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LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

NASA NOAA USDA

LACIE PHASE II ACCURACY ASSESSMENT

FOURTH INTERIM REPORT

and

DRAFT OF THE PHASE I AND PHASE II ACCURACY ASSESSMENT FINAL REPORT

NASA
National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston, Texas 77058

AUGUST, 1977

PROJECT WORKING DOCUMENT

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ACCURACY ASSESSMENT FINAL REPORT

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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PREFACE

This document was prepared by Lockheed Electronics Company, Inc. (LEC), Systems and Services Division, Houston, Texas, from materials provided by NASA and LEC. This work was done under contract NAS 9-15200 for the Earth Observations Division, Science and Applications Directorate, National Aeronautics and Space Administration, Lyndon B. Johnson Space Center.

NOTE: This report has been released as a "PROJECT WORKING DOCUMENT" to provide an expedited mechanism for making preliminary Accuracy Assessment results available within the Large Area Crop Inventory Experiment.

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ABBREVIATIONS

AA	Accuracy Assessment.
ACC	adjustable crop calendar.
agromet	agricultural/meteorological.
biowindow or biophase	biological window, biological phase – a Landsat data acquisition period that is related to the biostages of wheat development. The LACIE approach is based on the judgment that wheat can be separated adequately from other crops by analysis of up to four acquisitions of Landsat data during the growing season. The biowindow may be updated if there is a significant lag or advancement in the current crop calendar. The sequence chosen includes acquisitions during the following biowindows: 1. Crop establishment – from 50 percent tillering to 50 percent jointing (biostage 2.3 to 3.0). 2. Green – from 50 percent jointing to 50 percent heading (biostage 3.1 to 4.0). 3. Heading – from 50 percent heading to 50 percent soft dough (biostage 4.1 to 5.0). 4. Mature – from 50 percent soft dough to 50 percent harvest (biostage 5.1 to 6.0).
biostage	biological stage – the specific stage of development of a crop which can be recognized by a major change in plant structure; i.e., emergence after germination, jointing, heading, soft dough, ripening, and harvest, which are represented by integers on the Robertson Biometeorological Time Scale.
blind sites	LACIE sample segments chosen at random for which ground truth is obtained in order to test classification performance. The identity of the blind sites is withheld from the CAMS analysts so that these segments will be treated the same as the other segments.
BMTS	Biometeorological Time Scale.

CAMS	Classification and Mensuration Subsystem.
CAS	Crop Assessment Subsystem.
CCEA	Center for Climatological and Environmental Assessment — an organization of the National Oceanic and Atmospheric Administration, Columbia, Missouri.
classification	in computer-aided analysis of remotely sensed data, the process of assigning data points to various classes by a testing process in which the spectral properties of each unknown data point are compared with spectral properties typical of these classes.
classification error	a measure of the degree to which the LACIE CAMS either overestimates or underestimates the wheat acreage in a specific area.
CMR	CAS Monthly Report.
CRD	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.
crop calendar	a calendar depicting the biostages of the major crop types within a specified region during a calendar year.
crop calendar adjustment	an adjustment made to the normal crop calendar on the basis of current meteorological data.
CUR	CAS Unscheduled Report.
CV	coefficient of variation (standard deviation divided by the mean).
DAPTS	Data Acquisition, Preprocessing, and Transmission Subsystem.
Group 2 segment	LACIE segment in a county that historically produces small quantities of wheat/small grains; samples are allocated with probability proportional to size.
IE	Information Evaluation.
IMR	IE Monthly Report.

ITS	intensive test site — a LACIE segment in the United States or Canada on which detailed crop information is collected by using ground and airborne equipment.
JSC	Lyndon B. Johnson Space Center of NASA, Houston, Texas.
LACIE	Large Area Crop Inventory Experiment.
Landsat	Land Satellite — formerly called ERTS (Earth Resources Technology Satellite); operates in a circular, Sun-synchronous, near-polar orbit of Earth at an altitude of approximately 915 kilometers; orbits Earth about 14 times a day and views the same scene approximately every 18 days.
LEC	Lockheed Electronics Company, Inc.
MSE	mean square error.
MSS	Multispectral Scanner System or multispectral scanner — the remote sensing instrument on Landsat that measures reflected sunlight in various spectral bands or wavelengths.
NASA	National Aeronautics and Space Administration.
NOAA	National Oceanic and Atmospheric Administration.
90/90 criterion	criterion that the LACIE U.S. Great Plains at-harvest production estimate be within 10 percent of the true value with a probability of at least 0.9.
PPS	probability proportional to size.
Sample segments	the 5- by 6-nautical-mile areas used as samples in LACIE to make acreage estimates. They are selected by a sampling strategy which is described in appendix A.
USDA	U.S. Department of Agriculture.
USDA/ASCS	USDA Agricultural Stabilization and Conservation Service.
USDA/SRS	USDA Statistical Reporting Service.

U.S. Great Plains (USGP) (USSGP) (USNGP)	The U.S. Great Plains (USGP), an area encompassing the nine states of Colorado, Kansas, Minnesota, Montana, Nebraska, North and South Dakota, Oklahoma, and Texas; it is divided geographically into (1) the U.S. southern Great Plains (USSGP), which includes Colorado, Kansas, Nebraska, Oklahoma and Texas, and (2) the U.S. northern Great Plains (USNGP), which includes Minnesota, Montana, and North and South Dakota.

1. INTRODUCTION

The Large Area Crop Inventory Experiment (LACIE) is an interagency endeavor of the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the United States Department of Agriculture (USDA). Its purposes are (1) to demonstrate the economical benefit to be obtained by using remotely sensed data from the Land Satellite (Landsat) for agricultural applications, (2) to test the capability of a system utilizing remote sensing in conjunction with climatological, meteorological, and conventional data to produce timely estimates of the production of a major world crop prior to harvest, and (3) to validate the technology and procedures for such a system.

In accordance with the objectives of LACIE, the Accuracy Assessment (AA) effort is designed to check the accuracy of the products from the experimental operations throughout the growing season and thereby determine if the procedures used are adequate to accomplish the above objectives.

1.1 OBJECTIVES

The objectives of AA are as follows:

a. To determine whether the accuracy goal of the LACIE estimate of wheat production for a region or country is being met. The LACIE accuracy goal is a 90/90 at-harvest criterion for wheat production. This specifies that the at-harvest wheat production estimate for the region or country be within 10 percent of the true production 90 percent of the time.

b. To determine the accuracy and reliability of early season estimates and estimates made at regular intervals throughout a crop season prior to harvest. This includes a determination of the degree to which the 90/90 criterion is supported at these intervals during the crop season.

c. To study the various sources of error in the LACIE estimates of wheat production, area, and yield, quantify these errors where possible, and recommend procedures for reducing the error.

1.2 ACCURACY ASSESSMENT ACTIVITIES

In order to satisfy its objectives, AA carries out general types of evaluations and the results are presented in (1) monthly quick-look reports; (2) a number of interim reports leading up to a final report, and (3) certain special reports. The following paragraphs contain descriptions of the AA evaluations presented in the three types of reports.

1.2.1 ACTIVITIES REPORTED IN THE QUICK-LOOK REPORTS

The quick-look reports contain an evaluation by AA of the LACIE estimates reported in the Crop Assessment Subsystem (CAS) monthly reports (CMR's) and the CAS annual report (CAR). The quick-look reports are released one week following the release of a CMR or a CAR. The CMR's and CAR's contain the official LACIE estimates of wheat production, area, and yield, and the corresponding statistics. The true wheat production, area, and yield for the particular region or country are, of course, unknown. Therefore, to ascertain the accuracy of the LACIE estimates, comparisons are made with a reference standard. In the United States, the reference standard consists of the most recent (at the time of the comparison) estimates released by the Statistical Reporting Service of the USDA (USDA/SRS). In foreign countries, the reference consists of the most recent estimates released by the Foreign Agricultural Service of the USDA (USDA/FAS). The AA quick-look reports contain a comparison of the LACIE estimates of wheat production, area, and yield with the corresponding reference standard, as well as significance tests of no difference at the region or country level. If the significance test at the region or country level yields a significant difference, the relative difference calculated at the zone level (state in the U.S.) is used to indicate the problem areas.

1.2.2 ACTIVITIES REPORTED IN THE INTERIM AND FINAL REPORTS

The interim reports are released at regular intervals throughout the crop season. They contain the results of the previous quick-look reports, a discussion of the 90/90 criterion as it applies to the region for which the LACIE estimates of wheat production are available, and the results of investigations of the error sources in the LACIE wheat production estimate.*

Each interim report is built up from the previous one by including data that became available during the interim period. Technical comments on each report are solicited from a variety of sources and are used to upgrade subsequent reports. Early and mid-season evaluations are made in the first and second interim reports; late season and at-harvest evaluations are made in the third and fourth interim reports.

The fourth interim report also serves as a draft for the final report, which contains material which is similar to the interim reports but covers the entire year.

The above schedule was followed in Phase II. In Phase I there were no interim reports and the Phase I final report will be incorporated into the Phase II final report.

1.2.3 ACTIVITIES REPORTED IN AA UNSCHEDULED REPORTS

From time to time, special investigations are carried out that are of interest to LACIE but which are not required on a regular basis such as those mentioned above. These investigations are reported in AA unscheduled reports.

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*A detailed description of the error sources in LACIE is given in appendix A.

2. SUMMARY

2.1 PHASE I

Phase I of the LACIE project concentrated on the estimation of wheat acreage. Yield and production feasibility studies were also carried out but the Accuracy Assessment team investigated only the accuracy of acreage estimation.

The initial CAS estimates, which were made for each month from April through August, were considerably higher than the USDA/SRS estimates. This was attributed to (1) the practice of considering bare ground as "potential wheat" and counting it as wheat, (2) overestimation of the wheat proportions in segments having only a small amount of wheat, and (3) the classification of confusion crops as wheat. At the end of the season most of the segments were reworked using improved methods based on experience gained during the season. In particular, new procedures were developed to solve the three problems listed above.

These and other improvements used in the rework experiment resulted in at-harvest estimates that were much closer to the USDA/SRS estimates than those obtained during the regular season. At the U.S. Great Plains (USGP) level the relative difference* was -11 percent. An attempt was made to evaluate whether the acreage results could support the 90/90 criterion. For this purpose it was assumed that the acreage and yield estimates were unbiased and independent, and that the coefficients of variation (CV) for acreage (CV_A) and for yield (CV_Y) were equal. If this were true, the 90/90 criterion applied at a given level** would be satisfied if CV_A for that level

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*Relative difference is defined as $\frac{\text{LACIE-SRS}}{\text{LACIE}}$.

**In Phase I the 90/90 criterion was applied at the national level; in Phase II it was applied at the USGP level.

was less than 4.25 percent and if the acreage estimate was unbiased. In Phase I the estimate of CV_A at the national level was 3.74. Therefore, the 90/90 criterion would have been satisfied if the acreage estimate were unbiased. In fact some bias would be allowed, since 3.74 is somewhat smaller than 4.25. The relative differences between the LACIE and USDA/SRS estimates indicated that some bias was indeed present, but no accurate estimate of this bias was performed in Phase I; therefore, it is not possible to say whether or not the results satisfied the 90/90 criterion at the national level.

The area of most concern in Phase I was North Dakota, which had a relative difference of -74.6 percent. Blind site investigations indicated that the source of this problem was sampling error. The experience gained in Phase I was used in developing the CAMS system for Phase II. Several changes were made on the basis of this experience. In particular, more sample segments were allocated to North Dakota, and the classification procedures developed for the CAMS rework experiment became the basis for the Phase II CAMS operations.

2.2 PHASE II

In Phase II, estimates were made for acreage, yield, and production. Generally the LACIE yield estimates were quite close to the USDA/SRS estimates and therefore can be considered satisfactory. However, the acreage and production estimates at the USGP level were low compared to the USDA/SRS estimates, due primarily to significant underestimates for spring wheat in the four U.S. northern Great Plains (USNGP) states and for winter wheat in Oklahoma.

For winter wheat in the USGP, the relative difference between the final LACIE production estimate and the USDA/SRS estimate was -7.2 percent. A significance test indicated that the LACIE estimate was not significantly different from the USDA/SRS estimate at the 10-percent level of significance. However, underestimation problems were still evident in Oklahoma. Investigations indicated that this underestimate was partially due (1) to drought conditions, which caused wheat signatures to differ significantly from those of normal wheat, and (2) the resulting late "greening up" of the winter wheat crop, which caused the actual greening up of the crop to vary considerably from the crop calendar for "normal" winter wheat.

For spring wheat production, the relative difference between the final LACIE and USDA/SRS estimates for the USGP region was -22.3 percent. North Dakota had a relative difference of -6.6 percent, indicating that the problems encountered with this state in Phase I largely had been solved. The major contributors to the spring wheat underestimate in Phase II were Minnesota (relative difference -89.6) and Montana (relative difference -67.4). The spring wheat proportions were obtained from small-grains proportion estimates produced by CAMS by using historical wheat/small-grains ratios. Spring wheat blind site investigation indicated that there was underestimation of the small grains proportions in Minnesota and Montana. One of the major causes for this was that strip fallow fields were not classified well. (Several other reasons are discussed later, in section 4.2.2.2.) Also, the blind site investigations indicated that sampling errors and incorrect estimates of wheat/small grains ratios further contributed to the underestimation.

For total wheat in the USGP, the relative difference between the final LACIE production estimate and the USDA estimate was -12.3, a statistically significant difference. The LACIE estimate was evaluated in terms of the 90/90 criterion using an estimate for the relative bias in the LACIE production estimate; it was found that the 90/90 criterion was not met. The CV for production, estimated to be 5 percent, was sufficiently small for the 90/90 criterion to be satisfied if the production estimate had a relative bias whose absolute value was less than approximately 4 percent. However, the estimate obtained was much larger than this. The large bias was due to acreage underestimation, particularly for spring wheat, and this problem will have to be solved for LACIE to meet its goals. In Phase III, several steps have been taken to solve the problems outlined above. In particular, (1) new classification procedures have been instituted which hopefully will reduce the bias in the classification results, (2) the number of sample segments has been increased from 431 to 601, and (3) an effort will be made to separate spring wheat from spring small grains and thereby avoid the error due to ratioing of wheat to small grains.

Finally, it can be inferred that an accuracy goal of 90/75 was achieved with the present estimates of the relative bias and CV of the LACIE wheat production estimate for the USGP. That is, with an estimate of -24.0 percent for the relative bias and an estimate of 5.0 percent for $CV(\hat{P})$, one is 90-percent confident that the LACIE estimate is within ±25 percent of the true wheat production of the USGP.

3. PHASE I ACCURACY ASSESSMENT

LACIE Phase I investigations conducted during the 1975 crop year concentrated on the identification and estimation of wheat acreage. Therefore, this section contains only assessments of Phase I acreage estimation results.

3.1 COMPARISON OF LACIE AND USDA/SRS ACREAGE ESTIMATES

Three different data bases were used to generate acreage estimates in Phase I; the results obtained with these data bases are described in sections 3.1.1 through 3.1.3.

3.1.1 THE CAS 1A DATA BASE

The 1A data base contained all the sample segments processed by CAMS. It was used with the initial quasi-operational system to produce acreage estimates for April through August. This operation was concerned primarily with "debugging" the system. The results are shown in table 3-1.

The LACIE estimates for April through July are for winter wheat only. Thus, the estimates listed under "Mixed Wheat" for these months should not be compared with the corresponding USDA/SRS estimates, which include spring wheat. The LACIE estimates for August include spring wheat and therefore all can be compared with the USDA/SRS values.

It will be seen that there is a large positive bias relative to the USDA results for all months. The overestimates were attributed to the following causes:

a. Most of the Landsat data acquired early in the growing season were acquired before the wheat had emerged, since real-time crop calendars were not available to use for computing acquisition dates until May of 1975. This period in the growing

TABLE 3-1.– MONTHLY ESTIMATES OF WHEAT ACREAGE BASED ON THE CAS 1A AND 1B DATA BASES COMPARED WITH SRS ESTIMATES.

[Acres × 10^3]

Region	April 1A	May 1A	June 1A	July 1A	August 1A	July 1B	August 1B	USDA/SRS (a)
Winter wheat								
Colorado	5 931	6 409	4 958	4 578	3 534	3 262	3 232	2 260
Kansas	13 892	15 543	17 306	17 620	17 378	17 545	17 726	12 100
Nebraska	5 628	6 403	6 095	6 091	6 665	5 370	6 507	3 070
Oklahoma	12 656	13 199	7 917	8 804	8 287	8 990	8 548	6 700
Texas	10 047	10 540	10 863	10 728	12 854	8 594	11 822	5 700
USSGP	48 154	52 094	47 139	47 821	48 718	43 763	47 835	29 830
Spring wheat								
Minnesota	–	–	–	–	4 619	–	4 619	2 844
N. Dakota	–	–	–	–	12 876	–	12 876	10 213
SW states	–	–	–	–	17 495	–	17 495	13 057
[b]Mixed wheat								
Montana	4 111	8 614	8 618	8 572	8 766	3 628	6 559	4 975
S. Dakota	8 689	8 562	5 390	5 390	8 233	2 113	8 416	3 003
MW states	12 800	17 176	14 008	13 962	16 999	5 741	14 975	7 978
USGP	60 954 (without spring)	69270	61 147	61 783	83 212	49 504	80 305	50 865

[a]January 1976 SRS estimate of wheat area for the crop year 1974-75.

[b]The August estimates include spring and winter wheat, the estimates for April through July include winter wheat only.

season was called biowindow 1A and covered the period from 50-percent planted to dormancy. The 1A data base received this name because it included data from this period. Area estimates were attempted using these data by declaring areas of seed bed preparation (i.e., bare ground) as "potential wheat" and including them in the estimates. Since fall plowing is done for various reasons, this produced overestimates. The biowindow 1A data represented the largest percentage by biowindow that was used in the April through July aggregations. It also influenced the August aggregation, but to a lesser extent.

b. There was a marked tendency to overestimate the proportion of wheat in Group II counties. This led to a thorough review of Group II aggregation in LACIE. It was determined that the Group II aggregation was satisfactory and that the problem was due to overestimation of sample segment proportions for segments having only a small amount of wheat. Most Group II segments fell into this category. Therefore, a new procedure, consisting of hand-counting all the wheat pixels for segments with a small amount of wheat, was instituted and was used in the CAMS rework procedure described below.

c. The classification of confusion crops as wheat also led to overestimates. This effect is particularly important in the spring and mixed wheat states where there are large quantities of other small grains which are difficult to distinguish from spring wheat. Each acquisition had an estimate for wheat alone and sometimes had an estimate for small grains (i.e., wheat plus confusion crops). If both were given, the small grains estimate was used.

In order to avoid the problems caused by the data from biowindow 1A, the 1B data base was formed.

3.1.2 AGGREGATIONS WITH THE 1B DATA BASE

The 1B data base was obtained by eliminating the data from biowindow 1A from the 1A data base. The remaining portion of biowindow 1 was called biowindow 1B and covered the period from dormancy to jointing. The 1B data base therefore consisted of all the data in the 1B biowindow plus all of the data for biowindows 2, 3, and 4.

Aggregations with the 1B data base were carried out for July and August. The results are given in table 3-1. In July the 1B estimates are all lower than the 1A estimates with the exception of those for Oklahoma. At the U.S. southern Great Plains (USSGP) level, the 1B estimate was 4.0×10^6 acres lower than the 1A estimate but was still 14.4×10^6 acres larger than the USDA/SRS estimate. At the USGP level, the 1B estimate was 12.3×10^6 acres lower than the 1A estimate but it cannot be compared with the USDA/SRS estimate since the latter includes spring wheat and the LACIE estimates for July do not.

In August, the differences between the estimates from the 1A and 1B data bases were smaller than in July. This was probably due to the smaller influence of biowindow 1 acquisitions for the 1A data base in August. In July, 106 acquisitions out of 232 were from biowindow 1; in August 87 out of 340 were from biowindow 1. The August estimates all can be compared with the USDA/SRS estimates. At the USSGP and USGP levels, the 1B estimates are slightly lower than the 1A estimates but are still much higher than the USDA/SRS estimates.

The improvements obtained from using the 1B data base were probably due mainly to a reduction in the amount of bare ground classified as wheat. However, bare ground was still classified as wheat in the 1B aggregations, and this probably accounted for a substantial part of the remaining overestimates. Also, factors b and c (section 3.1.1) are expected to have contributed to the 1B aggregations in the same way they did with the 1A aggregations.

3.1.3 THE CAMS REWORK EXPERIMENT

At the end of the season a new at-harvest estimate of wheat acreage was obtained by reworking the data using techniques based on experience acquired throughout the season. In particular:

a. Bare ground was not counted as wheat.

b. Acquisitions that appeared very difficult to interpret were not used.

c. All segments used had at least two acquisitions, of which one was biostage 2 or 3.

d. Multitemporal classification was used where appropriate.

e. CAMS gave estimates for small grains proportions for the spring wheat segments. These estimates were converted to estimates of spring wheat acreage by ratioing, using 1974 SRS statistics for spring wheat and small grains in the appropriate states.

f. The procedure of hand-counting pixels was used for classifying low wheat acreage segments. Usually, Group II segments fell into this category.

Two at-harvest estimates were made using the CAMS rework data. These two estimates differed only in regard to the inclusion of Group II segments. The results for both cases are shown in table 3-2. As can be seen, the area estimates are significantly better when the Group II segments are used in the aggregation.

In Phase I, the 90/90 criterion was applied at the national level. An approximate relation was derived which expressed the CV of production (CV_P) in terms of the CV of the area estimate (CV_A)

TABLE 3-2.– COMPARISON OF USDA/SRS AND LACIE AT-HARVEST ESTIMATES OF WHEAT AREA

(LACIE estimates based on CAMS rework data)

[Acres × 10^3]

Region	Number segments used/ allocated	USDA/SRS	LACIE without Group II	Relative difference, % (a)	CV, % (b)	LACIE with Group II	Relative difference, %	CV, %
Winter wheat								
Colorado	24/32	2 260	3 216	29.7	21.2	3 058	26.1	20.8
Kansas	55/84	12 100	12 582	3.8	9.59	12 940	6.5	7.07
Nebraska	23/35	3 070	3 606	14.9	38.6	2 657	-15.5	28.0
Oklahoma	29/40	6 700	5 702	-17.5	29.5	6 906	3.0	11.2
Texas	28/49	5 700	3 454	-65.0	43.4	4 218	-35.1	32.6
USSGP		29 830	28 560	-4.45	10.5	29 779	-0.17	6.95
Spring wheat								
Minnèsota	9/13	2 844	1 201	-136.8	122.9	2 150	-32.3	15.7
North Dakota	42/65	10 213	5 853	-74.5	14.8	5 853	-74.5	14.8
SW states	51/78	13 057	7 054	-85.1	24.0	8 003	-63.2	(c)
Total wheat								
Montana	39/60	4 975	4 052	-22.8	38.7	3 999	-24.4	25.9
South Dakota	23/33	3 003	4 094	26.7	19.6	4 154	27.7	17.7
MW states	62/93	7 978	8 146	2.06	22.0	8 153	2.15	(c)
USNGP	113/171	21 035	15 200	-38.4	16.2	16 156	-30.2	9.75
USGP	272/411	50 865	43 760	-16.2	8.84	45 935	-10.7	5.66
Projected to national	272/637				5.8			3.74

[a] $\frac{\text{LACIE} - \text{SRS}}{\text{LACIE}} \times 100.$

[b] CV = coefficient of variation = $\frac{\text{standard deviation}}{\text{LACIE}} \times 100.$

[c] Not available.

and the CV of the yield estimate (CV_Y), namely

$$(CV_P)^2 = (CV_A)^2 + (CV_Y)^2 + (CV_A \times CV_Y)^2.$$

If one further assumes $CV_A = CV_Y$, then the 90/90 criterion could be satisfied if $CV_A = CV_Y \leq 4.25$ percent.

It will be seen from table 3-2 that the CV for acreage projected to the national level was 3.74. Since this percentage was smaller than 4.25, it was possible to satisfy the 90/90 criterion even if there was a small amount of bias. However, since there was no ground truth available in Phase I, no estimate was made of the bias, and therefore it is not possible to say whether the results satisfied the 90/90 criterion.

An evaluation of the Phase I 90/90 criterion using production estimates was given in the LACIE Phase I Evaluation Report but is not reported here since in Phase I, AA evaluated acreage estimation only.

From the results presented in table 3-2, the area of most concern was North Dakota. More detailed error analysis based on ground truth and ancillary data in Kansas, North Dakota, Nebraska, and South Dakota permitted a further assessment of the sampling and classification errors. These analyses, discussed in section 3.2, indicated the source of the North Dakota problem to be sampling error.

After the regular CAMS rework estimates given in table 3-2 were made, there was a revision of the area in the pseudo counties (i.e., the part of the counties that is classified as agricultural as distinguished from nonagricultural). This caused a change in the estimates and CV's. The revised results are presented in table 3-3. Note that in most cases the CV's are smaller.

TABLE 3.3.– COMPARISON OF USDA/SRS AND LACIE AT-HARVEST ESTIMATES OF WHEAT AREA

(LACIE estimates based on CAMS rework data and revised pseudo county areas)

[Acres × 10^3]

Region	Number segments/used/allocated	USDA/SRS	LACIE with group II	Relative difference, %	CV, %
Winter wheat					
Colorado	24/32	2 260	3 058	26.1	20.0
Kansas	55/84	12 100	12 942	6.5	6.0
Nebraska	23/35	3 070	2 657	-15.5	31.0
Oklahoma	29/40	6 700	6 864	2.4	11.0
Texas	28/49	5 700	4 219	-35.1	21.0
USSGP		29 830	29 740	-0.3	6.0
Spring wheat					
Minnesota	9/13	2 844	2 150	-32.3	19.0
North Dakota	42/65	10 213	5 849	-74.6	10.0
SW states	51/78	13 057	7 999	-63.2	*
Total wheat					
Montana	39/60	4 975	3 947	-26.0	23.0
South Dakota	23/33	3 033	4 126	27.2	13.0
MW states	62/93	7 978	8 073	1.18	*
USNGP	113/171	21 035	16 072	-30.9	*
USGP	272/411	50 865	45 812	-11.0	4.6

*Not available.

3.2 ESTIMATION OF AREA ERROR USING BLIND SITE DATA

The expression "blind site" is merely a designation applied to selected operational segments for which, unknown to the analyst, ground truth data were acquired for evaluation purposes. The implementation of this approach occurred late in the growing season of LACIE Phase I. Thus, all of the selected sites were in the northern spring wheat regions.

High-resolution color infrared aerial photography over 29 LACIE segments in North Dakota and Montana was acquired in mid-August 1975. (The results from only 16 of these segments in North Dakota are relevant to the basic discussion which follows.) Simultaneously, field teams were collecting ground information for a substantial portion of these segments. These data were combined to obtain both field and total segment ground truth data. The small grain proportion estimates were compared statistically to the LACIE estimates for the 16 segments in North Dakota. This resulted in a direct computation of the classification error, CV_C, for segments in the state of North Dakota, as listed in table 3-4.

This table indicates a relative difference of -18 percent between the average LACIE proportion and the average ground-observed proportion. This is not indicative of a significant bias in view of the standard error. However, the difference between the ground-observed proportions and the SRS county proportions is commensurate with the underestimate obtained in North Dakota. Thus, for North Dakota it was concluded that sampling error resulting from nonrepresentative sample segments was the major source of the observed bias. Other investigations with full frame imagery confirmed that agriculture is very heterogeneous in this region and many of the LACIE segments did not adequately represent their county.

TABLE 3-4.— LACIE BLIND SITE DATA

[North Dakota spring small grains]

County	Fraction of area in small grains, percent		
	Ground truth (5x6 n. mi. segment)	LACIE (5x6 n. mi. segment)	SRS county (entire county)
Ward 1	13.2	17.1	33.8
Ward 2	26.8	8.2	33.8
Williams	3.7	0.0	27.5
McHenry 1	0.0	0.0	25.9
McHenry 2	0.3	0.0	25.9
Rolette	4.9	---	18.8
Ramsey	38.4	49.5	41.5
McKenzie 1	1.3	---	10.6
McKenzie 2	1.0	0.3	10.6
Mclean	29.3	28.4	31.7
Mercer	16.3	18.0	19.9
Oliver	15.6	---	16.2
Kidder	16.4	---	19.4
Sheridan	12.9	0.0	30.9
Adams	26.1	24.4	22.8
Hettinger	21.7	24.1	35.7
Burleigh	18.2	12.0	20.7
Morton	4.6	6.7	15.7
Richland	31.6	15.6	36.2
Sargent	35.0	32.3	34.7
	17.46 LACIE 16	14.78	---
Average	15.87 ALL 20	---	26.00

Variance of LACIE estimates is within allowable range, CV = 50 percent.

No apparent bias in LACIE estimate.

$Y = a + bX$ $a = 6.08$ $b = .7685$ $s_b = .2336$

$H_0 (b=1)$ $t = \frac{1-.7685}{.2336} = \frac{.2315}{.2336} \approx 1$

$H_0 (\bar{d}_i = 0)$ $t = \frac{\bar{d}}{s_d} = \frac{2.68}{1.90} = 1.39$

3.3 RESULTS OF PHASE I

Phase I comparisons of LACIE wheat acreage estimates with ground truth indicated that the LACIE classification technology was working fairly well and may have been adequate to support the 90/90 criterion applied at the national level. However, a definitive answer to the question of whether the 90/90 criterion was satisfied at the national level would require an estiamte of the bias in the acreage estimate, which was not done in Phase I. The experience gained in Phase I was valuable in developing the system for Phase II. Several changes were made on the basis of this experience. In particular, more segments were allocated to North Dakota, and the classification procedures developed for the CAMS rework experiment became the basis for the Phase II CAMS operations.

4. PHASE II ACCURACY ASSESSMENT

In Phase II, LACIE produced operational estimates for acreage, yield, and production. Each of these is discussed below in a separate section.

4.1 ASSESSMENT OF PRODUCTION ESTIMATION

This section consists of three parts: an assessment of how well LACIE met the 90/90 criterion (section 4.1.1), a comparison of LACIE and USDA/SRS wheat production estimates (section 4.1.2), and an investigation of the contribution of the first-order error sources to the production CV (section 4.1.3)

4.1.1 THE 90/90 CRITERION

The LACIE accuracy goal for the USGP region is a 90/90 at-harvest criterion for wheat production. This specifies that for any given year the probability shall be at least 0.90 that the at-harvest wheat production estimate for the USGP will be within 10 percent of the true production.

Let $\hat{P}$ be the LACIE at-harvest estimate of wheat production for the USGP and let P be the true wheat production for the USGP. Then the 90/90 criterion may be expressed by the following probability statement:

$$\Pr[|\hat{P} - P| \leq 0.1P] \geq 0.90 \qquad (4\text{-}1)$$

It is reasonable to assume for large sample sizes that $\hat{P}$ is normally distributed with mean P + B and variance $\sigma^2_{\hat{P}}$, where B is the bias of the estimator, $\hat{P}$. Under this assumption, it is shown in appendix A that equation (4-1) is equivalent to

$$\Phi\left[\frac{0.1 - 1.1\frac{B}{P + B}}{CV(\hat{P})}\right] - \Phi\left[\frac{-0.1 - 0.9\frac{B}{P + B}}{CV(\hat{P})}\right] \geq 0.90 \qquad (4\text{-}2)$$

where Φ represents the cumulative standard normal distribution and $CV(\hat{P})$ is the coefficient of variation of the estimator, $\hat{P}$, defined by

$$CV(\hat{P}) = \frac{\sigma_{\hat{P}}}{E(\hat{P})} = \frac{\sigma_{\hat{P}}}{P + B} \qquad (4\text{-}3)$$

The term $\frac{B}{P + B}$ is called the relative bias of $\hat{P}$.

Inference as to whether the LACIE accuracy goal has been met is made by estimating $\frac{B}{P + B}$ and $CV(\hat{P})$ and then ascertaining whether equation (4-2) is satisfied. Now, $CV(\hat{P})$ is estimated by $\frac{\hat{\sigma}_{\hat{P}}}{\hat{P}}$ where $\hat{\sigma}_{\hat{P}}$ is an estimate of the standard deviation of $\hat{P}$, and $\hat{P}$ is an unbiased estimate of P + B. If the true wheat production for the USGP were known, then $\frac{B}{P + B}$ could be estimated simply by $\frac{\hat{P} - P}{\hat{P}}$. However, P is unknown so the relative bias in the production estimate is estimated using the method described in appendix A (section A.3.3.3). This leads to an estimate of -24.0 percent for the relative bias. The 90-percent confidence limits for the bias in the production estimate, expressed as a percentage of the LACIE production estimate, are given by (-32.0, -16.6).

