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EVALUATION OF THE PROCEDURE FOR SEPARATING BARLEY FROM OTHER SPRING SMALL GRAINS

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16. Abstract

The major objectives of the investigation documented in this report are to evaluate the procedure for separating barley from the other small grains and to determine if the assumptions upon which the procedure is based hold true. Personnel who developed the procedure exercised the procedure by processing sample segments in the U.S. Northern Great Plains. The results of this processing were then compared to ground truth to obtain accuracy measurements. Results of testing the procedure indicate no difficulty in exercising the procedure correctly; however, there were differences in the labeling accuracies obtained by the evaluators from those obtained by the TY analysts. Reasons for some differences and a discussion of the procedural strengths and weaknesses are offered in the conclusions.

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EVALUATION OF THE PROCEDURE FOR SEPARATING BARLEY FROM OTHER SPRING SMALL GRAINS

Job Order 74-402

This report describes Classification activities of the Foreign Commodity Production Forecasting project of the AgRISTARS program.

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PREFACE

The main objective of this study was the evaluation of the procedure which separates barley from the other spring grains and which was developed for processing of the Transition Year segments. For this evaluation, a decision was made specifying that the procedure developers themselves would exercise the procedure in order not to confound procedural problems with implementation problems. Thus, it became necessary for the evaluation to proceed by first labeling the spring small grains.

The accuracy of the spring small-grain labels obtained in the labeling effort were, on the average, somewhat better than that in the Transition Year operations. The more accurate labels are thought to be due to improvements in the procedure for identification and labeling. Specifically, the departures from the previous procedure included a regionalization of the labeling process, the use of trend analysis, and the removal of time constraints from the actual processing. However, it is not within the scope of this report to include assessments of the labeling accuracies obtained here versus those obtained in the Transition Year operations. Therefore, no specific treatment of these differences will be discussed. Some comments are in order and are included in the conclusion.

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ACRONYMS

ACC	adjusted crop calendar
APU	agro-physical unit
CAMS	Classification and Mensuration Subsystem
CRD	Crop Reporting District
LACIE	Large Area Crop Inventory Experiment
NOAA	National Oceanic and Atmospheric Administration
PFC	production film converter
pixels	picture elements
TY	Transition Year
USDA	U.S. Department of Agriculture
USDA/ASCS	Agricultural Stabilization Conservation Service
USGP	U.S. Great Plains
USNGP	U.S. Northern Great Plains

1. INTRODUCTION

1.1 BACKGROUND

An objective of the Large Area Crop Inventory Experiment (LACIE) was to determine wheat acreage (ref. 1); however, throughout LACIE Phases I, II, and III, the analysts in the Classification and Mensuration Subsystem (CAMS) generated proportion estimates of all the spring small-grain and winter small-grain crops that they could identify within the 5- by 6-nautical-mile segments. In the regions where spring small-grain crops are grown, it was not possible for the LACIE analysts to separate the spring wheat from the other small grains. Therefore, it became necessary to mathematically proportion the other spring small grains (and flax, a confusion crop) and the spring wheat based on historical or other information (ref. 2). Thus, the inability to estimate wheat acreage directly remained an unresolved issue during LACIE.

In an initial developmental effort prior to the processing of LACIE Phase III data, a procedure was developed for estimating spring wheat. Guidelines based on LACIE Phase II data were used. This initial procedure was tested by making estimates on 18 North Dakota blind sites using LACIE Phase III data. A description of this procedure and the results obtained from its use are in reference 3. The procedure was only marginally successful, but the report showed that some of the procedural guidelines used were indeed valid. In particular, evaluation of the spectral aids in the form of green number versus brightness scatter plots of the grain categories [Kauth greenness and brightness (ref. 4)] showed potential for separating the spring grains provided that an acquisition at the correct growth stage was used.

In early 1978, the author of this report and others used data from 46 LACIE Phase III blind-site segments in the four U.S. Northern Great Plains (USNGP) states to develop a procedure which could be utilized to separate barley from the other spring small grains. The procedure relied on the observation that barley tends to become brighter than wheat during and after the soft-dough stage. This finding was later confirmed by W. A. Malila (ref. 5).

The current procedure, which is the subject of this report, was developed by using a combination of spatial and color details observed in the production film converter (PFC) products and spectral aids. Large-scale testing of the procedure was subsequently undertaken using the LACIE Transition Year (TY) Landsat data. During TY, three proportion estimates were to be produced from the spring-grain analysis. They were a "B" for barley estimate; an "S" for spring-wheat, plus oats, plus flax estimate; and a "W" for winter-wheat estimate, when applicable. Ratios would still be applied using a historical econometric model (ref. 6) to the S estimate in order to arrive at the final spring-wheat estimate. When S and B estimates were not possible through lack of the necessary Landsat data, the S and B estimates would be derived from the current spring-grain estimate using a regression model derived from other segments in the area (ref. 7).

1.2 OBJECTIVES

The objective of this study is to evaluate that portion of the direct wheat procedure used for labeling Landsat data as barley and other spring-grain signatures. The procedure, developed for use during TY, is documented in reference 8. The specific objectives of this study are:

a. To determine if the assumptions about the behavior of the relevant crops (upon which the procedure is based) hold true with the TY data [This includes studying the extendability of the procedure from the years upon which the development was based (crop years 1976 and 1977) to another year (crop year 1978).]

b. To measure how well key acquisitions are selected for separation and how well the decision boundaries are placed on the scatter plots (This includes studying the sensitivity of the results generated using this procedure to the errors in selection of the key acquisition.)

c. To evaluate the applicability of the procedure when exercised in larger geographic areas of varying soils, varying meteorological conditions, and varying cropping practices

d. To provide recommendations for further improvements of the procedure

As stated previously, the major objectives of this investigation were to evaluate the procedure for separating barley from the other small grains and to determine if the assumptions upon which the procedure is based hold true. In order to perform this evaluation using TY operational results, it would have been necessary to mount a separate but coordinated effort to assess TY operational errors. This type of assessment is both costly and subjective. The results of such an investigation would also be confounded with potential implementation problems. Therefore, TY operational results were not used. Instead, procedures development personnel themselves assessed the success of the procedure by processing a sample of segments. The results of this processing were then compared to ground truth to obtain accuracy measurements.

2. DATA SET

2.1 SELECTION OF SEGMENTS FOR EVALUATION

Blind sites are a group of segments representing a random sampling of the segments for spring small grains in the U.S. Great Plains (USGP) for which wall-to-wall ground-truth inventories are obtained. Blind sites were used as the ground-truth source during evaluation of the procedure.

The following criteria determined which segments were to be used in this study:

a. The TY blind sites with ground truth were in one of the four USNGP states: North Dakota, South Dakota, Minnesota, or Montana.

b. Segments were required to have sufficient cloud-free Landsat acquisitions with no technical problems, allowing accurate identification and estimation of spring small grains as specified in reference 8, paragraph 4.2.

2.2 GROUND-TRUTH DERIVATION

Ground truth for each segment evaluated was derived using the 1:24 000-scale annotated blind-site color infrared photography provided by the Agricultural Stabilization Conservation Service (ASCS) of the U.S. Department of Agriculture (USDA). Each of the 209 dots labeled in each segment was compared to the corresponding field in the annotated ASCS photograph. The reference Landsat acquisition used in making the comparison was the one used for barley labeling when the segment was analyzed. Ground-truth labels for the 209 dots were determined by experienced analysts comparing directly the ground-truth-annotated photography with the Landsat imagery. Tables B-1(a) through B-1(d) in appendix B provide a comparison of the 209-dot random estimates with the 209-dot ground truth percentages.

2.3 DATA AVAILABLE FOR EACH SEGMENT USED IN ANALYSIS

The USNGP states are presented in figure 2-1(a); the geographic locations of the blind-site segments used in this study are plotted on the reference map in figure 2-1(b).

In appendix A, table A-1 is a tabulation of the types of data available and used during the original analysis of each of the 45 segments selected. Each segment is believed to have at least sufficient acquisitions to identify spring grains as required in reference 8. Additional data such as Landsat full frames (when indicated), historical county-acreage percentages, references to blind-site signatures and percentages of previous years, and CAMS estimates from previous years were used as aids in spring-grain analysis as a matter of analyst preference. In addition to the aforementioned data for each segment, a historical crop calendar for each U.S. Crop Reporting District (CRD) and adjustments provided by the National Oceanic and Atmospheric Administration (NOAA) to reflect real-time segment spring-wheat conditions were available at the time of analysis for all segments. Significant impact made by each of the above types of reference data will be mentioned where appropriate throughout the report.

The bulk of detail in table A-1 of appendix A is provided to indicate exactly what data were available and used in analyzing each segment. The "late-heading-to-ripe" acquisition used for barley separation and labeling in each segment is designated in table A-1 by footnote.

In the "Remark" column of table A-1, the information indicates which segments meet the criteria of Code 33, a code indicating the absence of an acquisition showing the barley emergent signature as defined in section 5.3. The remark column also indicates those segments which were analyzed for the first time during TY or which had been relocated since LACIE Phase III processing. It should be noted here that historical county grain-acreage percentages were available for analyst use in North Dakota only on new or relocated segments. These data were available in other states for all segments.

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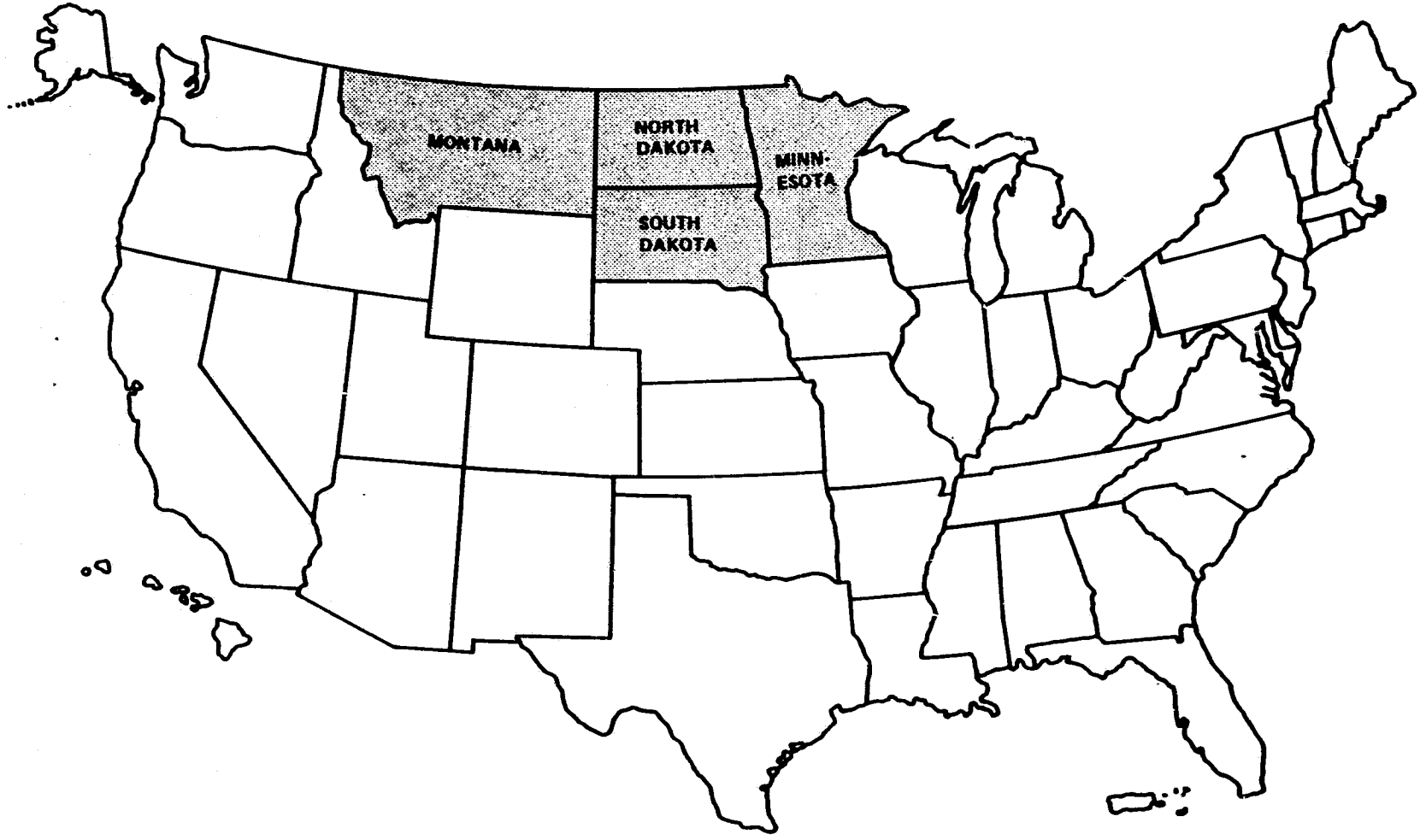


Figure 2-1(a).- The USNGP states.

