THE LARGE AREA CROP INVENTORY EXPERIMENT

LACIE PROJECT REVIEW MATERIAL

Presented By

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BIOGRAPHICAL SKETCH

R. B. MacDonald is presently Chief of the Earth Observations Division at the Johnson Space Center. He has designed and executed major efforts in the development and application of remote sensing technology. The foremost example is the Large Area Crop Inventory Experiment (LACIE), initiated in 1974. This multiagency project is to develop, test, and demonstrate in a "quasi-operational" environment the technology to produce agricultural crop production information on a global scale.

Before joining NASA in 1971, Mr. MacDonald served as Technical Director of the Laboratory for Application of Remote Sensing at Purdue University. He was chief architect of the 1971 Corn Blight Watch experiment, which involved more than 1000 participants from 17 federal and state agencies. This project was described as the largest experiment ever conducted in agriculture and is to this day still, perhaps, the most operational and complete demonstration of what remote sensing can do.

ABSTRACT

A Large Area Crop Inventory Experiment (LACIE) has been undertaken jointly by the U.S. Department of Agriculture (USDA), the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce, and the National Aeronautics and Space Administration (NASA) to prove out an economically important application of remote sensing from space.

The first phase of the experiment, which focused upon determination of wheat acreages in the U.S. Great Plains and upon the development and testing of yield models, has been completed. The results and conclusions are presented. The second phase of the experiment concentrated on the estimation of wheat acreage, yield, and production over several important production regions. The results are discussed. A preliminary assessment to date indicates that the performance goals of the experiment are being met.

INTRODUCTION

Organizations and personnel responsible for the maintenance and operation of food production systems, designers and developers responsible for incorporating research outputs into improved operational food production systems, and researchers concerned with developing the basic technology and methodology to produce ever greater quantities of food

with higher nutritional value vitally need timely and accurate information of the state of agricultural production and conditions of supporting natural resources on a worldwide scale. Events in recent years have clearly indicated that improved information of this type needs to be produced to permit the prediction of world food shortages far enough in advance to permit governments to deal properly with food crop supplies.

Small grains are man's most important food crops; these include the wheats, rice, barley, rye, and oats. The world grain trade has grown from 113 million tons a year in 1971-72 to approximately 154 million tons currently. The United States has been primarily responsible for this growth and continues to be the largest international trader of small grains; consequently, as a major supplier, the United States is dependent on the market demand around the world which is a function of the production in foreign countries. The price for crops the United States or any seller receives is established by the interactions of production and demand.

The price tag for the United States has increased significantly in recent years. Congressional legislation in the early 1970's removed restrictive export regulations and established a policy of full production. The largest U.S. exports are now in the agricultural category; U.S. farm exports increased from $8 billion in fiscal year 1972 to nearly $22 billion in fiscal year 1975; in comparison, U.S. aerospace exports in 1975 were at a new high of $7.8 billion. It is interesting to note that, on the average, one out of every three acres harvested in the United States and one dollar in four of farm income are currently dependent on export sales.

Wheat is the most abundant of the small grains and provides 20 percent of the total food calories consumed by the world's populations (ref. 1). It is also by far the most internationally traded small grain. Wheat is the largest nonforage crop in the world and the second largest in the United States, which grows 14 percent of the world total and is second only to the U.S.S.R. as a producer. In 1975, nearly 70 million acres were harvested from 75 million acres planted in the United States. Approximately 2.1 billion bushels or 58 million metric tons were produced from this acreage (ref. 2). Over 575 million acres are estimated to be planted throughout the world each year.

BACKGROUND

In the early 1960's, the NASA, in cooperation with the USDA and on the advice of the Committee on Remote Sensing for Agricultural Purposes of the National Academy of Science, initiated research to investigate the feasibility of assessing agricultural conditions with automated remote sensing techniques. A consortium of universities, NASA, and USDA research groups was tasked to conduct these investigations. The principal groups were the Willow Run Laboratories of the University of Michigan and the Laboratory for Agricultural Remote Sensing at Purdue University. This consortium made steady progress from 1965 through 1973.

Certain milestone events were posted during this interval. In 1965, multispectral measurements were collected with existing ground-based sensors and with the first aircraft scanner developed at the University of Michigan. Data acquired by this scanner over agricultural fields were analyzed by a digital data processing system which was assembled at Purdue University in 1966, clearly showing the feasibility of automatically identifying wheat and other major crop types (ref. 3). In 1967, 1968 specifications for the first Earth Resources Technology Satellite (ERTS; now known as Landsat) to be equipped with a multispectral scanner (MSS) were established. Interestingly, a LACIE-type experiment (ref. 3) was proposed as a first agricultural experiment that should be conducted by such a system. In 1969, the ERTS was simulated by a camera system (ref. 4) flown on Apollo IX and indicated the promise of the future ERTS-A (ref. 5). In 1971, the corn crops in the United States were victims of a new disease — the southern corn leaf blight. The technology was thrown into services in the Corn Blight Watch experiment to survey the 1971 crop over a seven-state region every 2 weeks throughout the 1971 corn-growing season. This effort provided considerable experience to the LACIE (ref. 6). In 1972, the ERTS-A was successfully launched. The Earth Observations Division of the Science and Applications Directorate at the Lyndon B. Johnson Space Center (JSC) NASA conducted joint experiments with the USDA establishing the feasibility of surveying major crop types from space with the multispectral remote sensing technology (ref. 7). All of these events led directly to the proposal (ref. 8) of the LACIE in 1973. Severe shortages in wheat production occurring in 1972 stimulated the development of the experiment.

The LACIE was formally initiated late in 1974. It was announced November 6, 1974, and described briefly by Secretary of State Kissinger at the World Food Conference in November 1974 (ref. 9) as follows:

> 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 BRIEF DESCRIPTION OF THE LARGE AREA CROP INVENTORY EXPERIMENT

The LACIE is a cooperative project of the USDA, the NASA, and the NOAA of the U.S. Department of Commerce. The major goals of the experiment are:

a. To evaluate and demonstrate the capability of existing technology (remote sensing, data processing and analysis, and other associated technologies) to make improved

worldwide crop production information available to
decision makers in a cost-effective manner in a test
conducted in a quasi-operational environment.

b. To research and develop alternate approaches and tech-
niques which, upon evaluation, are qualified to be
incorporated into the LACIE quasi-operational system
where required to meet performance goals or to improve
efficiency.

