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July 1981

1980 U.S./CANADA WHEAT AND BARLEY EXPLORATORY EXPERIMENT SUMMARY REPORT

R. W. Payne

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16. Abstract

This report summarizes the results from the U.S./Canada Wheat and Barley Exploratory Experiment which was completed during FY 1980. The results indicate that the new crop identification procedures performed well for spring small grains and that they are conducive to automation. The performance of the machine processing techniques shows a significant improvement over previously evaluated technology. However, the crop calendars will require additional development and refinements prior to integration into automated area estimation technology.

The evaluation has shown the integrated technology is capable of producing accurate and consistent spring small grains proportion estimates. However, barley proportion estimation technology was not satisfactorily evaluated. Landsat sample segment data was not available for high-density barley of primary importance in foreign regions. The low density segments examined were judged not to give indicative or unequivical results.

It is concluded that, generally, the spring small grains technology is ready for evaluation in a pilot experiment focusing on sensitivity analyses to a variety of agricultural and meteorological conditions representative of the global environment. It is further concluded that a strong potential exists for establishing a highly efficient technology for spring small grains.

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SUMMARY REPORT

Job Order 72-414

This report describes the 1980 U.S./Canada Wheat and Barley Exploratory Experiment of the Foreign Commodity Production Forecasting project of the AgRISTARS program.

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PREFACE

The Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing is a program of research, development, evaluation, and application of aerospace remote sensing for agricultural resources. This program is a cooperative effort of the National Aeronautics and Space Administration, the U.S. Departments of Agriculture, Commerce, and the Interior, and the U.S. Agency for International Development.

The work which is the subject of this document was performed by the Earth Resources Applications Division, Space and Life Sciences Directorate, Lyndon B. Johnson Space Center, National Aeronautics and Space Administration and the Lockheed Engineering and Management Services Company, Inc. Tasks performed by Lockheed were accomplished under Contract NAS 9-15800.

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1. EXECUTIVE SUMMARY

The 1980 U.S./Canada Wheat and Barley Exploratory Experiment was designed to further develop state-of-the-art area estimation technology and test it in a foreign similar environment. Pre-AgRISTARS research had identified technical issues in the reliability and efficiency of estimating spring small grains in the U.S./Canada Northern Great Plains environment and in the separation of spring wheat from spring barley using remote sensing data. Approaches had been developed which provided potential improvement for solving these issues. This experiment was oriented to develop and test these approaches for potential further testing and development leading to foreign application.

Developmental activities were initiated to produce an advanced technology which was not only accurate but efficient and objective. The improvements were directed towards developing an automated area estimation technology with minimal analyst interaction as one component of a foreign commodity production forecasting system.

In response to these objectives, the Foreign Commodity Production Forecasting (FCPF) and Supporting Research (SR) projects developed improved crop identification procedures, machine processing techniques, and crop calendar models. The FPCF Project integrated this technology into the area estimation system and implemented the exploratory test and evaluation. The exploratory evaluation was conducted in order to better understand the performance of this newly developed technology before proceeding to a pilot experiment for evaluation under a larger and more varied set of agricultural and environmental conditions.

The techniques developed and integrated into the FCPF developmental area estimation component for evaluation during the 1980 U.S./Canada Wheat and Barley Exploratory Experiment were: (1) objective crop identification procedures designed to produce consistent and accurate spring small grains identification/labeling results, (2) advanced machine processing techniques developed to improve the estimation of crop area within the sample segments, and (3) recently developed crop calendar models designed to provide improved estimates of the crop development stages for wheat and barley.

The results of the experiment indicated that the new crop identification procedures performed well for spring small grains and that they are conducive to automation. The performance of the machine processing techniques shows a significant improvement over previously evaluated technology. However, the crop calendars will require additional development and refinements prior to integration into automated area estimation technology.

The evaluation has shown the integrated technology is capable of producing accurate and consistent spring small grains proportion estimates. However, barley proportion estimation technology was not satisfactorily evaluated. Landsat sample segment data was not available for high-density barley of primary importance in foreign regions. The low density segments examined were judged not to give indicative or unequivocal results.

It is concluded that, generally, the spring small grains technology is ready for evaluation in a pilot experiment focusing on sensitivity analyses to a variety of agricultural and meteorological conditions representative of the global environment. It is further concluded that a strong potential exists for establishing a highly efficient technology for spring small grains.

2. PURPOSE AND SCOPE

The purpose of this report is to summarize the results from the 1980 U.S./Canada Wheat and Barley Exploratory Experiment. The developmental activities and experiments reported in this document cover activities of the AgRISTARS Foreign Commodity Production Forecasting Project. These activities include component-level exploratory development, integration and testing of crop identification procedures, alternative computer classification techniques and candidate crop development stage models. Remote sensing research related to wheat and barley has also been conducted by the Environmental Research Institute of Michigan (ERIM) for the AgRISTARS Supporting Research Project and is reported elsewhere (Ref. 1).

3. INTRODUCTION

3.1 AgRISTARS PROGRAM

The Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) program is a 6-year program of research, development, and evaluation of the application of aerospace remote sensing to monitoring agricultural resources. The program began in fiscal year (FY) 1980. The AgRISTARS program is a cooperative effort of the National Aeronautics and Space Administration (NASA), the U.S. Departments of Agriculture, Commerce, and the Interior (USDA, USDC, and USDI), and the U.S. Agency for International Development (AID). The goal of this program is to determine the usefulness, cost, and extent to which aerospace remote sensing data can be used by the USDA to improve the objectivity, reliability, and timeliness of information required to carry out USDA missions (Ref. 2).

