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Inventory Technology Development

A Joint Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing

April 1983

THE 1980 U.S./CANADA WHEAT AND BARLEY EXPLORATORY EXPERIMENT FINAL REPORT - ADDENDA

VOLUME II

R. M. Bizzell and H. L. Prior

National Aeronautics and Space Administration

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16. Abstract

This report presents 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 to be capable of producing accurate and consistent spring small grains proportion estimates. However, barley proportion estimation technology was not satisfactorily evaluated. Landsat sample segment data were 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.

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THE 1980 U.S./CANADA WHEAT AND BARLEY EXPLORATORY EXPERIMENT
FINAL REPORT VOLUME II

Job Order 72-418

This report describes the 1980 U.S./Canada Wheat and Barley Exploratory Experiment of the Inventory Technology Development Department within the AgRISTARS program.

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LOCKHEED ENGINEERING AND MANAGEMENT SERVICES COMPANY, INC.

Under Contract NAS 9-15800

For

Earth Resources Applications Division

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

April 1983

LEMSCO-18629

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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AgRISTARS

FC-L2-04229
JSC-17815

A Joint Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing

Foreign Commodity Production Forecasting

December 1981

EVALUATION OF THE U.S./CANADA WHEAT AND BARLEY EXPLORATORY EXPERIMENT SHAKEDOWN TEST ANALYST LABELING RESULTS

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16. Abstract
The results of the 1980 U.S./Canada Wheat and Barley Exploratory Labeling Experiment Shakedown Test are presented in this document. This test was performed on six segments from the 1978 crop year. No major problems were found with the Reformatted Labeling Procedure as it was applied to these segments. The labeling accuracies obtained using this procedure were comparable with the labeling accuracies obtained using the Integrated Labeling Procedure. This indicates that the procedure is ready for testing with the recommended changes.

17. Key Words (Suggested by Author(s)) Exploratory experiment Labeling accuracy evaluation Reformatted labeling procedure Small grains labeling procedures 1980 U.S./Canada Wheat and Barley	18. Distribution Statement

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EVALUATION OF THE U.S./CANADA WHEAT AND BARLEY EXPLORATORY EXPERIMENT SHAKEDOWN TEST ANALYST LABELING RESULTS

Job Order 72-422

This report describes performance evaluation activities of the Foreign Commodity Production Forecasting of the AgRISTARS program.

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LYNDON B. JOHNSON SPACE CENTER
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December 1981

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PREFACE

The Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing is a multiyear program of research, development, evaluation, and application of aerospace remote sensing for agricultural resources, which began in fiscal year 1980. This program is a cooperative effort of the U.S. Department of Agriculture, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration (U.S. Department of Commerce), the Agency for International Development (U.S. Department of State), and the U.S. Department of the Interior.

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 Lockheed Engineering and Management Services Company, Inc. The tasks performed by Lockheed Engineering and Management Services Company, Inc., were accomplished under Contract NAS 9-15800.

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1. INTRODUCTION

The objective of the Foreign Commodity Production Forecasting (FCPF) project of the Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) program is to develop and test procedures for using aerospace and related technology. Specifically, this testing and development is done to provide more objective and reliable crop production forecasts several times during the growing season and to provide improved preharvest estimates for a range of countries and crops. During the first year of the project (1980), an exploratory study of at-harvest crop proportion estimates from 1979 Landsat data for spring small grains was conducted on 5- by 6-nautical-mile segments within the northern Great Plains. To produce segment-level estimates for this experiment, analysts identify and label target pixels (dots) which are taken from Landsat imagery. Usually these dots are taken from the set of 209 pixels at the intersection of every tenth line and every tenth sample in a line.

In one procedure for labeling these dots, the analyst assimilates information from image products, spectral aids, crop calendars, and assorted meteorological and agronomic data. The analyst then subjectively applies weights to these data to arrive at a label for the dot. This method of labeling dots is part of the Integrated Labeling Procedure (ref. 1) which was used during the Large Area Crop Inventory Experiment (LACIE) and the Transition Year. The accuracy of labeling using this method depends to a great extent on the ingenuity of the analyst doing the labeling. The results can vary greatly from analyst to analyst. However, because of the subjective nature of the technique and the amount of information examined, maximum use can be made of the available data. One problem with a subjective procedure is that it is not always obvious how the label is obtained. If the label is incorrect, one can only speculate as to the reason for the error.

