DOCUMENT RESUME

05608 - [B1C05948]

Crop Forecasting by Satellite: Progress and Problems. PSAD-78-52; B-183134. April 7, 1978. 21 pp. + 2 appendices (7 pp.).

Report to the Congress; by Elmer B. Staats, Comptroller General.

Issue Area: Science and Technology: Management and Oversight of Programs (2004); Food: Federal Involvement in U.S. Agricultural Commercial Export Sales (1714).
Contact: Procurement and Systems Acquisition Div.
Budget Function: General Science, Space, and Technology: Space Science, Applications, and Technology (254).
Organization Concerned: Department of Agriculture; National Aeronautics and Space Administration; National Oceanic and Atmospheric Administration; Department of Commerce.
Congressional Relevance: House Committee on Science and Technology; Senate Committee on Commerce, Science, and Transportation; Congress.

The Department of Agriculture (USDA), the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA) are trying to improve forecasts of foreign wheat production by using Landsat satellite imagery and weather data. The Large Area Crop Inventory Experiment (LACIE) is designed to determine the usefulness and cost-effectiveness of using Landsat data in conjunction with weather and climate data for forecasts of foreign wheat production. Findings/Conclusions: To date, LACIE has had mixed success in achieving its performance goals. The Phase II forecast accuracy was high for winter wheat in the Great Plains and low for spring wheat. Production forecast accuracy was low for Canadian wheat, and although the LACIE estimate for the Soviet Union was close to actual production, there were offsetting errors in the area and yield components. Current Landsat technology cannot adequately distinguish spring wheat from other grains. LACIE yield estimates have been less accurate where wheat yields are extremely high or low. To improve the estimates, models are being developed which will use daily rather than aggregated monthly weather data. The lack of reliable historical yield data for some LACIE countries also presents a problem. New research efforts are deemphasizing wheat forecasts and expanding LACIE techniques to other crops and applications. Recommendations: The Secretary of Agriculture should provide cognizant congressional committees with periodic assessments of the LACIE project, the experimentation with other crops, and the experiments with early warning of crop damage and crop condition assessment. (RRS)

-948

BY THE COMPTROLLER GENERAL

Report To The Congress

OF THE UNITED STATES

Crop Forecasting By Satellite: Progress And Problems

The Department of Agriculture, the National Oceanic and Atmospheric Administration, and NASA are trying to improve forecasts of foreign wheat production by using Landsat satellite imagery and weather data.

This Large Area Crop Inventory Experiment (LACIE), the most significant single effort under way to demonstrate a useful and cost-effective application for Landsat data, will end in July 1978. Agriculture then plans a new joint research effort deemphasizing wheat and expanding LACIE techniques to other crops and applications.

The Congress should be kept aware of LACIE's progress and follow-on efforts when considering the future direction of NASA's Landsat program and Agriculture's plans.

PSAD-78-52

APRIL 7, 1978

COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

B-183134

To the President of the Senate and
the Speaker of the House of Representatives

This report on the Large Area Crop Inventory Experiment discusses the progress and problems in research to improve the Department of Agriculture's foreign crop forecasting system. The experiment uses satellite imagery from the National Aeronautics and Space Administration's Earth Resources Technology Satellite (Landsat) to measure how many acres of wheat are growing, and also uses weather data to estimate the yield.

This review was performed as a part of our continuing effort to apprise the Congress of important issues involved in research and development projects.

We made our review pursuant to the Budget and Accounting Act, 1921 (31 U.S.C. 53), and the Accounting and Auditing Act of 1950 (31 U.S.C. 67).

Copies of this report are being sent to the Director, Office of Science and Technology Policy; the Director, Office of Management and Budget; the Administrator, National Aeronautics and Space Administration; and the Secretaries of Agriculture and Commerce.

Comptroller General
of the United States

COMPTROLLER GENERAL'S REPORT TO THE CONGRESS

CROP FORECASTING BY SATELLITE: PROGRESS AND PROBLEMS

D I G E S T

A 3-year, three-agency Federal project is developing technology to improve estimates of foreign wheat crops. It is called the Large Area Crop Inventory Experiment (LACIE) and is carried out as follows:

--The National Aeronautics and Space Administration's (NASA's) Earth Resources Technology Satellite (Landsat) provides data for estimating wheat acreage.

--The National Oceanic and Atmospheric Administration provides information to assist in estimating crop yield under various weather conditions.

--The Department of Agriculture--the user of wheat crop estimates--provides historical data and defines requirements for the project.

IMPORTANCE OF WORLD CROP INFORMATION

To date, LACIE has had mixed success in achieving its performance goals. Farmers, importers, exporters, agribusiness companies, Federal and State policymakers, foreign governments, and international organizations use foreign agricultural information. But if more accurate and timely information were available, these parties could better achieve their goals by making improved decisions on planting, fertilizing, harvesting, storing, and exporting. (See p. 5.)

Agriculture initially planned to implement an operational wheat-forecasting system if LACIE technology could produce cost-beneficial, improved estimates. However, this emphasis on wheat has changed, and Agriculture is planning a research program which will define the potential of the LACIE technology for other crops and applications. (See p. 2.)

The Congress should be kept aware of the results of this program and of the experimentation with other crops and applications.

LACIE PERFORMANCE

The LACIE project is developing new technology and, as to be expected with new technology, has had some technical problems, such as

--difficulty in distinguishing spring wheat from other grains (see p. 12),

--slow progress in developing methods for machine classification of wheat areas to reduce the need for heavy manual involvement in identifying wheat-growing areas (see p. 13), and

--using current yield models which use highly aggregated weather inputs that are not fully responsive to weather changes occurring for short periods over localized areas. (See p. 14.)

LACIE performance needs to be improved to meet its goals of 90-percent accurate production estimates, 9 out of 10 years. In the most important test country, the Soviet Union, the LACIE production estimate was close to the official estimate; however, this resulted from offsetting errors; i.e., the wheat area estimate was high by over 12 percent, and the wheat yield estimate was low by nearly 15 percent. (See p. 8.)