3.2 FCPF PROJECT

The objective of the Foreign Commodity Production Forecasting (FCPF) project is to develop and test procedures for using aerospace remote sensing technology to provide more objective, timely and reliable crop production forecasting in foreign areas. To develop technology for use in foreign areas, the FCPF project builds upon existing remote sensing technology, and extends this technology to additional crops and regions.

During the first year of the FCPF project, two exploratory experiments were performed using U.S. data to develop and evaluate techniques. These experiments were the U.S./Canada Wheat and Barley Exploratory Experiment (1) and the U.S. Corn/Soybean Exploratory Experiment. This report presents the results from the U.S./Canada Wheat and Barley Exploratory Experiment (Ref. 3).

3.3 U.S./CANADA WHEAT AND BARLEY EXPLORATORY EXPERIMENT

The overall objective of the 1980 U.S./Canada Wheat and Barley Exploratory Experiment was to develop, test and evaluate state-of-the-art technology for spring small grains, wheat and barley to establish a basis for further development of estimation technology to be applied in foreign regions, specifically the U.S.S.R., and indirectly, to Australia and Argentina. The technical emphasis for this exploratory experiment was to:

- Develop accurate and objective crop identification/labeling techniques (Ref. 4).
- Develop a machine processing technology with improved performance characteristics (Ref. 5).
- Develop alternative crop calendar/crop development stage models for making improved estimates of wheat and barley development (Ref. 6).

4. EXPERIMENT DESCRIPTION

Three tests were performed as part of this exploratory experiment. The first test was the labeling procedures test. The second was the evaluation of machine processing/classification technology. The third test was the crop calendar/crop development stage models test. The functional flow of a conceptual system which has these components incorporated into it is shown in Figure 1.

4.1 LABELING PROCEDURES TEST

The labeling procedures test was designed to test and evaluate a newly developed objective labeling procedure. The test was conducted in two phases.

- Phase 1 - A shakedown test using six 1978 segments.
- Phase 2 - An expanded test using 35 segments from a different crop year (1979).

The locations of the segments used in the test are shown in Figures 2 and 3.

The objectives of this test were:

- To determine the accuracy and objectivity of the newly developed spring small grains labeling procedure.
- To determine the accuracy of the barley estimation technology.

In both phases of the test, an objective labeling procedure (Ref. 7) was used to label Landsat pixels in each segment. Input data to the procedure consisted of Landsat multispectral scanner data, crop calendar information, and ancillary agronomic/meteorological data.

The procedure is designed to provide increasingly detailed labeling information at each step using a tree-structured decision logic (Fig. 4). The first step consists of a labeling logic which is used to separate the pixels into cropland and noncropland. The pixels labeled cropland in the first step are separated into spring small grains and other crops in the second step. In the third step, Landsat spectral aids are used for separating the spring small grains into barley and other spring small grains.

