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LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

CROP INVENTORY

LARGE AREA

EXPERIMENT

LACIE

NASA NOAA USDA

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Phase II Evaluation Report

National Aeronautics and Space Administration

LYNDON B. JOHNSON SPACE CENTER

Houston, Texas

JULY 1977

LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

PHASE II EVALUATION REPORT

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Large Area Crop Inventory Experiment

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EXECUTIVE SUMMARY

After 2½-years of operation, Phase I and Phase II of the LACIE have concluded on schedule, Phase III activities have begun and a transition phase has been approved.

During Phase I, the LACIE system components and technology were developed and successfully exercised. Analysis was primarily limited to the U.S. Great Plains "Yardstick" region. Area estimation was performed in a quasi-operational mode while yield and production estimation were performed in a feasibility test mode. Wheat acreage classification tests were also conducted on exploratory regions outside of the United States. Several improved technology approaches were developed for subsequent implementation in Phase II or Phase III.

In Phase II, quasi-operational wheat area estimation was extended to yield and production for the U.S. Great Plains "Yardstick" region and, in addition, for Canada and indicator regions of the Soviet Union.

The overall accuracy of LACIE wheat production estimates for the two growing seasons represented by Phases I and II strongly supports the contention that the technology is capable of providing improved early-season and at-harvest production estimates in major wheat-producing regions of the world outside the United States. Results of LACIE to date are particularly encouraging in the winter wheat regions of the world. The LACIE mid- to late-season estimates of winter wheat were adequate to support the LACIE 90/90 at-harvest goal for production. There is a tendency to underestimate spring wheat in the United States and Canada primarily as a result of underestimating spring wheat acreage. This underestimation tendency was not observed in either the U.S.S.R. spring or winter wheat region. Improvements implemented for Phase III are projected to decrease the size of the acreage underage. The accuracy of the LACIE yield estimates have been supportive of the 90/90 criterion through Phase I and Phase II. However, testing also reveals that yield models may not be adequately responsive to episodic events and therefore require improvement to achieve accurate estimates in years with extended episodal conditions.

A significant improvement in crop surveys should be expected in the future because the currently implemented remote sensing technology and approach are in the developmental stage. As LACIE activity proceeds, the technology, as well as understanding of factors which affect the accuracy of remote sensing crop surveys, is expected to improve greatly.

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this report is to document the results of Phase II of the Large Area Crop Inventory Experiment (LACIE). It is intended to provide executive-level managers of participating agencies with information to evaluate how well the objectives of this phase have been met.

These evaluation reports are published during and at the completion of each of the scheduled phases of LACIE. The Phase I interim and final evaluation reports (LACIE-00414, Feb. 1976 and LACIE-00418, May 1976) documented the initiation and first results of LACIE analysis. Two LACIE Phase II interim evaluation reports were issued. The first interim report (LACIE-00422, Sept. 1976) documented peak operational activity and the U.S. Great Plains drought. The second interim report (LACIE-00443, Jan. 1977) documented Northern Hemisphere "at-harvest" results and initial accuracy assessment analysis.

This final Phase II report documents LACIE activities during the 1976 Northern Hemisphere crop year. After a brief overview of the experiment, it presents the Phase II area, yield, and production estimates for U.S. Great Plains, Canada, and the U.S.S.R. (Union of Soviet Socialist Republics) spring and winter wheat regions. The accuracies of these estimates are compared with independent government estimates,* accuracy assessment of the U.S. Great Plains "yardstick" region based on a thorough "blind site" analysis is given, and reasons for variations in estimating performance are discussed.

Following the exposition of wheat estimates, the report covers other Phase II technical activities including operations, exploratory analyses, reporting, methods of assessment, Phase III and advanced system design, technical issues, and developmental activities.

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*Estimate data used for assessment of LACIE accuracy is described in the appendix.

Open issues are discussed and conclusions based on Phase II experience are summarized.

1.2 LACIE OVERVIEW

1.2.1 Objectives

The Large Area Crop Inventory Experiment was initiated in 1974 as a "proof of concept" program. It was designed to assimilate remote sensing technology developed over the previous decade and apply the resultant experimental system to the task of monitoring a singularly important agricultural commodity (wheat). The experimental approach was to be modified as necessary and conceivable to demonstrate the technical and cost feasibility of global agricultural monitoring systems.

Timeliness and accuracy goals for LACIE were established in recognition of the essential requirements for global agricultural information. The experiment was designed to establish the feasibility of acquiring and analyzing Landsat data within a 15-day interval. Importantly, the at-harvest estimates were to be within 10 percent of the true estimate at the national level 90 percent of the time. An additional performance goal was to determine how early in the crop year estimates could be produced and with what accuracy and repeatability. Additionally, the estimates were to be made with repeatable and objective procedures. Qualitative judgments were to be kept to a minimum.

1.2.2 Elements and Participants

The experiment was composed of three major elements: (1) a quasi-operational element to acquire and analyze Landsat and meteorological data to make experimental estimates of area, yield, and production, (2) an off-line element to test and evaluate alternative approaches as required to meet the performance goals of the experiment, and (3) an element to research and develop alternative approaches.

The experiment has been jointly conducted by personnel from NASA, USDA, and NOAA.* They represent the many disciplines (including physics, plant pathology, engineering, agronomy, statistics and mathematics, soil sciences, agro-meteorology, economics, and plant physiology) important to meeting the objectives of the experiment.

The major components of the quasi-operational element of the experiment include Landsat and its acquisition and preprocessing subsystem; the World Meteorological Organization (WMO) weather reporting system; the NOAA development and operational facilities in Washington, D.C., and Columbia, Missouri, and the analysis, compilation, and evaluation activities at the NASA Johnson Space Center (JSC) in Houston, Texas. The experiment also draws significantly on the expertise of USDA personnel in Washington, D.C., as well as university and industrial research personnel.

Because of the complexity and importance of LACIE, periodic technical reviews have been held where invited experts have reviewed LACIE results, discussed specific technical issues, and made specific recommendations. This process has made significant contributions to LACIE.

1.2.3 Phases and Schedule

The experiment was scheduled to be conducted in three phases on a timeline as shown in figure 1-1, with the following objectives: (1) In Phase I, the technology to estimate the proportion of regions planted to wheat would be implemented and tested, and similarly the technique to estimate the yield from specific acreages would be developed and tested. (2) In Phase II, the technology as modified during Phase I would be further tested over expanded geographic regions and modified as required. (3) In Phase III, the modified technology would be tested and evaluated over a still wider range of geographic conditions. In addition, a transition phase has been approved. In the transition phase,

*NASA — National Aeronautics and Space Administration, USDA — U.S. Department of Agriculture, and NOAA — National Oceanic and Atmospheric Administration of the DOC — Department of Commerce.

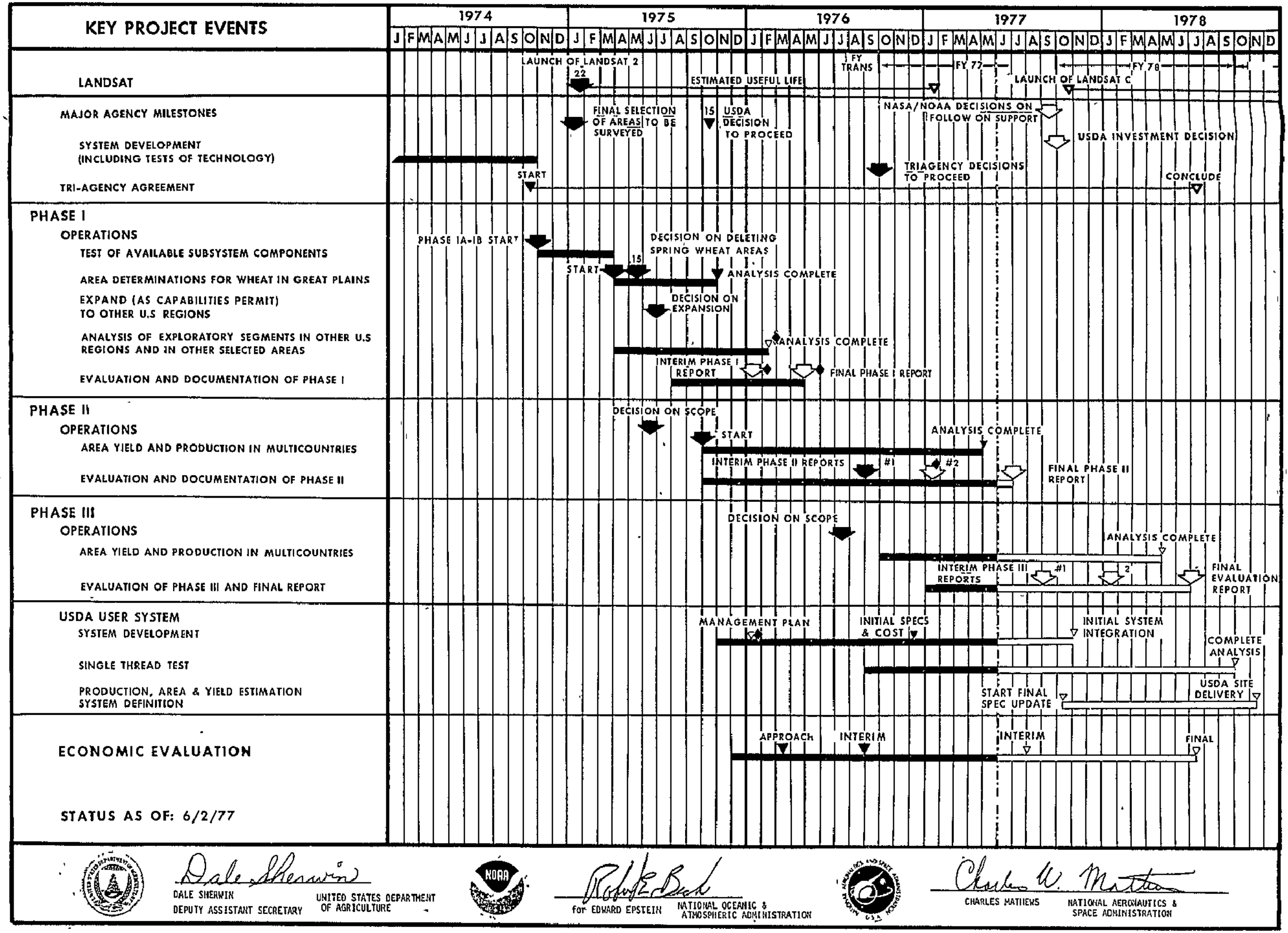

Figure 1-1.– LACIE Schedule Level 1 as of June 2, 1977.

LACIE will complete, document, and transfer technology developed in the experiment to USDA for application, experimentation and testing.

1.3 THE LACIE TECHNICAL APPROACH

The LACIE approach utilizes the direct observational capabilities afforded by Landsat together with estimates of weather variables to estimate production. This approach requires that each geographic subregion (selected to be relatively homogeneous with regard to wheat acreage and yield) in a country be monitored to (1) forecast the quantity of wheat acres available for harvest (both winter and spring, individually, in each subregion) and (2) to forecast the expected productivity for each subregion (yield) of the acres available for harvest. The total wheat production for each subregion is then obtained by the product of available acres for harvest and yield for harvested acres. The production forecasts for all subregions are then summed to obtain the country-level forecast. In addition, the subregional forecasts of acres for harvest are summed to obtain a forecast of national acres for harvest. An average yield for all acres harvested nationally is then obtained which is, by definition, the acreage-weighted average. This acreage-weighted average yield is a desirable estimate to have since, when multiplied by the national acreage, it will reproduce the national production estimate. The LACIE stratification and sampling approach shares similarities with the domestic approach utilized by the timely and accurate SRS (Statistical Reporting Service of the USDA) survey system.

Within each of the subregions described in the opening paragraph, Landsat multispectral data is collected each 18 days from selected 5 × 6 n.mi. segments randomly drawn from each stratum. Within each segment, wheat or small grains are distinguished from non-wheat or non-small grains by monitoring the temporal development of the crops, from wheat planting through harvest. The areal percentage of wheat or small grains in each segment in the stratum is then estimated and, thereby, an average percent for the stratum can be determined. The average areal percent wheat or small grains can then be multiplied by the total agricultural acreage* in the stratum to estimate total wheat acres for the stratum. In segments where the Landsat data is used to estimate small grains, historic ratios of wheat-to-small-grains acreage are used to estimate the current year wheat acreage.

The yield for harvested wheat acres is forecast in LACIE through the use of regression models which utilize weather-related variables obtained from the ground-based stations of the National Weather Services in each country and relayed internationally by the WMO network. These models are referred to as agrometeorological models. The first-generation models currently used in LACIE were developed around monthly averages of temperature and precipitation and derived variables which combine the two. In the U.S. Great Plains yardstick area, there are both winter and spring wheat models, covering 12 areas. The yield and climatic data base used to derive the U.S. models is approximately 45 years in length. The historic yield data is obtained by aggregating the USDA/SRS estimates of harvested acreage and production to obtain yield in bushels per harvested acres, individually, for both winter and spring wheat in each of the 12 subregions. The climatic data consists of monthly climatic division averages of precipitation and temperature. These averages are weighted using acres harvested to obtain the monthly average temperature and total precipitation for a given region. A piecewise linear trend is used to model the technology trend.

For a more detailed illustration of the LACIE technical approach, see *LACIE: A Look to the Future*, a paper presented to the Eleventh International Symposium on Remote Sensing of Environment at the Environmental Research Institute of Michigan, Ann Arbor, Michigan, April 1977.

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*Stratum agriculture is delineated on full-frame Landsat imagery and planimetered to determine total agriculture acreage within a stratum. Agricultural land is defined as the total land area contained within all 5 × 6 mile segments whose centers are in the agricultural strata. Agriculture is defined to be any area of the image for which field patterns are evident.

2.0 EVALUATION OF PHASE II RESULTS

2.1 ACCURACY OF ESTIMATES

Results of LACIE to date are particularly encouraging in the winter wheat regions of the world where, in Phases I and II, the LACIE survey estimates have greatly exceeded expectations. The LACIE technology has produced encouraging early and excellent mid-season estimates. In addition, the winter wheat estimates at harvest were adequate to support the 90/90 criterion. For the U.S. winter wheat yardstick region, the 90/90 criterion was exceeded for the June and later estimates [figs. 2-1 and 2-2(a) and tables 2-I and 2-II(a)].[1] The June estimates were based on Landsat data acquired through the first week in May. Therefore, an operational system with a 14-day turnaround could have produced quite an accurate estimate in mid-May, some 1½ to 2 months prior to harvest. The LACIE estimates of area for harvest in the LACIE May 7 report, based on Landsat acquisitions acquired through early April, were to within four percent of the SRS May estimates for harvest — in addition, the coefficient of variation of the LACIE area estimate was supportive of a 90/90 production estimate.

2.1.1 Winter Wheat

In the U.S.S.R. winter wheat indicator region [fig. 2-2(b) and table 2-II(b)], all indications point to survey estimate accuracies comparable to those in the United States. While the excellent yardstick estimates are not available[2] for comparison at the U.S.S.R. indicator region level, the computed confidence

[1] See section 2.1.3 for introduction to figures and tables.

[2] The FAS estimates shown in figure 2-2(d) are derived from country level estimates, assuming a fixed hectarage ratio between the country and indicator region level. Analysis of these ratios for the past 17 years indicates a year-to-year variation in this ratio of about five percent.

of the LACIE acreage survey estimates indicate accuracies supportive of the 90/90 criterion.

Only one significant problem has been encountered to date in the winter wheat survey regions. During Phase II, Oklahoma and other states of the southern Great Plains, experienced generally dry conditions through April 1976. These conditions created poor wheat stands and subsequent acreage underestimates. In some cases, sparsely vegetated fields were not detected as "emerged" acreage in the Landsat or even the aircraft-ground-truth color-infrared imagery. The April rains greatly improved the wheat stands. However, the drought-altered growth cycle misled the analysts in late season to believe the late-recovering wheat to be a spring-planted crop. A tendency to underestimate wheat area in Oklahoma was not observed in Phase I, LACIE estimates being to within three percent of the SRS. Episodal events such as the drought-altered growth cycle in Oklahoma, just described, are a part of the learning process. As more of these situations are encountered, the technology will adapt to accurately estimate their impact on acreage, yield, and production. Phase III will see a greatly enhanced episode monitoring effort.