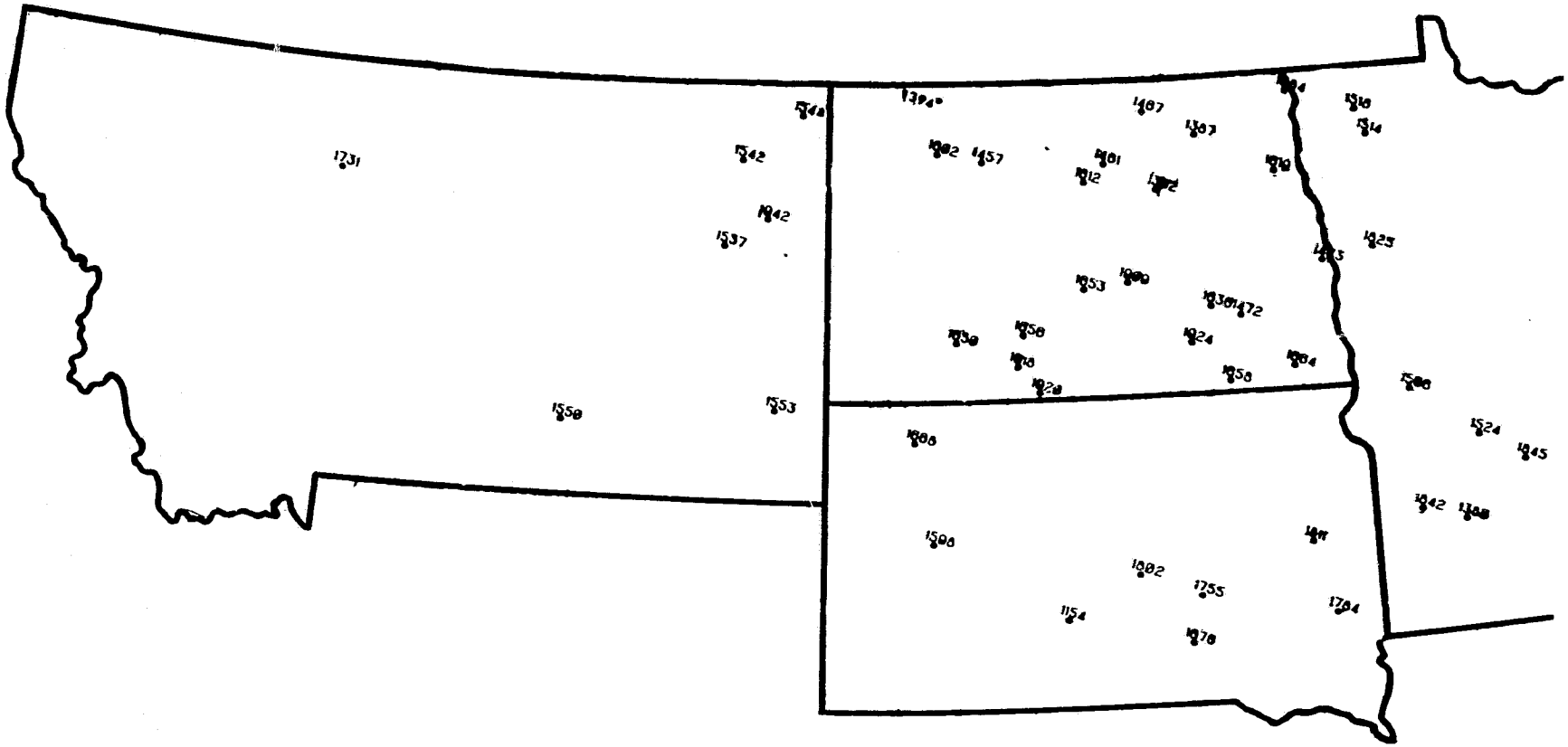


Figure 2-1(b).- The geographic locations of blind-site segments.

3. THE PROCEDURE

3.1 ASSUMPTIONS

Listed below are the principles or basic assumptions upon which the procedure for the separation of TY spring small grains and barley is based.

a. Barley matures earlier than other spring grains.

b. Barley becomes brighter and less green within a definite growth-stage range and can be identified (separated from other small grains) using color changes which occur at this stage in the Landsat imagery products and in the green number versus brightness scatter plots of the 209 dots.

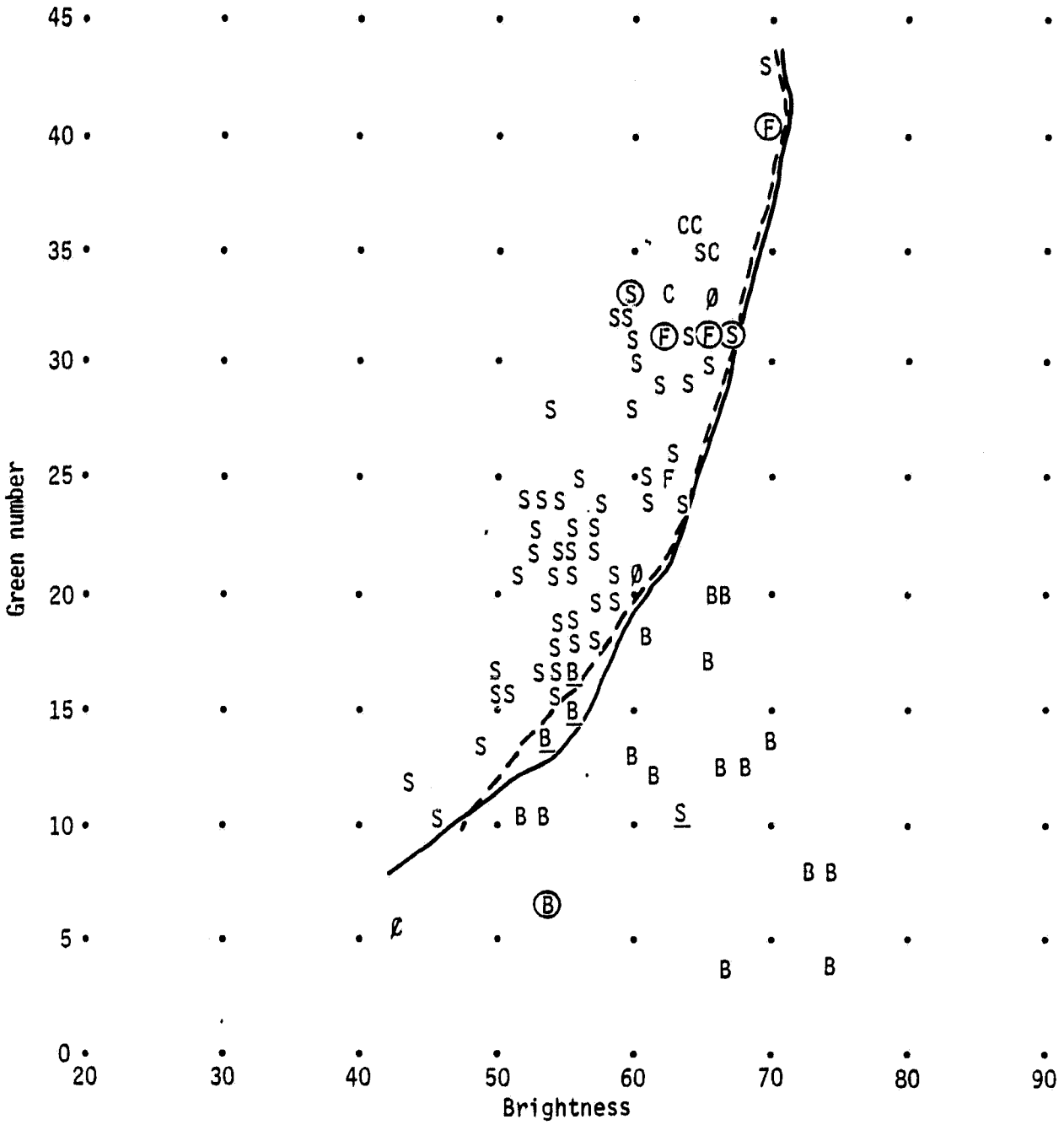
3.2 APPLICATION

The procedure requires that the analysts identify all spring small grains and determine whether the correct acquisition is present to allow the separation of barley. For those segments not having the critical barley acquisition, the analyst labels the segment for total spring small grains only and does not attempt to label barley. The following steps are to be completed for those segments that do have an acquisition in the barley separation window; these steps are taken after the spring grains have been identified in accordance with reference 8.

a. Identify the acquisition in the barley separation window. (This is the acquisition in which fields of the least mature spring grains have reached the late-heading stage but in which none have been harvested.)

b. Label the more advanced (brighter and yellower) signatures in the PFC products as definite barley (B); the less advanced signatures (less bright and more red) as other spring small grains (S); the mixed or uncertain spring small-grain signatures (V or Q). Label all 209 dots in the dot grid of the segment identifying all the spring small grains with one of the four alphabetic characters: B, S, V, or Q.

c. Generate a green number versus brightness scatter plot (fig. 3-1) of the spring small-grain dots. In those cases in which barley is separable, the barley dots assume a scattered distribution apart from the cluster of the



Legend:

B	Barley dot correctly identified	Ø	Oats dot correctly identified
(B)	Barley dot labeled nongrain (omission)	S	Spring-wheat (or durum) dot correctly identified
B	Barley dot labeled S (confusion)	(S)	Spring-wheat dot labeled nongrain (omission)
C	Nongrain labeled S (commission)	S	Spring-wheat dot labeled B (confusion)
ℓ	Nongrain labeled B (commission)	——	Analysts decision boundary
F	Flax dot correctly identified	- - -	Optimal decision boundary
(F)	Flax dot labeled nongrain (omission)		

Figure 3-1.- The green number versus brightness scatter plot.

other grains. Specifically, the barley dots will be generally below and to the right of the main spring-grains cluster. A comparison of scatter plots at 18-day intervals will illustrate to the reader the general drift of the barley dots as they separate from the other small grains. Examples are contained in reference 8 which documents the procedure in detail.

d. Decide the final labels for those dots of questionable identity by using the dot distribution in the scatter plot and the color details in the imagery. If some dots are very difficult to label, they should be proportioned as B or S dots in the same ratio as the B and S dots already identified.

4. APPROACH

4.1 INTRODUCTION

Two analysts were designated to evaluate the procedure. These analysts were both highly experienced and heavily involved in the development phase of the procedure. The analysts themselves implemented the procedure on test sites having available ground truth. The results were then evaluated using the ground truth. The barley procedure was implemented by executing the whole labeling procedure for spring small grains as described in reference 8. First, the spring small-grain dots were identified and labeled; then, the barley dots were separated from the other spring small-grain dots. Procedures similar to those used in other LACIE accuracy assessment reports were used to evaluate the results. These procedures are documented in reference 9.

4.2 LABEL TERMINOLOGY USED

For purposes of this study, the following symbols will apply when referring to the spring small grains:

SW = spring wheat

Ø = oats

B = barley

F = flax

S = spring wheat + oats + flax

SG = S + B (spring small grain or spring grain)

4.3 METHODOLOGY

The labels obtained by consensus opinion of the two analysts were recorded on dot-label forms in use by LACIE analysts. These labels and the corresponding ground-truth labels, as determined by the analysts using the ASCS-annotated 1:24 000-scale aerial photography, were subsequently recorded on a form designed to allow dot-by-dot comparisons (ref. 9, fig. 1). To estimate the

degree of success of the labeling experiment, the following determinations were made from the analyst labels and the ground-truth labels for the segments:

a. Random estimates of the proportion of spring small grains in the segments were computed from the labels of the 209 grid dots and compared with the wall-to-wall ground-truth random-dot proportion estimations.

b. Labeling accuracy estimates were obtained by direct comparison of the labels of dots determined by analysts to corresponding labels derived using ground-truth information. Ground-truth labels were determined by direct comparison of an annotated ASCS photograph to the appropriate Landsat acquisition (base date). The accuracy calculations included omission and commission errors of the categories of interest. The categories of interest include spring small grains (SG) and nonspring small grains (N). The spring small grains were further categorized into spring small grains less barley [spring wheat + oats + flax (S)] and barley (B).

c. Error causes were obtained by characterizing the errors in labeling using procedures previously developed and used in LACIE (ref. 9). These procedures consist of a subjective attempt to characterize labeling errors. The analysis was done for each labeled dot and the results were summarized at the state level.

d. Scatter plots of the key acquisitions with ground-truth labels were generated to aid in the assessment of errors in the barley separation process. Specifically, they were used to determine if the barley behaved as expected and if it were separable on the expected acquisition or on an alternate acquisition. Conversely, if the barley exhibited the expected behavior, the scatter plots were used to determine if the decision boundary was misplaced.

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5. RESULTS

5.1 SPRING-GRAIN 209-DOT RANDOM ESTIMATE

A total of 45 segments was labeled for spring small grains; of these, 40 segments were labeled for barley also. Proportion estimates at the segment level were obtained as simple random estimates from 209 dots of the 209-dot grid that was labeled. The results obtained for proportion errors at the state level are shown in table 5-1; the results at the segment level are shown in tables B-1(a) through B-1(d) in appendix B. These tables indicate that the small grains were underestimated slightly in all states except South Dakota. The overestimate in South Dakota is due to the overestimation of one segment which was overestimated by 15 percent as shown in table B-1(b). The barley estimate was within about 1 percent of the barley proportion obtained from ground truth.

TABLE 5-1.- AVERAGE ABSOLUTE PROPORTION ERROR

State	Number of segments		$\hat{P} - P$, percent		
	SG	S and B	S	B	SG
North Dakota	22	19	-0.97	-1.12	-2.52
South Dakota	8	7	2.27	-1.10	0.81
Minnesota	8	7	-2.83	0.51	-2.16
Montana	7	7	-1.24	-0.62	-1.85
All states	45	40	-0.78	-0.75	-1.81

Symbol definitions:

SG - Spring small grains
S - Spring wheat + oats + flax
B - Barley

Highlights of the data shown previously in table 5-1 and tables B-1(a) through B-1(d) of appendix B are outlined below.

a. North Dakota

(1) Estimates of spring small grains (22 segments)

- The highest error occurred in agro-physical unit (APU) 21 where the individual segment estimates range from 2 percent to 15 percent under the ground-truth estimates. The average underestimate in this APU was about 9 percent, over nine segments. Most of this error was concentrated in three segments.

- The remaining segments in North Dakota had proportion errors of less than about 6 percent with all but two having errors of less than about 3 percent.

- The total commission errors (138 dots) compensated for more than one-half of the omission errors (253 dots), and the resulting proportion error was about -6.9 percent relative error when compared to the spring-grain ground truth.

(2) Estimates of barley (19 out of 22 segments with a barley (B) window)

- Proportion error in North Dakota barley estimates ranged from about -8 percent to +4 percent. Most of the barley dots that were misidentified were labeled S.

- Some segments had a large relative error in the proportion of barley; typically, these were segments with small amounts of barley (0.5 percent to 7 percent).

b. South Dakota

(1) Estimates of spring small grains (8 segments)

- Table B-1(b) in appendix B indicates that all but one segment had proportion errors which were less than 5 percent. The average error over the eight segments was +0.8 percent. However, segment 1154 was overestimated by 15.7 percent; it is an outlier. If this segment is removed from the averages, the remaining seven

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segments result in an average underestimation of 2 percent. This indicates the same pattern of slight underestimation evident in the other three spring small-grain states. In segment 1154, most of the commission errors were due to winter wheat being called spring small grains. (See section 5.3 for causes of labeling error.)