From figure A-1 in appendix A it can be seen that if the relative bias is greater than +10.0 percent or less than -11.0 percent, then the 90/90 accuracy goal cannot be achieved for any value of the CV. Therefore, the estimate of -24.0 percent for the relative bias indicates that the 90/90 accuracy goal for the USGP has not been achieved.

It can be shown, however, that an accuracy goal of 90/75 is achievable with the present estimates of the relative bias and CV of the LACIE wheat production estimate for the USGP. That is, with an estimate of -24.0 percent for the relative bias and an estimate of 5.0 percent for $CV(\hat{P})$, the probability that the LACIE estimate is within ±25 percent of the true wheat production for the USGP is 0.9.

4.1.2 COMPARISON OF LACIE AND USDA/SRS PRODUCTION ESTIMATES

These comparisons are designed to monitor how well LACIE is performing relative to the USDA/SRS estimates, and also to detect any problems that may exist.

The LACIE and USDA/SRS production estimates are shown in figure 4-1 and table 4-1. In table 4-1, estimates are given for each state in the nine-state USGP region and for the following regions:

a. The USSGP region consisting of Colorado, Kansas, Nebraska, Oklahoma and Texas. These states have winter wheat only and therefore could also be called the "winter wheat states." LACIE estimates of wheat production are available for the USSGP from February through October.

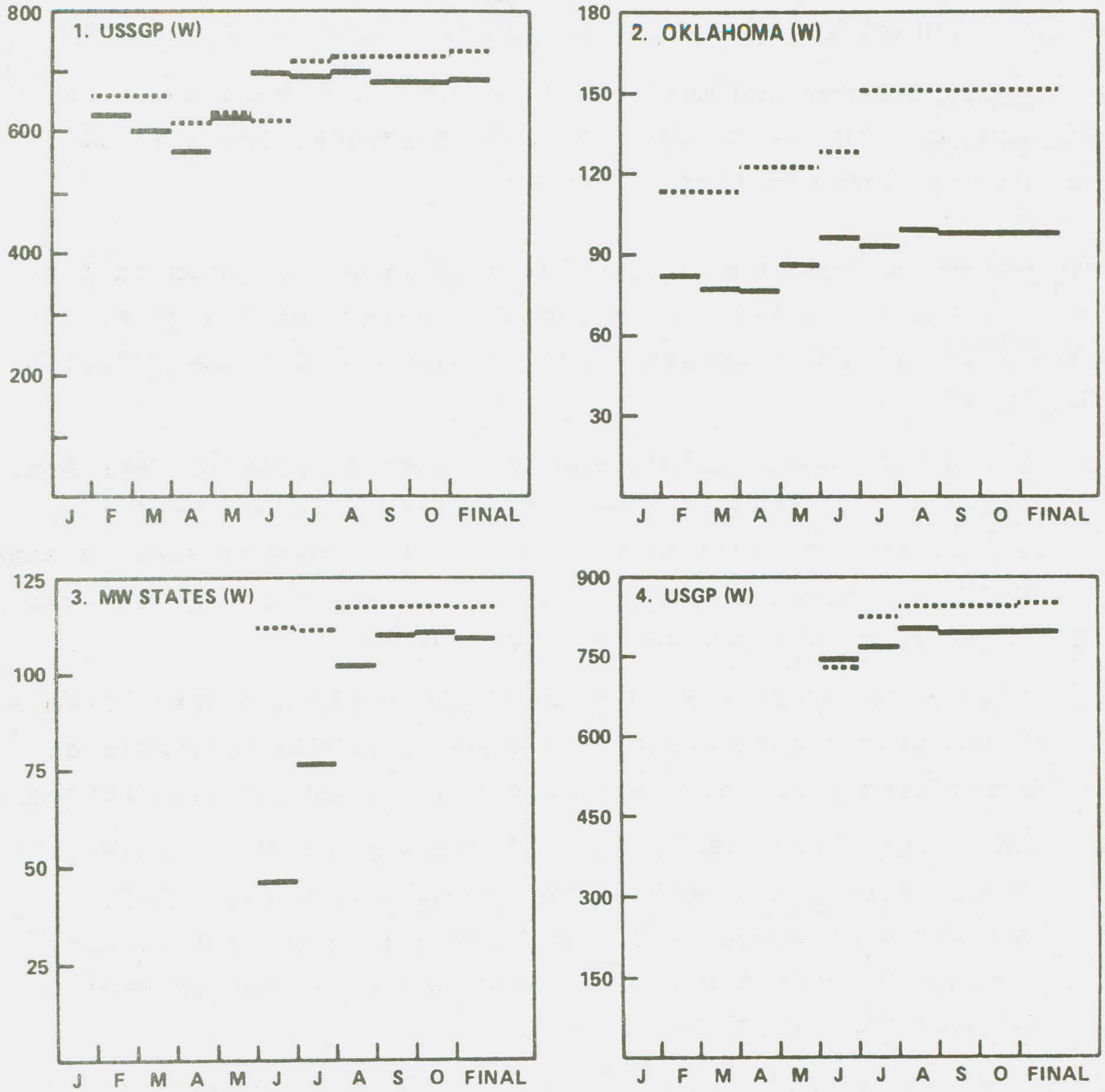
b. The spring wheat (SW) states of Minnesota and North Dakota. These states have spring wheat only. LACIE estimates of wheat production are available from August through October.

c. The mixed wheat (MW) states of Montana and South Dakota. These states have both spring and winter wheat. LACIE estimates of wheat production are available from August through October for spring wheat and from June through October for winter wheat.

d. The U.S. northern Great Plains (USNGP) region made up of the two spring wheat states and the two mixed wheat states.

e. The USGP region made up of the nine states of the USSGP and the USNGP.

In the following discussion winter wheat is considered first, followed by spring wheat, then total wheat (winter wheat plus spring wheat). Figure 4-1 and table 4-1 are arranged in this order.



LEGEND
LACIE
USDA/SRS
W = WINTER WHEAT
S = SPRING WHEAT
T = TOTAL WHEAT

Figure 4-1.– LACIE and USDA/SRS production estimates [bushels × 10^6].

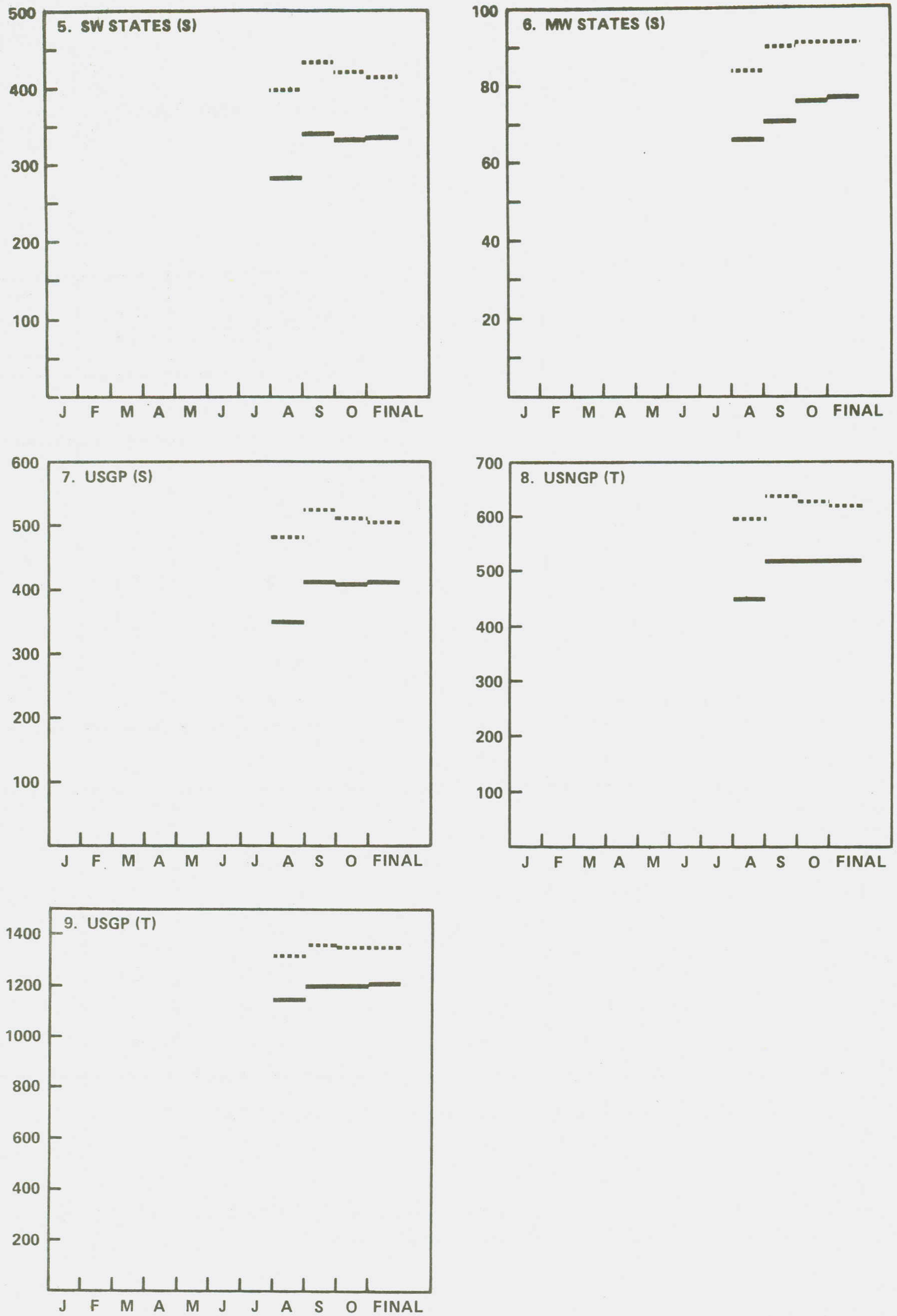


Figure 4-1.— Concluded.

TABLE 4-1.— COMPARISON OF USDA/SRS AND LACIE
PRODUCTION ESTIMATES
[Bushels × 10^3]

Region	USDA/SRS (a)	LACIE	Relative difference (%)	CV (%)	Test statistic
February					
Winter Wheat					
Colorado	48 110	76 418	37.0	33	
Kansas	327 500	258 074	-26.9	17	
Nebraska	92 200	151 762	39.2	23	
Oklahoma	113 250	80 264	-41.1	29	
Texas	75 600	59 550	-26.9	28	
[b]USSGP	656 660	626 068	- 4.9	11	-.45[N]
March					
Winter Wheat					
Colorado	48 110	60 759	20.8	32	
Kansas	327 500	269 638	-21.5	14	
Nebraska	92 200	124 342	25.8	19	
Oklahoma	113 250	76 041	-48.9	25	
Texas	75 600	66 676	-13.4	32	
[b]USSGP	656 660	597 456	- 9.9	10	-.90[N]

[a]The USDA/SRS estimates for February and March are the December 1, 1975 estimates.

[b]The five-state USSGP region.

[N]The LACIE estimate is not significantly different from the USDA/SRS estimate at the 10-percent level.

TABLE 4-1.— Continued.

Region	USDA/SRS	LACIE	Relative difference (%)	CV (%)	Test statistic
April					
Winter Wheat					
Colorado	42 840	56 089	23.6	32	
Kansas	286 000	255 147	-12.1	13	
Nebraska	95 200	118 458	19.6	19	
Oklahoma	121 800	74 823	-62.8	22	
Texas	66 300	59 559	-11.3	22	
USSGP	612 140	564 076	- 8.5	8	-1.06^N
May					
Winter Wheat					
Colorado	41 800	55 285	24.4	31	
Kansas	302 400	283 124	- 6.8	12	
Nebraska	94 400	110 496	14.6	19	
Oklahoma	121 800	84 699	-43.8	21	
Texas	70 200	86 910	19.2	17	
USSGP	630 600	620 514	- 1.6	8	-0.2^N

TABLE 4-1.– Continued.

Region	USDA/SRS	LACIE	Relative difference (%)	CV (%)	Test sta-tistics
		June			
Winter Wheat					
Colorado	41 800	61 191	31.7	28	
Kansas	279 500	326 677	14.4	11	
Nebraska	97 350	128 692	24.4	17	
Oklahoma	127 600	94 975	-34.4	17	
Texas	70 200	84 094	16.5	17	
USSGP	616 450	695 629	11.4	7	1.63*
Montana	90 600	13 527	-569.8	192	
S. Dakota	20 800	31 553	34.1	46	
[c]MW states	111 400	45 080	-147.1	63	
[d]USGP	727 850	740 709	1.7	8	.21[N]
		July			
Winter Wheat					
Colorado	48 400	51 492	6.0	30	
Kansas	321 900	334 107	3.7	11	
Nebraska	96 000	132 118	27.3	16	
Oklahoma	151 200	92 052	-64.3	18	
Texas	98 700	80 797	-22.2	17	
USSGP	716 200	690 566	- 3.7	7	.53[N]
Montana	93 620	30 082	-211.2	53	
S. Dakota	16 640	45 096	63.1	27	
MW states	110 260	75 178	-46.7	27	
USGP	826 460	765 744	- 7.9	7	-1.13[N]

*The LACIE estimate is significantly different from the USDA/SRS estimate at the 10-percent level.

[c]The mixed wheat states, Montana and South Dakota.

[d]The nine-state United States Great Plains region.

TABLE 4-1.— Continued.

Region	USDA/SRS	LACIE	Relative difference (%)	CV (%)	Test statistic
August					
Winter Wheat					
Colorado	48 400	50 024	3.2	29	
Kansas	327 450	338 078	3.1	10	
Nebraska	96 000	130 547	26.5	16	
Oklahoma	151 200	98 156	-54.0	18	
Texas	103 400	80 637	-28.2	18	
USSGP	726 450	697 442	-4.2	7	.60[N]
Montana	96 640	55 788	-73.2	36	
S. Dakota	19 760	45 096	56.2	26	
MW states	116 400	100 884	-15.4	23	
USGP	842 850	798 326	-5.6	7	-.80[N]
Spring Wheat					
Minnesota	122 518	55 490	-120.8	42	
N. Dakota	272 700	226 034	-20.6	17	
[e] SW states	395 218	281 524	-40.4	16	
Montana	63 095	29 188	-116.2	29	
S. Dakota	20 350	36 719	44.6	18	
MW states	83 409	65 907	-26.6	17	
USGP	478 663	347 431	-37.8	13	-2.91*
[f] Total Wheat					
Montana	159 735	84 976	-88.0	20	
S. Dakota	40 110	81 815	51.0	14	
MW states	199 845	166 791	-19.8	12	
[g] USNGP	595 063	448 315	-32.7	11	-2.97*
USGP	1 321 513	1 145 757	-15.3	6	-2.55*

[e] The spring wheat states, Minnesota and North Dakota.

[f] Spring wheat plus winter wheat.

[g] The four-state United States northern Great Plains region.

TABLE 4-1.– Continued.

Region	USDA/SRS	LACIE	Relative difference (%)	CV (%)	Test sta-tistic
September					
Winter Wheat					
Colorado	48 400	52 924	8.5	29	
Kansas	327 450	339 974	3.7	10	
Nebraska	96 00	110 972	13.5	16	
Oklahoma	151 200	96 491	-56.7	18	
Texas	103 400	81 312	-27.2	18	
USSGP	726 450	681 673	-6.6	7	$-.94^N$
Montana	96 640	62 877	-53.7	30	
S. Dakota	19 760	45 904	57.0	26	
MW states	116 400	108 781	-7.0	21	
USGP	842 850	790 454	-6.6	7	$-.94^N$
Spring Wheat					
Minnesota	130 256	77 230	-68.7	29	
N. Dakota	300 040	261 197	-14.9	12	
SW states	430 296	338 427	-27.1	11	
Montana	65 410	35 064	-86.5	25	
S. Dakota	24 300	35 908	32.3	19	
MW states	89 710	70 972	-26.4	15	
USGP	520 006	409 399	-27.0	10	-2.70*
Total Wheat					
Montana	162 050	97 941	-65.5	15	
S. Dakota	44 060	81 812	46.1	13	
MW states	206 110	179 753	-14.7	10	
USNGP	636 406	518 180	-22.8	10	-2.28*
USGP	1 362 856	1 199 853	-13.6	5	-2.72*

TABLE 4-1.– Continued.

Region	USDA/SRS	LACIE	Relative difference (%)	CV (%)	Test sta-tistic
October					
Winter Wheat					
Colorado	48 400	52 924	8.5	29	
Kansas	327 450	339 974	3.7	10	
Nebraska	96 000	110 972	13.5	16	
Oklahoma	151 200	96 491	-56.7	18	
Texas	103 400	81 312	-27.2	18	
USSGP	726 450	681 673	-6.6	7	$-.94^{N}$
Montana	96 640	63 758	-51.6	29	
S. Dakota	19 760	45 904	57.0	26	
MW states	116 400	109 662	-6.1	20	
USGP	842 850	791 335	-6.5	7	$-.94^{N}$
Spring Wheat					
Minnesota	126 344	66 589	-89.7	32	
N. Dakota	290 320	263 703	-10.1	12	
SW states	416 664	330 292	-26.2	11	
Montana	66 658	40 240	-65.7	25.	
S. Dakota	24 300	35 675	31.9	18	
MW states	90 958	75 915	-19.8	.16	
USGP	507 532	406 207	-24.9	10	-2.49*
Total Wheat					
Montana	163 208	103 998	-56.9	13	
S. Dakota	44 060	81 579	46.0	13	
MW states	207 268	185 577	-11.7	9	
USNGP	623 932	515 869	-20.9	8	-2.61*
USGP	1 350 382	1 197 542	-12.8	5	-2.56*

TABLE 4-1.— Concluded.

Region	USDA/SRS	LACIE	Relative difference (%)	CV (%)	Test statistic
Final					
Winter Wheat					
Colorado	47 300	52 924	10.6	29	
Kansas	339 000	344 472	1.6	10	
Nebraska	94 400	110 972	14.9	16	
Oklahoma	151 200	96 491	-56.7	18	
Texas	103 400	81 312	-27.2	18	
USSGP	735 300	686 171	-7.2	7	-1.03^N
Montana	98 560	62 167	-58.5	30	
S. Dakota	17 460	45 904	62.0	26	
MW states	116 020	108 071	-7.4	20	
USGP	851 320	794 242	-7.2	7	-1.03^N
Spring Wheat					
Minnesota	126 244	66 589	-89.6	32	
N. Dakota	284 050	266 529	-6.6	12	
SW states	410 294	333 118	-23.2	11	
Montana	68 735	41 058	-67.4	24	
S. Dakota	22 060	35 675	38.2	18	
MW states	90 795	76 733	-18.3	15	
USGP	501 089	409 851	-22.3	10	-2.23*
Total Wheat					
Montana	167 295	103 225	-62.1	13	
S. Dakota	39 520	81 579	51.6	13	
MW states	206 815	184 804	-11.9	9	
USNGP	617 109	517 922	-19.2	8	-2.40*
USGP	1 352 409	1 204 093	-12.3	5	-2.46*

The CV's in table 4-1 were computed by the methods described in appendix A (section A.3.3.2). For the major regions, a significance test was performed to determine if the LACIE estimate was significantly different from the USDA/SRS estimate. The test statistic is given in the last column of table 4-1 and the method is described in appendix A (section A.2).

Winter Wheat

Plots 1 through 4 in figure 4-1 show the estimates for winter wheat. Plot 1 shows that the LACIE estimates for the USSGP region were lower than the USDA/SRS estimates for every month except June; they were lower than the USDA/SRS final estimate for every month including June. The LACIE estimate was particularly low in April, due mainly to low acreage estimates in Kansas, Oklahoma and Texas, which were affected by drought (see section 4.2.2.1). However, the LACIE estimate improved considerably in May and again in June. The June LACIE estimate was considerably better than the June USDA/SRS estimate relative to the final USDA/SRS estimate. The final LACIE estimate had a relative difference of -7.2 percent. The significance test showed that the LACIE estimate was not significantly different from the USDA/SRS estimate for any month except June. In this case it was the USDA/SRS estimate that was low (relative to the final USDA/SRS estimate).

The most serious problem in the USSGP region was in Oklahoma (plot 2), where the wheat production was consistently underestimated throughout the season due to underestimates of wheat acreage. Also, Montana was underestimated by a wide margin, primarily due to underestimation of acreage, and South Dakota was overestimated by a wide margin due to overestimation of both acreage and yield.

The production estimates for winter wheat in the two mixed wheat states are shown in plot 3. They were very low in June but increased throughout the season and had a relative difference of -7.4 percent for the final estimate.

Plot 4 shows the estimates for the total winter wheat in the USGP region. The relative difference for the final estimate was -7.2 percent. The LACIE estimate was not significantly different from the USDA/SRS estimate for any month or for the final estimate.

Spring Wheat

Plots 5 through 7 show the estimates for spring wheat production. The LACIE estimates were consistently low in the spring wheat states, the mixed wheat states, and the overall USNGP. The significance tests show that the LACIE estimates for the USNGP region were significantly different from the USDA/SRS estimate for every month and for the final estimate. These underestimates in production were due to underestimates of spring wheat acreage, since the yields were overestimated by LACIE except in September when they were slightly less than the USDA/SRS estimate. (See plot 7 in figure 4-2.) This tendency to underestimate spring wheat acreage is discussed further in section 4.2.2.2. Looking at the individual states, the largest underestimates occurred in Minnesota and Montana. In both cases the problem was primarily due to underestimates in acreage. In South Dakota there was a large overestimate due to overestimation of the yield.

Total Wheat

Plot 8 shows the total wheat in the four-state USNGP region. It was consistently underestimated and the LACIE estimate was significantly different from the USDA/SRS estimate for every month and for the final estimate.

The wheat production estimates for the nine-state USGP region are shown in plot 9. The LACIE estimate was consistently low. The final estimate had a relative difference of -12.3 percent due to an underestimate of 57×10^6 bushels (relative difference -7.2 percent) in the winter wheat crop and an underestimate of 91×10^6 bushels (relative difference -22.3 percent) in the spring wheat crop. The LACIE estimate was significantly different from the USDA/SRS estimate for every month and for the final estimate.

4.1.3 FIRST-ORDER PRODUCTION ERROR COMPONENTS

The first-order production error components consist of yield prediction error and acreage estimation error. Acreage estimation error is further subdivided into sampling error and classification error. The effect of each error component on production is assessed by determining the reduction in the estimate for the CV of production when this error component is set equal to zero. Details of the method employed are given in appendix A (section A.3.3.5).

Table 4-2 shows the results for the CV's of the Phase II final estimates when acreage and yield errors are omitted. It will be seen that omitting the yield error leads to larger reductions in

TABLE 4-2.— REDUCTIONS IN THE PRODUCTION CV CAUSED BY OMITTING VARIOUS ERRORS

Region	Total CV, %	Acreage error omitted		Yield error omitted		Classification error omitted		Sampling error omitted	
		CV, %	Reduction, %	CV, %	Reduction, %	CV, %	Reduction, %	CV, %	Reduction, %
Winter Wheat									
USSGP	7.0	5.3	24.3	4.5	35.7	6.5	7.1	5.9	15.7
Spring Wheat									
USNGP	10.0	7.5	25.0	6.3	37.0				
Total Wheat									
USGP	5.2	4.4	15.4	3.7	28.8				

the CV for all three regions listed. This indicates that the yield error has a more dominant effect than the acreage error on the production CV.

Table 4-2 also shows the results when sampling and classification errors are omitted. The estimates of classification and sampling errors are presented in section 4.2.3. The spring wheat regions were not included due to the small number of blind sites available for estimating these errors. The results indicate that sampling contributes slightly more error than classification to the production error. However, it is reasonable to believe that the sampling and classification errors contribute about equally to the production error, since the difference between the two fracational reduction rates is rather small and may well be statistically insignificant.

4.2 ASSESSMENT OF ACREAGE ESTIMATION

This section contains three major subsections: a comparison of LACIE and USDA/SRS wheat acreage estimates (section 4.2.1), a discussion of classification error (section 4.2.2), and a discussion of the variance of sampling and classification error (section 4.2.3).

4.2.1 COMPARISON OF LACIE AND USDA/SRS ACREAGE ESTIMATES

The USDA/SRS and LACIE acreage estimates are shown in figure 4-2 and table 4-3. These are in the same format as table 4-1 and figure 4-1 except that the estimates are for acreage rather than production.

Winter Wheat

Plots 1 through 4 in figure 4-2 show the acreage estimates for winter wheat.

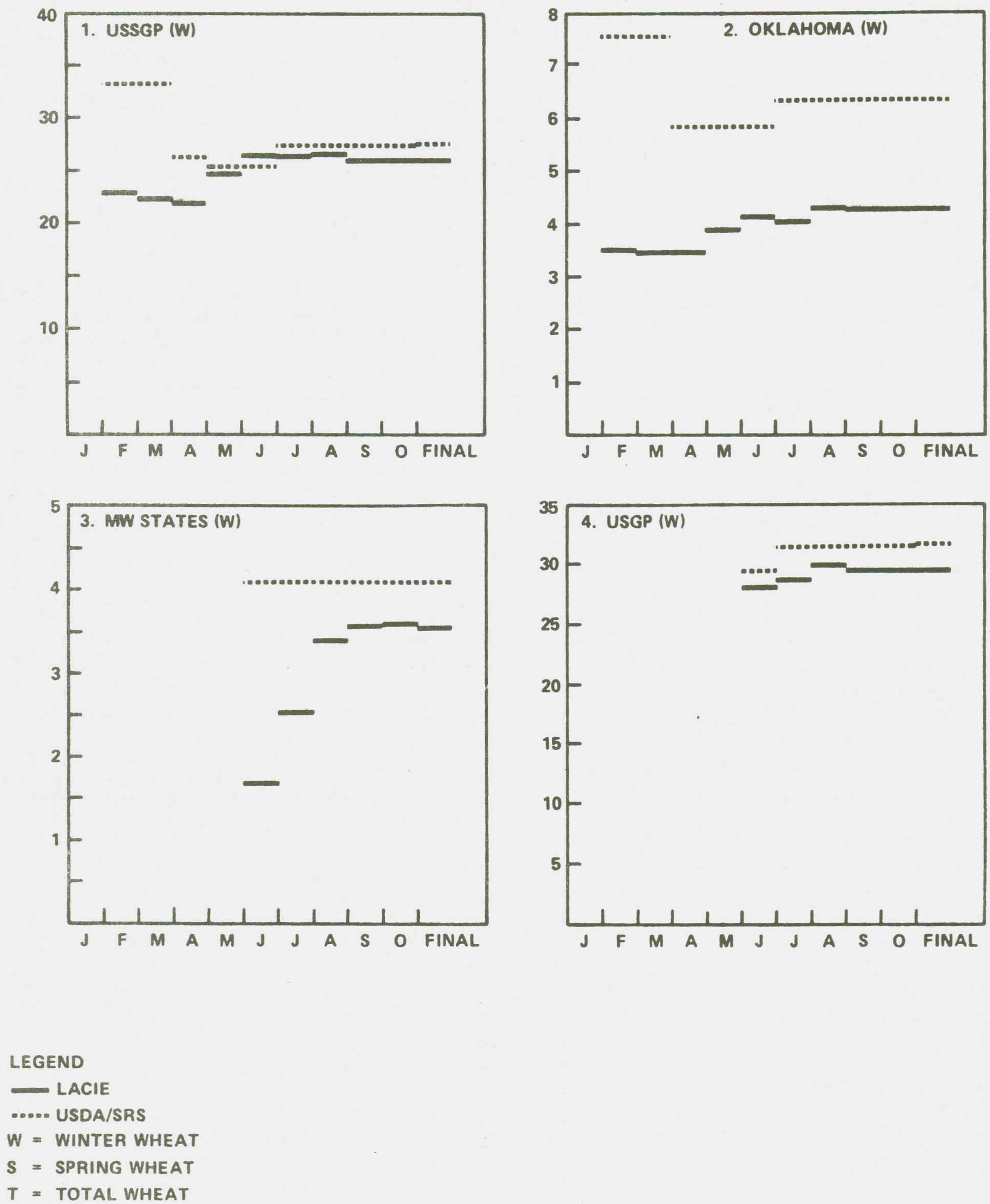


Figure 4-2.— LACIE and USDA/SRS acreage estimates [acres × 10^6].

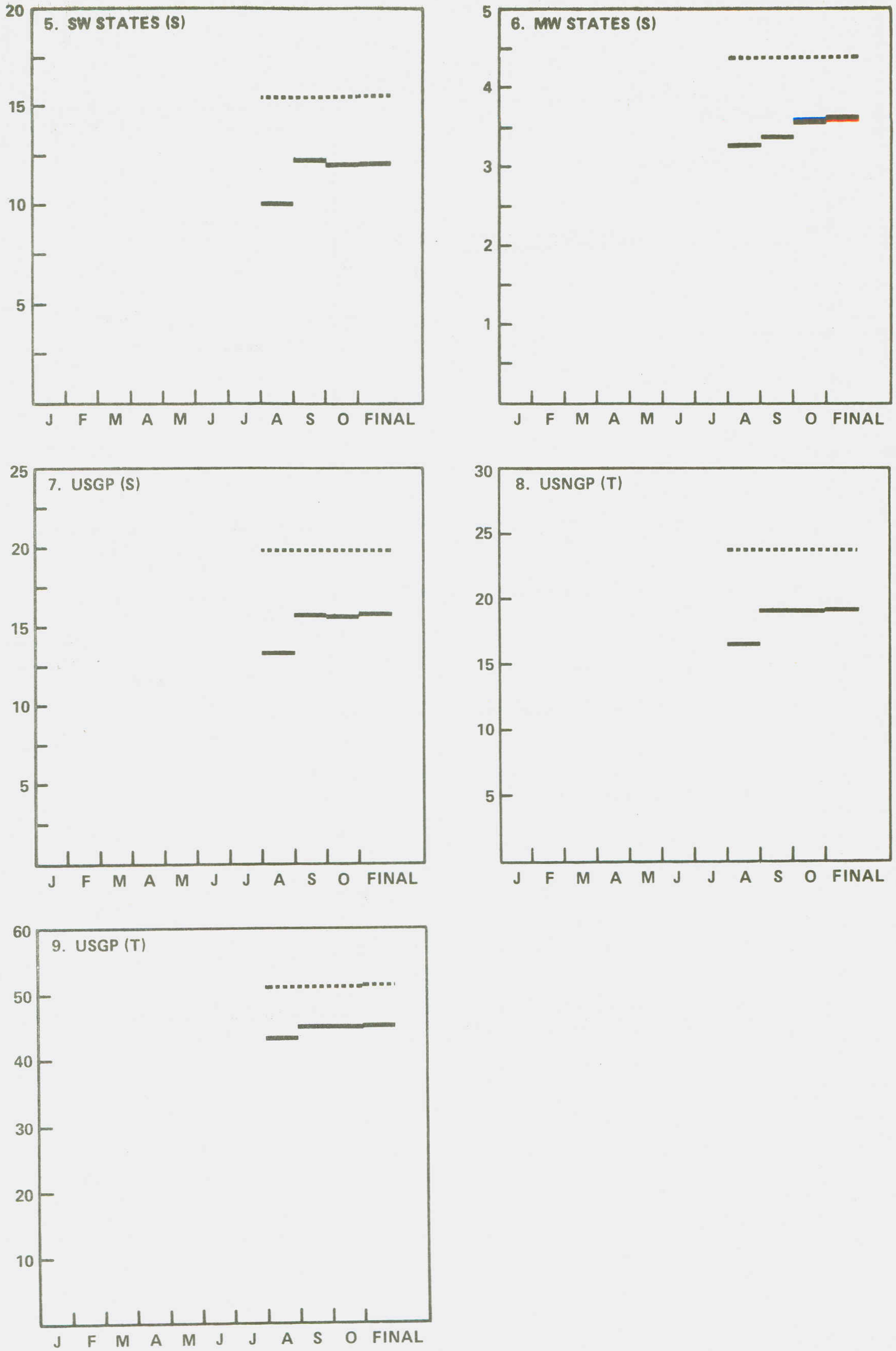


Figure 4-2.— Concluded.