2.1.2 Spring Wheat

The results of 2 years in the U.S. northern Great Plains and 1 year in Canada [figs. 2-2(c) and 2-2(d) and tables 2-II(c) and 2-II(d)], indicate a greater tendency to underestimate spring wheat acreage in the Western Hemisphere than is seen for winter wheat. However, such a tendency is not observed in the U.S.S.R.* for either spring [fig. 2-2(e)] or winter wheat. As was identified at the end of the LACIE Phase I, some spring small grains cannot yet be reliably differentiated from spring wheat using

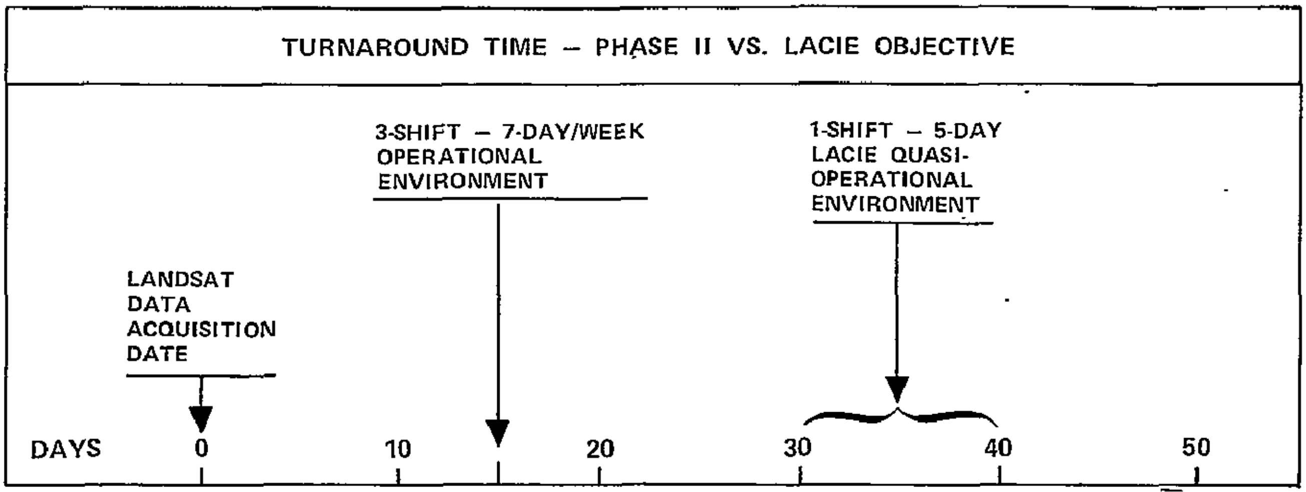
*The FAS estimates shown in figure 2-2(e) are derived from country level estimates assuming a fixed ratio between the country and indicator region level. Analysis of these ratios for the past 17 years indicates a year-to-year variation in this ratio of about 45 percent.

Landsat data alone. Spectrally, these crops are similar as are their growth cycles. Therefore, until procedures could be developed and tested in Phase II for use in Phase III to improve discriminability of these crops, historic ratios of these acreages were used to reduce the Landsat estimates of total small grains to an estimate of wheat acreage. The use of these historic ratios introduced additional error into the spring wheat acreage estimates, particularly in the Phase II crop year for which the planting of wheat in preference to non-wheat small grains had greatly increased from previous years. In many instances, the current ratios were significantly larger than the historic ones used in LACIE. This was responsible for a significant amount of the underestimate of wheat acreage in Canada. There is however, in addition to the ratio factor, a similar tendency to underestimate spring small grains acreage in the United States and Canada. This is verified by the comparisons of the Landsat estimates to ground-observed small grains acreage in the LACIE blind sites. The cause is partially a result of the greatly increased tendency toward strip-fallow practice in the spring wheat regions. Strip-fallow fields, small compared to the Landsat resolution, are difficult to detect and measure in the Landsat imagery (see fig. 3-1). The absence of the U.S.S.R. spring wheat hectarage underestimation problem may be indicative of more stable year-to-year ratios of spring wheat to other small grains ratios (resulting from governmental controls) and a decrease in strip-fallow practice.

2.1.3 Figures and Tables Comparing LACIE and USDA Estimates

In interpreting the figures and tables comparing LACIE and USDA [SRS and the FAS (Foreign Agricultural Service)] estimates it should be realized that the LACIE system operates one shift, 5 days per week, requiring about 30 to 40 days after the date of the latest Landsat acquisition used in acreage to produce an acreage report. The USDA/SRS reports acreage estimates about 14 days after that same date.

A LACIE-like operational system on a three-shift, 7-day-per-week schedule would require no more than 14 days to extract an acreage report from the same Landsat data. To illustrate how estimates of an operational system would compare with those of USDA/SRS, LACIE Phase II estimates for the southern Great Plains were replotted (fig. 2-1 and table 2-I) using dates 30 days earlier than the actual reporting dates that are used in figure 2-2(a-e) and table 2-II(a-e).



2.1.4 Growth Stage Regimes and Accuracy

An additional dimension to the accuracy of the LACIE survey estimates is the period in the growth stage of wheat when the Landsat data is acquired. Generally, three distinct regimes emerge in this regard: (1) An *early-season regime* when a majority of the Landsat data used in area estimation was acquired in the emergence-to-jointing period of wheat development (LACIE Biowindow 1), (2) a *mid-season regime* when a majority of the data was acquired in the jointing-to-mature (green-to-senescence) period of wheat development (LACIE Biowindows 2 and 3), and (3) an *at-harvest regime* when most of the data has been acquired through harvest (Biowindow 4). These periods are indicated on the abscissa of figures 2-2(a) through (e). Note that for each country, the area estimates steadily increase through the growing season. In the case of U.S. southern Great Plains winter wheat, the *early-season* area estimates are substantially below the final estimates. In fact, they are about as much below the final estimate as the initial SRS area estimates (dashed line) are above it. The *mid-season* estimates increase substantially and are not significantly different than the final estimates. The *at-harvest* estimates increase just slightly and are somewhat more accurate; i.e., more in agreement with SRS/FAS estimates than the mid-season ones.

An analysis of ground truth and other data shows that this phenomenon is purely physical in nature and not merely a statistical artifact. In the *early-season* reports, when a majority of the Landsat data is acquired in Biowindow 1, the wheat plant sizes vary from about an inch to over a foot in height with percentages of field area in vegetative ground cover varying from almost none to somewhat less than 40 percent. Observations from ground truth indicate that fields with less than 20-percent vegetative ground cover do not provide a sufficiently "pink" response in color-infrared Landsat imagery. That is, sparsely vegetated fields are not discernible as vegetation by the analyst. Since the analyst procedures call for the identification of detectable wheat (as opposed to an estimate of wheat planted), these *early-season* estimates are low, a result of incomplete emergence of all wheat.

By mid-season, the wheat has completely emerged and the LACIE acreage estimates agree quite well with ground truth.

2.2 BLIND SITE EVALUATION OF CLASSIFICATION ACCURACY

2.2.1 Proportion Estimation Accuracy

Results of comparisons of LACIE estimates to the 103 blind site ground-derived estimates of wheat proportion indicate that there is a moderately large variation between these estimates at a segment level; however, this variation is sufficiently small to be more than adequate to support 90/90 estimates at the

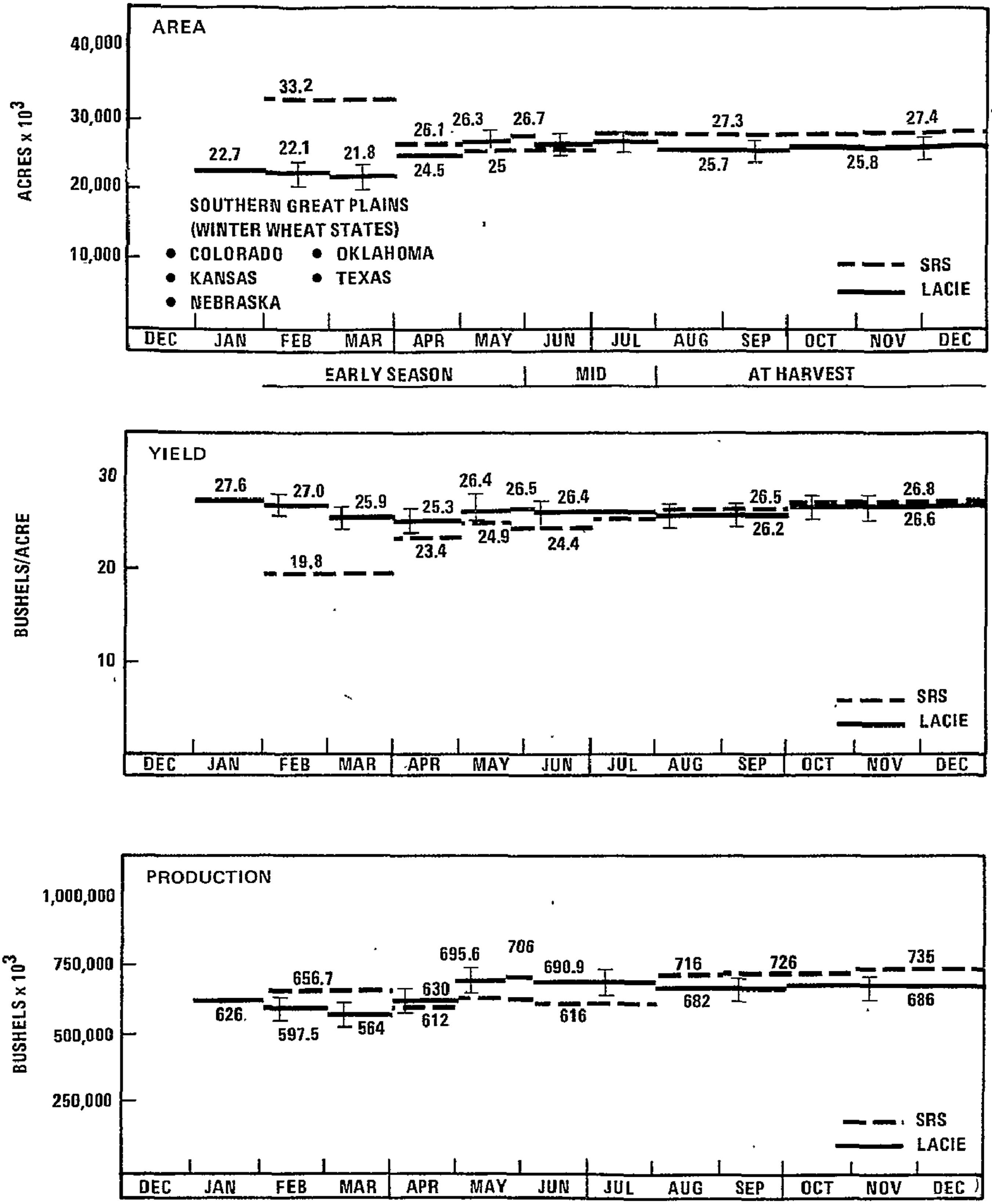


Figure 2-1.– Monthly comparison of LACIE and USDA estimates for the southern Great Plains, assuming a 14-day turn-around system.

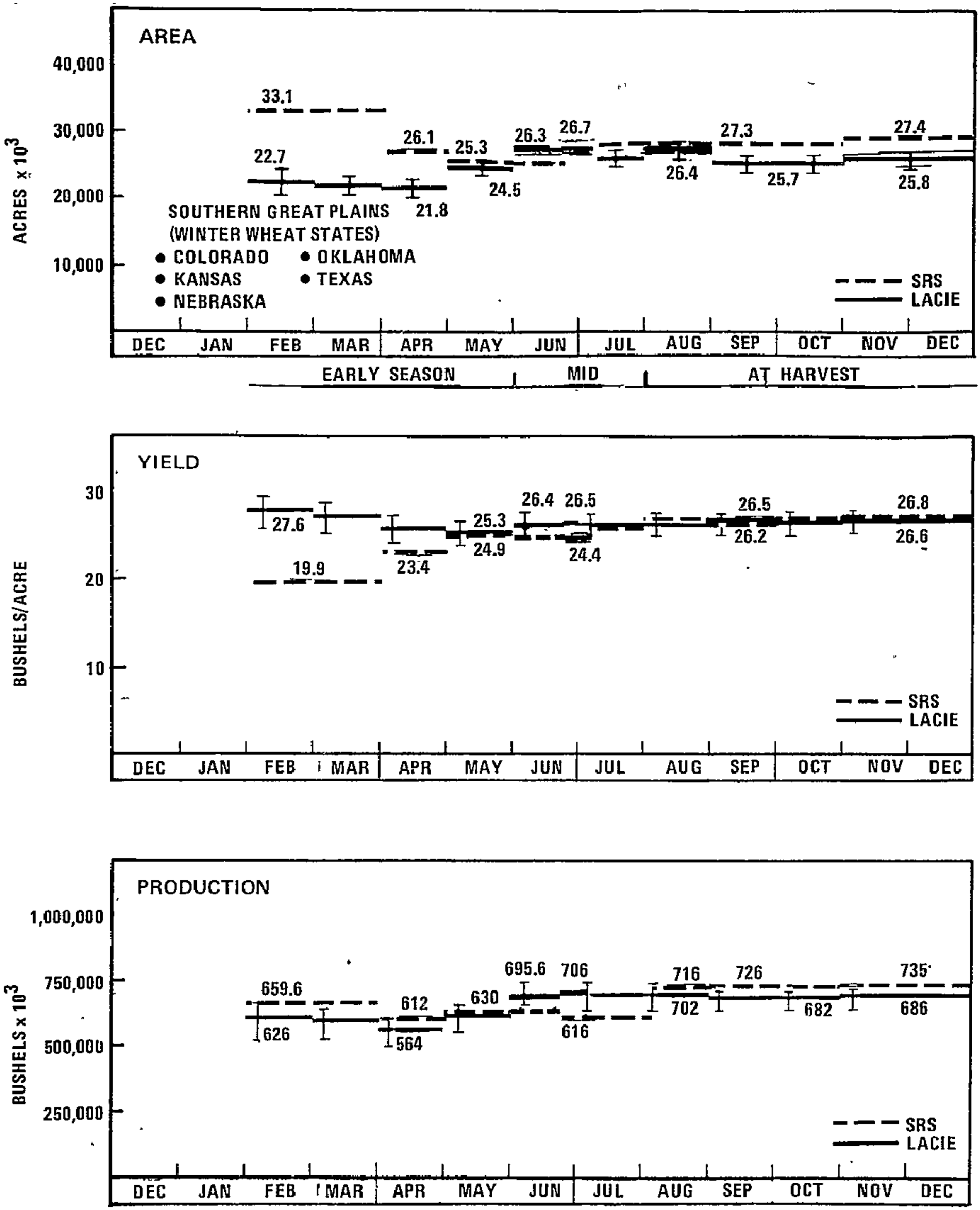
TABLE 2-I.— COMPARISON OF LACIE AND USDA ESTIMATES ASSUMING A 14-DAY TURNAROUND SYSTEM

(U.S. southern Great Plains — 5 states)

May 27, 1977		EARLY SEASON (JANUARY)	MID SEASON (MAY)	HARVEST JULY
AREA				
ACRES x 10^6	SRS	33.2	25.3	27.3
	LACIE	22.7	26.3	25.8
	R/D	-46.3%	3.8%	-5.8%
	CV	9%	5%	5%
YIELD				
BUSHELS/ACRE	SRS	19.9	24.9	26.2
	LACIE	27.2	26.4	26.6
	R/D	26.83%	5.7%	-1%
	CV	7%	5%	5%
PRODUCTION				
BUSHELS x 10^6	SRS	659.6	630.6	716
	LACIE	626	695.6	686
	R/D	-5.3%	9.3%	-4.4%
	CV	11%	7%	7%

R/D = RELATIVE DIFFERENCE
CV = COEFFICIENT OF VARIATION

SOUTHERN GREAT PLAINS
(WINTER WHEAT STATES)
- COLORADO
- KANSAS
- NEBRASKA
- OKLAHOMA
- TEXAS



(a) Southern Great Plains. 5/7/77

Figure 2-2.— Comparison of LACIE Phase II and USDA estimates.