(2) Estimates of barley (7 segments)

- The worst barley estimate occurred in segment 1784 where most of the barley was called other spring grains. This resulted in underestimating the barley by 6.7 percent, which is equivalent to having missed 78 percent of the barley in the segment. The remaining barley estimates were within 3 percent of the ground-truth estimate.

c. Minnesota

(1) Estimates of spring small grains (8 segments)

- Spring small-grain estimates in Minnesota range from 1 percent to 4 percent under the ground-truth estimates. The resulting underestimation in acreage was about 2 percent.
- Five of the eight sites had a relative error of less than 10 percent. The main problem in the other three sites was spring wheat being called nonwheat.
- The total commission errors (40 dots) compensated for more than one-half of the omission errors (74 dots), increasing the proportion estimate accuracy.

(2) Estimates of barley (7 segments)

- The barley estimates were, for the most part, very accurate (within 1 percent with one exception), but there were only 20 barley dots to be found in all the segments in this state. Of these, only 11 were identified correctly and the remaining nine were committed from mostly oats.
- The barley was correctly estimated to be 0 percent in the two segments with no barley.

d. Montana

(1) Estimates of spring small grains (7 segments)

- Montana estimation errors ranged from underestimation of about 4 percent to overestimation of 0.5 percent. The average underestimation was 1.8 percent.
- Three segments out of the four with the worst underestimates accounted for most of the underestimation; all were from APU 22. These errors were caused mostly by mislabeling of spring small grains as winter wheat due to early development. (See section 5.3.)

(2) Estimates of barley (7 segments)

- Barley estimate errors were low, ranging from a 3-percent underestimate to a 1-percent overestimate. The relative error was quite high because of the low number of dots. There were only 20 barley dots (about 10 percent of the spring small grains). Of the 20 dots, only 4 were correctly labeled.

5.2 LABELING ACCURACY

Labeling data for each spring small-grain category are tabulated in table C-2 in appendix C; the results are presented at the state level for both the set of 45 segments that were labeled for spring small grains and the subset of 40 segments that were labeled for barley. Tables C-2(a) through C-2(e) contain segment level data. The information from these tables is summarized and depicted in the confusion matrices shown in table 5-2(a) through 5-2(e). These tables display the labeling accuracy and confusions for the spring small grains, the barley, and the other spring-small grains. The accuracies for spring small grains are based on the set of 45 segments and the accuracies for barley and other spring small grains are based on the set of 40 segments. Tables 5-2(a) through 5-2(e) reflect that the overall labeling accuracy for those dots that were correctly identified as spring small grains was about 90 percent for the four-state area and also for each state separately, with exception of South Dakota where it was 82 percent. The primary reason for the lower accuracy in South Dakota is that this state has a higher than average

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TABLE 5-2.- SPRING GRAIN AND BARLEY LABELING ACCURACY FOR THE USNGP

(a) The four-state area

Analyst label

Ground-truth label	SG	N
SG	$\frac{1956}{2375} = 0.82$	$\frac{419}{2375} = 0.18$
N	$\frac{255}{6691} = 0.04$	$\frac{6436}{6691} = 0.96$

Overall labeling accuracy:

$$\frac{8392 \text{ Correctly labeled}}{9066 \text{ Number dots labeled}} \times 100 = 92.57\%$$

Analyst label

Ground-truth label	S	B	N
S	$\frac{1401}{1767} = 0.79$	$\frac{57}{1767} = 0.03$	$\frac{309}{1767} = 0.18$
B	$\frac{110}{341} = 0.32$	$\frac{189}{341} = 0.56$	$\frac{43}{341} = 0.12$
N	$\frac{192}{6026} = 0.03$	$\frac{34}{6026} = 0.01$	$\frac{5800}{6026} = 0.96$

Overall labeling accuracy:

$$\frac{7390 \text{ Correctly labeled}}{8134 \text{ Number dots labeled}} \times 100 = 90.8\%$$

Separation percentages

Separation of barley and other spring small grains for those pixels correctly labeled spring small grains:

$$\frac{S{:}S + B{:}B}{S{:}S + S{:}B + B{:}S + B{:}B} \times 100 = \frac{1590}{1757} \times 100 = 90.5\%$$

Separation of barley given that a barley pixel was correctly identified as spring small grains:

$$\frac{B{:}B}{B{:}B + B{:}S} \times 100 = \frac{189}{299} \times 100 = 63.2\%$$

Separation of the other small grains given that an other small-grain pixel was correctly identified as spring small grains:

$$\frac{S{:}S}{S{:}B + S{:}S} \times 100 = \frac{1401}{1458} \times 100 = 96.1\%$$

Symbol definitions:

B — Barley
N — Nongrain + winter wheat + rye
S — Spring wheat + oats + flax
SG — Spring grains

B:B — Barley labeled barley
B:S — Barley labeled spring wheat + oats + flax
S:B — Spring wheat + oats + flax labeled barley
S:S — Spring wheat + oats + flax labeled spring wheat + oats + flax

TABLE 5-2.- Continued.

(b) North Dakota

Analyst label

Ground-truth label	SG	N
SG	$\frac{1407}{1660} = 0.85$	$\frac{253}{1660} = 0.15$
N	$\frac{138}{1903} = 0.05$	$\frac{2765}{2903} = 0.95$

Overall labeling accuracy:

$$\frac{4172 \text{ Correctly labeled}}{4563 \text{ Number dots labeled}} \times 100 = 91.4\%$$

Analyst label

Ground-truth label	S	B	N
S	$\frac{991}{1209} = 0.82$	$\frac{42}{1209} = 0.03$	$\frac{176}{1209} = 0.15$
B	$\frac{78}{268} = 0.29$	$\frac{164}{268} = 0.61$	$\frac{26}{268} = 0.10$
N	$\frac{102}{2459} = 0.04$	$\frac{18}{2459} = 0.01$	$\frac{2339}{2459} = 0.95$

Overall labeling accuracy:

$$\frac{3494 \text{ Correctly labeled}}{3936 \text{ Number dots labeled}} \times 100 = 88.77\%$$

Separation percentages

Separation of barley and other spring small grains for those pixels correctly labeled spring small grains:

$$\frac{S:S + B:B}{S:S + S:B + B:S + B:B} \times 100 = \frac{1155}{1275} \times 100 = 90.6\%$$

Separation of barley given that a barley pixel was correctly identified as spring small grains:

$$\frac{B:B}{B:B + B:S} \times 100 = \frac{164}{242} \times 100 = 67.8\%$$

Separation of the other small grains given that an other small-grain pixel was correctly identified as spring small grains:

$$\frac{S:S}{S:B + S:S} \times 100 = \frac{991}{1033} \times 100 = 95.93\%$$

Symbol definitions:

B — Barley
N — Nongrain + winter wheat + rye
S — Spring wheat + oats + flax
SG — Spring grains

B:B — Barley labeled barley
B:S — Barley labeled spring wheat + oats + flax
S:B — Spring wheat + oats + flax labeled barley
S:S — Spring wheat + oats + flax labeled spring wheat + oats + flax

TABLE 5-2.- Continued.

(c) South Dakota

Analyst label

Ground-truth label	SG	N
SG	$\frac{113}{158} = 0.72$	$\frac{45}{158} = 0.28$
N	$\frac{57}{1311} = 0.04$	$\frac{1254}{1311} = 0.96$

Overall labeling accuracy:

$$\frac{1367 \text{ Correctly labeled}}{1469 \text{ Number dots labeled}} \times 100 = 93.06\%$$

Analyst label

Ground-truth label	S	B	N
S	$\frac{73}{113} = 0.68$	$\frac{2}{113} = 0.02$	$\frac{34}{113} = 0.03$
B	$\frac{16}{33} = 0.48$	$\frac{10}{33} = 0.30$	$\frac{7}{33} = 0.12$
N	$\frac{51}{1216} = 0.04$	$\frac{6}{1216} = 0.005$	$\frac{1159}{1216} = 0.95$

Overall labeling accuracy:

$$\frac{1246 \text{ Correctly labeled}}{1362 \text{ Number dots labeled}} \times 100 = 91.5\%$$

Separation percentages

Separation of barley and other spring small grains for those pixels correctly labeled spring small grains:

$$\frac{S:S + B:B}{S:S + S:B + B:S + B:B} \times 100 = \frac{87}{105} \times 100 = 82.9\%$$

Separation of barley given that a barley pixel was correctly identified as spring small grains:

$$\frac{B:B}{B:B + B:S} \times 100 = \frac{10}{26} \times 100 = 38.5\%$$

Separation of the other small grains given that an other small-grain pixel was correctly identified as spring small grains:

$$\frac{S:S}{S:B + S:S} \times 100 = \frac{77}{79} \times 100 = 97.4\%$$

Symbol definitions:

B — Barley
N — Nongrain + winter wheat + rye
S — Spring wheat + oats + flax
SG — Spring grains

B:B — Barley labeled barley
B:S — Barley labeled spring wheat + oats + flax
S:B — Spring wheat + oats + flax labeled barley
S:S — Spring wheat + oats + flax labeled spring wheat + oats + flax

TABLE 5-2.- Continued.

(d) Minnesota

Analyst label

Ground-truth label	SG	N
SG	$\frac{277}{351} = 0.79$	$\frac{74}{351} = 0.21$
N	$\frac{40}{1224} = 0.03$	$\frac{1184}{1224} = 0.97$

Overall labeling accuracy:

$$\frac{1461 \text{ Correctly labeled}}{1575 \text{ Number dots labeled}} \times 100 = 92.76\%$$

Analyst label

Ground-truth label	S	B	N
S	$\frac{194}{259} = 0.75$	$\frac{8}{259} = 0.03$	$\frac{57}{259} = 0.22$
B	$\frac{5}{20} = 0.25$	$\frac{11}{20} = 0.55$	$\frac{4}{20} = 0.20$
N	$\frac{21}{1098} = 0.02$	$\frac{8}{1098} = 0.01$	$\frac{1069}{1098} = 0.97$

Overall labeling accuracy:

$$\frac{1274 \text{ Correctly labeled}}{1377 \text{ Number dots labeled}} \times 100 = 92.5\%$$

Separation percentages

Separation of barley and other spring small grains for those pixels correctly labeled spring small grains:

$$\frac{S:S + B:B}{S:S + S:B + B:S + B:B} \times 100 = \frac{205}{218} \times 100 = 94.0\%$$

Separation of barley given that a barley pixel was correctly identified as spring small grains:

$$\frac{B:B}{B:B + B:S} \times 100 = \frac{11}{16} \times 100 = 68.8\%$$

Separation of the other small grains given that an other small-grain pixel was correctly identified as spring small grains:

$$\frac{S:S}{S:B + S:S} \times 100 = \frac{194}{202} \times 100 = 96.0\%$$

Symbol definitions:

B — Barley
N — Nongrain + winter wheat + rye
S — Spring wheat + oats + flax
SG — Spring grains
B:B — Barley labeled barley
B:S — Barley labeled spring wheat + oats + flax
S:B — Spring wheat + oats + flax labeled barley
S:S — Spring wheat + oats + flax labeled spring wheat + oats + flax

TABLE 5-2.- Concluded.

(e) Montana

Analyst label

Ground-truth label	SG	N
SG	$\frac{159}{206} = 0.77$	$\frac{47}{206} = 0.23$
N	$\frac{20}{1253} = 0.02$	$\frac{1233}{1253} = 0.98$

Overall labeling accuracy:

$$\frac{1392 \text{ Correctly labeled}}{1459 \text{ Number dots labeled}} \times 100 = 95.41\%$$

Analyst label

Ground-truth label	S	B	N
S	$\frac{139}{186} = 0.75$	$\frac{5}{186} = 0.03$	$\frac{42}{186} = 0.22$
B	$\frac{11}{20} = 0.55$	$\frac{4}{20} = 0.20$	$\frac{5}{20} = 0.25$
N	$\frac{18}{1235} = 0.01$	$\frac{2}{1253} = 0.02$	$\frac{1233}{1253} = 0.98$

Overall labeling accuracy:

$$\frac{1376 \text{ Correctly labeled}}{1459 \text{ Number dots labeled}} \times 100 = 94.3\%$$

Separation percentages

Separation of barley and other spring small grains for those pixels correctly labeled spring small grains:

$$\frac{S:S + B:B}{S:S + S:B + B:S + B:B} \times 100 = \frac{143}{159} \times 100 = 89.9\%$$

Separation of barley given that a barley pixel was correctly identified as spring small grains:

$$\frac{B:B}{B:B + B:S} \times 100 = \frac{4}{15} \times 100 = 26.7\%$$

Separation of the other small grains given that an other small-grain pixel was correctly identified as spring small grains:

$$\frac{S:S}{S:B + S:S} \times 100 = \frac{139}{144} \times 100 = 96.5\%$$

Symbol definitions:

B — Barley

N — Nongrain + winter wheat + rye

S — Spring wheat + oats + flax

SG — Spring grains

B:B — Barley labeled barley

B:S — Barley labeled spring wheat + oats + flax

S:B — Spring wheat + oats + flax labeled barley

S:S — Spring wheat + oats + flax labeled spring wheat + oats + flax

proportion of barley with respect to the spring small grains coupled with a low barley labeling accuracy. However, the barley in this state represents only 10 percent of the barley in the four-state area; therefore, there was little effect on the overall labeling accuracy for the USNGP.

Labeling of barley (given that the ground truth identifies a dot as barley) was not as successful as the overall labeling accuracy, and it turned out to be 56 percent for the four-state area. Note that the barley population is only 16 percent of the total spring small-grain population. Its distribution is such that it heavily overlaps the distribution of the other spring small grains. This overlap region represents a much higher proportion of the barley than that of the other spring small grains. Therefore, the labeling accuracy is correspondingly lower.

On a state-by-state basis, the labeling accuracy for dots which were identified as barley by the ground truth was about 60 percent for two states, North Dakota and Minnesota. Labeling accuracy for South Dakota and Montana was about 25 percent. These last two states contributed only 50 ground-truth barley dots from the 341 total barley dots. Thus, North Dakota and Minnesota dominate the overall accuracy which turns out to be 56 percent as mentioned previously.

Most of the barley that was mislabeled was confused by the analysts as being other spring grains. This consisted of about 30 percent of the total ground-truth barley. The remaining 10 percent was called nonsmall grains.

5.3 ERROR CHARACTERIZATIONS: SPRING SMALL GRAINS

Error characterizations for this test were produced with procedures similar to those described in reference 9. Briefly, an analyst studied each labeling error and attempted to ascribe the error to one of a standard set of causes which had been identified previously. The standard set of causes for mislabeling was determined from past experiences. The causes are explained in appendix D, table D-1.

