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Supporting Research

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CROP CALENDARS FOR THE U.S., U.S.S.R., AND CANADA IN SUPPORT OF THE EARLY WARNING PROJECT

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16. Abstract

For the 1980 requirements of the Early Warning Project, crop calendars for wheat and barley are required for the U.S., the U.S.S.R., and Canada. In this report, new crop calendars are produced for U.S. regions where several years of periodic growth stage observations are available on a CRD basis. Preexisting crop calendars from the LACIE are also collected as are U.S. crop calendars currently being created for the Foreign Commodities Production Forecast project. For the U.S.S.R. and Canada, no new crop calendars are created because no new data are available. Instead, LACIE crop calendars are compared against simulated normal daily temperatures and against the Robertson wheat and Williams barley phenology models run on the simulated normal temperatures. Severe inconsistencies are noted and discussed. For the U.S.S.R., spring and fall planting dates can probably be estimated accurately from satellite or meteorological data. For the starter model problem, the Feyerherm spring wheat model is recommended for spring-planted small grains, and the results of an analysis are presented. For fall-planted small grains, use of normal planting dates supplemented by spectral observation of an early stage is recommended. The importance of non-meteorological factors as they pertain to meteorological factors in determining fall planting is discussed. Crop calendar data available at the Johnson Space Center for the U.S., U.S.S.R., Canada, and other countries are inventoried.

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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 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 is comprised of a balanced program of remote sensing research, development, and testing which addresses 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 (DCLC)
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. Specific areas of these projects to which phenological information is pertinent include classification, acreage and yield estimation, and detection of episodal events.

For identification in satellite imagery of factors affecting crop production over large areas, it is necessary to have information about the expected course of crop development (and hence spectral appearance) in any area. The simplest approach is to gather information about crop development in previous years. For the Large Area Crop Inventory Experiment (LACIE), such information was collected primarily in the U.S., but also in Canada, the U.S.S.R., China, India, and other countries. The information was used to produce historical or normal crop calendars in several formats. In this study, we used additional U.S. data to generate new U.S. crop calendars, we evaluated LACIE crop calendars for the U.S.S.R and Canada, and we prepared an inventory of crop development data available at the Johnson Space Center.

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2. U.S. CROP CALENDARS

For nine states in the U.S., we have 5 or more years of periodic observations of crop development on a Crop Reporting District (CRD) level. The crops and CRD's covered by these data are shown in table 1. Additionally, in Louisiana, Mississippi, Arkansas, Ohio, Kentucky, Michigan, and Wisconsin, we have 50-percent dates for some stages of major crops for 4 to 5 years.

During the LACIE, crop calendars were prepared for many of the wheat-growing states, based on limited data or data of uncertain quality. Table 2 lists all the states for which various types of crop development data or crop calendars are available at the Johnson Space Center.

The periodic observations of crop development were processed to calculate 10-, 50-, and 90-percent stage dates by fitting to a linear transformation of the logistic curve as follows:

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

Linear transformation: $\ln(\frac{100}{P} - 1) = \ln b - at$

where

P = percent at stage

t = Julian date of stage observation

a,b = arbitrary coefficients to be fitted

e = base of natural logarithm

$\ln$ = function of the natural logarithm

After fitting, the curve was reverse substituted with 10, 50, and 90 percent in order to obtain the appropriate stage dates. The 10-, 50-, and 90-percent dates for stages of each crop are to be found by state, crop, and CRD in reference 10. Each curve was then plotted against the Julian date at 10-day intervals to obtain plots of crop development (ref. 10).

TABLE 1.- CRD'S WITH PERIODIC CROP CALENDAR DATA BY STATE AND CROP

Crop	CRD number by State								
	Colorado (8)	Iowa (19)	Kansas (20)	Minnesota (27)	Montana (30)	Nebraska (31)	North Dakota (38)	South Dakota (46)	Texas (48)
Corn	2,6,7,9	1-9	1-9	1,4,5,7	1,2,3,5, 7,8,9	1,2,3,5, 7,8,9		1-9	1,2,5,6, 7,8,10,11, 12,13,14
Soybeans		1-9	4,5,6, 7,8,9	4,5,7		2,3,5,6, 8,9		3,6,9	1-15
Spring wheat				1,4,5,7	1,2,3,5, 7,8,9			1-9	
Sorghum	2,6,9		1-9			1,2,3,5, 6,7,8,9		1-9	1,2,3,4,6, 7,8,13
Oats		1-9		1,4,5,7				1-9	
Spring barley	1,2,6,7, 8,9			1,4,5,7	1,2,3,5, 7,8,9		1-9	1-9	
Rye				1,4,5,7				1-9	
Winter wheat	2,6,7,9		1-9		1,2,3,5, 7,8,9	1,2,3,5, 6,7,8,9		1-9	1,2,3,4,5, 6,7,9,10,1 11,13
Rice									
Cotton									1-15
Winter barley	2,6,7,9								