Because of these undesirable features, it was recognized that a more systematic and objective labeling procedure was required. If a systematic labeling procedure could be developed, the skill requirements for analysts could be reduced, the resulting labels would be less variable, and the reasons for errors would be more easily identified. In addition, the analyst activities required to produce proportion estimates for sample segments could be significantly reduced or eliminated by automation.

The Reformatted Labeling Procedure (see appendix A), for wheat and barley was developed to meet these requirements. It is based on a decision tree labeling logic. The labeling decision is obtained by answering a series of questions, with the answer to one question leading to the next question, until the end of the decision path is reached. The end point of the path determines the final label. By recording the answers to each question involved in the decision logic, it is possible to determine not only whether the label is correct but why incorrect labels were obtained.

The U.S./Canada Wheat and Barley Exploratory Labeling Experiment (ref. 2) provides the first evaluation of the labeling logic in the Reformatted Labeling Procedure. In this experiment, both the Reformatted and Integrated Labeling Procedures were used to produce dot labels using Landsat data from two crop years (1978 and 1979).

There were two tests performed in this labeling experiment. The first test (Shakedown Test) was performed using a limited number of segments from the 1978 crop year. The Reformatted Labeling Procedure was developed using data from this crop year. However, the six segments involved in the Shakedown Test were not used in developing the procedure. The main purpose of the test was to determine if there were any major problems with the procedure before it was applied in the second test to segments from the 1979 crop year. This was to be determined from the labeling accuracy and not from proportion estimation accuracy. The study of proportion estimation was the subject of a supplemental experiment.

The second test (Test 2) was designed to be a more extensive test of the procedure using data from a different crop year (1979). In this test the Integrated Labeling Procedure was applied to the same segments as the Reformatted Labeling Procedure. This provided a standard for comparison.

This report, however, presents a brief description of the procedure and the results of the first test only.

2. DESCRIPTION OF THE REFORMATTED PROCEDURE

To understand the results of this evaluation, one must have knowledge of the steps in the procedure. A detailed explanation of these steps is given in reference 2. This section will provide an outline of the procedure.

The Reformatted Labeling Procedure is based on a decision tree labeling logic which produces progressively more detailed dot labeling. The first step in the procedure is to determine which Landsat acquisitions should be used in the decision process. On the basis of crop calendar information, four acquisition windows are defined. If an acquisition is available in one of these windows, it is used in the decision process. The following list indicates the biostages corresponding to the four acquisition windows (biostage lengths are shown in parentheses).

1. pre-emergence for spring wheat (23 days)
2. spring wheat, headed (20 days)
3. barley, ripe (12 days)
4. spring wheat, harvested (15 days)

An additional window (time period A) is defined between windows 3 and 4.

The major steps in the decision logic are shown in figure 2-1. The first decision separates the spectrally pure dots from the impure dots. The impure dots are those which exhibit more than one crop signature for the acquisitions used. Dots may be impure because they are on the borders of fields or because the acquisitions are not adequately registered with each other. Only the pure dots are labeled by the procedure[1].

---

[1] For labeling impure dots, a different approach was used. First, the pure dots were labeled. Second, through examination of the Landsat imagery, the analyst determined the field with which to associate the impure dot based on the spatial and spectral characteristics of the impure dot and adjacent fields. A comparison was then made between the multitemporal spectral signatures of the field associated with the impure dot and the fields within which pure dots had been labeled earlier. A labeling decision on the impure dot was then made on the basis of the closest subjective matching.