A summary of the error characterization results for this test is given in tables 5-3(a) and 5-3(b). The error characterizations for each segment are found in appendix D, tables D-2(a) through D-2(e). Some salient points that can be made from the results of the error characterizations for each state are outlined below.

a. North Dakota

In North Dakota, 60 percent of the omission errors were ascribed to an abnormal behavior of the crop as seen in the Landsat imagery. The abnormal behavior consisted of (1) late development of the crop which contributed 51 percent, (2) abnormal signatures (or unexpected colors) which contributed 7 percent, and (3) early development which contributed 2 percent. In this state, more than one-half of the dots in omission errors ascribed to the late development of the crop came from three segments: 1394, 1457, and 1920. The large majority of grain fields omitted in segment 1394 were extremely late; none were harvested on September 4; and only a few were harvested on September 21. In segment 1457, the grain omitted was not entirely emerged on June 23 (a July 11 acquisition would have been highly beneficial), and the late fields looked like summer crops on August 16. In segment 1920, the lateness of the grain in the southerly location and the adjusted and historical crop calendars for the area were misleading and were the major causes for the mislabeling. The historical Robertson biostage was 5.6 for the reference date; the Robertson biostage adjusted was 6.0; and the actual Robertson biostage was 4.4 according to 18-day ground observations. The contribution to omission errors due to late grain in these three segments alone was about 4 percent. Thus, the labeling accuracy of spring small grains in North Dakota would have been 89 percent instead of 85 percent if the late grain in these segments had been labeled correctly.

The most noticeable commission error was that of nongrain following the temperal color sequence of small grain. An example of this error cause is the 42 dots or 2.5 percent committed to grain in North Dakota. Most of these dots (38) were committed to the category of other small grains

TABLE 5-3.- PERCENTILE SUMMARY OF ERROR CAUSES BY STATE

(a) Omission errors

Error causes	North Dakota		South Dakota		Minnesota		Montana	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Lack of acquisitions	-	-	11	24.4	3	4.1	5	10.6
Behind ACC, late development	130	51.4	7	15.6	18	24.3	8	17.0
Ahead of ACC, early development	5	2.0	-	-	7	9.5	9	19.1
Abnormal small-grain signature (not expected color)	17	6.7	1	2.2	16	21.6	6	12.8
Abnormal nonsmall-grain signature (not expected color)	-	-	-	-	-	-	-	-
Subtotal	152	60.1	19	42.2	44	59.5	28	59.6
Double cropping practice or weeds	7	2.8	4	8.9	1	1.4	1	2.1
Volunteer wheat	-	-	-	-	-	-	-	-
Detectable field destruction	-	-	-	-	-	-	-	-
Nondetectable field destruction	-	-	-	-	-	-	-	-
Subtotal	7	2.8	4	8.9	1	1.4	1	2.1
Wrong acquisition used for labeling	-	-	-	-	-	-	-	-
Inadvertent error (clerical), inconsistency	9	3.6	4	8.9	4	5.4	2	4.3
Subtotal	9	3.6	4	8.9	4	5.4	2	4.3
Unlike other causes; segment unique causes	17	6.7	4	8.9	5	6.8	4	8.5
Border or edge pixels	39	15.4	4	8.9	14	18.9	5	10.6
Narrow fields	28	11.1	8	17.8	5	6.8	2	4.3
Controversial ground truth	1	0.4	2	4.4	1	1.4	5	10.6
Subtotal	85	33.6	18	40.0	25	33.8	11	23.4
Total omission errors	253	100	45	100	74	100	47	100

TABLE 5-3.- Concluded.

(b) Commission errors

Error causes	North Dakota		South Dakota		Minnesota		Montana	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Lack of acquisitions	1	0.7	-	-	8	20.0	-	-
Code 33 data deficiency	6	4.3	-	-	3	7.5	-	-
Behind ACC, late development	2	1.4	-	-	-	-	2	10.0
Ahead of ACC, early development	-	-	-	-	-	-	1	5.0
Abnormal small-grain signature	-	-	-	-	-	-	-	-
Abnormal nonsmall-grain signatures (including winter wheat)	42	30.4	41	71.9	9	22.5	5	25.0
Subtotal	51	37.0	41	71.9	20	50.0	8	40.0
Wrong acquisition used for labeling	-	-	-	-	-	-	-	-
Inadvertent error (clerical), inconsistency	30	21.7	3	5.3	-	-	2	10.0
Subtotal	30	21.7	3	5.3	-	-	2	10.0
Some differences could be detected between this signature (color sequence) and other spring small-grain signatures; unlike other causes; segment unique causes (some look like spring small grains, but some do not)	23	16.7	3	5.3	16	40.0	5	25.0
Border or edge pixels	28	20.3	7	12.3	3	7.5	1	5.0
Narrow fields	6	4.3	2	3.5	1	2.5	2	10.0
Controversial ground truth	-	-	1	1.8	-	-	2	10.0
Subtotal	57	41.3	13	22.8	20	50.0	10	50.0
Total commission errors	138	100	57	100	40	100	20	100

(spring wheat + oats + flax). The highest errors were caused by sunflower fields (10 dots) and canary seed fields (9 dots) that looked like spring wheat. The sunflowers committed from one segment represented 55.6 percent of all sunflower dots committed to spring grains in North Dakota and 50 percent of all sunflower dots committed to spring grains in the four-state area. Thus, most of the commission error problems of committing sunflowers to wheat came from one segment. There was only one site in which canary seed was labeled spring small grains.

b. South Dakota

Reasons for the omission errors in South Dakota were fairly well distributed among the list of error causes. The largest single source of error was ascribed to lack of a key acquisition that would have enabled the analyst to identify some of the spring small grains. Specifically, dots in this error category did not show detectable emergence in the available acquisitions in any of the three segments in which this type of error occurred. Thus, spring small-grain labels would have had to be ascribed to some dots on the basis of its preemergence and the all-ripe or harvest acquisitions.

The commission errors in South Dakota were due to causes discussed in section 5.1. The error committed in segment 1154 was that of labeling winter-wheat dots as spring small grains. Thirty-three out of the 41 dots in this error category occurred in this segment. The reasons for this error follow. First, a black-looking signature in the early spring was interpreted to be abandoned and replowed winter wheat. Second, the historical crop calendar indicated that winter wheat should have been harvested at a time when, in reality, it was still green vegetation.

c. Minnesota

The major omission error causes in Minnesota were late development of the spring small grains and abnormal signatures. The omission error from these causes was 45 percent of the total.

The major cause for commission errors in Minnesota was confusion caused by the similarity of nongrain signatures to spring small-grain signatures. Causes for the similarity of signatures in many cases could not be determined. Some signatures, such as corn signatures in segment 1524, were exactly the same as small-grain signatures in all acquisitions (abnormal nonsmall-grain signature). Some signatures, such as corn in segment 1566, were similar in all but one or two of the acquisitions (abnormal signatures, segment unique). In this latter case, an incorrect assumption would be made; for example, an expected plowed signature was not observed because the crop was plowed a little earlier or later than expected.

d. Montana

Reasons for omission errors in Montana, as in South Dakota, were fairly evenly distributed among the list of error causes. In Montana, however, the total omission error was 23 percent, whereas in South Dakota, it was 28 percent. The highest source of error was ascribed to the combination of early and late development of the small-grain crops. Late crops were confused with summer crops; early crops were confused with winter wheat. There was also some confusion with idle fallow due to the fact that some small-grain fields never reached the color which is typical of green vegetation.

Commission errors in Montana were, for the most part, distributed evenly among the causes, although the two largest contributors to commission errors were caused by signatures that were similar to those of small grains.

5.4 ERROR CHARACTERIZATIONS: BARLEY

In order to determine the degree of success of the procedure to separate barley from the other spring small grains, a technique was used which is similar to that used for characterizing errors in labeling spring small grains. Specifically, an attempt was made to ascribe each error to a standard set of

previously defined causes. A tabulation of the errors and error causes can be found in table 5-4 along with information regarding the acquisition and decision boundary selection.

The barley procedure contains two steps which are key to the success of the separation process: the selection (by an analyst) of the acquisition in which barley can be separated from the other small grains and the placement on a green number versus brightness scatter plot of a decision boundary to reflect the separation as perceived by the analyst. In order to assess how well these two steps were executed by the analyst, the evaluators used ground truth to label scatter plots of the separation acquisition that was actually used by the analyst plus ground truth of the previous and the following acquisitions. The evaluators drew a decision boundary that would best separate barley from the other small grains on the ground-truth plots. Those dots that had different labels than those determined by the original analyst were then recorded. The results of this exercise are also shown in table 5-4 for each of the other small-grain crops which were originally mislabeled as barley and those for barley originally mislabeled as other small grains.

Table 5-4 indicates that only about 10 percent of the other small-grain picture elements (pixels) that were mislabeled as barley can be attributed to the selection of the decision boundary and none to the selection of the separation acquisition. Conversely, 2 percent of the barley pixels mislabeled as other small grains are attributable to the boundary selection and only 1 percent to the acquisition selection. Therefore, neither the selection of a decision boundary nor the selection of a separation acquisition appears to have been a major cause of error in the separation of barley from the other small grains.

Table 5-4 also shows that the major cause for mislabeling other small grains as barley was the typical barley-like behavior of these pixels. That is, they acquired a brighter, less red signature in the separation acquisition; or, alternately, they migrated toward the lower right of the scatter plot. In some cases, it was determined that this happened because of hail damage; but in most cases, no apparent reason could be found. Thirty-four pixels or

TABLE 5-4.- ERROR CHARACTERIZATIONS FOR LABELING OF BARLEY

Error cause	Spring wheat labeled barley (1400 ground-truth spring-wheat dots)				Oats labeled barley (319 ground-truth oats dots)				Flax labeled barley (48 ground-truth flax dots)				Total other spring grains labeled barley (1767 ground-truth dots)				Barley labeled other spring grains (341 ground-truth barley dots)			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Lack of acquisitions	1			1									1			1	4			4
Crop behind crop calendar (late development)	1			1									1			1	53	1		52
Crop ahead of crop calendar (early development)	7	1		6	3	1		2					10	2		8	0			0
Not expected signature, odd colors					6	1		5					6	1		5	9			9
Destroyed field	1			1									1			1	1			1
Narrow fields					2			2					2			2	7			7
Border or edge pixel	1			1	1			1					2			2	12	1		11
Barley-like behavior, no apparent reason	19	1		18	15	2		13					34	3		31				
Spring-wheat-like behavior, no apparent reason																	21		1	20
Disagreement with ground truth													0			0	3			3
Totals	30	2		28	27	4		23	0				57	6		51	110	2	1	107

Symbol definitions:

A — Number mislabeled

B — Can be recovered with better boundary

C — Can be recovered with better acquisition

D — Number nonrecoverable

60 percent of the labeling errors of other spring small grains as barley were due to this one problem. The second most prevalent cause for mislabeling other spring small grains as barley was the early development of some of the spring grains which caused the signatures to display a turning appearance at the same time as "normal" barley. Ten pixels or 18 percent of the errors fall into this category. It should be noted that the difference between this error category and the one described above is that the ground truth did confirm the earliness of the development of the crop in the latter case but did not in the earlier case.

The main cause for labeling errors in which barley was labeled as other spring small grains was the late development of barley. Fifty percent of the errors or 53 out of the 110 mislabeled dots were due to this problem. Thus, 15 percent of the barley, which these 53 dots represent, is essentially the proportion of the ground-truth barley for which the assumption that barley matures earlier than wheat was not confirmed by the test.

The second most predominant cause for labeling barley as other spring small grains was that barley acquired a very weak turning signature at the expected time. Thus, the analysts could detect the turning signature (little brighter, less red, more pink) with the aid of ground truth but could not detect it at the time in which the original analysis was done. A similar statement can be made with respect to the scatter plot. That is, the dots had only partially migrated to the barley region of the plot but were mostly mixed with spring-wheat dots. In this case, the ground-truth annotation did not confirm that these barley dots were late in development, although many of them may have been.

Finally, it should be noted that flax was never confused with barley, whereas oats was the spring small-grain crop most likely to be labeled barley.

5.5 ERRORS BY CROP CATEGORY

Computations in table 5-5 were done to determine if any one small-grain crop is more likely to be omitted than others or if any one crop is more likely to

TABLE 5-5.- CAUSES OF OMISSION AT THE SPRING SMALL-GRAIN LEVEL BY GRAIN CATEGORY FOR THE USNGP

Grain category	Number of dots in category	Labeling error cause											Total	Percent omitted
		α	γ_1	γ_2	θ	μ	ϵ_1	ϵ_2	π	λ	ϕ	σ		
Spring wheat and durum wheat	1602	9	98	12	17	6	15	10	38	12	15	6	238	14.86
Oats	356	7	32	8	9	6	11	3	10	5	8		99	27.81
Flax	57	1	20		10		2		2				35	61.40
Barley	360	2	13	1	4	1	2		12	2	7	3	47	13.06
Total spring small grains	2375	19	163	21	40	13	30	13	62	19	30	9	419	
Contribution to the total error for each error cause (proportion of all pixels in the ground-truth category)		0.8	6.86	0.88	1.68	0.55	1.26	0.55	2.61	0.8	1.26	0.38		17.64

Symbol definitions:

α A lack of informative acquisitions (useful to labeling) contributed to the labeling error.

γ_1 Crop was behind the ACC, late planting and development.

γ_2 Crop was ahead of the ACC, early planting and development.

ϵ_1 The dot was on a single narrow field; the signature may or may not have been overridden by surrounding signatures of other categories.

ϵ_2 The dot encompassed multiple strips so narrow that they presented a single, integrated signature. Field width was not resolvable by the Landsat scanner.

θ The signature of the target crop did not follow the expected temporal color sequence of small grain throughout the acquisition.

λ Clerical error — the error-pixel clearly followed a temporal sequence for its category. Since other dots with the same temporal sequence were consistently identified correctly, then this error was a clerical error.

μ Double cropping practice of a second crop or weeds became the dominant signature and caused an increase in the infrared response after grain harvest.

π Border or edge pixel — spectral and spatial confusion occurs between two or more fields of different types due to misregistration of acquisitions or confusion as to field size or shape.

σ The author disagrees with the ground-truth overlay label, but it was reluctantly accepted as being valid.