LACIE COSTS

LACIE and related efforts planned through fiscal year 1978 will cost about $54 million, not including NASA personnel costs. The total costs of the follow-on research program involving the three agencies have not been determined. However, Agriculture is investing a substantial amount of funds in computer equipment, and in programs and related items to establish a facility near the Johnson Space Center, where much of the research will be carried out. (See pp. 16 and 17.)

CONTINUING EFFORTS

Agriculture planned to implement the Application Test System--designed to test LACIE wheat-estimating techniques in an operational environment. It has, however, decided to extend experimentation to other crops and applications, such as early warning of crop damage and crop condition assessment. It will also defer a Landsat-based wheat information system until further experimentation and evaluation is completed. (See p. 17.) Project plans in 1974 called for the performance of a cost/benefit analysis to evaluate the usefulness and cost-effectiveness of a LACIE-type system in providing foreign crop information. The analysis will assess benefits based on expected improvements in timeliness and accuracy of information from a LACIE-type system for forecasting wheat. Accordingly, the reasonableness of the benefits set forth should be carefully examined if the analysis is used in deciding whether a crop-forecasting system based on LACIE technology should be carried out. The analysis will be carried out in 1978 but will not be completed by the end of the LACIE project in July 1978. (See p. 18.)

RECOMMENDATION TO THE SECRETARY OF AGRICULTURE

Since there have been technical problems in reaching LACIE objectives and the research direction has changed, GAO recommends that the Secretary of Agriculture provide cognizant congressional committees with periodic assessments of the LACIE project, the experimentation with other crops, and the experiments with early warning of crop damage and crop condition assessment. (See p. 21.)

AGENCY COMMENTS

The issues in this report have been discussed with LACIE officials in the three participating agencies, and their comments have been incorporated as appropriate. NASA believes that LACIE area and yield estimates for the Soviet Union should not be compared to the Soviet's figures for area and yield because

the latter are suspect. However, the LACIE project makes this comparison, and Agriculture reports the figures in its regular periodic reports.

Contents

		Page
DIGEST		i
CHAPTER		
1	INTRODUCTION	1
	What is the Large Area Crop Inventory Experiment?	1
	Who will benefit from LACIE?	2
	Reason for our review of LACIE	2
	Scope of review	3
2	ORIGIN AND NEED FOR LACIE	4
	Importance of world crop information	5
	How crop information can be used	5
	How LACIE works	6
3	LACIE STATUS	7
	LACIE performance	7
	Origin and appropriateness of the LACIE accuracy criteria	10
	LACIE scope changes	11
	Technical problems	11
	LACIE yield models	14
	LACIE costs	16
4	DEPARTMENT OF AGRICULTURE'S PLANS	17
	Status of the LACIE cost/benefit analysis	18
5	CONCLUSIONS AND RECOMMENDATION	20
	Recommendation	21
APPENDIX		
I	Letter dated January 30, 1978 from the NASA Director, Government/Industry Affairs	22
II	Principal officials responsible for activities discussed in this report	27

ABBREVIATIONS

ATS	Application Test System
FAS	Foreign Agricultural Service
LACIE	Large Area Crop Inventory Experiment
Landsat	Earth Resources Technology Satellite
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
SRS	Statistical Reporting Service
USDA	Department of Agriculture

CHAPTER 1

INTRODUCTION

In July 1972, the National Aeronautics and Space Administration (NASA) launched its first Earth Resources Technology Satellite (Landsat); a second was placed in orbit in January 1975; a third was launched in March 1978; and a fourth is scheduled for launch in 1981. The purpose of these Earth-viewing satellites is to test the use of data acquired from space to help manage our environment and natural resources. The instruments aboard measure the intensity of sunlight reflected from the Earth's surface. These measurements are then converted into electronic signals, transmitted to Earth, and recorded on magnetic tapes. These tapes can be reconstructed into photographic images. Because different materials on the Earth's surface reflect light differently, the reconstructed image identifies the different substances on Earth viewed by the instruments, e.g., water, forests, and wheat. Resource managers then use the images and tapes to monitor the Earth's resources.

Several Federal agencies, State and local governments, private companies, and foreign countries have conducted experiments using data in crop forecasting, land use assessment, water resources management, mineral and petroleum exploration, and map preparation. The knowledge and experience gained through these and similar experiments will provide the basis for deciding whether the United States should proceed with the design and development of an operational Earth resources survey system.

The major effort currently taking place using Landsat data is the Large Area Crop Inventory Experiment (LACIE) which is the subject of this report.

WHAT IS THE LARGE AREA CROP INVENTORY EXPERIMENT?

LACIE is a joint effort of the Department of Agriculture (USDA), NASA, and the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce.

The purpose of LACIE is to determine the usefulness and cost-effectiveness of using Landsat data in conjunction with weather and climate data to improve USDA forecasts of foreign wheat production. LACIE's success will be based on its ability to improve the accuracy and timeliness of current USDA foreign wheat forecasts. Furthermore, the improved information must provide benefits in excess of the costs to obtain it. Recent USDA decisions have, however,

redirected the emphasis away from developing a wheat-only estimating system.

WHO WILL BENEFIT FROM LACIE?

The Foreign Agricultural Service (FAS) of the Department of Agriculture is responsible for collecting statistical data on stocks, production, imports, exports, and consumption of various commodities throughout the world. This data is presently collected from reports submitted by agricultural attaches, foreign government and foreign private publications, contacts with Government officials and private trade personnel, and by visiting foreign countries and obtaining firsthand knowledge of an agricultural situation or problem. Data from these sources is summarized and periodically reported for public use. The data is also used for internal USDA management purposes. Users of these reports include farmers, storage companies, transporters, importers, exporters, traders, and brokers. Any improvement in the accuracy and timeliness of the data should result in better informed decisions.