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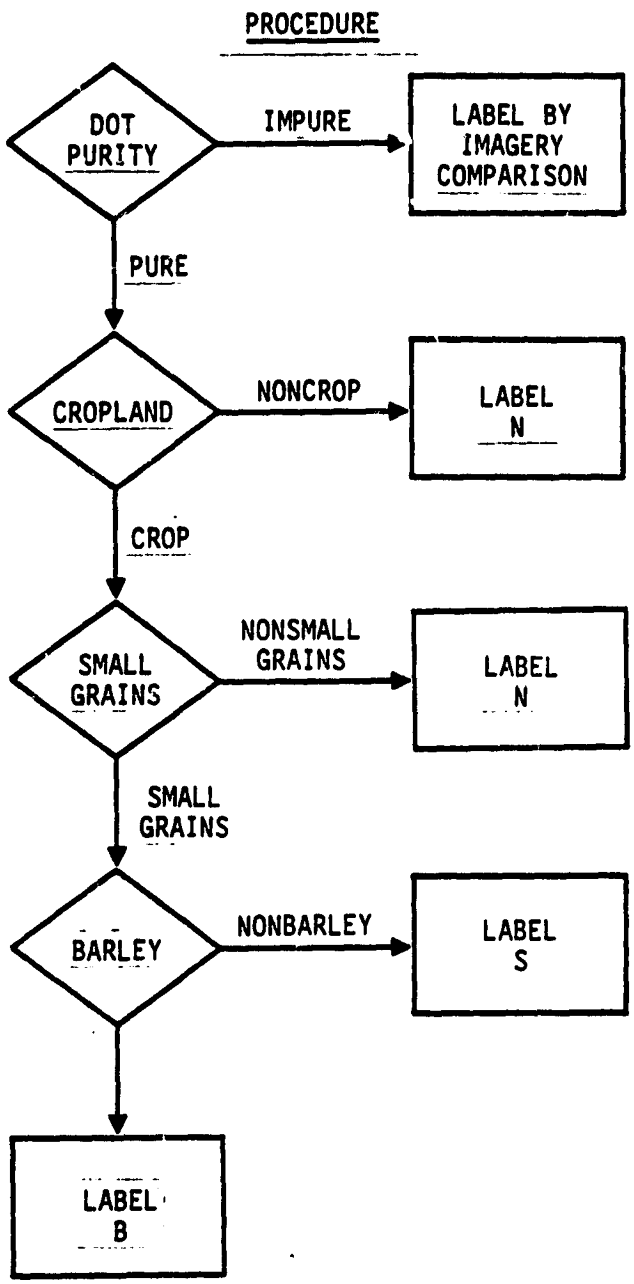

Figure 2-1.- Shakedown Test results for the reformatted procedure.

The second major step in the decision logic separates the pure dots into those with cropland signatures and those with noncropland signatures. The logic involved in this step is based on the color of the dot on the production film converter (PFC) product [figure 2-2, (ref. 3)]. The path used to arrive at the cropland/noncropland decision is defined by the answers to questions 1a, 1b, 1c, 2, 3, and 4 (see figure 2-1). The noncropland dots are labeled as nonsmall grains.

The third major step separates the dots labeled cropland into those with small grains signatures and those with nonsmall-grains signatures. The logic in this step involves the green number (refs. 4 and 5) and brightness for the dot on each of the acquisitions (figure 2-3). Each of the green number and brightness decisions is given a number so that the path taken through the decision logic can be identified.

The fourth major step separates the dots labeled small grains into those with barley signatures and those with signatures corresponding to other small grains (ref. 6). This decision is based on a green number versus brightness plot of the small grains dots for the acquisition in window 3.

