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LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

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PHASE II SECOND INTERIM EVALUATION REPORT

National Aeronautics and Space Administration

LYNDON B. JOHNSON SPACE CENTER

Houston, Texas

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LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

PHASE II

SECOND INTERIM EVALUATION REPORT

Approved By:

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Large Area Crop Inventory Experiment

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EXECUTIVE SUMMARY

After two years of operation, Phase I of the LACIE has been concluded, Phase II is nearly complete, and Phase III has begun.

Phase I analysis was primarily limited to the United States Great Plains "yardstick" region. Its emphasis was on identifying and resolving technological problems and the development of a workable system to estimate wheat area, yield, and production for this area.

The wheat regions surveyed experimentally by LACIE during Phase I were logically expanded in Phase II to include portions of Canada and the U.S.S.R. Also, classification tests were conducted on exploratory segments in five other major wheat-growing countries in the Northern and Southern Hemispheres.

The results of two years of LACIE strongly support 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.

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; presently, we have a limited understanding of factors which affect the accuracy of remote sensing crop surveys and this understanding is expected to improve greatly as LACIE activity proceeds.

1. PURPOSE AND SCOPE

This is the Second Interim Phase II Evaluation Report of the Large Area Crop Inventory Experiment (LACIE). The first Phase II Interim Evaluation was submitted in September 1976. The final Phase II Evaluation Report is scheduled for publication July 1, 1977.

The purpose of these reports is to document the results of LACIE Phase II and to provide senior managers in participating LACIE agencies with an evaluation of the experiment. These reports provide information regarding how well the LACIE objectives have been met during the period covered by the reports and provide information to support management decisions related to future agency/multiagency commitments.

The First Interim Evaluation Report provided results of activity through the summer of 1976, by which time analysis of Northern Hemisphere winter wheat data was nearly complete, that of spring wheat was getting underway, and only a beginning had been made on detailed accuracy assessment. Essentially, this report presents final results for the Northern Hemisphere, the initial accuracy assessments based on blind site analysis in the yardstick region, and an update on general project activity.

For a synopsis of activity prior to Phase II and for an understanding of key events before the initiation of the experiment, the reader is referred to the Phase I Evaluation Report, LACIE-00418, May 1976.

In appendix A, a treatment of the background of LACIE is provided for those unfamiliar with the experiment. This appendix contains a brief history of the development of the technology preceding LACIE and an overview of the technical approach and schedule currently being followed in LACIE.

2. INTERIM EVALUATION OVERVIEW OF PHASE II

2.1 GENERAL

After 2 years of experience with LACIE, the current state of the technology and the operational capability that has been demonstrated provide strong evidence that the design expectations of the LACIE wheat survey operations have been exceeded.

The data volume throughput requirements have been met or exceeded. In Phase I, the requirement of processing 15 to 20 segments per day was satisfied. This requirement was expanded for Phase II to 34 segments per day and was exceeded with a peak volume of 45 segments per day being achieved.

During Phase I, 692 segments were processed through the system, resulting in 2299 acquisitions at JSC of which 1066 were analyzed. In Phase I, only one acquisition in each of four biowindows was analyzed. In Phase III, all acquisitions are analyzed. In Phase II, there were 1683 segments generated and of the 9300 acquisitions at JSC, 9300 were analyzed.

Improved performance in Phase II is further indicated in the declining number of man-hours of "contact" time required by the analyst in segment processing. The average man-hours per segment in Phase I was approximately 12 hours. This average was reduced to 6 hours in Phase II, and the average for Phase III is projected to be 3 hours.

Scheduled monthly reports for wheat area, yield, and production estimates were, with two exceptions, completed and issued on time. Additional unscheduled reports were also produced to treat special situations. Upon completion, the U.S. LACIE reports were mailed to the U.S. Department of Agriculture/Statistical Reporting Service (USDA/SRS) prior to the lock up at which official estimates are established.

2.2 ACCURACY OF SURVEY ESTIMATES

2.2.1 AREA SURVEYS

2.2.1.1 Winter Wheat

The Phase II results in the United States and the U.S.S.R. indicate that the early season area estimates were sufficiently accurate to meet the design parameters of the experiment. Experience of 2 years in the United States and 1 year in the U.S.S.R. indicates near- and at-harvest area estimates of winter wheat are adequate to support the 90/90 accuracy criterion.

One significant problem has been encountered in Phase II in early season area estimation for winter wheat. Exceptionally dry conditions in Oklahoma caused an underestimate of wheat area in that geographical region. In Phase I, the early season area estimates for winter wheat in this state were within the acceptable limits of accuracy.

2.2.1.2 Spring Wheat

Phase I and Phase II experience indicates that improved techniques, now being developed for use in Phase III, are required to separate spring wheat from other small grains. The results of 2 years of experience in the U.S. northern Great Plains and 1 year in Canada indicate a tendency to underestimate spring wheat area using ratioing, although 1 year of experience in the U.S.S.R. spring wheat area indicates no apparent problem in the estimates.

From Phase I results and the early evaluations of Phase II results, it can be concluded that small grains are being accurately estimated.

2.2.2 YIELD SURVEYS

Two years experience with the first generation yield models and 10-year tests indicate that, on the average, LACIE performance in yield estimation is acceptable in countries where adequate historic and current meteorological data are available. It has also become apparent that improved yield models are required in a year when unusual weather conditions prevail.

Evaluation results convey the need for improved yield models which require less historic data in countries such as Argentina, Brazil, and China, where the data are, at best, considered unreliable or at worst, are nonexistent. The use of meteorological satellite data should be accelerated to assist in alleviating this problem area.

2.2.3 PRODUCTION SURVEYS

In the U.S. Great Plains region, LACIE technology has produced excellent early season production estimates. The at-harvest estimates marginally satisfied the 90/90 criterion in Phase I and marginally missed satisfying the 90/90 criterion in Phase II. Evaluation results indicate the problems are due to underestimates of wheat area in the spring wheat states. The underestimates of spring wheat area in Canada also resulted in an underestimation of spring wheat production for that country.

In the U.S.S.R., all indications are that the 90/90 criterion has been satisfied and that early season estimates are sufficiently accurate to meet the performance goals.

2.3 OPEN ISSUES AND CONCLUSIONS

Drawing on Phase I results and the results of Phase II to date, a number of open issues remain which are being pursued during

Phase III. The most significant issues are:

a. There are technical problems in using Landsat data to distinguish between wheat and other small grains especially in the spring wheat regions. Wheat will be differentiated where possible, and when this is not possible, a ratioing technique based on the historical prevalence of wheat will be used to develop an estimate, for wheat, from the small grains estimate.

b. Signature extension, the utilization of spectral characteristics from one area for recognition in a different area, was not sufficiently successful in Phase I to be continued as an operational technique. Efforts during Phase II did not progress as rapidly as was required and no operational signature extension will be attempted through Phase III. This remains, however, an important technology area that is under development in the Research, Test, and Evaluation program.

c. Partitioning of the LACIE survey regions into areas which are similar from agrophysical and remote sensing aspects is being implemented. Such partitions are important if potential improvements in local recognition, sampling, use of ancillary data, development of image interpreter keys for Landsat data analysis, and yield modeling are to be realized. When signature extension becomes operational, partitions will be vital in defining areas within which to attempt extension.

d. Improvements to the sampling strategy and aggregation procedures for mixed spring and winter wheat areas are being implemented.

   In these regions, the sample allocation is currently based on historical total wheat contained in a political subdivision; however, independent area estimates for spring and winter wheat are required for separate spring and winter production estimates. The allocated segments are proportioned spring or winter based on the historical proportion in the political subdivision containing the segments. A method of utilizing all allocated segments in both the spring and winter wheat aggregations and estimating the variance of the estimates is being developed and implemented for maximum sampling efficiency and minimum variance.

In LACIE Phase I and II, segments in 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, data was only collected during the appropriate growing season.

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 the probability of both winter and spring wheat being grown in a sample segment area. The Phase III data collection scheme for the mixed areas will provide the satellite data required to estimate the total wheat produced in a segment. In addition, spring and winter yield and production estimates will be made for all segments in the mixed areas.

e. In the yield estimation activity, it is clear that improved models are both desirable and possible. Development of models which relate yield more closely to actual plant growth conditions is underway and these refined models will be tested early in Phase III.

f. Small fields in Phase II exhibited two basic technical problems: (1) because of a LACIE system constraint on the minimum field size it became very difficult, and in many cases impossible, to define sufficient training samples for the classifier; and (2) missing spectral signatures or worse, signatures with little or no variance resulted in invalid computations in the classification algorithms. A revised procedure has been developed for use in Phase III which utilizes individual Landsat picture elements (pixels) for signature training and clustering of the entire LACIE segment area for statistics computation and subsequent classification. Testing of this approach with Phase II blind site data was so encouraging that it will be the basis of all Phase III segment processing because of its substantial improvements in efficiency and performance.

In conclusion, the following major points should be noted:

a. Results of 2 years of LACIE experience strongly support the contention that remote sensing technology utilizing Landsat data for area estimation, together with an agrometeorological model approach for yield estimation, is capable of providing improved early season and at-harvest production estimates in major wheat producing regions of the world.

b. Although the currently implemented technology does satisfy initial user requirements, significant improvements in estimation accuracy can be expected as more is learned about the factors which affect the accuracy of remote sensing crop surveys (atmosphere, sensor limitations, crop planting and growth patterns, and area and yield variability.)

3. EVALUATION OF PHASE II TECHNICAL ACTIVITY

3.1 OBJECTIVES

A detailed statement of the objectives of the experiment is given in the LACIE Project Plan. For Phase II the major objectives were the following:

a. Test the total system, including yield and production components over the Phase I (U.S. Great Plains yardstick) region, with emphasis on early season estimates.

b. Expand the study area to include area, yield, and production in Canada and two major "indicator" regions in the U.S.S.R.

c. Expand exploratory analyses in other countries; in China, concentrate coverage to improve understanding in one important province.

d. Continue isolation of problems and modifications of the technology to improve the system for Phase III.

e. Initiate effort in an advanced system designed by the USDA to provide an operational design and cost evaluation based on evolving LACIE technology.

3.2 ACHIEVEMENTS AND EVALUATION

The activities, achievements, and evaluations discussed in this section represent the highlights of Phase II to date.