TABLE 2-II.— COMPARISON OF LACIE PHASE II AND USDA ESTIMATES

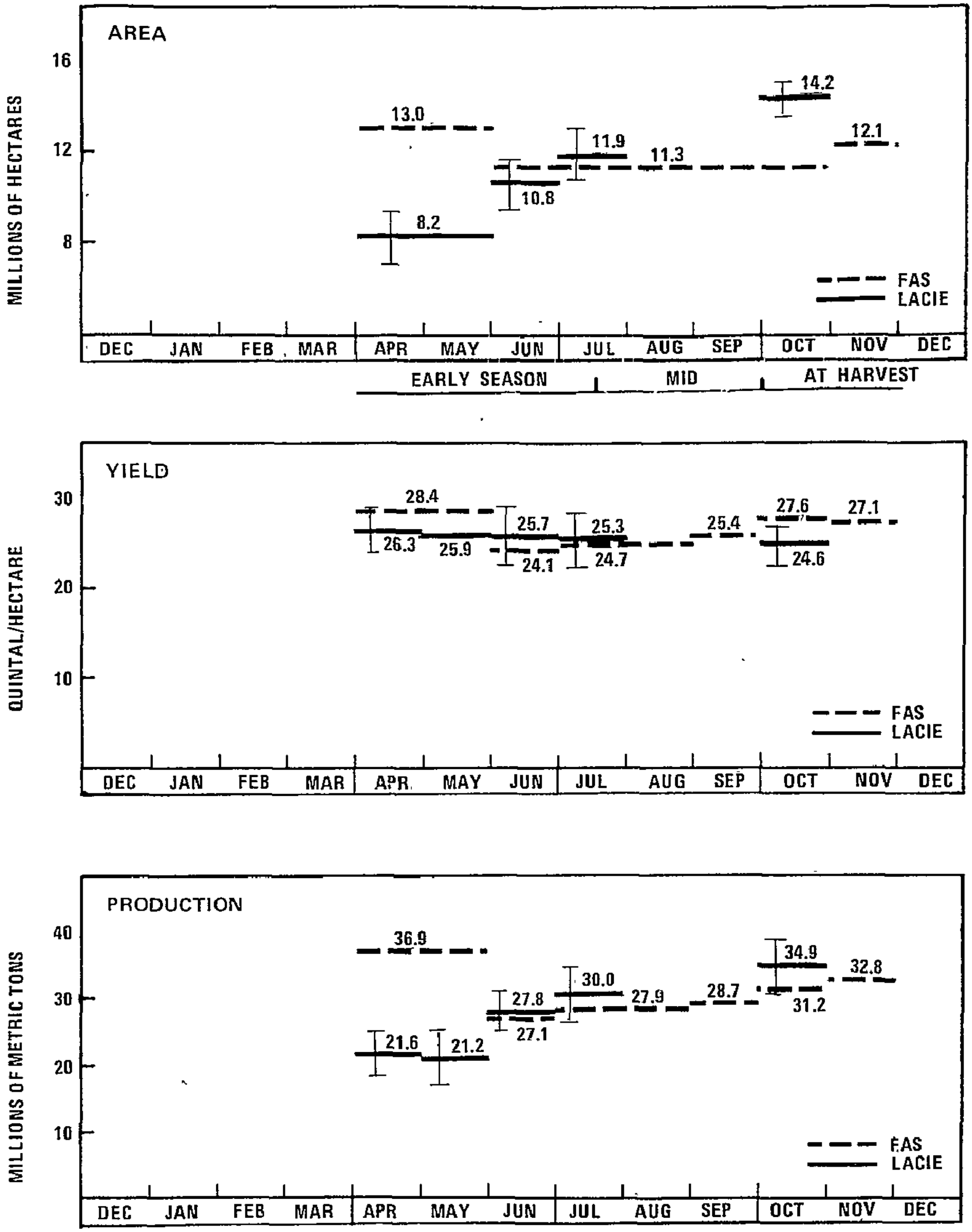
(a) U.S. southern Great Plains — 5 states

May 27, 1977		EARLY SEASON *(JANUARY)	MID SEASON *(MAY)	HARVEST *(JULY)
AREA				
ACRES x 10^6	SRS	33.1	27.3	27.4
	LACIE	22.7	26.7	25.7
	R/D	-45.8%	2.2%	-6.6%
	CV	9%	5%	5%
YIELD				
BUSHELS/ACRE	SRS	19.9	24.4	26.2
	LACIE	27.6	26.5	26.5
	R/D	27.9%	7.9%	1.1%
	CV	7%	5%	5%
PRODUCTION				
BUSHELS x 10^6	SRS	659.6	616	726
	LACIE	626.0	706	682
	R/D	-5.4%	12.7%	-6.4%
	CV	11%	7%	7%

R/D = RELATIVE DIFFERENCE
CV = COEFFICIENT OF VARIATION
* = EFFECTIVE OPERATIONAL RELEASE DATE 14 DAYS FOLLOWING LATEST LANDSAT ACQUISITION DATE.

SOUTHERN GREAT PLAINS (WINTER WHEAT STATES)

- COLORADO
- KANSAS
- NEBRASKA
- OKLAHOMA
- TEXAS



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(b) U.S.S.R. winter wheat indicator region.

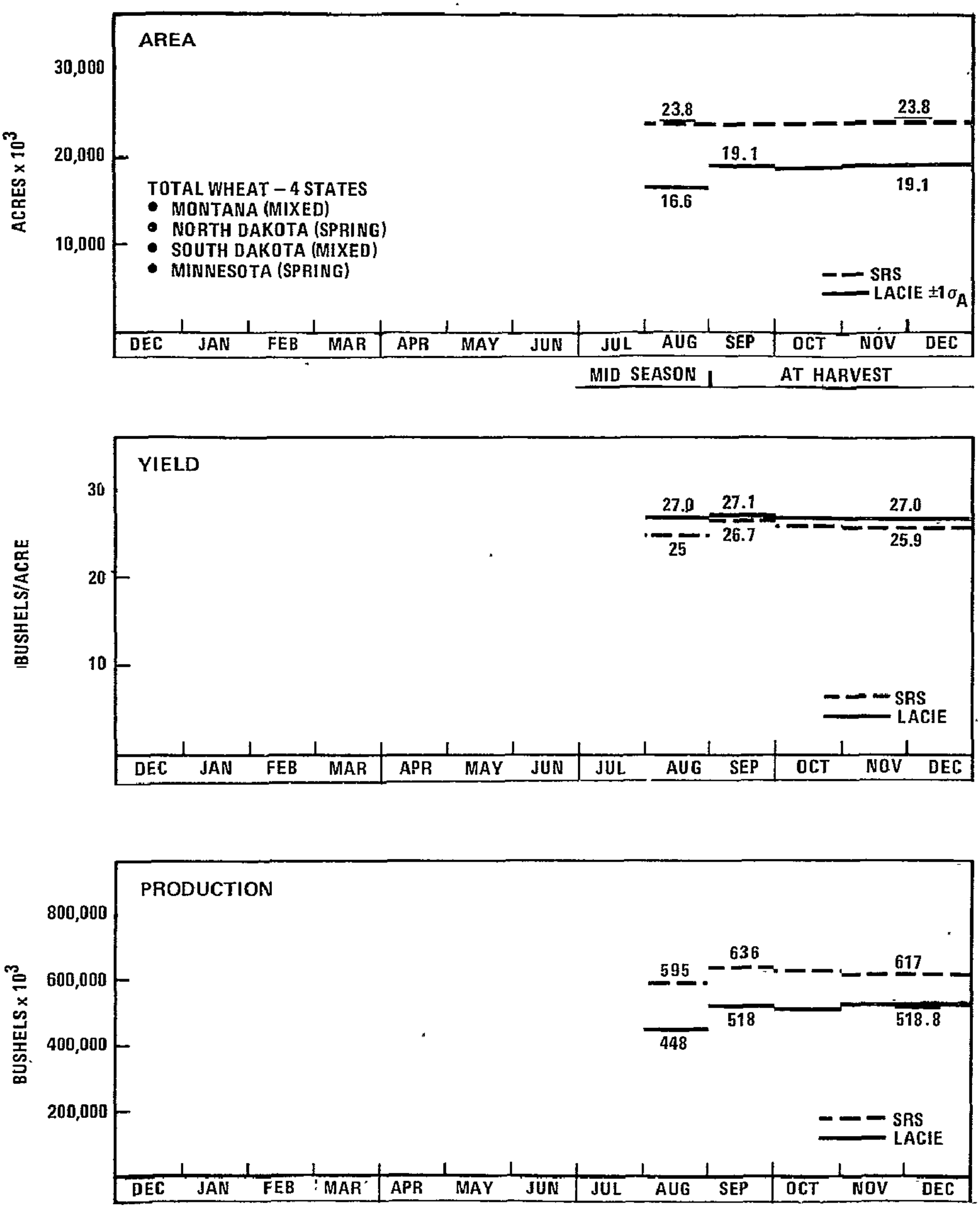
Figure 2-2.- Continued.

TABLE 2-II.– Continued.

(b) U.S.S.R. winter wheat indicator region.

May 27, 1977		EARLY SEASON *(JUNE)	MID SEASON *(JULY)	HARVEST *(OCTOBER)
AREA				
MILLIONS OF HECTARES	FAS	11.3	11.3	11.3
	LACIE	10.8	11.9	14.2
	R/D	-4.1%	5.2%	20.3%
	CV	7%	6%	6%
YIELD				
QUANTAL/ HECTARE	FAS	24.0	24.7	27.6
	LACIE	25.7	25.3	24.6
	R/D	6.6%	2.4%	-12.3%
	CV	4%	6%	5%
PRODUCTION				
MILLIONS OF METRIC TONS	FAS	27.1	27.9	31.2
	LACIE	27.8	30.0	34.9
	R/D	2.5%	7.1%	10.6%
	CV	7%	8%	7%

R/D = RELATIVE DIFFERENCE
CV = COEFFICIENT OF VARIATION
* = EFFECTIVE OPERATIONAL RELEASE DATE 14 DAYS FOLLOWING LATEST LANDSAT ACQUISITION DATE.



(c) U.S. 4 states — total wheat.

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Figure 2-2.— Continued.

TABLE 2-II.– Continued.

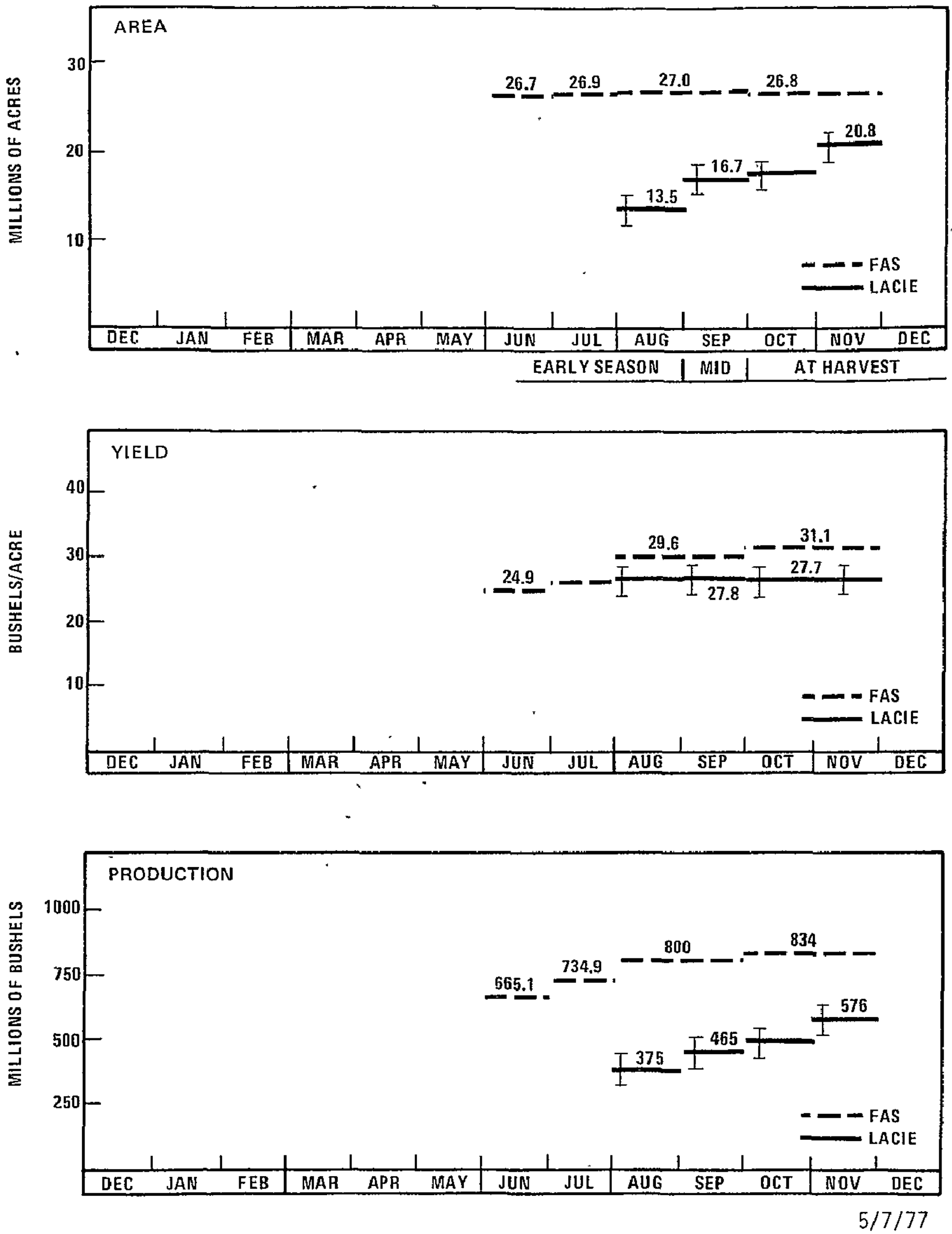
(c) U.S. 4 states – total wheat.

May 27, 1977		EARLY SEASON *(JULY)	MID SEASON *(AUGUST)	HARVEST *(SEPTEMBER)
AREA				
ACRES x 10^6	SRS	23.8	23.8	23.8
	LACIE	16.6	19.1	19.1
	R/D	-43.3%	-24.6%	-24.6%
	CV	9.4%	6.2%	6.7%
YIELD				
BUSHELS/ACRE	SRS	25	26.7	25.9
	LACIE	27	27.1	27.0
	R/D	7.4%	1.5%	4.0%
	CV	29.6%	27.6%	27.7%
PRODUCTION				
BUSHELS x 10^6	SRS	595	636	617
	LACIE	448	518	515.8
	R/D	-32.8%	-22.7%	-19.6%
	CV	11.6%	8.9%	8.7%

R/D = RELATIVE DIFFERENCE
CV = COEFFICIENT OF VARIATION
* = EFFECTIVE OPERATIONAL RELEASE DATE 14 DAYS FOLLOWING LATEST LANDSAT ACQUISITION DATE.

TOTAL WHEAT - 4 STATES

- MONTANA (MIXED)
- NORTH DAKOTA (SPRING)
- SOUTH DAKOTA (MIXED)
- MINNESOTA (SPRING)



(d) Canada spring wheat region.