The experiment is being conducted over three consecutive crop
seasons in a 3-1/2 year timespan and is divided into three
corresponding phases. Each phase is designed to build on the
experience of the previous phase(s). Phase I was conducted
during the 1975 crop year and concentrated on a system test
to identify and estimate the wheat acreage within selected
U.S. wheat growing regions and to test wheat recognition
analysis in other regions selected throughout the world.
During this phase, mathematical wheat yield models were
developed and yield feasibility determinations conducted
over selected regions in the United States. Phases II and
III concentrated on bringing all elements of a system
together in a quasi-operational environment to test the
technology's capability to develop area, yield, and produc-
tion estimates for U.S. test regions and other major wheat-
producing regions of the world.

The LACIE is composed of two elements conducted in parallel.
A major effort involves the operation of an experimental
system throughout the crop season to produce periodic esti-
mates of wheat acreage, yield, and production in selected
regions and to evaluate the accuracy of those estimates. A
second element is involved with researching and developing
improved approaches for possible incorporation and testing
in the experimental system. It is believed that the exten-
sive testing conducted in the LACIE program is essential to
advancing the technology to a level where it is ready to be
included in a future operational system.

A decision to require *no* ground truth in the analysis of
Land Satellite (Landsat) data is an important factor in the
technical approach selected in LACIE. In order to have an
approach thought to be more operationally feasible and cost
effective, *no* use of current season ground truth is made to
derive LACIE acreage estimates.

It is also important to note that the systems that support
the experiment have been assembled, for the most part, from
available components designed for research and development.
The LACIE is intended to test the techniques and functions
necessary for crop production inventorying and *not* to provide
a streamlined, cost-effective operational system. The intent
is to utilize the experimental results to support, as a con-
current effort, the design of a user-oriented operational
system and an associated estimate of the performance and
cost of such a future system.

Performance is evaluated on a number of criteria. These
include the accuracy, timeliness, and objectivity of esti-
mates produced from the experimental processes of LACIE as

early as possible in a crop year and periodically throughout the season. In the United States, estimates are first made in the December-February time frame and then regularly on a monthly basis from April to the end of harvest. Landsat data are analyzed within approximately 30 days after satellite acquisition in such fashion that a 15-day-total operational capability is demonstrated. The LACIE estimates are produced using objective and repeatable procedures and are *not* modified using current season intelligence from other sources. The accuracy goal of the LACIE is a 90/90 at-harvest criterion for wheat production information. This specifies that production estimates which are made at harvest for a region or country be within 90 percent of the true production, 90 percent of the time, i.e., 9 years out of 10. In addition, the LACIE is to establish the accuracy and reliability of early season estimates and of estimates made at regular intervals throughout a crop season prior to harvest. The 90/90 at-harvest goal is based on the premise that information of this quality, with an associated timeliness and objectivity, would be an improvement over what is available from conventional sources of wheat production estimates for regions outside the United States.

The LACIE is designed to estimate wheat production at a regional or country level for selected major producing regions of the world. Each region to be surveyed is stratified into relatively homogeneous parts within which production tends to be more uniform. Wheat acreage and yield for each stratum are estimated and multiplied together to obtain an estimate of the production for the stratum. These estimates of production in the strata are then added to arrive at an estimate of production at regional and/or country levels. Wheat acreage and yield are each treated in the strata and aggregated to form estimates of both acreage and yield at regional and country levels.

Wheat area estimates are derived from analysis of Landsat MSS data (ref. 10) collected over 5- by 6-mile sample segments, statistically located over the survey region. The segments represent approximately 2 percent of the agricultural areas in each of the survey regions. Mathematical models are used to calculate an estimate of the wheat acreage for the total survey region from the wheat acreage estimates made for the 5- by 6-mile sample segments. Statistical pattern recognition analysis of the multispectral data acquired by Landsat over the samples is performed to identify wheat on a computerized system at NASA/JSC.

Yield is estimated with mathematical models relating yield to principal meteorological conditions and other factors which determine the yield of wheat. Precipitation and temperature are primary variables in the LACIE models. Initially, these data are being obtained from the World Meteorological network of ground weather stations. In later stages of the experiment, the use of supplemental meteorological data from weather satellites is planned. The yield models have been programmed on digital computers at the National Meteorological Center of NOAA and are run with current estimates of meteorological conditions to produce yield estimates for all strata.

Additionally, wheat growth models have been developed relating the physiological growth stage of wheat to the responsible factors. These factors are primarily day length and daily maximum and minimum temperatures. Estimates of crop stage, produced by these models, are being utilized initially in the analysis of the Landsat data but will also be important to the operation of improved yield models in the later phases of LACIE.

The first phase of LACIE concentrated on the hard, red wheat crop area of the United States and was completed in April 1976. The selected region is comprised of nine states in the U.S. Great Plains[1] which, on the average, accounts for 90 percent of the summer and spring, hard, red wheat and is 70 percent of the total U.S. wheat crop. This region has been referred to as the "yardstick" area and is included in all phases of the experiment. Additionally, exploratory segments were analyzed in other major wheat producing regions around the globe.

Winter wheat is normally found in the southern portions of wheat producing regions and is a fall-planted crop which is harvested in the late summer. Spring wheat is confined to areas with more severe winters and is a spring-planted crop which is harvested in late summer. Normally, the yields of winter wheat varieties are higher than the yields of spring wheat.

In Phase II, the LACIE system was augmented to make periodic estimates of yield and production throughout the crop season. Also, the wheat regions experimentally surveyed by LACIE were logically expanded to include portions of Canada and the U.S.S.R. Periodic estimates of acreage, yield, and production were developed and assessed throughout the 1976 crop season. Again, exploratory segments were selected in other regions in the Northern and Southern Hemispheres. The final selection of regions for Phase III will be based on Phase II results.

Much of the detailed assessment of performance of the technical approach is accomplished with ground data collected over the yardstick area. A number of sample sites, approximately 30 square miles in size, have been selectively located throughout the area. These are referred to as intensive test sites and were selected to support assessment analysis. In addition, a number of the 5- by 6-mile sample segments are randomly selected from the various stratum after wheat acreage proportion estimates have been completed. Ground-truth data are then collected over these blind[2] sites to support an evaluation of the LACIE approach.