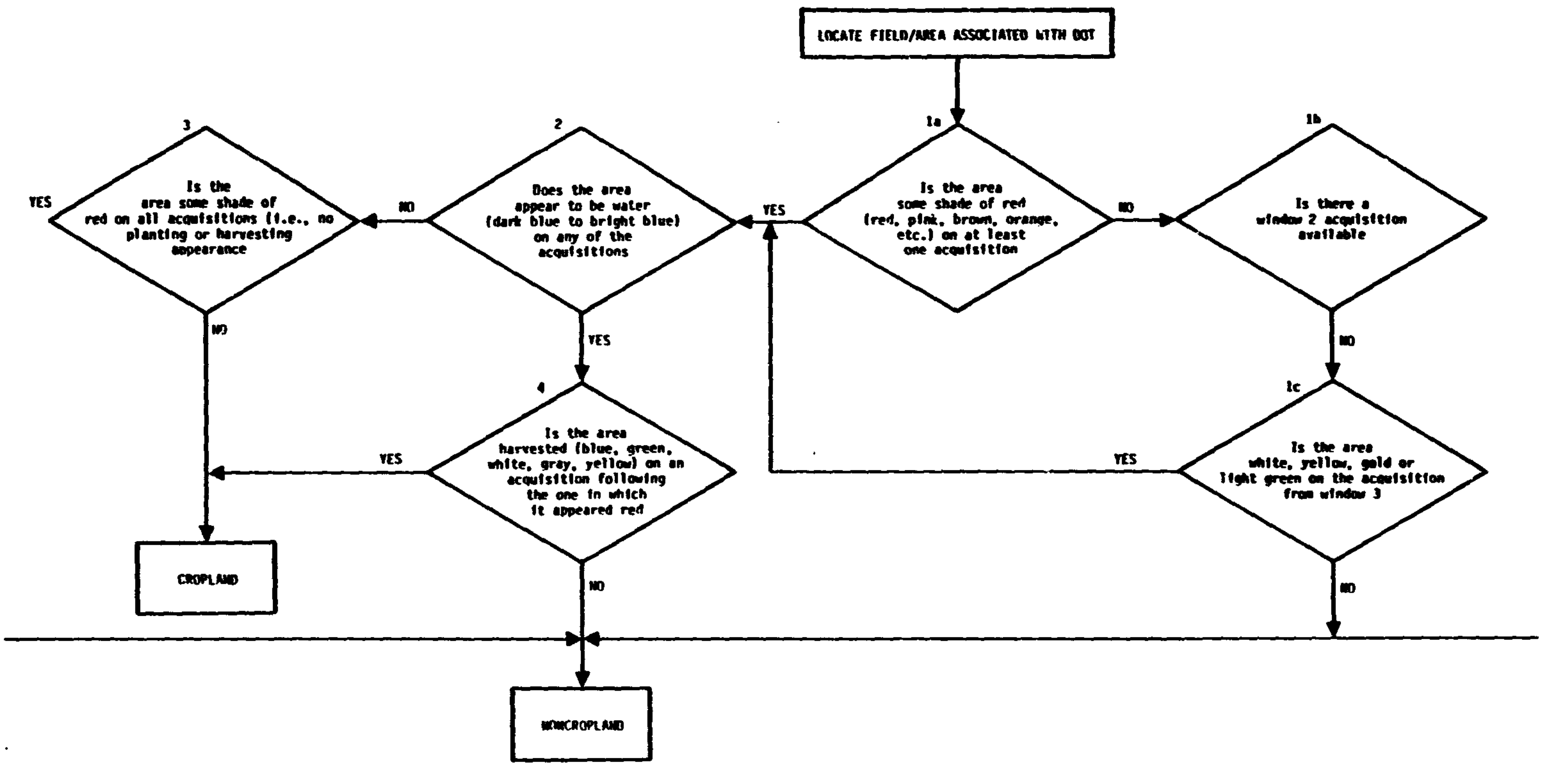

Figure 2-2.- Decision logic for cropland and noncropland.

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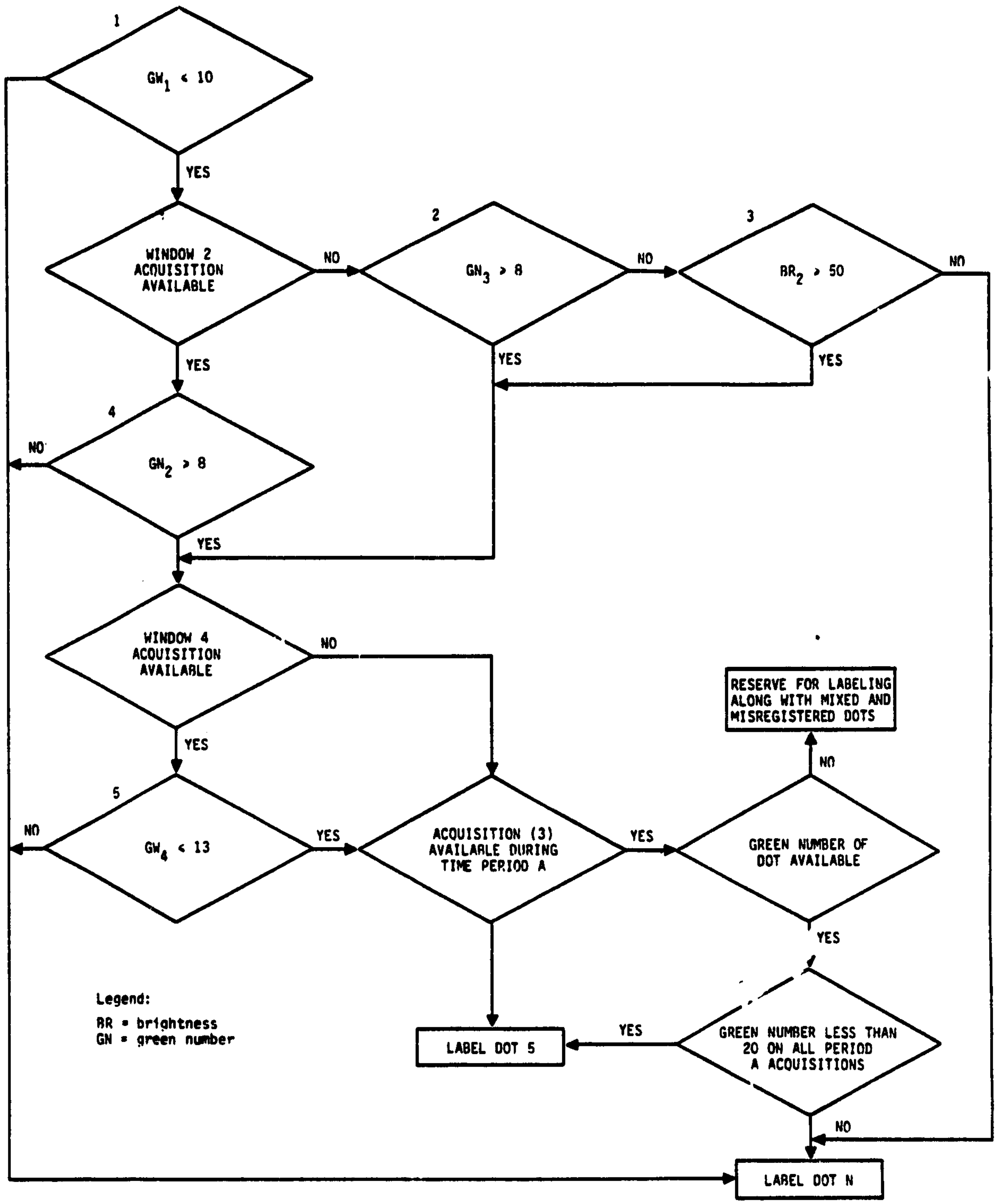