USDA initially planned to implement an operational wheat-forecasting system if LACIE technology could produce better information on foreign wheat production and the benefits exceeded the cost in obtaining the information. This emphasis on wheat has changed, however. USDA has recently reviewed its requirements and does not, at this time, foresee implementing a wheat-only operational system. USDA is now planning a research program which will define the potentials of the LACIE technology to other crops and applications.

REASON FOR OUR REVIEW OF LACIE

When the fourth Landsat is launched in 1981, NASA's investment in the Landsat experimental project will exceed $650 million. If the experimental project is to evolve into an operational Earth resources observation system, benefits to be gained should justify the costs to be incurred. In our June 10, 1977, report entitled "Landsat's Role in an Earth Resources Information System" (PSAD-77-58), we stated that a Government commitment to support an operational Landsat system was premature and that such action should be taken only if further study reveals that the benefits to be gained justify the resources required to establish the system.

LACIE is the most significant single effort currently under way to demonstrate a useful and cost-effective application for Landsat data.

On June 13, 1977, we testified on Senate Bill 657, "Earth Resources and Environmental Information System Act of 1977," before the Subcommittee on Science, Technology and Space, Senate Committee on Commerce, Science and Transportation. We pointed out that the outcome of the LACIE project should be considered carefully in any decision on whether the Landsat system should go operational. We told the Subcommittee Chairman that we would provide the Congress with information on the status of the project.

This report provides the Congress with information on the progress being made and problems encountered in the LACIE effort which could affect Landsat's ability to improve the USDA foreign-crop-forecasting system and decisions to implement an operational Landsat system.

SCOPE OF REVIEW

Our review of the LACIE project included work at the headquarters of NASA, USDA, and NOAA in Washington, D.C.; and NASA's Johnson Space Center, Houston, Texas. We reviewed project plans, evaluation reports, crop production reports, correspondence, and other documents; and held discussions with officials at each location.

The LACIE project is being conducted in three phases. The results of the third phase were not available during our review; therefore, our evaluation covers the first two phases only. In January 1978, NASA provided us the preliminary Phase III results. We have not reviewed this data, but include it for information only in appendix I.

CHAPTER 2

ORIGIN AND NEED FOR LACIE

After the launch of the first Landsat in 1972, several agricultural investigations were conducted, including evaluations of the usefulness of Landsat data to identify crop species and field boundaries. In addition, the development of crop acreage estimates using computer-aided interpretation techniques was tested. Based on the results of these investigations, NASA proposed that a large-scale test be conducted to develop, verify, and demonstrate the capability of satellites to inventory and monitor crops over large geographic areas with the objective of improving the accuracy and timeliness of USDA foreign crop forecasts.

In October 1974, the three participating agencies agreed to undertake the LACIE effort. NASA was to develop and demonstrate the technology for estimating wheat area and production; USDA was to define requirements and provide historical data; and NOAA was to develop models that reflect expected crop yield under various weather conditions. Plans called for LACIE to cover 3 crop years, and wheat was selected as the test crop. Test areas were picked in the United States, the Soviet Union, China, India, Brazil, Argentina, Australia, and Canada.

At the 1974 Rome World Food Conference, the Secretary of State announced plans to conduct the LACIE effort to assist in the management of the world's food supply. Foreign participation in the experiment was not solicited; however, Canada has been providing a limited amount of ground data, and several foreign countries have shown an interest in LACIE results. A NASA official told us that foreign assistance is obtained only when offered by the country, i.e., NASA does not make the initial request.

LACIE's objective is to develop the technology needed to improve foreign wheat production forecasts. The United States' test areas are included (1) because of the need to have onsite observations to train personnel and refine techniques for identifying wheat by using satellite data and (2) also because they serve as a "yardstick" for evaluating the progress of the project. The techniques developed in the United States are then extended to foreign countries, where onsite verification may not be possible.

IMPORTANCE OF WORLD CROP INFORMATION

FAS is responsible for collecting, analyzing, and disseminating foreign agricultural information. World-wide agricultural information is primarily obtained from agricultural attaches located in more than 100 countries. Their reports contain current and near-term outlook information on production and supply of agricultural products, trade, foreign government policies, prices, competitive situations, and market opportunities.

Farmers, importers, exporters, agribusiness companies, Federal and State policymakers, foreign governments, and international organizations use this information. Decisions based on the information should improve to the extent that its accuracy and timeliness can be improved.

HOW CROP INFORMATION CAN BE USED

More accurate and timely information can produce better decisions leading to significant U.S. benefits. While it is not easy to envision all benefits, the following are some possibilities:

--U.S. farmers could make better planting decisions with improved information. Since some crops in the United States are planted months later than elsewhere (particularly Southern Hemisphere countries), farmers could adjust the acreage allotted to various crops to reduce expected world shortages or oversupply and achieve higher profits.

--Updated information throughout the growing season allows farmers to make investment decisions concerning their crops in the field. If world conditions for wheat are poor and higher prices seem likely, U.S. farmers may decide to increase the use of irrigation, fertilizer, and pesticides to achieve higher yields. If reliable information is available early enough, additional acreage may also be planted even though its expected yield may be lower. On the other hand, if information indicates a wheat surplus and a weakening in prices, investments in the crop in the field may be reduced. In the case of winter wheat, it could be plowed under and other crops planted.

--U.S. farmers have the opportunity to borrow funds from the Government to store grains in anticipation of higher prices. Decisions to store a crop are

critical because of the costs involved. However, if available information indicates a wheat surplus, it may be beneficial to sell much of the crop for future delivery at harvest if indications are that prices will fall later in the year.

Besides these benefits, there are indirect benefits which might be achieved with more timely and accurate information. Fertilizer, pesticide, and equipment needs could be more accurately predicted. This would aid suppliers in reducing inventory costs and might reduce shortages of these items.

HOW LACIE WORKS

To develop wheat production estimates, LACIE must have data on the number of acres of wheat being grown and the yield per acre. Simply stated, production equals the number of acres in wheat multiplied by yield per acre.