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

[2]Sites are referred to as blind sites because LACIE analysts are not aware of which sites have been selected prior to their completion of the initial analysis and development of resultant LACIE estimates.

In addition to the intensive and blind-site segments, the LACIE relies upon data compiled by the Statistical Reporting Service (SRS) of the USDA as a reference for determining the accuracy of the LACIE estimates in the yardstick area. The SRS data tend to be quite accurate at a national level and markedly degraded at smaller geographic levels. To date, estimates of errors in the SRS estimates have not been incorporated into the LACIE performance analysis. Thus, SRS estimates are used as best estimates of the acreage, yield, and production at the national and regional levels. Only a very crude estimate of LACIE performance can be made outside the United States where relatively poor "truth" data is available.

Several hundred other sites denoted as "exploratory" segments have been selected in the major wheat producing regions of the world to be analyzed in Phases I and II in order to begin to identify the unique characteristics of different wheat producing areas of the world.

DISCUSSION OF RESULTS

The experiment was extremely successful in piecing together a total system capable of processing the quantities of Landsat data scheduled in Phase I. Approximately 2604 acquisitions from 693 segments were analyzed in total; 411 of these segments form the selected sample population in the Great Plains yardstick region. Although the satellite passes over each segment every 18 days, the probability of Landsat's seeing a segment is approximately 60 percent due to cloud cover.

An average of about 12 hours was required for analysis in Phase I to derive a wheat proportion estimate for a 5- by 6-mile sample segment. An average total of 30 days was taken to move a segment from its moment of acquisition by Landsat through to a final proportion estimate. It is estimated that in an operational environment, the required time could conservatively be reduced to less than 15 days.

In Phase II, a total of 9276 qcquisitions over 1720 segments was collected and analyzed. The system was augmented in Phase II with a higher speed computer processor to support the increased processing loads planned in Phases II and III. The average time required for a computer classified analysis of a sample segment was reduced from 12 hours to 6 hours in Phase II. In Phase II, every cloud-free Landsat acquisition over each segment was reviewed by the analyst for computer classification rather than restricting the analysis to one acquisition for each of four crop biowindows as in Phase I. This change was effected to improve the accuracy of early season estimates and was based on Phase I experience. In order to handle the increased data load, two additional types of analysis routines were added. A "no change" analysis routine required an analyst to overlay a computer classification map from a previous acquisition over a color-infrared image created from the new acquisition and manually determine if any significant change in wheat acreage had taken place. The average time required

for this was approximately 1 hour. A third type of routine
required an analyst to manually interpret a color-infrared
image made from the Landsat multispectral data and count
wheat pixels[1] where less than 5 percent of the sample seg-
ment was judged to be in wheat. The average time for this
type of analysis was approximately 2-1/2 hours. Thus far,
Phase II experience indicates that considerable accuracy
improvement was realized in the early season estimates by
utilizing every cloud-free Landsat acquisition. As addi-
tional experience is gained regarding the optimum biowindows
for identifying wheat, it is expected that selected acquisi-
tions will be adequate.

In Phase II, the LACIE system was successful in acquiring
and processing the meteorological data from the World Mete-
orological Organization (WMO) stations through the yield
and crop growth models programmed on digital computers.
Thirty-day average values of precipitation and temperature
were utilized in the yield models in Phase II. Daily maxi-
mum and minimum temperatures were collected as inputs for
the wheat growth stage model.

Again, the LACIE system proved extremely successful in
being able to acquire, process, and interpret the data
volumes and rates required. No significant problem is
anticipated in the later phases, based on the experience
to date.

Significant experience was acquired in Phase I in the anal-
ysis of Landsat data to estimate wheat acreage. A consid-
erable amount of time was required to locate and eliminate
system and analysis bugs in the experiment. One significant
analysis bug dramatically affected the early season LACIE
acreage estimates until it was located during the latter
half of Phase I. Bare soil was correctly classified as such
but was erroneously aggregated as wheat acreage in early
estimates. This led to high overestimates of wheat acreages
in both the spring and winter wheat area reports until
early acquisitions were replaced by later season data. Near
the end of Phase I, this and other less significant bugs
were corrected, and a final analysis of all the Landsat
acquisitions was completed.

Some further explanation is required to understand and
interpret LACIE results. Elementary statistical theory
indicates that a good statistical estimator has several
properties. It should be unbiased, i.e., the expected
value of the estimator should be equivalent to the true
value; and the precision or variance of the estimator
should be relatively small. In LACIE, a statistical indi-
cator, the coefficient of variation, the standard deviation
of the LACIE estimate divided by the mean of the estimate,
is used to describe the variability of the LACIE estimates.
The relative difference between the LACIE estimate and the
true value, as approximated by SRS, ground truth, or some

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[1] Each of the individual resolution elements acquired by the
Landsat MSS is referred to as a picture element or pixel.

other comparative source, and expressed as a percentage of the LACIE estimate, is analyzed for the presence of bias in the evaluation of the accuracy of LACIE. Without a time series of LACIE estimates developed over a number of years, it is difficult to definitively and directly estimate any existing bias. In the LACIE, the relatively simple T-test is used to test the relative difference for statistical significance, i.e., bias. As previously discussed, the accuracy performance goal of LACIE is the 90/90 criteria. If the estimate is unbiased, the random component, as estimated by the coefficient of variation (c.v.), can be on the order of 6 percent at the regional or country level. If the estimate has a 10 percent bias, then the c.v. must be zero to meet the 90/90 goal. If this allowable coefficient of variation of 6 percent for unbiased estimates is equally proportioned to acreage and yield, then the coefficient of variation can be on the order of 4.25 percent for acreage and for yield estimates. Thus, if the estimates are unbiased, the c.v.'s can be 4.25 percent or smaller; however, in the presence of a bias, the c.v.'s must be proportionately smaller. Thus, the LACIE estimates for yield, acreage, and production are analyzed in terms of whether or not relative difference from a true value is judged to be statistically significant and thus indicative of a bias. Additionally, the coefficient of variation is analyzed in terms of the aforementioned simplified allocation of error to the acreage and yield estimations.