AREA ESTIMATION OVERVIEW

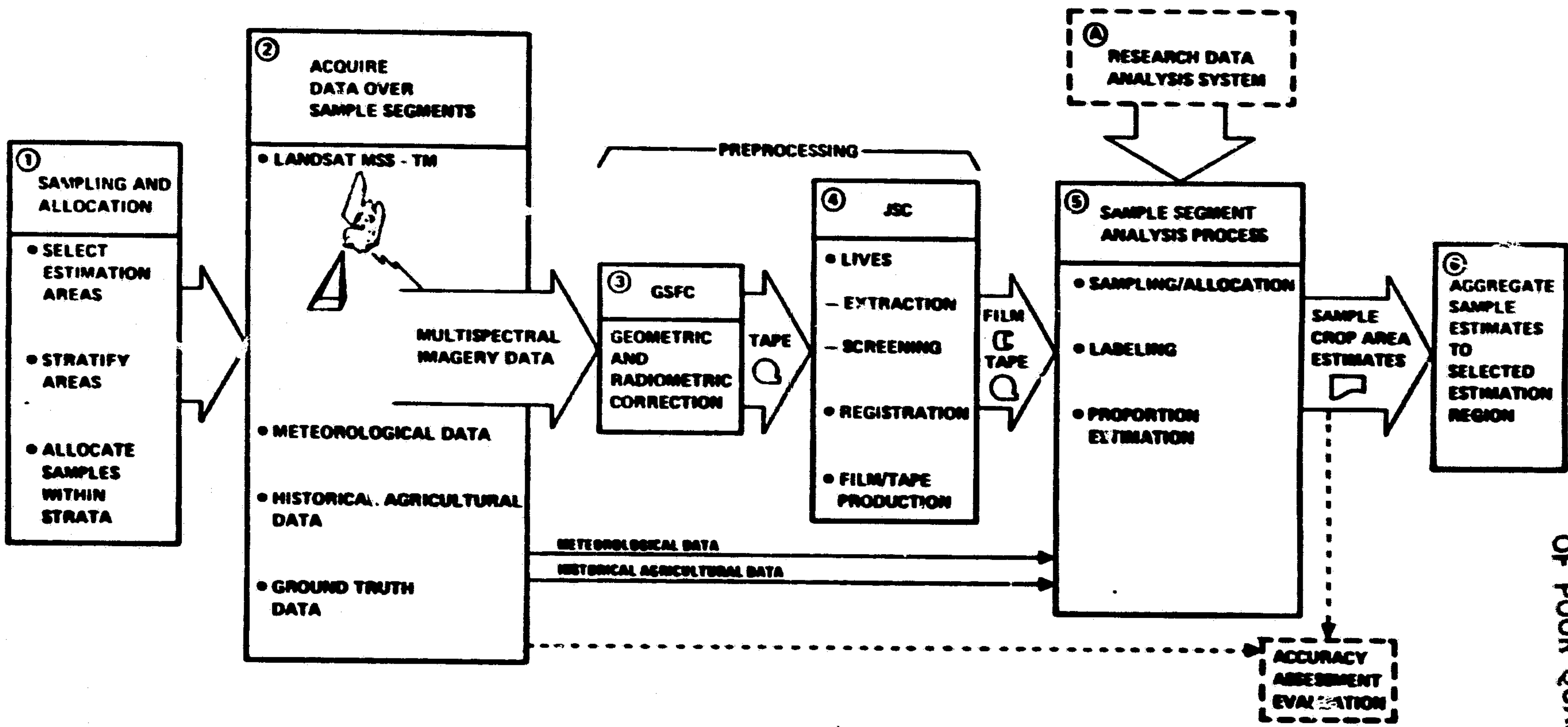


Figure 1. - A Functional Flow of the FCPF Area Estimation Approach

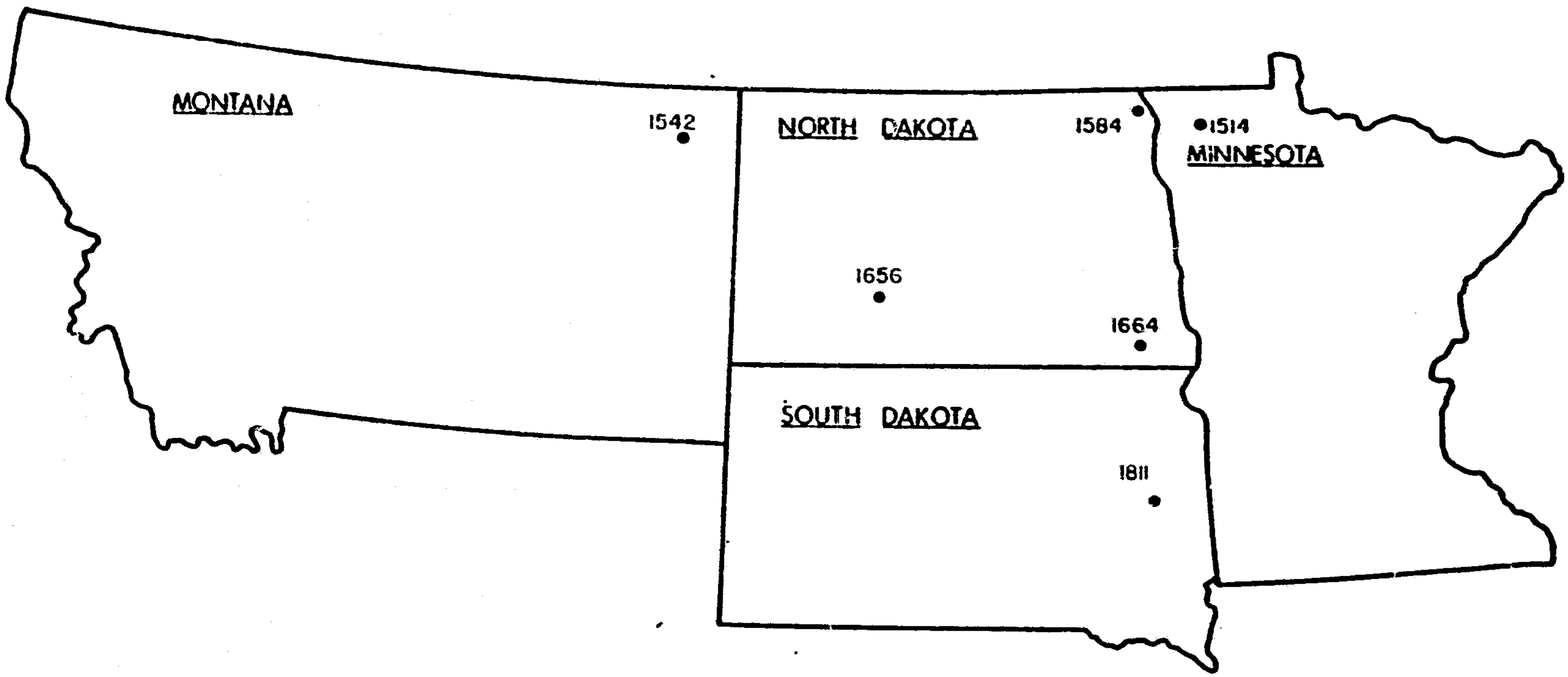