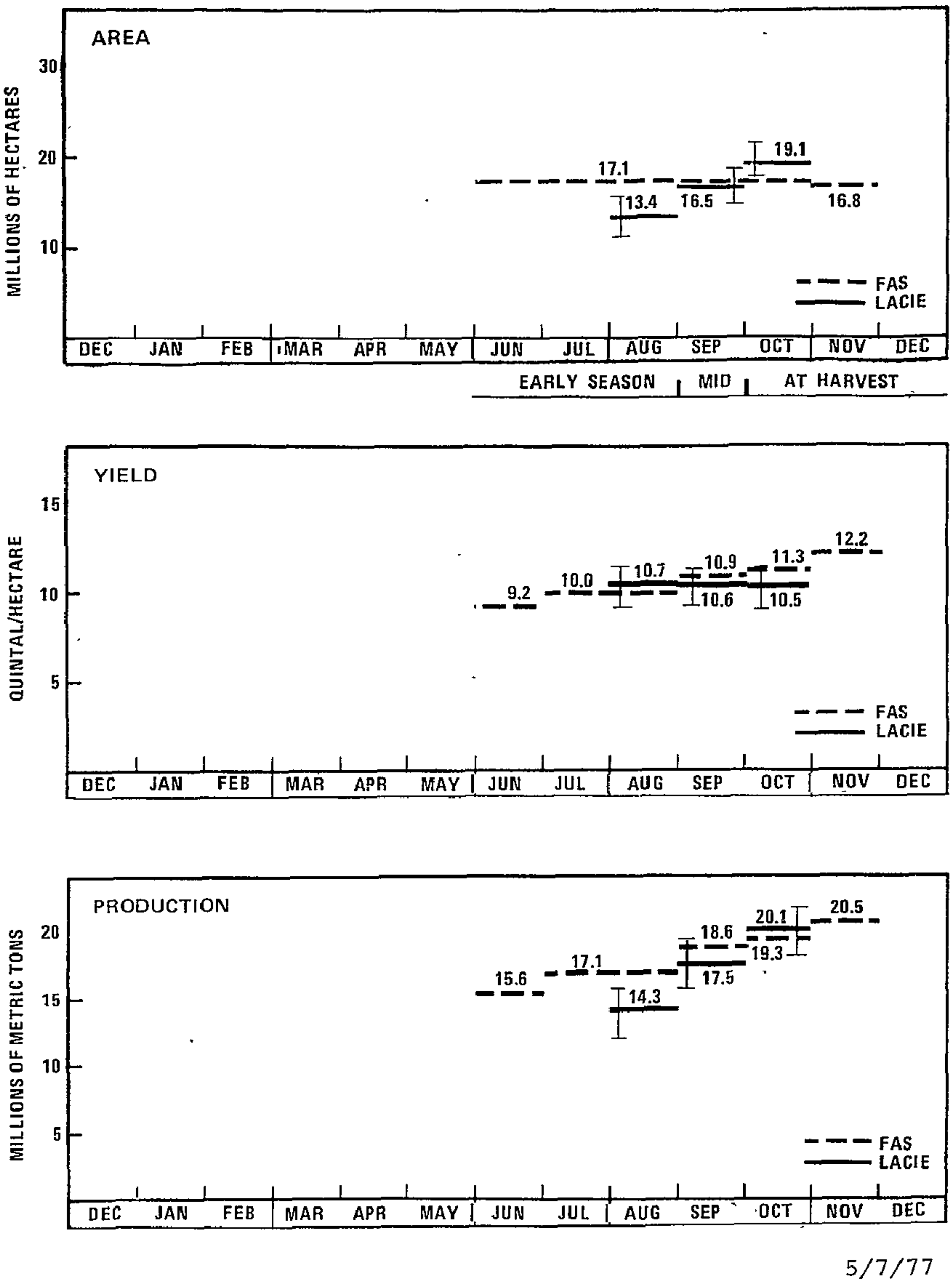
Figure 2-2.– Continued.

TABLE 2-II.– Continued.

(d) Canada spring wheat.

May 27, 1977		EARLY SEASON *(JULY)	MID SEASON *(AUGUST)	HARVEST *(SEPTEMBER)
AREA				
ACRES x 10^6	FAS	27	26.8	26.8
	LACIE	13.5	17.3	20.8
	R/D	-100%	-55%	-29%
	CV	4%	3%	3%
YIELD				
BUSHELS/ACRE	FAS	29.6	29.6	31.1
	LACIE	27.7	27.8	27.7
	R/D	-6%	-17.4%	-12%
	CV	4%	4%	3%
PRODUCTION				
BUSHELS x 10^6	FAS	800	800	834
	LACIE	375	481	576
	R/D	-113.3%	-83%	-57%
	CV	5%	5%	5%

R/D = RELATIVE DIFFERENCE
CV = COEFFICIENT OF VARIATION
* = EFFECTIVE OPERATIONAL RELEASE DATE 14 DAYS FOLLOWING LATEST LANDSAT ACQUISITION DATE.



(e) U.S.S.R. spring wheat indicator region.

Figure 2-2.— Continued.

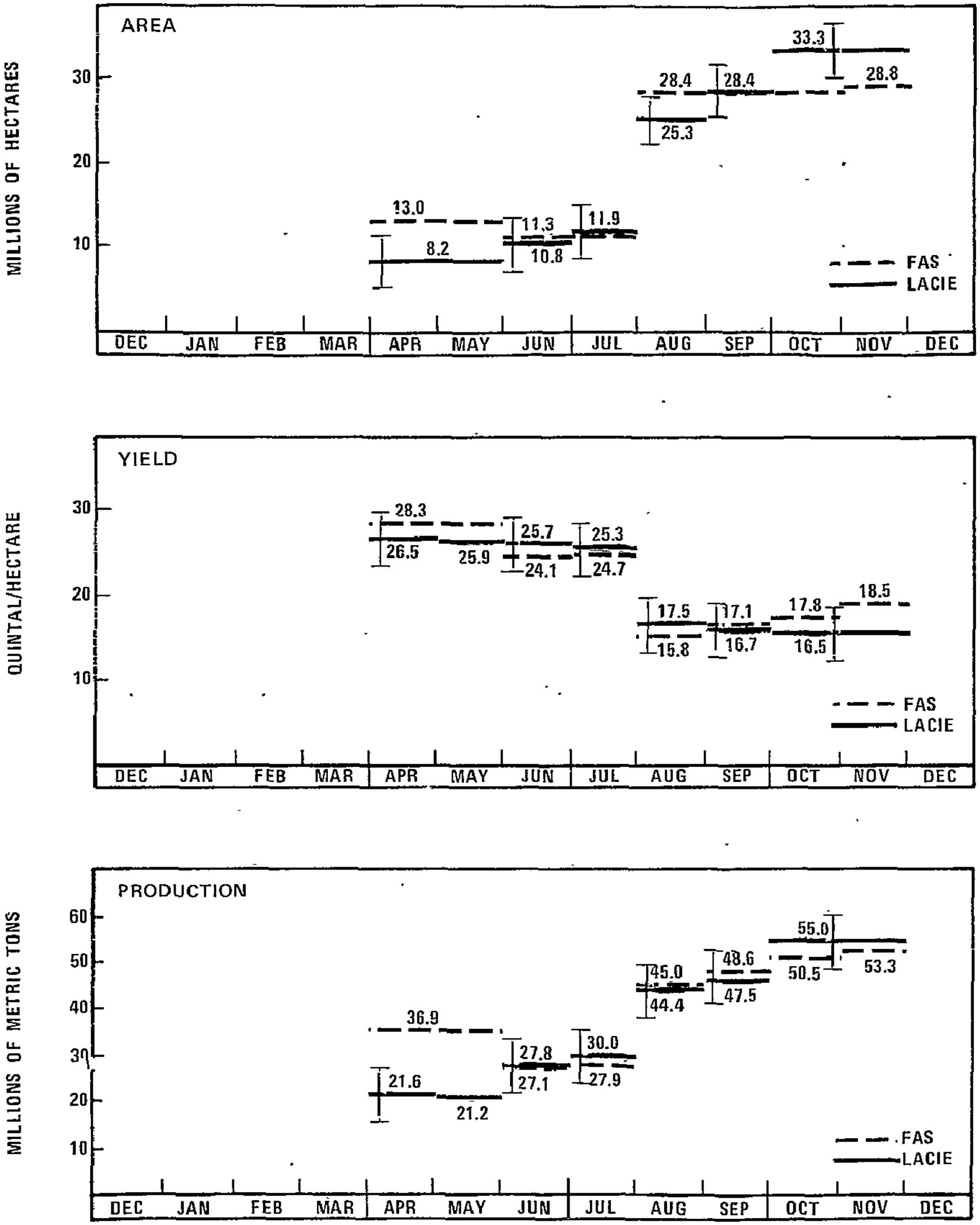
TABLE 2-II.— Continued.

(e) U.S.S.R. Spring wheat indicator region.

May 27, 1977		EARLY SEASON *(AUGUST)	MID SEASON *(SEPTEMBER)	HARVEST *(OCTOBER)
AREA				
MILLIONS OF HECTARES	FAS	17.1	17.1	17.1
	LACIE	13.4	16.5	19.1
	R/D	-27.2%	-3.3%	10.6%
	CV	7%	5%	4%
YIELD				
QUANTAL/ HECTARE	FAS	10	10.9	11.3
	LACIE	10.7	10.6	10.5
	R/D	6.5%	-2.8%	-7.6%
	CV	9%	8%	8%
PRODUCTION				
MILLIONS OF METRIC TONS	FAS	17.1	18.6	19.3
	LACIE	14.3	17.5	20.1
	R/D	-19.6%	-6.3%	4%
	CV	11%	9%	9%

R/D = RELATIVE DIFFERENCE
CV = COEFFICIENT OF VARIATION

* = EFFECTIVE OPERATIONAL RELEASE DATE 14 DAYS FOLLOWING LATEST LANDSAT ACQUISITION DATE.



(f) U.S.S.R. total wheat (indicator regions).

5/7/77

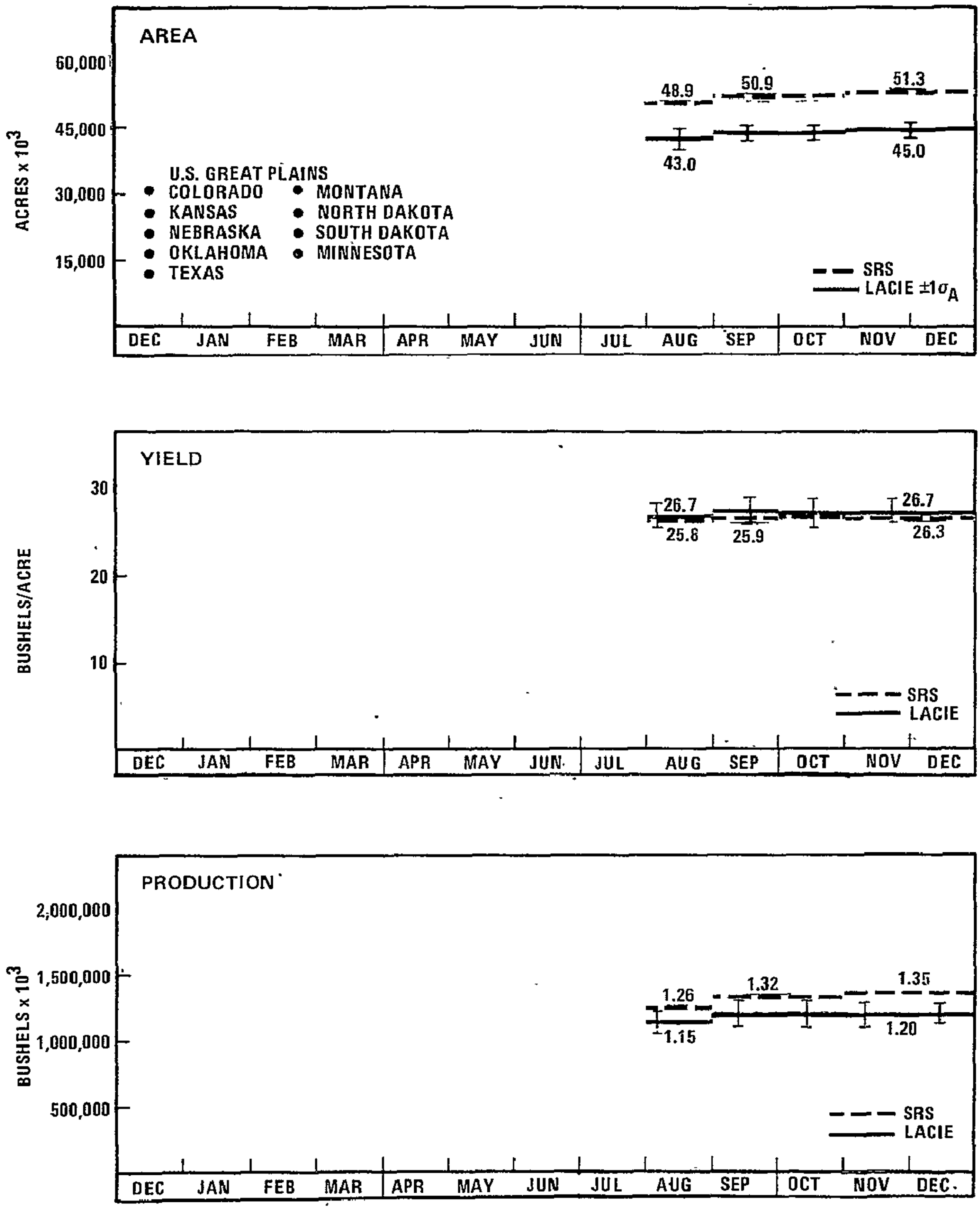
Figure 2-2.— Continued.

TABLE 2-II.— Continued.

(f) U.S.S.R. total wheat (indicator regions).

May 27, 1977		EARLY SEASON SPRING *(AUGUST) WINTER *(JUNE)	MID SEASON SPRING *(SEPT.) WINTER *(JULY)	HARVEST SPRING *(OCT.) WINTER *(OCT.)
AREA				
MILLIONS OF HECTARES	FAS	28.4	28.4	28.4
	LACIE	24.2	28.4	33.3
	R/D	- 18%	0%	14.7%
	CV	7.9%	6.5%	5.6%
YIELD				
QUANTAL/ HECTARE	FAS	15.6	16.4	17.8
	LACIE	17.4	16.7	16.5
	R/D	10.3%	1.8%	- 7.9%
	CV	5.7%	6.2%	6.8%
PRODUCTION				
MILLIONS OF METRIC TONS	FAS	44.2	46.5	50.5
	LACIE	42.1	47.5	55.0
	R/D	- 5%	2.1%	8.2%
	CV	10.4%	10.4%	9.3%

R/D = RELATIVE DIFFERENCE
CV = COEFFICIENT OF VARIATION
* = EFFECTIVE OPERATIONAL RELEASE DATE 14 DAYS FOLLOWING LATEST LANDSAT ACQUISITION DATE.



(g) U.S. total wheat (9 states).

5/7/77

Figure 2-2.— Concluded.

TABLE 2-II.– Concluded.

(g) U.S. total wheat (9 states).

May 27, 1977		EARLY SEASON *(JULY)	MID SEASON *(AUGUST)	HARVEST *(SEPTEMER)
AREA				
ACRES x 10^6	SRS	48.9	50.9	51.3
	LACIE	43.0	44.8	45.0
	R/D	-13.7%	-13.6%	-14%
	CV	5%	4%	4%
YIELD				
BUSHELS/ACRE	SRS	25.8	25.9	26.3
	LACIE	26.6	26.8	26.7
	R/D	3%	3.35%	1.5%
	CV	4%	4%	4%
PRODUCTION				
BUSHELS x 10^9	SRS	1.26	1.32	1.35
	LACIE	1.15	1.20	1.20
	R/D	-6%	-10%	-12.5%
	CV	6%	5%	5%

R/D = RELATIVE DIFFERENCE
CV = COEFFICIENT OF VARIATION

* = EFFECTIVE OPERATIONAL RELEASE DATE 14 DAYS FOLLOWING LATEST LANDSAT ACQUISITION DATE.

U.S. GREAT PLAINS

- COLORADO
- KANSAS
- NEBRASKA
- OKLAHOMA
- TEXAS
- MONTANA
- NORTH DAKOTA
- SOUTH DAKOTA
- MINNESOTA

national level.* Primarily this is because the variation of the aggregated estimate decreases in proportion to the square root of the number of segments used in the aggregation: a result of the statistical independence of the segment estimates.

There is, however, a tendency to underestimate the wheat area in a region as observed from ground truth. Of the 103 blind sites investigated in the Southern Great Plains and the 33 in the Northern Great Plains, a majority of the segments are underestimated to some extent. For segments with larger proportions of wheat, there is a stronger tendency to underestimate, as can be seen from figure 2-3(a) and (b). As the growing season progresses toward harvest, the tendency to underestimate decreases, as a result of increasing wheat emergence [see table 2-III(b)]. In table 2-III(b), the relative mean difference (RMD) between the LACIE/Landsat estimates and the ground-based estimates of wheat proportions has been computed for the blind site acquisitions upon which the LACIE wheat area estimates were based for the U.S. LACIE crop reports, released monthly (beginning February 1976 through the final estimate for 1976). The final column of table 2-III(a) indicates the percent of the segments for which underestimate was observed.