Figure 2-3.- Decision logic for pure cropland dots.

3. SHAKEDOWN TEST WITH 1978 DATA

3.1 EXPERIMENT DESIGN

In the Shakedown Test, all 209 dots for six segments were labeled using data from the 1978 crop year. The actual number of dots evaluated per segment varied downward from 209 because of clouds, cloud shadows, data dropouts, striping, or missing ground-truth inventory. The loss was a small percentage of the dots. The locations of the segments are shown in figure 3-1. Each of the segments was labeled by two analysts working independently. By comparing the two sets of labeling results, the consistency of the procedure could be evaluated. Five of these six segments were previously processed using the Integrated Labeling Procedure (ref. 7). These labeling results were used to compare the accuracy of the Reformatted Labeling Procedure with the accuracy of the Integrated Labeling Procedure.

3.2 OVERALL LABELING ACCURACY FOR FINAL LABELS

Table 3-1 shows the labeling accuracy for each of the categories labeled (non-small grains, barley, and other small grains). The labeling accuracy is shown for all the dots labeled and for those dots which were determined by the analyst to be pure, mixed, or misregistered. The labeling accuracy was greater for the pure dots (which were labeled using the decision logic) than for the impure dots (which were labeled by comparison with the pure dot labels). The numbers in parentheses show the percentage of dots correctly labeled when both analysts agreed on the label. The labeling accuracies were, in general, greater when there was agreement between the analysts.

Table 3-2 shows a comparison, on a segment-by-segment basis, between accuracy obtained using the Reformatted Labeling Procedure and that obtained using the Integrated Labeling Procedure. Overall, the Reformatted Labeling Procedure produced labeling accuracies which were comparable to the accuracies for the Integrated Labeling Procedure. For some segments, the Reformatted Labeling Procedure obtained better results in certain categories than did the Integrated Labeling Procedure, while on other segments, the reverse was true.

TABLE 3-1.- ANALYST LABELING ACCURACY

[Percent correctly labeled]

Crop category	All dots	Pure dots	Mixed dots	Misregistered dots
Nonsmall grains	91(95)	94(97)	73(78)	82(91)
Small grains (except barley)	72(82)	74(84)	66(83)	55(63)
Barley	51(49)	50(51)	60(-)	50(-)
Total small grains	77(86)	79(87)	73(86)	67(76)

Note: The numbers in parentheses show the percentage of dots correctly labeled when both analysts agreed on the label.

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TABLE 3-2.- SEGMENT-LEVEL RESULTS FOR SHAKEDOWN TEST

Segment number	Procedure	Correctly labeled dots, %			Segment A characteristics
		Small grains	Barley	Nonsmall grains	
1542	Reformatted	91	-	93	25% small grains (no barley)
	TY	42	-	96	3% other crops
1584	Reformatted	86	44	88	50% small grains 11% barley
	TY	93.4	45	94	Acquisitions deficient for barley
1656	Reformatted	57	-	95	75% noncropland 7% small grains
	TY	52.6	-	97	No barley
1664	Reformatted	70	31	95	38% small grains 8% barley
	TY	87	54.5	94	27% other crops
1811	Reformatted	56	36	81	25% small grains 2% barley
	TY	70	0	94	40% other crops
Overall	Reformatted	76	52	91	
	TY	75	55	95	

Note: Segment 1514 was not processed during the TY.