FIGURE 2. - 1978 SEGMENT LOCATIONS FOR THE LABELING PROCEDURES SHAKEDOWN TEST

1979 SEGMENTS

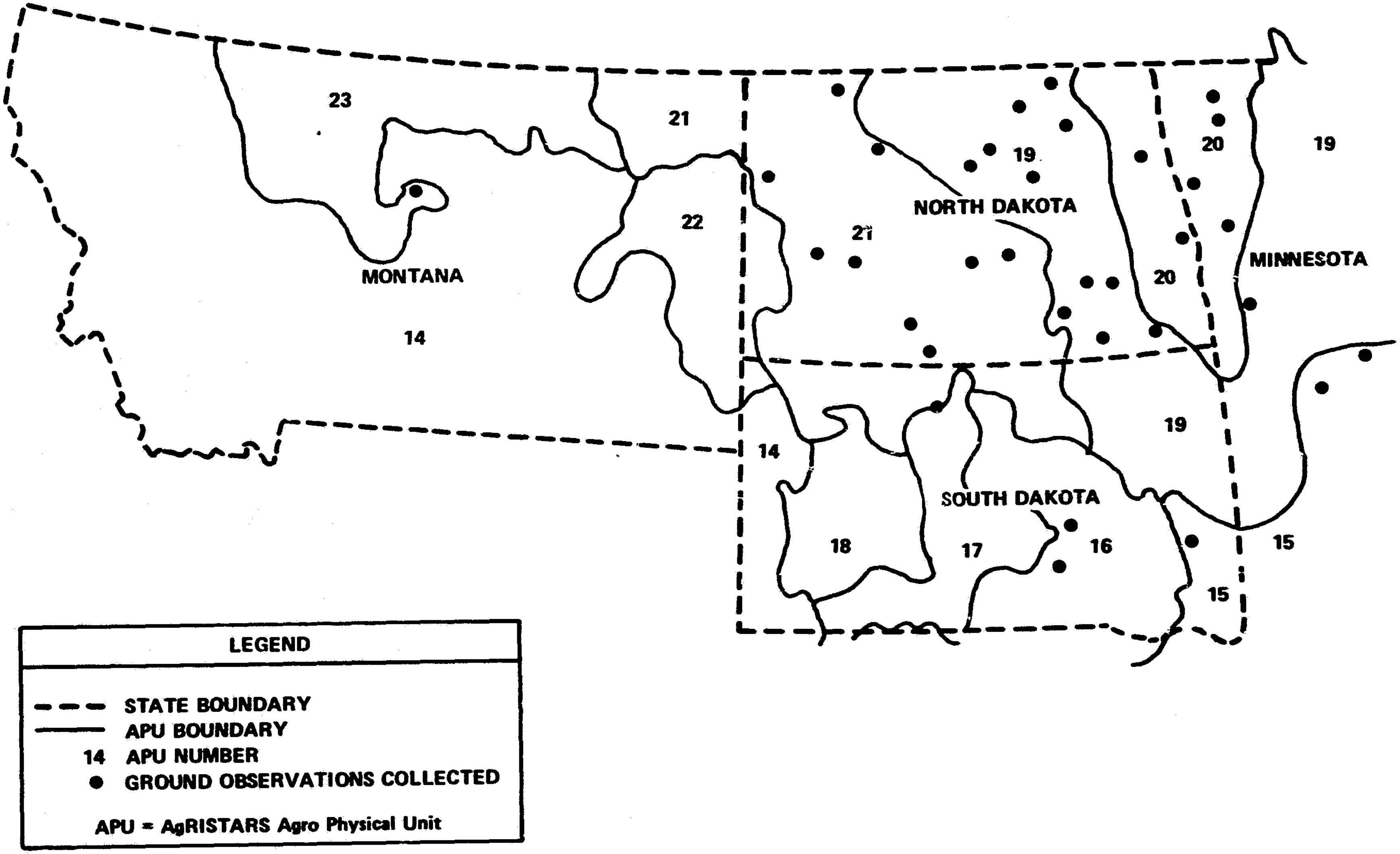


Figure 3 — Segment locations for the 1979 Landsat data.