Landsat is vital to LACIE because wheat acreage is determined from Landsat imagery which is acquired for 5 x 6 nautical-mile sample segments statistically located over the survey region. These sample segments, which represent approximately 2 percent of the agricultural areas in each survey region, are analyzed for wheat content. The proportion of wheat in the sample segment is then projected to the region represented by the sample segment to derive an estimate for the entire region.

The yield per acre is estimated using mathematical models which relate wheat yield to meteorological conditions. Precipitation and temperature are primary variables in the yield models and are obtained from the World Meteorological Organization's network of weather stations.

The area and yield data are combined into a LACIE production estimate which, for determining accuracy, is compared to data compiled by USDA through its current operational system of crop forecasting.

The Statistical Reporting Service (SRS) compiles this data for U.S. crops, and FAS compiles the foreign data.

CHAPTER 3

LACIE STATUS

LACIE PERFORMANCE

LACIE performance results, to date, have been mixed. The project plan required the preparation of forecasts and estimates 1/ of wheat production, area, and yield. The criterion or goal is at-harvest production estimates that have 90/90 accuracy at the country level. That is, LACIE at-harvest production estimates should be within 10 percent of actual production, 9 years out of 10 for each LACIE country. In this section, LACIE performance is evaluated through Phase II in the context of the 90/90 production criterion. Project officials will complete a final evaluation of the LACIE performance by July 1978. (For a discussion of the origin and appropriateness of the 90/90 criterion, see p.10.)

Phase I

The LACIE project is being conducted in three phases, extending over 3 global wheat years. The first (1974-75 wheat year) included only the Great Plains. In this phase, LACIE produced an at-harvest production estimate which was within 5 percent of the USDA estimate for the winter wheat States. The production estimate for spring wheat, however, was about 25 percent lower than the USDA estimate. The predominant cause was a large underestimation of spring wheat acreage, which is the component provided by Landsat. Even though the spring wheat estimate did not achieve the success criteria, the combined LACIE winter and spring estimate was still sufficiently accurate for the total production estimate to be within 10 percent of the final USDA figure.

Results of Phase I are shown on the following page.

1/The use of forecast or estimate is related to time. A forecast is made prior to harvest, while an estimate is made at or after harvest.

Relative Difference Between LACIE At-harvest Estimates and USDA Final Estimates for Phase I

	Great Plains		
	Production	Area	Yield
	(percent)		
Southern Great Plains (winter wheat)	5.0	-0.1	4.2
Northern Great Plains (spring wheat)	-24.9	-30.1	4.7
Total	-5.6	-10.7	4.3

Phase II

In Phase II (1975-76 wheat year), LACIE made forecasts and estimates for the Great Plains, Canada, and the Soviet Union. At-harvest production estimates for the Great Plains and Canada failed to meet the 90/90 criterion. Considerable underestimation of spring wheat acreage in both countries was the primary cause. In Canada, LACIE yield estimates were also underestimated.

LACIE estimated area, yield, and production in two indicator regions of the Soviet Union. Because regional statistics were not yet available, LACIE projected the results from the indicator regions to the full country level based on historical proportions of wheat grown in these areas. Until the actual proportions are known, the accuracy of LACIE estimates cannot be fully assessed. However, based on available data, the Phase II evaluation report shows that the LACIE projections resulted in overestimates of acreage by more than 12 percent and underestimates of yield by about 15 percent for winter and spring wheat combined when compared to USDA's final estimates. Therefore, the low relative difference between the LACIE and USDA production estimates for the Soviet Union is the result of offsetting errors in the LACIE area and yield estimates.

Phase II results are shown on the following page.

Relative Difference Between LACIE At-harvest Estimates and USDA Final Estimates for Phase II

	Great Plains (note a)		
	Production	Area	Yield
	(percent)		
Southern Great Plains (winter wheat)	-7.2	-6.3	-0.9
Northern Great Plains (spring wheat)	-22.3	-26.3	3.2
Total	-12.3	-13.9	1.4

	Canada (note b)		
	Production	Area	Yield
	(percent)		
Total	-44.8	-28.8	-12.2

a/Great Plains figures updated by USDA following issuance of LACIE Phase II Evaluation Report.

b/Grows spring wheat only.

	Soviet Union		
	Production	Area	Yield
	(percent)		
Winter wheat	-5.1	15.3	-23.9
Spring wheat	3.7	11.5	-8.8
Total	-0.2	12.6	-14.8

NASA does not consider the above results for area and yield to be reliable indicators of LACIE performance in the Soviet Union. NASA's position is that since the Soviets provide much of the data which USDA uses to develop estimates of Soviet production, the estimates are immediately suspect.

It is NASA's opinion that the data for the area and yield components are unreliable, because of the unsystematic methods used by the Soviet Union to obtain the data. NASA does

believe, however, that the total production figure is reasonably accurate.

Therefore, it is NASA's opinion that only the USDA total production estimate for the Soviet Union should be used as a basis for evaluating LACIE performance accuracy, and the USDA-published area and yield estimates should be disregarded.

We recognize NASA's concern with the validity of the Soviet-provided figures. However, LACIE project officials use these figures as a basis to measure the accuracy of LACIE estimates. Further, the Soviet figures are used by USDA in its regular periodic crop reports.

Phase III

During Phase III, LACIE is making forecasts and estimates of wheat production, area, and yield for the Great Plains and expanding coverage of the Soviet Union to the entire country. At the time of our review, the 1976-77 wheat crop was not yet harvested, and since the LACIE criterion is 90/90 accuracy at-harvest, it would be premature to assess LACIE accuracy for Phase III until that time. NASA provided preliminary Phase III results, which are included in appendix I without our analysis. The results indicate some improvements and some continuing problems.

ORIGIN AND APPROPRIATENESS OF THE LACIE ACCURACY CRITERIA

In 1973, when NASA proposed the LACIE project, the 90/90 performance goal was suggested as the measure of LACIE success. USDA officials agreed with this goal because they believed that such accuracy was significantly better than the performance of the current USDA system.