TABLE 2.- CRD'S OF VARIOUS STATES FOR WHICH CROP CALENDAR INFORMATION IS AVAILABLE

State	CRD number by type of information				
	LACIE	Color bar graph	50-percent dates	Period'c observations	Published state booklets
Alabama					
Alaska					
Arizona	5,7				
Arkansas	6				
California	51				
Colorado	all			all	
Connecticut					
Delaware					
Florida					
Georgia					
Hawaii					
Idaho	1,9	1,7,8,9			
Illinois		all		all	
Indiana	all	all		all	
Iowa			all	all all	
Kansas	all	all	all	all all	
Kentucky			all		
Louisiana			all		
Maine					
Maryland	2				
Massachusetts					
Michigan			all		
Minnesota	1,4,5,7			1,4,5,7	
Missouri	9				
Mississippi			all		
Montana	all	all	all	all	
Nebraska	all	all		all	
Nevada					
New Hampshire					
New Jersey					
New Mexico					
New York					
North Carolina					
North Dakota	all	all		all all	
Ohio		all	all		
Oklahoma	all	all		all	
Oregon		1,2,3,7,8			
Pennsylvania	5				
Rhode Island					
South Carolina					
South Dakota	all	all	all	all all	
Tennessee	2				
Texas	1,2,3,4, 7,8,11	11,12,21,22,30, 40,51,52,60,70, 81,82,90,96,97			
Utah	1				
Vermont					
Virgina					
Washington	3,5,9	1,2,3,5,9			
West Virginia					
Wisconsin			all		
Wyoming					

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For the states with 4 or 5 years of 50-percent dates for stages of various crops, mean 50-percent dates and standard deviations are in reference 10 as well as the crop calendar plots produced for the LACIE. The glossy color photographs of bar graphs are not included in this report because of difficulty of reproduction. We believe that the new crop calendars based on periodic observations over known periods are generally more accurate than the LACIE crop calendars and should be preferred for regions where they are available.

Recently, statewide crop calendars have been produced for many crops for 10 states in the U.S. These crop calendars include documentation of data sources and an evaluation of the reliability of the crop calendars. Eventually, almost all of the continental U.S. will be covered by these crop calendars. Currently available crop calendars are in reference 10.

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3. U.S.S.R. AND CANADA CROP CALENDARS

For the LACIE, normal crop calendars were prepared for numerous regions of the U.S.S.R. and Canada based on limited historical phenology data or data of uncertain quality. To check the quality of the U.S.S.R. normal crop calendars, we decided to run the Robertson (1968) spring and winter wheat and Williams (1974) spring barley phenology models on simulated long term average daily maximum and minimum temperatures. The daily temperatures were estimated from 20-year mean monthly temperatures for economic regions using a second order harmonic. A constant difference of 20° C between daily maximum and minimum temperatures was assumed to get simulated daily values of maximum and minimum temperatures. A better simulation could probably be done by varying the difference between maximum and minimum temperatures by season and by location, but data were not available to do this. The Robertson and Williams models were run using 30 or 60 consecutive planting dates around the planting dates specified in the LACIE crop calendars. Russian crop calendars, phenology model outputs, and simulated daily temperatures are in reference 11. U.S.S.R. crop calendars, latitudes, planting periods, and availability of long term mean monthly temperatures are summarized in table 3. For several economic regions where temperatures were not available, LACIE crop calendars could not be compared to the phenology models.

For Canada, long term mean monthly maximum and minimum temperatures were available for portions of the provinces of Alberta, Saskatchewan, and Manitoba. The Robertson and Williams spring wheat and barley models were run for those regions on simulated daily temperatures. The LACIE crop calendars, simulated daily temperatures, and phenology model outputs are in reference 12. Crop calendars, planting dates, and latitudes are summarized in table 4.

In the Robertson and Williams phenology models, jointing is defined as the beginning of stem elongation. The LACIE crop calenders are probably reporting jointing when the first internode of the stem has elongated sufficiently to raise the first node above the ground, about a week later than the model definition.

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TABLE 3.- SUMMARY OF LACIE U.S.S.R. CROP CALENDAR

Oblast or ASSR	Economic region		Latitude	Planting periods		
	Name	Number		WW	SB	SW
Estonia	Baltics	0100	58.50	244-254	110-120	--
Latvia	Baltics		57.30	244-254	110-120	--
Lithuania	Baltics		55.00	244-254	110-120	--
Kaliningrad	Baltics		54.70	244-254	110-120	--
L'vov	W. Ukraine	0300	50.50	240-259	100-110	--
Volyn	W. Ukraine		51.50	240-259	100-110	--
Kiyev	C. Ukraine	0400	50.50	240-260	108-117	--
Chernigov	C. Ukraine		51.00	240-250	102-110	--
Kirovograd	C. Ukraine		48.50	220-268	70-120	70-120
Poltava	N.E. Ukraine	0500	50.00	228-252	83-109	--
Sumy	N.E. Ukraine		50.50	230-246	97-112	--
Dnepropetrovsk	E. Ukraine	0600	48.30	228-252	85-108	--
Moldavia	Moldavia	0800	46.50	238-249	90-101	--
Krasnodar	Krasnodar	0900	45.00	258-270	90-101	--
Stavropol'	NE. Caucasus	1000	45.00	240-285	60-119	65-115
Rostov	NE. Caucasus		48.00	215-263	70-129	80-130
Dagestan	NE. Caucasus		43.00	294-324	70-129	--
Kabardino-Balkar	NE. Caucasus		43.50	254-271	70-129	--
Checheno-Ingush	NE. Caucasus		43.00	294-314	70-129	--
Kalmyk	NE. Caucasus		46.50	294-314	80-100	--
Belgorod	W. Black Soil	1100	50.70	245-263	97-110	--
Kursk	W. Black Soil		51.50	202-231	90-149	90-140
Orel	W. Black Soil		53.00	234-246	109-127	105-120
Lipetsk	E. Black Soil	1200	52.70	244-264	92-108	--
Tambov	E. Black Soil		52.70	244-264	97-110	--
Voronezh	E. Black Soil		51.00	210-255	80-129	80-130
Bryansk	Central	1300	53.00	244-254	110-120	--
Vladimir	Central		56.00	227-243	110-120	120-130
Ivanovo	Central		57.00	228-238	110-120	120-130
Kalinin	Central		57.00	223-233	133-150	130-150
Kaluga	Central		54.50	226-242	133-150	120-130
Moscow	Central		55.50	225-243	133-150	120-130
Ryazan'	Central		54.50	226-242	133-150	120-130
Smolensk	Central		55.00	244-254	110-120	--
Yaroslavl'	Central		58.00	224-224	110-120	115-130
Gor'kiy	Volga-Vyatsk	1400	56.50	235-253	110-120	--
Mari	Volga-Vyatsk		56.50	235-253	110-120	--
Mordva	Volga-Vyatsk		54.50	235-250	110-120	102-142
Chuvash	Volga-Vyatsk		55.50	232-254	110-120	105-145
Tatar	Upper Volga	1500	55.50	232-252	110-120	105-145
Ul'yanovsk	Upper Volga		54.00	200-259	80-130	80-130
Kuybyshev	Middle Volga	1600	53.00	200-259	80-139	95-140
Penza	Middle Volga		53.00	200-259	80-139	80-130
Saratov	Middle Volga		51.50	258-273	80-139	--
Astrakhan'	Lower Volga	1700	47.00	295-315	80-100	--
Volgograd	Lower Volga		49.70	259-273	80-100	--
Udmurt	NW. Urals	1800	57.00	219-230	120-145	110-140
Bashkir	S. Urals	1900	54.00	221-248	110-160	110-160
Orenburg	S. Urals		52.00	221-248	110-160	95-145