3.2.1 SYSTEM DESIGN, DEVELOPMENT, AND OPERATION

The LACIE data acquisition and analysis system (including various elements at different locations) has generally performed well and has been significantly upgraded during Phase II. Data processing is proceeding on schedule, with processing rates for Landsat data exceeding expectations. At the end of Phase I, three shortcomings of the data systems 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 aggregation system. The logistics on analysis products have improved and are reflected in the analysis time per segment which was 41 days in Phase I and is currently 25 days.[1] The other shortcomings have been corrected.

The most significant areas of progress and activity for Phase II are discussed below.

a. The component of the LACIE system used for analysis of Landsat data has been augmented with a special purpose (array) processor, which has resulted in a substantial decrease in the computer time utilized per segment. This has enabled the expansion of the Phase II program to be pursued within available resources.

b. Additional analysts were hired and trained to permit all Phase II analyses to proceed without signature extension; i.e., with local training for each segment.

c. The Phase I approach to Landsat data analysis, which sequentially involved image interpreters and data processing specialists in the analysis of a single segment, was modified to a team approach. The team approach has demonstrated benefits in accuracy, efficiency, and reduced cost and overhead. This approach is evolving further to an operation in which each analyst does the entire analysis task. Further, analysts are assigned to specific regions in which they become particularly competent.

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[1] It should be noted that in Phase I only one acquisition per biowindow was analyzed, whereas in Phase II all Landsat acquisitions are being utilized.

d. Various hardware problems on the Landsat data analysis system were encountered with components such as the special purpose processor and the production film converter. These problems were overcome without major delays to processing.

e. As episodal events, such as the drought in the south-central U.S. Great Plains and in South Dakota, were encountered, LACIE analysis proceeded as a normal part of the project. Landsat-1 data were acquired and analyzed along with Landsat-2 data, and special provisions were made for full-frame imagery via Goddard Space Flight Center (GSFC) and the USDA Salt Lake City Laboratory.

f. The activity to gather ground data on selected segments to obtain segment-level data on classification accuracy after the analysis had been completed was very important in Phase I. This activity has been expanded in Phase II and was initiated earlier in the season.

g. Foreign exploratory segments were reselected in several countries to make the exploratory analyses more meaningful through better representation of the agriculture. New analysis techniques are being evaluated for the small-field problem identified in China and India.

h. Models to make adjustments to the crop calendar have been developed for Canada, China, the indicator regions of the U.S.S.R., and the Southern Hemisphere countries. Data to operate these models in the Southern Hemisphere are not yet suitable for operational use.

i. Other models which start or initialize the crop calendar models were also developed early in Phase II. For spring wheat, these models provided a satisfactory method of initiating the crop calendar when only meteorological conditions were known; in Phase I actual planting dates from field observations were used. For winter wheat, the model did not improve results over the use of the nominal-planting date.

j. 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 implemented and are being run operationally in Phase II.

k. The capability to combine area and yield estimates to aggregate through various levels to full countries and to compute the standard statistics of the estimates were enhanced beyond the Phase I capability. The current capability permits a greater degree of analyst interaction and more flexibility in data base development and in the format of reports. Difficulties were experienced in acquiring accurate statistics for yield aggregation on a timely basis. This problem is still being investigated.

l. An automatic status and tracking system for Landsat data and for various other data products has been implemented and is operating efficiently.

3.2.2 RESULTS REPORTING

Except for the July spring wheat reports for the U.S.S.R. and Canada, all scheduled reports of area, yield, and production estimates (some without yield and production variance values) have been produced on schedule. Insufficient Landsat data were available in July for spring wheat area estimates in Canada and the U.S.S.R.

These reports are provided to the USDA LACIE office in Washington and to the USDA/SRS. In the case of domestic (U.S.) reports, they are mailed prior to the "lockup" at which official estimates are made.

In addition to the scheduled reports, special reports on the drought-affected regions in the United States have been prepared.

3.2.3 ACCURACY OF SURVEY ESTIMATES

Preliminary Phase II results indicate overall improvement from Phase I in estimation accuracies. In the U.S. Great Plains yardstick region, the at-harvest LACIE estimate of area, yield, and production for winter wheat in the southern Great Plains do not differ significantly from the SRS estimates (fig. 3-1). Statistically, the relative difference from the SRS estimates for area is -1 percent; for yield, -1 percent; and for production, 6 percent.

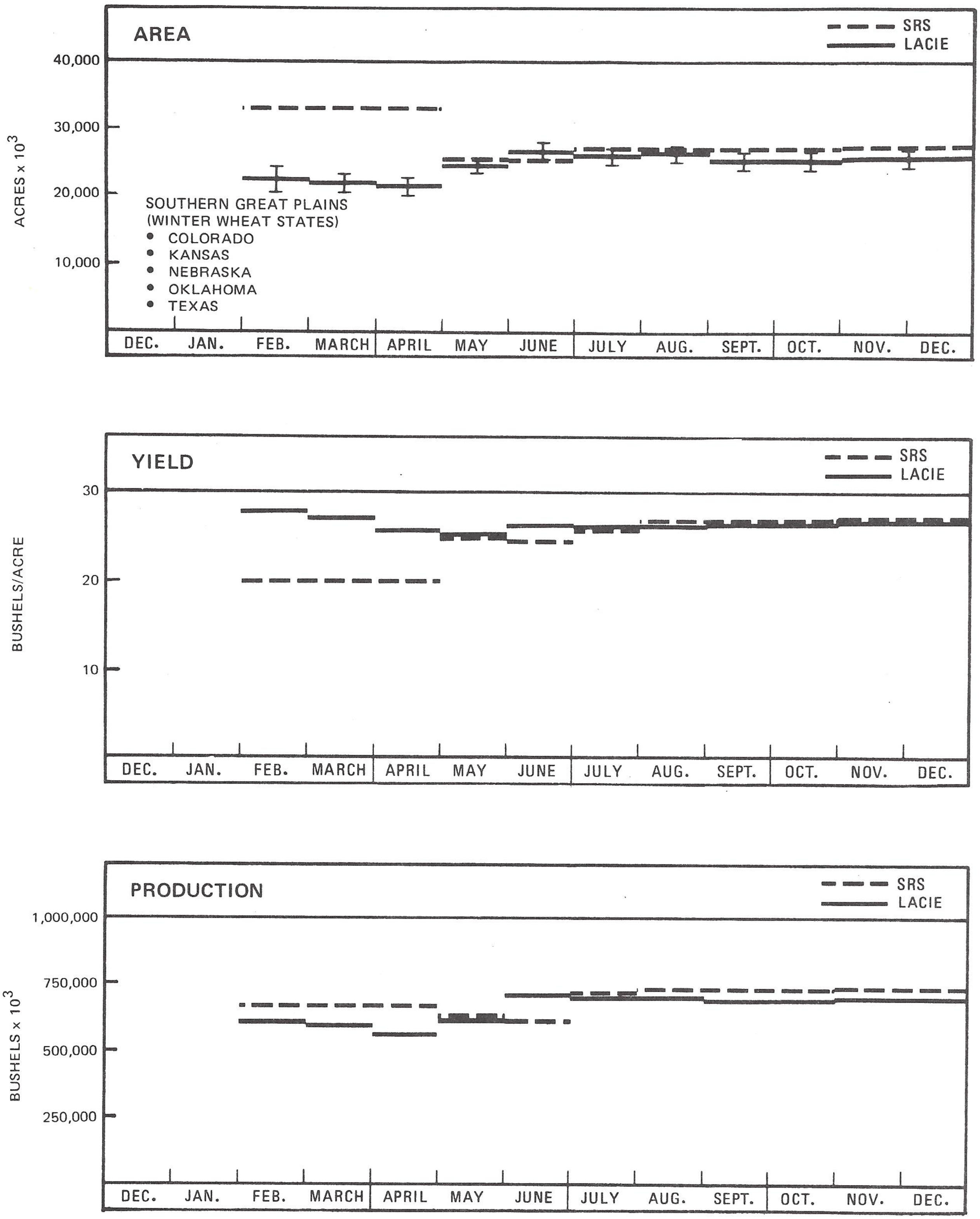
The coefficient of variation for area estimates in Phase II was less than the variation in Phase I and is indicative of improved reliability. The Phase I coefficient of variation for area estimates was 7 percent, compared to the Phase II coefficient of variation of 5 percent. LACIE early season estimates, based on Landsat data acquired in April or later, agreed to within approximately 6 percent with SRS harvest estimates.

The very early season estimates in the southern portion of the yardstick region were of particular interest in Phase II. The results, once the crop was established, are very encouraging. The 90/90 criterion was met by the LACIE early season estimates in all reports after April.

May, June, and July estimates agreed quite well with estimates based on the SRS objective yield and enumerative survey conducted in June. It should be noted that an operational system with a 14-day Landsat data turnaround would have met the 90/90 criterion by April, 2-1/2 months before harvest.

The early season estimates, again for the southern portion of the yardstick region, show a significant difference from SRS estimates. The early season area estimates of February and March were not

MONTHLY COMPARISON OF LACIE AND SRS ESTIMATES
(SOUTHERN GREAT PLAINS)



LACIE SENSITIVE
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Figure 3-1.

accurate enough to support the 90/90 criterion — a result of a significant underestimate of area for harvest (11 and 18 percent, respectively, under the LACIE July estimate).

It should be noted, however, that this difference is believed to reflect the fact that LACIE is measuring the area in standing vigorous wheat. Early in the season, the wheat which is visible can be considerably less than the area which will eventually be harvested. As the crop became generally established, the LACIE area estimates increased and came to agree quite well with the near-harvest area estimates of SRS. In contrast, SRS early season estimates were larger than the area eventually harvested. These early season SRS estimates are for area seeded to wheat and, as a result of the inevitable abandonment, the SRS estimates tend to be high early in the season.

The seasonal behavior of LACIE estimates can be related to important causal factors.

a. Only standing vigorous wheat can be detected by Landsat; thus, LACIE area estimates were low in the pre-May reports. Tests conducted over blind sites in February and March, using ground and aircraft observations, indicated that standing vigorous wheat is accurately measured by Landsat. Thin stands resulting from drought, insect damage, grazing, etc., are not visible in either the aircraft or Landsat color infrared (CIR) imagery. In comparisons over four blind sites, LACIE estimates of standing vigorous wheat differed from that detected on aircraft CIR imagery by less than 4 percent, a difference not considered significant.

b. During March and April, a decline in the LACIE area estimate was reported. This was, however, spurious and apparently due to sampling error. Area increased slightly in those segments common to the February, March, and April reports. By chance, segments newly acquired after February reduced the magnitude of the overall estimates.

c. As growth resumed in April, following winter dormancy, the vigorous standing wheat area and the LACIE estimates increased substantially. A 16-percent increase in the LACIE area estimate was noted from the April to the May report (April data). Area stabilized after May with the May estimate being only 3 percent under the latest LACIE area estimate. A conceptual plot of this seasonal behavior is given in figure 3-2.