ϕ Segment-unique causes — the error did not match any of the causes of a general nature. The pixel had insufficient spectral information to cause correct categorization, but some correlation could be made with the correct category after the ground truth was known.

contribute to a particular error cause than others. The error causes are broken down for each of the crops in this table.

Data from table 5-5 indicate that flax is the crop most likely to be omitted and with a 61 percent probability. The main cause of mislabeling is the lateness of the crop and consequent confusion with summer crops. About two-thirds of the omissions were due to this cause. The other one-third was due to abnormal signatures, namely, signatures that never attained a good green vegetation signature (red, light red, and orange).

The second most likely small-grain crop to be omitted is oats. This omission occurred for about one-third of the pixels or 28 percent. The main cause of mislabeling was also the lateness of the crop.

Because of its abundance, the largest contributor to the omission errors was spring wheat, lateness being the main cause. Sixty-two percent of the small-grain pixels omitted were spring wheat. Note, however, that the percentages of wheat omitted (15 percent) and barley omitted (13 percent) were much lower than those for the other categories.

Late development of the spring small-grain crops and their consequent confusion with summer crops was the largest single cause of omission. This is true for the spring small grains as a whole and also for each individual crop. It contributed 7 percent out of the 18 percent total omission errors.

Table 5-6 is a summary of the relative importance of the lateness of a crop as a cause of omission errors for each of the individual spring small-grain crops.

5.6 SEPARATION OF BARLEY BY GEOGRAPHIC REGION

The separability of the barley from the other spring small grains was determined from ground truth by placing an optimum decision boundary between these two categories in the scatter plot of the acquisition with the most separation. The separability was then defined to be the percent of barley pixels on the barley side of the decision boundary.

TABLE 5-6.- RELATIVE IMPORTANCE OF LATENESS OF THE CROP AS CONTRIBUTOR TO THE OMISSION ERROR

Grain	Percent of the crop omitted due to lateness of the crop	Percent of the crop omitted due to all causes of error
Flax	35 (20 of 57 dots)	61.4 (35 of 57 dots)
Oats	9 (32 of 356 dots)	27.8 (99 of 356 dots)
Wheat	6 (98 of 1602 dots)	14.9 (238 of 1602 dots)
Barley	4 (13 of 360 dots)	13.1 (47 of 360 dots)

Figure 5-1 is a map of the four-state area depicting the locations and separability of segments that were processed. Segments coded with a red circle had barley separability of less than 60 percent. Thus, it can be seen that in western Minnesota and southeastern North Dakota is an area in which there is a preponderance of segments with barley separability greater than 60 percent. Otherwise, there seems to be no other well-defined geographic patterns. It should be noted, however, that other areas of high accuracy may exist, but the map would not show them because of the lack of sufficient sites to show a pattern. For example, figure 5-2, which depicts the separability of 1977 crop year data, appears to indicate that there is a region in Montana where the separability is also greater than 60 percent for six out of seven sites. In 1978, there was only one site in the same region. Thus, at best, there are indications that barley can be identified with high accuracy for segments along part of the North Dakota and Minnesota border.

Another observation that should be noted is that the preponderance of segments, which were used for the development of the barley separation procedure, also occur in the area of western Minnesota and southeastern North Dakota (fig. 5-2). Since the data used for development were from the 1977 crop year, this fact could be taken as an example of extendability from one year to another, at least for that area in which there are indications that barley can be identified. Areas shown to have separability in 1977 are indicated in figure 5-1 with brown outlining for comparison.

ORIGINAL PAGE
COLOR PHOTOGRAPH

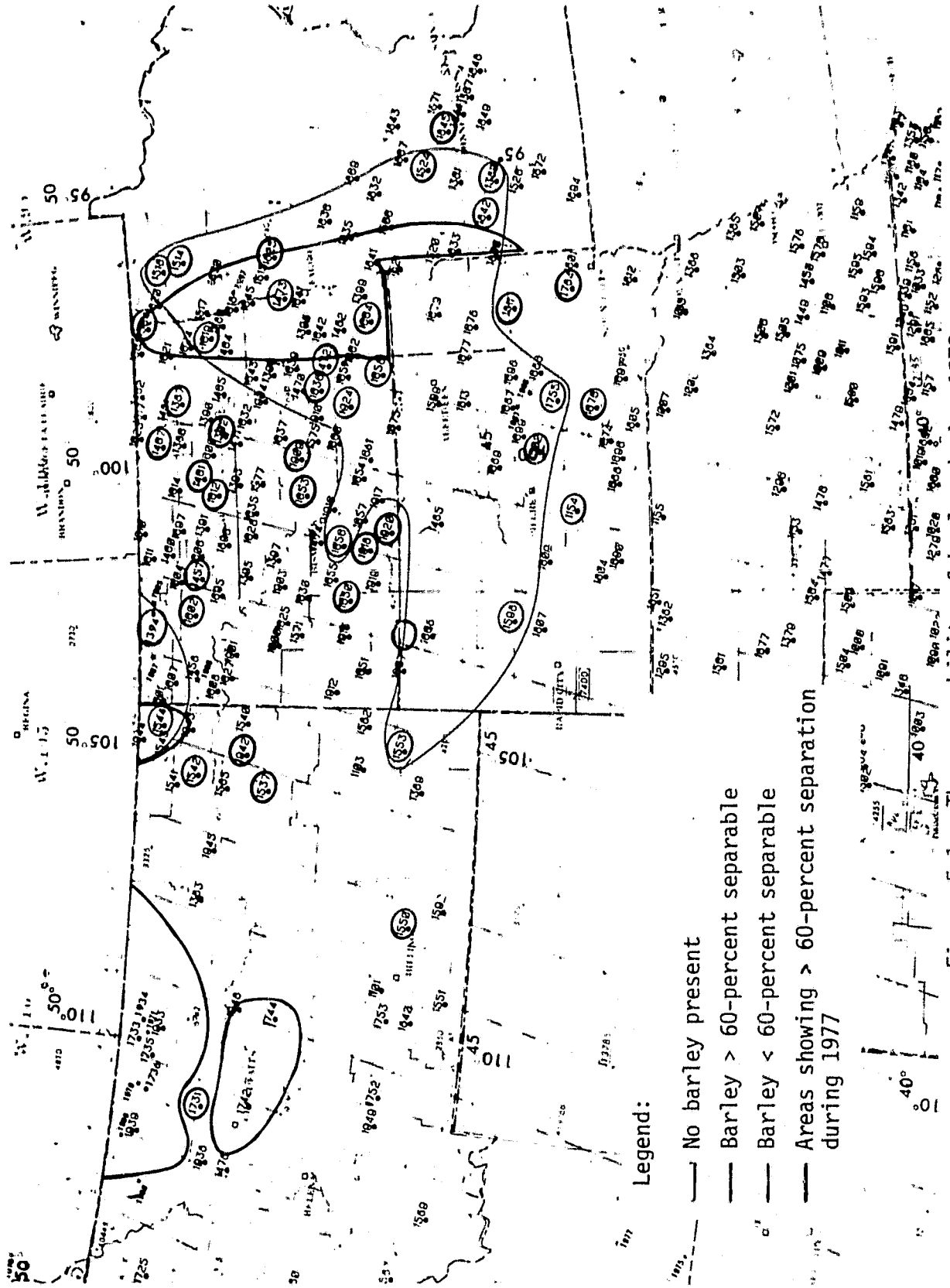

Figure 5-1.- The separability of barley during 1978.

ORIGINAL PAGE
COLOR PHOTOGRAPH

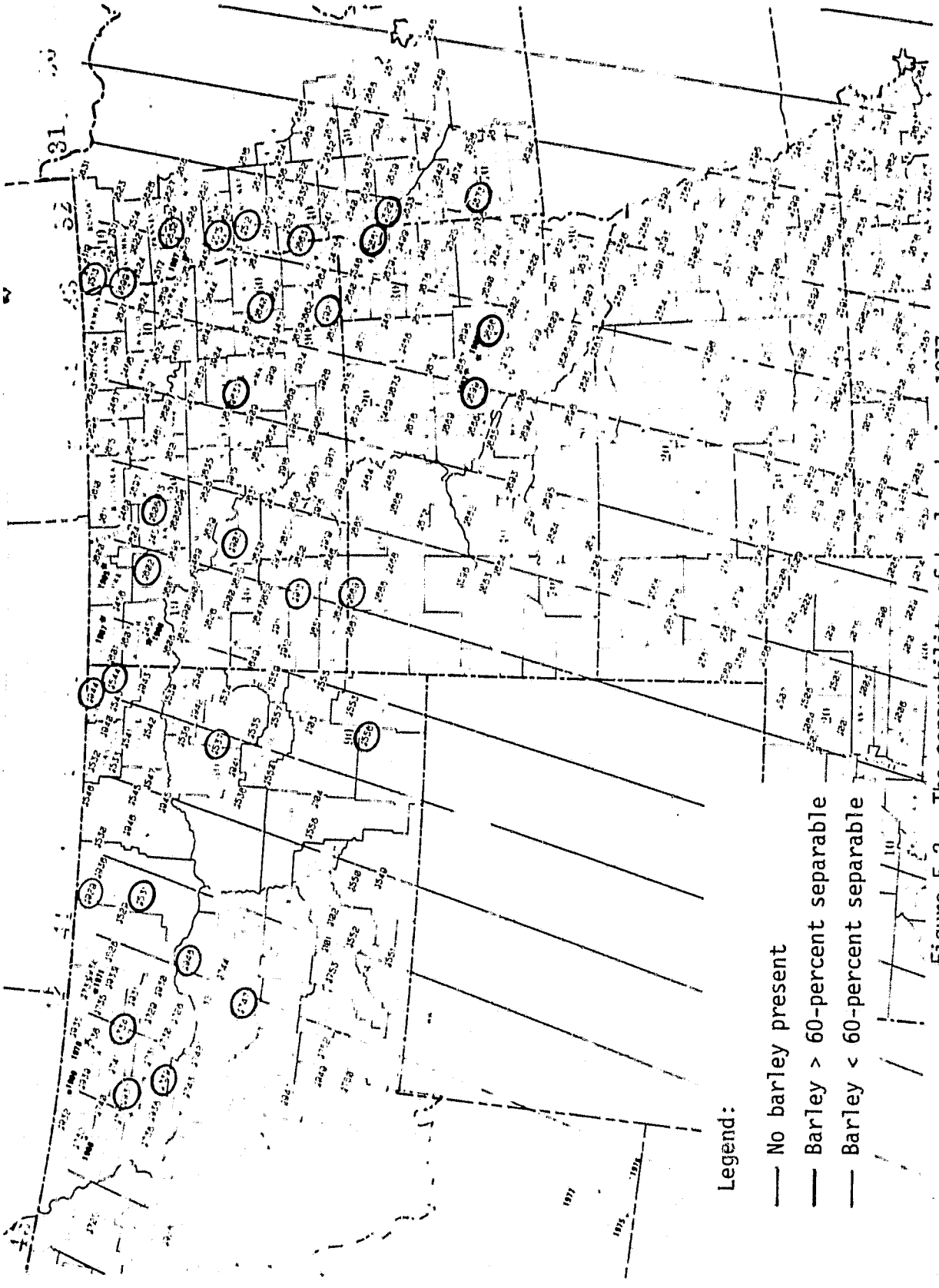

Figure 5-2.- The separability of barley during 1977.

Finally, figure 5-3 is a map that depicts the relative concentration of barley-growing regions in the four-state area. It can be observed that the area of western Minnesota and eastern North Dakota are also areas where high concentrations of barley exist.

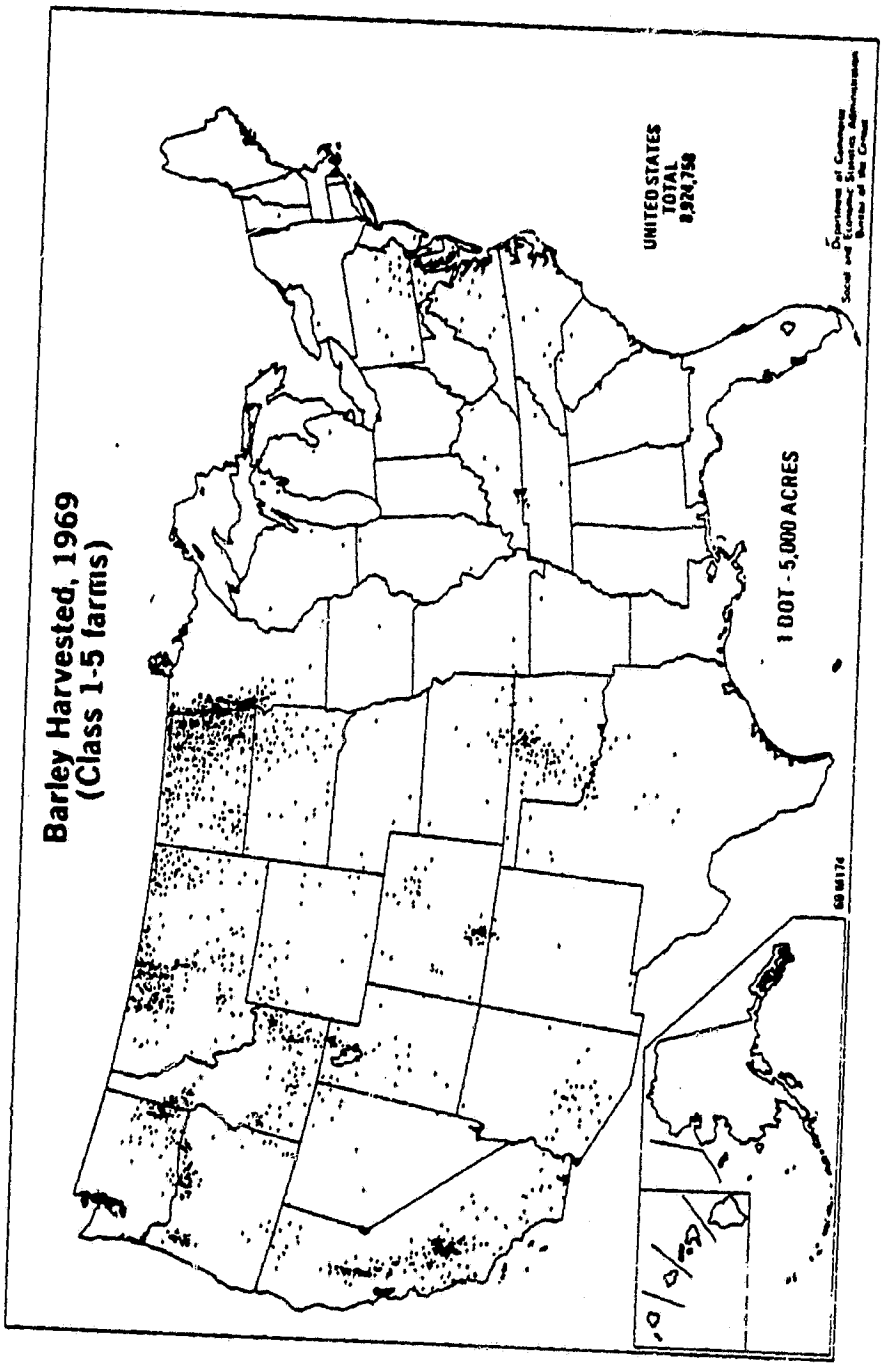

Figure 5-3.- The barley producing areas of the United States.