2.2.2 Analyst Labeling Performance

A review of the LACIE blind site data on a field-by-field basis indicates that the majority of the segment wheat-proportion underestimation results from wheat signatures labeled as non-wheat in the manual analysis process. On the average, the analyst correctly labels 60 to 70 percent of all wheat fields and some 80 to 90 percent of all non-wheat fields for an overall correct labeling average of 80 to 85 percent. The lower accuracy for wheat creates a slight dominance of errors of omission and thus the observed tendency to underestimate wheat proportion. This dominant omission

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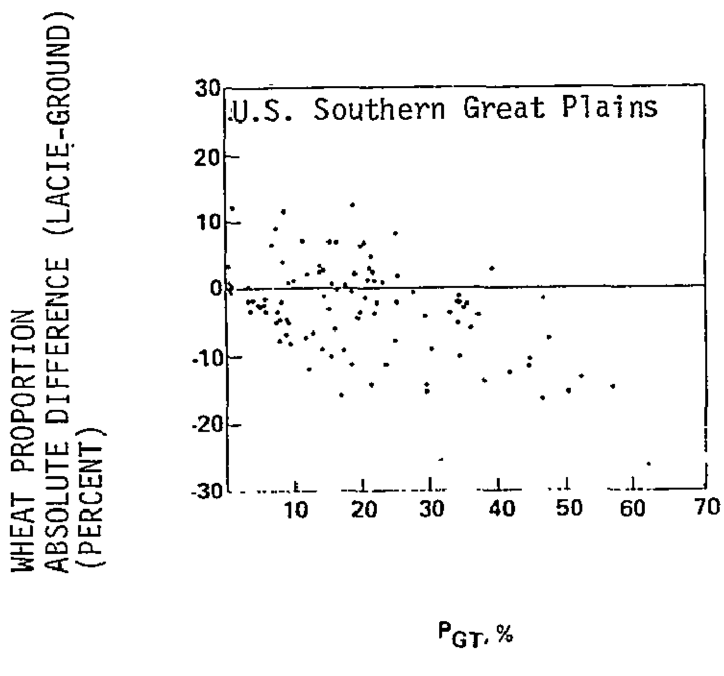
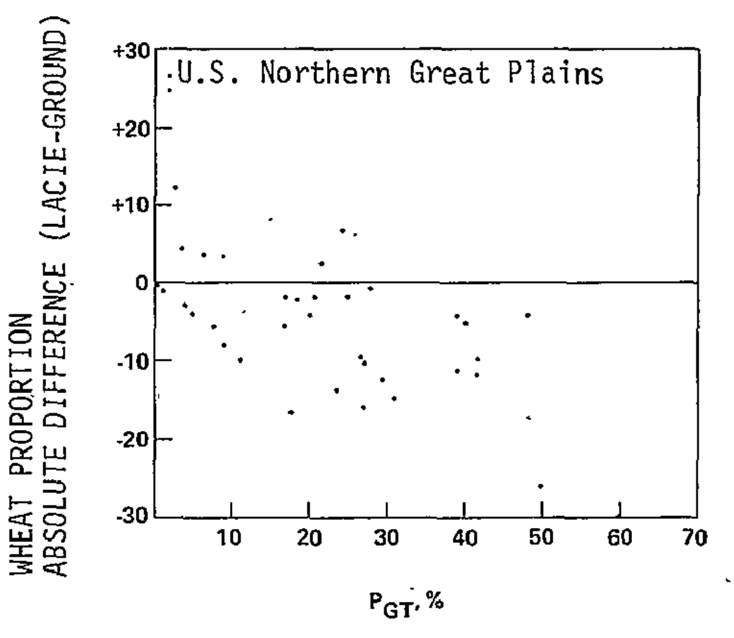
*See LACIE Phase II Accuracy assessment Report (LACIE-CD00450).



(a) Southern Great Plains winter wheat.



(b) Northern Great Plains spring wheat.

Figure 2-3.— LACIE wheat proportion estimates versus blind site ground truth.

TABLE 2-III.– COMPARISON OF LACIE ESTIMATES TO GROUND-OBSERVED PROPORTIONS

(a) Over winter wheat blind sites in the U.S. Great Plains.

WINTER WHEAT			
Month	No. of segments	RMD, %	% of segments underestimated
February	71	-30.6	83
March	95	-26.2	79
April	95	-26.2	79
May	95	-21.4	75
June	95	-15.7	72
July	95	-16.2	70
August	95	-15.2	71
September	95	-13.3	68
October	95	-13.7	68
Final	95	-13.2	68

(b) Over all available spring wheat blind sites in the U.S. Great Plains.

SPRING WHEAT			
Month	No. of segments	RMD, %	% of segments underestimated
August	33	-41.6	88
September	33	-25.6	82
October	33	-24.1	79
Final	33	-22.6	79

error results from the "wheat conservative" analyst procedure — to be more fully discussed momentarily. There are two major classes of wheat signatures which most frequently are mislabeled: (1) The first major class includes wheat signatures which were outside the range of wheat signatures usually observed. Generally, these signatures were associated with very thin stands of wheat (in some cases drought affected or incompletely emerged) which appeared only faintly pink on the color-infrared image. Also in this first class were (a) signatures for wheat fields developing either significantly ahead or behind their nominal development calendar, and (b) highly variable signatures acquired from strip-fallow areas with field widths small compared to the Landsat spatial resolution of about 80 meters (see fig. 3-1). (2) The second major class of mislabeled wheat occurred for those wheat signatures which (for a particular combination of Landsat acquisitions) were also characteristic of non-wheat signatures.

A detailed analysis of the ground and meteorological information in the 1976 crop year indicated that the primary agrometeorological conditions responsible for acreage underestimation in Phase II were as follows: (a) For the winter wheat region, the early drought in 1976 followed by late April rains created atypical growth conditions in which wheat signatures were not visible early in the year and then "greened" up later than expected. Many such fields were misidentified by the analyst. The primary region affected by this problem was the State of Oklahoma and a portion of the Texas Panhandle. The Landsat estimates of wheat proportion agree favorably in the other southern Great Plains winter wheat states. (b) There is an increased tendency to underestimate in the northern Great Plains spring wheat region [table 2-III(b)]. A more detailed investigation of these blind sites indicates that strip-fallow fields whose widths are small compared to the Landsat resolution, are a major source of the observed underestimation (see fig. 3-1). These fields were difficult to classify with the Phase II procedures. In addition to the strip-fallow problem, some of the same problems observed in the U.S. southern Great Plains winter wheat region were also observed in the northern Great Plains spring wheat region.

Much of the discrimination between wheat and non-wheat vegetation is based on the temporal differences observed between the wheat and non-wheat signature cycles over a complete growing season. With Landsat, there is at least an 18-day interval between observations: even greater periods elapse if cloud cover obscures the target on a particular overpass. Thus, a given collection of Landsat cloud-free acquisitions may be inadequate to permit all of the wheat signatures to be uniquely associated with wheat.

The misidentification of abnormally developing wheat signatures should decrease as more experience is gained with the variety of growing conditions to which wheat is subjected from year to year. Another significant reduction in signature confusion between wheat and other crops will result from improved sensors. But regardless of how much experience is gained or how good the sensors become, there will always remain a problem with labeling "confusion crop signatures"; i.e., signatures which, for a variety of reasons, are not unique to a given crop. The labeling procedure utilized to date in LACIE can be described as a "wheat conservative" procedure. That is, a particular signature is labeled wheat only in case there is a high degree of confidence that the signature is uniquely associated with wheat. If the signature is not typical of signatures normally observed for wheat or in a significant number of cases is also observed as a non-wheat signature, the signature will be labeled as non-wheat. This "wheat conservative" tendency is verified by examining the analyst labeling errors in the blind site data. The analyst-labeled wheat fields are, in almost all cases, called wheat fields by ground observers; very rarely does an analyst label a non-wheat field as wheat. However, the analyst labels a significant number of ground-observed wheat fields as non-wheat. The "wheat conservative" procedure obviously has a built-in negative bias. However, a "wheat liberal" alternative of labeling a signature as wheat if there were a reasonable chance that it *might be* wheat would lead to an overestimate of wheat. Therefore, the problem in dealing with non-unique or unusual signatures boils down to the following: How can such signatures be labeled in a manner which produces a minimally biased wheat proportion estimate?

2.2.3 Improved Classification Procedure Development

The LACIE research, test, and evaluation program is investigating a procedure which has two features: First, the procedure includes a means for the analyst to specify quantitatively the certainty with which each signature is uniquely associated with wheat or with non-wheat. Second, a method is being developed which permits this "figure of certainty" to be utilized in the proportion estimation process in such a way as to minimize the estimation bias resulting from non-unique signatures. However, for the near term, the LACIE design effort has focused on the development of (1) spectral products and ancillary information which will increase the ability of the analyst to correctly identify wheat signatures, (2) more automated machine processing procedures which eliminate all non-essential manual functions so that the analyst may concentrate on signature labeling, and (3) more optimum machine processing procedures from the point of view of producing minimally biased proportion estimates, given correct signature labels. This approach will be described in section 3.1.1.

2.3 YIELD MODEL PERFORMANCE

Yield models for Canada (16 crop reporting districts) and for the U.S.S.R. indicator regions (a total of 36 districts) were developed, tested, and operationally implemented in Phase II.

Regarding the performance of the first-generation yield models employed in LACIE, 2 years of experience with the models and tests of them over 10 years of historic data indicate adequate performance in estimating wheat yields at the national levels of those countries for which adequate historic and current meteorological data are available. At levels below the national level, investigations have shown a need to improve the LACIE yield model's response to extreme weather conditions. In South Dakota, for example, 1975-76 was an extremely dry year with wheat yields estimated by SRS to be only 11 bushels per acre. The LACIE South Dakota yield model estimated 17 bushels per acre. It would have estimated 13 bushels per acre, even if zero values for precipitation had been entered into the model throughout the year. The tendency to over or underestimate yields in areas and in years for which there are large deviations from the average yield is common to overly simple crop-yield model forms which cannot adequately reflect the total dynamic range of the plant's response to its environment.

A second-generation approach to yield modeling is to be evaluated in selected regions for Phase III. The second-generation models employ improvements such as a versatile soil moisture budget (as opposed to precipitation input alone), response to moisture and temperature tied to actual development state, and use of daily (as opposed to monthly) weather variables.

Also, adjustments will be made to the yield strata for Phase III to pseudozone levels (several crop reporting districts) to permit estimates of the production error that account for correlations between yield strata. The quantitative magnitude of errors discovered in the variance estimation procedures for the LACIE yield estimates was investigated as well.

In spite of difficulties inherent with the first-generation models, they have served LACIE well. In fact, LACIE yields were quite variable from month to month. They reflected the early dry season by a reduction in the yields followed by a corresponding increase through harvest.

2.4 OPERATIONAL PERFORMANCE

2.4.1 Data Rates

Wheat segment data acquired by Landsat had to be processed through the quasi-operational element of the LACIE system at much higher rates in Phase II than in Phase I. In order to achieve the necessary throughput rates for Phase II, new procedures that reduced by one-half the analyst time required for analysis of a segment were implemented (see table 2-IV). The number of segments for which data was acquired was increased, and the number of acquisitions analyzed per segment was also increased. Only the first acquisition in each Phase I segment biowindow was analyzed. During the Phase II growing season, every segment acquisition that met the quality standards in initial processing at Goddard Space Flight Center (GSFC) was passed to JSC for analysis. In addition, supplementary data was acquired to monitor the southern Great Plains drought, bringing the number of Phase II Landsat acquisitions to a total of 27,000.

TABLE 2-IV.— COMPARISON OF PHASE I AND PHASE II DATA RATES

PHASE	NUMBER OF SEGMENTS STUDIED	NUMBER OF ACQUISITIONS			ANALYSIS TIME PER SEGMENT
		BY LANDSAT	AVAILABLE FOR ANALYSIS	ANALYZED	
I	692	7,500	2649	1627	12 hrs.
II	1683	27,000	9148	9148	6 hrs.

2.4.1.1 Initial GSFC Processing. - Except for a peak processing load in late June and early July, initial processing at GSFC remained current. Even during the peak load, the backlog did not exceed 5 days of data. Data rejections for operational reasons were minimal. The rejection rates were 50 percent due to cloud cover, 10 percent due to correlation failure, and five percent due to bit-slip and other technical problems.

2.4.2 Area Estimation Analysis

The automated analysis system at JSC was augmented with a computer parallel processor to support increased data loads. The average contact time required for the manual portion of a sample segment was reduced from 12 hours for Phase I to 6 hours for Phase II by more efficient analysis procedures. A new, "no-change" analysis procedure required the analyst to overlay a computer classification map from a previous acquisition over a color-infrared image created from a new acquisition and manually determine if there had been a significant change in wheat area. If the change was more than two and one-half percent, the new image would be processed. The "no-change" procedure could be performed in about 1 hour.

Some low-acreage segments did not contain an adequate amount of wheat training data for automated analysis. The routine for these segments required an analyst to manually interpret a color-infrared image made from the Landsat multispectral data and handcount picture elements where less than five percent of the sample segment was in wheat. The time required for this procedure was about 2½ hours per segment. The procedures used in Phase II produced an average throughput of 68 acquisitions per day during the peak summer months (compared with a peak of 16 per day in Phase I). This throughput rate was considerably higher than had been predicted and, accordingly, backlog did not accrue to predicted levels. Table 2-V shows the four categories of data acquisitions that were not processed at JSC. Category 5 in the table shows the percentage of acquisitions that were usable in the aggregated wheat area estimates and the methods of analysis employed.

TABLE 2-V.— UTILIZATION OF PHASE II LANDSAT DATA AT JSC

CATE-GORY	DISPOSITION OF LANDSAT DATA ACQUISITIONS AT JSC	PERCENT OF TOTAL REC'D
1	Poor data quality, not processed	10
2	Showed pre-emergent or dormant stages of wheat; used in later analyses	16
3	Next-day acquisition available; not processed	19
4	Showed non-agriculture; not processed	2
5	Produced usable wheat area estimate data (a) Machine processed-17%; (b) Hand-count analysis-9%; (c) No change from previous analysis-27%	53

2.4.3 Meteorological Data Processing

In Phase II, the LACIE system successfully acquired and processed meteorological data from WMO stations through automated yield models utilizing 30-day average values of precipitation and temperature. Although daily maximum and minimum temperatures were collected as inputs for the wheat growth-stage model, significant problems were encountered in producing timely and accurate crop calendars.

2.4.4 Results Reporting

With the exception of the early spring wheat reports, for which insufficient data were readily available, the generation of LACIE monthly estimates of wheat area, yield, and production were produced on schedule. All scheduled reports of winter wheat area, yield, and production for the U.S. Great Plains and the U.S.S.R. were released on time. However, the July report for spring wheat in the same areas had to be delayed until sufficient Landsat data was available, and it was published in August. Some Phase II reports were submitted without variance values for yield and production estimates. A final report released on December 17, 1976 contained corrected estimates of variance for all yield, acreage, and production estimates.

Annual reports were prepared for each country, and estimates included in the annual reports were revised to reflect error corrections in input data bases and changes in aggregations procedures. Addenda and supplemental appendices including further analyses of Landsat data and estimates of statistical parameters (variance, coefficient of variation, etc.) associated with previously submitted estimates of wheat area, yield, and production were prepared.

All of the LACIE wheat estimation reports were provided to the USDA LACIE office in Washington, D.C., and to the Statistical Reporting Service (SRS) of USDA. The domestic (U.S.) reports were mailed to USDA in Washington prior to the "lockup" at which official USDA wheat production estimates are announced.

In addition to scheduled reports, special reports on the drought-affected regions of the United States were prepared and distributed in accordance with LACIE and USDA procedures.

2.4.5 Exploratory Analysis

To prepare for more extensive monitoring of global wheat, Landsat data for segments in the U.S.S.R., China, India, and the Southern Hemisphere were acquired for exploratory analysis. The segments designated for exploratory studies were examined in Phase II to test repeatability of Phase I analysis, to examine the effectiveness of Phase II technology, and to identify special problems encountered. Exploratory segments in several countries were changed to eliminate non-agricultural segments or to explore new regions. After the selection and approval process was completed, the Phase II exploratory segments numbered 261, compared to the 253 for which Landsat data was acquired and processed in Phase I.

Landsat data for the exploratory segments were acquired and processed using the normal Phase II data flow and procedures. Biowindows were defined to GSFC, and Landsat II data was acquired at every opportunity. Those acquisitions passing the cloud cover screening and quality checks at GSFC were sent to JSC for LACIE processing. About 45 percent of the exploratory acquisitions that were processed yielded usable area estimate data. In LACIE Phase II quasi-operational analysis, this was comparable to the 46 percent usable for the U.S.S.R. and the 47 percent for Canada but was somewhat lower than the 66 percent of data acquisitions that produced usable estimates for the U.S. Great Plains.

2.4.5.1 U.S.S.R. - The Phase II approach of interpreting every acquisition yielded significant knowledge about the wheat growing regions of the U.S.S.R. The experience with these data produced a recommendation that Biowindow 1 should open earlier than in Phase II in order to obtain additional information on seed bed preparation for use in more accurate identification of wheat when combined with subsequent acquisitions.

Winter wheat signatures in the U.S.S.R. were much like those seen in the United States. For some of the drier areas, where the wheat signatures were very weak, the late-fall and early-season interpretation of winter grains was difficult since it was hard to determine if anything was actually growing in many of the fields. Computer classifications were difficult to accomplish for segments where there was a small percentage of wheat. The spectral signature of wheat was confused with natural vegetation in these areas. This confusion should be less during Phase III because imagery from Phase II will be available for reference.