An underestimation of acreage area in drought affected Oklahoma was the major source of observed relative difference at the five-state level. The Phase I Oklahoma estimate was accurate to within 3 percent, whereas the Phase II LACIE estimates for Oklahoma were lower than the SRS by about 37 percent. In Oklahoma the wheat percentage of 16 of the 20 blind sites were underestimated by the Classification and Mensuration Subsystem (CAMS). In only five cases did significant adjustments occur using acquisitions obtained after biowindow 2, and in all cases the estimate did not improve.

Investigation of the blind site aircraft photography, ground observations and Landsat analyses indicated that the source of the classification errors were analyst misidentifications of certain wheat fields as nonwheat. Very rarely were nonwheat fields misidentified as wheat. The wheat fields which were most often mislabeled were found to be affected by drought and winter kill, green bugs, heavy grazing of cattle, and late planting. In addition, many fields recovered in April as a result of above normal precipitation that month and late developing fields were apparently interpreted by the analyst to be spring planted crops. In summary, the early season drought conditions, followed by adequate moisture in late spring created an underestimate of

INTERPRETATION OF WHEAT GROWTH SITUATION

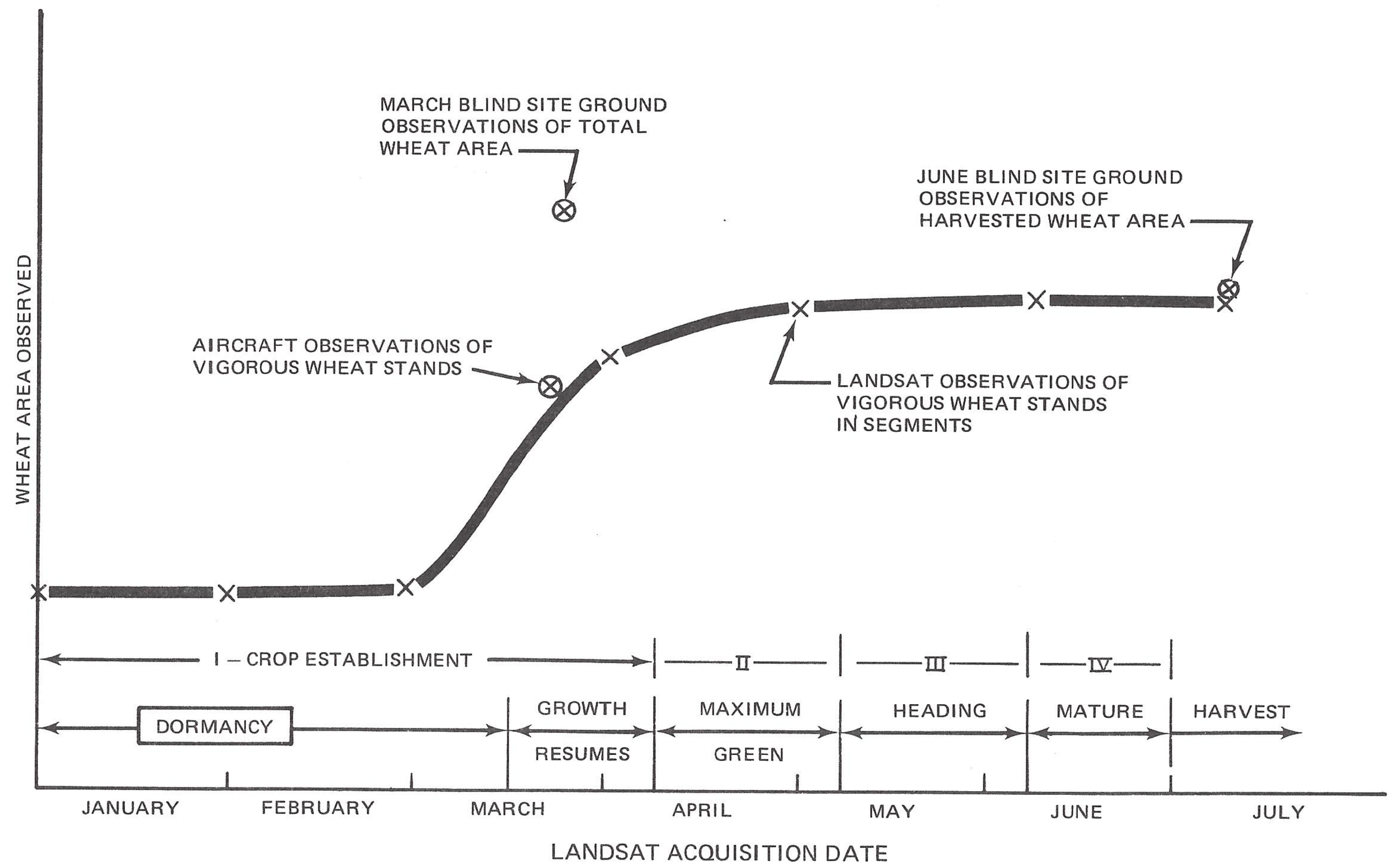

Figure 3-2.

wheat area as a result of mislabeled wheat fields which were late developing fields, thin stands, or unusual wheat color infrared signatures resulting from the stressed condition of the wheat.

At the U.S. Great Plains level, area underestimation in the spring wheat regions caused near-end of season estimates to be 13 percent under SRS estimates (figs. 3-3, 3-4, and 3-5). While preliminary estimates of the coefficient of variation in production indicates a much improved reliability in the estimates from Phase I, the estimate is judged not to satisfy the 90/90 criterion. The coefficient of variation observed in Phase II would permit a ±2.5 percent bias and still satisfy the 90/90 criterion. In all likelihood, however, the observed relative difference of -13 percent indicates a bias of -2.5 percent or greater since -2.5 percent ± 1.645 coefficient of variation = -2.5 percent ± 9.2 percent does not include the -13 percent relative difference observed to date in Phase II. Thus the Phase I tendency to underestimate spring wheat area in North Dakota was also seen in Phase II in the U.S. and Canada (fig. 3-6). The addition of samples and improved ratioing greatly improved the North Dakota estimates from Phase I.

The underestimation problem does not carry into the U.S.S.R. The U.S.S.R. LACIE spring and winter wheat estimates appear to be fairly accurate, with a tendency to be somewhat high (figs. 3-7 and 3-8). The LACIE spring wheat estimates generally agree with the Foreign Agricultural Service (FAS), with the FAS area estimates being 10 percent less than the LACIE. Similarly, the LACIE winter wheat estimates may be somewhat high. The FAS estimates are 20 percent less than LACIE . No firm conclusions can be drawn at this time since FAS estimates are not nearly as reliable as are the U.S. yardstick estimates.

An intensive effort is underway to isolate the problem sources for spring wheat estimates in the United States and Canada.

MONTHLY COMPARISON OF LACIE AND SRS ESTIMATES (PURE SPRING WHEAT STATES)

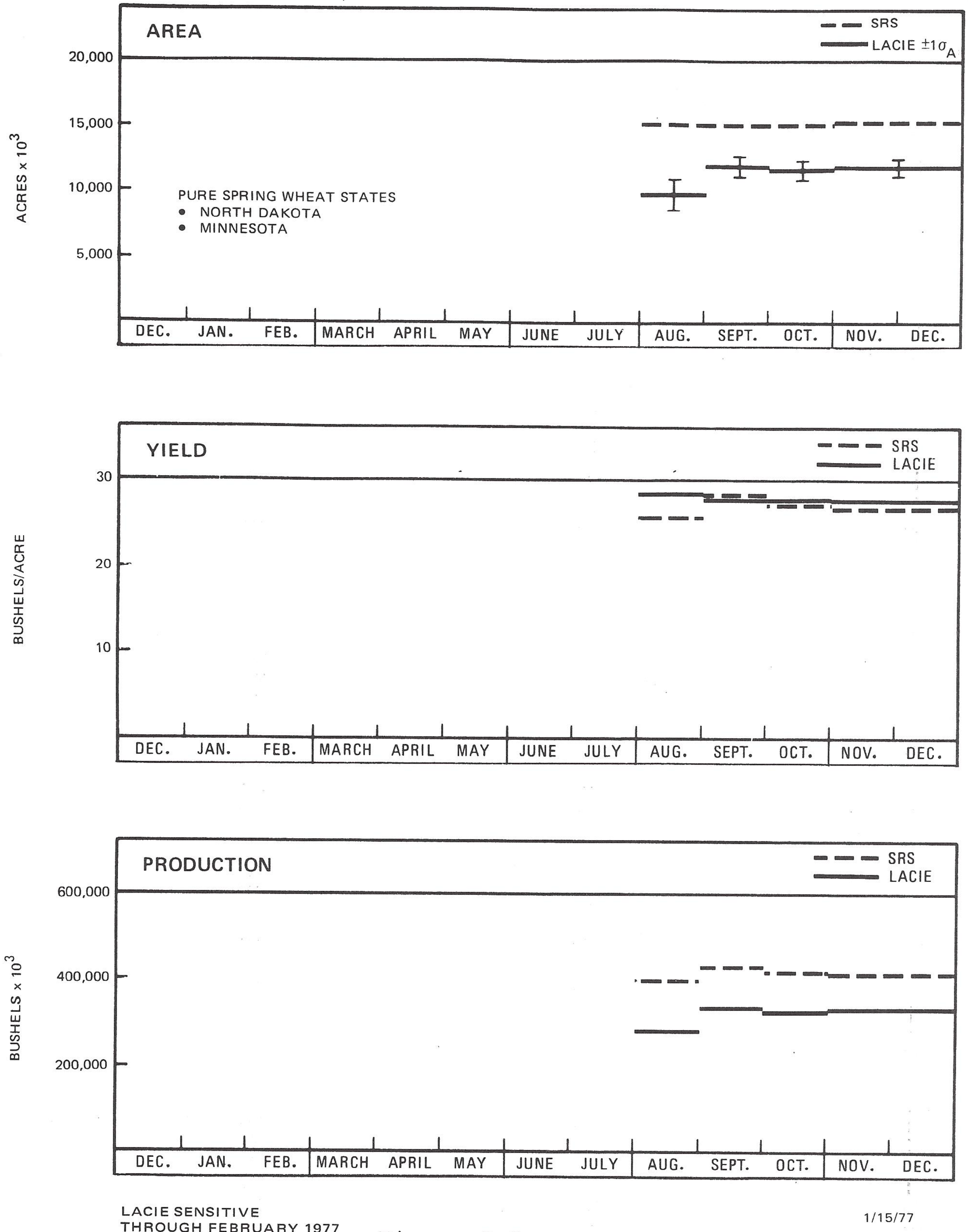

Figure 3-3.