After isolation and correction of all significant analysis and implementation bugs and upon reworking the data, the resulting wheat area estimate at harvest for the U.S. Great Plains was deemed marginally satisfactory in consideration of the 90/90 at-harvest goal for wheat production. However, the LACIE Great Plains area estimate was approximately 46 000 000 acres, compared to the SRS end-of-year estimate of 51 000 000 acres, or about 10 percent below the baseline figure. This relative difference is statistically significant at the 10-percent level. A major contribution to this underestimate occurred in North Dakota and is believed to be a sampling problem. It is also believed that an improved allocation and an increase in the number of samples on the basis of a better geographic partitioning of agricultural lands into a more homogeneous strata would reduce any bias to a tolerable level. The use of Landsat imagery is critical to defining adequate strata. The c.v. computed for the LACIE area estimator was about 5.7 percent, which was slightly above the desired 4.25 percent needed to meet the 90/90 production goal. Because the data loss due to early implementation problems resulted in a reduction in the number of LACIE sample segments, this random error component is expected to be reduced to or below the target of 4.25 percent in Phases II and III.

Additionally, accuracy was examined for selected sample segments and the results indicated that the Landsat data and the classification technology estimated small grains area within a sample segment accurately enough to meet the performance goals. In North Dakota, where 20 such sites were examined in detail, no significant difference was detected between the LACIE and ground observations over the sample segments.

The estimated c.v. of the random classification error was
also acceptably small. These analyses indicated that bias,
introduced by factors such as Landsat resolution, lack of
spectral resolution, and the classifier are *not* excessive.
Results of these tests did indicate a difficulty in dif-
ferentiating wheat from other closely related small grains.
However, in those cases, wheat area estimates were obtained
through the reduction of the small grain area estimates in
accordance with the historic prevalence of these crops.

Twelve yield regression equation models, developed in
Phase I for the Great Plains region, were tested with his-
toric data for the years from 1965 to 1975. SRS estimates
of wheat acreage were used to weight the meteorological
parameters because no LACIE estimates exist for that
10-year record. Initial tests indicated that the yield
estimates, combined with SRS estimates of acreage, margin-
ally would not satisfy the 90/90 production criteria given
equal or greater errors in the area estimates. Additional
analysis of the problem revealed that a significant source
of the yield estimation error was in the form of the model
which resulted in unrealistically high or low yield esti-
mates for extremely high or low values of temperature or
precipitation. To correct this situation, the meteorologi-
cal input values were not permitted to exceed specific
upper and lower bounds. The models, when retested, were
found to be acceptable. In 10 out of 11 years, the yield
estimates, when combined with acreage as estimated by SRS,
were found to be within tolerance of the true production —
again, as determined by the SRS historic reports.

For the 1975 crop year, the estimated yield for the Great
Plains was 4.3 percent higher than the value estimated by
the SRS. The c.v. was estimated to be 2.3 percent.

When the Phase I (1975 crop year) LACIE area estimates were
combined with the yield estimates for the same period, the
resulting production estimates met the 90/90 goal in the
Great Plains yardstick area. This produced an at-harvest
production estimate for the U.S. Great Plains of
1 291 098 bushels compared to 1 363 400 bushels as esti-
mated by the SRS. The LACIE production estimate was
5.6 percent below the SRS final estimate. With a c.v. of
5.9 percent and a deviation of ±76 174 bushels, a differ-
ence of 5.6 percent is not significant (i.e., could likely
be a random fluctuation), and the estimator was judged to
satisfy the accuracy goal. It is important to note that
an allocation of 637 sample segments was originally made
to provide LACIE with a capability for making U.S. acreage
estimates at the country level, having approximately a
2-percent sampling error, i.e., the error due to the number
and location of sample segments. Early in the experiment,
the decision was made to concentrate on the nine-state
hard, red wheat region as a yardstick area to permit expen-
sive, in-depth accuracy assessment analysis to be conducted
throughout the duration of the experiment. The yardstick
includes approximately 70 percent of the U.S. wheat crop
and is representative of an extremely wide range of condi-
tions of weather, cropping and agricultural practices, and

field sizes. The 411 segments are considered to have an associated sampling error in excess of 2 percent for the Great Plains region. Thus, in Phase I, a major question was the adequacy of 411 segments to support the accuracy goal at the yardstick level. At the end of Phase I, it was concluded that the allocation was marginally acceptable with certain exceptions, such as in the North Dakota area. Landsat imagery was analyzed to measure the variability of the proportion of small grains over the strata. This measure, together with the correlation of the proportion of wheat to small grains, permitted an improved estimation of the number and location of segments to be made. On the basis of such analysis, the number of segments in North Dakota was increased in Phase II. A study in Phase II also investigated the need to restratify the total survey region into agricultural and nonagricultural areas and further augment the original 411 segments to provide a sampling error on the order of 2 percent at the nine-state level in Phase III.

On the basis of an evaluation of Phase I final results, it was concluded that the technology and state of understanding was sufficient to expand the experiment to include additional wheat-producing regions in Phase II.

LACIE was particularly interested in the repeatability of Phase I results in the Phase II crop year. In addition, critical attention was placed on an evaluation of how well the yield models would perform in foreign regions where historic data was thought to be of considerable poorer quality than that of the United States. Also in question was an issue of how well the models might perform under abnormal weather conditions that might occur in some parts of the United States, Canada, or the U.S.S.R. Fortuitously, the 1976 crop year did provide a somewhat radical departure from normal weather patterns in the U.S. Great Plains yardstick region. The monthly average precipitation for the five winter wheat states is shown in table I. It should be noted that much of the above-average November precipitation occurred at a time when the crop was entering dormancy.

As a result of an evaluation of the Phase I experience, significant changes were made for Phase II. These included the following:

a. A requirement was instituted to have the complete analysis of a segment conducted by a single analyst or analyst team as opposed to having a series of different analysts perform the different functions required to develop a proportion estimate for a 5- by 6-mile sample segment. This afforded analysts an opportunity to develop an understanding of the interactions of the various analysis procedures, thus leading to a more accurate final estimate.

b. Every cloud-free acquisition of each sample segment was to be analyzed as opposed to utilizing one acquisition in each of four different biowindows. This change was required because of the uncertainty of estimating the

biowindow of wheat at a specific time as well as a lack
of understanding of the best times to differentiate
wheat from other confusion vegetation.

c. Agricultural areas were differentiated from nonagri-
cultural areas using full-frame Landsat imagery.