The question of the current system's accuracy was raised when the Office of Management and Budget requested USDA to study it. In August 1977, the USDA LACIE project office released a study which examined the accuracy of the production, area, and yield estimates under the current wheat-estimating system. The study involved six of the foreign countries included in LACIE and covered the period 1966-75. The People's Republic of China was excluded because no USDA crop estimates were available. For some countries, data was not available for the entire 10 years. The study concluded that Canada was the only country for which 90/90 accuracy was achieved under the current system.

Because the production estimate is composed of the acreage and yield estimates, the impact that each of these components has on the production estimate must also be considered. The study shows that under the current estimating system, yield errors were greater than the acreage errors for all countries except Brazil. In the case of the Soviet Union, the study points out a number of problems in obtaining reliable data on Soviet wheat.

LACIE SCOPE CHANGES

Originally, LACIE was to provide wheat estimates in seven foreign countries and the Great Plains during the final phase ending in July 1978. This coverage was reduced to the Soviet Union and the United States, with very little effort being conducted in other LACIE countries. The primary reasons for the change in scope are discussed under the following caption, "Technical Problems."

Experimental work for the remaining six countries was scheduled to be completed during an extended LACIE effort running through fiscal year 1979. However, based on a recent review of its remote-sensing data needs, USDA has changed the emphasis from continuing to develop wheat estimates in the remaining six countries to expanding the LACIE techniques to other crops, applications, and countries. According to USDA officials, it has recently been recognized that the successful application of LACIE technology depends on its usefulness in a wide range of situations.

TECHNICAL PROBLEMS

Technical problems in meeting LACIE goals arise from limitations in Landsat's capabilities and the inability to readily extract information using current data-processing techniques. The limitations include difficulty in distinguishing spring wheat from other grains and the inability to locate small fields. Further, some method must be developed to permit machine rather than manual interpretation of data. In order to work on these problems, resources were diverted from work pertaining to India, Brazil, Argentina, and Australia. The technical problems discussed here reflect the status through Phase II. NASA provided preliminary Phase III results, which show some improvements in these problem areas. The results are shown in appendix I as provided by NASA without our analysis.

Difficulty in distinguishing wheat

One problem with Landsat imagery is the difficulty in distinguishing spring wheat from other grains. As a result, two other area-estimating techniques, which are not dependent on Landsat data, have been tested. The first technique uses the historical proportion of wheat to other grains grown in an area to calculate the current proportion of wheat in the area under study. This approach can result in inaccuracies because the ratios of grains in prior years may not be the same ratios currently being planted in a given area. The ratio technique was used in the Great Plains, Canada, and the Soviet Union during Phase II. Spring wheat acreage was considerably underestimated in the Great Plains and Canada, and overestimated in the Soviet Union. Thus, it is unlikely that a single corrective factor can be used for all countries; needed improvements will have to be made on a country-by-country basis. In Phase III, this technique is continuing to be used in five Great Plains States and the Soviet Union.

Since the first ratio technique did not provide the desired accuracy, another technique is being tested which uses models based on economic data to predict the ratio of wheat to other grains. The theory behind this modeling technique is that economic data can be correlated to the ratios of grain planting. Both a United States and a Canadian model are being developed. Each is a regression model based on economic data and previous year production and surplus stock variables. For example, typical components of a model may be the seasonal average price of wheat, the seasonal average price of barley, participating wheat acreage allotments, and market restrictions. This technique was evaluated and, although the results proved inadequate to meet a 90/90 criterion, tests are continuing with this technique in four of the Great Plains States in Phase III. As with the first ratio technique, the economic models do not rely on Landsat data. NASA reported that there has been some success in Phase III in a technique to use Landsat data directly to separate other small grains from wheat.

Two modifications have been made to the sensors on the Landsat spacecraft launched in March 1978. However, it is not yet known whether the modifications will provide any improvement in the ability to distinguish wheat from other grains. If continued research does not produce positive results in this area, reliance on ancillary data for acreage estimating will continue at least until 1981, when a more advanced satellite is launched. It may even continue beyond 1981 if the fourth Landsat sensor is not adequate

for distinguishing wheat from other grains. This will not be known until experiments have been conducted.

Small field limitations

Another technical problem with Landsat imagery is the inability to locate small fields. The smallest unit of Landsat spatial resolution 1/ is a data element approximately one acre in size. During the first two LACIE phases, the process for classifying wheat in each Landsat sample segment was to analyze contiguous groups of data elements several acres in size instead of each individual data element. As a result, classification errors occurred when wheat fields were smaller than the groups of data elements analyzed. This is a significant problem in accurately estimating wheat production since India, Canada, and China grow wheat in fields much smaller than those found in the United States and the Soviet Union.

NASA has implemented a new wheat classification procedure in Phase III which will permit initial analysis of each data element in a Landsat sample segment. NASA hopes that by analyzing each data element, the small fields heretofore missed will be identified. Results from the new procedure were not available during our review. NASA reported that Phase III preliminary results with the new technique were very good.

Heavy manual involvement

The first step in identifying wheat requires that an analyst distinguish wheat as well as other grains by analyzing Landsat imagery. This is a time-consuming task, and it is highly desirable to develop a method in which only a small part of the total available sample segments is manually interpreted. Then the interpretation will be extended to all available segments by machine classification. This process is referred to as "signature extension."

This technology was tested in Phase I but was considered inadequate to reach the needed performance goals. It worked in only about 20 percent of the cases tested. As a result, signature extension was dropped as a quasi-operational tool during the latter part of Phase I. Research efforts continued into Phase II but did not progress as rapidly as was

---

1/The smallest size of an object that can be recorded by a given sensor.

expected; therefore, no operational signature extension is being attempted during Phase III.

Signature extension continues to be developed and will probably be included as part of the new research effort to be carried out by the three agencies. The current research is directed towards developing a means to

--partition a region into strata of nearly constant soil type, climatology, cropping practices, and other similar factors;

--minimize the effect of atmospheric haze on the interpretation of spectral characteristics for each strata; and

--select with a computer program the fewest number of sample segments within each strata which need image interpretation.