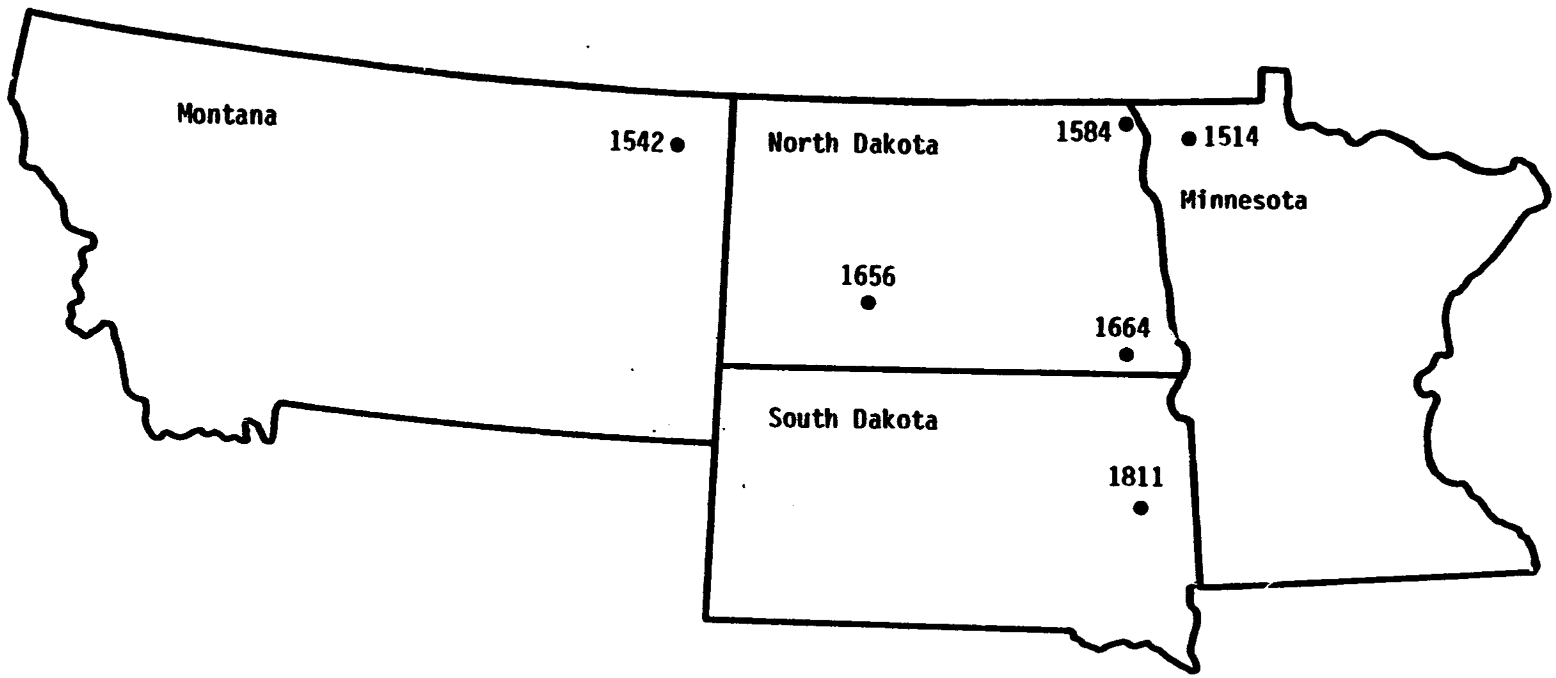

Figure 3-1.- Locations of segments used in the Shakedown Test.

The barley labeling accuracy was not very high for either procedure, with only half of the barley being labeled correctly. However, the segments involved in this test had an average barley proportion of only 5 percent, with two segments containing no barley at all. Because of the nature of the barley/other-small-grains labeling technique, the labeling accuracy for barley cannot be adequately tested if a reasonable amount of barley is not present. Therefore, in all of the subsequent discussions, barley is considered part of the small-grains category, and labeling accuracies are evaluated for small-grains/nonsmall-grains labeling only.

The labeling accuracies for individual crops are shown in table 3-3. None of the nonsmall grain crops were consistently mislabeled, and of the small-grains crops, only flax was incorrectly labeled more often than it was correctly labeled. [This type of labeling error for flax[2] was observed in LACIE Phase III (ref. 8) and the Transition Year (ref. 9). Because there is so little flax, it is difficult on the basis of these and prior results to decide whether flax should be identified as a small grain or as a nonsmall grain.]