TABLE 3.- Concluded.

Oblast or ASSR	Economic region		Latitude	Planting periods		
	Name	Number		WW	SB	SW
Chelyabinsk	NE. Urals	2000	54.00	221-248	110-160	95-155
Kurgan	NE. Urals		55.50	221-248	110-160	110-160
Sverdlovsk	NE. Urals		58.50	233-246	110-160	95-110
Tyumen'	NE. Urals		58.00	223-255	96-110	130-150
Kustanay	Kustanay	2200	52.50	223-255	110-159	80-130
Kemerovo	W. Siberia	2600	54.50	233-243	130-138	150-170
Omsk	W. Siberia		56.00	233-243	110-160	110-155
Altay	Altay	2700	52.30	233-243	100-159	100-150
Georgia	Transcaucasus	2800	42.00	256-273	100-159	--
Azerbaijan	Transcaucasus		40.30	295-315	100-159	--
Armenia	Transcaucasus		40.10	256-273	100-159	--
S. Kazakhstan	S. Kazakhstan	2900	48.00	256-273	100-159	80-103
Kzyl-Orda	S. Kazakhstan		44.80	256-273	100-159	--
Chimkent	S. Kazakhstan		43.70	307-327	100-159	50-80
Dzhambul	S. Kazakhstan		44.30	230-289	100-159	--
Dzhezkazgan	S. Kazakhstan		47.50	230-289	100-159	--
Alma-Ata	S. Kazakhstan		44.00	240-299	100-159	--
Taldy-Kurgan	S. Kazakhstan		45.00	240-299	100-159	--
Vostochno	S. Kazakhstan		48.50	215-229	100-159	--
Uzbek	Central Asia	3000	42.00	296-315	100-159	--
Kirgiz	Central Asia		41.00	256-285	100-159	65-95
Turkmen	Central Asia		39.00	290-319	100-159	105-125
Krasnoyarsk	E. Siberia	3100	52.00-60.00	290-319	100-159	105-155
Irkutsk	E. Siberia		56.00	290-319	130-146	130-145
Chita	E. Siberia		52.00	290-319	130-142	110-130
Buryat	E. Siberia		52.00	290-319	130-142	70-120
Tuva	E. Siberia		64.00	290-319	130-142	110-130
Far East	Far East	3200	44.00-60.00	290-319	90-110-139	110-125
Amur	Far East		53.00	290-319	90-	110-125

TABLE 4.- SUMMARY OF LACIE CANADA CROP CALENDARS

Province and region	Latitude	Planting period	
		SW	SB
Alberta			
South (area 1)	51°	90-155	--
Central (area 2)	56°	115-163	--
North (area 3)	57°	124-163	--
Lethbridge (S.)	49.7°	95-140	105-152
Edmonton (C.)	53.5°	98-145	110-162
Beaver Lodge (N.)	55.2°	98-145	122-170
Lacombe (S.)	52.5°	100-145	115-163
Saskatchewan			
Southeast (area 1)	49.7°	90-155	--
Regina-Wyeth (area 2)	50.0°	90-155	--
South central (area 3)	49.8°	90-155	--
Southwest (area 4)	49.8°	90-155	--
East central (area 5)	51.2°	105-163	--
Central (area 6)	51.5°	105-163	--
West central (area 7)	51.6°	105-163	--
Northeast (area 8)	52.7°	118-158	--
Northwest (area 9)	53°	118-158	--
Indian Head (SE.)	50.6°	100-145	105-150
Scott (WC.)	52.4°	90-145	110-155
Saskatoon (C.)	52.2°	100-145	110-158
Melfort (NE.)	52.85°	95-142	120-165
Swift Current (SC.)	50.4°	102-149	105-150
Regina (RW)	50.47°	90-136	105-149
Manitoba			
Southeast	50°	90-155	--
South central	49.7°	90-155	--
Southwest	49.8°	90-155	--
North	50.5°	118-158	--
Brandon (SW.)	49.85°	100-145	110-155
Morden (SC.)	49.2°	90-140	110-155
Winnepeg (SE.)	49.8°	90-140	110-155

