.00				
Stage 4.0, soybeans	0.53	1.00			
Stage 1.0, winter wheat			1.00		
Stage 6.0, corn			0.13	1.00	
Stage 6.0, soybeans			0.22	0.15	1.00

[a]Some small tables have been combined.

TABLE 9.— COVARIANCE AND CORRELATION MATRICES FOR SOUTH DAKOTA

Crop	Stage 1.0, corn	Stage 1.0, sorghum	Stage 4.0, spring wheat	Stage 4.0, oats	Stage 4.0, barley	Stage 4.0, rye	Stage 4.0, winter wheat
Covariance matrix							
Stage 1.0, corn	47.23						
Stage 1.0, sorghum	21.35	34.36					
Stage 4.0, spring wheat	18.87	8.48	24.46				
Stage 4.0, oats	7.82	11.00	12.43	20.89			
Stage 4.0, barley	10.46	10.33	7.70	10.96	21.65		
Stage 4.0, rye	0.47	1.89	4.25	4.24	0.41	18.02	
Stage 4.0, winter wheat	5.37	2.57	9.14	7.86	3.37	7.83	13.16
Correlation matrix							
Stage 1.0, corn	1.00						
Stage 1.0, sorghum	0.53	1.00					
Stage 4.0, spring wheat	0.56	0.29	1.00				
Stage 4.0, oats	0.25	0.41	0.55	1.00			
Stage 4.0, barley	0.33	0.38	0.33	0.52	1.00		
Stage 4.0, rye	0.02	0.08	0.20	0.22	0.02	1.00	
Stage 4.0, winter wheat	0.22	0.12	0.51	0.47	0.20	0.51	1.00

Crop	Stage 3.0, corn	Stage 3.0, soybeans	Stage 7.0, spring wheat	Stage 7.0, oats	Stage 7.0, barley	Stage 7.0, rye	Stage 7.0, winter wheat
Covariance matrix							
Stage 3.0, corn	20.43						
Stage 3.0, sorghum	6.27	19.82					
Stage 7.0, spring wheat	2.46	6.29	44.79				
Stage 7.0, oats	2.79	7.30	27.85	30.56			
Stage 7.0, barley	9.88	8.11	20.51	14.53	41.67		
Stage 7.0, rye	9.47	7.84	25.53	19.65	28.37	45.16	
Stage 7.0, winter wheat	9.14	7.70	10.10	8.58	23.19	19.21	39.65
Correlation matrix							
Stage 3.0, corn	1.00						
Stage 3.0, sorghum	0.31	1.00					
Stage 7.0, spring wheat	0.08	0.21	1.00				
Stage 7.0, oats	0.11	0.30	0.75	1.00			
Stage 7.0, barley	0.34	0.28	0.47	0.41	1.00		
Stage 7.0, rye	0.31	0.26	0.57	0.53	0.65	1.00	
Stage 7.0, winter wheat	0.32	0.27	0.24	0.25	0.57	0.45	1.00

Crop	Stage 1.0, rye	Stage 1.0, winter wheat	Stage 6.0, corn	Stage 6.0, sorghum
Covariance matrix				
Stage 1.0, rye	19.03			
Stage 1.0, winter wheat	6.48	21.44		
Stage 6.0, corn	-17.06	-11.35	85.01	
Stage 6.0, sorghum	-6.20	-9.31	50.05	66.21
Correlation matrix				
Stage 1.0, rye	1.00			
Stage 1.0, winter wheat	0.32	1.00		
Stage 6.0, corn	-0.42	-0.27	1.00	
Stage 6.0, sorghum	-0.17	-0.25	0.67	1.00