3.3 CROPLAND/NONCROPLAND LABELING ACCURACY

The labeling accuracy for the cropland/noncropland decision logic is shown in table 3-4. The dots considered in evaluating the cropland/noncropland labeling accuracy were those which the analyst had decided were pure. The labeling accuracy obtained as a function of the path taken through the decision logic is also shown in table 3-4. None of the paths through the decision logic consistently produced wrong answers. It should be noted that an affirmative response to question 1a occurred 84 percent of the time. In those instances when an affirmative was given, question 3 became the decision maker. While the labeling accuracy for the dots following this path which received a noncropland label was consistent with the labeling accuracies for other pathways leading to a noncropland label, the labeling accuracy for the dots following this path which received a cropland label was lower than the labeling accuracy

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[2]Although flax is not a small grain, its spectral signature is similar and is considered as grouped with the small grains.

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TABLE 3-3.- ANALYST LABELING ACCURACY FOR INDIVIDUAL CROPS

Crop	Number of dots labeled	Crops correctly labeled, % (nonsmall grains or small grains)
Nonsmall grains:		
Alfalfa	58	81
Corn	155	78
Sunflower	109	92
Sugar beets	14	79
Grass	112	93
Hay	137	91
Pasture	539	95
Trees	12	83
Water	34	94
Nonagricultural	111	96
Homestead	23	87
Idle	257	89
Small Grains:		
Spring barley	111	83
Spring wheat	443	81
Flax	34	41
Spring oats	92	62
Duram wheat	16	100

TABLE 3-4.- LABELING ACCURACY FOR CROPLAND/NONCROPLAND

(a) Overall labeling accuracy

Crop type	Correctly labeled dots, %
Cropland	84(90)
Noncropland	74(82)

(b) Accuracy by path through the decision logic

Answers to questions						Labeling decision	Total dots labeled, %	Correctly labeled dots, %	Crops which most frequently produce errors
1a	1b	1c	2	3	4				
Y	-	-	N	N	-	Crop	52	77(85)	Grass, pasture, nonagricultural, idle
Y	-	-	N	Y	-	Noncrop	32	82(86)	Alfalfa, corn, spring wheat, barley
N	Y	-	-	-	-	Noncrop	9	84(95)	Spring wheat, barley
N	N	Y	N	N	-	Crop	3	90(92)	Idle
N	N	N	-	-	-	Noncrop	2	85(-)	Spring wheat

Note: The numbers in parentheses reflect the percentage of labeled dots when both analysts agreed on the label.

of the other pathway leading to a cropland label. Because 66 percent of the areas of these segments was cropland and because the labeling accuracy for the dots labeled cropland by decision 3 was lower than the labeling accuracy for the dots labeled noncropland, it can be seen that there were more noncropland dots incorrectly labeled than there were cropland dots incorrectly labeled. This, however, presents no later problem since the incorrectly labeled noncropland dots remain in the flow of the decision logic. They may still be labeled nonsmall grains. In fact, for this reason if one of these categories were to have a low labeling accuracy, it would be better that it be for the dots labeled cropland. Thus, the fact that the labeling accuracy for the dots labeled cropland is lower than the labeling accuracy for dots labeled noncropland is not disturbing. There did not appear to be any major problems with the cropland/noncropland decision logic.

3.4 SMALL GRAINS/NONSMALL GRAINS LABELING ACCURACY

Table 3-5 shows the labeling accuracy for the small-grains/nonsmall-grains decision logic. The dots used in evaluating the small-grains/nonsmall-grains labeling accuracy are those which were correctly identified as cropland by the analyst. The accuracy for this logic appears to be quite good, especially when there is agreement between the analysts on the label. From the table 3-5(b), accuracy as a function of path through the decision logic, it can be seen that a wide variety of paths through the logic are used. None of the paths appear to produce consistently incorrect answers. This would indicate that there are no major problems with the logic.

As stated previously, there was not enough barley in these segments to determine if the barley separation procedure was working properly. However, the accuracy in separating barley from other small grains is presented in table 3-6. The dots used to determine this accuracy are those which were correctly labeled as small grains by the analyst. Only about half of the barley is correctly labeled, while almost all of the other small grains are labeled correctly.