Spring wheat signatures for the U.S.S.R. do not appear as strong as do those for the United States, but the fields are larger. Multitemporal computer processing was used to separate spring grains signatures from those of natural vegetation. Good estimates were derived for the spring wheat indicator region because of good Landsat image data and little signature confusion to complicate interpretations.

2.4.5.2 China. - The major problems encountered in processing Landsat data acquired for segments in China were the small sizes of the fields and inadequate ancillary data. This could result in a lower confidence level in the results of China segment analysis than for the U.S. Great Plains. Without additional information on the confusion crops, crop-calendar accuracy is much more important in China because crop identification is based on growth-stage color alone. In regions with small fields, winter wheat fields could not be followed multitemporally because of the small field size and single-pixel misregistration. In order to train on single-pixel fields, a simple and basic procedure was developed for classifying on an off-line processor. This procedure was tested and expanded to include faster and more accurate classification methods for the quasi-operational system.

2.4.5.3 India. - The first LACIE identification of dwarf wheat by use of Landsat data was made on imagery from India. This was evidenced by a lack of signatures in Biophases I and II but the same signatures as regular wheat in Biophase III.

Phase II classification procedures were found to be inadequate for segments with small fields analyzed for India. An investigation was initiated for a new method of small field classification. This technique was tested and evaluated during Phase II and served as the basis for the small fields approach and procedures to be implemented in Phase III.

2.4.5.4 Southern Hemisphere. - During the latter parts of Phase II (January 1977), a decision was made to suspend the processing of the Southern Hemisphere segments. This decision was done primarily because the Southern Hemisphere countries were not to be part of Phase III and because of Landsat tape recorder problems and severe requirements on available resources during that time. Although some number of acquisitions for Australia, Argentina, and Brazil were analyzed, the effort was minimal.

2.5 ACCOMPLISHMENTS

The goals and accomplishments of Phase II, summarized in table 2-VI, represent the technical and operational highlights discussed in this section.

2.5.1 System Development and Operation

The LACIE data acquisition and analysis system (including the various quasi-operational elements at their several locations) generally performed well and was significantly upgraded during Phase II. Data processing proceeded on schedule, with processing rates for Landsat data exceeding expectations.

At the end of Phase I, three shortcomings of the data system were identified. These were the relatively long time it took to get analysis products (film, computer runs, etc.) returned to the analyst, the absence of an automated status and tracking system, and the availability of only a relatively simple data aggregation system. During Phase II, these problems were effectively corrected, and a great deal of progress was made toward achieving an efficient and responsive system identifying and measuring wheat areas using Landsat data. Implementation of improvements in the LACIE quasi-operational system such as the direct communication link between GSFC and JSC, an automated status and tracking system, and an interactive automated wheat area aggregation system, the special-purpose (array) computer parallel processor, and the "no-change" analysis routine helped to overcome Phase I deficiencies and meet the objectives of Phase II. Several new data acquisition strategies were also introduced. These included monitoring winter wheat seed-bed preparation, use of duplicate data for monitoring spring and winter wheat in mixed spring and winter wheat areas, maintaining good full-frame Landsat reference scenes, and monitoring episodic events, such as drought, with every available acquisition from Landsat 1 or 2.

TABLE 2-VI.— SUMMARY OF LACIE PHASE II GOALS AND ACCOMPLISHMENTS

GOAL	ACCOMPLISHMENT
TEST THE LACIE SYSTEM OVER THE U.S. GREAT PLAINS "YARDSTICK" REGION WITH EMPHASIS ON EARLY SEASON ESTIMATES.	TEST SUCCESSFULLY CONDUCTED OVER THE "YARDSTICK" REGION FOR SPRING AND WINTER WHEAT EARLY SEASON THROUGH AT-HARVEST ESTIMATES.
EXPAND THE LACIE STUDY AREA TO CANADA AND TWO INDICATOR REGIONS IN THE U.S.S.R.	STUDY AREA EXPANDED THROUGH U.S.S.R. SPRING AND WINTER WHEAT INDICATOR REGIONS AND ALL CANADIAN WHEAT.
EXPAND THE LACIE EXPLORATORY ANALYSIS TO OTHER MAJOR WHEAT PRODUCING COUNTRIES.	SMALL-FIELD ANALYSIS WAS CONDUCTED IN CHINA AND INDIA. SOUTHERN HEMISPHERE ACTIVITIES WERE DEFERRED DUE TO LANDSAT RECORDER PROBLEMS.
MODIFY AND IMPLEMENT LACIE SYSTEM COMPONENTS TO SUPPORT INCREASED PHASE II AND PHASE III REQUIREMENTS.	A SPECIAL PURPOSE (ARRAY) PROCESSOR WAS ADDED TO REDUCE SEGMENT COMPUTER TIME. A SMALL-FIELDS ANALYSIS PROCEDURE WAS DEVISED AND IMPLEMENTED. THE "NO-CHANGE" ANALYSIS PROCEDURE INCREASED EFFICIENCY. THE HIGHLY AUTOMATED PROCEDURE I ANALYSIS METHOD WAS DESIGNED FOR PHASE III IMPLEMENTATION.
DESIGN AND BEGIN DEVELOPMENT OF A USDA USER ADVANCED SYSTEM.	THE PROCUREMENT OF THE USDA SINGLE-THREAD SYSTEM IS IN PROGRESS FOR IMPLEMENTATION DURING PHASE III.
EVALUATE PERFORMANCE FOR ACCURACY, TIMELINESS, AND UTILITY.	A GREATLY EXPANDED ACCURACY ASSESSMENT PROGRAM WAS IMPLEMENTED — FULL-SEGMENT GROUND OBSERVATIONS WERE CONDUCTED OVER 151 U.S. SEGMENTS AND UTILIZED TO ASSESS THE LACIE CLASSIFICATION AND SAMPLE ERRORS. GROUND DATA WAS WITHHELD FROM LACIE ANALYSTS UNTIL AFTER THE CONCLUSION OF PHASE II PROCESSING. THE EFFECT OF CLOUD COVER ON LACIE ESTIMATION BIAS WAS THOROUGHLY EXAMINED AND INDICATED A NEGLIGIBLE EFFECT.
CONDUCT PARALLEL AND SUPPORTIVE RESEARCH, TEST, AND EVALUATION TO INVESTIGATE IMPROVED TECHNOLOGY.	PHASE I AND PHASE II RESEARCH TEST AND EVALUATION EFFORTS INITIATED PRIOR TO LACIE PHASE I, RESULTED IN A MUCH IMPROVED MACHINE CLASSIFICATION PROCEDURE, A NEW APPROACH TO YIELD MODELING, NEW SAMPLE STRATEGY, AN IMPROVED CLUSTERING ALGORITHM, IMPROVED SIGNATURE EXTENSION TECHNIQUES AND DEVELOPMENT OF A FIELD MEASUREMENTS DATA BASE FOR FUTURE RESEARCH. OTHER IMPROVEMENTS INCLUDED AUTOMATED STATUS AND TRACKING, INTERACTIVE AREA AGGREGATION, MORE RESPONSIVE CROP CALENDARS, AI COLOR KEYS, AND USE OF FULL-FRAME LANDSAT REFERENCE DATA.

To compensate for Phase II analysis being done without signature extension and with computer signature training still required for each segment analysis, additional data analysts were employed. Also, the Phase I practice of sequentially utilizing image interpreters and data processing specialists in each segment analysis was changed to a team approach. This evolved into an operation in which every analyst could perform both functions, producing benefits in accuracy, efficiency, and reduced costs. Further, analysts were given specific geographic regions for analysis to increase their accuracy through familiarity with the assigned regions.

Various hardware problems with the Landsat data analysis system components (notably the special purpose processor and the production film converter) were overcome without major delays.

2.5.2 Crop Calendar Models

An adjustable crop calendar model was developed during Phase II. Based on estimated planting date, and daily maximum and minimum temperatures, it permits tracking of both spring and winter wheat development. This model is not applicable to some varieties of wheat, such as the dwarf Mexican variety. Data to operate or test the model in Southern Hemisphere regions was not available.

Other methods to start crop calendar models were also developed early in Phase II. For spring wheat, these methods were adequate to initiate the crop calendar when only meteorological conditions were known. For winter wheat, the method did not improve results over the nominal planting date.

2.5.3 Exploratory and Blind Site Segments

2.5.3.1 Exploratory Segments. - Exploratory wheat segments were reselected in several countries to achieve better representation of agriculture. New Landsat data analysis techniques were evaluated for the small-fields problem identified in China and India.

2.5.3.2 Blind Site Segments. - The activity to gather ground data for selected blind site segments to be used in segment level assessment of Landsat data classification accuracy was expanded in Phase II from 29 Phase I blind sites to 151 Phase II blind sites. The Phase II sites were initially visible earlier in the growing season than in Phase I.

2.5.4 Analyst-Interpreter Color Keys

A two-volume set of reference books depicting, in color, representative Landsat data acquisitions corresponding to wheat-growing strata in the U.S. Great Plains was completed, published, and distributed for use by analyst-interpreters (AI's). Referred to as AI keys, these volumes describe the areas depicted and provide a starting point for evaluating current data acquisitions from the same locations.

2.6 RESEARCH, TEST, AND EVALUATION

The Phase II research, test and evaluation program was largely focused on two problems:

1. Classification technology improvement, and
2. development of advanced wheat yield models.

2.6.1 Classification Technology Improvement

2.6.1.1 Improved Area Estimation - Procedure 1. - During Phase II, a new approach to estimate the wheat area in each LACIE segment was developed. The details of this approach (called Procedure 1) are discussed in section 3.1.1. Preliminary results from simulation and testing using ground truth labeling show:

a. The total complement of 209 dots (picture elements) from which a random selection is made to initiate clustering and to perform bias correction is an adequate sample size to represent the frequency distribution of all pixels in a Landsat sample segment scene.
b. Of the 209 dots, only 100 or less are needed for clustering and bias correction.

c. The multitemporal classification is at least as good, and often better, than that which can be obtained with a field-trained classifier as was done in Phases I and II of LACIE.

d. The procedure will give an unbiased estimate of segment wheat acreage, given correct ground truth labels.

2.6.1.2 Signature Extension. - It was anticipated at the inception of LACIE that in order to substantially reduce the time required for manual analyst interpretation, an effective signature extension routine was needed. Basically, the signature extension concept implies that, from a given collection of LACIE sample segments, it is possible to manually interpret only a small subset of these segments and thereby obtain representative "signatures" for all wheat. These signatures could subsequently be applied to computer classification of wheat in all the sample segments.

Initially, it was realized that a number of static variables such as soil color, sun angle, crop calendar, and cropping practices affect the spectral response of crops. The first research approach to solve the signature extension problem attempted to divide an area into strata of nearly constant values of the above variables and then to extend signatures within each strata by training on one segment and extending to another in the same stratum. To make the concept work, a means for stabilizing the signatures within a strata to compensate for variations due to dynamic or short-lived variables, such as haze, was needed.

During Phase II, two test areas were stratified (Kansas and North Dakota). This stratification was done using soil associations, land use, climatology data, and full-frame Landsat imagery. To compensate for dynamic variation, several haze correction algorithms were developed. These algorithms were of two basic types. In one, each segment was corrected by first estimating the corrective linear transformation using Landsat spectral data from that segment and then applying that transformation to each pixel in the segment. In the other, a relative linear transformation was estimated for the purpose of removing haze differences between a given pair of recognition and training segments.

Evaluations of these haze correction approaches demonstrated that when uniform haze was present, a significant amount of correction was possible. However, the application of a haze correction to the above-mentioned strata was not sufficient for an adequate signature extension approach when training was done on one segment at a time. This led to the formulation of a more sophisticated approach during the second half of Phase II in which the effects of additional variables, other than haze and those used in stratification, were accounted for through a spectral sampling of segments. In this approach, spectral groups were formed using all the segments within a given stratum. The subset of segments of minimal size, which spectrally represented those groups, constituted the training segments. One ramification of this approach is that multisegment training may be required; i.e., training is done on a group of segments rather than on a single segment. Haze correction in this approach is used to minimize the spectral variance across segments due to haze and hence to minimize the number of training segments required.

This signature extension approach is being performed on Landsat data of the test areas and tested against the LACIE Kansas and North Dakota blind site data. First, in these tests, each segment is sun-and-haze corrected to minimize within-strata variance across segments. Next, the segments are transformed to "soil brightness" and "green development" coordinates (cf. later discussion in this section). This is followed by a spatial clustering of each segment into pseudo-agricultural fields; i.e., spatial groupings that have a tendency to coincide with areas enclosed within actual field boundaries. Finally, all the psuedo-agricultural fields within a strata are clustered, and the smallest set of the LACIE segments which, collectively, have data in each cluster forms the training set for signature extension.

Preliminary test results show that a three-to-one efficiency over local signature training can be achieved by this approach

In the course of developing a theoretical understanding of signature extension, a spectral characterization which relates the biological growth stages of a crop to the spectral response of that crop was developed. In this characterization, the multispectral scanner vector response from a crop canopy is decomposed into orthogonal components which can be related to soil background brightness, the amount of green development, the amount of yellow development, and a "noise" component. As a spinoff of this research, it was found that the projection of the canopy response onto the green development axis was a good indicator of drought; and, in Phase II, a greenness number based on this projection and on the soil brightness projection was developed to map drought areas in the U.S. Great Plains.

2.6.2 Yield

During Phase II, advanced yield models for spring and winter wheat were developed and partially tested. These models incorporate concepts which should prove to be a substantial improvement over the models which are currently being used by LACIE:

a. The models are keyed to a predicted crop calendar rather than to a Julian calendar (as are the current LACIE models); i.e., each model is, in essence, a sequence of prediction models in which a given member of that sequence predicts at-harvest yield from weather-related variables (and constants) measured within a specific growth interval of wheat.
b. The models estimate soil moisture through the use of a versatile soil-moisture budget.
c. Potential yield changes due to various temperature and precipitation regimes is estimated.
d. Effects of added nitrogen and improved plant varieties are estimated.

All of the weather-related variables in these models will be measured using ground-based meteorological stations at first;

but in the future, some variables could be measured using satellite measurement techniques. One approach is to estimate evapotranspiration (ET) using, as one variable, leaf area index as estimated from Landsat. In Phase II, a yield model term utilizing satellite estimates of ET was developed. Preliminary indications are that incorporation of Landsat data will improve yield estimation accuracies.

2.6.3 Field Measurements

In addition to the signature extension and yield research progress was made in the LACIE field measurements program, which is conducted over three "supersites" in Finney County, Kansas; Williams County, North Dakota; and Hand County, South Dakota. Landsat, aircraft, helicopter spectrometer, and field spectrometer data are gathered as nearly simultaneously as possible over these sites. Data from this program is being used to research critical problems in LACIE and in future applications such as sensor design and multicrop identification procedures development.