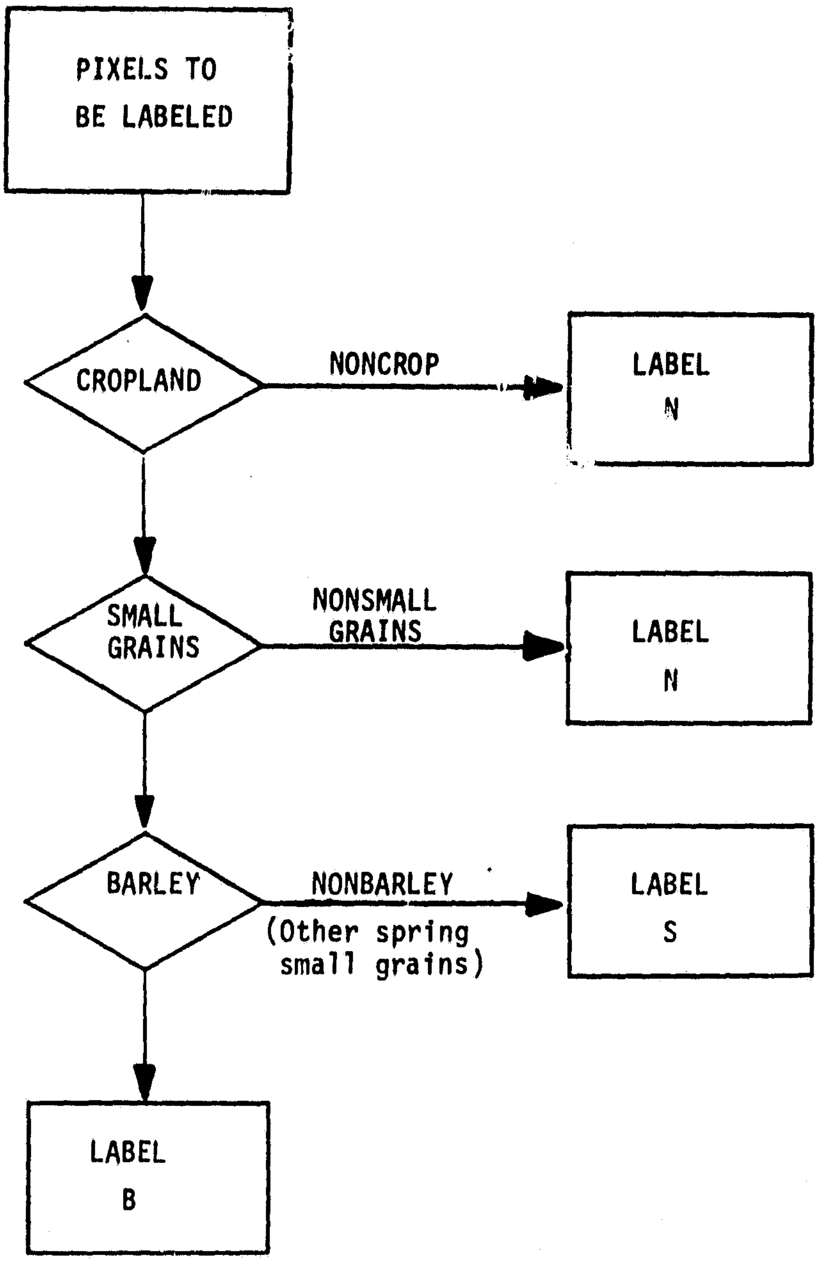


Figure 4. Diagram showing the major steps in the objective labeling logic which leads to identification of barley and other spring small grains.

The segments in the Labeling Procedure Test were processed, independently, by two analysts in order to evaluate the repeatability and objectivity of the procedure. The evaluations were performed by comparing the labeling results from the Integrated Analysis Procedure (Ref. 8) to the segment ground truth inventories. An error characterization study was performed to determine if any changes to the labeling procedure were required to improve the objectivity or accuracy.

4.2 MACHINE PROCESSING/CLASSIFICATION TEST

The machine processing/classification test consisted of processing and classifying the same 1979 U.S. Spring Wheat Region segments used in the Labeling Procedures Test. The objective of the test was to evaluate the accuracy and efficiency of alternative classification techniques.

A need for more efficient use of labeled samples in segment proportion estimation had previously been established by studies which showed that simple random sampling could produce results equivalent to maximum likelihood classification. The Supporting Research (SR) Project developed a Bayes approach to proportion estimation using a stratified sample in response to this deficiency (Ref. 9). This technique was integrated with the labeling procedure to form a proportion estimation component. It was included in the exploratory experiment for evaluation.

The following alternative techniques for allocating samples and estimating crop proportion within each segment were evaluated (Ref. 10).

- Random Sample/Relative count - this technique allocates samples randomly and estimates crop proportions by determining the number of samples in a crop category and dividing by the total number of samples.
- Proportional Allocation/Relative Count - samples are allocated to clusters proportional to the cluster sizes and the estimate is generated by determining the number of samples in a crop category per cluster and weighing the estimate by cluster size.

- Proportional Allocation/Bayes Estimator - the samples are allocated to clusters proportional to cluster size and proportion estimation is calculated using the Bayes Estimator.
- Bayes Sequential Allocation/Bayes Estimator - samples are allocated to clusters sequentially in an attempt to minimize the mean square error (MSE) and a proportion estimate is calculated using the Bayes Estimator.

In the last three evaluations, the samples were stratified using the CLASSY clustering algorithm (Ref. 11, 12, 13).

4.3 CROP DEVELOPMENT STAGE MODEL TEST

The crop development stage model test consisted of estimating the planting date and phenological development stages of wheat and barley in 49 segments within the U.S. Spring Wheat Region. Figure 5 shows the location of the segments used in the test.

The objectives of this test were:

- To evaluate alternative models.
- To determine which combination of planting date and phenological development stage models most accurately estimate the development of wheat and barley.
- To determine if the various models are sufficiently accurate to be incorporated into objective labeling procedures.

The models evaluated in this test are:

- Planting-date models tested
  - Normal Planting-date Model (Ref. 14)
  - Feyerherm Planting-date Model (Ref. 15)
- Wheat Phenological Development Stage Models tested
  - Original Robertson Wheat Model (Ref. 17)
  - Improved Robertson Wheat Model, Version 1 (Ref. 15)
  - Improved Robertson Wheat Model, Version 2 (Ref. 15)

DATA SET

- FORTY-NINE SEGMENTS IN THE SPRING WHEAT AREAS OF THE U.S. GREAT PLAINS.
- 1979 PERIODIC OBSERVATIONS COLLECTED BY ENUMERATORS AT 9 TO 18 DAY INTERVALS CORRESPONDING TO LANDSAT OVERPASS DATES.