MONTHLY COMPARISON OF LACIE AND SRS ESTIMATES (TOTAL WHEAT — 4 STATES)

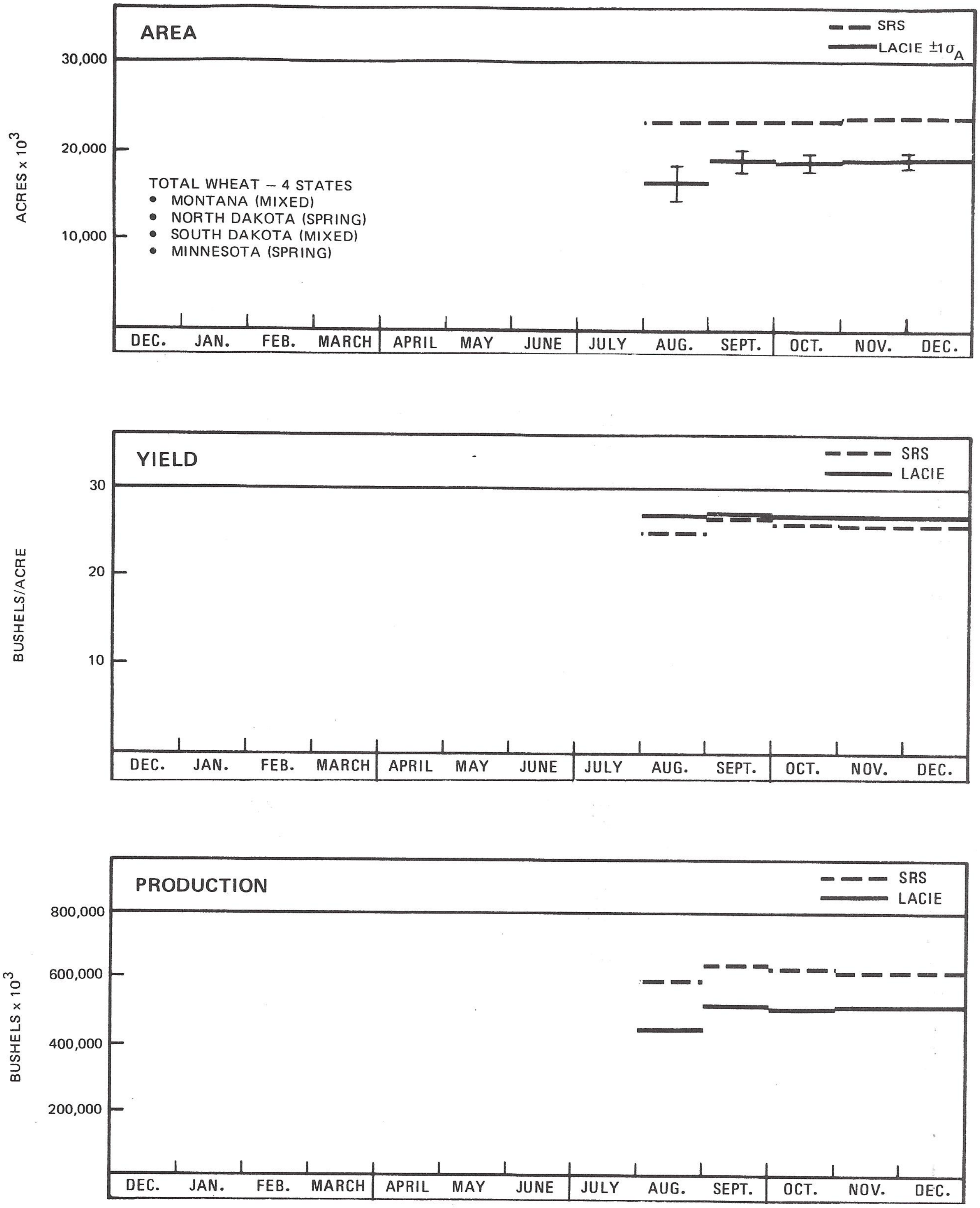

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Figure 3-4.

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MONTHLY COMPARISON OF LACIE AND SRS ESTIMATES
(U.S. GREAT PLAINS)

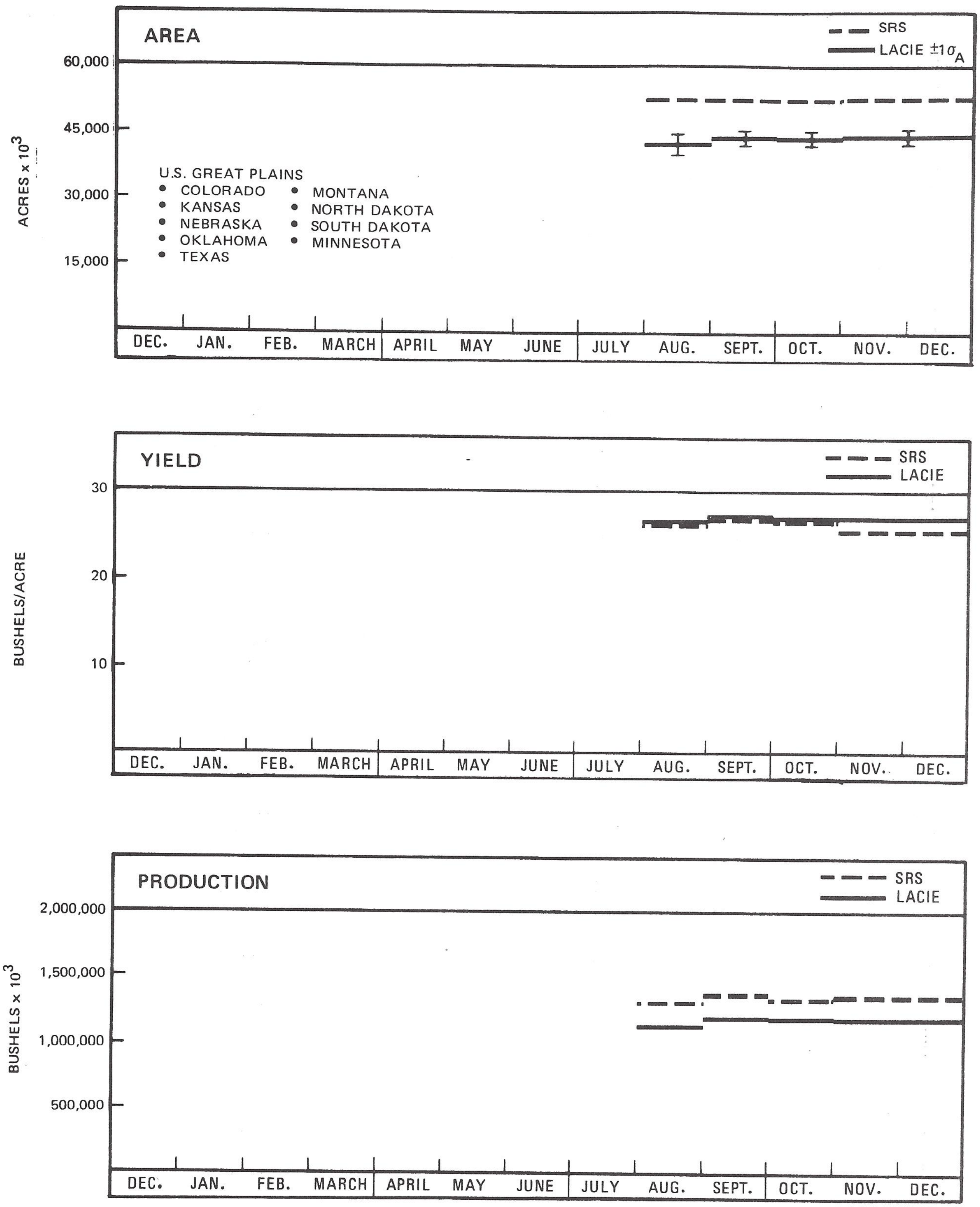

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Figure 3-5.

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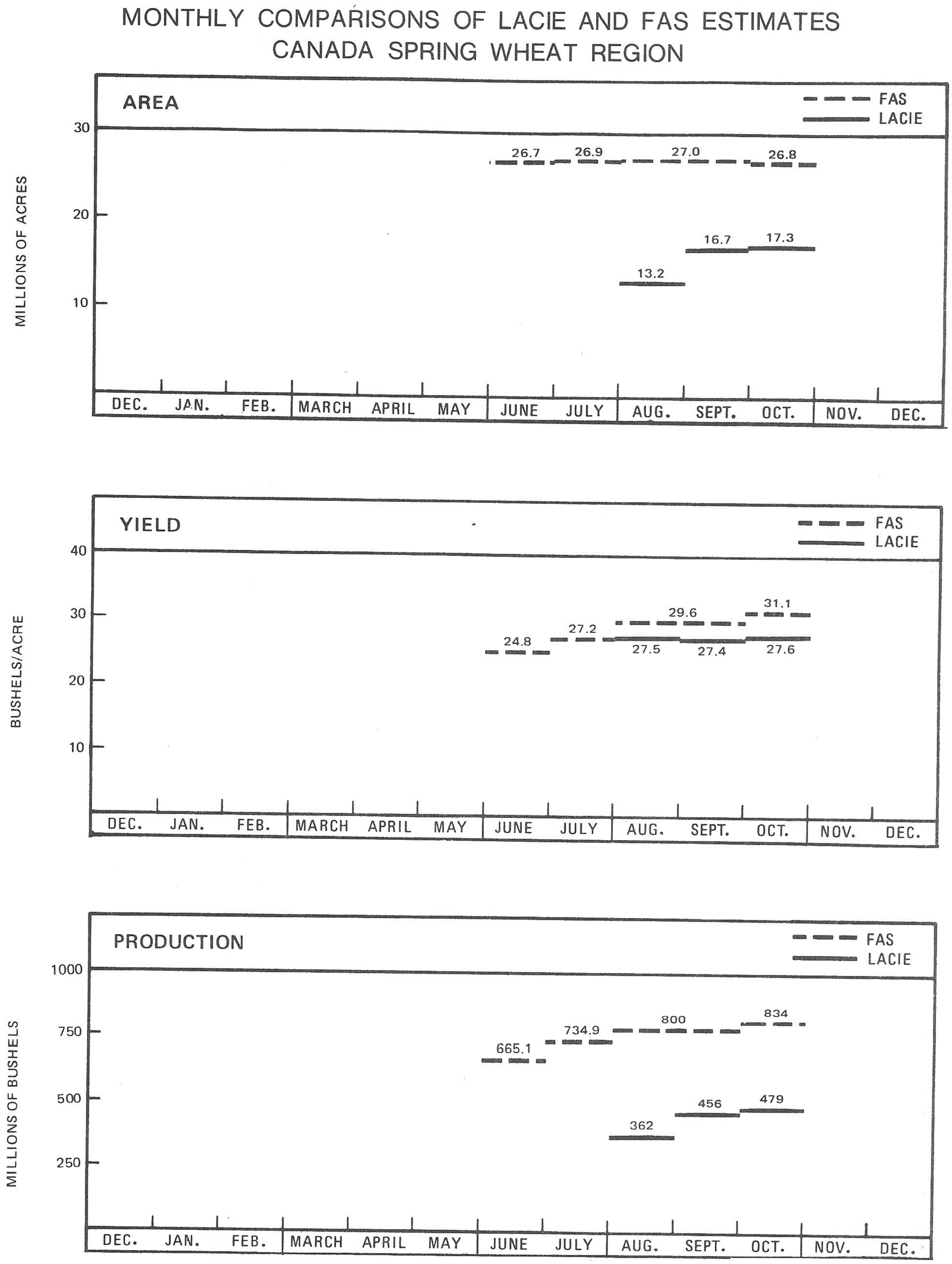