2.7 TECHNOLOGICAL ISSUES

As a result of the LACIE experience through Phase II in five of the world's major wheat crops (U.S. spring and winter, U.S.S.R. spring and winter, and Canadian spring), several technological issues were surfaced which required further study and development prior to Phase III. In summary, these were:

a. Differentiation of small grains. - Spring wheat was not reliably differentiated from other small grains. Specifically, in Phase I, analysis of 20 North Dakota blind sites revealed that spring barley, a crop very similar in appearance and growth cycle to spring wheat, was not being reliably distinguished from spring wheat. In some segments, spectral separation did exist. This separation was not observed in enough segments to permit sufficiently accurate analysis over all. Efforts were begun in late Phase I to develop improved analysis procedures — procedures which could take advantage of the spectral separability that exists between these crops. For Phase II, however, the classification and mensuration procedures were used to estimate total small grains, and ratios based on the historic proportions of spring wheat to other small grains were used to convert to Landsat-based estimates of small grains to spring wheat estimates.

b. Historic ratios of spring wheat to other small grains. In Phase II, the ratios from the latest year for which data were available were used to estimate spring wheat, given the Landsat-based estimates of total small grains. In most cases, the current-year prevalence of wheat had increased considerably over the historic value. In Canada, where the latest available crop-district data was for 1971, the ratios had increased by as much as 50 percent. In the United States, the increase over 1975 averaged some 10 percent. Thus, the use of the historic ratios in Phase II contributed to an underestimate of about 10 percent in the four U.S. spring wheat states and by larger percentages in Canada.

c. Classification underestimates of small grains. - Analysis of 138 LACIE blind sites indicated that winter wheat acreage was being underestimated by some 6 to 10 percent and spring grains by a little less than 10 percent. The primary factor causing underestimates was discovered to be misidentification, by the image analyst, of certain abnormal spectral signatures of wheat. Generally, these signatures were found to represent sparse wheat stands or crops with unusually late development cycles resulting from the early dry season in 1976. This problem was aggravated somewhat in the northern Great Plains states as a result of the increased use of the strip-fallow planting practice in which field dimensions are usually small compared to the Landsat resolution (see figure 3-1). Analyses over LACIE intensive test sites showed that, for the most part, the LACIE analysts correctly identified 60 to 70 percent of all wheat fields and 80 to 90 percent of all non-wheat fields. This tendency to make more errors of omission (i.e., miss wheat) than commission (i.e., mistake non-wheat for wheat) is fairly consistent in Phase II and explains the observed underestimates of wheat area.

d. Machine classification procedures. - The first-generation machine processing technology, implemented prior to Phase I and utilized through Phase II, was a non-optimum technology from two viewpoints: (1) The analyst was involved in functions for which a machine algorithm is better suited. The analyst was required to delineate the multivariate structure of the multispectral data utilizing temporal sequences of color-infrared images. In many cases the analyst missed signatures, resulting in unacceptable classification. In addition, the analyst was required to select a representative subset of the fields for training the computer and was required to manually specify the Landsat coordinates of the field vertices to the computer. This was a time-consuming job, and it was often an impossible job in small-field situations such as those encountered in the strip-fallow regions of the northern United States (see fig. 3-1). In Phase II, extensive research, development, and testing was conducted to obtain an improved clustering algorithm for automatically delineating the multivariate structure of the data, and research was conducted to develop a more optimum way to select training samples. (2) Even with correct analyst labels for all signatures, the Phase II machine algorithm for acreage estimation was not a theoretically unbiased procedure.

The maximum-likelihood decision rule is, theoretically, set up to maximize the probability of correct classification, as opposed to minimizing variance and bias of the wheat proportion estimate. While empirical tests with correctly labeled fields indicated that the bias introduced by Phase II procedure was reasonably small, a theoretically unbiased procedure was considered desirable. A new machine processing algorithm was developed for Phase III to optimize the man-machine interaction. This procedure is discussed in section 3.1.1, Improved Machine Processing Procedure.

e. Sampling strategy. - Sampling modifications made at the end of Phase I in North Dakota proved successful in Phase II. At the end of Phase I, an analysis of the North Dakota acreage estimate using the 20 North Dakota blind sites indicated that significant bias was being introduced by a small sample size. As a result of these studies, the sample complement of 42 Phase I samples was increased to 65 for Phase II. Phase II analyses indicated that this modification significantly reduced sample error and, on this basis, 200 additional samples will be added to the Phase III sample network for the entire Great Plains.

f. Improved yield models. - While the yield models have performed well for 2 crop years in several important regions, they tended to under- or over-estimate yields in regions experiencing extreme weather conditions. While the extreme weather conditions have been somewhat local within the LACIE regions, the models are not expected to perform well in a year for which a country is subjected to extreme conditions over a majority of its wheat regions. New models designed to be more responsive over a wider range of agrometeorological conditions have been developed and are being tested in Phase III.

g. Signature extension. - The utilization of spectral characteristics (signatures) from one area to classify wheat in a distant area (signature extension) was not sufficiently successful in Phase I to be considered operational. The Phase I evaluation of signature extension involved a straightforward attempt to utilize the signature statistics from one segment to classify arbitrarily selected distant segments. Little effort was made to correct for atmosphere- or sun-angle induced signature differences between segments or to match segments based on potential signature similarity due to similar crop mixes, soils, growth stage, etc. In late Phase I, efforts were initiated within the LACIE research program to develop partitioning (grouping wheat segments into areas of similar signatures) and signal correction technology. This effort was designed to concentrate on developing technology to accomplish both signature correction and segment matching (partitioning). Tests and evaluation of this technology at the end of Phase II indicated that while significant improvements had been realized, the technology was not yet ready for operational implementation in Phase III. Therefore, Phase III continues with signature statistics developed individually for all segments.

h. Sampling mixed spring and winter wheat. - In LACIE Phase I and II, segments in areas containing both spring and winter wheat (mixed wheat areas) were arbitrarily designated winter or spring in proportion to the historical percentage of winter or spring grains grown in the area. Once these segments were so designated, each segment was analyzed only for spring or only for winter wheat acreage and data was only collected during the growing season appropriate to either the winter or the spring wheat crop calendar but not both. In Phase III, data will be collected in the mixed wheat areas for the "total wheat" growing season, essentially all year. This is based on the definition that a mixed area has a probability of both winter and spring wheat being grown in a sample segment. The Phase III data collection scheme for the mixed areas will provide the satellite data required to estimate both spring and winter wheat grown in all segments, as opposed to the Phase II mode of utilizing one set of segments for winter wheat and a different set for spring wheat. Aggregation and variance estimation methodology has been developed and implemented to permit operation in this improved mode.

3.0 SUPPORT FOR PHASE III

3.1 TECHNOLOGICAL MODIFICATIONS FOR PHASE III

Substantial improvements in remote sensing crop surveys can be expected in the future. For Phase III, the highest priority lies with technological improvements for identifying spring wheat directly from the Landsat data. Procedures, utilizing improved analyst aids, such as interpretation keys and displays of quantitative spectral data, are being developed. In addition, econometric models for the prediction of wheat-to-small-grains ratios will be developed and tested in Phase III. These models will predict the current ratios of wheat to small grains resulting from influential factors such as historical crop and livestock patterns, current year growing conditions (available soil moisture, etc.), economic conditions, and prevailing government farm programs. In Phase III and the transition years beyond, LACIE will implement improved partitioning of the survey region into subregions which are climatologically and agriculturally homogeneous. Such partitioning will render sampling strategies more efficient and thus more cost-effective. In addition, the agro-climatic data compiled to effect partitioning will improve the understanding of the agro-climatic properties of the survey regions and thus improve the ability to correctly classify crop acreage and estimate yield.

3.1.1 Improved Machine Processing Procedure

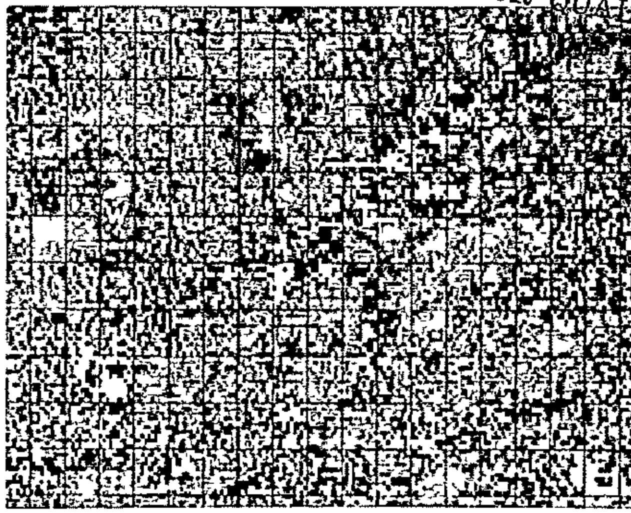
The LACIE experience with analysis of Landsat data has evolved a vastly improved technology for the automatic machine processing of complex data structures inherent in multidate acquisition of multispectral data.

As a result of this evolution, an improved automatic processing procedure, called Procedure 1 (P1), was developed during Phase II and will be implemented by mid-Phase III of LACIE.

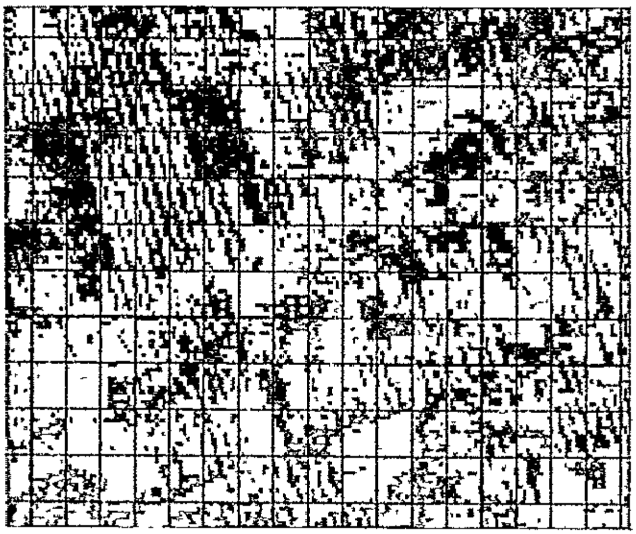
The procedure can be described as highly optimum in the sense that (a) the need for manual intervention is almost eliminated from the machine processing sequence, (b) every measurement in the scene, as well as the full dimensionality of the spectral data is utilized in statistics computation prior to maximum likelihood classification, and (c) with correct analyst determinations of crop identity for a very small sample of the segment, the machine processing procedure will provide an unbiased estimate of the segment crop proportion.

Procedure 1 has automated many of the functions that were previously performed manually and incorporates the following important new features: (1) As shown in figure 3-1(a), pixels (white dots) are randomly selected within the segment and presented to the analyst for labeling as wheat or non-wheat using image interpretation techniques. The analyst submits these labels to the machine which, without further intervention by the analyst, executes the remaining functions. (2) Machine clustering is performed to delineate the spectrally homogeneous modes within the multispectral/multidate segment data, and a color map is generated displaying the cluster groups [fig. 3-1(b)]. (3) The spectral properties of these homogeneous groups are then automatically compared by the machine to the spectral properties of the randomly selected pixels which have been labeled with analyst-determined crop identifications. Based on its "closeness" or "similarity" to the labeled pixels, each cluster is labeled wheat or non-wheat. In addition, "conditional" clusters whose properties are significantly different from any signatures labeled by the analyst are automatically flagged for more intense examination. A color map is generated to display these conditional clusters. The unconditionally labeled wheat clusters are all displayed in a single color, with the non-wheat clusters in different color, as shown in figure 3-1(c). If later examination by the analyst of the spectral and

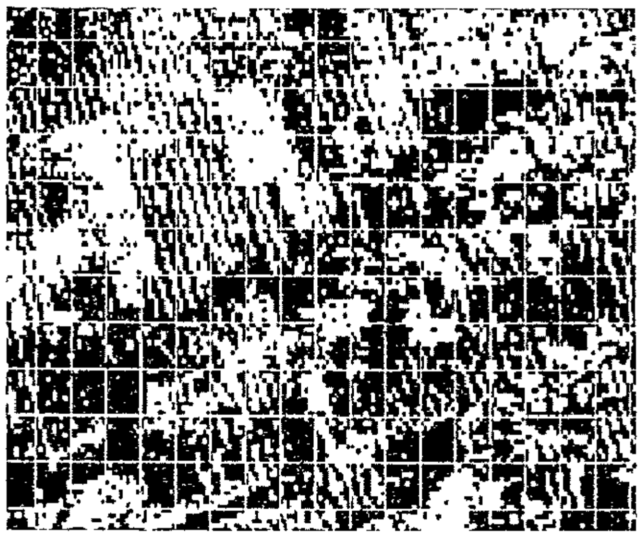
(a) Color-infrared image. Wheat emergent stage; W — winter grains, N — non-winter grains.



(b) Cluster map. Bright blue, bright green, bright cyan — winter grains; other colors — non-winter grains.



(c) Conditional cluster map. Green — winter grains; yellow — non-winter grains; blue — conditional.



(d) Classification map. White — winter grains, gray — non-winter grains, black — thresholded.

Figure 3-1.— Small fields classification sequence for Fergus, Montana, segment (Nov. 11, 1976).

spatial properties of these conditional clusters produces a non-concurrence with the label assigned by the automatic labeling logic, the analyst may then change the label or, if the cluster comprises only a small part of the scene, as in figure 3-1(c), may assume that the automatic bias correction will account for any significant error introduced. Only in cases where significant numbers of conditional clusters occur would the analyst be required to resubmit the segment data for additional analysis.

Following the machine-clustering and automatic-labeling logic, the labeled clusters of all 22,932 scene pixels are characterized parametrically by the machine as multivariate normal distributions. Means and covariances are computed utilizing all measurements in each cluster. Each pixel is then machine classified as wheat or non-wheat [fig. 3-1(d)] utilizing a maximum-likelihood decision rule. This machine-processing-algorithm sequence processes up to four temporal acquisitions of four-channel Landsat multispectral data. The four-channel, four-date Landsat data is treated by the machine as a 16-dimensional measurement vector. In case a fifth acquisition is obtained, a feature-selection algorithm automatically selects the "best" three of the four acquisitions resident in the data base and replaces the "worst" acquisition by the incoming acquisition. Upon completion of classification, the frequency of agreement between the machine-assigned labels and the analyst-assigned labels is automatically computed from a comparison over a sample of analyst-labeled dots, independent of the dots utilized in automatic cluster labeling. This frequency is used by the machine to correct its wheat-proportion estimate for bias resulting from causes such as automatic-cluster-labeling errors, etc. The frequency of agreement is also used as a performance measure; i.e., an indication of a need for possible rework.

The bias correction capability allows an incoming Landsat acquisition to be automatically processed utilizing analyst labels from an earlier acquisition. If the analyst reviews the labels and decides that there has been no significant change in them, then an automatic estimate has been obtained utilizing more recent Landsat data with potentially improved spectral separability. Even should the analyst review indicate the need for a modest number of label changes, the estimate can be updated without reprocessing simply by utilizing the bias correction procedure to account for shifts in crop identities.

In summary, once the analyst assigns labels to each spectral class, the bias-corrected wheat-proportion estimate is obtained without further need for intervention on the part of the analyst. The analyst also receives many products which permit a quantitative assessment of the quality of the segment estimate. In many cases where problems are encountered, several diagnostic products are provided to the analyst to facilitate rework.

From an operational viewpoint, these procedures will be much less labor intensive than the first-generation ones. Analyst "contact" time for segment analysis has been steadily declining from about 12 hours in Phase I to 6 hours in Phase II and a projected 3 hours in Phase III with Procedure 1, an efficiency increase by a factor of four over Phase I performance. In addition, the Phase III procedures should provide the analyst with improved and more repeatable decision-making procedures. The spectral differences between wheat and non-wheat, small grains and non-small grains as observable on multiple Landsat acquisitions have proven invaluable to LACIE analysts when manually identifying wheat or small grains in order to train the classifier. However, because of technical difficulties, not much use was made of multitemporal spectral data in the machine-processed estimates during Phase II.

3.1.2 Improved Sensors, Yield Models, and Sampling

3.1.2.1 Sensors. Landsat C, to be launched in the near future, will have improved spectral range and spatial resolution in comparison to Landsat 2. This should significantly improve classification and area estimation accuracies. For LACIE, however, the improved spatial resolution resulting from GSFC improved preprocessing capability and the Return Beam Vidicon will be utilized in a limited mode only as a result of the unavailability of funding required to interface with the new GSFC preprocessing system.

3.1.2.2 Yield Models. - Phase II yield models will be modified only slightly for Phase III. In addition, improved yield models developed in Phase II will also be implemented and tested. These models include agronomic variables not now included but which are known to affect yield. In addition, the importance of these variables will be made a function of crop growth stage to reflect the changing importance of these different variables throughout the growing season. LACIE will also be monitoring episodic events more intensely to assess their impact on yield.

3.1.2.3 Sampling. - Phase III will include an evaluation of a second-generation sample strategy. In addition, the first-generation strategy was modified for Phase III. To expedite the task of error isolation, a decision was made to reduce the magnitude of non-classification error to a level much smaller than classification error. Therefore, 200 U.S. segments were added to the 400 existing Phase II segments. The Landsat full-frame data acquired in LACIE was also utilized to improve the sample frame by deleting segments which fell into areas with no agriculture and randomly reallocating them to agricultural areas. More than 700 such segments were relocated in the U.S.S.R.

The first-generation sampling strategy is a stratified random strategy where the strata and sample allocations are based on historic data only. These strata are necessarily confined to political reporting boundaries. The second-generation approach utilizes Landsat full-frame imagery, along with climatological and soil information to develop the strata and to determine the optimal segment allocations to the strata. Such an approach was known from the outset of LACIE to be an improvement over the use of historic data, particularly in countries whose historic data is sparse. However, this approach was not possible to implement until late in Phase II because of the unavailability of Landsat imagery for foreign countries and the lack of techniques for discerning the small-grains crops on the imagery. A year and one-half of data collection by Landsat and a similar amount of image analysis experience in LACIE have made implementation of such techniques possible.