Signature extension is currently being evaluated in a contract awarded by NASA. A machine-processing technique has been developed which may reduce the amount of manual interpretation. The number of samples classified will remain the same; however, the area classified manually within each segment will be reduced by a factor of about 3 to 1. NASA reported that the new procedure used in Phase III reduced the manual data-handling time for each segment from 12 to 3 hours.

Increased data requirements

When the decision was made to expand coverage of the Soviet Union to include the entire country, the number of sample segments increased by 30 percent over the initial Phase III plan. Further, the number of samples in the Great Plains increased by nearly 37 percent in an attempt to reduce the sampling error. Also, an additional 244 sample segments were added to test a new sampling strategy. Overall, these new data requirements increased the number of sample segments by more than 800. Since these sample segments constitute an increase in the processing requirements of a system already at capacity, further reductions were made in the amount of Landsat data to be acquired in Canada and China.

LACIE YIELD MODELS

The yield models under development by NOAA utilize historical yield and meteorological data in conjunction with current meteorological data to forecast current yields.

The yield models do not use Landsat data; however, the yield models are of equal importance in formulating LACIE production estimates.

LACIE yield results through Phase II were mixed. In the Great Plains during Phases I and II, LACIE yield estimates were well within 10 percent of the official SRS estimates. However, the yield estimate for Canadian spring wheat in Phase II was underestimated by about 12 percent, and preliminary data indicates the yield estimates for winter and spring wheat in the Soviet Union were also underestimated by more than 23 percent and 8 percent, respectively.

SRS officials believe the current models can be expected to perform poorly when yield is extremely high or low. In Phase II, LACIE underestimated the yield of Canadian spring wheat, which was much higher than normal, and preliminary data indicates the same thing happened with the Soviet Union's crop.

In the Great Plains, wheat yields were close to normal, and LACIE yield estimates were more accurate.

SRS officials believe the use of highly aggregated weather inputs to predict wheat yields makes the current yield models insensitive to abnormal years. Since the models employ monthly weather inputs, the existence of critical stress conditions over short periods is not properly reflected. In addition, LACIE/NOAA and SRS officials acknowledged that the yield models are not fully sensitive to unusual weather events which occur for short periods over localized areas. Research is being conducted to determine if Landsat data can be used to help alleviate this limitation.

LACIE/NOAA officials recognize the limitations of the yield models employed in Phases I and II. When substantial crop damage due to rust, disease, pestilence, etc., occurs, subjective judgments of yield must still be made.

Another problem inherent with the yield models is the reliance on historical yield data. Because of the way the yield models are constructed, inaccuracies in the historical data base will be reflected in the LACIE yield estimates. Historical yield data from foreign countries is less reliable than domestic estimates and, according to LACIE officials, improved yield models which require less historic data are needed for several LACIE countries. Work is ongoing to develop more accurate yield models.

The most challenging problem is to develop a yield model for the People's Republic of China, where historic yield data is nonexistent. There have been no official crop reports from the People's Republic of China since 1957. While LACIE/NOAA officials believe adequate current and historical meteorological data is available, verification of any yield model would, at best, be severely limited. Partly due to the lack of reliable yield data, the People's Republic of China was not included in Phase III.

LACIE COSTS

During fiscal year 1977, NASA, USDA, and NOAA estimated that LACIE and related research costs through fiscal year 1978 would total about $54 million. Contributions from the participating agencies through this period are as follows:

	Fiscal year 1975	Fiscal year 1976	Fiscal year 1976t (note a)	Fiscal year 1977	Fiscal year 1978	Fiscal year 1975-78
	(000 omitted)					
NASA (note b)	$8,800	$9,000	$2,100	$9,800	$8,000	$37,700
USDA	950	2,000	500	2,850	3,300	9,600
NOAA	700	700	175	700	700	2,975
Total	$10,450	$11,700	$2,775	$13,350	$12,000	$50,275

a/ Transition quarter.

b/ NASA costs do not include funds for satellite procurement and operations, Civil Service personnel salary costs, and outside research contracts related to LACIE. (Outside contracts related to LACIE and awarded by NASA through June 1977 totaled about $3.7 million.)

The estimates shown above include costs for contractor support, computer programming and operations, in-house research, yield model development, and test and evaluation activities. Civil Service personnel costs are included for USDA and NOAA.

CHAPTER 4

DEPARTMENT OF AGRICULTURE'S PLANS

In early 1977, USDA was planning to implement a user system designed to be an operational test of the LACIE-developed techniques for estimating wheat. The Application Test System (ATS), to be established at or near the Johnson Space Center, was to concentrate on wheat. However, in late 1977 these plans changed. Based on a review of its remote-sensing requirements, USDA decided to change the emphasis of the ATS from a wheat-only estimating system to a system covering a wider range of crops and applications. The precise scope has not yet been defined; however, the three participating agencies in the LACIE project are currently preparing the detailed plans for a new joint research, development, and testing project to begin in 1979 and to extend into the 1980s. The general objective of the new work will be to extend LACIE technology and develop new techniques for other crop situations and applications, such as early warning of crop damage and crop condition assessment. USDA has lead responsibility for evaluating these techniques.

The follow-on research currently being planned will involve work at both the Johnson Space Center and the ATS facility. The scope of effort and role each agency will have is not completely defined at this time. Because of this, estimates of the total costs associated with the follow-on work are not yet available; however, USDA is investing in computer equipment, programs, and related items to be located at the ATS facility, and the three agencies have requested about $9 million for fiscal year 1979 operations.

USDA recently developed estimates of the cost of an operational system based on LACIE-developed technology. The estimates compare the costs of a single and multi-crop system and reflect USDA requirements only. The costs for satellite procurement and operations are not included. USDA's estimated costs are shown below.