In addition to such changes, a large experience factor was
carried forward into Phase II. It is important to note
that in Phase I very little experience with the refined
technology had been obtained in the early season reporting.
Therefore, major emphasis in Phase II was placed on evalu-
ating LACIE performance in early season estimating in the
U.S. Great Plains, Canada, and U.S.S.R. In Phase II, just
as in Phase I, LACIE estimates were required to be produced
prior to the availability and release by official USDA
sources. All the evaluation of performance at the regional
level was done against the official estimates after their
release.

The 1976 wheat year turned out to be an abnormal one; the
Great Plains in particular was struck by drought in both
the spring and winter wheat areas and generally proved to
be a difficult challenge for USDA forecasting services as
well as for LACIE.

Although, Phase II has been concluded, only the results
through June 30, 1976, will be discussed in this paper. As
a result of data sensitivity, the complete results for
Phase II cannot be published until 120 days after the final
SRS operational report is released in 1976.

It is important to understand the way in which the refer-
ence system functions because LACIE estimates are evaluated,
in part, against the USDA system in the Great Plains yard-
stick region. It became apparent to LACIE Phase I experi-
menters that acreage and yield estimates produced by the
reference system (SRS) during the first half of the season
are not estimates of the same quantities being estimated by
LACIE. In December, SRS makes a measurement of acres
seeded and estimates yield for seeded acres and production
on trend from the five previous years. Current year condi-
tion reports are also utilized. LACIE early season estimates
are for emerged acreage and yield for acres for harvest.
Normally, the USDA estimate is converted to acres for har-
vest in May on a basis of mail surveys and measurements of
the farm sample plots. In 1976, SRS produced a special
report because of the severe drought in the Great Plains.
In this particular situation, the SRS necessarily used a
weather model to estimate yield for acres for harvest. In
a normal year, objective measurements are made only on field
visits to sample fields each month after April through har-
vest in order to derive monthly yield estimates. A measure-
ment is made of acres for harvest during late June and
reported on June 30. This is the most accurate measurement
of acres for harvest up to that point in the year. The
estimates made by SRS in 1976 are shown in figure 1. As
opposed to this, LACIE observes wheat that is sufficiently
developed to be detectable in the Landsat data. It is then

assumed that these acres are *acres for harvest*. These acres
are monitored for significant changes using Landsat data
throughout the season until after harvest. Yield is esti-
mated on the basis of weather conditions from early season
through to harvest.

The SRS estimates in the yardstick region for the five
winter wheat states is shown in figure 1. It is interesting
to note that a major adjustment was made to *acres for
harvest* in April. Also, a second major adjustment was made
to *acres for harvest* in the June 30 enumerative survey. A
major adjustment was made by SRS in April in yield. These
adjustments are reflected in the production estimates. A
significant upward estimate was made for production on the
basis of the June 30 acreage and June yield updates. The
LACIE estimates for Phase II are shown in figure 2. It
should be noted that the average age of data in the LACIE
estimates is on the order of 45 days. In an operational
system, the LACIE estimates would, therefore, be delivered
a month earlier. Considering this, it can be seen that the
May LACIE area estimate agrees well with the April SRS
acreage estimate. The June 1 acreage estimate agrees quite
well with the SRS June 30 best *acreage-for-harvest* estimate.

The LACIE yield estimates appear to have accurately pre-
dicted the yields throughout the season. A significant
adjustment in June was later substantiated by a July SRS
yield adjustment. It would appear that the LACIE produc-
tion estimates also accurately reflected the changing condi-
tions in the Great Plains through June. LACIE was estimating
wheat production significantly higher in June than was SRS.
However, the end of July SRS adjustment served to substan-
tiate the accuracy of the LACIE June estimate. Again, in
an operational system, the LACIE June estimate would have
been achieved in May. In summary, the LACIE production
estimate for the southern portion of the yardstick area
reached the 90/90 goal in May, as compared to the SRS refer-
ence estimates, and exceeds the goal for there through the
late June-early July period. In fact, the -8.9 percent
relative difference between the LACIE May estimate and the
SRS early July estimate is not statistically significant at
the 90-percent level with a c.v. of 5.9 percent. The c.v.
of 5.9 percent is considerably less than the 8 percent
required at the 5-state level to meet the 90/90 criterion
at the Great Plains level. The relative difference in pro-
duction in early June is on the order of 1/2 percent with a
c.v. of 5.4 percent. This clearly exceeds the 90/90 goal
even at the 5-state level. The relative difference between
the LACIE May area estimate and the SRS June 30 acreage esti-
mate is approximately -7 percent with a c.v. of 5.6 percent.
The relative difference of the LACIE early June acreage esti-
mate and the SRS early June 30 estimate is about -3.4 percent
with a c.v. of 5.2 percent. Thus, it appears that the LACIE
early season estimates in Phase II are actually approaching,
and then exceeding, the 90/90 goal in the May-June time
frame. Estimates for the U.S.S.R. winter wheat indicator
region were first developed in April. It should be noted,
however, that the Landsat data contributing to these esti-
mates could have been arrived at in February.

Table II compares at-harvest Phase I and Phase II area,
yield, and production estimates for the five-state winter
wheat portion of the U.S. yardstick region. The early
season and monthly estimates for this area are shown in
table III. A monthly comparison of LACIE and SRS estimates
are charted in figure 2. The LACIE estimates for the winter
wheat region of the U.S.S.R., together with estimates com-
piled by the Foreign Agricultural Service (FAS) of the
USDA are shown in table IV and figure 3. It is interesting
to note that the situation appears to follow the pattern of
the Great Plains. A relative difference of 22 percent is
indicative of a bias between what LACIE detected as wheat
and what was reported to have been seeded. Again, a fall
drought created a general reduction in fall germination.
It was suspected that the June report made from later
Landsat acquisitions should indicate a significantly
greater estimate of acres for harvest on the rationale that
many wheat fields had not previously developed to a detect-
able stage because of the drought. As can be seen, the
LACIE June estimate, incorporating data from April through
mid-May, increased significantly. Production was within
2 percent of the FAS estimate, acreage was under the FAS
estimate by 5 percent, and yield was over the FAS estimate
by some 4 percent. The c.v. of the LACIE April area esti-
mate was approximately 9 percent and 7 percent for the June
estimate. Thus, the c.v.'s are within the 9-1/2 percent
required at the indicator region level to meet the
90/90 goal at the national level. The crop report esti-
mates as compared to reference sources are summarized in
tables II, III, and IV and charted on figures 1, 2, and 3.
The remainder of Phase II concentrated on the spring wheat
estimates in the northern areas of the U.S. Great Plains
region, all of Canada, and an indicator area in the spring
wheat region of the U.S.S.R. These results will be dis-
cussed in a future report.