The concept of running a phenology model on normal weather data was tested by running the Robertson spring wheat model on South Dakota daily temperatures simulated from long term monthly average temperatures. The model stage dates were generally within 5 to 10 days of the historical average stage dates for heading and ripe as shown in table 5. Phenological response to weather and planting date variability over several years will not necessarily average in the same way that weather variability averages, and the Robertson and Williams models are not proven to be accurate for the U.S.S.R., so we cannot assume that the phenology model stage dates are generally better than the LACIE crop calendar stage dates.

This technique of running a phenology model on long term average daily weather variables can be used to evaluate crop calenders in areas where historical phenology data are inadequate or to generate new crop calenders where none are available.

In the following sections, the LACIE crop calenders are evaluated as to earliness or lateness for planting, heading, and ripe dates in the U.S.S.R. and for planting, jointing, heading, and ripe dates in Canada. Comments are based on the simulated daily temperatures, on the output of the phenology models, and on general characteristics of wheat and barley. Where possible, some specific correction is indicated. Because the available temperature data are the means of very large areas, they may differ greatly from temperatures at any particular point in a region.

3.1 GENERAL COMMENTS: U.S.S.R.

In the U.S.S.R., winter small grains are planted by calender date within about a 2-week period specific to each area, provided fields are not too wet to work.[1] Spring small grains are planted after about 3 days of 40° F or greater mean temperatures, again provided the fields are dry enough to work. In the New Lands, spring planting is done by date in the middle of May so that

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[1] Pat Ashburn, personal communication, 1980.

TABLE 5.- NORMAL AND ROBERTSON PHENOLOGY MODEL ESTIMATES FOR 10-, 50-, AND 90-PERCENT DATES FOR SOUTH DAKOTA CRD'S[a]

CRD	Percent	Planting	Heading			Ripe		
			Robertson	Normal	Error (R-N)	Robertson	Normal	Error (R-N)
1	10	105	168	172	-4	199	198	1
	50	117	172	178	-6	202	212	-10
	90	128	178	184	-6	207	226	-19
2	10	99	166	170	-4	194	197	-3
	50	111	168	176	-8	196	202	-6
	90	123	173	183	-10	200	206	-6
3	10	99	168	170	-2	196	198	-2
	50	108	169	176	-7	197	202	-5
	90	118	172	181	-9	199	207	-8
4	10	92	166	168	-2	197	195	2
	50	109	169	174	-5	200	203	-3
	90	125	176	179	-3	206	211	-5
5	10	101	164	166	-2	192	194	-2
	50	111	167	172	-5	194	200	-6
	90	122	171	177	-6	198	207	-9
6	10	103	165	167	-2	193	197	-4
	50	110	167	172	-5	195	204	-9
	90	117	170	178	-8	197	212	-15
7	10	96	165	169	-4	196	199	-3
	50	109	169	175	-6	200	204	-4
	90	123	175	182	-7	206	208	-2
8	10	95	161	163	-2	190	196	-6
	50	106	164	171	-7	192	200	-8
	90	118	169	179	-10	196	205	-9
9	10	100	162	166	-4	189	192	-3
	50	107	164	171	-7	191	196	-5
	90	114	166	177	-11	193	200	-7

[a]Normal 10-, 50-, and 90-percent dates for planting, heading, and ripe stages for South Dakota spring wheat and Robertson phenology estimates for heading and ripe dates run on daily maximum and minimum temperatures simulated from long term mean monthly temperatures with $T\ mean = T\ max - 10°\ F$
$= T\ min + 10°\ F$

flowering occurs after the hottest part of the season. Once planting begins, CRD-sized areas are planted in about 3 to 5 days.[1] Therefore, tracking the movement of planting activities across the U.S.S.R. by satellite may allow accurate estimates of planting dates. Where satellite data are unavailable, a meteorological starter model may give acceptable results.

Jointing should occur 20 to 30 days before heading, but in most of the crop calendars, jointing is listed only 10 to 20 days before heading. This is clearly in error.

Generally, late plantings at a given site should mature in fewer days than early plantings, because of the effects of long days and high temperatures. The only exceptions would be when ripening occurs after late August and is further delayed by cooling conditions in the fall. This means that stages of later plantings should generally be slightly closer together than stages of earlier plantings. The forms of the Robertson model used in this study do not always reflect this principle because of unrealistic response curves in the models for day length, Tmax, and Tmin.

Spring planting should not occur before mean air temperature is about 45° F (soil temperature about 42° F). This will, of course, occur earlier or later than the normal date in a given year. Some of the regions for which normal temperatures are available are quite large. The Far East Region covers 16° of latitude, the East Siberia region covers 8° of latitude, and several regions cover more than 5° of latitude. Differences in temperature and even more differences in day length across such regions could account for some differences in plant growth stages and planting dates. Except for areas far north or south of the center of an economic region, it is probably reasonable to expect earliest plantings in any year not more than 3 weeks before mean temperature reaches 40° F and to expect the mean beginning of planting not before the mean temperature reaches 45° F.

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[1] Pat Ashburn, personal communication, 1980.