TABLE 4-3.— COMPARISON OF USDA/SRS AND LACIE ACREAGE ESTIMATES

[Acres × 10^3]

Region	n/M (a)	USDA/ SRS (b)	LACIE	Relative difference (%)	CV (%)	Test sta- tistic
February						
Winter Wheat						
Colorado	13/32	2 830	3 539	20.0	26	
Kansas	43/84	13 100	8 013	-63.5	12	
Nebraska	13/35	3 400	4 500	24.4	18	
Oklahoma	30/40	7 550	3 499	-90.0	24	
Texas	31/49	6 300	3 170	-98.7	25	
USSGP	130/240	33 180	22 721	-46.0	9	-5.11*
March						
Winter Wheat						
Colorado	25/32	2 830	2 768	-2.2	25	
Kansas	61/84	13 100	8 536	-53.5	8	
Nebraska	21/35	3 400	3 632	6.4	13	
Oklahoma	36/40	7 550	3 450	-118.8	18	
Texas	42/49	6 300	3 725	-69.1	30	
USSGP	185/240	33 180	22 111	-50.1	8	-6.26*

[a] n is the number of segments used; M is the number of segments allocated.

[b] The USDA/SRS estimates for February and March are the December, 1975, estimates of seeded acreage.

*The LACIE estimate is significantly different from the USDA/SRS estimate at the 10-percent level.

TABLE 4-3.– Continued.

Region	n/M (a)	USDA/ SRS	LACIE	Relative difference (%)	CV (%)	Test sta- tistic
April						
Winter Wheat						
Colorado	25/32	2 040	2 768	26.3	25	
Kansas	62/84	11 000	8 536	-28.9	8	
Nebraska	22/35	3 400	3 583	5.1	13	
Oklahoma	36/40	5 800	3 450	-68.1	18	
Texas	44/49	3 900	3 479	-12.1	20	
[c]USSGP	189/240	26 140	21 816	-19.8	7	-2.82*
May						
Winter Wheat						
Colorado	26/32	1 900	2 807	32.3	24	
Kansas	70/84	10 800	9 392	-15.0	6	
Nebraska	27/35	2 950	3 653	19.2	13	
Oklahoma	38/40	5 800	3 897	-48.8	16	
Texas	47/49	3 900	4 810	18.9	14	
[c]USSGP	208/240	25 350	24 559	-3.2	6	-.53[N]

[a]n is the number of segments used; M is the number of segments allocated.

[c]The five-state U.S. southern Great Plains region.

[N]The LACIE estimate is not significantly different from the USDA/SRS estimate at the 10-percent level.

*The LACIE estimate is significantly different from the USDA/SRS estimate at the 10-percent level.

TABLE 4-3.— Continued.

Region	n/M (a)	USDA/ SRS	LACIE	Relative difference (%)	CV (%)	Test sta- tistic
June						
Winter Wheat						
Colorado	26/32	1 900	2 995	36.6	23	
Kansas	75/84	10 750	10 535	-2.0	6	
Nebraska	30/35	2 950	4 104	28.1	12	
Oklahoma	38/40	5 300	4 148	-39.8	14	
Texas	47/49	3 900	4 556	14.4	15	
USSGP	216/240	25 300	26 338	3.9	5	-.78[N]
Montana	10/38	3 020	488	-518.9	193	
S. Dakota	8/10	1 040	1 159	10.3	43	
[d]MW states	18/48	4 060	1 647	-146.5	65	
[e]USGP	234/288	29 360	27 985	-4.9	6	-.81[N]
July						
Winter Wheat						
Colorado	30/32	2 200	2 867	23.3	25	
Kansas	78/84	11 100	10 795	-2.8	6	
Nebraska	32/35	3 000	4 133	27.4	11	
Oklahoma	40/40	6 300	4 025	-56.5	15	
Texas	47/49	4 700	4 314	-8.9	15	
USSGP	227/240	27 300	26 134	-4.5	5	-.09[N]
Montana	21/38	3 020	1 044	-189.3	52	
S. Dakota	9/10	1 040	1 482	29.8	23	
MW states	30/48	4 060	2 526	-60.7	25	
USGP	257/288	31 360	28 660	-9.4	5	-1.88*

[a]n is the number of segments used; M is the number of segments allocated.

[d]The mixed wheat states, Montana and South Dakota.

[e]The nine-state U.S. Great Plains region.

[N]The LACIE estimate is not significantly different from the USDA/SRS estimate at the 10-percent level.

*The LACIE estimate is significantly different from the USDA/SRS estimate at the 10-percent level.

TABLE 4-3.– Continued.

Region	n/M (a)	USDA/ SRS	LACIE	Relative difference (%)	CV (%)	Test statistic
August						
Winter Wheat						
Colorado	31/32	2 200	2 830	22.3	24	
Kansas	78/84	11 100	10 932	-1.5	5	
Nebraska	32/35	3 000	4 086	26.6	11	
Oklahoma	40/40	6 300	4 305	-46.3	15	
Texas	47/49	4 700	4 310	-9.0	16	
USSGP	228/240	27 300	26 463	-3.2	5	-.64[N]
Montana	22/38	3 020	1 911	-58.0	35	
S. Dakota	9/10	1 040	1 482	29.8	23	
MW states	31/48	4 060	3 393	-19.7	22	
USGP	259/288	31 360	29 856	-5.0	5	-1.00[N]
Spring Wheat						
Minnesota	10/13	3 826	1 741	-119.8	40	
N. Dakota	31/85	11 540	8 161	-41.4	14	
[f] SW states	41/98	15 366	9 902	-55.2	13	
Montana	14/22	2 315	1 127	-105.4	28	
S. Dakota	14/23	2 050	2 169	5.5	12	
MW states	28/45	4 365	3 296	-32.4	12	
USGP	69/143	19 731	13 198	-49.5	10	-4.95*
[g]Total Wheat						
Montana	36/60	5 335	3 038	-75.6	19	
S. Dakota	23/33	3 090	3 651	15.4	13	
MW states	59/93	8 425	6 689	-26.0	11	
[h] USNGP	100/191	23 791	16 591	-43.4	9	-4.82*
USGP	328/431	51 091	43 054	-18.7	5	-3.74*

[a]n is the segment used; M is the number of segments allocated.

[f]The spring wheat states, Minnesota and North Dakota.

[g]Spring wheat plus winter wheat.

[h]The four-state U.S. northern Great Plains region.

[N]The LACIE estimate is not significantly different from the USDA/SRS estimate at the 10-percent level.

*The LACIE estimate is significantly different from the USDA/SRS estimate at the 10-percent level.

TABLE 4-3.— Continued.

Region	n/M (a)	USDA/ SRS	LACIE	Relative difference (%)	CV (%)	Test sta- tistic
September						
Winter Wheat						
Colorado	32/32	2 200	2 704	18.6	24	
Kansas	81/84	11 100	10 989	-1.0	5	
Nebraska	33/35	3 000	3 399	11.7	11	
Oklahoma	40/40	6 300	4 261	-47.9	14	
Texas	47/49	4 700	4 344	-8.2	16	
USSGP	233/240	27 300	25 697	-6.2	5	-.39[N]
Montana	35/38	3 020	2 103	-43.6	29	
S. Dakota	9/10	1 040	1 452	28.4	23	
MW states	44/48	4 060	3 555	-14.2	20	
USGP	277/288	31 360	29 252	-7.2	5	-1.44[N]
Spring Wheat						
Minnesota	10/13	3 826	2 551	-50.0	27	
N. Dakota	67/85	11 540	9 650	-19.6	5	
SW states	77/98	15 366	12 201	-25.9	7	
Montana	19/22	2 315	1 291	-79.3	23	
S. Dakota	18/23	2 050	2 095	2.1	13	
MW states	37/45	4 365	3 386	-28.9	12	
USGP	114/143	19 731	15 587	-26.6	6	-4.43*
Total Wheat						
Montana	54/60	5 335	3 394	-57.2	14	
S. Dakota	27/33	3 090	3 547	12.9	12	
MW states	81/93	8 425	6 941	-21.4	9	
USNGP	158/191	23 791	19 142	-24.3	6	-4.05*
USGP	391/431	51 091	44 839	-13.9	4	-3.48*

[a] n is the segment used; M is the number of segments allocated.

[N] The LACIE estimate is not significantly different from the USDA/SRS estimate at the 10-percent level.

[*] The LACIE estimate is significantly different from the USDA/SRS estimate at the 10-percent level.

TABLE 4-3.– Continued.

Region	n/M (a)	USDA/ SRS	LACIE	Relative difference (%)	CV (%)	Test sta- tistic
October						
Winter Wheat						
Colorado	32/32	2 200	2 704	18.6	24	
Kansas	81/84	11 100	10 989	-1.0	5	
Nebraska	33/35	3 000	3 399	11.7	11	
Oklahoma	40/40	6 300	4 261	-47.9	14	
Texas	47/49	4 700	4 344	-8.2	16	
USSGP	233/240	27 300	25 697	-6.2	5	-1.24[N]
Montana	36/38	3 020	2 131	-41.7	28	
S. Dakota	9/10	1 040	1 452	28.4	23	
MW states	45/48	4 060	3 583	-13.3	19	
USGP	278/288	31 360	29 280	-7.1	5	-1.42[N]
Spring Wheat						
Minnesota	11/13	3 826	2 198	-74.1	30	
N. Dakota	79/85	11 540	9 735	-18.5	5	
SW states	90/98	15 366	11 933	-28.8	7	
Montana	20/22	2 315	1 487	-55.7	24	
S. Dakota	19/23	2 050	2 079	1.4	13	
MW states	39/45	4 365	3 566	-22.4	12	
USGP	129/143	19 731	15 499	-27.3	6	-4.55*
Total Wheat						
Montana	56/60	5 335	3 618	-47.5	12	
S. Dakota	28/33	3 090	3 531	12.5	12	
MW states	84/93	8 425	7 149	-17.8	8	
USNGP	174/191	23 791	19 082	-24.7	5	-4.94*
USGP	407/431	51 091	44 779	-14.1	4	-3.53*

[a]n is the segment used; M is the number of segments allocated.

[N]The LACIE estimate is not significantly different from the USDA/SRS estimate at the 10-percent level.

*The LACIE estimate is significantly different from the USDA/SRS estimate at the 10-percent level.

TABLE 4-3.— Concluded.

Region	n/M (a)	USDA/ SRS	LACIE	Relative difference (%)	CV (%)	Test sta- tistic
Final						
Winter Wheat						
Colorado	30/32	2 200	2 704	18.6	24	
Kansas	81/84	11 300	11 125	-1.6	5	
Nebraska	33/35	2 950	3 399	13.2	11	
Oklahoma	40/40	6 300	4 261	-47.9	14	
Texas	47/49	4 700	4 344	-8.2	16	
USSGP	233/240	27 450	25 833	-6.3	5	-1.26[N]
Montana	36/38	3 080	2 079	-48.1	28	
S. Dakota	9/10	970	2 452	33.2	23	
MW states	45/48	4 050	3 531	-14.7	19	
USGP	278/288	31 500	29 364	-7.3	5	-1.46[N]
Spring Wheat						
Minnesota	11/13	3 893	2 198	-77.1	30	
N. Dakota	79/85	11 520	9 856	-16.9	5	
SW states	90/98	15 413	12 054	-27.9	7	
Montana	20/22	2 335	1 516	-54.0	22	
S. Dakota	19/23	2 020	2 079	2.8	13	
MW states	39/45	4 355	3 595	-21.1	12	
USGP	129/143	19 768	15 649	-26.3	6	-4.38*
Total Wheat						
Montana	56/60	5 415	3 595	-50.6	12	
S. Dakota	28/33	2 990	3 531	15.3	12	
MW states	84/93	8 405	7 126	-17.9	8	
USNGP	174/191	23 818	19 180	-24.2	5	-4.84*
USGP	407/431	51 268	45 013	-13.9	4	-3.48*

[a] n is the segment used; M is the number of segments allocated.

[N] The LACIE estimate is not significantly different from the USDA/SRS estimate at the 10-percent level.

* The LACIE estimate is significantly different from the USDA/SRS estimate at the 10-percent level.

Plot 1 shows that the LACIE estimates for the USSGP region were lower than the USDA/SRS estimates for every month except June.

The statistical tests showed that the LACIE estimates for February, March, and April were significantly different from the corresponding USDA/SRS estimates. These lower estimates are expected early in the season, because a significant number of wheat fields have not yet "greened up" enough to have a characteristic wheat signautre. In 1976 this effect was especially apparent in Kansas, Oklahoma, and Texas because these states were affected by drought. In May and June, the LACIE estimate for the USSGP improved and was not significantly different from the USDA/SRS estimate from May through the final estimate. In June, it was closer to the final USDA/SRS estimate (which held from July on) than the June USDA/SRS estimate. The final LACIE estimate had a relative difference of -6.3 percent and a CV of 5 percent.

The most serious problem in the USSGP region was the underestimates for Oklahoma, shown in plot 2. Blind site investigations (section 4.2.2) indicate that the major source of the underestimate in Oklahoma was due to analyst-mislabeled fields resulting from early dry conditions and an unusual wheat growth cycle following spring rains. In the latter case, the wheat was late in greening up and had signatures that were quite different from normal wheat. In fact, comparisons of LACIE blind site ground observations, aircraft photography and analyst labels on a field-by-field basis indicated that the analysts rarely misidentified nonwheat fields as wheat, but the underestimate resulted primarily from labeling wheat fields as nonwheat.

The winter wheat acreage estimates for the two mixed wheat states are shown in plot 3. These estimates were very low in June but increased throughout the season. The relative difference for the final estimate was -14.7 percent.

Plot 4 shows the total USGP winter wheat estimates. The final estimate had a relative difference of -7.3 percent. July was the only month for which the LACIE estimate was significantly different from the USDA/SRS estimate.

Spring Wheat

Plot 5 shows the spring wheat in the spring wheat states, Minnesota and North Dakota. There was consistent underestimation by LACIE but there was a considerable improvement in September. Part of this was due to a change in the ratios of wheat to small grains that were used to calculate the wheat acreage. For spring wheat, CAMS normally determines only small grains proportions, and the wheat proportions are then calculated by multiplying these by the historical wheat-to-small-grains ratios for the county in which the segment is located. A change in these ratios accounted for 48 percent of the improvement in North Dakota and 53 percent of the improvement in Minnesota. In North Dakota a further 36 percent of the improvement was due to the addition of 21 new segments. These new segments were added to North Dakota to correct a sampling problem identified during Phase I. It is also expected that there was a undersampling problem in Minnesota, since the acreage has increased from 829 000 acres in 1969 (the year that was used for the sampling allocation) to 2 844 000 acres in 1976. Blind site investigations (section 4.2.2.2) indicated a number of causes for the underestimate in North Dakota, including strip fallow areas, weak or missing signatures, and poor acquisition histories.

Plot 6 shows the spring wheat estimates for the two mixed wheat states, Montana and South Dakota. They show consistently low estimates in the total, but the estimates improved as the season progressed. The improvement was due partly to improved spring-wheat-to-small-grains ratios. The final spring wheat estimate for the mixed wheat states had a relative difference of

-21.1 percent. The results presented in table 4-3 show that there was an underestimation problem in Montana, where the relative difference for the final estimate was 54.0 percent. Investigations (section 4.2.2.2) indicated that this was due largely to underestimates of wheat proportions in strip fallow areas, which did not classify well.

The monthly estimates for the total spring wheat in the USGP region are shown in plot 7. The LACIE estimates were consistently low and were significantly different from the USDA/SRS estimates for every month and for the final estimate. Of the four states contributing to the total spring wheat estimate, only for one, South Dakota, was the spring wheat acreage not consistently underestimated. This indicates a serious underestimation problem for spring wheat. In addition to the reasons given above, blind site studies discussed in section 4.2.2.2 indicate that this underestimation was also due to errors in the ratios of wheat to small grains that were used to calculate the wheat acreage.

Total Wheat

Plot 8 shows the total wheat in the four-state USNGP. It was consistently underestimated and was significantly different from the USDA/SRS estimate for every month and for the final estimate. The final estimate had a relative difference of -24.2 percent due to underestimates of spring wheat in Montana, Minnesota, and North Dakota, and of winter wheat in Montana.

Plot 9 shows the total wheat in the nine-state USGP region. The LACIE estimate was consistently low and was significantly different from the USDA/SRS estimate for every month and for the final estimate. The final estimate had a relative difference of -13.9 percent due to an underestimate of 2.2×10^6 acres (relative difference -7.3 percent) in the winter wheat acreage and an underestimate of 4.1×10^6 acres (relative difference of -26.3 percent) in the spring wheat acreage.

4.2.2 INVESTIGATIONS OF CLASSIFICATION ERROR

Blind site investigations for winter and spring wheat are discussed separately in this report. Refer to section 4.2.2.1 for discussion of winter wheat investigations and 4.2.2.2 for spring wheat investigations.

4.2.2.1 Winter Wheat Blind Site Investigations

The winter wheat blind site investigation consisted of two parts: (1) an early-season investigation for April, and (2) a late-season investigation for October. A different set of blind sites was used in each investigation and each is described separately in the following paragraphs.

Early Season Investigation

The LACIE Phase II examination of early season acreage estimation involved evaluations of acquisitions acquired after emergence and through February; these acquisitions were classified by the CAMS and passed to CAS. Forty blind sites were selected randomly from these acquisitions, and aircraft photography was obtained. Field overlays were prepared and then used by the USDA/ASCS to acquire ground truth land-use information. Classification and ground truth data were obtained for 29 of the 40 blind sites and for 6 intensive test sites. This was the basic data set used in the early season acreage estimation evaluations, the results of which are reported in table 4-4.

A review of table 4-4 shows that the average of LACIE estimates over the 35 sites in the five states of the USSGP was less (-9.17 percent) than the average of ground-observed proportions in these states. More detailed investigations were then

TABLE 4-4.– ESTIMATES OF EARLY SEASON SMALL-GRAIN PERCENTAGES FOR 29 BLIND SITES AND 6 INTENSIVE TEST SITES IN THE USSGP

Region	Number of segments	$\hat{\bar{X}}$, %	$\bar{X}$, %	$\hat{\bar{X}} - \bar{X}$, %
Colorado	2	2.30	10.15	-7.85
Kansas	14	22.50	29.80	-7.30
Texas	10	9.80	19.58	-9.78
Nebraska	3	13.43	21.76	-8.33
Oklahoma	6	21.48	35.06	-13.58
Overall 5-state	35	16.50	25.97	-9.17

conducted over a subset (20) of the blind sites, where comparisons of analyzed Landsat and aircraft imagery could be made. These assessments showed:

a. Visual interpretations of Landsat and aircraft color infrared signatures were very similar when acquisition dates were within 10 days of each other.

b. Overall, many wheat fields had little if any wheat signatures (pink) on either the aircraft or Landsat color infrared products, indicating that thin stands of wheat were not being detected.

c. Many reasons for thin (undetectable) wheat stands were identified – most stemming from drought effects; e.g.,

- Eight of the twenty segments showed drought effects.
- Six of the twenty segments were damaged by mosaic virus, army worms, or greenbugs.
- Heavy grazing of cattle was also identified as a cause, inasmuch as it is a common practice in some areas until mid-March, regardless of drought conditions.

The drought effects were studied further over a representative intensive test site (ITS) in the fall drought area (Rice County, Kansas). Acquisitions and classifications over this site showed no significant change until after favorable weather occurred in the spring (March). At that time, a significant improvement in detectable wheat signatures was noted, and the LACIE estimates began to approach ground truth estimates ($\hat{X}$ = 47 percent wheat, X = 50 percent wheat).

Late Season Investigation

The early investigation was conducted with only 30 blind sites, because when those studies were begun, ground truth data were available for only a limited number of blind sites. However, by October, the data had been obtained for many more blind sites in the five-state winter wheat region. As a result, a new investigation was performed using 103 blind sites and the CAMS classification results for these blind sites corresponding to the October LACIE estimates. The results are shown in figure 4-3 and tables 4-5 and 4-6.

Figure 4-3 shows plots of the proportion error $\hat{X} - X$ as a function of X where $\hat{X}$ is the CAMS wheat proportion estimate and X is the ground truth wheat proportion. These plots are for the five individual states and the total USSGP five-state region. Points lying above the horizontal line $\hat{X} - X = 0$ correspond to overestimation of wheat proportions by CAMS, and points lying below the line correspond to underestimation.

The plots in figure 4-3 indicate that there is an overall trend toward negative values of $\hat{X} - X$ as X increases for the five-state region and for each of the individual states except Colorado. In other words, for these regions, CAMS tends to underestimate the true wheat proportion when the true wheat proportion is large. In fact, for X > 28 percent, there is only

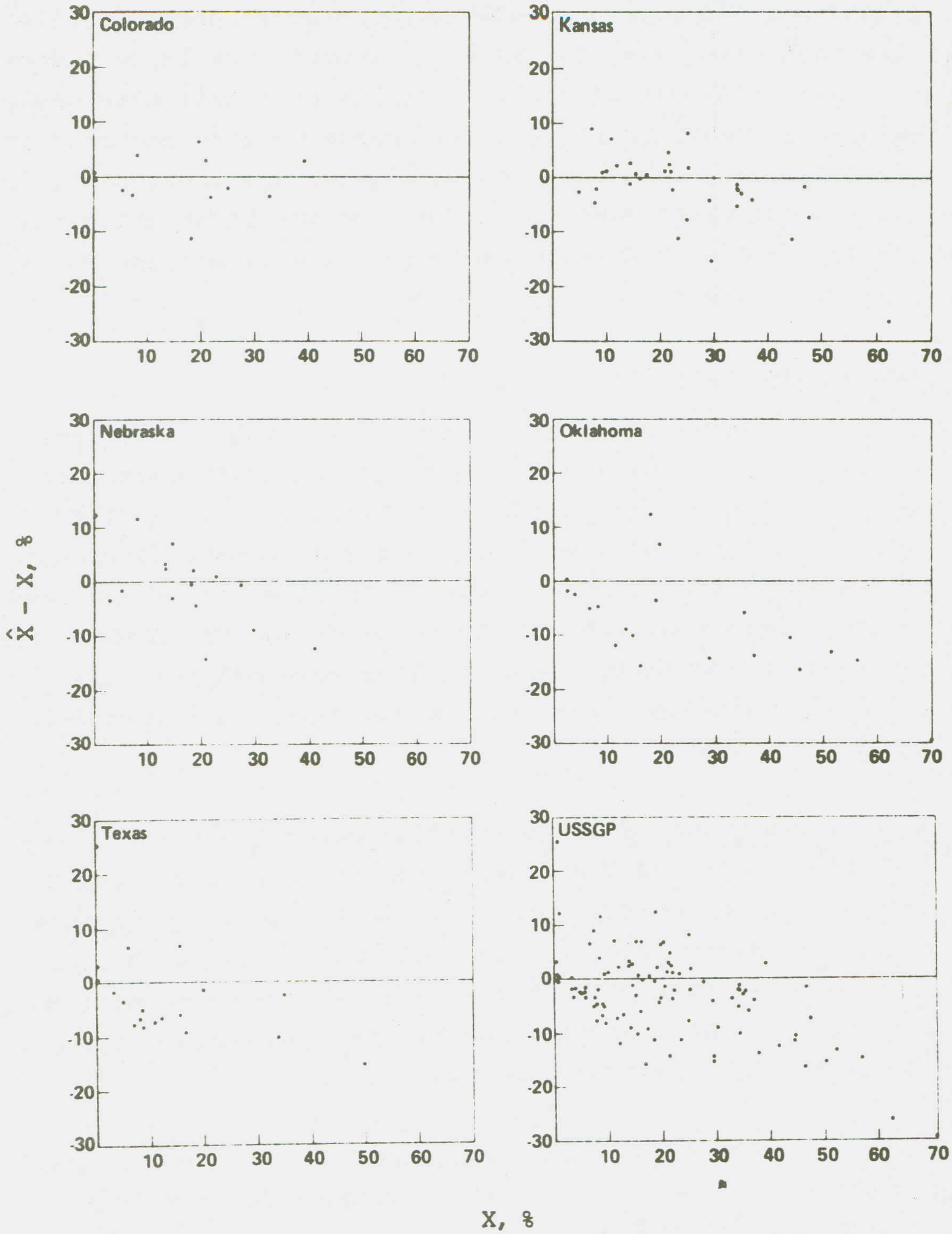


Figure 4-3.– Plot of winter wheat proportion estimation errors versus ground truth winter wheat proportions for blind sites in the USSGP.

one blind site out of 26 in the five-state region for which the CAMS result is not an underestimate relative to ground truth. Also, figure 4-3 indicates that underestimates occur in Oklahoma and Texas for all values of X. In Oklahoma, 17 of 20 (85 percent) of the blind sites were underestimated, as were 15 of 19 (79 percent) in Texas. A statistical analysis of these data follows.

A statistical analysis of the data shown in figure 4-3 was performed using the technique described in appendix A (section A.3.1.1). The results are shown in table 4-5. It lists the following factors: (1) the number of blind sites for which data were available for each state or region, (2) the number of segments allocated to each state or region, (3) the average ground truth wheat proportion, $\bar{X}$, (4) the average CAMS wheat proportion estimate $\hat{X}$, (5) the average difference $\bar{D} = \bar{\hat{X}} - \bar{X}$, (6) the standard error $S_{\bar{D}}$ of $\bar{D}$, and (7) 90-percent confidence limits for the average error μ_D.

In order to determine if the average difference for a particular region is significantly different from zero, we need only observe whether the corresponding confidence interval contains zero. If it does, the average difference is not significantly different from zero, i.e., there is insufficient evidence to conclude that there is a bias due to classification error. If it does not contain zero, then the hypothesis of no bias is rejected at the 10-percent level of significance.

In the following paragraphs the results presented in table 4-5 are discussed separately for each state and for the USSGP. The discussion also includes preliminary results from an investigation by CAMS to determine the causes of classification error. At the end of the 1976 crop year, the data for one-half of the blind sites in the USGP were released to CAMS for evaluation of the accuracy and sources of error in the operational analysis

TABLE 4-5.– WINTER WHEAT BLIND SITE RESULTS FOR THE USSGP

Region	n (a)	N (b)	$\bar{X}$	$\bar{\hat{X}}$ (c)	$\bar{D}$	$S_{\bar{D}}$	90% Confidence limits for μ_D (d)
Colorado	13	32	14.62	14.54	-.08	1.0	(-1.97, 1.81)
Kansas	34	84	23.89	22.00	-1.89	0.91	(-3.43, -0.35)*
Nebraska	18	35	14.12	14.78	0.65	1.15	(-1.35, 2.65)
Oklahoma	20	40	24.19	17.60	-6.58	1.51	(-9.19, -3.97)*
Texas	18	49	12.61	11.83	-0.78	1.58	(-3.53, 1.97)
USSGP	103	240	19.10	17.17	-1.93	0.58	(-2.89, -0.97)*

[a]Number of blind sites.

[b]Number of segments allocated.

[c]Winter wheat estimates from the October CMR.

[d]μ_D is the population average difference.

*$\bar{D}$ is significantly different from zero at the 10-percent level of significance.

during Phase II. These evaluations were carried out in most cases by the analyst that conducted the original interpretation and classification. In the following paragraphs these studies will be referred to as the "CAMS investigation."

Oklahoma

The results for Oklahoma (table 4-5) show that the 90-percent confidence interval for μ_D is given by (-9.19, -3.97). This interval does not contain zero. Hence, we conclude that there is a negative bias in the CAMS estimates for the segments allocated to Oklahoma. The CAMS investigation showed that underestimates were due to atypical, weak, and missing signatures, small fields, and spotty stands. Some of these effects were attributed to drought conditions. Only one of the segments checked in the CAMS investigation was overestimated; hail damage of wheat at harvest was the cause of the overestimate.

Kansas

In table 4-5 it is also observed that a "significant" bias occurs for the state of Kansas. However, inspection of the data plotted in figure 4-3 reveals one outlier, a difference of -25.56 percent, corresponding to a ground truth of 61.56 percent wheat. Omitting this one outlier yields an estimate of the bias that is not significantly different from zero. From the CAMS investigation it was concluded that in Kansas, overestimates were due to pasture, fallow, and sorghum being included as wheat. Underestimates were usually caused by missed wheat signatures; i.e., wheat signatures that were not included in the training data.

Texas

For Texas, 79 percent of the blind sites were underestimated. However, the $S_{\bar{D}}$ was so large that there was insufficient evidence to conclude that a bias existed. Inspection of the data plotted in figure 4-3 for Texas reveals an outlier, a difference of +25.31 percent, corresponding to a ground truth of 0.69 percent; i.e., an extreme overestimate of a trace of wheat. If this outlier is omitted the results do indicate a negative bias. The CAMS investigation showed that the overestimate for this outlier was due to red fallow fields and tan pasture fields which were classified as wheat. No explanation was found for the red fallow signatures. The underestimates that occurred for most of the segments were generally due to atypical signatures. Some stands of wheat were spotty.

Colorado and Nebraska

Neither of the average differences for the other two states, Colorado and Nebraska, were significantly different from zero, nor were any apparent outliers observed. The analysts in CAMS were apparently having some success in identifying wheat for these two states. The CAMS investigation showed that in Colorado overestimates were caused by confusion crops such as spring wheat and winter rye being classified as winter wheat; underestimates were caused by missed signatures in drought areas and by strip crop areas not being resolvable by the Landsat system. In the latter case the wheat pixels were all essentially border pixels and therefore many were misclassified as nonwheat.

In Nebraska overestimates were caused by atypical wheat signatures and small fields. Underestimates in Nebraska were due to missed signatures, the absence of key acquisitions such as biowindow 2, some narrow fields that were missed, and some wheat fields that were never picked up on the imagery.

USSGP

At the USSGP five-state level, there was sufficient evidence to conclude that the CAMS wheat proportion estimates were significantly different from the ground wheat proportions at the

90-percent level. The average difference at this level was -1.93 percent with a standard error of 0.58 percent.

Variation of Proportion Error Throughout the Season

Table 4-6 presents the results of a blind site investigation to study the variation of classification error throughout the season.

At the time this investigation was performed (December), all the blind site data were available, but all of the segments could not be used since CAMS estimates for the whole season were not available for all of them. It is, of course, desirable that the same number of segments be used for each month. It was found that 95 segments had data for March through the end of the season, but only 71 segments had data for February.

In table 4-6 four quantities relating to the classification error are given: the mean square error (MSE), the mean difference ($\bar{D}$), the relative mean difference (RMD) and the percentage of the segments in which the LACIE underestimated the at-harvest wheat proportions. There was a declining trend in the MSE throughout the season. The final figure represents a 55-percent reduction from the February estimate.

The $\bar{D}$ and the RMD showed the same behavior; i.e., a general reduction in the size of the error as the season progressed. These errors were all negative, indicating underestimates by LACIE. From February through the final estimate there was a 58-percent reduction in the magnitude of the $\bar{D}$ and a 57-percent reduction in the magnitude of the RMD.

The percentage of segments underestimated by LACIE also decreased throughout the season, falling from 83 percent in February to 68 percent for the final estimate.

TABLE 4-6.– COMPARISON OF LACIE ESTIMATES TO GROUND-OBSERVED PROPORTIONS OVER WINTER WHEAT BLIND SITES IN THE USGP

Month	No. of Segments	MSE (a)	$\bar{D}$, % (b)	RMD, % (c)	Percent underestimated (d)
February	71	157.5	-6.46	-30.6	83
March	95	112.8	-5.43	-26.2	79
April	95	112.8	-5.43	-26.2	79
May	95	102.5	-4.44	-21.4	75
June	95	89.5	-3.25	-15.7	72
July	95	90.4	-3.35	-16.2	70
August	95	75.0	-3.16	-15.2	71
September	95	65.3	-2.76	-13.3	68
October	95	69.6	-2.84	-13.7	68
Final	95	70.8	-2.74	-13.2	68

[a] $MSE = \frac{\sum\left(\hat{X}_i - X_i\right)^2}{n}$ where $\hat{X}_i$ is the wheat proportion estimate for the *ith* segment, X_i is the ground-observed, harvested wheat proportion for the *ith* segment, and n is the number of segments.

[b] $\bar{D} = \frac{\sum\left(\hat{X}_i - X_i\right)}{n} = \bar{\hat{X}} - \bar{X}$.

[c] $RMD = \bar{D}/\bar{X}$.

[d] This column contains the percentage of blind site segments in which LACIE underestimated the wheat proportions.

All these estimates thus indicate a general improvement in the CAMS estimates as the season progressed.

4.2.2.2 Spring Wheat Blind Site Investigations

The spring wheat blind site investigation was conducted in 33 segments in the four USNGP states of Minnesota, Montana, North Dakota, and South Dakota. Figure 4-4 shows plots of the proportion error $\hat{X} - X$ as a function of X, where $\hat{X}$ is the CAMS wheat proportion estimate and X is the ground truth wheat proportion estimate. The plots are for each of the four USNGP states and for the USNGP total spring wheat. Points lying above the horizontal line $\hat{X} - X = 0$ correspond to overestimation of wheat proportions by CAMS, and points lying below the line correspond to underestimation by CAMS.