6. CONCLUSIONS

The main objective of this investigation was to assess the success of the TY procedure to separate and label barley and the other small grains. Results of testing the procedure indicate that there was no particular difficulty in exercising the procedure correctly whenever it was applied. Decision lines were drawn on the plot of the appropriate acquisition using ground-truth labels, and the decision boundary was found to be very little different from the one provided by the analysts supporting this study.

Because the labeling accuracy for spring small grains obtained by the evaluators turned out to be somewhat different from that obtained by the TY analysts, some comments are in order. Specifically, the average accuracy for labeling spring small grains in the four-state area was about 70 percent in TY (ref. 10) and about 82 percent when obtained as part of the work conducted in this investigation. It is apparent that the difference in accuracy is dominated by the difference in the labeling for North Dakota. Overall labeling accuracies in the other states were comparable with those in TY with one exception in South Dakota. The accuracy in that state was affected by a large commission error that occurred in one segment in which late winter wheat was labeled spring wheat. It was outside the scope of the present investigation to search for the reason for the difference in accuracy. However, the following argument can be made: the regionalization of the segments to be labeled as a different approach to the analysis, the inclusion of trend analysis of past cropping practices as part of the labeling process (ref. 11), and the removal of any time constraints for segment processing influenced somewhat the final outcome of the labeling accuracy obtained.

Another subject to be addressed regarding the labeling of small grains includes the problems identified that were found to affect the accuracy of labeling. The major problem consists in the confusion that results when crops develop at different times or at different rates from that expected by the analysts for "normal" crops. Thus, late winter-wheat fields were confused with spring grains, and late spring grains were confused with summer crops.

It was not determined if the error was caused by normal variations from the average crop calendars or if the crop calendars themselves were in error. In either case, the deviations were usually of the magnitude of 2 weeks and as high as 4 weeks. Also in the former case, the analyst did not have, for the most part, the information that would allow one to assess the variability of the crop's development stages around the average. Some state level information (from state agricultural reports) regarding crop stages was used.

A variation of these types of problems occurred when nonsmall-grain crops followed approximately the same temporal pattern as the small-grain crops. This crop pattern was apparently the case for some of the commission errors, especially between sunflowers and spring grains. In this case, analysts attempted to detect differences in signatures but were not always successful.

From an overall point of view, the barley separation procedure turned out to be successful for the labeling of spring grains. Namely, given a pixel was correctly labeled as spring grains, the probability was around 90 percent that it would be correctly labeled either barley or other spring-small grains.

The procedure was only partially successful at detecting and labeling barley. The probability of correctly labeling barley pixels was only 56 percent. The barley labeling problems were caused, at least in part, by the fact that barley did not always exhibit the expected behavior, particularly in South Dakota and Montana. Another problem with the accuracy of barley labeling was simply the extensive overlap of the spectral distribution of barley with the distribution of the other small grains. This problem coupled with the fact that the population of barley is small compared to the population of the other small grains results in the proportion of barley pixels in the overlap region being very high with respect to the barley population. This is not the case with the other small grains. The successfulness of the procedure can be summarized by concluding that the assumptions upon which the procedure is based are not necessarily true; barley does not always mature prior to other spring small grains and the assumption that barley becomes brighter and less green within a definite growth stage range is also not necessarily true.

There is a region in western Minnesota and southeastern North Dakota, however, where the barley procedure appears to work well. In this region, the separability (as defined in section 5.6) was 81 percent. Also, a high density of barley is grown there. Thus, it appears that the extendability of the procedure is confined to this region of high density barley. The extendability to the remaining parts of the four-state area is tenuous at best.

Further development of the barley procedure should include further investigations into the similarities and differences in planting and development of barley and the other small grains and the effect of geographic, functional, and meteorological influences. Also, the development of methodologies for detecting these differences when they exist should also be included. Specifically, it appears that when barley is planted late with respect to the other small grains, it becomes more difficult to detect with the current procedure but may still be detectable. Conversely, early developing (or early harvested) wheat or oats will normally be called barley.

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Foreign Commodity Production Forecasting

EVALUATION OF THE PROCEDURE FOR SEPARATING BARLEY FROM OTHER SPRING SMALL GRAINS

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APPENDIX A

DATA AVAILABLE FOR EACH SEGMENT

TABLE A-1.- DATA AVAILABLE FOR EACH SEGMENT

State	APU number	Segment number	Acquisitions available					Availability of historical county grain percentages	Availability of LACIE Phase II and III blind-site grain percentages	Availability of prior year CAMS estimate	Remarks
			Preplanting/ planting	Partial emergence	All emergence (all red)	Turning (late heading through ripening)	Harvest/ postharvest				
North Dakota	19	1387	X	X		[a]78216	X	X			New segment, code 33
		1392	X	X	X	78208		X			New segment
						[a]78217					
		1461	X	X	X	78209	X			X	
						[a]78217					
						78236					
		1467	X	X	X	78208				X	
						[a]78218					
		1472	X			[a]78216				X	Code 33
						78243					
		1612	X	X	X	78218					
						78236					
		1636	X	X	X	78207	X			X	
						[a]78216					
						78226					
		1658	X			[a]78207	X				Code 33
						78243					
		1664	X			[a]78206	X				Code 33
						78233					
		1924	X	X	X(01)	[a]78208	X(01)				
						78217					
						78226					

[a]Date used for barley labeling.

Symbol definition:

X — Available

TABLE A-1.- Continued.

State	APU number	Segment number	Acquisitions available					Availability of historical county grain percentages	Availability of LACIE Phase II and III blind-site grain percentages	Availability of prior year CAHS estimate	Remarks
			Preplanting/ planting	Partial emergence	All emergence (all red)	Turning (late heading through ripening)	Harvest/ postharvest				
North Dakota	20	1473	X			78197	X	X			New segment
						[a]78207					
						78224					
		1584	X			78198		X			New segment
						[a]78216					
						78243					
		1619	X			78198	X		X	X	
						[a]78207					
						78216					
North Dakota	21	1394	X	X		78211	X	X			New segment
						[a]78219					
						78228					
						78238					
						78247					
						78264					
		1457	X	X		78228	X		X	X	
		1602	X	X	X	78228	X		X	X	
		1650	X(01)	X	78191	78218	X		X	X	
					[a]78209	78228	X				
						78236					
		1653	X	X	X	[a]78209				X	
						78217					
		1656	X	X	X	[a]78209			X		
						78218					

[a]Date used for barley labeling.

Symbol definition:

X — Available

TABLE A-1.- Continued.

State	APU number	Segment number	Acquisitions available					Availability of historical county grain percentages	Availability of LACIE Phase II and III blind-site grain percentages	Availability of prior year CAMS estimate	Remarks
			Preplanting/ planting	Partial emergence	All emergence (all red)	Turning (late heading through ripening)	Harvest/ postharvest				
North Dakota	21	1909	X	X	X(01)	78208			X		
						[a]78217					
		1918	X			[a]78209	X				Code 33
						78218					
						78236					
		1920	X		X	[a]78209			X		
						78217					
						78236					
South Dakota	15	1784	X	X		78196	X	X			New segment
						78223					Code 33
						78241					
	16	1676	X	X		78206	X	X			New segment
						78207					Code 33
		1755	X	X		78197	X	X		X	Code 33
						[a]78198					
						78207					
						78215					
						78216					
	17	1154	X		78190	78217		X			New segment
					[a]78208	78226					
		1802	X			78243		X			New segment
	18	1598		X	X	[a]78209	X	X		X	
						78218					
						78219					
						78227					

[a]Date used for barley labeling.

Symbol definition:

X — Available

TABLE A-1.- Continued.

State	APU number	Segment number	Acquisitions available					Availability of historical county grain percentages	Availability of LACIE Phase II and III blind-site grain percentages	Availability of prior year CAMS estimate	Remarks
			Preplanting/ planting	Partial emergence	All emergence (all red)	Turning (late heading through ripening)	Harvest/ postharvest				
South Dakota	19	1811	X		[a]78197	78215	X	X			New segment
						78224					Code 33
						78232					
						78233					
South Dakota	21	1668		X	FF	78219		X		X	
						78228					
						78245					
Minnesota	15	1380	X	X	X	[a]78196	X	X			New segment
						78204					
						78205					
		1524	X			[a]78196		X	X		
						78222(01)					
		1845				[a]78204	X	X		X	
						78213					
Minnesota	19	1566	X		X	—	X	X			New segment
		1842	X		X	78196	X	X			
						[a]78205					
Minnesota	20	1514	X			[a]78206	X	X			
						78224					
		1518	X	X	X	[a]78206	X	X		X	
						78224					
		1825	X		X	78196	X	X	X	X	
						78205					
						[a]78206					

[a]Date used for barley labeling.

Symbol definition:

X — Available
FF — Full frame only

TABLE A-1.- Concluded.

State	APU number	Segment number	Acquisitions available					Availability of historical county grain percentages	Availability of LACIE Phase II and III blind-site grain percentages	Availability of prior year CAMS estimate	Remarks
			Preplanting/ planting	Partial emergence	All emergence (all red)	Turning (late heading through ripening)	Harvest/ postharvest				
Montana	21	1542	X	X	X	78212(01)	X	X	X	X	
						[a]78222					
						78231					
		1544	X	X	X	78221	X	X	X	X	
						[a]78230					
						78239					
Montana	22	1537	X	X	X	78213	X	X			Moved
						[a]78222					
						78231					
		1553	X		X	78211	X	X		X	
						[a]78220					
		1942	X	X	X	[a]78221	X	X		X	
						78230					
Montana	23	1731		X		78207	X	X			
						78208					
						[a]78216					
						78235					
						78243(01)					
Montana	1-4	1550				[a]78223		X			No spring small grains

[a]Date used for barley labeling.

Symbol definition:

X — Available

APPENDIX B

PROPORTION ESTIMATES FOR ALL THE SEGMENTS IN THE STUDY

TABLE B-1.- SPRING SMALL-GRAINS 209-DOT RANDOM ESTIMATES

(a) North Dakota

APU number	Segment number	Label estimate ($\hat{P}$), percent				Ground truth (P),[a] percent				Actual error ($\hat{P}$ - P), percent			Relative error $\frac{\hat{P} - P}{P}$		
		Category													
		S	B	SG	N	S	B	SG	N	S	B	SG	S	B	SG
19	1387	43.5	10.5	54.0	46.0	35.9	18.2	54.1	46.0	+7.6	-7.7	-0.1	+0.21	-0.42	0.00
	1392	33.8	2.9	36.7	63.3	26.1	4.8	30.9	69.1	-7.7	-1.9	+5.8	+ .30	- .40	+ .19
	1461	46.6	7.7	54.3	45.7	50.5	3.8	54.3	45.7	-3.9	+3.9	0.0	- .08	+1.02	.00
	1467	50.7	4.3	55.0	45.0	45.5	10.5	56.0	44.0	+5.2	-6.2	-1.0	+ .11	- .59	- .02
	1472	28.5	10.6	39.1	60.9	30.0	12.1	42.1	57.9	-1.5	-1.5	-3.0	- .05	- .12	- .06
	1612			13.4	86.6			15.8	84.2			-2.4			- .15
	1636	38.9	3.8	42.7	57.3	39.9	2.9	42.8	57.2	-1.0	+0.9	-0.1	- .03	+ .31	.00
	1658	35.4	7.2	42.6	57.4	34.0	9.1	43.1	56.9	+1.4	-1.9	-0.5	+ .04	- .21	- .01
	1664	28.9	6.6	35.5	64.5	29.9	5.6	35.5	64.5	-1.0	+1.0	0.0	- .03	+ .18	.00
	1924	31.8	2.5	34.3	65.7	35.3	1.5	36.8	63.2	-3.5	+1.0	-2.5	- .10	+ .67	- .07
20	1473	33.8	20.3	54.1	45.9	30.4	20.3	50.7	49.3	+3.4	0.0	+3.4	+ .11	.00	+ .07
	1584	45.0	6.7	51.7	48.3	38.3	14.8	53.1	46.9	+6.7	-8.1	-1.4	+ .17	- .55	- .03
	1619	34.4	9.6	44.0	56.0	34.0	12.0	46.0	54.0	+0.4	-2.4	-2.0	+ .01	- .20	- .04

Symbol definitions:

B — Barley

N — Nongrain + winter wheat + rye

S — Spring wheat and oats and flax

SG — Spring small grains

[a]Ground-truth proportions computed from the 209-dot ground-truth labels (section 2.2). Results presented in this table may differ from any previously presented evaluation results based on digitized ground truth.

TABLE B-1.- Continued.