In summary, two years of LACIE have produced results which
strongly support a contention that remote sensing supported
by Landsat, together with an agro-meteorological approach
to estimating yield, is capable of providing superior early
season and at-harvest estimates in major wheat producing
regions of the world. Although the technology needs to be
further evaluated in Phase III, thus far the results have
been most encouraging. It is also important to note that
significant improvement should be expected in the future.
The current implemented remote sensing technology and
approach is in the early developmental stage. In addition,
there is only a limited understanding of the factors which
affect the accuracy of remote sensing crop surveys. The
techniques developed and evaluated in LACIE do appear to
provide a suitable base at this time for the design and
testing of an optimized system for the USDA. The USDA,
within LACIE, is currently in the process of developing
the conceptual design for such a system.

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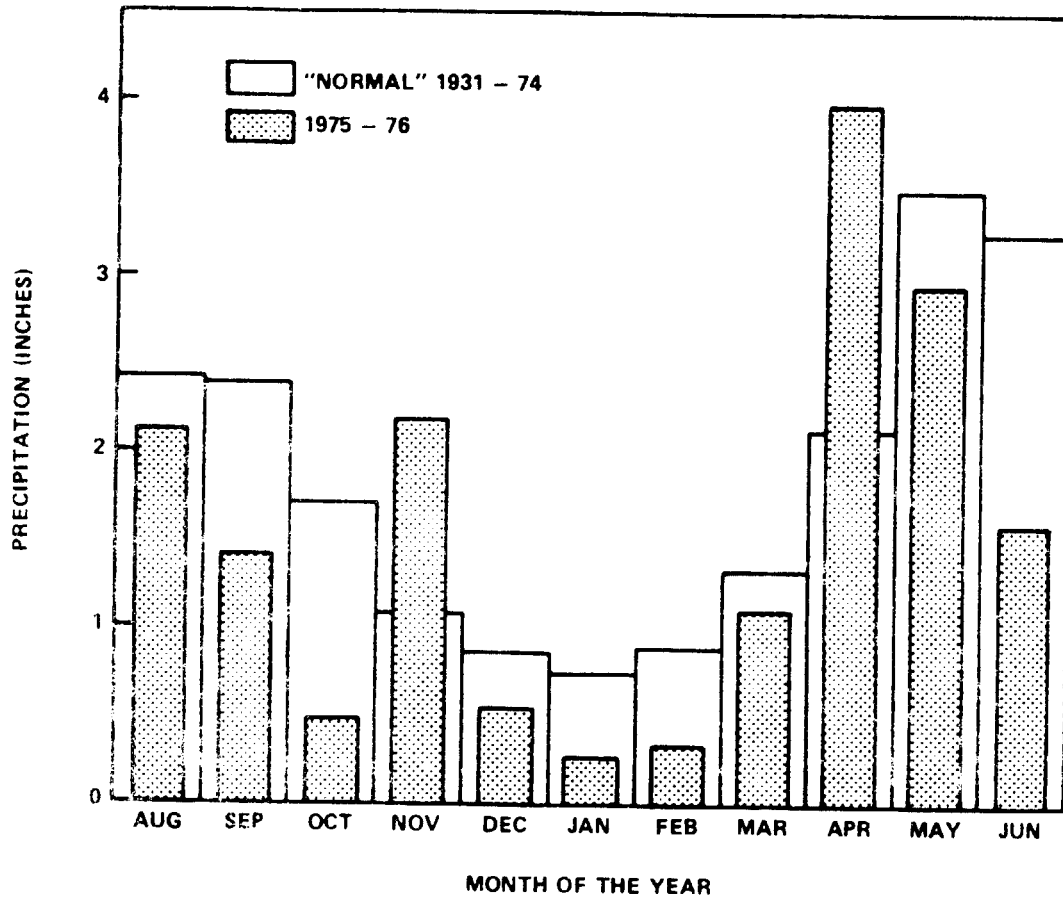## TABLE I.— MONTHLY AVERAGE PRECIPITATION FOR WINTER WHEAT STATES IN "YARDSTICK" REGION

TABLE II.— A COMPARISON OF PHASE I AND PHASE II RESULTS FOR THE FIVE-STATE WINTER WHEAT PORTION OF THE NINE-STATE YARDSTICK REGION

[Comparison with SRS estimates: relative
difference ± coefficient of variation
of LACIE estimate]

Period	Area	Yield	Production
Phase I (1975)	-0.13% ± 7%	4% ± 3%	5% ± 7%
Phase II (1976)	-6% ± 5%	-0.4% ± 2%	-6% ± 5%

TABLE III. — MONTHLY COMPARISONS OF LACIE AND SRS ESTIMATES FOR U.S. SOUTHERN GREAT PLAINS WINTER WHEAT

[P = production $\times 10^6$ bushels; A = acreage $\times 10^6$ acres; Y = yield bushels/acre.]