3.1.1 BALTICS: ECONOMIC REGION 0100

Estonia, Latvia, Lithuania, and Kaliningrad - The period between jointing and heading is 10 days too short in all cases. Otherwise, crop calendars look reasonable. The crop calendars probably should be corrected by moving the planting dates 5 days earlier and the harvest dates 5 days later.

3.1.2 WEST UKRAINE: ECONOMIC REGION 0300

L'vov and Volyn - The period between jointing and heading is about 10 days too short in all cases. The periods of entering jointing and heading are longer than implied by the short planting periods. The placement of the stages looks reasonable. The best correction probably would be to shorten the periods of entering jointing and heading and make the mean of the entering jointing period 10 days earlier than it is.

3.1.3 NORTH CENTRAL UKRAINE: ECONOMIC REGION 0400

Same comments as for West Ukraine.

3.1.4 NORTHEAST UKRAINE: ECONOMIC REGION 0500

Same comments as for West Ukraine. Also, the model indicates jointing may be 10 days early for winter wheat, but this is not certain.

3.1.5 EAST UKRAINE: ECONOMIC REGION 0600

Dnepropetrovsk - Jointing is probably 10 days too late for spring barley. The jointing to heading period is about 10 days too short in all cases. Fall planting may be 10 to 20 days early.

3.1.6 MOLDAVIA: ECONOMIC REGION 0800

Same comments as for West Ukraine. Also, for the spring-planted grains, the planting to jointing period is too long relative to the whole growing period. The crop calendars probably should be corrected by making jointing 5 to 10 days earlier.

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3.1.7 KRASNODAR: ECONOMIC REGION 0900

The jointing to heading period is 5 to 10 days too short. Otherwise, the stages look reasonable. The crop calendars probably should be corrected by making jointing 5 to 10 days earlier.

3.1.8 NORTHEAST CAUCASUS: ECONOMIC REGION 1000

Stavropol', Rostov, Dagestan, Kabardino-Balkar, Checheno-Ingush, and Kalmyk - Planting of winter wheat in Dagestan, Checheno-Ingush, and Kalmyk is about 30 days too late. Spring grains are planted 30 days too early in Stavropol and 10 days too early in Rostov. The jointing to heading period is 5 to 15 days too short in all cases. For spring barley, the model is underestimating the rate of development during the last stages for late plantings. The crop calendars should be corrected by shortening the planting periods to 30 days starting in late March and mid-September. Make jointing 5 to 15 days earlier.

3.1.9 WEST BLACK SOIL: ECONOMIC REGION 1100

Belgorod, Kursk, and Orel - The 70-day entering jointing period following a 10-day planting period in Orel is incorrect. Probably winter wheat jointing should start in early or middle May in all three areas. Planting of spring grains is 10 to 15 days too early in Belgorod and Kursk. The jointing to heading period is 5 to 15 days too short in all cases. For Orel winter wheat, set jointing on May 1 to May 25. Make jointing 5 to 10 days earlier elsewhere. Shorten the planting period to 30 days or less in all cases.

3.1.10 EAST BLACK SOIL: ECONOMIC REGION 1200

Lipetsk, Tambov, and Voronezh - Planting of spring grains is 10 to 20 days early in Voronezh and lasts 20 to 30 days too long. For winter wheat, jointing, heading, and ripe periods may be 10 to 20 days early in Lipetsk and Tambov. The jointing to heading period is 10 to 20 days too short in all cases except for winter wheat at Voronezh. Correct the calendar by setting planting in April and September. Make jointing to harvest of winter wheat 10 to 20 days later in Lipetsk and Tambov. Make the heading to harvest period about 10 days later in all cases except for winter wheat in Voronezh.

3.1.11 CENTRAL: ECONOMIC REGION 1300

Bryansk, Vladimir, Ivanovo, Kalinin, Kaluga, Moscow, Ryazan, Smolensk, and Yaroslavl - There are 3 crop calendars here: Bryansk and Smolensk are identical; Vladimir, Ivanovo, Kaluga, Moscow, Ryazan, and Yaroslavl are identical; and Kalinin is a third pattern. The same comments apply as for West Ukraine. Otherwise, everything looks reasonable.

3.1.12 VOLGA-VYATSK: ECONOMIC REGION 1400

Gor'kiy, Mari, Mordva, and Chuvash - There is no spring barley for these regions in the LACIE crop calendars. Winter wheat jointing is starting 20 days early in Mari and Mordva. The jointing to heading period is 5 to 20 days too short in all cases. Sixty-day entering jointing periods in Mari and Mordva do not follow from the 20-day planting periods. Otherwise, the stages look reasonable. Correct the calendar by shortening the entering jointing period to 20 days. Delay heading to harvest periods sufficiently to give a 20 to 30 day jointing to heading period.

3.1.13 UPPER VOLGA: ECONOMIC REGION 1500

Tatar and Ul'yanovsk - Spring small grains planting in Ul'yanovsk is 20 days too early. The jointing to heading period is 5 to 15 days too short in all cases, except for winter wheat in Tatar where jointing is 15 to 25 days too early. Correct the calendar by starting spring planting in late April and winter wheat jointing in early May. Delay heading to harvest stages sufficiently to give a 20 to 30 day jointing to heading period.

3.1.14 MIDDLE VOLGA: ECONOMIC REGION 1600

Kuybyshev, Penza, and Saratov - Planting of spring small grains is 10 days too early in Kuybyshev and 20 days too early in Penza. For fall planted grains, jointing in the spring is 10 to 20 days too early in all cases. The jointing to heading period is 5 to 15 days too short in all cases. Correct the crop calendar by starting spring planting in early April and winter wheat jointing in late April. Delay heading to harvest stages 5 to 15 days in all cases.