3.2 BEYOND PHASE III

As currently envisioned, LACIE is a major step toward developing a remote sensing survey technology capable of global food and fiber monitoring. The contribution of LACIE will be a demonstration of "proof of concept" of this new technology for significantly improving currently available information on one major global crop — wheat. By the end of LACIE Phase III, it is anticipated that the experiment will have demonstrated the utility of remote-sensing-survey technology over several countries, will have identified key areas where the technology needs improvement, and will have brought the USDA advanced system to a point of initial testing. At this time, a transition period will be required to complete, document, and transfer the LACIE technology to an evolving USDA system to exploit the experimental accomplishments of LACIE. In this overall development, demonstration, and application program focused on a global food and fiber monitoring system, the next logical steps are (1) the continuing refinement of the technology and subsequent transfer of both skills and technology to an application test system within USDA and (2) the adaption of the LACIE experience and technology to multi-crop food and fiber inventory applications.

Early in LACIE Phase II, an effort was initiated to accomplish the transfer of technology to the USDA for further evaluation. This effort is now an approved follow-on to LACIE and is officially designated LACIE Transition. The objective of LACIE Transition is the orderly transfer of proven technology to USDA facilities and personnel for further test and evaluation.

In addition to the transition efforts, the technology developed in LACIE will be adapted to inventory production of other food and fiber crops. These may include corn, rice, soybeans, and non-food crops scuh as forest and timber inventories. It will also be adapted to monitor forage conditions within the world's important rangeland. This increased capability could conceivably be developed and incorporated in the mid to late 1980's in a second-generation global food and fiber monitoring system.

The goals of LACIE, LACIE Transition, and the technology expansion to a multi-crop application will continue to require a strong supporting research and technology development effort within the research community. In this regard, LACIE can be considered as a paradigm for the multi-crop application. That is, estimation of production for other crops will involve estimation of the same fundamental elements involved in wheat production estimation: crop area, average plant or producing unit population per unit area, and average productivity per producing unit. It should be emphasized that the estimation approach utilized to date in LACIE is not the only approach which can be taken to estimating these quantities. And, quite possibly, modifications of the LACIE approach will produce a more optimum survey approach for applications different than global wheat estimation. However, all such approaches will involve, to a large extent, the same data input and analysis systems required for LACIE as well as many of the same solutions to technology problems.

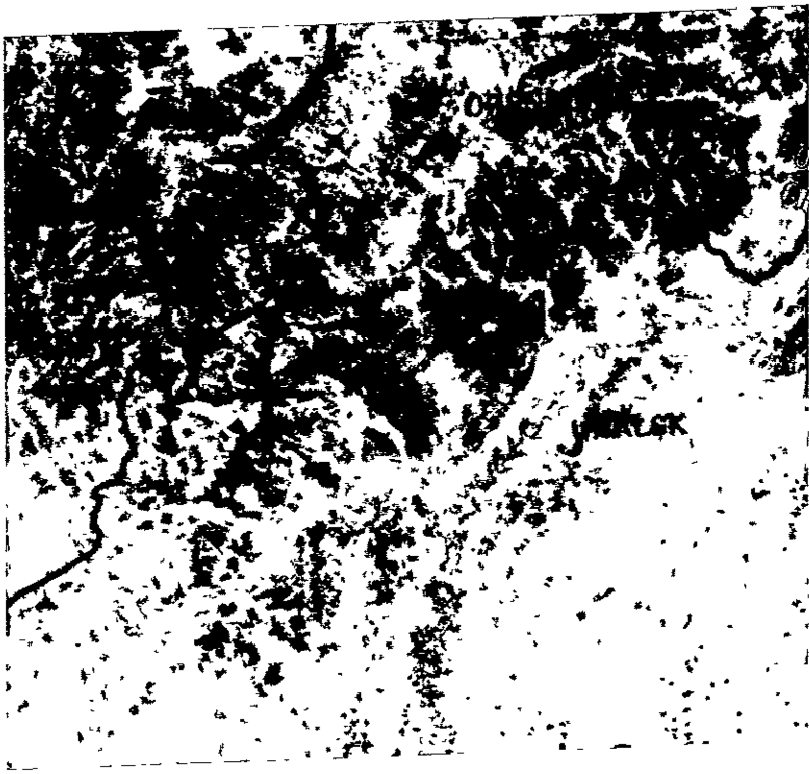
To be more specific, the LACIE approach to date has utilized primarily Landsat data to estimate wheat area for harvest and primarily meteorological data to estimate the average productivity, or yield, for each hectare harvested. In a sense, this separation is artificial; there is much information in the spectral data relating not only to total acreage but also to the plant population density within the acreage. There is, in addition, information relating to plant condition and, thus, average yield. In addition to plant environment, plant characteristics which can be measured well in advance of harvest are known to be correlated with final yield. Therefore, a model which includes the effects on yield of not only the plant's environment but also its physical characteristics (height and stand density — from which early yield estimates based on soil moisture may be made) will be a significant improvement over models utilizing only meteorological data. Potential quantitative connections through modeling involve efforts which relate leaf-area index to evapotranspiration, leaf-area duration to yield, and leaf-area index to Landsat spectral response. With the advent of thermal sensing on Landsat C, additional information will be available which is a potential predictor variable for crop yields.

Conversely, meteorological data also contain much information relevant not only to average productivity but also to planted and harvested acreage. For example, the LACIE early-season estimates of emerged acreage are a function both of the total wheat planted and that expected to be harvested. This fraction within a segment is related to the average growth stage within the segment which is, in turn, strongly related to the segment temperature and precipitation history. Therefore, in early season, the LACIE estimates of emerged acreage could be used in a regression model, involving both temperature and precipitation inputs, to predict the total acreage to emerge at a later date. The emerged detectable acreage is, of course, also related to the acreage to be harvested through meteorological and economic factors. Based on an analysis of these factors, mdoels could be developed which relate acreage at any one point in time to that anticipated for harvest.

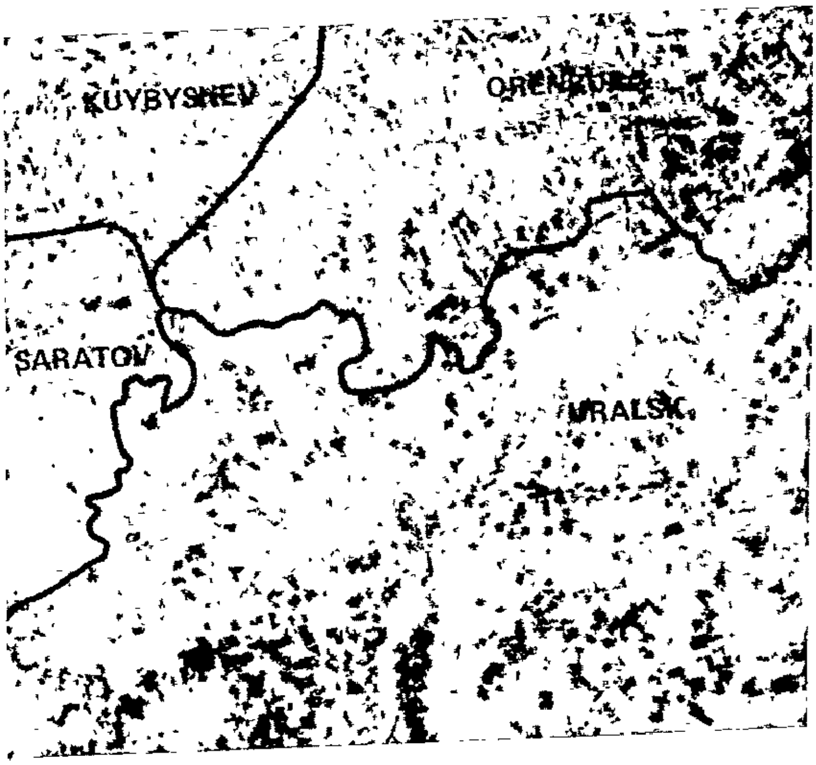
Considering, then, that meteorological and spectral data are both strongly related to total area, plant population density, plant condition, and, therefore, total production, it is anticipated that the survey models utilized for LACIE will evolve toward forms which simultaneously account, in a more integral fashion, for these effects. In such a form, the production, area, and yield estimators would each involve predictor variables based on both spectral and meteorological and even agronomic and economic data such as fertilizer application rates, cropping practices, and prices.

Another arena for development within the near future is improved sensing and measurement of the basic predictor variables themselves. To date, LACIE has utilized first-generation earth-resources satellites along with meteorological data obtained from the ground stations. With the advent of the second-generation earth-resources satellite, Landsat C, and the development of a capability to utilize environmental satellite data to obtain more complete coverage for temperature and precipitation estimates, the survey estimates should significantly improve. The LACIE analysis experience has indicated that the Landsat data itself contains information regarding temperature and moisture, as these factors are manifest in crop condition and loss of vigor resulting from drought (see fig. 3-2). Parameters such as soil moisture or, alternatively, precipitation and temperature can probably be more reliably and accurately estimated from a combination of Landsat-type and meteorological satellites.

The direction for the future, then, is the development of crop production estimation models based on both agrometeorological and spectral data which account for the influence of these data on



(a) Normal moisture conditions (June 17, 1976).



(b) Drought conditions (June 23, 1975).

Figure 3-3.— Full-frame Landsat images of the Saratov, U.S.S.R., region.

both area and productivity. In addition, these models and approach must be adapted to the other major global food and fiber crops. Improvements in survey estimates will also be derived from basic improvements of the predictor variables themselves as a second generation of land satellites become available and as the use of environmental satellite data is incorporated along with land satellite data to estimate these parameters.

The LACIE participants have begun to look ahead and to plan a technology development program required to support the future implementation of global food and fiber monitoring systems. A methodology to best insure a suitable technology base, together with an adequate understanding of its use, needs to be developed over the next year or two and vigorously implemented, if its output is to be available for the mid-to-late 1980's.

APPENDIX

APPENDIX A

DATA USED FOR ASSESSMENT OF LACIE ACCURACY

A.1 ESTIMATES OF THE STATISTICAL REPORTING SERVICE (SRS).

The SRS estimates throughout the growing season in the U.S. for a large number of agricultural commodities. For winter wheat, the estimates have different bases at different times of the season as follows:

1. December-March – Estimates are for seeded area and come from the December enumerative survey of fall-planted crops and the fall mail survey. Yield for seeded area is derived from mail survey estimates of condition made by farm operators. Such condition estimates are correlated to historical records of harvested production per unit of seeded area to relate estimated condition to expected production per unit of seeded area.
2. April – This year, a special April report was added and SRS used a weather model together with December area both modified by results from the mail survey to convert to area for harvest and yield for harvested area.
3. May-June – At this point in the season SRS normally uses mail survey and the objective yield survey to estimate area and yield for harvested area.
4. July-September – In June 30 enumeration the first accurate estimate of area for harvest is made, and yield for harvested area is estimated from objective yield survey (actual field measurements of such factors as plant density, etc.).
5. December – This report reflects revised estimates of area harvested, yield and production. Estimates are based on mail surveys, farm census data from each state, grain shipments and various other sources of check data.

For spring wheat a similar sequence of estimates is made as follows:

1. January – First report of intentions to plant. Data in this report is based on mail surveys.
2. April – Second report of planted area and intention. Data in the report is based on mail surveys.
3. June – First estimate of area planted. Data in this report is based on the June enumerative survey, and the June area survey.
4. October and December – Reports as for winter wheat.

A.2 ESTIMATES OF THE FOREIGN AGRICULTURAL SERVICE (FAS)

The FAS makes estimates throughout the growing season in various foreign countries for various agricultural commodities. For wheat in the USSR, different bases are available at different times of the year as follows:

1. February time frame – The production of winter wheat is scaled from the planned production of small grains using historic data. Area is similarly scaled and a yield is computed, this provides an informal figure internal to USDA and is not a published estimates.
2. June – The initial estimate of small grains production and area is published and includes inputs from attache reports, historic trends; meteorological data, etc. In late June an initial estimate of winter wheat is made using the same data sources.
3. July and later – Refined estimates for all small grains, based on the same sources as for June estimates additional field observations by visiting USDA teams and USSR data as available.

These FAS estimates are not considered sufficiently reliable for a comparison standard, not even the final production estimates (see figure A-1). Moderately reliable production estimates based on U.S.S.R. reports are available at the country level about 6 months after harvest and at the indicator level about 1 year after harvest. Even though real-time information

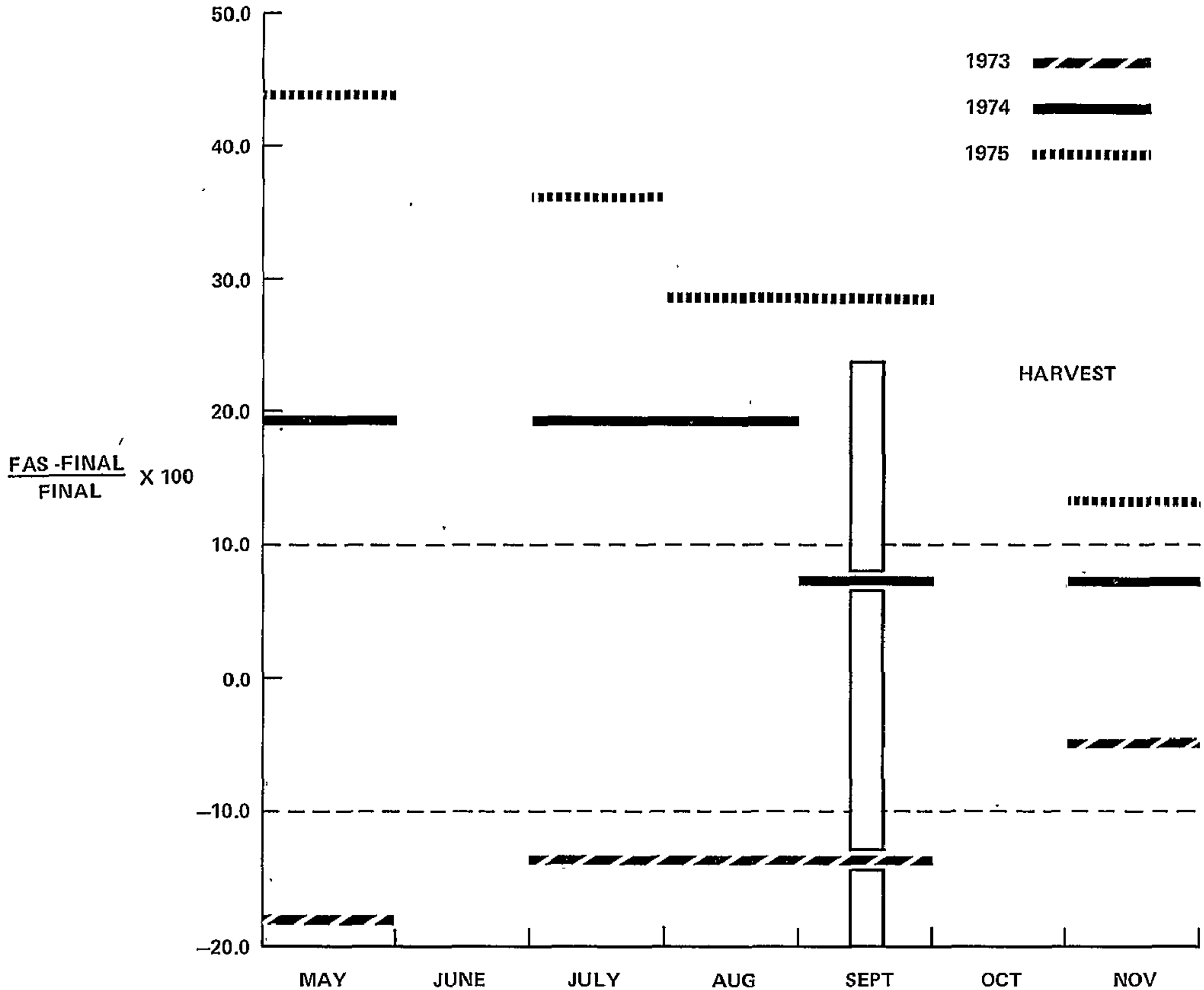


Figure A-1.— Relative difference between USDA/U.S.S.R. seasonal and final U.S.S.R. wheat production estimates.

(1973-1975)

is unavailable in the U.S.S.R. and other foreign countries, much can be inferred regarding LACIE performance in these regions by examining the similarities and differences, at the segment level, between the foreign test sites and the U.S. test sites where detailed ground information has been acquired. Therefore, LACIE estimates are made in foreign areas to help further understand differences and similarities in performance relative to the U.S. yardstick area.