	December			February			March			April			May			June			Late June			July		
	P	A	Y	P	A	Y	P	A	Y	P	A	Y	P	A	Y	P	A	Y	P	A	Y	P	A	Y
SRS	659	3.32	19.9							611	25.7	23.8	631	25.4	24.9	617	25.3	24.4		27.3		716	27.3	26.2
LACIE	-	-	-	674	24.4	27.6	603	22.3	27.0	566	21.9	25.8	638	25.5	25.0	699	26.4	26.4		26.9		695	26.2	26.5
R.D.				2.0	-36	27.8	-9.2	-48.9	26.0	-7.9	-17.4	7.75	1.2	~0	~0	11.8	4.3	7.6		-1.5		-3.0	-4.0	1.1
C.V.				9.0	9.0	2.0	7.5	8.0	3.3	7.0	7.0	3.0	5.9	5.6	2.8	5.4	5.2	2.3		5.3		5.3	5.3	2.3

R.D. = Relative Difference
C.V. = Coefficient of Variation

TABLE IV.— PHASE II RESULTS OF COMPARISON OF LACIE AND INDEPENDENT ESTIMATES IN USSR WINTER WHEAT INDICATOR REGION

[Area = Acres $\times 10^6$; yield = bushels per acre; production = bushels $\times 10^8$]

Date / Source	February[a]			April			June			July		
	Area	Yield	Production	Area	Yield	Production	Area	Yield	Production	Area	Yield	Production
FAS	32.1	42.0	13.5				28.1	36.4	10.3	28.1	37.5	10.6
LACIE				20.2	39.2	8.0	26.6	37.4	10.1	29.2	37.9	11.2

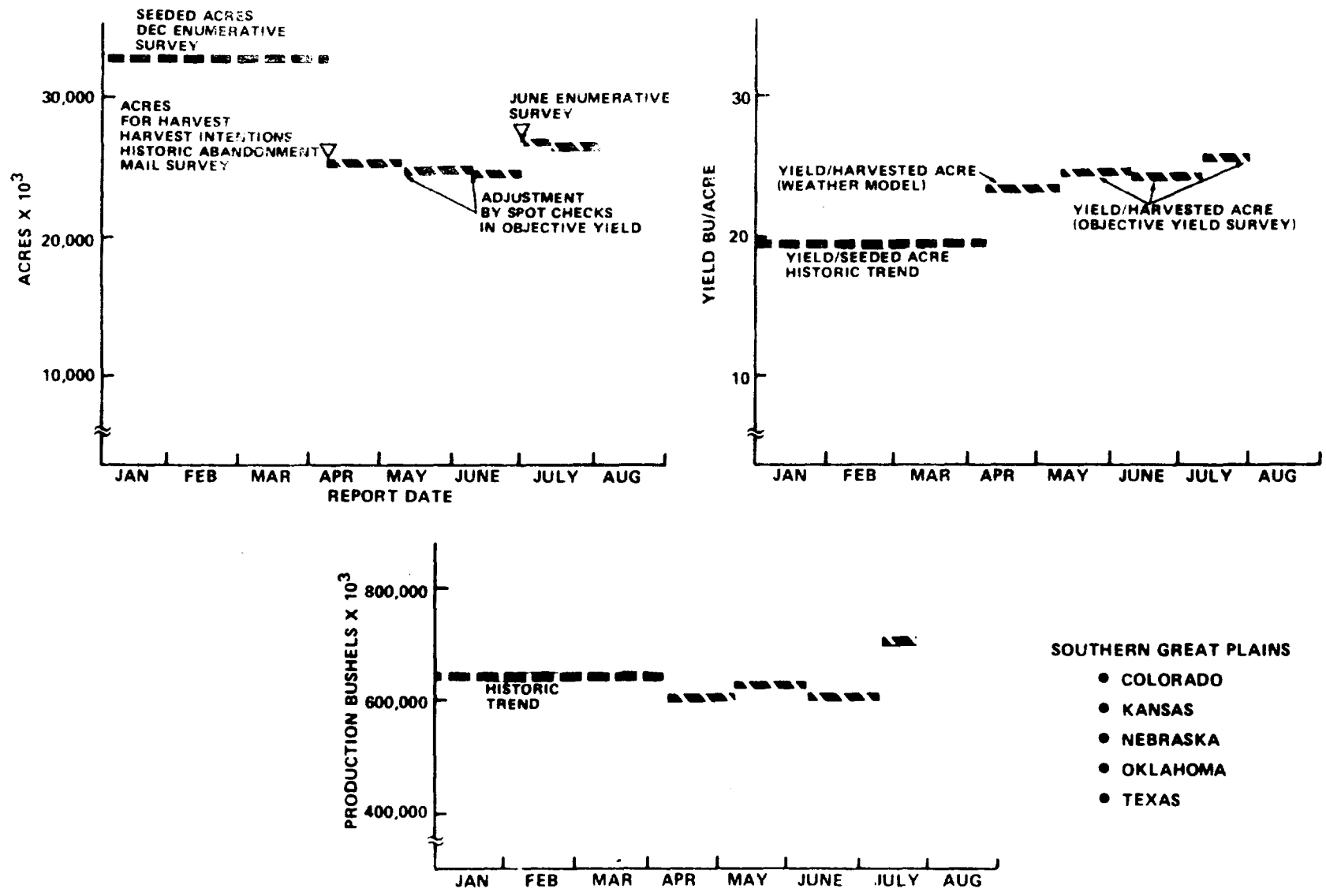[a] FAS February projection is not released as an estimate.