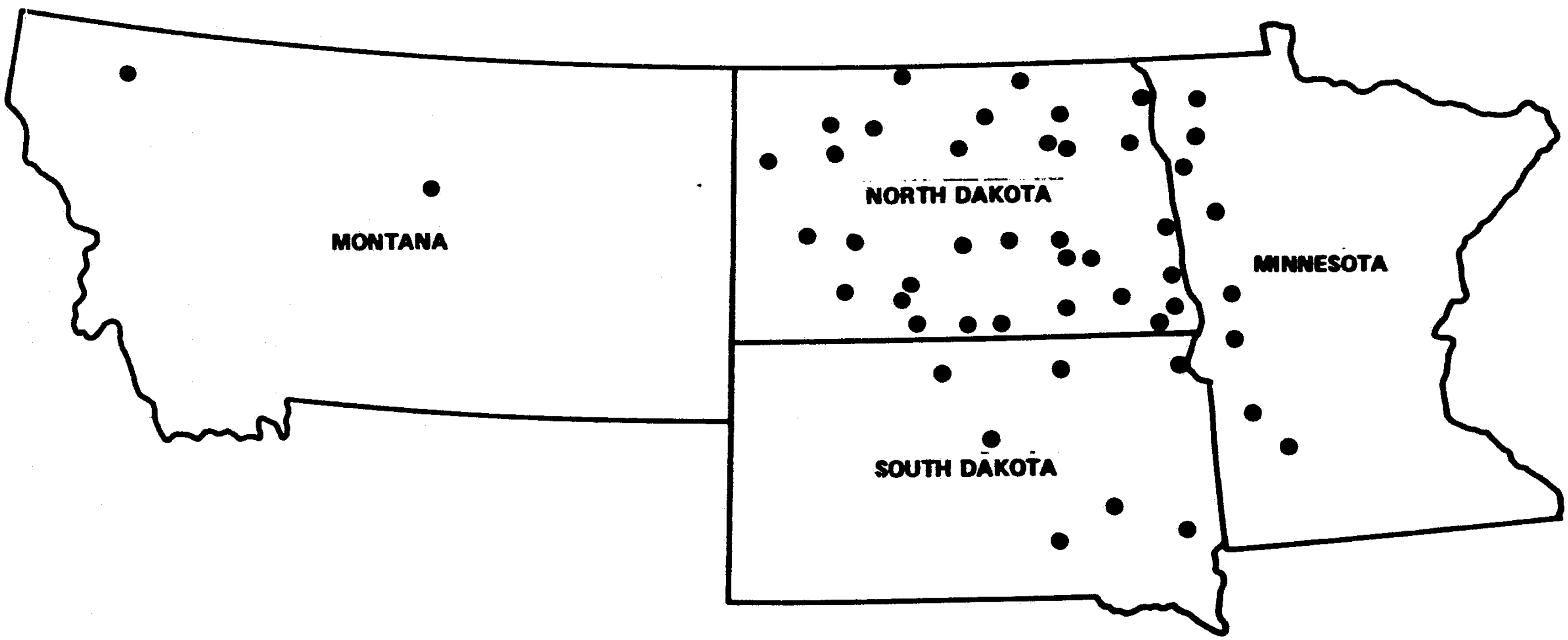


Figure 5. - Segments Used in the Crop Development Stage Model Test

- Barley Phenological Development Stage Model tested
  - Williams Barley Model (Ref. 16)

The Feyerherm and the Normal planting-date models were evaluated on their ability to accurately predict the median planting dates in the segments. The basis for comparison was the ground truth median planting dates. The ground truth median planting dates for spring wheat and barley were obtained by calculating the date at which 50 percent of the spring wheat and barley fields in each of the segments were observed to be planted. Discrepancies between ground truth and the models were measured in number of days.

The performances of the three Robertson growth stage models were evaluated using the ground truth median growth stages as the basis for comparison. Observed median planting dates were used to initiate the models. The ground truth median growth stages for spring wheat and barley were obtained by calculating the observed median stage for spring wheat and barley fields within each of the segments for each of the dates on which the stages were observed. The comparison of the models' prediction versus the observed crop stage yielded errors in terms of crop stages associated with each of the models.

The barley growth stage model was evaluated using the observed median planting dates for barley to initiate the models and subsequently comparing the model prediction of stage with the ground truth median growth stages for barley.

5. EXPERIMENT RESULTS

5.1 LABELING PROCEDURES TEST RESULTS

The shakedown test of the objective labeling procedure using 1978 Landsat data indicated:

- Excellent Spring Small Grains labeling accuracy results. The overall accuracy was 76%.
- Labeling results were comparable to an analyst intensive procedure performed on 1978 data (76% versus 75%).
- Consistency between the analysts was very good. Overall, the agreement on labels was 85%.

The expanded labeling test using the 1979 data provided the following results:

- Labeling accuracy results for spring small grains were similar to the Integrated Analysis Procedure, although slightly lower, 66% for the objective labeling procedure versus 76% for the Integrated Analysis Procedure.
- The 1979 error characterization study identified the areas requiring improvements to the objective labeling procedure.
  - The procedure processed only 25% of the available segments.
  - Confusion of pasture with small grains was a problem.
  - Crop calendar improvements were required in order to better select acquisitions for processing.

The wheat/barley separation procedure results are:

- Segments with 10% and above barley were not available for testing.
- Segments were not available which have both winter wheat and spring barley as in the foreign similar environment.
- The labeling accuracy was approximately 50% in low density barley segments; those containing 5% or less.

5.2 MACHINE PROCESSING/CLASSIFICATION TEST RESULTS

Results of the machine processing/classification test based upon ground truth input labels are:

- A significant increase in the precision of segment proportion estimates was obtained by CLASSY stratification (Table 1).
  - This was the first time a machine processing technique had performed better than the technique of using simple random sampling and making the proportion estimate by relative count.
  - It requires 3 times as many labeled pixels for a randomly sampled segment in order to achieve same proportion estimation precision as when CLASSY stratification is used.
- Segment proportion estimation bias and mean square error (MSE) are significantly reduced by machine processing/CLASSY stratification when compared with the results from random sampling (Table 1).
- There is not a significant difference in the performance of the three machine allocation and estimation techniques: (1) proportion allocation/Relative Count, (2) proportional allocation/Bayes Estimator, and (3) Bayes Sequential allocation/Bayes Estimator.