The plots in figure 4-4 show a tendency toward underestimation in every state except South Dakota. Twenty-eight of the thirty-three sites in the USNGP were underestimated by CAMS. In the plot for the USNGP there appeared to be a slight dependence on the value of X (i.e., the underestimates seem to be greater for larger values of X), but this trend was less pronounced than that shown in figure 4-3 for the USSGP.

The statistical analysis of these data is presented in table 4-7. The quantities listed are the same as those in table 4-5.

Table 4-7 shows that the LACIE acreage estimates were low for all of the states; however, the only state in which the underestimate is statistically significant at the 10-percent level of significance is North Dakota. The CAMS investigation* found many factors

*See section 4.2.2.1.

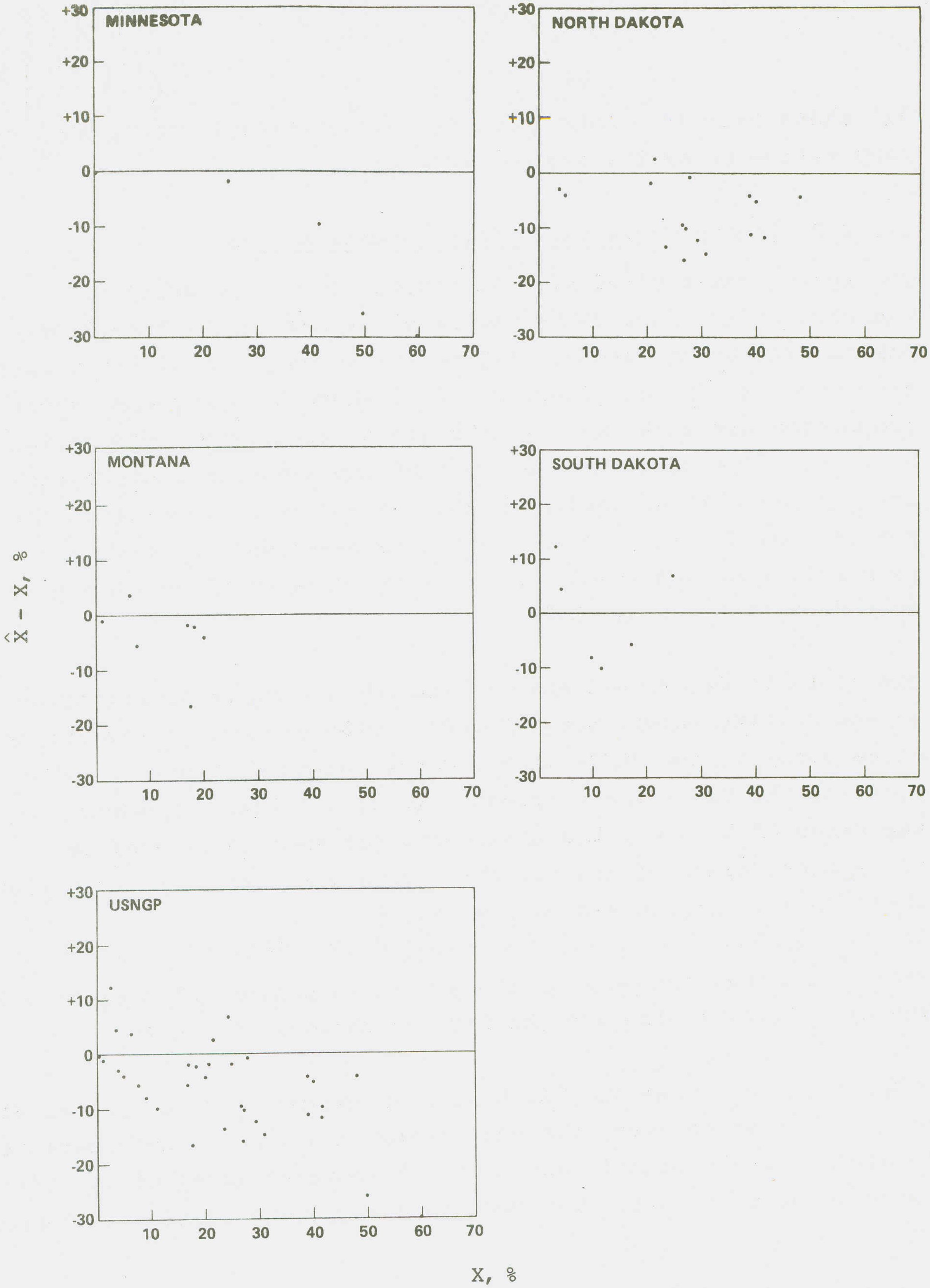


Figure 4-4.— Plots of spring wheat proportions estimation errors versus ground truth values for blind sites in the USNGP.

TABLE 4-7.— SPRING WHEAT BLIND SITE RESULTS FOR THE USNGP

Region	n	N	$\bar{X}$	$\bar{\hat{X}}$ (a)	$\bar{D}$	$S_{\bar{D}}$	90% Confidence Limits for μ_D
Minnesota	5	13	35.43	22.60	-12.82	5.11	(-23.71, 1.93)
North Dakota	17	85	26.64	20.82	-5.82	1.95	(-9.22, -2.42)*
Montana	7	22	12.71	8.57	-4.13	1.95	(-7.92, 0.34)
South Dakota	6	23	11.34	11.17	-0.17	3.20	(-6.62, 6.28)
USNGP	35	143	22.48	16.97	-5.51	1.44	(-7.95, -3.07)*

[a]Final estimates from the CAS annual report for the 1976 crop year.

*μ_D significantly different from zero at the 10-percent level of significance.

which contributed to the underestimate in North Dakota. Among these were:

a. Strip fallow areas unresolvable by the Landsat system

b. Weak or missing signatures

c. Poor color balance on Landsat images due to the transformation that is applied to the Landsat data before the images are made

d. The absence of early biowindow acquisitions

e. The omission of some late-planted spring wheat because its signature was behind the adjustable crop calendar for jointing

f. Problems in choosing training fields caused by small fields or the absence of identifiable field patterns

For Minnesota, Montana, and South Dakota, the analysis did not indicate that there was a bias in the CAMS estimates. However, for these states the number of data points was small. Therefore, the inference of "no bias" should not be regarded as reliable.

Minnesota

In Minnesota underestimation generally occurred in segments with very high wheat density and was caused by unusual wheat signatures, e.g., red-green, light green and dark green. There is some evidence that these unusual signatures were the result of color distortions in the Landsat imagery.

Montana

In Montana underestimation was usually due to strip fallow areas which were not classified well. Some overestimates were due to hay being classified as wheat even though the two were not confused in the training fields.

South Dakota

In South Dakota both overestimates and underestimates were caused by drought conditions. There was noticeable difference between the Landsat data for this area and for the USSGP. In the spring, wheat and small grains appeared very similar to pasture, alfalfa, and corn on the PFC products due to stress caused by drought. At harvest time, some corn was grazed or cut for silage and some alfalfa was cut and, because of drought, never reappeared. In both cases it was difficult to distinguish these crops from harvested small grains. Many small grains were not harvested, but were fall plowed and could not be distinguished from harvested small grains by CAMS; therefore, wheat was overestimated. Underestimates were due to missing signatures from poor stands of small grains and poor acquisition histories.

USNGP

For the blind sites in the USNGP, the analysis indicated a bias in the CAMS wheat proportion estimates. The average difference was -5.51 percent with a standard error of 1.44 percent.

Contribution of the Classification and Ratio Errors to the Ratioed Wheat Proportion Estimation Errors at the Segment Level

Let $\hat{r}_i$ and $\hat{X}_i$, i = 1, 2, ...n be the estimates of r_i and X_i, respectively, for the i*th* blind site,

where

r_i = the ground observed ratio of wheat-to-small grains proportion

X_i = the ground observed small grains proportion

n = the number of blind sites

In this discussion, $\hat{r}_i$ is the CAS ratio (Phase II) of the wheat-to-small-grains proportion determined from 1975 county level SRS estimates, and $\hat{X}_i$ is the Phase II CAMS final estimate for the small grains proportion.

The bias (B) and the mean-squared error (MSE) of the wheat proportion estimate for a segment may be estimated by

$$\hat{B} = \frac{1}{n} \sum_{i=1}^{n} \left(\hat{r}_i \hat{X}_i - r_i X_i \right)$$

and

$$M\hat{S}E - \frac{1}{n} \sum_{i=1}^{n} \left(\hat{r}_i \hat{X}_i - r_i X_i \right)^2$$

It is clear that these errors are both caused by two factors: the CAMS classification of small grains and the estimated ratio of wheat to small grains. The contribution of a particular error factor may be measured by the reduction in the bias or mean-squared error which would be achieved if that error factor were omitted. Specifically, the following formulas are used in this study.

a. Proportion bias estimate without ratio error:

$$\hat{B}' = \frac{1}{n} \sum_{i=1}^{n} \left(r_i \hat{X}_i - r_i X_i \right)$$

b. Proportion bias estimate without classification error:

$$\hat{B}'' = \frac{1}{n} \sum_{i=1}^{n} \left(\hat{r}_i X_i - r_i X_i \right)$$

c. Proportion mean squared error without ratio error:

$$\hat{MSE}' = \frac{1}{n} \sum_{i=1}^{n} \left(r_i \hat{X}_i - r_i X_i \right)^2$$

d. Proportion mean-squared error without classification error:

$$\hat{MSE}'' = \frac{1}{n} \sum_{i=1}^{n} \left(\hat{r}_i X_i - r_i X_i \right)^2$$

Table 4-8 presents the numerical results obtained for 37 spring wheat blind sites for Phase II in Minnesota, Montana, North Dakota, and South Dakota.

TABLE 4-8.— PHASE II FINAL RESULTS FOR SPRING WHEAT BLIND SITES IN USNGP

Category	Estimate of bias, %	Standard dev. of bias	Reduction in bias, %	90% Confidence limits for bias	Mean squared error	Reduction in mean squared error, %
Phase II final result	-4.89	9.70	—	(-7.58, -2.19)	115.36	—
No ratioing error	-2.45	8.54	49.9	(-4.82, -0.07)	76.91	33.3
No classification error	-3.12	4.03	36.2	(-4.23, -2.00)	25.50	77.9

From table 4-8 it can be seen that the reduction in bias is not much larger when there is no ratioing error than when there is no small grain classification error. On the other hand, a much larger reduction in mean-squared error is obtained when there is no small grain classification error than when there is no ratioing error. This indicates that the major problem is the classification of small grains. If the classification problem is solved, or at least reduced, then a bias still exists due to ratioing. Hence, both problems need to be attacked, with more emphasis on the classification problem.

Variation of Proportion Error Throughout the Season

Table 4-9 shows the results of a blind site investigation to study the variation of classification error throughout the season. All 33 segments were used. The definitions of the quantities listed are the same as those given in section 4.2.2.1 in connection with table 4-6.

TABLE 4-9.— MEASUREMENTS OF CLASSIFICATION ERROR (LACIE ESTIMATES VERSUS GROUND-OBSERVED PROPORTIONS) OVER ALL AVAILABLE BLIND SITES IN THE USGP

SPRING WHEAT					
Month	No. of segments	MSE	$\bar{D}$, %	RMD, %	[a]% under-estimated
August	33	158.5	-9.29	-41.6	88
September	33	120.1	-5.72	-25.6	82
October	33	115.3	-5.38	-24.1	79
Final	33	110.1	-5.05	-22.6	79

[a]This column contains the percentage of blind site segments in which LACIE underestimated the wheat proportion.

The mean-squared classification error dropped from 158.5 in August to 110.1 at the end of the season — a decrease of 30 percent.

The average difference $\bar{D}$ was negative for all months, indicating that the wheat proportions were consistently underestimated throughout the year. The magnitude of the errors declined 45 percent in the period from August to the final estimate. In spite of these reductions there was still substantial underestimation at the end of the season. At that time the wheat proportion in 79 percent of the sites was still being underestimated by LACIE.

4.2.2.3 Bias Due to Classification Error

Ground truth information from blind site data obtained at harvest was used to estimate bias due to classification. The procedure is described in appendix A, section A.3.1.4. In addition to the assumption of normality for $\hat{X}$, it is based on the following assumptions:

a. The blind sites within a state are representative of the sample segments allocated to the state.

b. The estimates of classification bias at the segment level are assumed to be independently and identically distributed for each allocated segment within a state.

c. The acreage estimates are uncorrelated at the state level and any bias in a state acreage estimate is due to classification.

d. The derived state level yield estimates are uncorrelated and are unbiased.

e. The state level acreage and yield estimates are uncorrelated.

f. The bias due to the Group III ratio estimates is negligible.

Under these assumptions, the segment level classification bias for each state is estimated by the average difference between the CAMS wheat proportion estimates and the ground truth wheat proportions as determined from the blind sites within each state. The state level acreage bias is then estimated by aggregating this segment level classification bias estimate for each segment acquired in the state in Phase II. The results are given in table 4-10. The estimated acreage bias is significantly less than zero for the USGP region, the four-state spring wheat region

TABLE 4-10.– ESTIMATES OF THE BIAS AND RELATIVE BIAS OF THE LACIE ACREAGE AGGREGATION ESTIMATES USING BLIND SITES

Region	LACIE acreage estimate ($\hat{A}$) (10^3 acres)	Aggregated acreage bias ($\hat{B}$) (10^3 acres)	Relative bias $\frac{\hat{B}}{\hat{A}}$ (%)	Standard deviation of $\hat{B}$ (10^3 acres)	90% confidence limits for B (10^3 acres)
Winter wheat					
Colorado	2 704	-26	-1.0	275.6	
Kansas	11 125	-988	-8.9	473.2	
Nebraska	3 399	199	5.9	381.4	
Oklahoma	4 261	-2 583	-60.6	590.9	
Texas	4 344	-483	-11.1	953.9	
USSGP	25 833	-3 881	-15.0	1 305.6	(-6 029,-1 733)
USSGP (excluding Oklahoma)	21 572	-1 298	-6.0	1 164.2	(-3 213,617)
Montana	2 079	-913	-43.9	768.9	
South Dakota	1 452	-470	-32.4	255.9	
USGP	29 364	-5 264	-17.9	1 536.6	(-7 792,-2 736)
Spring wheat					
Minnesota	2 198	-2 275	-103.5	908.2	
Montana	1 516	-827	-54.6	393.3	
North Dakota	9 856	-2 385	-24.2	801.9	
South Dakota	2 079	-37	-1.8	592.0	
USNGP	15 649	-5 524	-35.3	1 404.6	(-7 835,-3 213)
Total wheat					
USGP	45 013	-10 788	-24.0	2 078.2	(-14 207,-7 369)

of the USNGP, the seven-state winter wheat region of the USGP, and the five-state winter wheat region of the USSGP. However, if Oklahoma is excluded from the five-state winter wheat region of the USSGP, no bias is indicated for this region.

4.2.3 ESTIMATION OF THE WITHIN-STRATUM ACREAGE VARIANCES DUE TO CLASSIFICATION AND SAMPLING ERRORS

In order to estimate the within-stratum acreage variances due to sampling and classification errors, one first constructs the following three basic regression models: (1) true segment proportion versus historical stratum proportion, (2) LACIE segment proportion versus ground truth segment proportion, and (3) LACIE segment proportion versus historical stratum proportion. Then, the regression equations are used to obtain the estimates for $\sigma_s^2 + \sigma_H^2$, σ_c^2, and $\lambda^2\sigma_s^2 + \sigma_c^2$, where $\lambda^2\sigma_s^2$, σ_c^2 and σ_H^2 represent, respectively, the contribution due to classification, the contribution due to sampling, and the variance of the residuals resulting from the regression of the current stratum proportion onto the historical stratum proportion. Assuming that σ_H^2 is much smaller than σ_s^2, σ_H^2 can be ignored in practice. Finally, the maximum likelihood estimation technique, assuming normality, is used to obtain the optimal estimates for sampling and classification variances. The detailed description of this method is presented in appendix A.

Table 4-11 provides the estimates of the acreage variances (within stratum) due to classification and sampling errors. These estimates were obtained using the CAMS proportion estimates given in the CAS Final Report, the ground truth proportions for the winter wheat blind sites, from the early season ground truth observations, and the country proportions from the 1974 census.

As indicated in table 4-11, sampling contributes more error than classification does to the estimates of within-stratum acreage

TABLE 4-11.- ACREAGE VARIANCES DUE TO CLASSIFICATION AND SAMPLING ERRORS

Area	M*	N**	Within-stratum acreage variance	Variance contribution		Fractional error	
				Due to classification	Due to sampling	Due to classification	Due to sampling
Colorado	13	19	105.9	20.8	85.1	0.197	0.803
Kansas	34	47	104.2	34.5	69.7	.332	.668
Nebraska	18	15	54.6	27.2	27.4	.498	.502
Oklahoma	20	20	199.7	47.0	152.7	.235	.765
Texas	19	28	150.9	55.0	95.9	.364	.636
Minnesota	5	9	163.1	65.3	97.8	.400	.600
Montana	7	13	120.7	85.6	35.1	.709	.291
N. Dakota	14	44	221.8	104.5	117.3	.471	.529
S. Dakota	6	13	183.0	144.7	38.3	.791	.209

*M = Number of blind sites used
**N = Total number of processed segments — M

variances for the winter wheat states. No interpretation can be made for the spring wheat states due to (1) the lack of consistency of the results among those states, and (2) the limited number of blind sites used for the error estimation.

4.3 COMPARISON OF LACIE AND USDA/SRS YIELD ESTIMATES

Winter Wheat

The LACIE and USDA/SRS monthly winter wheat yield estimates for the USSGP, the state of Oklahoma, the mixed wheat states of Montana and South Dakota, and the USGP are displayed in plots 1 through 4 of figure 4-5. The estimates and their corresponding relative differences and CV's are presented in table 4-12. Also presented in the table is the test statistic used for determining whether the LACIE estimate is significantly different from the corresponding USDA/SRS estimate. This test statistic was calculated only at regional or higher levels, not at state levels. At the USSGP level, the LACIE estimates were significantly different from the USDA/SRS estimates only for the early season months of February, March, and April. The February and March estimates of yield for USDA/SRS were actually estimates derived by dividing the USDA/SRS production forecast for these months by estimates of seeded (or planted) acres. Therefore, the SRS estimates for these two months were yield per planted acre, rather than yield per harvested acre, which is forecast by LACIE. Hence, it is not surprising that these two estimates were significantly different for February and March. However, none of the monthly LACIE estimates were significantly different from the USDA/SRS final estimate at this level.

The monthly winter wheat yield estimates by LACIE and USDA/SRS for Oklahoma are displayed in plot 2 of figure 4-5 and the corresponding relative differences are given in table 4-12. Plot 2 indicates that the large underestimate of wheat production by

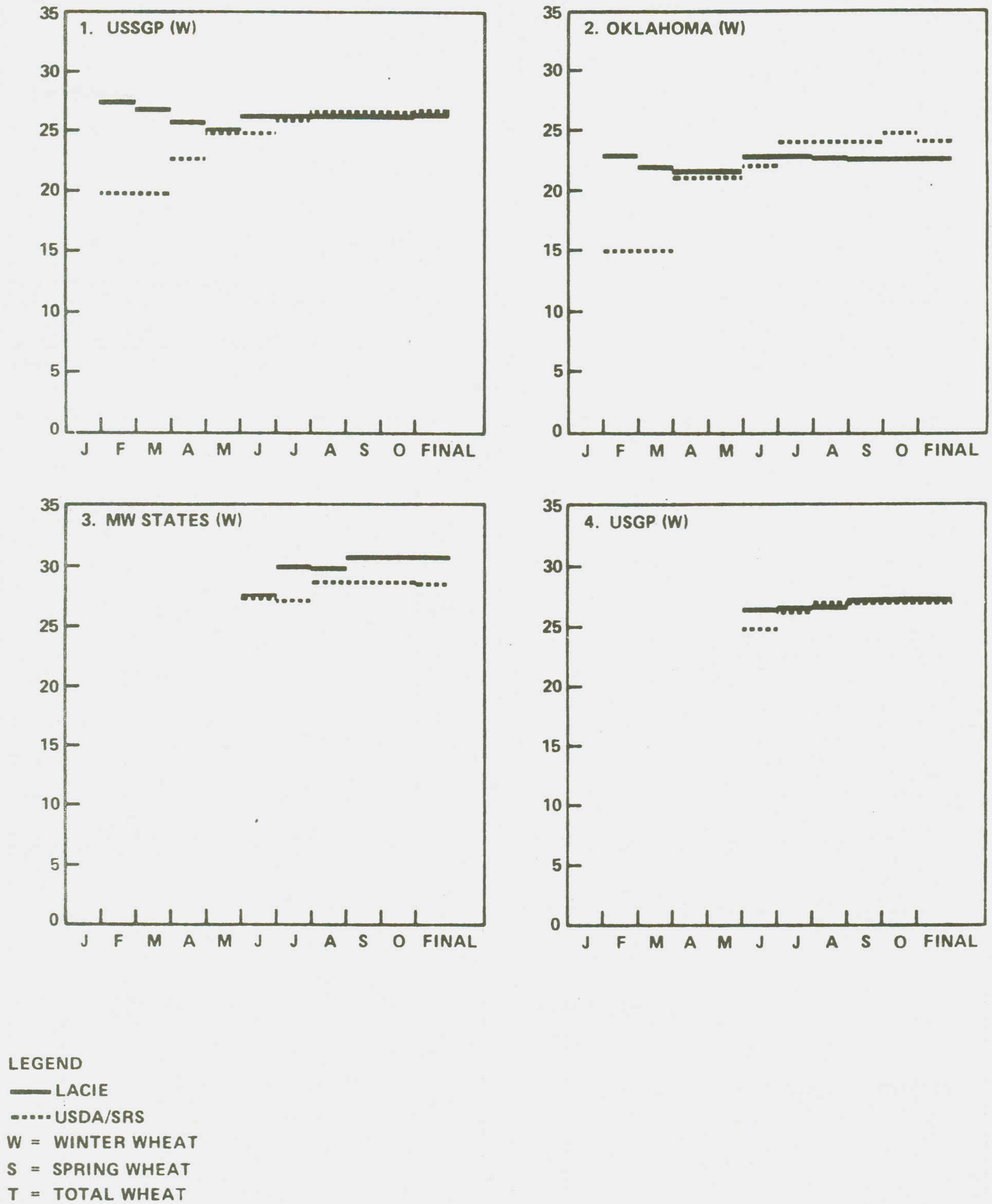


Figure 4-5.— LACIE and USDA/SRS yield estimates [bushels/acre].

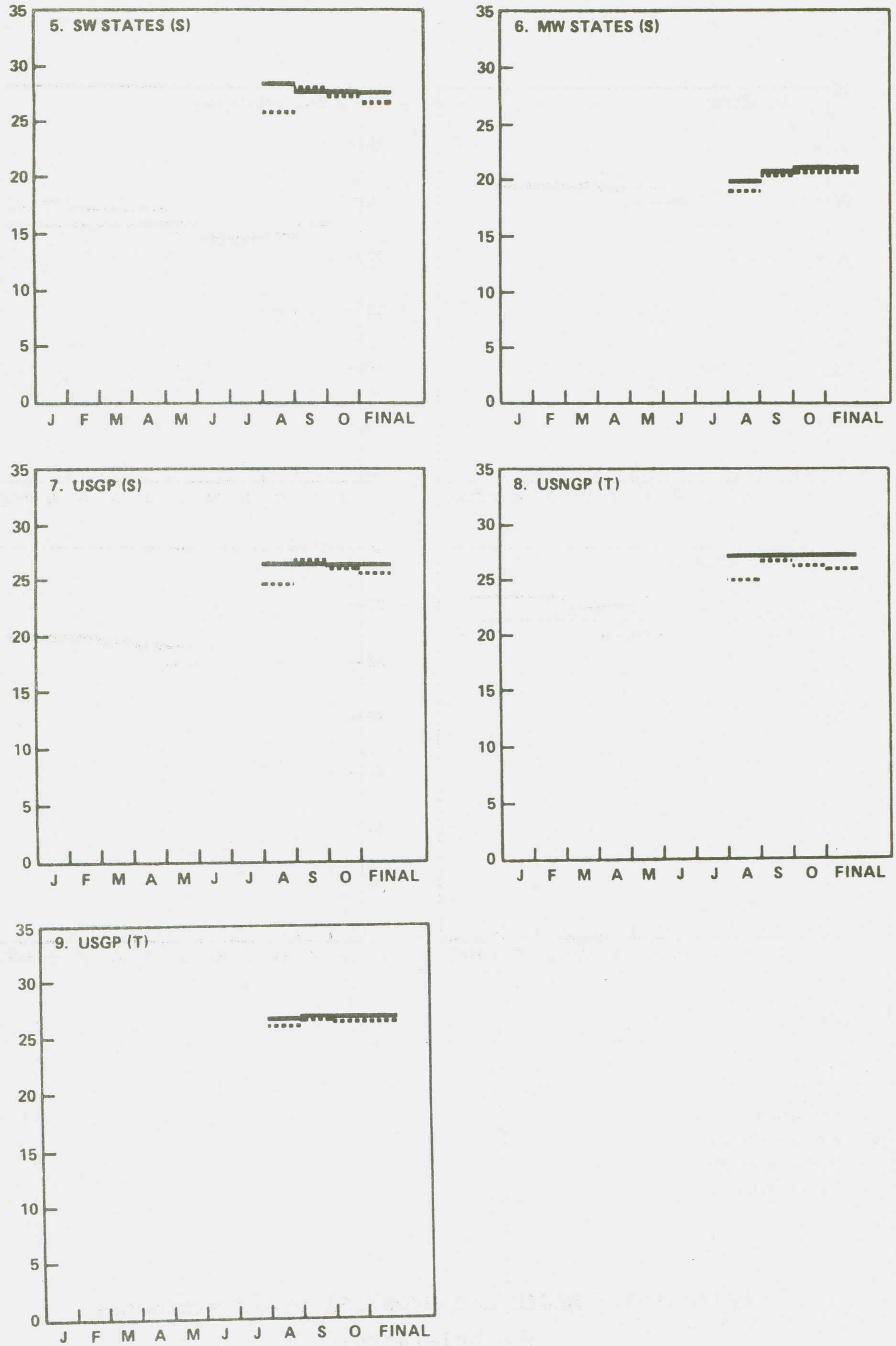


Figure 4-5.— Concluded.

TABLE 4-12.— COMPARISON OF USDA/SRS AND LACIE YIELD ESTIMATES

[Bushels/acre]

Region	USDA/SRS (a)	LACIE	Relative difference (%)	CV (%)	Test statistic
February					
Winter Wheat					
Colorado	17.0	21.6	21.3	21	
Kansas	25.0	32.2	22.4	12	
Nebraska	27.1	33.7	19.6	14	
Oklahoma	15.0	22.9	34.5	17	
Texas	12.0	18.8	36.2	19	
USSGP	19.8	27.6	28.3	7	4.04*
March					
Winter Wheat					
Colorado	17.0	22.0	22.7	21	
Kansas	25.0	31.6	20.9	12	
Nebraska	27.1	34.2	20.8	14	
Oklahoma	15.0	22.0	31.8	17	
Texas	12.0	17.9	33.0	18	
USSGP	19.8	27.0	26.7	7	3.81*

[a]The USDA/SRS yield estimates for February and March were obtained by dividing the production estimates by the corresponding acreage estimates.

*The LACIE estimate is significantly different from the USDA/SRS estimate at the 10-percent level.

TABLE 4-12.– Continued.

Region	USDA/SRS (a)	LACIE	Relative difference (%)	CV (%)	Test statistic
April					
Winter Wheat					
Colorado	21.0	20.3	-3.4	21	
Kansas	26.0	29.9	13.0	10	
Nebraska	28.0	33.1	15.4	14	
Oklahoma	21.0	21.7	3.2	14	
Texas	17.0	17.1	0.6	14	
[b]USSGP	22.7	25.9	12.4	6	2.06*
May					
Winter Wheat					
Colorado	22.0	19.7	-11.7	20	
Kansas	28.0	30.1	7.0	10	
Nebraska	32.0	30.2	-6.0	14	
Oklahoma	21.0	21.7	3.2	14	
Texas	18.0	18.1	0.6	13	
[b]USSGP	24.9	25.3	1.6	6	.27[N]

[b]The five-state United States southern Great Plains region.

[N]The LACIE estimate is not significantly different from the USDA/SRS estimate at the 10-percent level.

TABLE 4-12.— Continued.

Region	USDA/SRS (a)	LACIE	Relative difference (%)	CV (%)	Test statistic
June					
Winter Wheat					
Colorado	22.0	20.4	-7.8	17	
Kansas	26.0	31.0	16.1	9	
Nebraska	33.0	31.4	-5.1	13	
Oklahoma	22.0	22.9	3.9	10	
Texas	18.0	18.5	2.7	12	
USSGP	24.4	26.4	7.6	5	1.52^N
Montana	30.0	27.7	-8.3	12	
S. Dakota	20.0	27.2	26.5	15	
[c]MW states	27.4	27.4	0	9	
[d]USGP	24.8	26.5	6.4	5	1.28^N
July					
Winter Wheat					
Colorado	22.0	18.0	-22.2	17	
Kansas	29.0	30.9	6.1	9	
Nebraska	32.0	32.0	0	12	
Oklahoma	24.0	22.9	-4.8	10	
Texas	21.0	18.7	-12.3	12	
USSGP	26.2	26.4	0.8	5	0.16^N
Montana	31.0	28.8	-7.6	9	
S. Dakota	16.0	30.4	47.4	15	
MW states	27.2	29.8	8.7	9	
USGP	26.4	26.7	1.1	5	0.22^N

[c]The mixed wheat states, Montana and South Dakota.

[d]The nine-state United States Great Plains region.

TABLE 4-12.— Continued.

Region	USDA/SRS (a)	LACIE	Relative difference (%)	CV (%)	Test statistic
August					
Winter Wheat					
Colorado	22.0	17.7	-24.3	17	
Kansas	29.5	30.9	4.5	9	
Nebraska	32.0	32.0	0	12	
Oklahoma	24.0	22.8	-5.3	10	
Texas	22.0	18.7	-17.6	20	
USSGP	26.6	26.4	-0.8	5	$-.16^{N}$
Montana	32.0	29.2	-9.6	9	
S. Dakota	19.0	30.4	37.5	14	
MW states	28.7	29.7	3.4	8	
USGP	26.9	26.7	-0.7	5	$-.14^{N}$
Spring Wheat					
Minnesota	32.0	31.9	-0.3	11	
N. Dakota	23.6	27.7	14.8	11	
[e]SW states	25.7	28.4	9.5	9	
Montana	27.3	25.9	-5.4	9	
S. Dakota	9.9	16.9	41.4	14	
MW states	19.1	20.0	4.5	9	
USGP	24.3	26.3	7.6	7	1.08^{N}
[f]**Total Wheat**					
Montana	29.9	28.0	-6.8	4	
S. Dakota	13.0	22.4	42.0	5	
MW states	23.7	24.9	4.8	4	
[g]USNGP	25.0	27.0	7.4	6	1.23^{N}
USGP	25.9	26.6	2.6	4	$.65^{N}$

[e]The spring wheat states, Minnesota and North Dakota.

[f]Spring wheat plus winter wheat.

[g]The four-state United States northern Great Plains region.

TABLE 4-12.– Continued.

Region	USDA/SRS (a)	LACIE	Relative difference (%)	CV (%)	Test sta-tistic
September					
Winter Wheat					
Colorado	22.0	19.6	-12.2	17	
Kansas	29.5	30.9	4.5	9	
Nebraska	32.0	32.7	2.1	12	
Oklahoma	24.0	22.6	-6.2	10	
Texas	22.0	18.7	-17.6	5	
USSGP	26.6	26.5	-0.4	5	$-.08^N$
Montana	32.0	29.9	-7.0	9	
S. Dakota	19.0	31.6	39.9	14	
MW states	28.7	30.6	6.2	8	
USGP	26.9	27.0	0.4	5	$.08^N$
Spring Wheat					
Minnesota	34.1	30.3	-12.5	11	
N. Dakota	26.0	27.1	4.1	11	
SW states	28.0	27.7	-1.1	9	
Montana	28.3	27.2	-4.0	9	
S. Dakota	11.9	17.1	30.4	13	
MW states	20.6	21.0	1.9	8	
USGP	26.4	26.3	-0.4	7	$-.05^N$
Total Wheat					
Montana	30.4	28.9	-5.2	5	
S. Dakota	14.3	23.1	38.1	5	
MW states	24.5	25.9	5.4	4	
USNGP	26.7	27.1	1.5	7	$.21^N$
USGP	26.7	26.8	0.4	4	$.10^N$

TABLE 4-12.– Continued.