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Figure 3-6.

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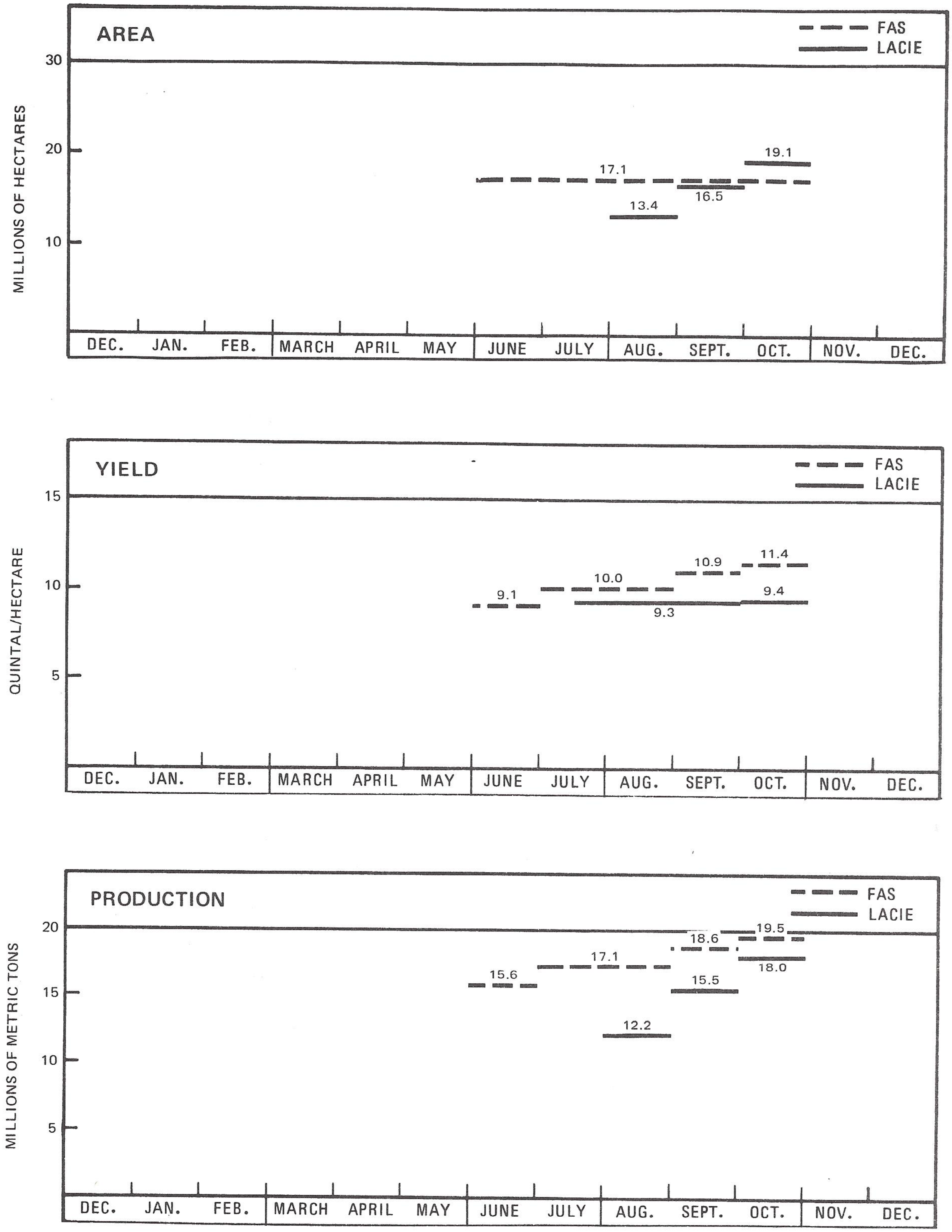
MONTHLY COMPARISONS OF LACIE AND FAS ESTIMATES

U.S.S.R. SPRING WHEAT INDICATOR REGION



LACIE SENSITIVE
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Figure 3-7.

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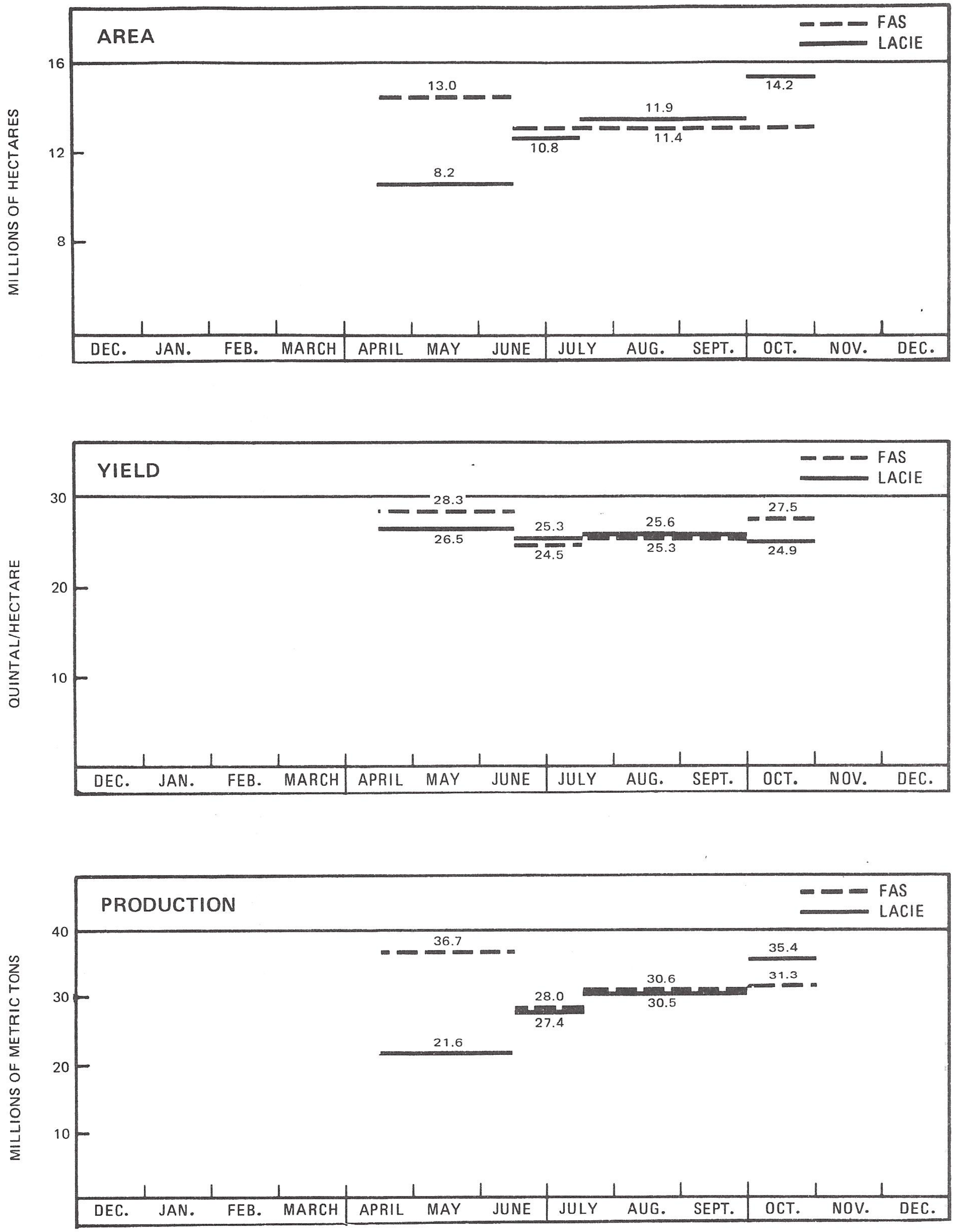
MONTHLY COMPARISONS OF LACIE AND FAS ESTIMATES
U.S.S.R. WINTER WHEAT INDICATOR REGION



LACIE SENSITIVE
THROUGH FEBRUARY 1977

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Figure 3-8.

The most probable causes have been isolated and potential solutions identified. One problem source is the application in the spring wheat region of previous years' ratios of wheat to total small grains to estimate current wheat acreage.

As previously discussed, a contributing factor in Oklahoma was the misidentification from the imagery of wheat signatures which appear different from normal wheat signatures caused by thin stands and late developing wheat. Too few samples in some regions (e.g., Minnesota) also contributed to inaccuracies in the estimates.