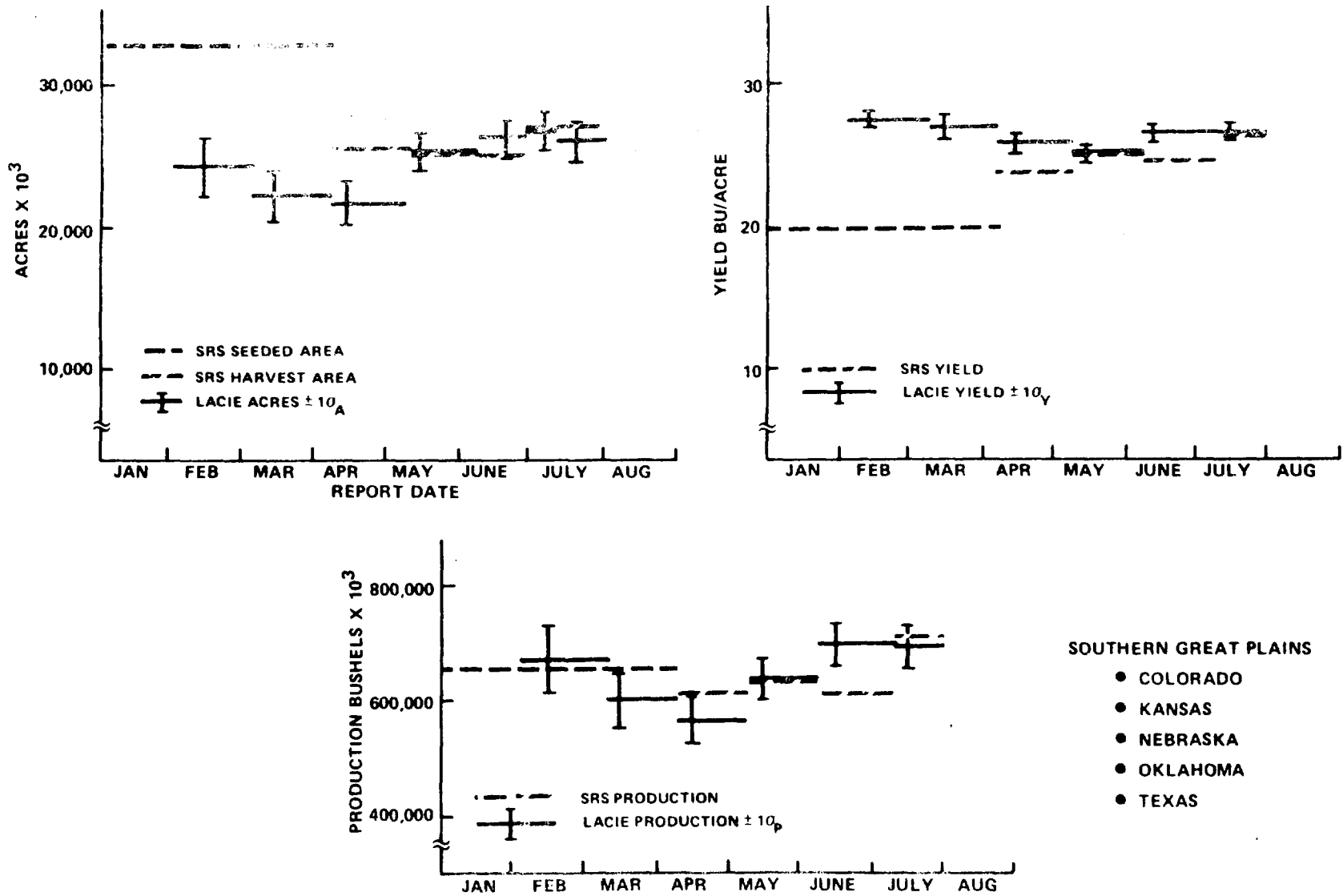**Figure 1.— SRS estimates in yardstick region (southern Great Plains).**

Figure 2.— Monthly comparison of LACIE and SRS estimates in yardstick region (southern Great Plains).
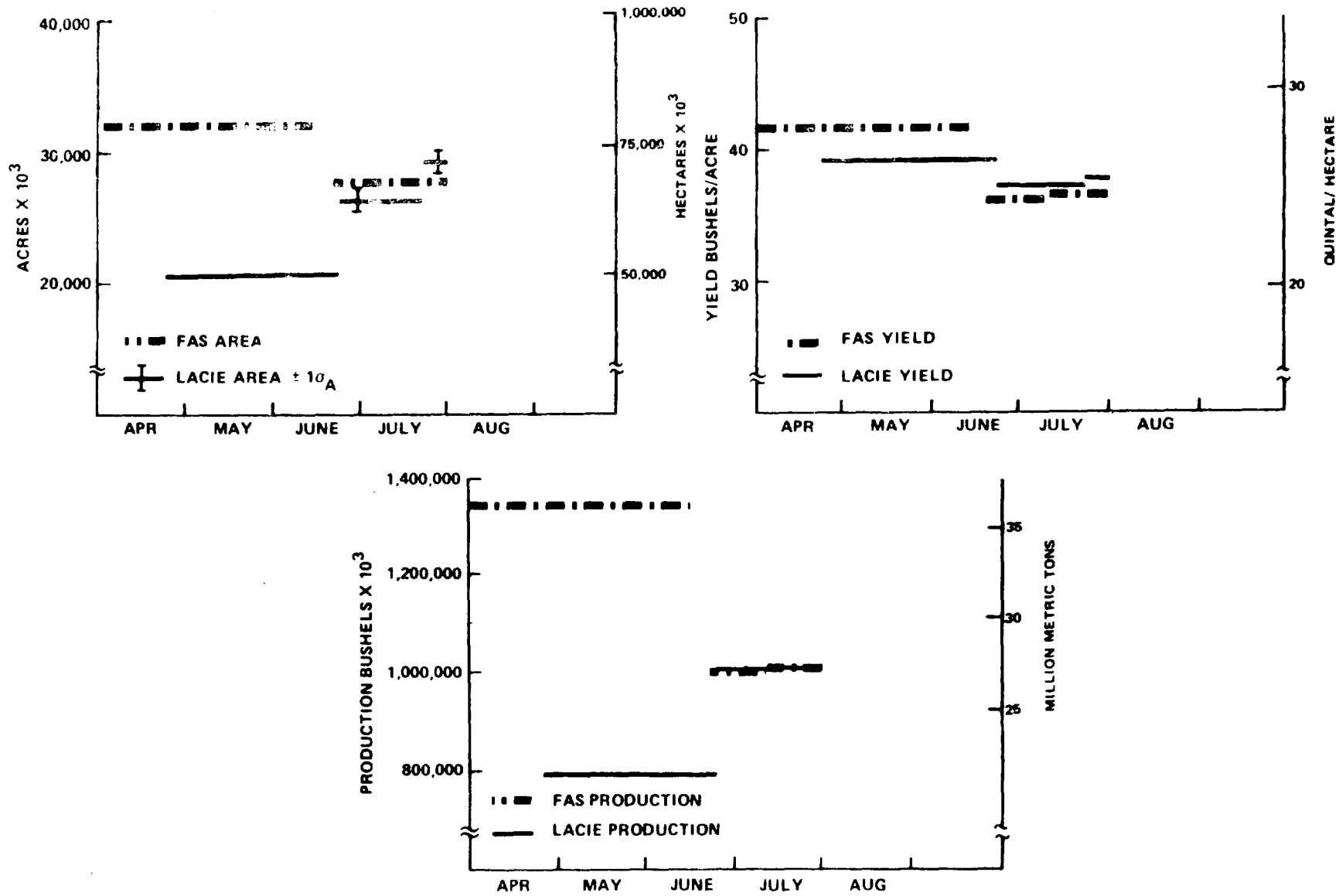
Figure 3.— Monthly comparisons of LACIE and FAS estimates for the
U.S.S.R. winter wheat indicator region.