Region	USDA/SRS (a)	LACIE	Relative difference (%)	CV (%)	Test statistic
October					
Winter Wheat					
Colorado	22.0	19.6	-12.2	17	
Kansas	29.5	30.9	4.5	9	
Nebraska	32.0	32.7	2.1	12	
Oklahoma	24.7	22.6	-9.3	10	
Texas	22.0	18.7	-17.6	5	
USSGP	26.6	26.5	-0.4	5	$-.08^N$
Montana	32.0	29.9	-7.0	9	
S. Dakota	19.0	31.6	39.9	14	
MW states	28.7	30.6	6.2	8	
USGP	26.9	27.0	0.4	5	$.08^N$
Spring Wheat					
Minnesota	33.0	30.3	-8.9	11	
N. Dakota	25.2	27.1	7.0	11	
SW states	27.1	27.7	2.2	9	
Montana	28.8	27.1	-6.3	9	
S. Dakota	11.9	17.2	30.8	13	
MW states	20.8	21.3	2.3	8	
USGP	25.7	26.2	1.9	7	$.27^N$
Total Wheat					
Montana	30.6	28.7	-6.6	5	
S. Dakota	14.3	23.1	38.1	5	
MW states	24.6	26.0	5.4	4	
USNGP	26.2	27.0	3.0	6	$.50^N$
USGP	26.4	26.7	1.1	4	$.28^N$

TABLE 4-12.– Concluded.

Region	USDA/SRS (a)	LACIE	Relative difference (%)	CV (%)	Test statistic
Final					
Winter Wheat					
Colorado	21.5	19.6	-9.7	17	
Kansas	30.0	31.0	3.2	9	
Nebraska	32.0	32.7	2.1	12	
Oklahoma	24.0	22.6	-6.2	10	
Texas	22.0	18.7	-17.6	5	
USSGP	26.8	26.6	-0.8	5	$-.16^{N}$
Montana	32.0	29.9	-7.0	9	
S. Dakota	18.0	31.6	43.0	14	
MW states	28.6	30.6	6.5	8	
USGP	27.0	27.0	0.0	5	0^{N}
Spring Wheat					
Minnesota	32.4	30.3	-6.9	11	
N. Dakota	24.7	27.0	8.5	11	
SW states	26.6	27.6	3.6	9	
Montana	29.4	27.1	-8.5	9	
S. Dakota	10.9	17.2	36.6	13	
MW states	20.8	21.3	2.3	8	
USGP	25.3	26.2	3.4	7	$.49^{N}$
Total Wheat					
Montana	30.9	28.7	-7.7	5	
S. Dakota	13.2	23.1	42.9	5	
MW states	24.6	25.9	5.0	4	
USNGP	25.9	27.0	4.1	6	$.68^{N}$
USGP	26.4	26.7	1.1	4	$.28^{N}$

LACIE for this state was not due to the yield predictions. The LACIE estimates of yield were only slightly lower than the corresponding USDA/SRS estimates from July to the final estimate.

The winter wheat yield estimates by LACIE and USDA/SRS for the two-state mixed wheat region of Montana and South Dakota are exhibited in plot 3. The LACIE yield estimates were consistently lower than the USDA/SRS yield estimates in Montana and consistently higher in South Dakota. Combining the two resulted in a consistent overestimation by LACIE over USDA/SRS for the two-state total. The overestimation in South Dakota was due to the incapability of the LACIE yield model for this state to forecast the impact of the unusually dry weather conditions for this crop year. This indicates the need for improved yield models at the zone level for predictions in extreme weather conditions.

The monthly total winter wheat yield estimates for the seven states in the USGP region are given in plot 4. At this level, the LACIE estimates were not significantly different from the USDA/SRS estimates for any of the months reported. In fact, the two final estimates were identical.

Spring Wheat

The LACIE and USDA/SRS spring wheat yield estimates for the two-state spring wheat region of Minnesota and North Dakota are given in plot 5 and the corresponding relative differences are reported in table 4-12. The monthly LACIE estimates of yield for Minnesota were consistently lower than the USDA/SRS estimates. On the other hand, the LACIE estimates of yield for North Dakota were consistently higher than the USDA/SRS estimates. As a result, the LACIE two-state total estimates were very close to the USDA/SRS estimates except for the month of August.

Plot 6 displays the monthly estimates of spring wheat yield by LACIE and USDA/SRS for the two-state mixed wheat region. Table 4-12 contains the corresponding relative differences for these plots. The LACIE estimates of yield for South Dakota were considerably higher than the USDA/SRS estimates. Recall that the same situation occurred for the winter wheat yield estimates for this state. The LACIE yield estimates for Montana, however, were lower but much closer to the corresponding USDA/SRS estimates, except for August when the LACIE estimate was slightly higher. The two-state total spring wheat estimates by LACIE were, as a result, higher but very comparable to the USDA/SRS estimates.

The total spring wheat yield estimates for the four states in the USNGP are given in plot 7. Table 4-12 shows the corresponding relative differences and CV's. The LACIE estimates were not significantly different from the corresponding USDA/SRS estimates for any month reported.

Total Wheat

The LACIE and USDA/SRS monthly total wheat yield estimates for the USNGP are displayed in plot 8 and the relative differences and CV's corresponding to this plot are shown in table 4-12.

The LACIE estimates were consistently higher than the USDA/SRS estimates for all four months, but were not significantly different from them.

The monthly total wheat yield estimates obtained by LACIE and USDA/SRS for all nine states in the USGP are displayed in plot 9 and the corresponding relative differences and CV's are given in table 4-12. The two estimates were not significantly different for any month reported. Hence, the LACIE yield estimates at this level were considerably more accurate (as compared to USDA/SRS estimates) than the LACIE acreage estimates for Phase II.

5. PHASE I SPECIAL STUDIES

A number of special studies that were carried out in Phase I are discussed in this section. With the exception of the crop calendar study described in section 5.5, they are all concerned with the effects of various factors on classification accuracy.

5.1 A STUDY OF THE EFFECTS OF SITE, BIOPHASE, AND AI

5.1.1 INTRODUCTION

A study was conducted to investigate the effects of three major factors — site, biophase, and analyst interpreter (AI) — on errors in the estimation of segment small grains proportions. All 14 AI's operating within CAMS for the LACIE Phase I operations participated in this experiment. The test was run on two intensive test sites (ITS's): segment 1969, Toole County, Montana, and segment 1976, Franklin County, Idaho. These segments were selected because MSS data were available for all four biophases. (Classifications for at least one biophase were missing for all the other ITS's.) Each AI was required to interpret each biophase acquisition for each segment. This resulted in a total of 56 small grains proportion estimates for each segment. The data are given in table 5-1. Table 5-2 lists some general observations made regarding these two sites.

The analysis of variance (ANOVA) approach was used to analyze the data. Let $\hat{X}$ be the CAMS proportions expressed as a fraction rather than a percentage as in table 5-1 and let X be the ground truth proportion. The transformed data T obtained from the standard equation

$$T = \sin^{-1}\sqrt{\hat{X}} \qquad (5\text{-}1)$$

TABLE 5-1.— CAMS PROPORTION ESTIMATE, PERCENTAGE OF SMALL GRAINS

AI	ITS 1969, biophase				ITS 1976, biophase			
	1	2	3	4	1	2	3	4
A	18.8	46.7	50.3	46.6	29.4	29.2	36.7	50.4
B	51.3	36.0	53.6	56.4	49.1	25.2	12.1	30.5
C	16.8	37.4	60.2	31.0	41.0	10.9	17.2	25.7
D	31.4	13.8	53.0	39.3	8.6	15.7	5.6	16.4
E	12.8	47.2	54.6	57.6	23.5	22.6	19.6	32.4
F	35.5	46.6	56.8	57.6	0.0	9.8	0.0	0.0
G	67.5	48.0	52.0	37.0	37.0	25.7	30.5	36.0
H	17.2	41.6	49.0	48.4	22.6	17.8	26.3	26.2
J	25.0	39.7	48.6	38.1	22.6	21.9	30.9	17.4
K	32.1	68.2	32.8	32.1	48.7	10.3	39.4	28.7
L	7.5	44.9	57.4	46.7	42.4	19.6	27.8	35.8
M	25.0	42.5	66.2	47.2	44.2	30.5	35.1	2.9
N	55.2	42.3	38.1	48.3	26.8	21.7	20.2	20.1
O	89.2	36.8	36.1	36.7	49.0	38.3	25.4	48.9
Average per biophase	34.7	42.2	50.6	44.5	31.8	21.4	23.4	26.5
Ground truth	38.3	38.3	38.3	38.3	26.0	26.0	26.0	26.0

TABLE 5-2.— DIFFERENCES IN PHYSICAL CHARACTERISTICS OF INTENSIVE TEST SITES

Factor	Segment	
	1969	1976
Location	Toole County, Montana	Franklin County, Idaho
Size	3.7 by 11 km (2 by 6 n. mi.)	5.6 by 5.6 km (3 by 3 n. mi.)
Small-grain proportion	37.7%	26%
CAMS results	Overestimated in biophases 2, 3, and 4; underestimated in biophase 1	Underestimated in biophases 2, 3, and 4; overestimated in biophase 1
Imagery	10% to 15% cloud cover for biophases 2 and 3	Good
AI	More consistent	Higher variability
Ancillary data	More small grains; less winter wheat; strip cropping	Less small grains; more winter wheat; random field contour; irrigated fields in biophase 1

was used in an attempt to satisfy the uniform variance assumption of the ANOVA model. The difference

$$t = \sin^{-1}\sqrt{\hat{X}} - \sin^{-1}\sqrt{X} \qquad (5\text{-}2)$$

was the response variable to quantify errors in proportion estimates.

5.1.2 ANOVA MODEL

The experimental design is a three-way classification with the following model:

$$t_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + {}_{k} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + e_{ijk} \qquad (5\text{-}3)$$

where

μ = Mean response

α_i = Effect of *ith* site

β_j = Effect of *jth* biophase

$(\alpha\beta)_{ij}$ = Interaction between *ith* site and *jth* biophase

γ_k = Effect of *kth* AI

$(\alpha\gamma)_{ik}$ = Interaction between *ith* site and *kth* AI

$(\beta\gamma)_{jk}$ = Interaction between *jth* biophase and *kth* AI

$(\alpha\beta\gamma)_{ijk}$ = Three-way interaction between *ith* site, *jth* biophase, and *kth* AI

and e_{ijk} is the random error component. It is assumed that $(\alpha\beta\gamma)_{ijk} \equiv 0$ and e_{ijk} is independent and identically distributed as normal with mean 0 and variance σ_e^2. The model is a mixed one in which biophase and AI are considered "fixed" effects and site a random effect. The two sites are considered to constitute a random sample from a large population of sites.

The objectives of this experimental study can now be stated in terms of testing the following hypotheses:

- No "main" effect due to
  - a. site
  - b. biophase
  - c. AI
- No interaction between
  - d. site and biophase
  - e. site and AI
  - f. biophase and AI

5.1.3 RESULTS AND CONCLUSIONS

An examination of data in table 5-1 indicates that proportion estimates varied considerably more in biophase 1 than in other biophases for segment 1969 but not for segment 1976. This suggests that it may be inappropriate to assume the error variance component to be the same for all combinations of sites and biophases or of sites, biophases, and AI's. To explore this conjecture further, analyses of variance were carried out both with and without biophase 1 data. The numerical results obtained for the ANOVA performed on all 112 data points are given in table 5-3(a). Because there was no replication of the data, an unbiased estimate of the error variance could not be obtained; only one observation was available for each combination of factors. The residual mean square error provided an unbiased estimate of the error variance and the three-way interaction (ITS/biophase/AI) variance component.

thus a better evaluation of other factors could be made. Data for table 5-3(c) were obtained by pooling the sums of squares due to biophase, ITS × biophase, and AI × ITS × biophase in table 5-3(b). Once again the same conclusion was reached; i.e., there was significant interaction between ITS and AI, and the ITS effect was highly significnant. Averaging over sites, no significant differences between AI's were found, but this finding has little significance since it was already seen that AI's performed inconsistently between the two sites; i.e., the AI × site interaction was significant.

Based on the above analysis, it was concluded that:

a. The CAMS error in proportion estimation varied significantly from one ITS to another.

b. There was significant difference in the relative performance between AI's from one segment to another.

c. Biophase 1 caused interaction between ITS and biophase. If the two ITS's were not a random sample from a larger population, inference about the site factor could not be widely applied.

5.2 FOUR-AI STUDY OF THE EFFECT OF SMALL GRAINS PROPORTION, AMOUNT OF TRAINING DATA, AND BIOPHASE

In this experiment, four AI's working independently, analyzed all of the acquisitions over the 23 Phase 1 ITS's listed in appendix C. The results were used to study (1) the effect of the proportion of small grains in the segment on proportion error (section 5.2.1), (2) the effect of the amount of training data on proportion error (section 5.2.2), and (3) the effect of biophase on labeling accuracy (section 5.2.3).

Since the latter was assumed to be zero, the residual mean square error became an unbiased estimate of the error variance. On this basis, when F-tests were applied at the 5-percent level of significance, the following conclusion was reached: There was a significant interaction between ITS and AI, and between ITS and biophase, but no significant interaction between biophase and AI. Because of the significant interactions, one cannot arrive at any definitive conclusion about the significance of the individual factors of site, AI, and biophase.

Data investigation suggested that biophase 1 was causing the interaction between ITS and biophase. On the average, proportions were underestimated in biophase 1 and overestimated in biophases 2, 3, and 4 for segment 1969 but the reverse was the case for segment 1976. The data also revealed a lack of homogeneity between biophase 1 and other biophases, and this may be the cause of some of the interaction.

When biophase 1 was omitted in the data analysis, the results of the ANOVA were as listed in table 5-3(b). The F-test was applied on the same basis as for the (a) portion of the table and the following results were obtained:

a. There was significant interaction between ITS and AI.

b. There was no significant interaction between ITS and biophase.

c. The site effect was highly significant.

d. There was no significant interaction between AI and biophase.

e. The biophase effect was not significant.

Since biophase was not a significant factor in terms of its main effect or its interaction with other factors, it could be "replicated"; i.e., sums of squares involving biophase terms could be pooled to form a more precise estimate of error variance, and

TABLE 5-3.– ANALYSES OF VARIANCE OF INTENSIVE TEST SITE DATA

(a) With biophase as a factor

Source of variation	Degrees of freedom	Sum of squares	Mean square error	F-ratio
Site	1	0.11113	0.11113	4.21
Biophase	3	.02419	.00806	.11
AI	13	.70676	.05437	1.10
ITS vs biophase	3	.22339	.07446	[a]2.82
ITS vs AI	13	.64351	.04950	[a]1.87
Biophase vs AI	39	.91976	.02358	.89
Residual (site vs biophase vs AI)	39	1.03020	.02642	
Total	112	3.65894		

(b) Without biophase 1

Source of variation	Degrees of freedom	Sum of squares	Mean square error	F-ratio
Site	1	0.26860	0.26880	[b]13.64
Biophase	2	.01933	.00967	1.54
AI	13	.40112	.03086	.74
ITS vs biophase	2	.01259	.00629	.32
ITS vs AI	13	.54343	.04180	[a]2.12
Biophase vs AI	26	.34931	.01344	.68
Residual (site vs biophase vs AI)	26	.51247	.01971	
Total	83	2.01685		

(c) With biophase treated as a replicate

Source of variation	Degrees of freedom	Sum of squares	Mean square error	F-ratio
Site	1	0.26860	0.26880	[b]16.8
AI	13	.40112	.03086	.73
Site vs AI	13	.54343	.04180	[a]2.61
Error	56	.89370	.01596	

[a]Significant at the 5-percent level.

[b]Significant at the 1-percent level.

5.2.1 EFFECT OF THE PROPORTION OF SMALL GRAINS IN THE SEGMENT

Figure 5-1 is a plot of proportion error as a function of ground truth small grains porportions. Proportion error is defined as

$$\hat{X} - X$$

where

$\hat{X}$ = CAMS estimated small grains proportions

X = Ground-observed small grains proportions.

The plot shows that the sites that were low in small grains were mostly overestimated and the sites that were high in small grains were mostly underestimated. The same type of plot was made for each biophase, each AI, and each group of ITS's within a state. All plots reflected the same behavior as that depicted in figure 5-1. This behavior can be explained theoretically as follows: Let X be the proportion of small grains in a segment and $\hat{X}$ its estimate made by CAMS. Then, the expected proportion error (i.e., bias) can be expressed as

$$E(\hat{X}) - X = X(1 - \alpha) + (1 - X)\ \beta - X \qquad (5\text{-}4)$$

$$= \beta - (\alpha + \beta)X$$

where α denotes the proportion of small grains pixels classified as "other" (i.e., non-small-grains) and β is the expected proportion of "other" pixels classified as small grains. So, for a fixed value of $(\alpha + \beta)$, the bias in $\hat{X}$ is a decreasing function of X. Moreover, if $X \leq 1/2$,

$$E(\hat{X}) - X \geq (\beta - \alpha)/2 \qquad (5\text{-}5)$$

$$\geq 0, \text{ provided } \beta \geq \alpha$$

and if $X > 1/2$,

$$E(\hat{X}) - X < (\beta - \alpha)/2 \qquad (5\text{-}6)$$

$$< 0, \text{ provided } \beta < \alpha$$

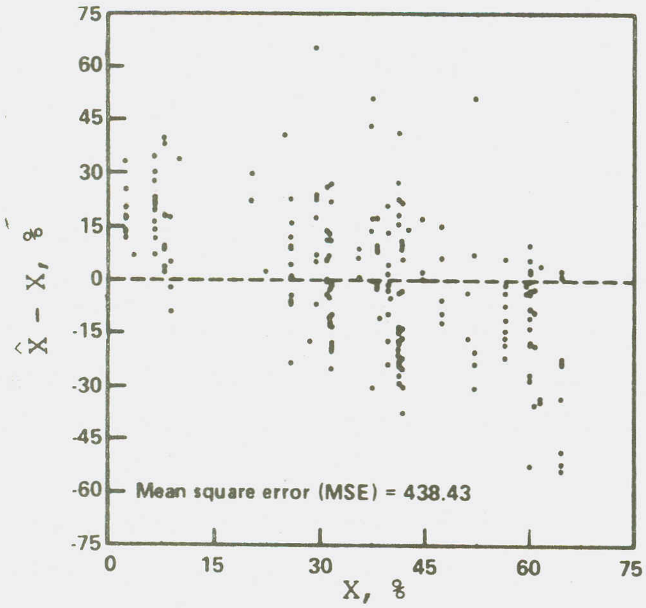


Figure 5-1.— Proportion error versus ground truth small grains proportions.

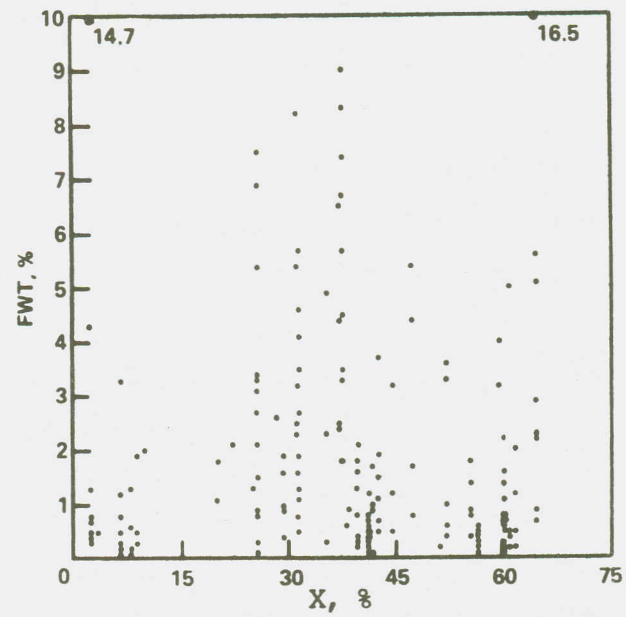


Figure 5-2.— Fraction of the classified wheat thresholded versus ground truth small grains proportions.

Data depicted in figure 5-1 seems to suggest that the conditions in equations (5-5) and (5-6) regarding the two types of errors are "fairly" well satisfied when X is very small or X $\geq$ 1/2.

Thresholding

For a further explanation of these two types of errors, and thus dependence of proportion error on X, the thresholding aspect of the CAMS operation was investigated. Since thresholded pixels were considered as "other", it was likely that fewer pixels classified as small grains would be thresholded from sites that had low small grains density; whereas, more pixels classified as small grains would be thresholded in sites with high small grains density. To determine whether thresholding could be a factor contributing to the trend depicted in figure 5-1, the fraction of the ground truth area which was actually small grains, but was thresholded out (FWT) was plotted versus the ground truth small grains proportion (figure 5-2). The ground truth area is the portion of a segment for which ground truth was collected. FWT is the difference between a proportion estimate with no threshold and a proportion estimate with a 1-percent threshold. Data in figure 5-2 show no trend in FWT when plotted against X; thus, thresholding can probably be discarded as an explanation of the results depicted in figure 5-1.

5.2.2 EFFECT OF THE AMOUNT OF TRAINING DATA

Since each of the four AI's worked independently, there were four different sets of training data for each ITS/biophase combination, each having a different number of pixels. Figure 5-3 shows a plot of proportion error versus the number of training pixels. Although one can see a slight reduction in proportion error as the number of training pixels increased, only a limited amount of information can be gained by the study of this plot, the reason being that the amount of training data selected by the AI's was very much site dependent. That is, the four AI's tended to choose only slightly different amounts of training data within a given site, but the amount varied considerably from one ITS to another, since proportion error was found to be highly dependent on site. Figure 5-3 reflects mainly the differences in sites but does not reveal much about the effect of the number of training pixels.

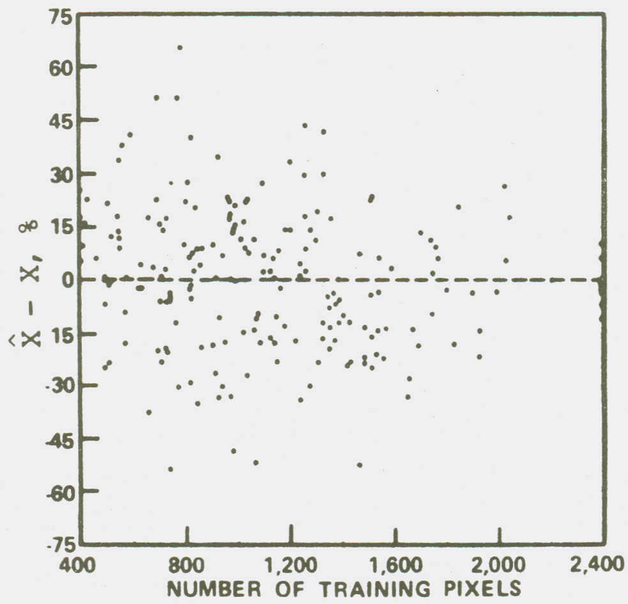


Figure 5-3.— Proportion error versus the number of training pixels.

5.2.3 EFFECT OF BIOPHASE ON LABELING ACCURACY

An effort was made to determine which biophase, or combination of biophases, provided the most success in labeling training fields. The area of ground truth varied from one ITS to another, whereas the AI-selected training fields were taken from any place within the segment. The accuracy data presented in table 5-4 refer only to those fields which were selected from the ground truth area of each segment.

The labeling accuracies varied a great deal from ITS to ITS but were relatively consistent for fields within sites. Thus, the tabulated results, which were based on two or more sites, were not very accurate as measures of average expected performance.

TABLE 5-4.— TRAINING FIELD LABELING ACCURACY BY BIOPHASE

Biophase	PCLW	PCLO	Number of sites averaged
1	0.404	0.715	22
1, 2	.583	.946	9
1, 3	.677	.821	8
1, 4	.660	.876	3
1, 2, 3	.538	.946	3
1, 2, 4	.847	.346	1
1, 3, 4	.900	.922	3
1, 2, 3, 4	.235	.927	2

In summary, it appears that the accuracy of CAMS wheat proportion estimation, as well as training field labeling, is site dependent. This is partly a result of the small grains density in a site/segment. The proportion estimates were found to be relatively high for low-density sites and lower for high-density sites.

5.3 CAMS REWORK EXPERIMENT

Several serious implementation problems were uncovered in the initial Phase I quasi-operational CAMS system. These were corrected and the Landsat data reanalyzed by CAMS. The resulting area estimates were referred to as the CAMS rework estimates.

An experiment was designed to test the ability of the CAMS rework operations to improve small grains proportion estimates for segments that had been processed previously. Eleven ITS's were selected for the experiment, including three in Kansas and three in Texas, with the remaining five segments distributed in Montana and in North and South Dakota. The Kansas and Texas sites were selected to provide information on the USSGP. The remaining sites were selected to augment the knowledge acquired from the blind site study of the mixed and spring wheat sites in the USNGP.

The acquisition dates were selected to be representative of imagery available in actual operations. No more than one acquisition per biophase was used, and biophases were determined by actual crop calendars. All sites were ITS's over which at least two passes had been made, and each had an acquisition from either biophase 2 or 3 (table 5-5).

The sites were worked by each of four AI/Data Processing Analyst (AI/DPA) Teams randomly selected from teams which were familiar with CAMS rework methodology. Each AI/DPA Team reviewed the initial processing of each segment and accepted or reworked it for an estimate of the proportion of small grains in the segment.

5.3.1 COMPARISON OF CAMS REGULAR VERSUS CAMS REWORK RESULTS

Table 5-6 shows the results of the comparison of CAMS regular versus CAMS rework results. In 27 percent of the cases (12 out of 44), the results were improved by the CAMS rework procedure; in 23 percent of the cases (10 out of 44), the results were made worse by the CAMS rework procedure. In the other cases the segment was either declared unworkable or the original result was accepted. These results did not give any clear indication of whether or not the CAMS rework procedure gives better results than the CAMS regular procedure.

5.4 BLIND SITE PROPORTION ERRORS IN CAMS REGULAR AND REWORK PROCEDURES

Ground truth was collected from North Dakota and Minnesota LACIE operational segments which had been acquired and processed for at least two biophases. These sites were selected after biophase 2, thus providing a greater proportion of three and four acquisitions from a segment and allowing multitemporal processing. Aircraft

TABLE 5-5.— ACQUISITIONS FOR CAMS REWORK EXPERIMENT

Segment	Acquisition number for biophase			
	1	2	3	4
1687	74133		75205	
1960	74291		75150	
1962	74324	75131		
1963	74289	75131		
1965	75155	75191		
[a]1967				
1969	75161	75179	75215	75233
1970	75142	75179		75233
1978	74291		75133	
1979	74291		75133	
1980	74291		75133	
1986	75150	75169	75187	

[a]Not suitable for processing because of lack of ground truth.

TABLE 5-6.— COMPARISON OF CAMS REGULAR VERSUS REWORK RESULTS

I = Improved results
W - Worse than original
N = Original accepted
U = Segment declared unworkable

Segment	AI/DPA Team			
	A	B	C	D
1687	I	W	I	U
1960	N	N	N	N
1962	I	I	N	W
1963	I	I	N	W
1965	N	N	W	N
1969	N	I	W	I
1970	N	W	W	W
1978	N	N	N	I
1979	N	N	N	N
1980	N	W	I	W
1986	I	I	U	U
Totals	12 I's	3 U's	10 W's	19 N's

photography was obtained for each of the 25 segments and photo-interpreted to obtain ground truth small grain proportions. (For some representative segments this ground truth was corroborated by visual inspection on the ground.)

Small grain proportion estimates obtained for these segments with CAMS regular and rework procedures were compared with their ground truth proportions. The CAMS regular estimates were those obtained using the regular CAMS operational procedures applied to the last acquisition available for each blind site. The CAMS reworked estimates were obtained for 19 segments. Of these, 10 were actually reprocessed and for the other nine segments, the original classification was declared acceptable by the rework team. This acceptance qualifies a segment to be considered a "reworked" segment.

Figures 5-4 and 5-5 show the CAMS proportion errors plotted as a function of the ground truth proportions. These figures appear to show that proportions were overestimated by the CAMS regular procedure and underestimated by the CAMS rework procedure; however, in both cases, the Wilcoxon matched-pairs signed-rank test* failed to reject the hypothesis of symmetric proportion errors around zero.

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*R. P. Runyon and A. Haber, Fundamentals of Behavioral Statistics, Addison-Wesley Publishing Co., Reading, Mass., 1971, pp 263-265, 308, etc.

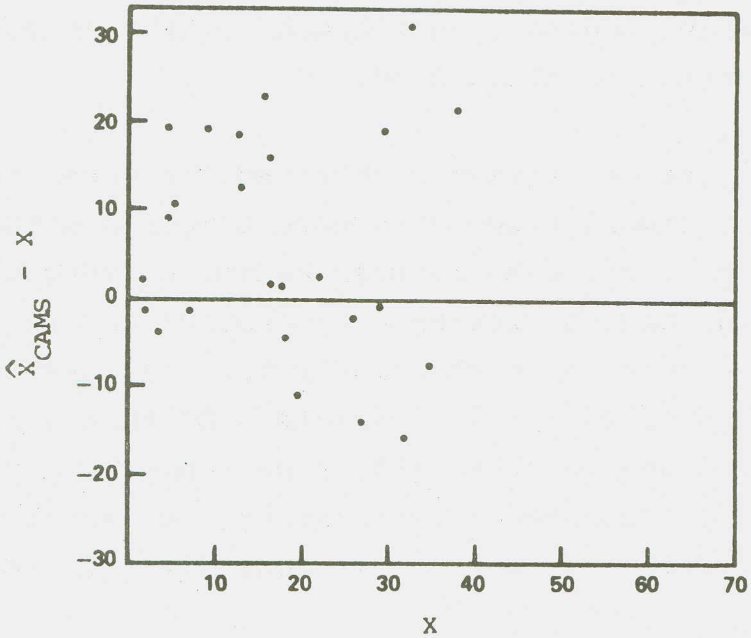

Figure 5-4.– Errors in the CAMS regular estimates as a function of X.

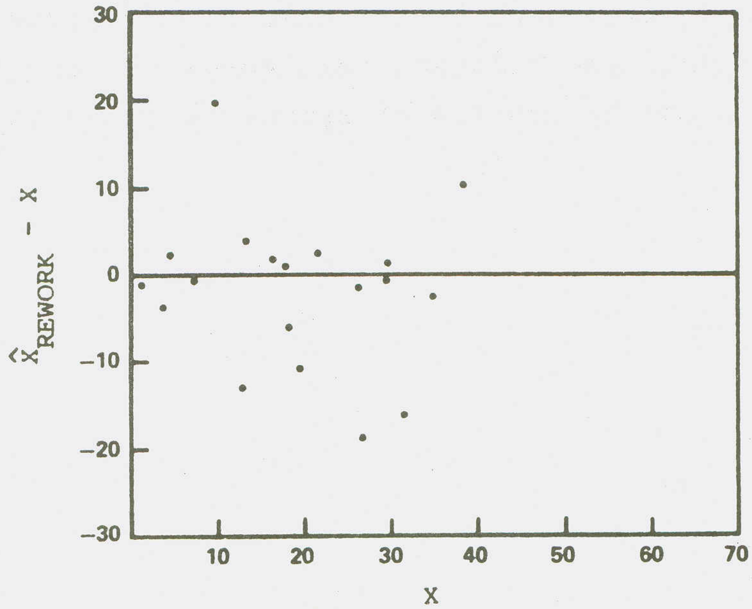

Figure 5-5.– Errors in the CAMS reworked estimates as a function of X.

5.5 CROP CALENDAR VERIFICATION

To assess the performance of the adjustable crop calendar (ACC) the ACC output for the USGP region CRD's in which the Phase I ITS's were located was compared to average crop calendar output and to ground truth. The ACC for each ITS used in comparison is listed in table 5-7. Because ground-truth data were not received by the Data Acquisition, Preprocessing, and Transmission Subsystem (DAPTS) of the LACIE, data sets for the following ITS's were not analyzed and thus were not included in this study.