Potential solutions are being examined to resolve these problem sources. One possibility is the development of a model to project changes from one year to another in ratios of wheat to other small grains. Another approach is to provide improved training field identification and selection aids to the analysts in the form of quantitative spectral values, analyst/interpreter keys to improve the detection of weak or unusual wheat signatures, and random field selection to obtain a more representative sample of wheat fields. Increasing the number of LACIE sample segments in selected regions is also being undertaken.

A results summary of the LACIE blind sites indicates that there are no statistically significant errors in Phase II winter wheat blind sites, except in Oklahoma. The relative difference of -5.6 percent over 83 winter wheat blind sites in Texas, Colorado, Kansas, and Nebraska is not considered to be statistically significant. The relative difference of -36 percent in Oklahoma explains most of the Phase II Oklahoma underestimates.

Preliminary examination of 28 of 60 Phase II northern Great Plains blind sites indicates no significant small grains classification error. The overall relative difference of -3.3 percent is not considered significant, although the underestimate of -16 percent observed in 13 blind sites in North Dakota is significant. These North Dakota results are similar in magnitude to the underestimate of -16 percent in 20 blind sites in North Dakota during Phase I. The blind site results for the southern Great Plains are given in table 3-1.

In addition to the ratioing and classification errors discussed, it is concluded that an important portion of the U.S. spring wheat area underestimate is due to sampling error. To alleviate this condition, the U.S. sample complement will be increased from 440 to 600 samples for Phase III.

Analyses of blind site data indicate the LACIE technology is capable of providing reliable estimates of small grain areas. The problem of reliably separating wheat from other small grains persists. More sophisticated techniques for ratioing will be applied for Phase III. Improved Phase III classification procedures may provide more reliable means of separating wheat from small grains.

It is anticipated that Phase III classification procedures and more accurate crop calendars will provide added reliability to estimates of small grain areas, particularly in small field regions or in drought and in disease affected areas.

3.2.4 PHASE III SUPPORT

Detailed preparation and planning for Phase III was highlighted by conducting the Phase III Operational Readiness Review (ORR), paper simulation of data product flow, training, and support of design and implementation of new technology for Phase III. Modifications of the scope of Phase III were required because of the design life of the Landsat tape recorder and the realignment of resources to support new technology development. The Phase III

TABLE 3-1.— BLIND SITE RESULTS FOR THE SOUTHERN GREAT PLAINS

State	Segments	Ground-observed average, %	LACIE, %	Relative difference, % (a)
Colo.	13	14.62	13.77	-6.2
Kans.	34	23.89	22.00	-8.6
Nebr.	18	14.12	14.78	4.4
Okla.	20	24.19	17.60	-37.0
Tex.	18	12.61	11.83	-6.5
	103	19.10	17.07	[b]-11.9

[a] Relative difference = $\frac{\text{LACIE} - \text{ground truth}}{\text{LACIE}} \times 100\%$.

[b] Excluding the Oklahoma blind sites, the relative difference is -5.6 percent.

scope will include full country processing of the United States and the U.S.S.R. and portions of Canada, India, and China.

A Phase III ORR was conducted to review the state of readiness of LACIE for Phase III data processing, analysis, and reporting. Two Phase III ORR's will be held because of technical modifications which are being made, i.e., implementation of a new sampling strategy in limited areas, upgraded yield models in limited areas, IMAGE-100 (USDA-operated system to process portions of Canada and China) application, and potential changes in classification procedures. The October ORR addressed overall status with emphasis on the period from November 1976 through March 1977. A delta ORR will be held in mid-March to address the readiness of LACIE for processing the remainder of Phase III data and the new system methodology. The throughput capability of LACIE will be readdressed for the delta ORR. Much experience will be gained in the next 5 months in terms of system throughput, analysis procedures, backlog management, acquisition prediction model verification, etc., along with better information on the expected data load for the remainder of the year.

On December 2, 1976, a LACIE Phase III paper simulation was conducted for the purpose of establishing the origin and flow of data products within and between subsystems and to assure that the transfer of products between organizations was properly executed. Each subsystem plus Accuracy Assessment and the Systems Facilities Branch gave presentations. Specifically, each presenter was asked to provide a comprehensive data flow functionally depicting the disposition of each of his input/output products.

Overall, the simulation reflected a degree of project maturation not evident a year ago when the Phase II simulation was conducted. In particular, the completeness of the data flows, the provisions for product statusing, and the relatively minor number of product conflicts verify this fact. In flagging those areas which require action, none was considered insurmountable.

3.2.5 ADVANCED SYSTEM DESIGN

The USDA User System was established in LACIE Phase II, commencing with the User Advanced System Design Management Plan prepared in January 1976. During the spring of 1976, a contract was awarded to Ford Aerospace for design support. Government personnel working with the contractor established functional requirements, defined initial specifications, prepared two feasible designs, simulated one of the designs, and conducted a Critical Design Review (CDR).

CDR discussions identified problem areas to be resolved in consultation with LACIE management. For example, it was agreed that the best four of the five bands of Landsat-C data (including the thermal band) would be available to the system for processing; average processing time was 1-1/2 hours for a sample segment without regard to data reduction using technology available about January 1977 and the full-frame image dimensions were set at 2340 lines of 3240 pixels each. These parameters were then incorporated into the system/subsystem specifications and the feasible design.

Phase II activities on the Advanced System culminated with briefings to USDA management and Office of Management and Budget (OMB) representatives. As a result of these briefings, permission was obtained to continue with planning and development of the User Advanced System.

Plans to design and implement such an advanced system were developed early in Phase II and the early activity has been staffed and initiated. Before the end of Phase II, an initial design, cost estimate, and a performance simulation will have been completed.

3.3 TECHNICAL ISSUES

Several technical issues have been identified, the resolution of which will involve substantive technical modifications. In each case, the modifications will be implemented before or during the early part of Phase III for use in a limited test area. Specifically, these are:

a. A revised sampling strategy has been devised to improve the accuracy of the LACIE estimates. This will be tested in two states in the yardstick region, and possibly, in a limited portion of the U.S.S.R.

b. Improved yield models which relate plant behavior more directly to the meteorological variables are under development. Such models have been developed for Kansas and North Dakota in the yardstick area and for a winter wheat oblast and a spring wheat oblast in the U.S.S.R.

c. Provisions are being made for daily meteorological data to support the more refined yield models described in item b above.

d. Develop interpretation keys or guides for the United States, Canada, and the U.S.S.R.

e. Partitioning of study areas into regions of similar spectral and crop characteristics will be carried out to support the development of improved sampling techniques, yield models, and interpreter keys.

f. The winter wheat crop calendar experiences significant error in low latitudes. A recalibration of this model based on winter wheat data is under study.

g. Overlapping models and omission of some strata from all models resulted in difficulty in interpreting statistics for yield. These discrepancies are being eliminated.

3.4 RESEARCH, TEST, AND EVALUATION ACTIVITY

During Phase II, the supporting research program was largely focused on two primary problems. One was the development of a signature extension approach for wheat area estimation, and the other was the development of advanced wheat yield models.

3.4.1 SIGNATURE EXTENSION

It was anticipated at the inception of the LACIE that in order to substantially reduce the time required for manual analyst interpretation, a signature extension concept was needed. Basically, this 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 deduce the "signatures" of wheat which can 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, cropping practices, etc., affect the spectral response of crops. Thus, as a simple first attempt at solving the signature extension problem, the first research approach was to stratify the area to be sampled on these variables and then attempt signature extension within each strata. To make the concept work, a means for stabilizing the signatures within a strata to compensate for variations due to dynamic or short-time varying 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. In addition, 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 which was intended to remove haze distortion between a given pair of recognition and training segments.

Evaluations of these haze correction approaches demonstrated that when uniform haze was present, correction was possible. However, it was concluded that the application of a haze correction algorithm of this type to the above-mentioned strata was not sufficient to realize a signature extension approach, except possibly in situations in which several acquisitions of the segment were obtained during critical growth stages. This led to the formulation of a more statistically based approach in the second half of Phase II in which the effects of additional variables, other than haze and those stratified on, were accounted for through a spectral sampling of segments. In this approach, spectral groups were formed using all the segments within a given stratum, and the subset of segments of minimal size, which spectrally represented those groups, were picked as the training segments. One ramification of this approach was that multisegment training may be required; i.e., training was on a group of segments rather than on a single segment. Haze correction in this approach was used to minimize the spectral variance across segments due to haze and, hence, to minimize the number of training segments required.

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.

3.4.2 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. Plant stress due to various temperature and precipitation regimes is estimated.

d. Affects of added nitrogen are estimated.

All the weather related variables in the above 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 spproach is to estimate evapotranspiration (ET) using, as one variable, leaf area index as estimated from Landsat. In Phase II, a successful evaluation of a satellite ET model was demonstrated.

3.4.3 OTHER

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 are being used to research critical problems in LACIE and in future application.

APPENDIX A

LACIE BACKGROUND AND TECHNICAL INFORMATION

APPENDIX A

LACIE BACKGROUND AND TECHNICAL DESCRIPTION

A.1 BACKGROUND

The need for crop inventory information was stated[1] by the U.S. Department of Agriculture (USDA) as follows:

> "To permit rational decisions in areas such as production, marketing, transportation, and international trade, we must have up-to-date, accurate information on world food supplies and world food needs. The Department of Agriculture has been assigned the responsibility for collecting and reporting crop production information to the public."

In anticipation of helping to fulfill information needs such as stated above, the remote sensing community has for several years been developing a key part of a new technology for conducting large-scale crop inventories.

Some of the major events in the development and application of this technology were as follows:

Late 1950's	Surveys of agricultural terrain by black and white aerial photography using camouflage detection film (reflective infrared)
Early 1960's	Development of airborne multispectral scanners and large-scale digital-processing techniques

[1]From a presentation by Clayton K. Yeutter, Assistant Secretary for International Affairs and Commodity Programs, U.S. Department of Agriculture, to the Committee on Science and Technology, U.S. House of Representatives, February 4, 1975.

1966 First computer-aided classification of wheat and other crops using airborne multispectral scanner data.

1969 Apollo multiband camera experiment (S-065) simulating Landsat spectral bands. First computer-aided classification of wheat and other crops using satellite data.

1971 Corn Blight Watch Experiment, first large area agricultural effort; used both image analysis and computer-aided analysis of airborne multispectral scanner data.

1972 Landsat-1 launched; the start of many agriculturally-oriented investigations by Landsat scientific investigators, including several by representatives of the USDA and NASA and one joint project on crop identification.