	Single Crop	Multi-crop
	(millions)	
Investment costs	$9.8	$29.4
Annual operating cost of the system	$4-5	$8-9

Department officials emphasized that these estimates are for a fully operational crop-estimating system and are

not meant to reflect in any way the costs associated with the follow-on research effort. The estimates are subject to periodic revision as information is updated and requirements adjusted. The estimates are developed to

--keep USDA officials informed as to the probable investment and annual operating costs of alternative crop information systems based on LACIE-developed technology,

--provide the cost component for benefit/cost analyses, and

--provide a baseline for evaluating proposed design and system changes.

STATUS OF THE LACIE COST/BENEFIT ANALYSIS

LACIE is the largest and most costly single effort undertaken to demonstrate the usefulness and cost-effectiveness of Landsat data in a practical application. Agricultural crop forecasting is considered one of the most important applications. A 1974 economic assessment indicated that significant benefits were possible from the application of Landsat data, particularly in crop forecasting. These benefits, however, were based on undemonstrated capabilities and the assumption that improvements in Landsat technology would be realized.

In the 1974 project plan, the three participating agencies agreed to perform their own cost/benefit analysis to evaluate the usefulness and cost-effectiveness of a LACIE-type system in providing foreign crop information. USDA is responsible for this effort, and to date has concentrated on user requirements for improved wheat production forecasts and the estimated cost of present and LACIE-based forecasting systems. An analysis of benefits of improved wheat production information will be made in 1978; however, it will not be completed by the end of the LACIE project in July 1978.

As part of the overall cost/benefit analysis, USDA in 1976 contracted for a study of the usefulness of improved foreign wheat production information to its agencies. The contractor was to identify situations in which decisions based on improved foreign crop information would achieve benefits, but was not tasked to quantify the benefits of improved information. The study identified several situations in USDA wheat programs where foreign wheat production information is considered and concluded that

--the major use for improved foreign wheat information is in the administration of wheat exports;

--earlier and more accurate world wheat information would be of greatest value when strong world demand and short domestic supply exist; and

--among USDA officials, the strong interest in improved wheat information is for its value in stabilizing prices.

The study indicated a greater need for improving yield estimates than for improving acreage estimates. This finding is consistent with the USDA/LACIE study (discussed on p. 10.), which showed that FAS yield estimates require considerably more improvement than acreage estimates.

The remainder of the USDA evaluation is being performed in two parts. The first part, to identify the cost and performance of the current USDA forecasting system and estimate these factors for an operational LACIE-type system, has been completed. This information is being used to assess the benefits of a LACIE-type system qualitatively, rather than quantitatively.

The second part of the evaluation will be a quantitative analysis of the benefits of improved information from a LACIE-type system. USDA economists plan to refine and extend existing econometric models for measuring the benefits of information provided by the current system and improvements from a LACIE-type system. USDA economists believe prior efforts to quantify the benefits of agricultural forecasts were inadequate.

The quantitative assessment of benefits will be based on expected improvements in timeliness and accuracy of information from a LACIE-type operational system. The expected performance will be derived by adjusting actual LACIE results to account for expected improvements envisioned in an operational environment. This analysis will not be complete by the end of the LACIE project.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

The 3-year-old LACIE project is developing the technology to improve foreign wheat crop estimates by using Landsat data for estimates of the number of acres grown, and weather data for estimates of wheat yield per acre. The project will be completed on schedule; however, wheat estimates will have been made for only two of the seven foreign countries included in the original scope.

The reduction in scope was due primarily to technical problems.

To date, LACIE has had mixed success in achieving its performance goals. The Phase II forecast accuracy was high for winter wheat in the Great Plains and low for spring wheat, which resulted in the LACIE performance goal not being achieved. Production forecast accuracy was very low for Canadian wheat. Although the LACIE production estimate for the Soviet Union was close to actual production, there were offsetting errors in the area and yield components.

Current Landsat technology cannot adequately distinguish spring wheat from other grains. Two modifications have been made to the sensors on the Landsat spacecraft launched in March 1978; however, it is unknown at this time whether the modifications will improve the ability to distinguish wheat from other grains. The sensor on the fourth Landsat may provide the capability to estimate wheat acreage more accurately; however, this will not be known conclusively until the satellite is launched in 1981 and experiments are conducted.

LACIE yield estimates have been less accurate where wheat yields are extremely high or low. To improve the estimates, models are being developed which will use daily weather data rather than aggregated monthly data. The lack of reliable historical yield data for some LACIE countries also presents a problem, and work is under way to develop models requiring less historical data.

USDA has changed its plans to implement a user system to test LACIE techniques in an operational wheat-estimating system. USDA, NASA, and NOAA are currently planning a joint research program. This new research effort will deemphasize wheat and expand LACIE techniques to other crops and applications, such as early warning of crop damage and crop condition assessment.

USDA's cost-benefit analysis will not be complete by July 1978 when the LACIE project ends; however, it is in process. Because the analysis will use advanced econometric models and will be based on expected LACIE performance, we believe careful review of the study should be made before the results are used by decisionmakers.

RECOMMENDATION

Since there have been technical problems in reaching LACIE objectives and the research direction has changed, we recommend that the Secretary of Agriculture provide cognizant congressional committees with periodic assessments of the LACIE project, the experimentation with other crops, and the experiments with early warning of crop damage and crop condition assessment.

APPENDIX I

National Aeronautics and
Space Administration

Washington D C
20546

JAN 30 1978

L-7

Mr. Donald E. Day
Associate Director of Procurement
and Systems Acquisition Division
U.S. General Accounting Office
Washington, DC 20548

Dear Mr. Day:

Pursuant to the meeting with Mr. Joe Johnson and other GAO representatives on January 23, 1978, attended by Mr. William Stoney, Director of NASA's Earth Observation Program, and Mr. John Coulter of this office, I am submitting herewith the following NASA comments on the Draft GAO Proposed Report "Crop Forecasting by Satellite: Progress and Problems", Code 952165.

It is my understanding that the following comments are accepted by GAO without further revision: 1, 2, 3, 4, 9, 10, 12, 16, 17, 19, 23, 25, 27. [See GAO note p. 23.]