- Segment 1964, CRD 50, Ellis County, Kansas
- Segment 1962, CRD 50, Saline County, Kansas
- Segment 1968, CRD 20, Glacier County, Montana
- Segments 1687 and 1986, CRD 50, Hand County, South Dakota
- Segment 1967, CRD 10, Divide County, North Dakota

The Phase I biophases and their respective biological wheat stages are as follows:

Biophase	Biological wheat stage	
	Number	Activity
1	1	Planting
	2	Emergence
2	3	Jointing
3	4	Heading
4	5	Soft dough
	6	Ripening
	7	Harvest

TABLE 5-7.- ADJUSTABLE CROP CALENDAR FOR U.S. GREAT PLAINS INTENSIVE TEST SITES

County	Segment	CRD	Biophase 1		Biophase 2	Biophase 3	Biophase 4		
			Planting	Emergence	Jointing	Heading	Soft dough	Ripening	Harvest
Kansas (winter wheat)									
Finney	1960	30	9/20/74	9/24/74	4/20/75	5/17/75	6/13/75	6/27/75	7/02/75
Morton	1961	30	9/12/74	9/22/74	5/08/75	5/14/75	6/15/75	6/24/75	6/30/75
Rice	1963	50	9/20/74	9/27/74	4/05/75	5/11/75	6/14/75	6/28/75	7/02/75
Texas (winter wheat)									
Deaf Smith	1979	11	9/22/74	9/30/74	4/15/75	5/15/75	6/10/75	6/25/75	6/30/75
Oldham	1980	11	9/10/74	9/18/74	4/08/75	5/12/75	6/08/75	6/21/75	6/22/75
Randall	1978	11	9/15/74	9/23/74	4/10/75	5/10/75	6/05/75	6/20/75	6/23/75
Minnesota (spring wheat)									
Polk	1987	10	5/16/75	5/25/75	6/24/75	7/05/75	7/27/75	8/11/75	8/16/75
Montana (spring wheat)									
Hill	1971	20	5/15/75	5/25/75	7/08/75	7/20/75	8/08/75	8/20/75	9/12/75
Liberty	1970	20	5/16/75	6/02/75	7/11/75	7/28/75	8/15/75	9/08/75	9/17/75
Toole	1969	20	5/25/75	6/06/75	6/27/75	7/10/75	8/15/75	9/20/75	10/05/75
North Dakota (spring wheat)									
Burke	1965	10	5/24/75	6/03/75	7/03/75	7/16/75	8/05/75	8/27/75	9/08/75
Williams	1966	10	5/21/75	5/31/75	6/17/75	7/12/75	8/02/75	8/25/75	9/15/75

The crop calendar comparisons are graphically depicted and discussed in the following subsections.

5.5.1 KANSAS (WINTER WHEAT)

Segment 1960, Finney County

Finney County is located in the north-central portion of the CRD. The wide range between the ACC and the ground-truth curves is attributed to differences in jointing dates between the ITS and USDA/SRS state averages (fig. 5-6). The jointing data on which the ACC was started was May 6, 1975. This date was supplied by the USDA/SRS office in Kansas and represents the CRD average 50-percent jointing date. In comparison, the ITS 50-percent jointing date was April 20, 1975.

Segment 1961, Morton County

Located in the extreme southwest corner of the CRD, the data from this ITS may not be representative of the entire CRD. However, the meterological data used to effect the calendar adjustments were derived from stations located in Dodge City, Kansas, and Gage, Oklahoma. Dodge City, which is located in the extreme northeast corner of CRD 7, and Gage are equidistant from the ITS. An apparent discrepancy exists in the ground-truth data, inasmuch as the period between jointing and heading is too short to be realistic (fig. 5-6). If the dates for the other two ITS's are used as a guide, it would suggest that the jointing date is incorrect.

Segment 1963, Rice County

The location of this ITS is in the south-central part of the CRD. The ground-truth data do not compare favorably, especially in the early stages of development (fig. 5-6). The NOAA *Weekly Weather and Crop Bulletin* reported wheat development noticeably behind the normal curve on April 22, 1975. The state averages for Kansas

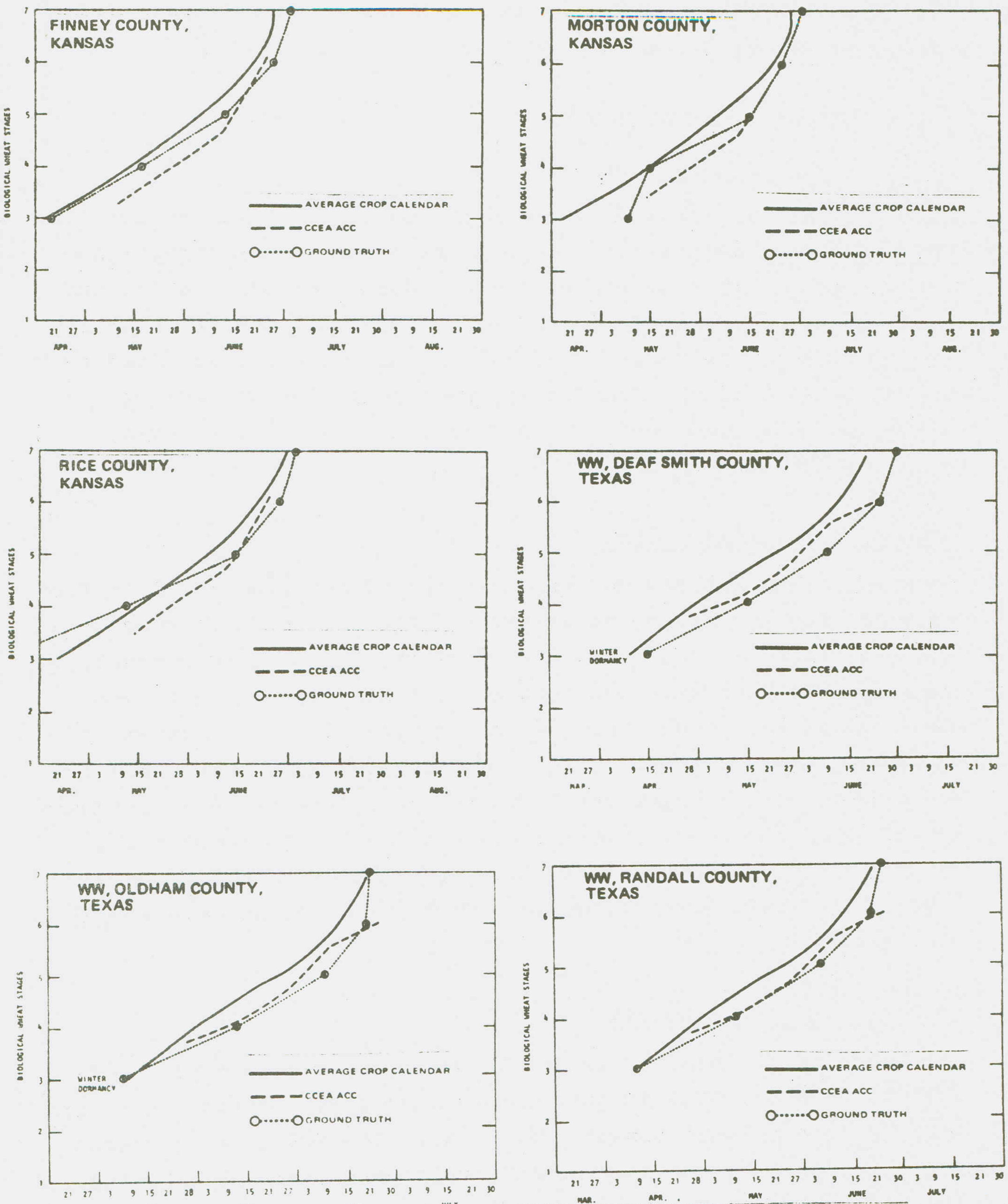

Figure 5-6.– Crop calendar comparisons (winter wheat).

reported 10 percent jointed compared to 45 percent in 1974 and a 40-percent average. The ITS ground-truth data reported 50 percent jointing on April 5. The state average reported the 50-percent jointing date as May 1. The 50-percent jointing date for the CRD, as supplied by the USDA/SRS, is May 3. The ground-truth date for 50-percent jointing is April 5. This, again, is the obvious contributor to the wide range between the ACC and ground truth from the jointing through the soft-dough stages. From all appearances, the ITS dates appear to be either (1) erroneous or (2) the development of wheat within the ITS for the 1975 season was a clear exception from the normal reported state and CRD averages.

The trend in all three of the comparisons for Kansas indicates a difference in the interpretation of the 50-percent jointing dates between the ITS-, the state-, and the CRD-level USDA/SRS averages. The biggest discrepancies between the ITS and ACC data are attributed to the difference in interpretation rather than to the location of the ITS within the CRD.

5.5.2 TEXAS (WINTER WHEAT)

Segment 1979, Deaf Smith County

Deaf Smith County is located in the west-central part of this CRD, which is in the Texas Panhandle. The minimum and maximum temperatures of record most representative of that area were obtained from Amarillo, Texas, approximately 64 kilometers (40 miles) east of the ITS and at a slightly lower elevation. The difference (warmer at the meteorological station because of the lower elevation) between the ITS temperature and the average temperature for the CRD would probably account for the slightly advanced CCEA crop calendar readings (plot 4, fig. 5-6).

Segments 1980 and 1978, Oldham and Randall Counties

These two ITS's are in close proximity to the nearest meteorological reporting station. Consequently, the minimum and maximum temperatures used to effect the adjustments will keep the ACC output in closer agreement with the ground truth (fig. 5-6.)

5.5.3 MINNESOTA (SPRING WHEAT)

Segment 1987, Polk County

The ACC was not run for Minnesota until June 24, 1975; consequently, no comparison was made through the jointing stage. Segment 1987, Polk County, is close to the center and should be representative of the CRD. The only discrepancy appears around the heading stage (figure 5-7). The meteorological data prior to the crop calendar adjustment date indicated unseasonably cool weather [with a -21° C (-6° F) deviation from the weekly normal temperature]. The NOAA *Weekly Weather and Crop Bulletin* for Minnesota covering the period of July 7 through 13, 1975, reported there was "small grain ripening in the southern two-thirds, but in important northern counties a lot of acreage not yet headed."

5.5.4 MONTANA (SPRING WHEAT)

Segment 1971, Hill County

The major difference between the ITS ground-truth data and the ACC output was the reported planting data for the CRD and for the ITS (fig. 5-7). The ACC model performed very well in the ITS throughout the season. This was a late season for Montana, which the ACC tracked very well.

Segments 1970 and 1969, Liberty and Toole Counties

Both of these ITS's are located in the northwest part and may not be representative of the other wheat-growing areas within the CRD. The most obvious discrepancy between the ground-truth data and

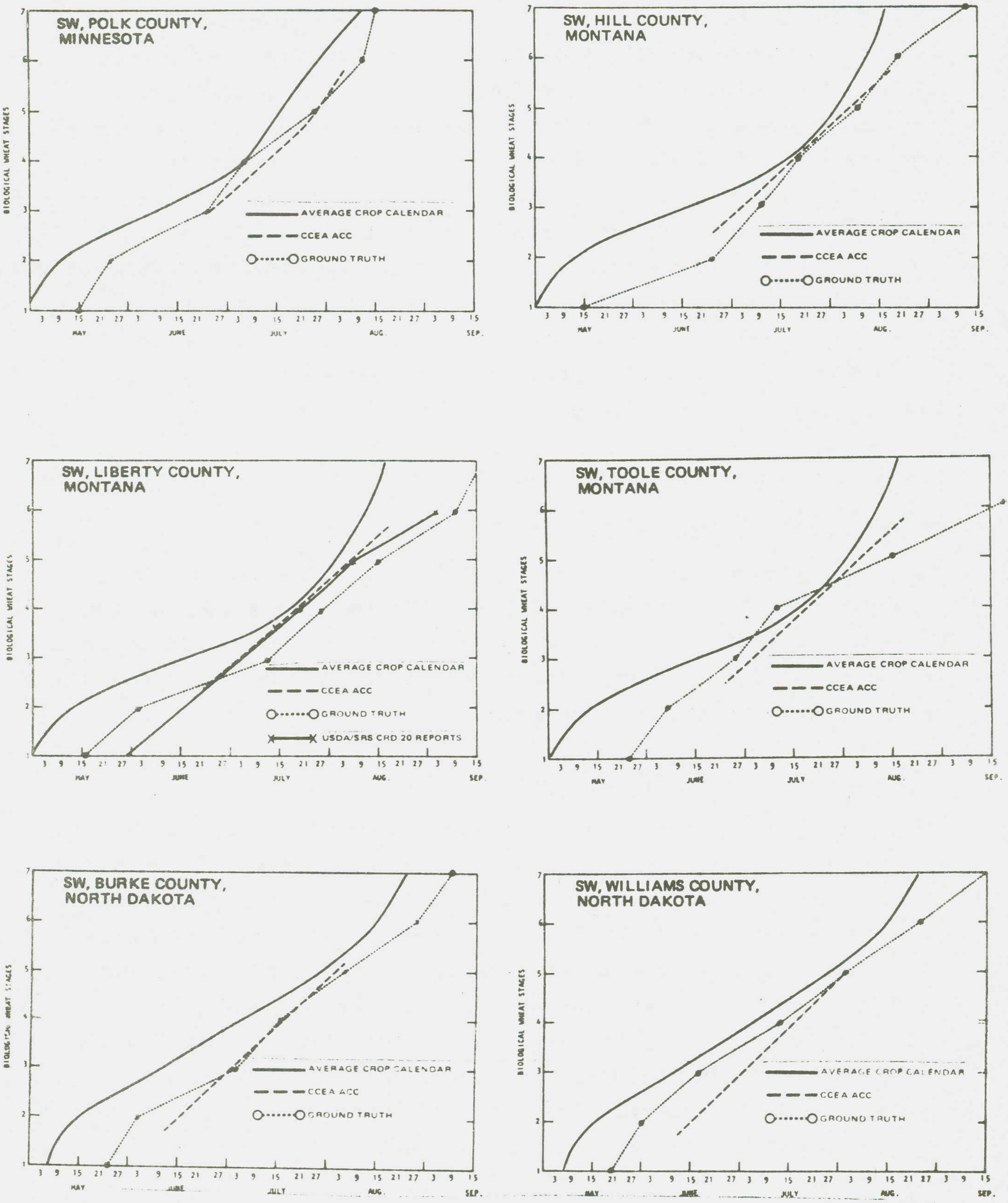

Figure 5-7.– Crop calendar comparisons (spring wheat).

ACC plots is the fact that the Liberty County ground-truth crop calendar is consistently slower than the ACC (fig. 5-7). The Toole County plot (plot 4) is first fast and then slow after the heading stage. This suggests unusually large differences in the development of wheat between the two ITS's, which are located only approximately 48 kilometers (30 miles) apart. The fact that one is slower and the other faster than the ACC indicates that the ACC may indeed be providing a good average for that CRD. A comparison against the USDA/SRS CRD average confirms this. (The USDA/SRS CRD average is plotted on the Liberty County plot. It is noteworthy that the 50-percent dates for emergence and jointing were not made available and are not plotted.)

5.5.5 NORTH DAKOTA (SPRING WHEAT)

Segment 1965, Burke County

The ITS planting date was May 24, 1975; the USDA/SRS planting date for the CRD as supplied to the CCEA for comparison to the model was May 30. After allowances were made for the difference in planting dates, no significant differences were apparent for the remainder of the crop calendar.

Segment 1966, Williams County

This ITS is located in the center of the county, which is in the southwest part of the CRD. The meteorological input is provided by Williston, North Dakota, minimum and maximum temperature reports. The reports from this station are more representative of the ITS than of the CRD because of the station's close proximity to the ITS. Elevation differences are minimal. The CRD planting date supplied by USDA/SRS to start the ACC was May 30, 1975; the ITS planting date was May 21 (fig. 5-7). This difference in dates accounts for the difference in the initial development stages between the ITS and the ACC plot.

5.5.6 RESULTS OF ACC ANALYSES

To summarize the evaluations in sections 5.5.1 through 5.5.5, the ACC performance for Phase I operations during the jointing-to-soft-dough stage for winter wheat and the planting-to-soft-dough stage for spring wheat in the U.S. Great Plains appeared to be quite good, assuming the validity of planting dates. The biggest discrepancies were early in the season – at jointing for winter wheat and at planting for spring wheat. An 8- to 10-day disagreement occurred between the dates the USDA/SRS reported for the CRD (which were used as starter dates for the ACC) and the ITS ground-truth data. The ITS ground truth and ACC output were closest to agreement at the heading and soft-dough stages. Indications are that more accurate starter dates would have allowed the ACC to perform more accurately throughout the spring and summer.

The results of the study show that

a. Accurate starter models for spring wheat are vital to good overall performance of the ACC.

b. Proper operation of the ACC for winter wheat before and through dormancy to provide an accurate estimate of jointing in spring is vital to the overall operation of the ACC for winter wheat.

6. PHASE II SPECIAL STUDIES

This section contains a description of several special studies performed in Phase II. All of the ITS investigations were considered to be special studies even if they were similar to the blind site studies reported in section 4.

6.1 ITS STUDY OF THE DEPENDENCE OF CAMS ERROR ON TRUE WHEAT PROPORTIONS

The ITS's were not aggregated by CAS but they were processed by CAMS as if they were regular sample segments; i.e., an estimate of the small grains proportion within the ITS was made using Phase II classification procedures. The analyst selecting the training data did not have access to the ground truth data.

Winter Wheat

In Phase II there were 32 acquisitions from 14 winter wheat ITS's located in Kansas, Washington, Idaho, Texas and Indiana. The CAMS errors for these acquisitions are plotted as a function of ground truth wheat* proportion in figure 6-1. The overall trend is similar to that observed in the blind site data (figure 4-3), i.e., there is a trend toward negative values of $\hat{X} - X$ as X increases. In fact, for X > 28 percent there is only one acquisition for which the CAMS result is not an underestimate relative to ground truth. Similar results were found for the blind site data (section 4.2.2.1). The data points in figure 6-1 do not constitute a random sample since in many cases two or three of them correspond to different acquisitions of the same segment. Therefore, a statistical analysis of these data was not performed.

*The CAMS wheat proportions were obtained by ratioing the CAMS small grains proportions.

Spring Wheat

In Phase II there were 16 acquisitions from 10 spring wheat ITS's. There were two from ITS's in North Dakota, two in Montana, and one in Minnesota. The other 11 acquisitions were from three ITS's in Canada.

Figure 6-2 shows a plot of the CAMS classification errors as a function of ground truth proportions. There is a tendency toward negative values of $\hat{X} - X$ as X increases, but it is less well developed than in the spring wheat blind site data (section 4.2.2.2). In particular, five out of the fifteen points for X > 25 percent correspond to positive values of $\hat{X} - X$. A statistical analysis was not performed on these data for the same reason given above for the winter wheat data.

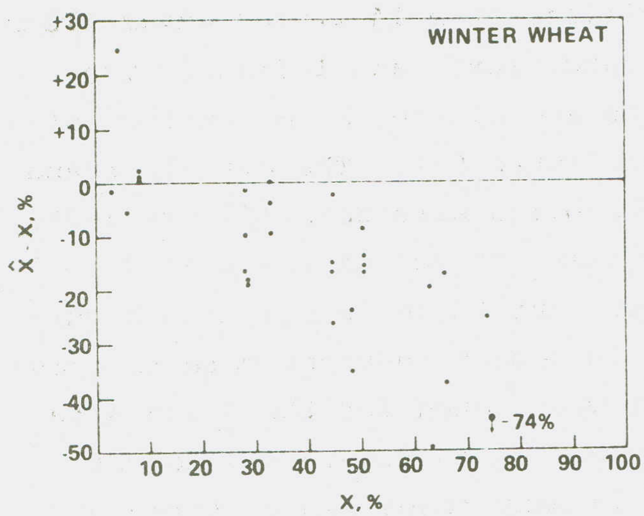

Figure 6-1.— Plot of CAMS classification error as a function of ground truth wheat proportions.

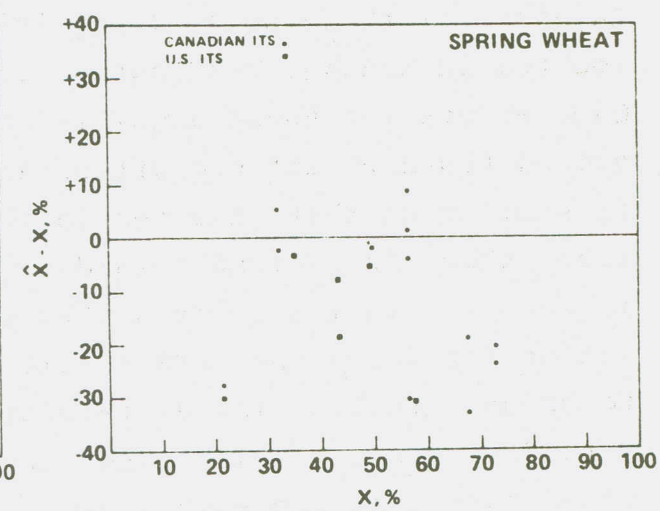

Figure 6-2.— Plot of CAMS classification error as a function of ground truth wheat proportions.

6.2 INVESTIGATION OF THE DEPENDENCE OF CAMS ERROR ON ACQUISITION DATE

In this section, "acquisition date" refers to the date of the last acquisition used to classify the CAMS data. The CAMS classifications were based on this acquisition and on all previous acquisitions. Two studies of the dependence of CAMS error on acquisition date were conducted in Phase II. One of these was an ITS investigation (section 6.2.1) and the other was a blind site investigation (section 6.2.2).

6.2.1 ITS INVESTIGATION

The data used in these investigations were the same as those used in the investigations reported in section 6.1 for both winter and spring wheat.

Winter Wheat

Figure 6-3 shows the plot of the winter wheat CAMS errors as a function of acquisition date. It will be seen that the estimates based on very early acquisitions (before December) have very large errors. For later acquisitions the only well developed trend seems to be a consistent underestimation. The overall average of $\hat{X} - X$ was -14.4 percent. When estimates based on acquisitions before December 1975 were omitted, the average of $\hat{X} - X$ was -9.6 percent.

Spring Wheat

Figure 6-4 shows the plot of the CAMS error as a function of the acquisition date for spring wheat. There is a clear tendency toward underestimation for early acquisitions and overestimation for late acquisitions. All the acquisitions before the first week in August led to underestimates and all the acquisitions after the first week in August led to overestimates.

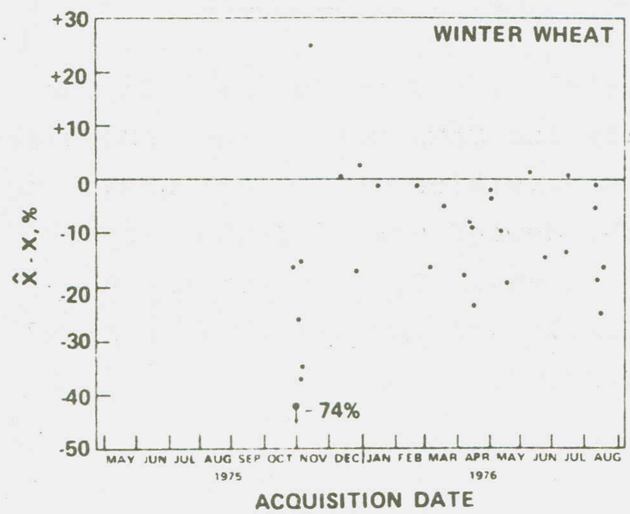

Figure 6-3.— Plot of CAMS error as a function of acquisition date for winter wheat.

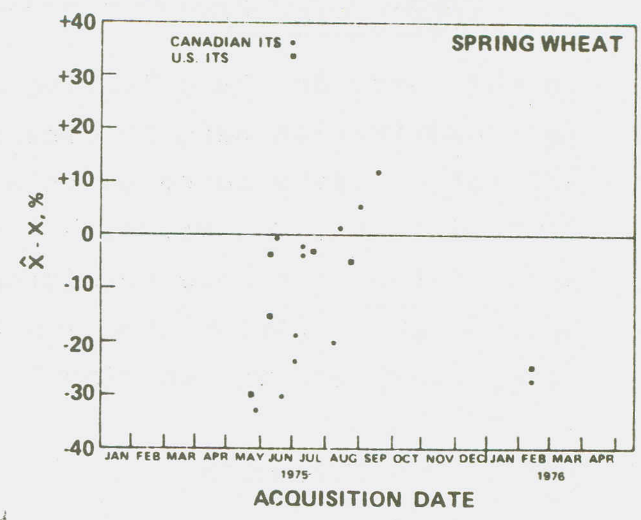

Figure 6-4.— Plot of CAMS error as a function of acquisition date for spring wheat.

6.2.2 BLIND SITE INVESTIGATION

In this investigation the average errors for blind site wheat proportions in the USGP were studied as a function of the month of the latest acquisition used by CAMS to obtain their estimate of wheat proportions. All of the winter wheat blind sites in the USGP for which data were available were used. Spring wheat was not studied because data were not available for enough segments.

Table 6-1 gives the mean squared error, the bias, and the standard deviation for each month from Novermber 1976 to July 1977. Also given is the number of sites for each month. Each site used had at least one acquisition in that month. Since the same set of sites was not used for each month, some of the variation from month to month was due to a corresponding change in the sample. The most interesting result shown in table 6-1 is the large drop in the mean squared error and standard deviation in April, followed by an increase in May and June. The same trend was observed for most of

TABLE 6-1.— FULL-MONTH CLASSIFICATION ERROR FOR WINTER WHEAT

Acquisition Period	MSE	Bias	Std Dev	Number of Sites
11/1 - 11/30	120.1	-4.5	10.1	36
12/1 - 12/31	161.8	-5.0	11.8	47
1/1 - 1/31	114.9	-5.5	9.3	61
2/1 - 2/29	123.5	-5.7	9.6	60
3/1 - 3/31	80.5	-1.3	8.9	64
4/1 - 4/30	45.2	-3.3	5.9	63
5/1 - 5/31	70.2	-0.9	8.4	82
6/1 - 6/30	84.3	-2.9	8.8	88
7/1 - 7/31	48.3	-0.6	7.0	58

TABLE 6-2.— MID-MONTH TO MID-MONTH CLASSIFICATION ERROR FOR WINTER WHEAT

Acquisition Period	MSE	Bias	Std Dev	Number of Sites
11/16 - 12/15	85.1	-3.4	8.7	27
12/16 - 1/15	191.8	-7.0	12.1	42
1/16 - 2/15	110.0	-5.1	9.2	65
2/16 - 3/15	108.6	-4.2	9.6	73
3/16 - 4/15	57.7	-1.1	7.6	59
4/16 - 5/15	54.7	-1.3	7.3	80
5/16 - 6/15	72.9	-2.7	8.1	92
6/16 - 7/15	70.6	-2.1	8.2	66
7/16 - 8/15	36.5	0.0	6.1	31

the individual states. Also, there was a significant decrease in the magnitude of the bias in March.

Table 6-2 gives similar results with the exception that the acquisition windows were shifted by 15 days in an attempt to assess the effect of sampling. The same overall pattern exists except that in this case "minimum" in the mean squared error and standard deviation is spread over the period of March 16 through May 15 and the decrease in the bias is in the period of March 16 through April 15.

6.3 ITS STUDY OF LABELING AND CLASSIFICATION ERRORS

After the normal processing was completed for a given ITS, accuracy assessment personnel randomly selected approximately 15 wheat and 15 nonwheat test fields in the ground truthed area of the ITS. The ground truthed area was usually 3 × 3 miles and in any case was always smaller than the segment area (5 × 6 nautical miles). The test fields were selected so as not to overlap any of the training fields chosen by the analyst.

The test fields were used to determine the probability of correct classification (PCC) by comparing the classification results for these fields with ground truth on a pixel-by-pixel basis.

Labeling error was studied by determining the percentage of training fields in the ground truthed area that were labeled correctly. Usually there were only eight to ten such fields since, in general, less than one-half of the total number of training fields were in the ground truthed area.

Winter Wheat

Table 6-3 shows the results obtained in the final classification for the winter wheat ITS's.

Labeling accuracy was determined for seven ITS's. For non-small grains (NSG) the labeling accuracy was 100 percent for five of the six cases, but for small grains (SG) the labeling accuracy was 100 percent for only three of the six cases. In three cases the labeling accuracy for SG was less than that for NSG, and in one case the labeling accuracy for SG was greater than that for NSG. Thus, the labeling accuracy was considerably better for NSG than for SG.

The probability of correct classification was determined for 11 of the winter wheat ITS's. In all but one of these the PCC for NSG was higher than for SG, and the average value for SG (63 percent) was considerably lower than that for NSG (86.9 percent). Thus, the error of omission (classifying SG as NSG) is considerably larger than the error of commission (classifying NSG as SG).

The fact that the PCC for SG is 27 percent lower than that for NSG whereas the labeling accuracy for SG is only 10 percent below that for NSG suggests that the low value for the PCC for SG was probably due in part to the analysts missing some SG signatures. This is probably a major cause of the observed under-estimation.

Spring Wheat

Table 6-4 shows the results obtained in the final classification for the spring wheat ITS's in the U.S. and Canada. Training field labeling accuracy was not available for these sites.

TABLE 6-3.— ITS WINTER WHEAT FINAL CLASSIFICATION RESULTS

Segment	State	Acq	$\hat{X}$	X	$\hat{X}$ - X	PCC		Labeling Accuracy	
						SG	NSG	SG	NSG
1961	Kansas	2006	8.8	8.2	0.6	HC	HC	HC	HC
1962	Kansas	3645	49.0	66.1	-17.1	62.7	78.3	100	100
1963	Kansas	2346	34.0	50.7	-16.7	66.5	94.8	75	100
1964	Kansas	1276	42.7	44.9	-2.2	93.4	79.5	100	100
1988	Kansas	1276	29.2	33.0	-3.8	67.4	97.3	—	—
1972	Washington	2316	48.8	74.0	-25.2	53.2	100	—	—
1973	Washington	1786	29.9	44.7	-14.8	78.9	99.5	100	100
1974	Washington	1426	43.6	63.1	-19.5	42.5	58.7	—	—
1976	Idaho	2266	26.8	28.2	-1.4	52.3	53.7	75	67
1977	Idaho	2276	9.6	28.7	-19.1	47.9	99.3	75	100
1978	Texas	1106	24.7	48.4	-23.7	51.1	99.5	80	100
1980	Texas	0566	1.6	3.0	-1.4	HC	HC	HC	HC
1982	Indiana	2266	0.6	6.0	-5.4	HC	HC	HC	HC
1983	Indiana	3215	29.1	4.5	24.6	78.0	95.8	—	—
Average			27.0	35.9	-8.9	63.0	86.9	86	95

Acq = Julian day; last digit indicates year; e.g., 2006 indicates that the segment processed was the 200th day of 1976.

HC = indicates that a hand count was performed.

$\hat{X}$ = CAMS small grains proportion estimate for the ground truthed area.

X = Ground observed proportion of small grains.

PCC = Estimate of the probability of correct classification.

SG = Small grains.

NSG = Non-small grains.

Labeling Accuracy = Percentage of training fields (in ground truthed area) correctly labeled.

TABLE 6-4.– ITS SPRING WHEAT FINAL CLASSIFICATION RESULTS

Segment	State/ County	Acq.	$\hat{X}$	X	$\hat{X} - X$	PCC	
						SG	NSG
1965	N. Dakota	2216	39.6	47.0	-7.4	48.6	97.9
1967	N. Dakota	1866	30.0	34.5	-4.5	—	—
1969	Montana	1566	28.0	45.0	-17.0	71.6	88.8
1971	Montana	1556	44.2	50.2	-6.0	94.8	95.4
1987	Minnesota	1456	45.8	56.2	-10.4	83.0	95.8
1958	Canada	2246	58.1	56.9	+1.2	92.8	89.0
1984	Canada	2436	38.2	33.2	+5.0	88.7	97.9
1985	Canada	1536	47.2	31.5	+15.7	95.8	92.9
1991	Canada	2186	53.0	72.9	-19.9	75.4	84.0
1995	Canada	1826	49.2	67.7	-18.5	86.9	99.2
Average			43.3	49.4	-6.1	81.9	93.4

Acq. = Julian day; last digit indicates year; e.g., 2006 indicates that the segment processed was the 200th day of 1976.

$\hat{X}$ = CAMS proportion estimate of small grains.

X = Ground observed proportion of small grains.

PCC = Estimate of the probability of correct classification.

SG = Small grains.

NSG = Non-small grains.