There had been acceptable progress in the development of techniques for the analysis of satellite-acquired multispectral data for the purpose of identification and measurement of wheat <u>areas</u>. This capability to identify and measure wheat area provided, however, only one component for the estimation of wheat production. For USDA crop-reporting purposes, production (i.e., area in wheat multiplied by yield for that area) is the quantity of primary interest. Although there is an expectation that satellite multispectral observations will contribute to yield determination at some future date, this technology was not sufficiently developed to be included in the LACIE mainstream program. An alternate approach, however, using meteorological data (from ground stations and/or satellites) in yield models was in the course of development and was considered the most promising for supporting initial large-scale demonstrations.

Interest in pursuing inventory techniques was intensified by grain-production shortfalls in some areas of the world in 1972 and 1973 and by an increase in consumption during those years. This interest spurred planning activity in NASA, USDA, and NOAA, and the time was judged appropriate for a large-scale experiment to validate the technology as applied to a crop-inventory system. This technology had been previously tested only in local situations and with very limited amounts of data. What was chosen as the crop for the initial experiment, and a preliminary project plan was developed in the fall of 1973.

An interagency Memorandum of Understanding (MOU) was drafted and detailed planning was carried out through the summer of 1974 with coordination among the three agencies. The general shape of the experiment was essentially defined by the middle of 1974 and all agencies began staffing the activity by the fall of 1974. An overall schedule for the project was approved in early November 1974.

The activity was announced November 6, 1974, and was described briefly by Secretary of State Kissinger at the World Food Conference in November 1974[2] as follows:

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[2]From a speech by H. F. Kissinger, Secretary of State of the United States of America, in Rome, Italy, November 4, 1974.

> "Our space, agriculture, and weather agencies will test advanced satellite techniques for surveying and forecasting important food crops. We will begin in North America and then broaden the project to other parts of the World. To supplement the World Meteorology Organization (WMO) on climate, we have begun our own analysis of the relationship between climate patterns and crop yields over a statistically significant period. This is a promising and potentially vital contribution to rational planning of global production."

A.2 TECHNICAL DESCRIPTION

The objective of the LACIE is to estimate production of wheat on a country-by-country basis. To estimate wheat production on a country basis, the country is subdivided into subareas called strata, where yield (quintal/hectare or bushel/acre) and the prevalence of wheat planted are rather uniform. Yield and the areal extent of wheat within each strata are determined by independent methods and then multiplied together to obtain wheat production (quintals or bushels) for the stratum. The production estimates in each stratum are then added to obtain production at other geographic levels. In addition, area and yield are estimated for each stratum and aggregated to determine wheat area and yield at regional and country levels.

Area is derived by classification and mensuration of Landsat Multispectral Scanner (MSS) data acquired on a sampling of about 2 percent of the agricultural area in all regions where wheat is a major crop. Maximum use is made of computer-aided analysis to provide the mose timely estimates possible.

Yield is estimated from statistical models which relate crop yeild to local meteorological conditions, notably precipitation and temperature. Initially, these data are being obtained from the World Meteorological Network of ground stations. As the experiment progresses, use of supplemental meteorological data from NOAA environmental satellites is planned.

The project has involved the assembly of a crop inventory system from available components designed for Research and Development (R&D). That is, the system is intended to test the function necessary for crop inventory but not to provide a streamlined, cost-effective operational tool. The intent is to utilize the experience gained to support, as a concurrent effort, the design of a user-oriented operational system and the prediction of the performance and cost of such a user system.

LACIE was planned to extend over three global crop seasons, each of which is considered a LACIE phase. The three phases overlap because they are based upon global crop growing seasons. The first phase concentrated primarily on the most important wheat-growing region of the U.S., the hard red wheat region in the U.S. Great Plains. This region comprises 9 states[3] which account for, typically, 90 percent of the hard red wheat and 75 percent of the total U.S. wheat.

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[3]Texas, Oklahoma, Kansas, Nebraska, Colorado, North Dakota, South Dakota, Montana, and Minnesota.

The second phase - the interim status of which is covered in this report - began in October 1975 and is devoted to replicating the inventory of wheat in the Great Plains yardstick region of the U.S. which was conducted in Phase I and to expanding the area studied to include Canada and two indicator regions in the USSR, one for spring wheat, and one for winter wheat. Selected sites in other countries will continue to be analyzed on an exploratory basis in preparation for further expansion in Phase III.

In Phase III, the LACIE capability should be able to support the estimation of wheat area, yield, and production in several countries, should such a scope be decided upon by the participating agencies. The current LACIE schedule is showin in figure A-1.

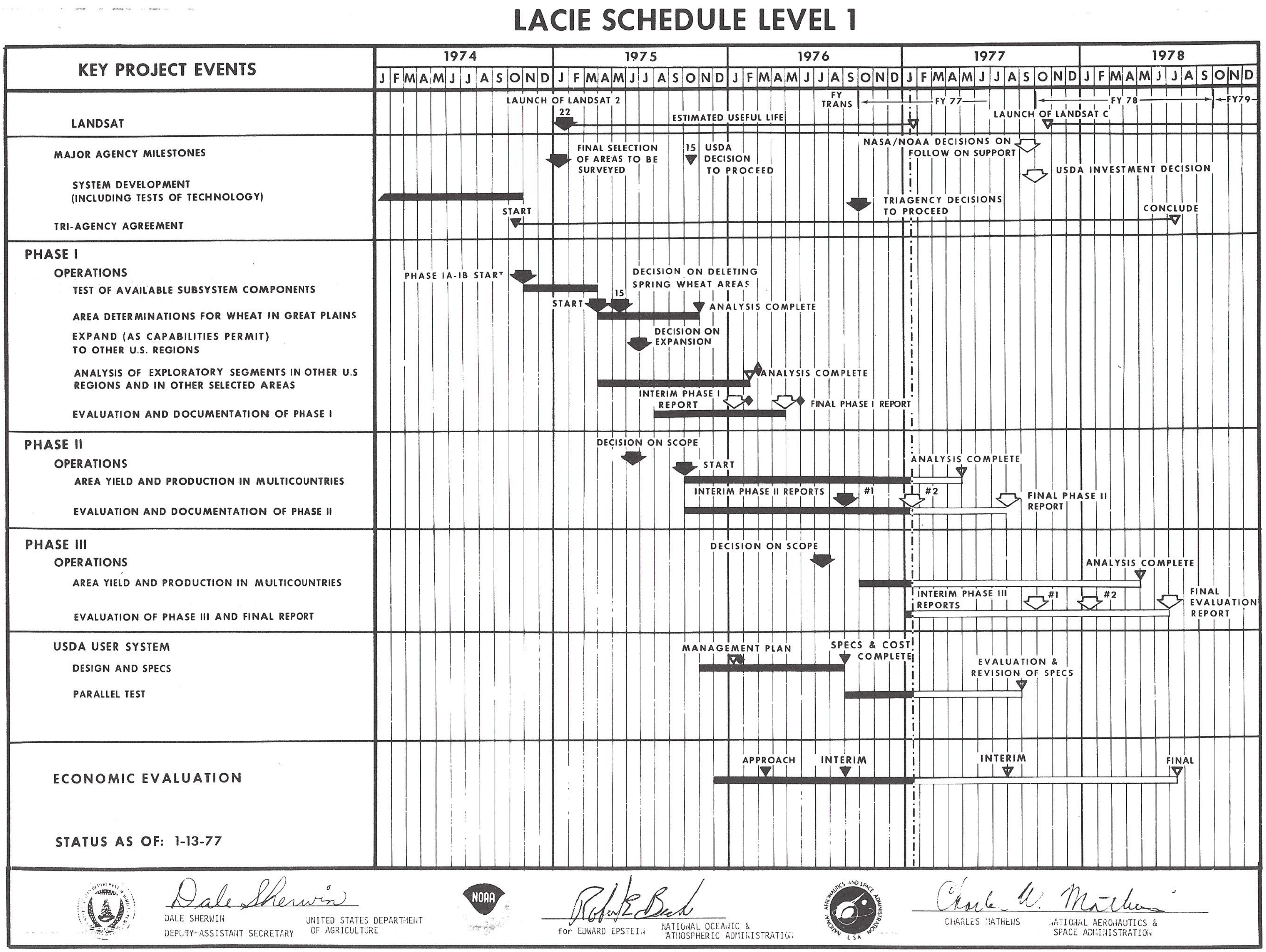
LACIE SCHEDULE LEVEL 1
KEY PROJECT EVENTS
1974
1975
1976
1977
1978
J F M A M J J A S O N D
LANDSAT
LAUNCH OF LANDSAT 2
22
ESTIMATED USEFUL LIFE
FY TRANS
FY 77
FY 78
FY79
LAUNCH OF LANDSAT C
MAJOR AGENCY MILESTONES
FINAL SELECTION OF AREAS TO BE SURVEYED
15
USDA DECISION TO PROCEED
NASA/NOAA DECISIONS ON FOLLOW ON SUPPORT
USDA INVESTMENT DECISION
SYSTEM DEVELOPMENT (INCLUDING TESTS OF TECHNOLOGY)
TRIAGENCY DECISIONS TO PROCEED
TRI-AGENCY AGREEMENT
START
CONCLUDE
PHASE I
OPERATIONS
TEST OF AVAILABLE SUBSYSTEM COMPONENTS
PHASE IA-IB START
DECISION ON DELETING SPRING WHEAT AREAS
15
AREA DETERMINATIONS FOR WHEAT IN GREAT PLAINS
START
ANALYSIS COMPLETE
EXPAND (AS CAPABILITIES PERMIT) TO OTHER U.S. REGIONS
DECISION ON EXPANSION
ANALYSIS OF EXPLORATORY SEGMENTS IN OTHER U.S REGIONS AND IN OTHER SELECTED AREAS
ANALYSIS COMPLETE
EVALUATION AND DOCUMENTATION OF PHASE I
INTERIM PHASE I REPORT
FINAL PHASE I REPORT
PHASE II
OPERATIONS
DECISION ON SCOPE
START
AREA YIELD AND PRODUCTION IN MULTICOUNTRIES
ANALYSIS COMPLETE
EVALUATION AND DOCUMENTATION OF PHASE II
INTERIM PHASE II REPORTS
#1
#2
FINAL PHASE II REPORT
PHASE III
OPERATIONS
DECISION ON SCOPE
AREA YIELD AND PRODUCTION IN MULTICOUNTRIES
ANALYSIS COMPLETE
EVALUATION OF PHASE III AND FINAL REPORT
INTERIM PHASE III REPORTS
#1
#2
FINAL EVALUATION REPORT
USDA USER SYSTEM
DESIGN AND SPECS
MANAGEMENT PLAN
SPECS & COST COMPLETE
PARALLEL TEST
EVALUATION & REVISION OF SPECS
ECONOMIC EVALUATION
APPROACH
INTERIM
INTERIM
FINAL
STATUS AS OF: 1-13-77
DALE SHERWIN
DEPUTY-ASSISTANT SECRETARY
UNITED STATES DEPARTMENT OF AGRICULTURE
NOAA
for EDWARD EPSTEIN
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION
CHARLES MATHEWS
NATIONAL AERONAUTICS & SPACE ADMINISTRATION

Figure A-1.