3.1.15 LOWER VOLGA: ECONOMIC REGION 1700

Astrakhan' and Volgograd - Winter wheat planting in Astrakhan' should be 30 days earlier in the fall, and spring stages should be 20 days later. In Astrakhan', all stages of spring grains should be 10 to 20 days later. The jointing to heading period is 10 to 15 days too short in all cases so stages after jointing should be an additional 10 to 15 days later.

3.1.16 NORTH WEST URALS: ECONOMIC REGION 1800

Udmurt - For winter wheat, jointing begins 15 to 20 days too late in the spring. The jointing to heading period is 5 to 25 days too short in all cases. Some long periods for entering stages do not agree with relatively short planting periods.

3.1.17 SOUTHERN URALS: ECONOMIC REGION 1900

Bashkir and Orenburg - Planting is 10 to 20 days too early and lasts 40 days too long for spring wheat. The jointing to heading period is 5 to 20 days too short in all cases.

3.1.18 NORTH EAST URALS: ECONOMIC REGION 2000

Chelyabinsk, Kurgan, Sverdlovsk, and Tyumen' - Spring grains are planted 20 to 30 days too early in Sverdlovsk and Tyumen'. In Chelyabinsk, the spring barley model does not allow ripening after day 236 which is probably an error in the model. In some cases, the jointing to heading period is up to 20 days too short. Correct the crop calendar by starting spring planting in late April and by making the entering jointing period last about 20 days starting in early June in Sverdlovsk and Tyumen'.

3.1.19 KUSTANAY: ECONOMIC REGION 2200

Planting for spring wheat should take 20 to 30 days starting in late April. The spring barley model does not allow ripening after day 239, which is probably an error in the model. The jointing to heading period is up to 20 days too short so stages after jointing should be 10 to 20 days later.

3.1.20 WEST SIBERIA: ECONOMIC REGION 2600

Kemerovo and Omsk - Except for a too short jointing to heading period, everything looks reasonable.

3.1.21 ALTAY KRAY: ECONOMIC REGION 2700

Everything looks reasonable.

3.1.22 TRANSCAUCASUS: ECONOMIC REGION 2800

Azerbaijan, Armenia, and Georgia - Winter wheat planting may be 20 days late in Azerbaijan, or it may be correct. The jointing to heading period is 10 to 15 days too short in all cases.

3.1.23 SOUTH KAZAKHSTAN: ECONOMIC REGION 2900

South Kazakhstan, Kzyl-Orda, Chimkent, Dzambul, Dzhezkazgan, Alma-Ato, Taldy-Kurgan, and Vostochno - Since this region covers about 10° of latitude, as well as 20° of longitude, the single set of normal temperatures that is available, probably does not represent all parts of the region equally well. In the southernmost area of Chimkent, fall planting appears to be 20 to 30 days early, and in the northern area of Dzhezkazgan, spring planting appears to be 20 to 30 days late. The jointing to heading period is up to 20 days too short in some cases.

3.1.24 CENTRAL ASIA: ECONOMIC REGION 3000

Uzbek, Kirgiz, and Turkmen - Fall planting seems to be 20 to 30 days too late in Uzbek and in Turkmen. Otherwise, except for the short period between jointing and heading in some cases, everything looks reasonable.

3.1.25 EAST SIBERIA: ECONOMIC REGION 3100

Krasnoyarsk, Irkutsk, Chita, Buryat, and Tuva - Spring planting in Buryat appears to start 30 to 40 days too early. The jointing to heading period is 10 to 20 days too short, in some cases.

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3.1.26 FAR EAST: ECONOMIC REGION 3200

Far East and Amur - The barley model does not run for the given planting dates except for day 110 at 60° N. The spring wheat data look reasonable except for the duration of the entering jointing period.

3.2 GENERAL COMMENTS: CANADA

For Canada during LACIE, crop calendars were prepared for spring wheat for several large areas of each of the prairie provinces of Alberta, Saskatchewan, and Manitoba. Additionally, crop calendars were prepared for spring wheat, spring barley, spring oats, and winter rye for several sites in each of these provinces. The set of crop calendars which only cover spring wheat shows an unrealistically long period between jointing and heading (about 60 days); and sometimes, the set shows a shift from a relatively short planting period and short stage entry periods through jointing to long stage entry periods after jointing.

As in the U.S.S.R., periods between stages should get shorter for later plantings until middle to late August when cooling temperatures will delay development.

Beginning of planting for spring barley is shown as occurring 10 to 25 days later than for spring wheat in almost all cases. However, the beginning of planting for spring wheat is frequently shown as the end of March, when night temperatures are usually well below 20° F and day temperatures are only occasionally above freezing. Based on normal temperatures, early planting probably does not begin until late April or May when low temperatures approach 30° F.

Harvest is shown as continuing into late October when low temperatures are well below 20° F. Since ripening is shown as ending 20 to 30 days earlier, that seems a bit late.

3.2.1 ALBERTA

3.2.1.1 South (Spring Wheat)

Planting is started 20 to 30 days too early and the jointing to heading period is 30 to 35 days too long, so delay early stages and advance later stages.

3.2.1.2 Lethbridge (Spring Wheat and Barley)

For spring wheat, planting is started 15 to 20 days too early, and the time between late jointing and late heading is 10 to 15 days too short. For spring barley, the heading to soft dough period may be a little too long.