The probability of correct classification was determined for nine sites. In all but two of them the PCC for NSG was larger than for SG. The average for SG (81.9 percent) was smaller than the average for NSG (93.4 percent) but the difference was less than that obtained for winter wheat. Also, the spring wheat accuracies for both SG and NSG are considerably higher than the corresponding accuracies for winter wheat.

6.4 EFFECT OF BIOPHASE ON PROPORTION ESTIMATION

Two studies were conducted in Phase II to investigate the effect of biophase on proportion estimation. In one of these the bias and standard deviation of the proportion errors were estimated for blind sites analyzed using various biophase combinations. It is described in section 6.4.1. In the second study the Wilcoxon matched-pairs signed-rank test was used to investigate whether proportion estimation errors using data from biophase 4 were different from those using data from biophase 1.

6.4.1 EFFECT OF VARIOUS BIOPHASE COMBINATIONS

Table 6-5 shows estimates of the bias and standard deviation for various combinations of biophase. All the winter wheat blind sites in the USGP were used. Spring wheat blind sites were not studied because sufficient data were not available.

TABLE 6-5.— CLASSIFICATION ERROR BY BIOWINDOW COMBINATION (WINTER WHEAT)

Combination	Bias	Std dev.	Number of Sites
1	-2.5	9.2	117
1-2	-0.8	6.8	72
1-3	-5.1	6.6	19
1-2-3	0.8	4.9	32
1-4	-6.1	14.1	19
1-2-4	-2.0	7.9	33
1-3-4	-5.5	6.6	17
1-2-3-4	+1.1	5.1	31

The best results were obtained using data from the biophase combinations 1-2 and 1-2-3. It will be seen that the last four combinations in table 6-5 are the same as the first four combinations except that biophase 4 has been added. In every case the magnitude of the bias and the standard deviation were increased by adding biophase 4 data, except for the combination 1-3, where the magnitude of the bias increased but the standard deviation remained the same. These results indicate that better estimates might be obtained if data from biophase 4 were not used.

6.4.2 BIOPHASE 1 VERSUS BIOPHASE 4

A test was made to determine whether the proportion estimates based on data from biophase 4 were significantly different from proportion estimates based on data from biophase 1. Since there were not enough paired data per state for biophases 1 and 4 for reliable comparison, the data for the five USSGP states were merged (i.e., for 23 blind sites) and a comparison of biophase data was made on this basis.

The Wilcoxon matched-pairs signed-rank test[1] was applied to $\hat{X}_1$ and $\hat{X}_4$ where $\hat{X}_1$ is the proportion of small grains estimated in a given blind site using biophase 1 data and $\hat{X}_4$ is a corresponding estimate using biophase 4 data.

The signed-rank test as applied here assumes that the differences $\hat{X}_1 - \hat{X}_4$ can be ordered in terms of a greater than or less than relation. Each rank is assigned the same algebraic sign as the

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[1] R.P. Runyon and A. Haber, Fundamentals of Behavioral Statistics, Addison-Wesley Publishing Co., Reading, Mass., 1971, pp. 263-265.

corresponding difference so that the direction as well as the magnitude of $\hat{X}_1 - \hat{X}_4$ is utilized in the test. The null hypothesis is made that the sums, T, of positive and negative ranks are equal with an assigned level of significance; i.e., positive and negative ranks of the same magnitude are equally likely.

Critical values of T are to be found in tables prepared by Wilcoxon[1] for various numbers, N, of samples (here N = 23). Under the null hypothesis the distribution of the differences $\hat{X}_1 - \hat{X}_4$ is symmetric about zero; i.e., a mistake of a given magnitude is equally likely using biophase 1 or 4.

Upon applying the test described, for a 10-percent level of significance, it was found that the null hypothesis could not be rejected. It follows that LACIE estimates made using data from biophase 4 could not be said to be different from estimates made on the basis of data from biophase 1.

6.5 ADJUSTABLE CROP CALENDAR ERROR

The adjustable crop calendar is designed to indicate to the CAMS analyst the growth stage of wheat and other crops in the segments he is analyzing. It can therefore be expected to have a considerable impact on the accuracy of the CAMS estimates. A study was performed to determine the accuracy of the ACC by comparing it with ground-observed growth-stage data.

Ground-observed growth-stage data were collected by USDA/ASCS personnel over eight ITS's in Texas and Kansas during the months of April through June. These ground-observed data were plotted along with comparable LACIE ACC-predicted wheat development data. One of the plots (from Deaf Smith County, Texas) is presented in figure 6-5.

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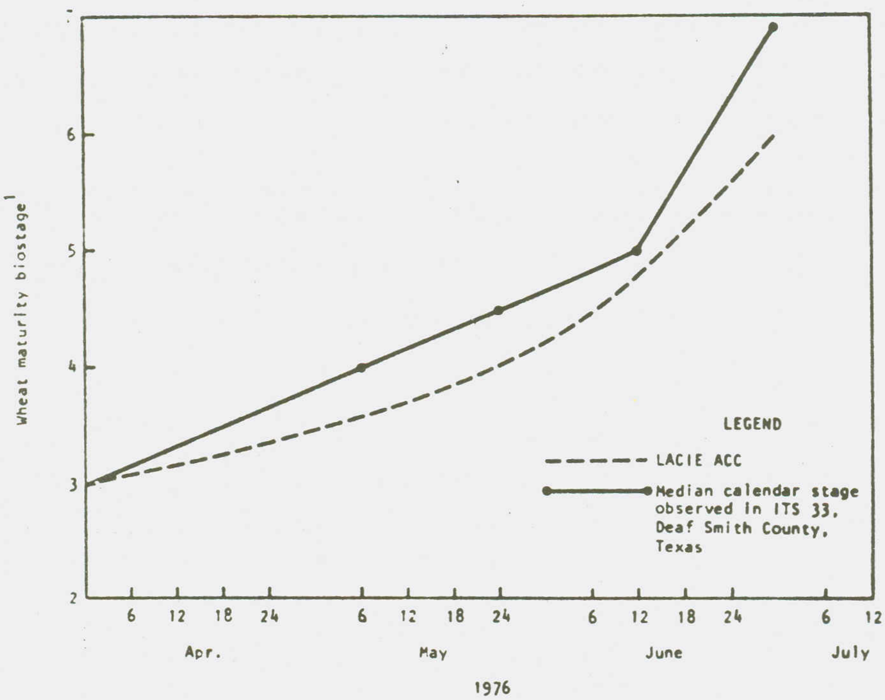
[1] Ibid, table J, p. 308.



[1]According to the Robertson Biometeorological Time Scale, the numbered biostages are: 1 = planting, 2 = emergence, 3 = jointing, 4 = heading, 5 = soft dough, 6 = ripening, and 7 = harvest.

Figure 6-5.— Plot of observed and predicted progression of crop calendar stages for the Deaf Smith County, Texas ITS.

Table 6-6 shows the differences $\overline{D}$ between the LACIE ACC estimates and the ground truth values for the sixth day of April, May, and June. A negative sign indicates the LACIE estimate was lower (i.e., "behind") the ground truth. It will be seen that in most cases the LACIE estimate was behind ground truth and that the difference got larger as the season progressed. In June all the ACC predictions were behind the ground truth stages.

TABLE 6-6.– COMPARISON OF LACIE ADJUSTABLE CROP CALENDAR WITH OBSERVED STAGES IN THE EIGHT INTENSIVE TEST SITES IN THE U.S. SOUTHERN GREAT PLAINS

[$\overline{D}$ in the BMTS units of the Robertson scale]

Site		Date		
County	State	April 6	May 6	June 6
Randall	Texas	-0.12	-0.33	-0.28
Deaf Smith	Texas	-.08	-.42	-.39
Oldham	Texas	.01	0	-.08
Ellis	Kansas	0	-.42	-.51
Rice	Kansas	0	-.44	-.38
Phinney	Kansas	-.17	-.04	-.38
Saline	Kansas	-.18	-.51	-.42
Morton	Kansas	-.16	0	-.08
Average		-.12	-.27	-.32

6.6 RELATION OF CAMS ERROR TO CROP CALENDAR ERROR

This investigation was performed to determine whether crop calendar error had an influence on the accuracy of CAMS estimates.

All of the ITS acquisitions described in section 6.1 which had crop calendar data were used. The classification errors were regressed on the crop calendar errors (measured in days). The correlation coefficients are shown in table 6-7. Significance tests applied to the correlation coefficients indicated that no significant correlation existed between crop calendar error and classification error for any of the four cases shown in table 6-7.

TABLE 6-7.— CORRELATION OF CROP CALENDAR ERRORS AND CLASSIFICATION ERRORS

	Winter wheat		Spring wheat	
	Sample size	r	Sample size	r
Adjustable crop calendar	9	.57	12	-.37
Nominal crop calendar	10	.27	13	.10

6.7 SUMMARY OF PHASE II TEST AND EVALUATION OF YIELD MODELS*

Eleven years of test yield predictions for the LACIE Great Plains model zones were evaluated for their combined and individual performances. The estimates were generated with the CCEA regression models as revised for LACIE Phase II with a "flagging" procedure for weather inputs and new trend segments. Also, characteristics of individual models were analyzed to identify first-order sources of strengths and weaknesses.

The hypothesis of the 11 years of simulated yield predictions meeting the LACIE 90/90 criterion was tested with a sign test. The hypothesis was accepted for the criterion applied at the country level, but was rejected with application of the criterion directly to the Great Plains area. Projection of the 90/90 criterion to individual zones may not be valid since yield errors for several zones appeared positively correlated.

*Details of these tests are reported in the LACIE document: Phase II Test and Evaluation of Yield Models for the U.S. Great Plains.

Three of the models showed a significant mean level bias which was attributed to differences between areas used to develop and test the models.

A check was made using the Phase II (1976) case to reconfirm that there are no apparent differences between applying the models at the district level or applying them to weather aggregated to the state level.

All but two of the models displayed a significant tendency to overestimate when yields were low and vice versa (a type of functional bias seen as restricted dynamic ranges).

Estimates by the complete weather versions of the Red River, Montana winter wheat and Colorado models did not produce mean square errors significantly smaller than the trend-only versions. Then, in a comparison using constant trend coefficients, the mean square errors for all zones were smaller than when the coefficients were recomputed after each additional year entered the regression. The coefficients for trend terms appeared to be the least stable.

APPENDIX A

PHASE II ACCURACY ASSESSMENT METHODOLOGY

A.1 INTRODUCTION

This appendix contains mathematical details of the techniques used in accuracy assessment. The methods used in comparing the LACIE estimates for acreage, yield, and production with the reference standard are presented in section A.2. The techniques used to study errors in the LACIE estimates are discussed in section A.3.

A.2 COMPARISON OF LACIE ESTIMATES WITH REFERENCE STANDARDS

The reference standards to which the LACIE estimates are compared are the USDA/SRS estimates for the United States and the FAS estimates for foreign countries. The statistic used for making these comparisons is the relative difference (RD) defined as follows:

$$RD = \left(\frac{\text{LACIE} - \text{STANDARD}}{\text{LACIE}} \times 100\% \right)$$

where LACIE stands for the LACIE estimate of wheat production, area, or yield and STANDARD represents the corresponding reference standard estimate. This definition expresses the difference between the two estimates as a percentage of the LACIE estimate.

Significance tests of no difference are made only at the region or country level for the LACIE production, area, and yield estimates for spring wheat, winter wheat, and total wheat. For a significance test, the LACIE estimate (of wheat production, area, or yield) is assumed to be approximately normally distributed with unknown mean μ and variance σ^2_{LACIE}. A test of the hypothesis

$$H_o : \mu = \text{STANDARD}$$

versus the alternative hypothesis

$$H_A : \mu \neq \text{STANDARD}$$

is then made using this assumption. The test statistic is given by

$$Z = \frac{\text{LACIE} - \text{STANDARD}}{\hat{\sigma}_{\text{LACIE}}} \tag{A-1}$$

which, under the null hypothesis, is approximately normally distributed with mean 0 and variance 1. The null hypothesis is rejected in favor of the alternative at the α-level of significance

$$|Z| > z_{\alpha/2}$$

where $z_{\alpha/2}$ is the $\left(1 - \frac{\alpha}{2}\right)$ critical point of the standard normal distribution. For $\alpha = 0.10$, $z_{\alpha/2} = 1.645$, and if $|Z| > 1.645$, it is concluded that the mean of the LACIE estimator is significantly different from the reference standard estimate.

The significance test is not made for subregions (e.g., state level in the U.S.) of the region or country, as pointed out earlier. However, if the significance test yields a significant difference at the region or country level, the relative difference calculated at the subregion levels is used to indicate problem areas.

A.3 ERROR SOURCES IN LACIE

The techniques used to study errors in the estimates of acreage, yield, and production are discussed respectively in section A.3.1, A.3.2, and A.3.3 of this appendix.

A.3.1 ACREAGE

This section contains a description of the methods used to estimate the following:

1. The errors in segment wheat proportion estimates (section A.3.1.1).
2. Wheat acreage at the state and higher levels (section A.3.1.2).

3. The variance of the wheat acreage estimates (section A.3.1.3).

4. The bias in the acreage estimates for large areas having ground truth available for a subset of their LACIE segments (section A.3.1.4).

5. The relative variances of the sampling and classification errors in stratum wheat acreage estimates (section A.3.1.5).

A.3.1.1 Error in Proportion Estimates at the Segment Level

This section describes the statistical calculations used to compare CAMS wheat proportion estimates for blind sites with the corresponding ground truth values. Let N be the number of segments allocated to a region (state or higher level) and let n be the number of blind sites selected randomly from these N segments. For a region, let $\hat{X}_i$ represent the CAMS estimate of the proportion of wheat in the *ith* segment and let X_i represent the ground truth proportion of wheat in the *ith* segment, where i = 1, ..., N. Then the average error μ_D is given by

$$\mu_D = \frac{1}{N}\sum_{i=1}^{N}\left(\hat{X}_i - X_i\right) \tag{A-2}$$

The estimate of μ_D is given by

$$\bar{D} = \frac{1}{n}\sum_{i=1}^{n}\left(\hat{X}_i - X_i\right) \tag{A-3}$$

where the summation is taken over the n blind sites. Letting $D_i = \hat{X}_i - X_i$, we may estimate the variance of $\bar{D}$ by

$$S_{\bar{D}}^2 = \left(\frac{1}{n} - \frac{1}{N}\right)\frac{\sum_{i=1}^{n}\left(D_i - \bar{D}\right)^2}{n-1} \tag{A-4}$$

Lower and upper confidence limits for the population average difference μ_D are given by

$$\mu_{D_L} = \bar{D} - t_{1-\alpha/2}S_{\bar{D}}\ ,\ \mu_{D_U} = \bar{D} + t_{1-\alpha/2}S_{\bar{D}} \tag{A-5}$$

where $t_{1-\alpha/2}$ is the value of the 1-α/2 percentage point, from the Student's t distribution with (n-1) degrees of freedom, corresponding to the desired confidence level of 1-α.

The hypothesis $\mu_D = 0$ (i.e., no bias) is rejected at the α-level of significance if $\left|\bar{D}/S_{\bar{D}}\right| > t_{1-\alpha/2}$, or equivalently, if the confidence interval given by equation (A-5) does not contain zero.

A.3.1.2 <u>Acreage Estimation</u>

This section gives a brief summary of the methods used to estimate wheat acreage. These methods are described in detail in appendix B of the CAS Requirements Document.*

A.3.1.2.1 Background of Sample Allocation

The LACIE sample allocation in the U.S. Great Plains (USGP) region is based upon a two-stage stratified sampling scheme in which counties represent the primary sampling units (substrata) and 5- × 6-nautical-mile segments are secondary sampling units. The criterion for determining the total sample size was the ability to achieve a sampling error of 2 percent or less for the country wheat acreage estimates and, hopefully, the ability to meet the 90/90 criterion goal for the production estimate.

Sample segments were allocated to the counties based on relative weights derived from agriculture and wheat acreage reported in 1969 agriculture census statistics. Depending upon the relative weights, counties were designated as Group I (at least one sample segment in the county), Group II (at most one sample segment in a county), or Group III (no sample segments in the county). All Group II counties in a CRD (stratum) were combined to determine the number of segments allocated to the Group II part of the CRD.

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*Crop Assessment Subsystem (CAS) Requirements Vol IV (Rev. B) (Change Notice, March 8, 1977), JSC-11329, LACIE C00200.

In this appendix any reference to the CAS Requirements Document indicates this specific document.

A probability proportional to size (PPS) procedure was applied to select the Group II counties in a CRD which were to receive these segments.

Once the number of segments to be allocated to each county was determined, the sample segments were selected at random within the agricultural area of the county. For further details of the LACIE sampling scheme refer to the CAS Requirements Document (JSC-11329).

A.3.1.2.2 Aggregation of Acreage Estimates

Wheat acreage estimates are made for each CRD, state, and region (group of states) in the USGP. However, no estimate is made for a state if it does not contain three or more segments satisfactorily processed by CAMS. Segment data may be lost due to the following cases of nonresponse:

1. The sample segment being obscured by cloud cover.
2. Landsat data quality being insufficient to permit processing.
3. Landsat data acquisition failing to register with the reference Landsat image.
4. Failure of acquisition/processing procedures to provide an acceptable estimate.

No replacement is allowed if a sample segment is not workable by CAMS.

A CRD acreage estimate consists of three components:

1. An acreage estimate for the Group I counties in the CRD for which segment data exist. (A group I county is treated as a Group III county if it does not have at least one segment with an acceptable proportion estimate.)
2. An acreage estimate for the entire set of Group II counties in the CRD if there is at least one segment with an acceptable

proportion estimate in this set of counties. (Otherwise, the Group II counties are all treated as Group III counties.)

3. An acreage estimate for the Group III counties, including the Group I and Group II counties being treated as Group III counties.

The wheat acreage estimates for these three components are computed using a stratified random sampling estimator for the Group I counties, a PPS estimator for the Group II counties, and a ratio estimator for the Group III counties.*

There are three categories of Group III acreage estimates, depending on the number of segments in a CRD for which data are available. Categories 1, 2, and 3 correspond respectively to three or more segments, one or two segments, and no segments having data available. The ratio used for the Group III estimator is the ratio of historical wheat acreages for Group III counties to Group I and Group II counties. For category 1 estimates it is based on acreages in the CRD. For category 2 and category 3 estimates it is based on acreages in the state containing the CRD for which the estimate is being made.

The CRD wheat acreage estimate is obtained from the sum of the wheat acreage estimates for Group I, II, and III counties. Next, aggregation of the CRD acreage estimates gives a state wheat acreage estimate, and summation of the state acreage estimates gives the regional wheat acreage estimate. For specific aggregation formulas, see appendix B in the Cas Requirements Document.

In a mixed wheat area, separate aggregations are performed for spring and winter wheat and the total wheat acreage estimate is obtained by summing the results. This is done at the CRD and higher levels.

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*For details on these standard estimation procedures, see Sampling Techniques by W.G. Cochran, Wiley, 1963.

A.3.1.3 Acreage Variance Estimation

The acreage variance estimation for a CRD requires an estimate of within-county variance for each of the Group I and Group II counties in the CRD. Often there is only one sample segment in a county and hence no direct estimate of the within-county variance is possible. Therefore, an indirect method is employed. This method uses a regression approach and is based on the assumption that the historical county proportions are well correlated with the CAMS proportions. The method consists of (1) forming homogeneous groups of counties in a state with respect to the within-county variability, (2) performing regression for the CAMS segment wheat proportion estimate onto the county historical wheat proportion, and (3) taking the residual mean square error (MSE) for an estimate of the within-county variance for each county in the group. This procedure for LACIE Phase II is described in the Technical Memorandum, "Large Area Crop Inventory Experiment (LACIE) Area Variance Estimate in the United States", by R. S. Chhikara and J. Chang, document number LEC-8054, April 1976.

For estimation of a CRD acreage variance, the acreage variance components for Group I and Group II counties are estimated independently. For Group I counties it is computed according to the variance formula for a stratified random sampling scheme.[1] The appropriate inputs of county sizes, number of sample segments, and within-county variance estimates are obtained using the above-mentioned procedure. Similarly, the variance formula for a PPS estimator[1] is employed to compute the Group II acreage variance estimate. It requires all of the inputs mentioned in the Group I case plus the probabilities of selection of Group II counties for sample allocation. These probabilities are those utilized in determining which of the Group II counties in a CRD receive sample segments.

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[1] Cf = Sampling Techniques, by W. G. Cochran, Wiley, 1963.

The acreage variance component for the Group III counties depends directly on Groups I and II variances and contributes to the CRD acreage variance indirectly through the ratio utilized to obtain the Group III acreage estimate. The formulas used to calculate the acreage variance for the Group III counties are described in appendix B of the CAS Requirements Document. As mentioned above, there are three categories of Group III acreage estimates and each category has a different formula for the variance estimate. For category 1 the variance estimate depends on the acreage estimates for all the Group I and Group II counties in the CRD; for categories 2 and 3 it depends on the acreage estimates for all of the Group I and Group II counties in the state.

If data are available for at least three segments in each CRD in the state, the acreage variance estimate is computed by adding the variance estimates for the CRD's in the state. Otherwise, the state variance estimate is obtained using an aggregation procedure which accounts for the dependence between various CRD acreage estimates in a state.

Since the state acreage estimates are obtained independently, the acreage variance estimates at both the regional and county levels are computed by adding the state acreage variance estimates.

In a mixed wheat area, separate aggregations are performed for estimating the variance of the spring and winter wheat acreage estimates at the CRD and higher levels. In each case the estimation procedure is the same as that described above for each aggregation level. The acreage variance estimates at the CRD and state levels for the total wheat case are obtained from the previously described variance formulas using total wheat acreage estimates for sample segments and the historical total wheat for counties in the area. For higher levels the total wheat acreage variance estimates are computed by taking the sum of the variance estimates for the states involved. The CRD and state level variance estimates for the total wheat case are not unbiased; therefore, the method of determining variance of a total wheat acreage estimate in a mixed wheat area is considered approximate.

A.3.1.4 Acreage Bias Estimation

The method for estimating bias described in this section is valid for any area having a sufficient number of blind sites to represent the bias. In this report it is applied at the state and higher levels.

The LACIE estimate of wheat acreage for a given area can be written

$$\hat{A} = \sum_{i=1}^{n} W_i \hat{X}_i \qquad \text{(A-6)}$$

where $\hat{A}$ is the estimated wheat acreage, $\hat{X}_i$ is the wheat proportion estimate in the *ith* LACIE segment, n is the number of processed LACIE segments, and $\{W_i\}_{i=1}$ are weights based on historical and cartographic data.*

Corresponding to $\hat{A}$ is the true acreage, A, which can be written

$$A = \sum_{i=1}^{n} W_i^* C_i \qquad \text{(A-7)}$$

*The precise definition of W_i depends on whether the *ith* segment is used as part of a Group III estimate.

where C_i is the true wheat acreage for the stratum containing the *ith* segment and W_i^* is the value of the weight which would give perfect Group III estimates of wheat acreage for unsampled counties.

We can now write

$$\hat{X}_i = C_i + \left(X_i - C_i\right) + \left(\hat{X}_i - X_i\right)$$

$$= C_i + \delta_i + \varepsilon_i$$

where X_i is the true wheat proportion of the *ith* segment, δ_i is the sampling error and ε_i is the classification error. Since sampling is unbiased, we assume $E\left(\delta_i\right) = 0$; however, we do not assume unbiased classification. Instead, let θ be an average segment bias; i.e.,

$$E\left(\varepsilon_i\right) = \theta$$

The bias in A is defined by $E(\hat{A} - A)$, which is thus given by

$$B = E(\hat{A} - A) = E\left(\sum_{i=1}^{n} W_i\hat{X}_i - \sum_{i=1}^{n} W_i^*C_i\right)$$

$$= \sum_{i=1}^{n} W_iE\left(C_i + \delta_i + \varepsilon_i\right) - \sum_{i=1}^{n} W_i^*C_i$$

$$= \sum_{i=1}^{n} \left(W_i - W_i^*\right)C_i + \theta \sum_{i=1}^{n} W_i \qquad \text{(A-8)}$$

Note that the first term of equation (A-8) represents a bias caused by the failure of the Group III ratios to be exact;

(i.e., $W_i \neq W_i^*$), whereas the second term is the average segment bias multiplied by the sum of the W_i.

At present, only the second term of equation (A-8) will be estimated, since good county-level data are not available for estimating the first term. The second term is estimated by (1) breaking up the large area into strata (not necessarily connected) for which the bias is assumed to be approximately constant; (2) estimating θ by $\hat{\theta} = \frac{1}{n_k} \sum_{i=1}^{n_k} \left(\hat{X}_i - X_i\right)$, the average proportion error on a segment level in the k*th* stratum; (3) aggregating $\hat{\theta}$ over the stratum, and (4) aggregating over strata.

If $\hat{\beta}$ represents the AA estimate of bias due to classification, a 90-percent confidence interval for β, the real bias, can be constructed by

$$(\hat{\beta} - 1.645\sigma, \hat{\beta} + 1.645\sigma)$$

where σ^2 is an estimate of the variance of $\hat{\beta}$.

If we assume $\mathrm{Var}\left(\varepsilon_i\right) = \sigma_{ck}^2$ (a constant) within the k*th* stratum, then σ_{ck}^2 can be estimated by

$$\sum_{i=1}^{n_k} \frac{\left(\hat{X}_i - X_i - \hat{\theta}\right)^2}{n_k - 1}$$

and $\mathrm{Var}(\hat{\beta})$ can be estimated using the CAMS variance aggregation formulas, in which the within-stratum variances are replaced by the estimates $\hat{\sigma}_{ck}^2$ and the acreage strata are replaced by these "classification variance estimation strata."

A.3.1.5 Contribution of Sampling and Classification to Acreage Estimation Error

This section describes the calculation of the contribution of sampling and classification errors to the variance of the LACIE production estimate.

A.3.1.5.1 Approach

The variance of the LACIE acreage estimate for a large area (e.g., zone) can be written

$$V^2 = \sum_i V_i \sigma_i^2$$

where σ_i^2 is the variance of the acreage estimate for the *ith* stratum and V_i is a weight which depends on the size of the stratum, the number of segments in the stratum, etc. (Refer to CAS Requirements Document, appendix B for details.)

The variance σ_i^2 represents a mean-squared deviation between the LACIE estimate for the stratum wheat proportion and the true stratum wheat proportion. This variance is caused mainly by two factors: sampling errors and classification errors.

In accuracy assessment, it is desirable to quantify the contribution of each of these error sources to the large area production estimate. The LACIE production estimate depends on acreage and yield estimation errors in a complicated way; hence, it is unrealistic to assume the error in the production estimate can be written as a sum of uncorrelated random variables representing acreage and yield errors. Instead, the effect of a particular error source is measured by the reduction in the LACIE production variance which would be achieved if that source were eliminated.

It will be assumed (section A.3.1.5.2) that the *ith* stratum acreage error variance σ_i^2 can be written $\sigma_i^2 = \sigma_c^2 + \lambda^2\sigma_s^2$, where σ_c^2 is a contribution due to classification, and $\lambda^2\sigma_s^2$ is a contribution due to sampling. To determine the effect of no classification error, the variance of the LACIE production estimate will be calculated using $\rho\sigma_i^2$ instead of σ_i^2 where ρ is an estimate of the ratio $\dfrac{\lambda^2\sigma_s^2}{\sigma_c^2 + \lambda^2\sigma_s^2}$. Similarly, the effect of no sampling error is estimated by replacing σ_i^2 by $(1 - \rho)\sigma_i^2$. This procedure is described in detail in section A.3.3.5 of this appendix. The following two sections describe the methods employed for estimating sampling and classification variances and the function ρ.

A.3.1.5.2 Acreage Regression Models

For strata with one sample segment, the LACIE estimate of the *ith* stratum wheat proportion can be written

$$\hat{X}_i = C_i + \left(X_i - C_i\right) + \left(\hat{X}_i - X_i\right)$$

$$= C_i + \varepsilon_i + \delta_i \qquad \text{(A-9)}$$

where

$\hat{X}_i$ = LACIE estimate of the wheat proportion in the sampled segment

C_i = true (current year) proportion of wheat in the stratum

X_i = true proportion of wheat in the sampled segment

ε_i = sampling error = $X_i - C_i$

δ_i = classification error = $Y_i - X_i$

It will be assumed that for some reasonably large area (e.g., a zone) the errors ε_i and δ_i have the following properties:

$$\varepsilon_i \text{ and } \delta_i \text{ are uncorrelated}$$

$$E(\varepsilon_i) = 0$$

$$E(\delta_i | X_i) = \lambda^* X_i + \theta$$

$$V(\varepsilon_i) = \sigma_s^2$$

$$V(\delta_i | X_i) = \sigma_c^2$$

It is also assumed that there is a linear model relating the current year strata proportions, C_i, to the historical proportions which will be denoted by Z_i; i.e.,

$$C_i = \alpha + \beta Z_i + \zeta_i \tag{A-10}$$

where $E(\zeta_i) = 0$, $V(\zeta_i) = \sigma_H^2$, and $Cov(\zeta_i, \varepsilon_i) = Cov(\zeta_i, \delta_i) = 0$.

From the above assumptions and definitions, three basic regression models are obtained:

a. True segment proportion versus historical stratum proportion — from the definition of ε_i,

$$X_i = C_i + \varepsilon_i$$

$$= \alpha + \beta Z_i + \zeta_i + \varepsilon_i \tag{A-11}$$

It follows that

$$E(X_i) = \alpha + \beta Z_i \tag{A-12}$$

$$V(X_i) = \sigma_H^2 + \sigma_s^2 \tag{A-13}$$

b. LACIE segment proportion versus ground truth segment proportion — from the definition of δ_i

$$\hat{X}_i = X_i + \delta_i \tag{A-14}$$

It follows that

$$E\left(\hat{X}_i | X_i\right) = X_i + \lambda^* X_i + \theta \tag{A-15}$$

$$V\left(\hat{X}_i | X_i\right) = \sigma_c^2 \tag{A-16}$$

Writing $\lambda = 1 + \lambda^*$, one obtains

$$E\left(\hat{X}_i | X_i\right) = \lambda X_i + \theta \tag{A-17}$$

$$V\left(\hat{X}_i | X_i\right) = \sigma_c^2 \tag{A-18}$$

c. LACIE segment proportion versus historical stratum proportion — from equations (A-12) through (A-18),

$$E\left(\hat{X}_i\right) = E_{X_i}\left(E\left(\hat{X}_i | X_i\right)\right) = E_{X_i}\left(\lambda X_i + \theta\right) = \lambda\left(\alpha + \beta Z_i\right) + \theta \tag{A-19}$$

$$V\left(\hat{X}_i\right) = E_{X_i}\left(V\left(\hat{X}_i | X_i\right)\right) + V_{X_i}\left(E\left(\hat{X}_i | X_i\right)\right) = \sigma_c^2 + \lambda^2\left(\sigma_H^2 + \sigma_s^2\right) \tag{A-20}$$

As stated previously, one would like to estimate $\rho = \dfrac{\lambda^2 \sigma_s^2}{\sigma_c^2 + \lambda^2 \sigma_s^2}$.

None of the three regression models permits an estimate of σ_s^2 separately from σ_H^2; i.e., one can only estimate $\sigma_s^2 + \sigma_H^2$, not σ_s^2 alone. If current year stratum proportions C_i were available, σ_H^2 could be estimated, but since this is not the case,

$$\rho^* = \frac{\lambda^2\left(\sigma_s^2 + \sigma_H^2\right)}{\sigma_c^2 + \lambda^2\left(\sigma_s^2 + \sigma_H^2\right)}$$ will be estimated instead of ρ. If $\sigma_H^2 << \sigma_s^2$ (a reasonable assumption) then $\rho^* \approx \rho$.