TABLE 10.— COVARIANCE AND CORRELATION MATRICES FOR WISCONSIN

Crop	Stage 1.0, corn	Stage 1.0, soybeans	Stage 3.0, corn	Stage 4.0, corn	Stage 4.0, oats	Stage 6.0, corn	Stage 6.0, soybeans	Stage 7.0, oats
Covariance matrix								
Stage 1.0, corn	30.41							
Stage 1.0, soybeans	25.97	29.98						
Stage 3.0, corn	34.49	31.15	49.07					
Stage 4.0, corn	41.65	38.76	57.87	75.28				
Stage 4.0, oats	36.39	30.28	45.06	53.64	59.38			
Stage 6.0, corn	14.83	15.66	19.78	30.29	9.97	50.24		
Stage 6.0, soybeans	0.70	4.03	-2.47	-0.57	-6.46	21.11	33.60	
Stage 7.0, oats	30.11	25.61	37.03	45.06	46.87	19.06	9.46	49.43
Correlation matrix								
Stage 1.0, corn	1.00							
Stage 1.0, soybeans	0.86	1.00						
Stage 3.0, corn	0.89	0.81	1.00					
Stage 4.0, corn	0.87	0.82	0.95	1.00				
Stage 4.0, oats	0.86	0.72	0.83	0.80	1.00			
Stage 6.0, corn	0.38	0.40	0.40	0.49	0.18	1.00		
Stage 6.0, soybeans	0.02	0.13	-0.06	-0.01	-0.14	0.51	1.00	
Stage 7.0, oats	0.78	0.67	0.75	0.74	0.87	0.38	0.23	1.00

to which the variances of the paired crop/stage combinations are linked. When an off-diagonal element is small relative to the diagonal elements, the paired crop/stage combination can be considered to vary independently. Analyses of the covariance matrices show very little in the way of consistent patterns in covariance between crop/stage combinations.

The correlation matrices indicate the degree to which stage data on a given crop might be used to predict either the stage date of another crop or the date of a later stage for the same crop. Low correlation is indicative of sensitivity to variation in environmental conditions between stages of the same crop and between different crops at similar stages. High correlation indicates either similar response between crops, small variations from average conditions in the data set, or a relative insensitivity to variable environmental conditions.

In Iowa, covariance and correlation matrices were quite high between corn planting, soybean planting, and oat heading, and between corn tasseling, soybean flowering, and oat harvest, and between corn dough and soybean podding. Correlation between corn and soybean harvest was low. Iowa correlations may be high in part because only four years of data were available in the USDA-supplied 50-percent dates which were used. For Nebraska, all covariances and correlations were generally low, possibly because data for each stage consisted of a different set of 5 years from 1965 to 1975; variation due to each year's individual effect was wiped out. However, the pattern of covariances is the same as for nearby states, but with lower absolute values.

In South Dakota, corn and soybean covariances and correlations were low except for a high correlation between harvest 50-percent dates. For the small grains, covariances and correlations were mixed, both high and low. Planting of winter wheat and of winter rye were poorly correlated.

For Minnesota, planting of corn and soybeans and heading of oats and of barley were highly correlated with each other but only moderately correlated with heading of spring wheat and poorly correlated with heading of winter rye. Corn tasseling and dough stages and soybean flowering and podding stages were moderately intercorrelated. Spring-wheat harvest was moderately correlated with tasseling of corn and with bloom of soybeans but was poorly correlated with the other small grains. Harvest dates of the other small grains were highly intercorrelated with each other but had low correlations with spring-wheat harvest and the tasseling and podding stages of corn and soybeans. Corn-harvest and soybean-harvest dates are highly correlated with each other but had poor correlations with winter-rye planting.

In Wisconsin and Ohio, corn and soybean planting were highly correlated with each other and with heading of winter wheat. In Wisconsin, corn planting, tasseling, and dough stages and oat heading and harvest stages were highly intercorrelated.

In Mississippi, all correlations between corn, sorghum, and soybeans were low.

4. CONCLUSIONS AND RECOMMENDATIONS

Analysis of this crop calendar information indicates that sufficient geographical interrelation and intercrop covariance exists. Some relations between crop stages can be developed to aid in extending limited data beyond the stages initially obtained. However, the sometimes high and erratic crop variances indicate that a larger data set should be obtained before such a project is attempted.