3.2.1.3 Lacombe (Spring Wheat and Barley)

For spring wheat, planting begins 20 days too early and the jointing to heading period is up to 15 days too short.

3.2.1.4 Central (Spring Wheat)

Planting may be started 5 to 10 days too early and the planting to jointing period is 10 to 15 days too short. The jointing to heading period ranges from 20 days too short (early planting) to 30 days too long (late planting). The heading to soft dough period is probably 10 to 20 days too long.

3.2.1.5 Edmonton (Spring Wheat and Barley)

For spring wheat, planting begins 20 to 30 days too early and the jointing to heading period for late planting is 10 days too short.

3.2.1.6 North (Spring Wheat)

Planting may begin 5 to 10 days early. The jointing to heading period is 20 days too long for late plantings. Late ripening in early October is probably 10 to 15 days too late.

3.2.1.7 Beaver Lodge (Spring Wheat and Barley)

For spring wheat, planting begins 20 to 30 days too early. The jointing to heading period is 5 to 10 days too short.

3.2.2 SASKATCHEWAN

3.2.2.1 Southeast (Spring Wheat)

Planting is started 30 days too early. The jointing to heading period is 40 to 45 days too long, and the soft dough to ripe period may be a few days too short. Early stages should be made later and later stages should be advanced.

3.2.2.2 Indian Head (Spring Wheat and Barley)

For spring wheat, the jointing to heading period is 5 to 10 days too short.

3.2.2.3 Regina-Wyeth (Spring Wheat)

Planting is started 30 days too early and the jointing to heading period is 30 to 35 days too long. Correct the crop calendar by making planting later.

3.2.2.4 Regina (Spring Wheat and Barley)

Planting for spring wheat is probably started about 30 days too early and, for barley, about 10 days too early.

3.2.2.5 South Central (Spring Wheat)

Planting is started 20 to 25 days too early and the jointing to heading period is about 10 days too short.

3.2.2.6 Swift Current (Spring Wheat and Barley)

Planting is started 15 to 20 days too early and the jointing to heading period is 5 to 10 days too short for both crops.

3.2.2.7 Southwest (Spring Wheat)

Planting is started about 30 days too early and the jointing to heading period is 30 to 35 days too long. Correct the crop calendar by delaying planting.

3.2.2.8 East Central (Spring Wheat)

Planting is started 20 to 30 days too early and the jointing to heading period is 10 to 20 days too long.

3.2.2.9 <u>Central (Spring Wheat)</u>

Planting is started 20 to 30 days too early. Correct the crop calendar by delaying planting.

3.2.2.10 <u>Saskatoon (Spring Wheat and Barley)</u>

Planting is started 20 days too early and the jointing to heading period is 5 to 10 days too short for spring wheat.

3.2.2.11 <u>West Central (Spring Wheat)</u>

Planting is started 20 days too early, the jointing to heading period is 10 to 25 days too long, and the heading to soft dough period may be 10 days too long. Correct the crop calendar by delaying planting.

3.2.2.12 <u>Scott (Spring Wheat and Barley)</u>

For spring wheat, planting is started 30 days too early, and for spring barley, the jointing and heading period is 5 days too short.

3.2.2.13 <u>Northeast (Spring Wheat)</u>

Planting is started possibly 10 days too early. The jointing to heading period ranges from 10 days too short to 30 days too long. The short planting period does not agree with the long stage entry periods after jointing.

3.2.2.14 <u>Melfort (Spring Wheat and Barley)</u>

Planting is started 20 days too early, and the jointing to heading period is 5 days too short for spring wheat. For spring barley, the jointing to heading period is 10 days too short.

3.2.2.15 <u>Northwest (Spring Wheat)</u>

Planting may be started 10 days too early, and the jointing to heading period ranges from 10 days too short to 30 days too long.

3.2.3 MANITOBA

3.2.3.1 Southeast (Spring Wheat)

Planting is started 30 days too early, and the jointing to heading period is 30 to 40 days too long. Correct the crop calendar by delaying planting.

3.2.3.2 Winnepeg (Spring Wheat and Barley)

For spring wheat, planting is started 20 to 30 days too early, and the jointing to heading period is 5 to 10 days too short.

3.2.3.3 South Central (Spring Wheat)

Planting is started 30 days too early, and the jointing to heading period is 30 to 40 days too long. Correct the crop calendar by delaying planting.

3.2.3.4 Morden (Spring Wheat and Barley)

For spring wheat, planting is started 30 days too early, and the jointing to heading period is a few days too short.

3.2.3.5 Southwest (Spring Wheat)

Planting is started 30 days too early, and the jointing to heading period is 30 to 40 days too long. Correct the crop calendar by delaying planting.

3.2.3.6 Brandon (Spring Wheat and Barley)

For spring wheat, planting is started about 20 days too early, and the jointing to heading period is 10 days too short.

3.2.3.7 North (Spring Wheat)

The jointing to heading period ranges from 10 days too short to 30 days too long. The long stage entry periods after jointing do not agree with the relatively short planting period and should be shortened.

4. STARTER MODELS

One of the major factors affecting plant development is the planting date (reference 6). Planting occurs in a relatively long period (20 to 60 days) in a region in any given year. Some years, the planting period may be earlier or later than the average (normal) planting period due to weather conditions or other factors. A meteorologically based starter model may attempt to predict the mean planting date or the shift in the planting period in a given year due to meteorological factors.