A.3.1.5.3 Normality Assumptions — Maximum Likelihood Estimation of ρ^*

Suppose a given zone has m blind site segments and n ordinary (i.e., not blind site) segments, and let the blind site segments be numbered 1 to m. It is assumed that ground truth wheat proportions $\{X_i\}_{i=1}^{m}$ are available for the blind sites and LACIE estimates $\{\hat{X}_i\}_{i=1}^{m+n}$ are available for all the segments. It is also assumed that historical wheat proportions $\{Z_i\}_{i=1}^{m+n}$ are available for the strata containing the segments. If $\sigma_H^2 << \sigma_s^2$ so that $\rho \approx \rho^*$ the regression models equations (A-11 through A-20) can be used to obtain

$$E\left(X_i\right) = \alpha + \beta Z_i;\ V\left(X_i\right) = \sigma_s^2 \qquad i = 1,\cdots,m$$

$$E\left(\hat{X}_i | X_i\right) = \lambda X_i + \theta;\ V\left(\hat{X}_i | X_i\right) = \sigma_c^2 \qquad i = 1,\cdots,m$$

$$E\left(\hat{X}_i\right) = \theta + \lambda\alpha + \lambda\beta Z_i;\ V\left(\hat{X}_i\right) = \lambda^2\sigma_s^2 + \sigma_c^2 \qquad i = m+1,m+n$$

If there is one segment per stratum, then the errors ε_i and δ_i are independent for different values of i, and hence the likelihood function of the sample can be written

$$L = \prod_{i=1}^{m} f\left(X_i,\hat{X}_i\right) \prod_{i=m+1}^{m+n} h\left(\hat{X}_i\right) \qquad \text{(A-21)}$$

where $f\left(X_i,\hat{X}_i\right)$ is the joint density of X_i and $\hat{X}_i$ for $i = 1,\cdots,m$ and$\left(h\ \hat{X}_i\right)$ is the density of $\hat{X}_i$ for $i = m+1,\cdots,m+n$.

The function $\prod_{i=1}^{m} f(X_i, \hat{X}_i)$ can be written $\prod_{i=1}^{m} f(X_i, \hat{X}_i) =$

$\prod_{i=1}^{m} f(\hat{X}_i | X_i)\ g(X_i)$ where $f(\hat{X}_i | X_i)$ is the conditional density

of $\hat{X}_i$ given X_i and $g(X_i)$ is the density function of X_i.

If normality is assumed, $\prod_{i=1}^{m} f(X_i, \hat{X}_i) = \prod_{i=1}^{m} \frac{1}{\sigma_c \sqrt{2\pi}}$

$$\exp\left\{-\frac{1}{2\sigma_c^2} \sum_{i=1}^{m} (\hat{X}_i - \lambda X_i - \theta)^2\right\} \frac{1}{\sigma_s \sqrt{2\pi}} \exp\left\{-\frac{1}{2\sigma_s^2} \sum_{i=1}^{m} (X_i - \alpha - \beta Z_i)^2\right\}$$

and

$$\prod_{i=m+1}^{m+n} h(\hat{X}_i) = \frac{1}{\left(\lambda^2\sigma_s^2 + \sigma_c^2\right)^{1/2}\sqrt{2\pi}} \exp\left\{-\frac{1}{2\left(\lambda^2\sigma_s^2 + \sigma_c^2\right)} \sum_{i=m+1}^{m+n} (\hat{X}_i - \lambda\alpha - \theta - \lambda\beta Z_i)^2\right\}$$

Letting $Q = -2\log L - \log 2\pi$,

$$Q = m \log \sigma_s^2 + m \log \sigma_s^2 + n \log(\sigma_c^2 + \lambda^2\sigma_s^2) + \frac{D_m}{\sigma_c^2} + \frac{T_m}{\sigma_s^2} + \frac{T_n}{\sigma_c^2 + \lambda^2\sigma_s^2} \tag{A-22}$$

where

$$D_m = \sum_{1}^{m} (\hat{X}_i - \lambda X_i - \theta)^2$$

$$T_m = \sum_{1}^{m} (X_i - \alpha - \beta Z_i)^2$$

$$T_n = \sum_{i=m+1}^{m+n} (\hat{X}_i - \lambda\alpha - \theta - \lambda\beta Z_i)^2$$

One attempts to maximize L by finding a stationary point of Q:

$$-\frac{1}{2}\frac{\partial Q}{\partial \alpha} = \frac{\sum_{1}^{m}(X_i - \alpha - \beta Z_i)}{\sigma_s^2} + \frac{\sum_{m+1}^{m+n}\lambda(\hat{X}_i - \lambda\alpha - \theta - \lambda\beta Z_i)}{\sigma_c^2 + \lambda^2\sigma_s^2} = 0 \qquad \text{(A-23)}$$

$$-\frac{1}{2}\frac{\partial Q}{\partial \beta} = \frac{\sum_{1}^{m} Z_i(X_i - \alpha - \beta Z_i)}{\sigma_s^2} + \frac{\sum_{m+1}^{m+n}\lambda Z_i(\hat{X}_i - \lambda\alpha - \theta - \lambda\beta Z_i)}{\sigma_c^2 + \lambda^2\sigma_s^2} = 0$$

(A-24)

$$-\frac{1}{2}\frac{\partial Q}{\partial \theta} = \frac{\sum_{1}^{m}(\hat{X}_i - \lambda X_i - \theta)}{\sigma_c^2} + \frac{\sum_{m+1}^{m+n}(\hat{X}_i - \lambda\alpha - \theta - \lambda\beta Z_i)}{\sigma_c^2 + \lambda^2\sigma_s^2} = 0 \qquad \text{(A-25)}$$

$$-\frac{1}{2}\frac{\partial Q}{\partial \lambda} = \frac{\sum_{1}^{m} X_i(\hat{X}_i - \lambda X_i - \theta)}{\sigma_c^2} + \frac{-n\lambda\sigma_s^2 + \sum_{i=m+1}^{m+n}(\beta Z_i + \alpha)(\hat{X}_i - \lambda\alpha - \theta - \lambda\beta Z_i)}{\sigma_c^2 + \lambda^2\sigma_s^2}$$

$$+ \frac{\lambda^2\sigma_s^2 T_n}{\left(\sigma_c^2 + \lambda^2\sigma_s^2\right)^2} = 0 \qquad \text{(A-26)}$$

$$\frac{\partial Q}{\partial \sigma_c^2} = \frac{m}{\sigma_c^2} + \frac{n}{\lambda^2\sigma_s^2 + \sigma_c^2} - \frac{D_m}{\sigma_c^4} - \frac{T_n}{\left(\lambda^2\sigma_s^2 + \sigma_c^2\right)^2} = 0 \qquad \text{(A-27)}$$

$$\frac{\partial Q}{\partial \sigma_s^2} = \frac{m}{\sigma_s^2} + \frac{n\lambda^2}{\lambda^2\sigma_s^2 + \sigma_c^2} - \frac{T_m}{\sigma_s^4} - \frac{T_n\lambda^2}{\left(\sigma_c^2 + \lambda^2\sigma_s^2\right)^2} = 0 \qquad \text{(A-28)}$$

Equations (A-23) through (A-29) must be solved for the parameters α, β, θ, λ, σ_c^2, and σ_s^2. If $\hat{\alpha}$, $\hat{\beta}$, $\hat{\theta}$, $\hat{\lambda}$, $\hat{\sigma}_c^2$, and $\hat{\sigma}_s^2$ represent the solution to equations (A-23) and (A-29), then the invariance theorem for maximum likelihood estimation can be used to obtain

$$\hat{\rho} = \frac{(\hat{\lambda})^2 \hat{\sigma}_s^2}{\hat{\sigma}_c^2 + (\hat{\lambda})^2 \hat{\sigma}_s^2} \tag{A-29}$$

as the maximum likelihood estimate of ρ.

The equations (A-23) through (A-29) are nonlinear but can be solved using numerical techniques. Newton's Method was used to solve the equations for this report; i.e., if $u^{(k)}$ is an estimate of the solution vector $u = (\hat{\alpha}, \hat{\beta}, \hat{\theta}, \hat{\lambda}, \hat{\sigma}_c^2, \hat{\sigma}_s^2)$ at the *kth* step, then

$$u^{(k+1)} = u^{(k)} - F^{-1} f\left(u^{(k)}\right) \tag{A-30}$$

where $f\left(u^{(k)}\right) = (f_1, \cdots, f_6)^T$ is the vector of the left sides of equations (A-23) through (A-29) evaluated at $u^{(k)}$ and $F = (F_{ij}) = \frac{\partial f_i}{\partial u_j}$.

In practice, it was slightly more simple to use the parameter transformations

$$r = \frac{\sigma_s^2}{\lambda^2 \sigma_s^2 + \sigma_c^2} \tag{A-31}$$

and

$$s = \lambda^2 \sigma_s^2 + \sigma_c^2 \tag{A-32}$$

and solve for α, β, θ, λ, r, and s. Again, the invariance theorem can be used to give

$$\hat{\rho} = \hat{\lambda}^2 \hat{r}$$

A.3.1.5.4 Accuracy of $\hat{\rho}$

Since $\hat{\rho}$ is an extremely complicated function of the data, it is impossible to write down the variance of $\hat{\rho}$ for finite sample sizes m and n. However, the asymptotic variance of $\hat{\rho}$ can be estimated using the information matrix; i.e., if

$$V = E\left\{\frac{-\partial^2 \log L}{\partial u_i \ \partial u_j}\right\}$$

and $g(u) = g\left(\hat{\alpha}, \hat{\beta}, \hat{\theta}, \hat{\lambda}, \hat{\sigma}_c^2, \hat{\sigma}_s^2\right)$ is a differentiable function of the parameter vector u, then the variance of g(u) is asymptotic to

$$[g'(u)]^T V^{-1} g'(u)$$

where

$$g'(u) = \left(\frac{\delta g}{\delta u_1}, \ldots, \frac{\delta g}{\delta u_6}\right)^T. \tag{A-33}$$

Thus, in our case, $g(u) = \dfrac{\lambda^2 \sigma_s^2}{\lambda^2 \sigma_s^2 + \sigma_c^2}$

$$g'(u) = \left[0, 0, 0,\ 2\lambda\sigma_s^2\sigma_c^2\left(\lambda^2\sigma_s^2 + \sigma_c^2\right)^{-2},\ -\lambda^2\sigma_s^2\left(\lambda^2\sigma_s^2 + \sigma_c^2\right)^{-2},\ -\frac{\lambda^2\sigma_c^2}{\left(\sigma_c^2 + \lambda^2\sigma_s^2\right)^2}\right] \tag{A-34}$$

To estimate V, the observations $\{X_i\}$, $\{Y_i\}$, and $\{Z_i\}$ and the estimated parameters $\left(\hat{\alpha}, \hat{\beta}, \hat{\theta}, \hat{\lambda}, \hat{\sigma}_c^2, \text{ and } \hat{\sigma}_s^2\right)$ were substituted into the matrix $H = (h_{ij}) = \dfrac{\partial^2 \log L}{\partial u_i \ \partial u_j}$. Then equation (A-33) was used to obtain an approximate variance for $\hat{\rho}$.

A.3.2 YIELD

This section contains a description of the methods used to predict yields (section A.3.2.1) and to estimate yield prediction error (section A.3.2.2). In Phase II no estimate of yield bias was made.

A.3.2.1 Yield Prediction

Most of the yield predictions made in LACIE are provided by the Center for Climatic and Environmental Assessment (CCEA) of NOAA. They are produced from multiple linear regression yield models* developed on historical weather and yield data. Usually these models cover a state but in some cases they cover part of a state or part of two states and in some cases they overlap.

In a given state there is either one yield stratum or two. In the first case the state yield prediction is that given by the CCEA model. In the second case the state yield prediction is given by:

$$Y = P/A \qquad \text{(A-35)}$$

where P is the production estimate (section A.3.3.1) and A is the acreage estimate (section A.3.1.2) for the state. The yield prediction at the region or country level is also obtained from equation (A-35), with P and A in that case being the production and acreage estimates at the corresponding level.

A.3.2.2 Estimation of the Yield Prediction Error

CCEA provides estimates of the yield prediction error at the stratum level. In the CAS Requirements Document it is shown that at the state, region, or country levels the estimate of the squared yield prediction error for a given area (state, region, or country) is

$$U^2 = \overline{Y}^2 \left[\frac{S^2}{P^2} + \frac{V^2}{A^2} - 2 \frac{\Sigma Y_i V_i^2}{P\, A} \right] \qquad \text{(A-36)}$$

*Wheat Yield Models for the United States (LACIE 00431), National Aeronautics and Space Administration, Johnson Space Center, Houston, Texas, June 1975.

where

S^2 = estimated squared prediction error of the production estimate P for the area

V^2 = estimated variance of the acreage estimate A for the area

Y_i = yield estimate for the *ith* pseudo zone in the area

V_i^2 = estimated variance of the acreage estimate for the *ith* pseudo zone in the area

In the case where there is only one yield stratum for a state, the yield prediction error for the state is given directly by the CCEA model.

A.3.3 PRODUCTION

This section contains descriptions of the methods used to do the following:

a. Estimate wheat production production (section A.3.3.1).

b. Estimate the variance in the wheat production estimate (section A.3.3.2).

c. Estimate the bias in the wheat production estimate (section A.3.3.3).

d. Evaluate whether LACIE is satisfying the 90/90 criterion (section A.3.3.4).

e. Determine the effect of errors in acreage, yield, sampling, and classification on the production variance (section A.3.3.5).

A.3.3.1 <u>Production Estimation</u>

At the CRD level the production estimate is obtained by multiplying the area estimate and the yield prediction for the CRD. The area estimate is made for the CRD itself but the yield prediction is made for a group of CRD's in a state (section A.3.2.1).

The production estimates for the state and higher levels are obtained by simply adding the estimates for all the CRD's in the area.

A.3.3.2 Production Variance Estimation

Since the production estimate is the product of an acreage estimate and a yield prediction, the measure of variability in the estimate should properly be called the production prediction error. However, in this report, this quantity will be called the production variance.

Since the yield predictions are made for a group of CRD's it is not possible to obtain independent production variance estimates at the CRD level. Hence, the estimates of production variance are made only at the state and higher levels.

To estimate the production variance for a state it is assumed that the yield strata do not cross a CRD. This seems a reasonable assumption and is expected to hold in almost all cases. Another assumption is that the yield strata are nonoverlapping. However, this does not hold for the North Dakota and Minnesota yield strata since CRD's 30 and 60 in North Dakota are a part of both yield strata. Similarly, there is an overlap in Nebraska and South Dakota where CRD 10 of Nebraska is common to both yield strata, and in Oklahoma and Texas where CRD 10 of Oklahoma is common to both Oklahoma yield stratum and the Texas Panhandle yield stratum. In Phase II, any such overlapping is ignored and production variance estimates are considered approximate.

Regarding the number of yield strata in a state, in Phase II only two cases occurred in the USGP, namely (1) a single yield model in a state, and (2) two yield models in a state.

Single Yield Model in a State

In the CAS Requirements Document it is shown that when there is only one yield model in a state, an estimate of the production variance is given by

$$S^2 = V^2Y^2 + U^2A^2 - V^2U^2 \quad \text{(A-37)}$$

where

P = state production estimate

Y = yield prediction for the state from the state yield model

U^2 = the estimated squared yield prediction error for the state

A = the state acreage estimate obtained by summing the acreage estimates for the CRD's in the state

V^2 = the estimated state acreage variance

Two Yield Models in a State*

When there are two yield models in a state, the state is divided into two pseudo zones corresponding to the intersections of the two yield strata with the acreage strata in the state. Let G_1 and G_2 denote the pseudo zones associated with yield strata 1 and 2 having yield estimates Y_1 and Y_2 respectively. The acreage estimates A_1 and A_2 for G_1 and G_2 are given by

$$A_t = \sum_{j \varepsilon G_t} A_j , \quad t = 1,2 \quad \text{(A-38)}$$

where A_j is the acreage estimate for the *jth* CRD in the state.

*This discussion is only for the nonoverlapping yield strata and does not address the problem of a mixed wheat zone.

It is shown in the CAS Requirements Document that an estimate of the production variance is given by

$$S^2 = \sum_{t=1}^{2} \left(V_t^2 Y_t^2 + U_t^2 A_t^2 - V_t^2 U_t^2 \right) + 2Y_1 Y_2 \sum_{j \varepsilon G_i} \sum_{k \varepsilon G_2} \psi_{jk} \qquad \text{(A-39)}$$

where U_t^2 is the estimated squared prediction error of Y_t, ψ_{jk} is the estimated covariance between A_j and A_k and V_t^2 is the estimated variance of the acreage estimate A_t given by

$$V_t^2 = \sum_{j \varepsilon G_t} V_j^2 + 2 \sum_{j \varepsilon G_t} \sum_{k \varepsilon G_t} \psi_{jk} \qquad \text{(A-40)}$$

Here V_j^2 is the acreage variance estimate for the j*th* CRD. For more details on these calculations see the CAS Requirements Document.

The production variance for a region or country is estimated by adding the estimated production variances for the states in the region or country. This, however, ignores the covariances between the state production estimates caused by some yield strata crossing the state boundaries, as mentioned earlier. This problem is being corrected during LACIE Phase III.

The procedure for estimating the production variance in a mixed wheat area is the same for spring wheat, winter wheat, and total wheat. However, in the case of total wheat, the yield prediction and yield prediction error required for this are obtained by combining the corresponding quantities for spring and winter wheat with relative weights based on the previous year's SRS spring and winter wheat acreages.

A.3.3.3 Production Bias Estimation

The production bias at the state level is given by

$$\begin{aligned} B_{P_i} &= E(\hat{P}_i - P_i) \\ &= E(\hat{P}_i) - P_i \\ &= E(\hat{A}_i \hat{Y}_i) - A_i Y_i \end{aligned} \qquad \text{(A-41)}$$

where A_i, Y_i, and P_i are respectively the true values of the acreage, yield, and production for the *Nth* state in question, and $\hat{A}_i$, $\hat{Y}_i$, and $\hat{P}_i$ are the corresponding estimates for these quantities. Assuming $\hat{A}_i$ and $\hat{Y}_i$ are independent, one obtains

$$B_{P_i} = E(\hat{A}_i)E(\hat{Y}_i) - A_i Y_i \qquad \text{(A-42)}$$

If one further assumes that Y_i is unbiased, then $E(\hat{Y}_i) = Y_i$, and

$$\begin{aligned} B_{P_i} &= Y_i[E(\hat{A}_i) - A_i] \\ &= Y_i B_{A_i} \end{aligned} \qquad \text{(A-43)}$$

where B_{A_i} is the acreage bias for the *ith* state. The quantities Y_i and B_{A_i} are unknown, but an estimate, $\hat{B}_{P_i}$ for B_{P_i} can be obtained by using the estimates for Y_i and B_{A_i} described in sections A.3.2.1 and A.3.1.4, respectively. Thus,

$$\hat{B}_{P_i} = \hat{Y}_i \hat{B}_{A_i} \qquad \text{(A-44)}$$

For the nine-state level, the production bias estimate $\hat{B}_P$ is simply given by $\hat{B}_P = \Sigma \hat{B}_{P_i} = \Sigma \hat{Y}_i \hat{B}_{A_i}$; and then the relative bias of the production estimate $(R(\hat{B}_P))$ can be obtained as

$$R(\hat{B}_P) = \frac{\Sigma \hat{Y}_i \hat{B}_A}{\Sigma \hat{A}_i \hat{Y}_i} \qquad \text{(A-45)}$$

A.3.3.4 Evaluating the 90/90 Criterion

Let $\hat{P}$ be the LACIE estimate of wheat production for the region or country, and let P be the true wheat production of the same region or country. The accuracy goal of the LACIE is a 90/90 at-harvest criterion for wheat production, which is given by the following probability statement.

$$\Pr\left[|\hat{P} - P| \leq 0.1P\right] \geq 0.90 \qquad \text{(A-46)}$$

This states that the accuracy goal is for the LACIE estimate of wheat production to be within 10 percent of the true wheat production with a probability of at least 0.9.

It is assumed that the LACIE estimate, $\hat{P}$, is normally distributed with mean P + B and variance $\sigma^2_{\hat{P}}$, where

$$B = E(\hat{P}) - P$$

Under this assumption, equation (A-46) may be written as

$$\Pr\left[\frac{-0.1 - 0.9\frac{B}{P+B}}{CV(\hat{P})} \leq Z \leq \frac{0.1 - 1.1\frac{B}{P+B}}{CV(\hat{P})}\right] \geq 0.90 \qquad \text{(A-47)}$$

where $Z = \frac{P - (P+B)}{\sigma\hat{P}}$ follows the standard normal distribution, N(0,1), and $CV(\hat{P})$ is the coefficient of variation of $\hat{P}$ defined by

$$CV(\hat{P}) = \frac{\sigma_{\hat{P}}}{E(\hat{P})} = \frac{\sigma_{\hat{P}}}{P+B} \qquad \text{(A-48)}$$

The term $\frac{B}{P+B}$ is called the relative bias of $\hat{P}$ and is given by

$$\frac{E(\hat{P}) - P}{E(\hat{P})} = \frac{B}{P+B}$$

It follows that the accuracy goal of LACIE is attained if

$$\Phi\left[\frac{0.1 - 1.1\,\frac{B}{P+B}}{CV(\hat{P})}\right] - \Phi\left[\frac{-0.1 - 0.9\,\frac{B}{P+B}}{CV(\hat{P})}\right] \geq 0.90 \qquad \text{(A-49)}$$

where Φ represents the cumulative standard normal distribution. Figure A-1 is a plot of the relative bias versus the coefficient of variation to the LACIE wheat production estimate necessary to satisfy equation (A-49), replacing the inequality sign with an equal sign.

Inference as to whether the LACIE accuracy goal has been met is made by estimating $\frac{B}{P+B}$ and $CV(\hat{P})$ and then ascertaining whether equation (A-48) has been satisfied. Although the LACIE accuracy goal applies to the at-harvest estimate of wheat production, discussion of the 90/90 criterion is made in each interim report as applied to the region for which the LACIE estimates of wheat production are available.

A.3.3.5 Effect of Errors in Acreage, Yield, Sampling, and Classification on the Production Variance

The production variance consists of two major error components: acreage and yield. The acreage error may be further subdivided into sampling and classification errors. The effect of a particular error is determined by the reduction in the production variance estimate when the error is omitted from the calculation of that estimate. These determinations are carried out at the state and higher levels.

At the state level there are two cases to consider: (1) one yield model in the state, and (2) two yield models in the state. When there is one yield model in a state the production variance with all the error components included is given by equation (A-37).

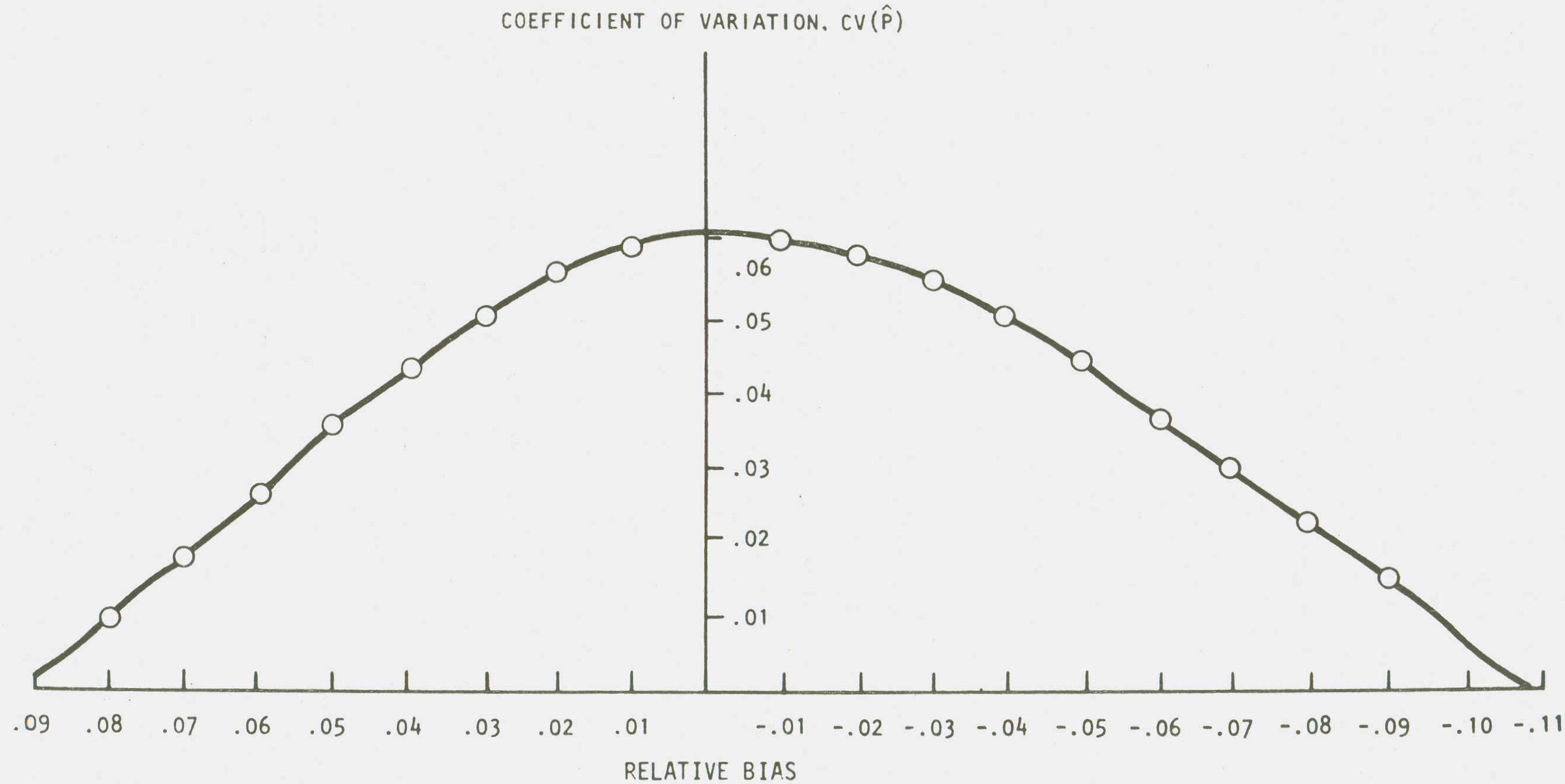

Figure A-1.– Diagram showing value of relative bias and CV($\hat{P}$) for which 90/90 criterion is satisfied.

In order to determine the variance without a given error term, equation (A-37) must be re-derived with that term omitted. Let S_A^2, S_Y^2, S_S^2 and S_C^2 be the state production variances without acreage, yield, sampling, and classification errors respectively. Using the above-mentioned procedure, one obtains the following expressions for these quantities:

$$S_A^2 = U^2\left(A^2 - V^2\right) \tag{A-50}$$

$$S_Y^2 = V^2\left(Y^2 - U^2\right) \tag{A-51}$$

$$S_S^2 = \left(1-\hat{\rho}\right)V^2\left(Y^2-U^2\right) + U^2A^2 \tag{A-52}$$

$$S_C^2 = \hat{\rho}\ V^2\left(Y^2-U^2\right) + U^2A^2 \tag{A-53}$$

Here U, V, Y and A are as defined in section A.3.3.2 and $\hat{\rho}$ is defined by equation (A-29). It should be noted that the expression for the production variance without acreage error, equation (A-50), is not the expression that would be obtained by simply setting the acreage variance, V, equal to zero in equation (A-37). A similar observation applies to equation (A-15).

When there are two yield models in a state the production variance with all the error components included is given by equation (A-39). In this case the estimates for S_A^2, S_Y^2, S_S^2 and S_C^2 are given by

$$S_A^2 = \sum_{t=1}^{2} U_t^2\left(A_t^2 - V_t^2\right) \tag{A-54}$$

$$S_Y^2 = \sum_{t=1}^{2} V_t^2\left(Y_t^2 - U_t^2\right) + 2Y_iY_2 \sum_{j\varepsilon G_1} \sum_{k\varepsilon G_2} \psi_{jk} \tag{A-55}$$

$$S_S^2 = \sum_{t=1}^{2} \left[\left(1-\hat{\rho}\right) V_t^2\left(Y_t^2 - U_t^2\right) + U_t^2\ A_t^2\right] + 2Y_iY_2 \sum_{j\varepsilon G_1} \sum_{k\varepsilon G_2} \psi_{jk} \tag{A-56}$$

$$S_C^2 = \sum_{t=1}^{2} \left[\hat{\rho}\ V_t^2 \left(Y_t^2 - U_t^2 \right) + U_t^2\ A_t^2 \right]$$

$$+ 2Y_1 Y_2 \sum_{j \varepsilon G_1} \sum_{k \varepsilon G_2} \psi_{jk} \qquad \text{(A-57)}$$

Here U_t, V_t, Y_t and A_t are as defined in section A.3.3.2 and $\hat{\rho}$ is defined by equation (A-29).

In order to calculate the quantities corresponding to S_A^2, S_Y^2, S_S^2, and S_C^2 at the regional and country levels, it is assumed that the state production estimates are independent. The corresponding quantities are then obtained by adding the estimates for the states in the area.

In Phase II the necessary software was not available to perform the calculations using equations (A-54)through (A-57). Therefore, the results in this report were obtained using equations (A-50) through (A-53).

APPENDIX C

PHASE I INTENSIVE TEST SITES

To accomplish the objectives of accuracy assessment, ground truth, aircraft photographs, and Landsat multispectral scanner imagery were gathered from 29 intensive test sites. Because of factors such as atmospheric effects and data dropout, acceptable imagery was available for only 23 intensive test sites, which were located in the States of Idaho, Indiana, Kansas, Montana, North and South Dakota, Texas, and Washington (table C-1). These states combine into four regions: the northwest Unites States, the Great Lakes, and the southern and northern Great Plains. Table C-2 presents a list of the ITS acquisitions by biophase according to the day of acquisition in 1975.

TABLE C-1.- LACIE PHASE I INTENSIVE TEST SITES

Segment	State	County	Center coordinates		Site size		Wheat type (a)	Acquired as (b)
			Lat., N	Long., W	N. mi.	Km		
1960	Kans.	Finney	38°04'12"	101°01'42"	5×6	9×11	W	W
1961	Kans.	Morton	37°16'00"	101°54'00"	↓	↓	W	W
1962	Kans.	Saline	38°41'48"	97°28'24"	3×3	5.6×5.6	W	W
1963	Kans.	Rice	38°17'00"	98°12'42"	↓	↓	W	W
1964	Kans.	Ellis	38°50'06"	99°13'00"	↓	↓	W	W
1965	N. Dak.	Burke	48°53'12"	102°10'00"	5×6	9×11	S	S
1969	Mont.	Toole	48°53'00"	111°46'36"	2×6	3.7×11	S&W	S
1970	Mont.	Liberty	48°44'00"	110°51'00"	↓	↓	S&W	S
1971	Mont.	Hill	48°42'00"	109°55'00"	↓	↓	S&W	S
1972	Wash.	Whitman 1	46°54'36"	117°15'30"	3×3	5.6×5.6	S&W	W
1978	Wash.	Whitman 2	46°50'24"	117°48'18"	↓	↓	S&W	W
1974	Wash.	Whitman 3	47°08'00"	117°26'18"	↓	↓	S&W	W
1975	Idaho	Oneida	42°04'30"	112°29'30"	↓	↓	S&W	W
1976	Idaho	Franklin	42°08'00"	111°58'00"	↓	↓	S&W	W
1977	Idaho	Bannock	42°56'30"	112°25'50"	↓	↓	S&W	W
1978	Tex.	Randall	35°09'30"	102°04'24"	↓	↓	W	W
1979	Tex.	Deaf Smith	34°52'12"	102°22'18"	↓	↓	W	W
1980	Tex.	Oldham	35°15'00"	102°32'00"	↓	↓	W	W
1981	Ind.	Shelby	39°27'36"	85°47'12"	↓	↓	W	W
1982	Ind.	Madison	40°13'30"	85°37'50"	↓	↓	W	W
1983	Ind.	Boone	40°05'42"	86°33'90"	↓	↓	W	W
1687	S. Dak.	Hand 1	44°35'00"	98°58'00"	5×6	9×11	S&W	S
1986	S. Dak.	Hand 2	44°21'00"	98°45'06"	↓	↓	S&W	S

[a]As indicated by ground truth: S = spring wheat; W = winter wheat; S&W = spring and winter wheat.

[b]S = spring wheat; W = winter wheat.

TABLE C-2.— INTENSIVE TEST SITE ACQUISITIONS LISTED BY BIOPHASE ACCORDING TO DAY OF ACQUISITION, 1975

Segment	Biophase			
	1	2	3	4
1687	133		205	
1960	291		150	
1961	291			169
1962	324	131		
1963	289	131		
1964	290			
1965	155	191		
1966				
1967	137	191		227
1968	143	180	216	
1969	161	179	215	233
1970	142	179		233
1971	142			
1972	268			218
1973	268		201	218
1974	268		182	218
[a]1975	159	178	195	213
1976	299	177	195	213
1977	299		196	214
1978	291		133	
1979	291		133	
1980	291		133	
[a]1981	105			176
1982	299	140		
1983	281	141		
1984		195		
1985				
1986	150	169	187	
1987				

[a]Segments moved to coincide with ground truth and thus reordered.