(a) North Dakota

APU number	Segment number	Label Estimate ($\hat{P}$), percent				Ground truth (P),[a] percent				Actual error ($\hat{P}$ - P), percent			Relative error $\frac{\hat{P} - P}{P}$		
		Category													
		S	B	SG	N	S	B	SG	N	S	B	SG	S	B	SG
21	1394	28.4	3.4	31.8	68.2	34.6	5.8	40.4	59.6	- 6.2	-2.4	- 8.7	-0.18	-0.41	-0.22
	1457			25.4	74.6			41.3	58.7			-15.9			- .38
	1602			33.0	67.0			30.6	69.4			+ 2.4			+ .08
	1650	23.9	0.5	24.4	75.6	30.1	0.5	30.6	69.9	- 6.2	0.0	- 6.2	- .21	0.00	- .20
	1653	18.0	1.5	19.5	80.5	21.4	0.5	21.9	78.1	- 3.4	+1.0	- 2.4	- .16	+2.00	- .11
	1656	4.8	1.9	6.7	93.3	8.1	1.0	9.1	90.9	- 3.3	+0.9	- 2.4	- .41	+0.90	- .26
	1909	18.7	0.5	19.2	80.8	18.7	2.9	21.6	78.4	0.0	-2.4	- 2.4	.00	-0.83	- .11
	1918	10.7	5.3	16.0	84.0	15.5	1.9	17.4	82.6	- 4.8	+3.4	- 1.5	- .31	+1.79	- .09
	1920	9.1	2.4	11.5	88.5	25.4	1.0	26.4	73.6	-16.3	+1.4	-15.3	- .64	+1.40	- .58
State error										- 0.97	-1.12	- 2.52	-0.03	-0.16	-0.07

Symbol definitions:

B — Barley

N — Nongrain + winter wheat + rye

S — Spring wheat and oats and flax

SG — Spring small grains

[a]Ground-truth proportions computed from the 209-dot ground-truth labels (section 2.2). Results presented in this table may differ from any previously presented evaluation results based on digitized ground truth.

TABLE B-1.- Continued.

(b) South Dakota

APU number	Segment number	Label estimate ($\hat{P}$), percent				Ground truth (P),[a] percent				Actual error ($\hat{P}$ - P), percent			Relative error $\frac{\hat{P} - P}{P}$		
		Category													
		S	B	SG	N	S	B	SG	N	S	B	SG	S	B	SG
15	1784	20.6	1.9	22.5	77.5	15.3	8.6	23.9	76.1	+ 5.3	-6.7	- 1.4	+ 0.35	-0.78	- 0.06
16	1676	5.7	2.4	8.1	91.9	6.2	0.0	6.2	93.8	- 0.5	+2.4	+ 1.9	- .08	∞	+ .31
	1755	5.7	2.4	8.1	91.9	6.2	3.8	10.0	93.3	- 0.5	-1.4	- 1.9	- .08	- .37	- .19
17	1154	14.8	1.4	16.2	83.8	0.5	0.0	0.5	99.5	+14.3	+1.4	+15.7	+28.6	∞	+31.4
	1802	0.0	0.0	0.0	100.0	4.5	0.0	4.5	95.5	- 4.5	0.0	- 4.5	- 1.0	0.00	- 1.0
18	1598	1.0	0.5	1.5	98.5	2.4	0.5	2.9	97.1	- 1.4	0.0	- 1.4	- .58	0.00	- .48
19	1811	21.3	0.0	21.3	78.7	21.3	2.9	24.2	75.8	0.0	-2.9	- 2.9	.00	-1.00	- .12
21	1668			7.5	92.5			11.2	88.8			- 3.7			- .33
State error										+ 2.27	-1.10	+ 0.81	+ 0.27	-0.45	+ 0.08

Symbol definitions:

B — Barley

N — Nongrain + winter wheat + rye

S — Spring wheat and oats and flax

SG — Spring small grains

[a]Ground-truth proportions computed from the 209-dot ground-truth labels (section 2.2). Results presented in this table may differ from any previously presented evaluation results based on digitized ground truth.

TABLE B-1.- Continued.

(c) Minnesota

APU number	Segment number	Label estimate ($\hat{P}$), percent				Ground truth (P),[a] percent				Actual error ($\hat{P}$ - P), percent			Relative error $\frac{\hat{P} - P}{P}$		
		Category													
		S	B	SG	N	S	B	SG	N	S	B	SG	S	B	SG
15	1380	6.7	1.0	7.7	92.3	10.0	0.5	10.5	89.5	-3.3	+0.5	-2.8	-0.33	+1.00	-0.27
	1524	12.9	0.0	12.9	87.1	13.9	0.0	13.9	86.1	-1.0	0.0	-1.0	- .07	0.00	- .07
	1845	6.0	0.0	6.0	94.0	9.5	0.5	10.0	90.0	-3.5	-0.5	-4.0	- .37	-1.00	- .40
19	1566			35.4	64.6			36.4	63.6			-1.0			- .03
	1842	13.4	0.0	13.4	86.6	14.0	0.0	14.0	86.0	-0.6	0.0	-0.6	- .04	0.00	- .04
20	1514	21.8	4.9	26.7	73.3	24.3	4.4	28.7	71.3	-2.5	+0.5	-1.9	- .10	+0.11	- .07
	1518	23.6	0.5	24.1	75.9	26.1	1.5	27.6	72.4	-2.5	-1.0	-3.5	- .10	- .67	- .13
	1825	29.2	8.2	37.4	62.6	36.3	3.5	39.8	60.2	-7.1	+4.7	-2.4	- .20	+1.34	- .06
State error										-2.83	+0.51	-2.16	-0.15	+0.35	-0.10

Symbol definitions:

B — Barley

N — Nongrain + winter wheat + rye

S — Spring wheat and oats and flax

SG — Spring small grains

[a]Ground-truth proportions computed from the 209-dot ground-truth labels (section 2.2). Results presented in this table may differ from any previously presented evaluation results based on digitized ground truth.

TABLE B-1.- Concluded.

(d) Montana

APU number	Segment number	Label estimate ($\hat{P}$), percent				Ground truth (P),[a] percent				Actual error ($\hat{P} - P$), percent			Relative error $\frac{\hat{P} - P}{P}$		
		Category													
		S	B	SG	N	S	B	SG	N	S	B	SG	S	B	SG
21	1542	24.0	0.5	24.5	75.5	24.0	0.0	24.0	76.0	0.0	+0.5	+0.5	0.00	+ ∞	+ 0.02
	1544	28.2	2.4	30.6	69.4	33.5	1.4	34.9	65.1	- 5.3	+1.0	-4.3	- .16	+ .71	- .12
22	1537	3.3	1.0	4.3	95.7	5.7	1.4	7.1	92.9	- 2.4	-0.4	-2.8	- .42	- .29	- .39
	1553	5.7	0.0	5.7	94.3	6.7	1.4	8.1	91.9	- 1.0	-1.4	-2.4	- .15	- 1.00	- .30
	1942	14.1	0.5	14.6	85.4	17.5	1.4	18.9	81.1	- 3.4	-0.9	-4.3	- .19	- .64	- .23
23	1731	4.8	1.0	5.8	94.2	1.9	3.8	5.7	94.3	+ 2.9	-2.8	+0.1	+ 1.53	- .74	+ 0.02
1-4	1550	0.5	0.0	0.5	99.5	0.0	0.0	0.0	100.0	+ ∞	0.0	+0.5	+ ∞	0.00	+ ∞
State error										- 1.24	-0.62	-1.85	- 0.10	- 0.45	- 0.13

Symbol definitions:

B — Barley

N — Nongrain + winter wheat + rye

S — Spring wheat and oats and flax

SG — Spring small grains

[a]Ground-truth proportions computed from the 209-dot ground-truth labels (section 2.2). Results presented in this table may differ from any previously presented evaluation results based on digitized ground truth.

APPENDIX C

DOT LABEL DATA FOR ALL SEGMENTS IN THE STUDY

TABLE C-1.- SYMBOL DEFINITIONS FOR TABLES C-2(a) THROUGH C-2(e)

Symbol	Definition
B:B	Barley labeled barley
B:N	Barley labeled nongrain + winter wheat + rye
B:S	Barley labeled spring wheat + oats + flax
F:B	Flax labeled barley
F:N	Flax labeled nongrain + winter wheat + rye
F:S	Flax labeled spring wheat + oats + flax
N:B	Nongrains + winter wheat + rye labeled barley
N:N	Nongrains + winter wheat + rye labeled nongrains + winter wheat + rye
N:S	Nongrains + winter wheat + rye labeled spring wheat + oats + flax
N:SG	Nongrains + winter wheat + rye labeled spring grains
O:B	Oats labeled barley
O:N	Oats labeled nongrain + winter wheat + rye
O:S	Oats labeled spring wheat + oats + flax
O:SG	Oats labeled spring grains
SG:N	Spring grains labeled nongrain + winter wheat + rye
SG:SG	Spring grains labeled spring grains
SW:B	Spring wheat labeled barley
SW:N	Spring wheat labeled nongrain + winter wheat + rye
SW:S	Spring wheat labeled spring wheat + oats + flax
SW:SG	Spring wheat labeled spring grains

TABLE C-2.- SPRING SMALL-GRAIN DOT-LABEL DATA FOR THE USNGP

(a) The four-state area

Part I. All segments with an estimate for barley (40 segments)

State	Category															Total correct[a]	Percentage correct
	SW:S[a]	SW:B	SW:N	B:B[a]	B:S	B:N	O:S[a]	O:B	O:N	F:S[a]	F:B	F:N	N:N[a]	N:S	N:B		
North Dakota	898/1039	25	116	164/268	78	26	76/136	17	43	17/34		17	2339/2459	102	18	3494/3936	88.77
South Dakota	18/29		11	10/33	16	7	57/79	2	20	2/5		3	1159/1216	51	6	1246/1362	91.48
Minnesota	123/152	2	27	11/20	5	4	71/98	6	21	0/9		9	1069/1098	21	8	1274/1377	92.52
Montana	138/180	3	39	4/20	11	5	1/6	2	3				1233/1253	18	2	1376/1459	94.31
Totals	1177/1400	30	193	189/341	110	42	205/319	27	87	18/48		29	5800/6026	192	34	7390/8134	90.85
Percentage correct	84.07	2.14	13.79	55.43	32.26	12.32	64.26	8.46	27.27	39.58		60.42	96.25	3.19	0.56	90.85	

Part II: All segments with an estimate for spring small grains (45 segments)

State	Category																
	SG:SG[a]	SG:N	N:N[a]	N:SG													
North Dakota	1407/1660	253	2765/2903	138													
South Dakota	113/158	45	1254/1311	57													
Minnesota	277/351	74	1184/1224	40													
Montana	159/206	47	1233/1203	20													
Totals	1956/2375	419	6436/6691	255													
Percentage correct	82.36	17.64	96.19	3.81													

[a]The number in the denominator represents the total of ground-truth dots in the category being labeled.

TABLE C-2.- Continued.

(b) North Dakota

Segment number	Category																		Total correct[a]	Percentage correct
	SG:SG[a]	SW:S[a]	SW:B	SW:N	B:B[a]	B:S	B:N	O:S[a]	O:B	O:N	F:S[a]	F:B	F:N	SG:N	N:N[a]	N:S	N:B	N:SG		
Part I. All segments with a barley estimate																				
1387	106/113	73/74		1	20/38	13	5	0/1		1				7	89/96	5	2	7	182/209	87.1
1392	59/64	48/52	2	2	3/10	5	2				1/2		1	5	126/143	16	1	17	178/207	86.0
1394	64/84	52/67		15	7/12	3	2	2/3		1	0/2		2	20	122/124	2		2	183/208	88.0
1461	105/113	69/84	12	3	2/8	5	1	6/10	2	2	9/11		2	8	87/95	8		8	173/208	83.2
1467	113/117	90/92		2	6/22	11	2	1/1			2/2			4	90/92	2		2	192/209	91.9
1472	76/87	47/56	4	5	16/29	5	4	3/5	1	1	0/1		1	11	116/120	4	1	5	181/207	87.4
1473	103/105	58/61	2	1	40/42	2					1/2		1	2	93/102	9		9	192/207	92.8
1584	104/111	72/75		3	14/31	16	1	0/1		1	2/4		2	7	94/98	4		4	182/209	87.1
1619	90/96	67/70		3	20/25	2	3	1/1						6	111/113	2		2	199/209	95.2
1636	77/89	62/73	1	10	5/6		1	7/10	2	1				12	107/119	12		12	181/208	87.0
1650	48/64	42/52		10	0/1	1		4/11	1	6				16	142/145	3		3	188/209	90.0
1653	38/45	28/31		3	0/1	1		8/12	1	3	0/1		1	7	159/161		2	2	195/206	94.7
1656	10/19	5/9		4	2/2			3/8		5				9	186/190	2	2	4	196/209	93.8
1658	80/90	53/58		5	15/19	4		7/7			1/6		5	10	110/119	9		9	186/209	89.0
1664	61/70	41/47	1	5	6/11	2	3	8/11	2	1	1/1			9	118/127	5	4	9	174/197	88.3
1909	29/45	17/28		11	1/6	5		6/11		5				16	153/164	11		11	177/209	84.7
1918	27/36	10/17	3	4	1/4	2	1	8/15	3	4				9	164/170	2	4	6	183/206	88.8
1920	22/55	15/40		25	1/2		1	3/12	3	6	0/1		1	33	152/154	1	1	2	171/209	81.8
1924	63/74	49/53		4	2/3	1		9/17	2	6	0/1		1	11	121/127	5	1	6	181/201	90.0
Subtotals	1275/1477	898/1039	25	116	164/268	78	26	76/136	17	43	17/34		17	202/1477	2339/2459	102	18	120	3494/3936	88.77
Percentage correct	86.32	86.43	2.41	11.16	61.19	29.10	9.70	55.88	12.5	31.62	50.00		50.00	13.68	95.12	4.15	0.73	4.88	88.77	
Part II. All segments with a spring small grain estimate																				
1457	47/86													39	117/123			6	158/209	75.6
1602	63/84													1	139/145			6	202/209	96.7
1612	22/33													11	170/176			6	192/209	91.9
Grand totals	1407/1660													253	2765/2903			138		
Percentage correct	84.76													15.24	95.25			4.75		

[a]The number in the denominator represents the total of ground-truth dots in the category being labeled.

TABLE C-2.- Continued.