The following comments (5, 13, 14, 20, 21, 26, 28) all concern the NASA position that the only relevant comparison that can be made with the Russian data is with the production numbers. After considerable discussion of the NASA position, the GAO agreed to include appropriate qualifications in the report so that the NASA position would be available to the reader.

[See GAO note p. 23.]

APPENDIX I

Sincerely,

Edward Z. Gray
Director
Government/Industry Affairs

cc: Mr. Joe Johnson, PSAD/GAO

Enclosures(2) * 1. NASA Comments on Draft GAO Report dtd 1/18/78
2. LACIE Phase III Results Summary (3 pages)

*GAO note: NASA's comments have been incorporated as appropriate.

PHASE III RESULTS SUMMARY

ESTIMATE ACCURACIES

IN THREE GLOBAL CROP YEARS, LACIE CROP SURVEY TECHNOLOGY HAS PRODUCED SIGNIFICANTLY IMPROVED WHEAT PRODUCTION INFORMATION.

- U.S. WINTER WHEAT SURVEY ESTIMATES SUPPORTIVE OF 90/90 CRITERION 1-1/2 - 2 MONTHS PRIOR TO HARVEST.

- USSR - THROUGHOUT PHASE III SEASON, LACIE PRODUCTION ESTIMATES REFLECTED REDUCED SOVIET SPRING WHEAT PRODUCTION.

  LACIE YIELD ESTIMATES PREDICTED LOW YIELDS FROM JUNE ON.

  AS IN PHASE II, LACIE SOVIET ESTIMATES LOOK GOOD - USSR WILL NOT RELEASE OFFICIAL WHEAT ESTIMATES UNTIL JANUARY.

- PHASE III MODIFICATIONS PRODUCED SIGNIFICANTLY IMPROVED SPRING WHEAT ESTIMATE IN COMPARISON TO PHASE II - HOWEVER, KEY TECHNICAL ISSUES REMAIN WITH SMALL FIELDS/REGISTRATION - SEPARATION OF SMALL GRAINS/WHEAT REQUIRES FURTHER DEMONSTRATION.

- U.S. YIELD ESTIMATES SIGNIFICANTLY BELOW SRS FOR FIRST TIME - TEST AND EVALUATION OF MODELS INDICATES NEED FOR FURTHER IMPROVEMENT. USSR YIELD ESTIMATES APPEAR REASONABLE AT THIS TIME.

APPENDIX I

LACIE CLASSIFICATION ACCURACY SUMMARY

- WINTER WHEAT
  - AT-HARVEST BLIND SITE RESULTS INDICATE THAT CLASSIFICATION ACCURACY IS ABOUT THE SAME AS IN PHASE II. WITH THE PHASE II UNDERESTIMATION PROBLEM IN OKLAHOMA NOT OCCURING IN PHASE III.
- SPRING WHEAT
  - AT-HARVEST BLIND SITE RESULTS INDICATE IMPROVED CLASSIFICATION ACCURACY OVER PHASE II. BIGGEST IMPROVEMENT WAS REDUCTION IN BIAS. TENDENCY TO UNDERESTIMATE STILL REMAINS.
- TOTAL
  - CLASSIFICATION ACCURACY IMPROVED FROM EARLY SEASON TO AT-HARVEST

APPENDIX I

U.S. GREAT PLAINS WHEAT SUMMARY - 1977

RELATIVE DIFFERENCE (%)

	AREA	YIELD	PRODUCTION
WINTER WHEAT	+4.35	-7.91	-4.04
SPRING WHEAT	-9.33	-12.36	-20.57
TOTAL WHEAT	-0.20	-9.45	-9.61

$$\text{RELATIVE DIFFERENCE \%} = \left[\frac{\text{LACIE} - \text{SRS}}{\text{SRS}} \right]$$

1/25/78

APPENDIX I

APPENDIX II

PRINCIPAL OFFICIALS RESPONSIBLE FOR ACTIVITIES DISCUSSED IN THIS REPORT

DEPARTMENT OF AGRICULTURE

	Tenure of Office	
	From	To
SECRETARY OF AGRICULTURE:		
Bob Bergland	Jan. 1977	Present
John A. Knebel (acting)	Nov. 1976	Jan. 1977
Earl L. Butz	Dec. 1971	Oct. 1976
ASSISTANT SECRETARY, INTERNATIONAL AFFAIRS AND COMMODITY PROGRAMS:		
Dale E. Hathaway	Apr. 1977	Present
Richard E. Bell	July 1975	Apr. 1977
Clayton Yeutter	Mar. 1974	June 1975
ADMINISTRATOR, FOREIGN AGRICULTURAL SERVICE:		
Thomas R. Hughes	July 1977	Present
David L. Hume	Sept.1973	July 1977

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ADMINISTRATOR:		
Robert A. Frosch	June 1977	Present
Alan M. Lovelace (acting)	May 1977	June 1977
James C. Fletcher	Apr. 1971	May 1977
DEPUTY ADMINISTRATOR:		
Alan M. Lovelace	June 1976	Present
George M. Low	Dec. 1969	June 1976
ASSOCIATE ADMINISTRATOR, OFFICE OF SPACE AND TERRESTRIAL APPLICATIONS:		
Anthony J. Calio	Oct. 1977	Present
Bradford Johnston	June 1976	Sept.1977
Leonard Jaffee (acting)	Apr. 1976	June 1976
Charles W. Mathews	Dec. 1971	Apr. 1976

APPENDIX II

DEPARTMENT OF COMMERCE

SECRETARY OF COMMERCE:		
Juanita M. Kreps	Jan. 1977	Present
Elliot L. Richardson	Feb. 1976	Jan. 1977
Rogers C. B. Morton	May 1975	Feb. 1976
John K. Tabor (acting)	Mar. 1975	Apr. 1975
Frederick B. Dent	Feb. 1973	Mar. 1975
ADMINISTRATOR, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION:		
Richard A. Frank	July 1977	Present
Robert M. White	Feb. 1971	July 1977
OFFICE OF ENVIRONMENTAL DATA SERVICE:		
Thomas S. Austin	July 1970	Present

(952165)