5.3 CROP DEVELOPMENT STAGE MODEL TEST RESULTS

The results from the test of planting-date models are:

- The Feyerherm Model is significantly better than the Normal Model for predicting both spring wheat and barley planting dates. (Fig. 6a and 6b, respectively)

Results from the test of the Wheat Phenological Development Stage Models are:

- There are no significant differences between the 3 models (Original Robertson and the two improved versions) in estimating the development stages from tillering to ripening.
- The improved Robertson Models, versions 1 and 2, appear to estimate the late heading and ripening stages of wheat more accurately than the original Robertson Model.

TABLE 1. PROPORTION ESTIMATION RESULTS

PROPORTION ESTIMATION TECHNIQUE	GROUND TRUTH LABELS		
	BIAS (%)	STD DEV	MSE
• Random Sample/Relative Count	-2.5	6.9	53
• Proportional Allocation/ Relative Count, CLASSY Stratification	0.0	4.0	16
• Proportional Allocation/ Bayes Estimator, CLASSY Stratification	0.5	3.8	14
• Bayes Sequential Allocation/ Bayes Estimator, CLASSY Stratification	0.4	4.7	22

Figure 6a

PLANTING DATE MODEL RESULTS FOR SPRING WHEAT

+ OVERALL STATISTICS INDICATE THE FEYERHERM MODEL IS CLOSER TO GROUND TRUTH THAN NORMAL MODEL IN PREDICTING SPRING WHEAT PLANTING DATES.

DISTRIBUTION OF ERRORS (IN DAYS) FOR THE FEYERHERM VS. THE NORMAL PLANTING DATE MODELS APPLIED TO SPRING WHEAT

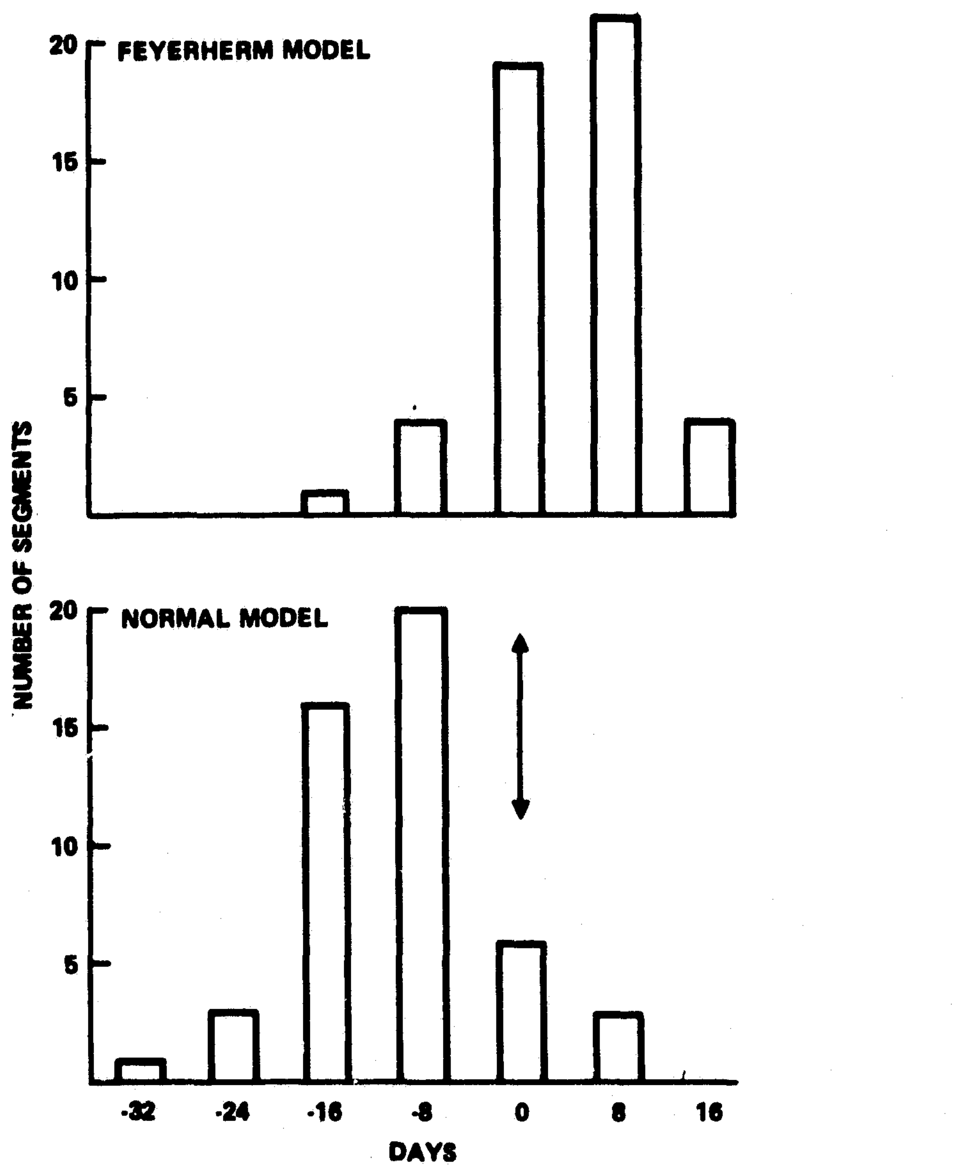
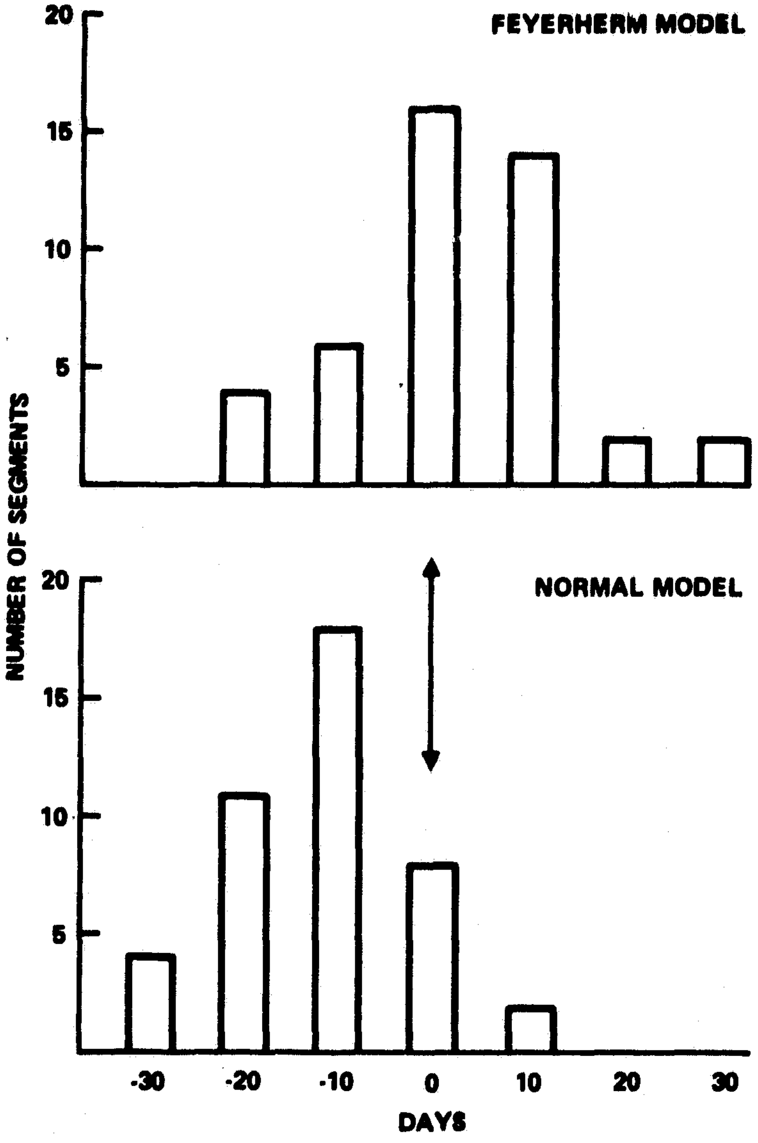