4.1 SPRING GRAINS

For spring planted grains, several approaches have been developed (refs. 1, 9, and 13) and evaluated (ref. 13). The Feyerherm model was found to be the best existing model (table 6).

Development of the Feyerherm spring wheat starter model was based on the concept that a cool, wet late spring could delay planting while a warm, dry condition permits early planting. The weather variations among seasons and regions were defined as a warming/planting (W/P) day. W/P is assigned a 0 to 1 value for each calendar day beginning January 19. (This date was arbitrarily chosen and coincides roughly with the coldest time of the year in the northern hemisphere.) Accumulated W/P days were then related to the percentage of wheat planted. When the accumulated W/P value reached 35.5 degree-days, it was assumed that 50 percent of the crop had been planted. The general form of the model was as follows:

$$WP = 0, \text{ if } TA \leq 32$$

$$WP = \alpha(TA - 32)(PRE), \text{ if } 32 < TA \leq 32 + \frac{1}{\alpha}$$

$$WP = 1, \text{ if } TA > 32 + \frac{1}{\alpha}$$

where

$$TA = \frac{Tmax + Tmin}{2}$$

Tmax = maximum daily air temperature (°F)

Tmin = minimum daily air temperature (°F)

TABLE 6.- RESULTS OF STARTER MODEL EVALUATION

N	Segment	Year	Normal		Feyerherm		Stuff-Phinney	
			RMSE	Bias[a]	RMSE	Bias[a]	RMSE	Bias[a]
45	1987	1975	5.993	2.489	5.651	1.489	15.339	14.178
8	1965	1975	8.254	0.125	8.329	1.125	16.359	14.125
5	1967	1976	5.495	5.000	14.184	14.000	16.162	16.000
2	1970	1976	15.652	14.000	6.964	-2.500	30.806	30.000
8	1965	1976	4.213	-1.250	18.688	-18.250	12.420	11.750
12	1987	1976	34.000	33.600	18.300	17.600	46.900	46.600
31	1966	1976	21.579	19.710	10.477	5.710	32.904	31.710
9	1687	1976	23.840	19.889	15.868	8.889	37.283	34.889
10	1687	1977	9.654	-5.000	12.215	-9.000	11.500	8.000
11	1987	1977	31.700	31.182	16.217	15.182	37.616	37.182
141	Total	75-77	18.518	11.647	11.90	3.831	27.486	23.619

[a]Error is defined as the estimated planting date minus the observed planting date. A positive bias indicates the model prediction was late, while a negative bias indicates the model prediction was early.

α = the threshold value

PRE = a value between 0 and 1 as a function of the previous 3 days of precipitation.

For spring wheat, Feyerherm assigned α = 0.1 and PRE = 1 since precipitation had an effect that was statistically insignificant.

4.2 WINTER GRAINS

Estimating the rate of planting of small grains in the fall is an extremely complex problem. Several factors combine to allow a long period for possible planting in any year and considerable flexibility as to when to plant in that period. For very early plantings, excessive vegetation before winter may reduce winter hardiness; however, excessive vegetation may be cut for silage or simply grazed off a few weeks before the beginning of dormancy, and the crop will winter harden. For extremely late plantings, insufficient crown and root development may lead to increased winter kill, if the winter cold is severe while the crop has little snow cover.

Within the rather long period (60 to 90 days) of safe planting, factors effecting a farmer's decision about when to plant are convenience, grazing plans, and soil moisture. Convenience may be affected by activities associated with another crop (summer crop or forage), off-farm employment, and seasonal availability of labor (before or after corn, soybean, or other major harvests). Excessive soil moisture makes it impossible to work in the fields. During dry conditions the farmer may wait for rain. However, since seeds will sit in dry ground for a substantial period, a farmer may plant in dry ground and hope for rain before the seeds are eaten or winter cold sets in. Thus, weather factors have very limited importance in determining the planting date.

A number of researchers have considered the problem of meteorologically-based starter models for winter wheat (refs. 2, 3, 8, and 9) but have been thwarted by the relative unimportance of meteorological constraints for determining planting date. The recommended approach is to use the normal planting dates until the crop is visible in spectral imagery, either in the fall or in early spring.

5. INVENTORY

Crop development data for the U.S. are shown in tables 1 and 2. Data available for the U.S.S.R. and Canada are shown in tables 3 and 4. Other sources of crop planting and development data for non-U.S. areas are listed below.

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6. SUMMARY

For the 1980 requirements of the Early Warning Project, crop calendars for wheat and barley are required for the U.S., the U.S.S.R., and Canada. In this report, new crop calendars are produced for U.S. regions where several years of periodic growth stage observations are available on a CRD basis. Preexisting crop calendars from the LACIE are also collected as are U.S. crop calendars currently being created for the Foreign Commodities Production Forecast task.

For the U.S.S.R. and Canada, no new crop calendars are created because no new data are available. Instead, LACIE crop calendars are compared against simulated normal daily temperatures and against the Robertson wheat and Williams barley phenology models run on the simulated normal temperatures. Severe inconsistencies are noted and discussed. For the U.S.S.R., spring and fall planting dates can probably be estimated accurately from satellite or meteorological data.

For the starter model problem, the Feyerherm spring wheat model is recommended for spring-planted small grains and results of an analysis are presented. For fall-planted small grains, use of normal planting dates supplemented by spectral observation of an early stage is recommended. The relative importance of non-meteorological factors relative to meteorological factors in determining fall planting is discussed. Crop calendar data available at the Johnson Space Center for the U.S., U.S.S.R., Canada, and other countries are inventoried.

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