(c) South Dakota

Segment number	Category																		Total correct[a]	Percentage correct
	SG:SG[a]	SW:S[a]	SW:B	SW:N	B:B[a]	B:S	B:N	O:S[a]	O:B	O:N	F:S[a]	F:B	F:N	SG:N	N:N[a]	N:S	N:B	N:SG		
Part I. All segments with a barley estimate																				
1154	1/1	1/1												0	175/208	30	3	33	176/209	84.2
1598 :	3/6	1/1			1/1			1/4		3				3	203/203				206/209	98.6
1676	12/13							10/13	2	1				1	191/196	2	3	5	201/209	96.2
1755	14/21	0/1		1	5/8	1	2	8/12		4				7	185/188	3		3	198/209	94.7
1784	40/50				4/18	11	3	25/32		7				10	152/159	7		7	181/209	86.6
1802	0/5	0/2		2				0/3		3				5	105/105				105/110	95.5
1811	35/50	16/24		8	0/6	4	2	13/15		2	2/5		3	15	148/157	9		9	179/207	86.5
Subtotals	105/146	18/29		11	10/33	16	7	57/79	2	20	2/5		3	41	1159/1216	51	6	57	1246/1362	91.48
Percentage correct	71.92	62.07		37.93	38.30	48.48	21.21	72.15	2.53	25.32	40.00		60.00	28.09	95.31	4.19	0.49	4.69	91.48	
Part II. All segments with a spring small grain estimate																				
1668	8/12													4	95/95				103/107	95.4
Grand totals	113/158													45	1254/1311			57	1349/1469	
Percentage correct	71.52													28.48	95.65			4.35	91.83	

[a]The number in the denominator represents the total of ground-truth dots in the category being labeled.

TABLE C-2.- Continued.

(d) Minnesota

Segment number	Category																	Total correct[a]	Percentage correct
	SG:SG[a]	SW:S[a]	SW:B	SW:N	B:B[a]	B:S	B:N	O:S[a]	O:B	O:N	F:S[a]	F:B	F:N	SG:N	N:N[a]	N:S	N:B	N:SG	
Part I. All segments with a barley estimate																			
1380	15/22	9/16		7	1/1			5/5						7	186/187		1	1	201/209	95.7
1514	44/59	23/28		5	5/9	2	2	14/16		2	0/6		6	15	136/147	6	5	11	178/206	86.4
1518	48/56	35/38		3	1/3	1	1	11/12		1	0/3		3	8	146/147	1		1	193/203	95.1
1524	18/28							18/26		10				10	166/174	8		8	184/202	91.1
1825	61/68	28/33	2	3	4/6	2		13/29	6	4				7	100/103	1	2	3	151/171	88.3
1842	22/26	19/22		3				3/4		1				4	157/160	3		3	179/186	96.3
1845	10/20	9/15		6	0/1		1	1/4		3				10	178/180	2		2	188/200	94.0
Subtotals	218/279	123/152	2	27	11/20	5	4	71/98	6	21	0/9		9	61/279	1069/1098	21	8	29	1274/1377	92.52
Percentage correct	78.14	80.92	1.32	17.76	55.0	25.0	20.0	72.45	6.12	21.43	0.00		100.0	21.86	97.36	1.91	0.73	2.64	92.52	
Part II. All segments with a spring small-grain estimate																			
1566	59/72													13	115/126			11	174/198	87.9
Grand totals	277/351													74/351	1184/1224			40		
Percentage correct	78.92													21.08	96.73			3.25		

[a]The number in the denominator represents the total of ground-truth dots in the category being labeled.

TABLE C-2.- Concluded.

(e) Montana

Segment number	Category																		Total correct[a]	Percentage correct
	SG:SG[a]	SW:S[a]	SW:P	SW:N	B:B[a]	B:S	B:N	O:S[a]	O:B	O:N	F:S[a]	F:B	F:N	SG:N	N:N[a]	N:S	N:B	N:SG		
1537	7/15	4/10		6	1/3	1	1	0/2	1	1				8	192/194	2		2	197/209	94.3
1542	46/50	46/50		4										4	153/158	4	1	5	199/208	95.7
1544	60/73	54/69	2	13	3/3			1/1						13	132/136	4		4	190/209	90.9
1550	0/0														208/209	1		1	208/209	99.5
1553	10/17	9/12		3	0/3	1	2	0/2		2				7	190/192	2		2	199/209	95.2
1731	9/12	1/3		2	0/8	7	1	0/1	1					3	194/197	2	1	3	195/209	93.3
1942	27/39	24/36	1	11	0/3	2	1							12	164/167	3		3	188/206	91.3
Totals	159/206	138/180	3	39	4/20	11	5	1/6	2	3				47	1233/1253	18	2	20	1376/1459	94.31
Percentage correct	77.18	76.67	1.67	21.67	20.00	55.00	25.00	16.67	33.33	50.00				22.82	98.48	1.36	0.16	1.52	94.31	

[a]The number in the denominator represents the total of ground-truth dots in the category being labeled.

APPENDIX D

CHARACTERIZATION OF LABELING ERRORS

TABLE D-1.- SYMBOL DEFINITIONS FOR TABLES D-2(a) THROUGH D-2(e)

Symbol	Definition
α	A lack of informative acquisitions (useful to labeling) contributed to the labeling error.
Code 33	A nongrain crop was committed to barley because of a holiday in Landsat coverage of the field from planting to senesence/harvest. A detectable infrared response was not present in any of the available acquisitions.
γ_1	Crop was behind the ACC, late planting and development.
γ_2	Crop was ahead of the ACC, early planting and development.
ε_1	The dot was on a single narrow field; the signature may or may not have been overridden by surrounding signatures of other categories.
ε_2	The dot encompassed multiple strips so narrow that they presented a single, integrated signature. Field width was not resolvable by the Landsat scanner.
θ	The signature of the target crop did not follow the expected temporal color sequence of small grain throughout the acquisitions.
λ	Clerical error — the error-pixel clearly followed a temporal sequence for its category. Since other dots with the same temporal sequence were consistently identified correctly, then this error was a clerical error.
μ	Double cropping practice of a second crop or weeds became the dominant signature and caused an increase in the infrared response after grain harvest.
ν	The signature of the nonsmall grain followed the expected temporal color sequence of small grain throughout the acquisitions.
π	Border or edge pixel — spectral and spatial confusion occurs between two or more fields of different types due to misregistration of acquisitions or confusion as to field size or shape.
σ	Author disagrees with the ground-truth overlay label, but it was reluctantly accepted as being valid.
ϕ	Segment-unique causes — the error did not match any of the causes of a general nature. The pixel had insufficient spectral information to cause correct categorization, but some correlation could be made with the correct category after the ground truth was known.
ω_1	Field destroyed by grazing, plowing, or discing. Analyst should be able to detect destruction of the field.
ω_2	Field destroyed by grazing, plowing, or discing. Analyst should not be able to detect destruction of the field.
O	Omission error
C	Commission error

TABLE D-2.- CHARACTERIZATION OF LABELING ERROR AT THE SPRING SMALL-GRAIN LEVEL FOR THE USNGP

(a) The four-state area

State	Labeling error causes[a]																												Total dots labeled	
	α		Code 33		γ_1		γ_2		θ		ν		μ		ϵ_1		ϵ_2		κ		λ		ϕ		σ		Total			
	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	Grain	Nongrain
North Dakota	0	1	0	6	130	2	5	0	17	0	0	42	7	0	17	6	11	0	39	28	9	30	17	23	1	0	253	138	1660	2903
South Dakota	11	0	-	-	7	0	-	-	1	0	0	41	4	0	7	2	1	0	4	7	4	3	4	3	2	1	45	57	158	1311
Minnesota	3	8	0	3	18	0	7	0	16	0	0	9	1	0	5	1	-	-	14	3	4	0	5	16	1	0	74	40	351	1224
Montana	5	0	-	-	8	2	9	1	6	0	0	5	1	0	1	1	1	1	5	1	2	2	4	5	5	2	47	20	206	1253
Totals	19	9	0	9	163	4	21	1	40	0	0	97	13	0	30	10	13	1	62	39	19	35	30	47	9	3	419	255	2375	6691
O, percent	0.8		0		6.86		0.88		1.68		0		0.55		1.26		0.55		2.61		0.80		1.26		0.38		17.64			
C, percent		0.38		0.38		0.17		0.04		0		4.08		0		0.42		0.04		1.64		1.47		1.98		0.13		10.74		

[a]Refer to table D-1 for definitions of symbols.

TABLE D-2.- Continued.

(b) North Dakota

Segment number	Labeling error causes																								Total		Total dots labeled	
	α		Code 33		Y_1		Y_2		θ		ν		μ		ϵ_1		ϵ_2		π		λ		φ		σ					
	0	C	0	C	0	C	0	C	0	C	0	C	0	C	0	C	0	C	0	C	0	C	0	C	0	C	0	C	Grain	Nongrain
1387					3	0					0	3							3	2	0	1	1	1			7	7	113	96
1392									3	0	0	6	1	0					0	2	0	4	1	5			5	17	64	143
1394					18	0					0	1							1	0	1	1					20	2	64	124
1461					3	0			1	0	0	5			0	1			2	1	1	0	1	1			8	8	113	95
1467					2	0			1	0											1	2					4	2	117	92
1472	0	1	0	1	3	0					0	1	1	0					5	1	0	1	1	0	1	0	11	5	87	120
1473					2	0					0	9															2	9	105	102
1584					1	0			3	0									3	2	0	2					7	4	111	98
1619					1	0									1	0			3	1			1	1			6	2	96	113
1636					4	0					0	2			2	1			2	5	0	2	4	2			12	12	89	119
1650					4	1							1	0			7	0	2	0	1	2	1	0			16	3	64	145
1653					3	0	1	0							0	1			1	0	2	0	0	1			7	2	45	61
1656					5	0					0	1			1	0	1	0	1	1			1	2			9	4	19	190
1658					9	0					0	4									1	3	0	2			10	9	90	119
1664							1	0	1	0	0	4			0	1			3	3	1	0	3	1			9	9	70	127
1909									4	0	0	2			4	0	1	0	7	3	0	3	0	3			16	11	45	164
1918			0	4	5	0					0	1			4	0					0	1					9	6	36	170
1920			0	1	22	0	1	0	1	0			2	0	2	0	2	0	1	1			2	0			33	2	55	154
1924					9	1			1	0									1	2	0	3					11	6	74	127
1457					36	0			2	0	0	1							1	1	0	3	0	1			39	6	86	123
1602											0	1			0	1			1	0	0	2	0	2			1	6	64	145
1612							2	0			0	1	2	0	3	1			2	3	1	0	1	1			11	6	33	176
Totals	0	1	0	6	130	2	5	0	17	0	0	42	7	0	17	6	11	0	39	28	9	30	17	23	1	0	253	138	1660	2903
0, percent C, percent	0	0.06	0	0.36	7.83	0.12	0.30	0	1.02	0.06	0	2.53	0.42	0	1.02	0.36	0.66	0	2.35	1.68	0.54	1.81	1.02	1.35	0.06	0	15.23	8.31		

[a]Refer to table D-1 for definitions of symbols.

TABLE D-2.- Continued.

(c) South Dakota

Segment number	Labeling error causes																				Total		Total dots labeled	
	α		γ_1		θ		ν		μ		ϵ_1		ϵ_2		π		λ		φ		σ					
	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	Grain	Nongrain
1154							0	31							0	2							0	33	1	208
1598									2	0			1	0									3	0	6	203
1668			3	0							1	0											4	0	12	95
1676							0	3							1	0	0	1	0	1			1	5	1	196
1755	3	0					0	1	1	0					0	1	3	0	0	1			7	3	21	188
1784			2	0			0	3	1	0	1	1			1	2			3	0	2	1	10	7	50	159
1802	5	0																					5	0	5	105
1811	3	0	2	0	1	0	0	3			5	1			2	2	1	2	1	1			15	9	50	157
Totals	11	0	7	0	1	0	0	41	4	0	7	2	1	0	4	7	4	3	4	3	2	1	45	57	158	1311
O, percent C, percent	6.96	0	4.43	0	0.63	0	0	25.95	2.53	0	4.43	1.27	0.63	0	2.53	4.43	2.53	1.90	2.53	1.90	1.27	0.63	28.48	36.08		

[a]Refer to table D-1 for definitions of symbols.

TABLE D-2.- Continued.

(d) Minnesota

Segment number	Labeling error causes[a]																								Total		Total dots labeled	
	α		Code 33		γ_1		γ_2		θ		ν		μ		ε		π		λ		φ		σ					
	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	Grain	Nongrain
1380					1	0	1	0	1	0	0	1			2	0	1	0			1	0			7	1	22	187
1514	2	4	0	3	2	0			7	0	0	1			0	1	1	1	2	0	0	1	1	0	15	11	59	147
1518					3	0	1	0	3	0			1	0			0	1							8	1	56	147
1524	1	4			3	0	1	0	1	0	0	3					2	0			2	1			10	8	28	174
1825					1	0	2	0	1	0	0	2			1	0	1	0	1	0	0	1			7	3	68	183
1842					1	0	1	0	1	0	0	1					1	1			0	1			4	3	26	160
1845					5	0	1	0			0	1					4	0			0	1			10	2	20	180
1566					2	0			2	0					2	0	4	0	1	0	2	11			13	11	72	126
Totals	3	8	0	3	18	0	7	0	16	0	0	9	1	0	5	1	14	3	4	0	5	16	1	0	74	40	351	1224
O, percent C, percent	0.85	2.28	0	0.85	5.13	0	1.99	0	4.56	0	0	2.56	0.28	0	1.42	0.28	4.00	0.85	1.14	0	1.42	4.56	0.28	0	21.08	11.38		

[a]Refer to table D-1 for definitions of symbols.

TABLE D-2.- Concluded.

(e) Montana

Segment number	Labeling error causes[a]																						Total		Total dots labeled	
	α		Code 33		γ_1		γ_2		θ		ν		μ		ϵ_1		ϵ_2		π		λ		φ		σ					
	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C			Grain	Nongrain
1537	3	0			1	0			2	0	0	2									2	0					8	2	15	194
1542					0	1	0	1															0	3	4	0	4	5	50	158
1544					4	1	2	0	1	0					1	0	1	1	3	0	0	2	1	0			13	4	73	136
1550											0	1															0	1	0	209
1553	2	0					1	0	3	0	0	1													0	1	7	2	17	192
1731					1	0					0	1							2	0			0	1	0	1	3	3	12	197
1942			2	0	6	0							1	0	0	1			0	1			3	1			12	3	39	167
Totals	5	0	2	0	12	2	3	1	6	0	0	5	1	0	1	1	1	1	5	1	2	2	4	5	5	2	47	20	206	1253
O, percent C, percent	2.43	0	0.97	0	5.83	0.97	1.46	0.49	2.91	0	0	2.43	0.49	0	0.49	0.49	0.49	0.49	2.43	0.49	0.97	0.97	1.94	2.43	2.43	0.97	22.82	9.71		

[a]Refer to table D-1 for definitions of symbols.