Figure 6b

PLANTING DATE MODEL RESULTS FOR BARLEY

+ OVERALL STATISTICS INDICATE THAT FEYERHERM IS CLOSER TO THE GROUND TRUTH THAN THE NORMAL IN PREDICTING BARLEY PLANTING DATES.

DISTRIBUTION OF ERRORS (IN DAYS) FOR THE FEYERHERM VS. THE NORMAL PLANTING DATE MODELS APPLIED TO BARLEY



Results from the test of the Barley Phenological Development Stage Models are:

- The Robertson Spring Wheat Models performed better than the Williams Barley Model.

None of the models predicted the wheat/barley separation period very accurately.

6. CONCLUSIONS AND RECOMMENDATIONS

The results from the Spring Small Grains labeling procedures evaluation indicate:

- Labeling results are comparable to the Integrated Analysis Procedure.
- The procedure is conducive to automation.
- Error sources are easily identified and quantified due to the tree-structured design of the procedure.
- Improvements to the labeling procedure are required to eliminate the confusion of pasture and spring small grains.
- Additional criteria for defining acceptable Landsat acquisitions for processing are required.

Results from the wheat/barley separation evaluation are:

- The labeling accuracy was approximately 50% in low-density barley segments.
- Because high-density barley segments were not available, the procedure was not adequately evaluated.
- Crop development stage models were insufficient for selecting the wheat/barley separation acquisition.

The machine processing/classification procedure results indicate:

- CLASSY stratification improved the precision of the proportion estimation procedures.
- Estimation bias and the mean square error (MSE) were significantly reduced over random sampling for the first time ever.

The crop development stage model test results indicate:

- The Feyerherm Planting Date Model performs better than the Normal Model for both spring wheat and barley.

- The performance of all three versions of the Robertson Spring Wheat Model is similar.
- The performance of the Robertson and Feyerherm Models appears to be satisfactory for integration into automated labeling procedures; however, further evaluation is recommended.

In summary, it is concluded that:

- The results of the exploratory experiment indicate a strong potential for establishing the basis for a highly efficient technology for evaluation in a foreign environment.
- A pilot experiment should be conducted in order to further develop, test, and evaluate the technology prior to conducting a foreign pilot. The pilot should be conducted on spring small grains in the U.S./Canada Northern Great Plains Region.
- Technology development should focus on the development and evaluation of techniques for efficient area estimation technology, sensitivity analysis of spring small grains area estimation procedures, and assessing performance to be expected in foreign countries.

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