APPENDIX B

DATA USED FOR ASSESSMENT OF LACIE ACCURACY

APPENDIX B

DATA USED FOR ASSESSMENT OF LACIE ACCURACY

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

The SRS makes 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 area 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.

A plot of the SRS estimates for winter wheat in the southern portion of the yardstick region for the 1975-76 crop year is given in figure B-1.

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.

B.2 <u>ESTIMATES OF THE FOREIGN AGRICULTURAL SERVICE (FAS)</u>

The FAS makes estimates throughout the growing season in various foreign countries for various agricultural commodities. For

SRS Estimates in Yardstick Region
(SOUTHERN GREAT PLAINS)

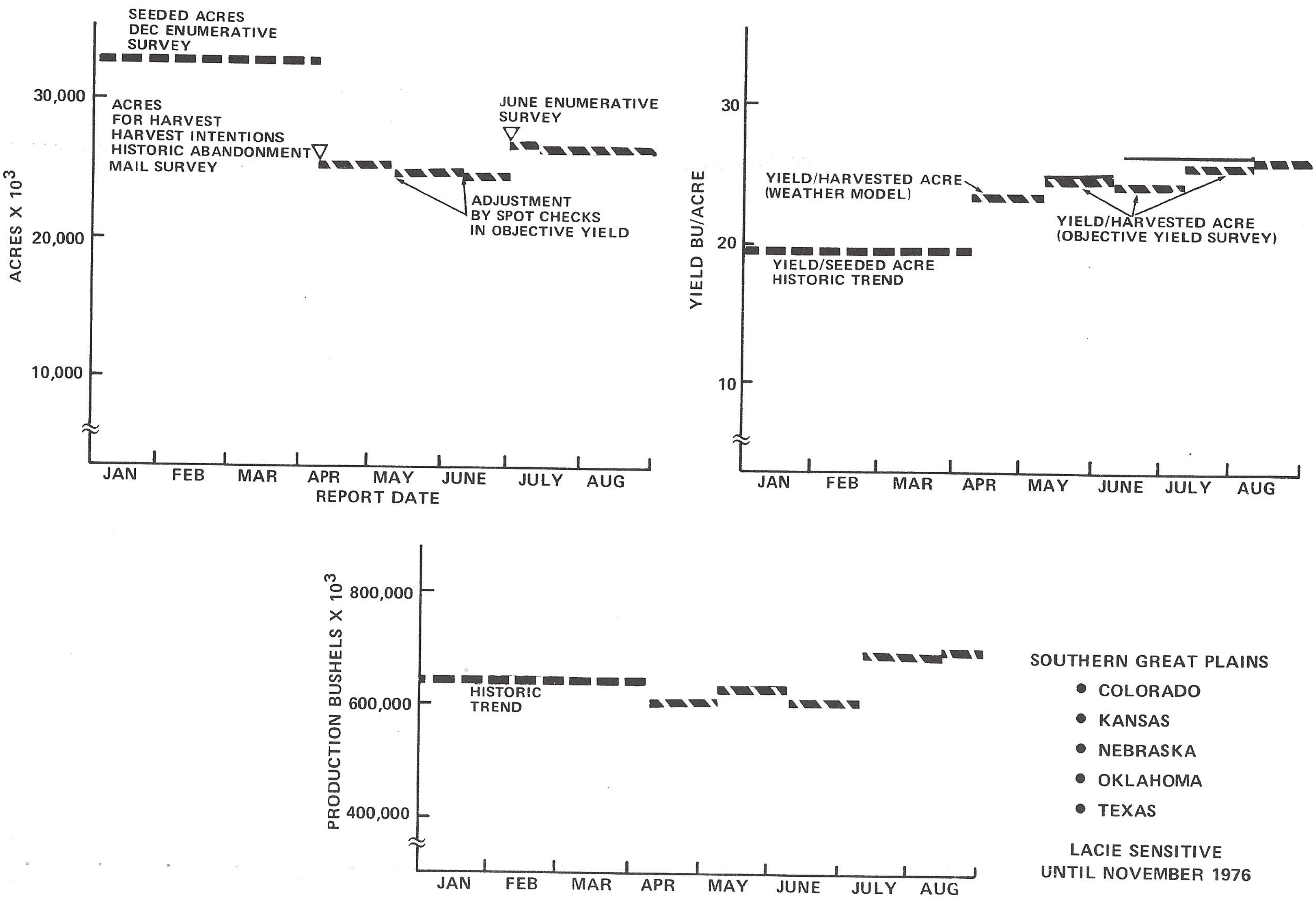

Figure B-1.

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 estimate.

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.

APPENDIX C

GLOSSARY OF LACIE TERMS

APPENDIX C

GLOSSARY OF LACIE TERMS

ABBREVIATIONS AND ACRONYMS

Biological Stage	Specific stages of development of a crop which can be recognized by a major change in plant structure, i.e., emergence after germination, jointing, heading, etc., and are represented by integers on the Robertson Biometeorological Time Scale.
Biowindow	A Landsat data acquisition period that is tied to the biostages of wheat development. The LACIE approach is based upon the judgement that wheat can be spectrally separated adequately from other crops by analysis of up to four acquisitions of Landsat data during the growing season. The biowindow opening and closing dates may be updated if there is a significant lag or advancement in the current crop growth. The sequence chosen includes acquisitions during the following biowindows: a. Crop establishment - from planting to the booting stage. b. Green - from the booting stage to the heading stage.

c. Heading - from the heading stage to the soft dough stage

d. Mature - from the soft dough stage to the harvest stage

Blind Site	A LACIE sample segment, chosen at random after normal analysis, used for testing classification performance.
CCEA	Center for Climatic and Environmental Assessment, an organization of the National Oceanic and Atmospheric Administration (NOAA), Columbia, Missouri.
Classification	In computer-aided analysis of remotely sensed data, the process of assigning data points to specified classes by a testing process in which the spectral properties of each unknown data point are compared with spectral properties typical of the subject being classified.
Classification Error	Classification error is a measure of the degree to which the LACIE Classification and Mensuration Subsystem (CAMS) can estimate the wheat area in one or more LACIE samples.
Crop Calendar	A calendar depicting the growth-development or biological stages of the major crop types within a specified region.

Crop Calendar Adjustment	An adjustment made, on the basis of current weather, to the normal crop calendar.
Crop Reporting District	A geographical area used by the U.S. Department of Agriculture for the collection and reporting of agricultural information. Each district consists of several counties.
GSFC	Goddard Space Flight Center, a NASA installation in Greenbelt, Maryland.
ITS	Intensive Test Sites; U.S. and Canadian locations in which detailed crop information is collected by using ground and airborne equipment.
JSC	The Lyndon B. Johnson Space Center, a NASA installation in Houston, Texas.
LACIE	Large Area Crop Inventory Experiment
Landsat	Formerly the Earth Resources Technology Satellite (ERTS). This earth-observing satellite operates in a circular, sun-synchronous, near-polar orbit at an altitude of approximately 915 km (494 n.m.). It orbits the earth 14 times a day and views the same scene every 18 days.
Landsat Data Set	The electronic or film products produced for a particular acquisition of a sample segment

Landsat Scene	The collection of the image data of one nominal framing area (195 km square) of the earth's surface; this includes data from each of four spectral bands or channels on the satellite multispectral scanner.
Mensuration	The act of measuring, in the case of LACIE, measuring surface area in a particular crop.
Multispectral	Pertaining to radiation from several discrete bands of the electromagnetic spectrum.
Multispectral Scanner or MSS	Multispectral scanner system sometimes referred to simply as the multispectral scanner is the remote sensing instrument on Landsat that measures reflected sunlight in various spectral bands or wavelengths.
Multitemporal Analysis	Analysis of data sets over the same area acquired at different times.
NASA	National Aeronautics and Space Administration
n.m.	Nautical mile. Equivalent to 1/60° at the earth equator, or approximately 1852 meters (6076 ft.).
NOAA	National Oceanic and Atmospheric Administration of the U.S. Department of Commerce.

Nonsupervised Classification	A procedure by which multispectral data are grouped into spectrally similar clusters.
Pixel	Picture element; refers to one instantaneous field of view (IFOV) as recorded by the multispectral scanner system. On the Landsat system it is equivalent to approximately 0.44 hectare (1.08 acres). One Landsat frame contains approximately 7.36×10^6 pixels.
R&D	Research and Development
RT&E	Research, Test, and Evaluation
Sample Segment	A 5x6 n.m. area selected by a stratified random sampling. Information on this area is recorded by the multispectral scanner and transformed into computer compatible tapes and film products.
Sampling Error	A measure of the degree to which the wheat area in the LACIE sample segments represents the wheat area contained in the survey region being sampled.
Scene Registration	The process of superimposing points on two data sets taken at different times.
Signature Extension	The analysis process using the spectral characteristics or "signature" of one sample segment to perform the classification on another sample segment.

SRS	Statistical Reporting Service, an agency of the U.S. Department of Agriculture
Supersite	A particular intensive test site for which additional ground data, such as radiation measurments, are acquired. Currently, there are three supersites: Williams County, North Dakota, Hand County, South Dakota, and Finney County, Kansas.
Supervised Classification	A procedure used in data processing in which remotely sensed data of known classes are used to establish the decision logic from which unclassified data are assigned to classes.
Test Field	The spatial sample of digital data of a known ground feature selected by the investigator which is used to validate the statistical parameters generated from training field samples.
Training Field	The spatial sample of digital data of a known ground feature selected by the analyst, from which the spectral characteristics are computed for use in supervised multispectral classification of remotely sensed data. The statistics associated with training fields provide the input to "train" the computer to discriminate between different classes in the scene.

USDA	United States Department of Agriculture
WMO	World Meteorological Organization