TABLE 3-5.- LABELING ACCURACY FOR SMALL GRAINS/NONSMALL GRAINS

(a) Overall labeling accuracy

Crop type	Correctly labeled dots, %
Small grains	88(94)
Nonsmall grains	89(92)

(b) Accuracy by path through the decision logic

Answers to questions						Labeling decision	Total dots labeled, %	Correctly labeled dots, %	Crops which most frequently produce errors
1	2	3	4	5	6				
Y	-	-	Y	-	Y	SG	22	94(96)	Corn, sunflower
Y	Y	-	-	N	-	NSG	15	73(78)	Spring wheat
Y	Y	-	-	-	Y	SG	13	97(98)	Hay
Y	-	-	Y	Y	Y	SG	10	94(95)	Sunflower
Y	Y	-	-	-	N	NSG	7	84(100)	Spring wheat
Y	Y	-	-	Y	Y	SG	6	88(90)	Corn
Y	-	-	Y	-	N	NSG	6	92(95)	Spring wheat
Y	Y	-	-	Y	-	SG	6	95(100)	-
N	-	-	-	-	-	NSG	5	81(87)	Spring oats
Y	N	N	-	-	-	NSG	3	95(100)	-

Note: The numbers in parentheses reflect the percentage of correctly labeled dots when both analysts agreed on the label.

NSG = nonsmall grains
SG = small grains

TABLE 3-6.- LABELING ACCURACY FOR SMALL-GRAINS/BARLEY DISCRIMINATION

Crop type	Correctly labeled dots, %
Small grains (except barley)	95(98)
Barley	61(54)

3.5 CONSISTENCY OF ANALYST LABELING

One of the important requirements for an objective labeling procedure is that it be consistent. In the Shakedown Test, each of the dots was labeled independently by two analysts. By comparing the results obtained by each of the analysts, the consistency of the procedure can be investigated. The first decision the analyst must make is whether the dot is pure or not. The results of this test showed that the analyst agreed on whether the dot was pure 77 percent of the time. The analysts agreed on the final label for the dot 85 percent of the time. Table 3-7 shows the consistency for the major steps in the procedure. Each of the percentage consistencies is based on those dots which were consistently labeled at the previous major step. The most interesting feature of these results is that the labeling is more consistent for pure dots (when the decision logic is used) than for mixed dots (which are labeled by comparison with pure dot labels).

3.6 RECOMMENDATIONS FOR CHANGES TO THE REFORMATTED PROCEDURE

The results of this test indicated that there were no major problems with the Reformatted Labeling Procedure. However, in order to determine if there could be some improvements to the procedure, an error characterization study was performed on the labeling from this test. The general conclusions from this study were that the consistent errors were due to atypical signatures and that there were no specific confusion crops. The error characterization did provide some suggestions for changes which would improve the procedure and reduce the chances of clerical error.

One of the most important recommendations concerned the handling of nonpure pixels. In the Reformatted Labeling Procedure, these pixels were reserved for labeling by imagery comparison after the pure pixels were labeled. This test showed that the labeling accuracy and consistency for these reserved pixels was less than for the pure pixels. Because of this difference, it was suggested that (if possible) the analyst should determine from the imagery which field to associate with the mixed pixel. Then a pure pixel should be designated in the field associated with the mixed pixel. The label for the mixed pixel could be

TABLE 3-7.- CONSISTENCY OF LABELING AS A FUNCTION OF DECISION LOGIC STEP

Decision logic step	Consistent labels, %		
	Overall	Pure dots	Mixed dots
Cropland/noncropland	80	85	48
Small grains/nonsmall grains	85	95	76
Small grains/barley	92	94	86

determined by applying the decision logic to the pure pixel associated with it. This should increase the labeling accuracy of the pure pixels associated with the mixed pixels to the same level as for the pure pixels.

Another recommendation involved question 3 of the cropland/noncropland decision logic. This question determined the cropland/noncropland decision 84 percent of the time and exhibited a lower labeling accuracy than did other paths. In addition, there was a certain amount of inconsistency in answering this question. The question asks whether the pixel is some shade of red on all acquisitions. It was recommended that the question be expressed in terms of the green number for the pixel rather than in terms of color on the imagery. This should make the question more objective.

Recommendations were made for improving the clarity of the procedure and reducing clerical errors. In particular, the use of the time period A acquisitions in the small-grains/nonsmall-grains decision logic was not clear in the original procedure. Figure 3-2 shows the logic after it was revised to make use of the time period A acquisitions clearer.

A number of review steps and internal consistency checks were incorporated into the label recording forms. This should help to eliminate clerical errors from the labeling process.

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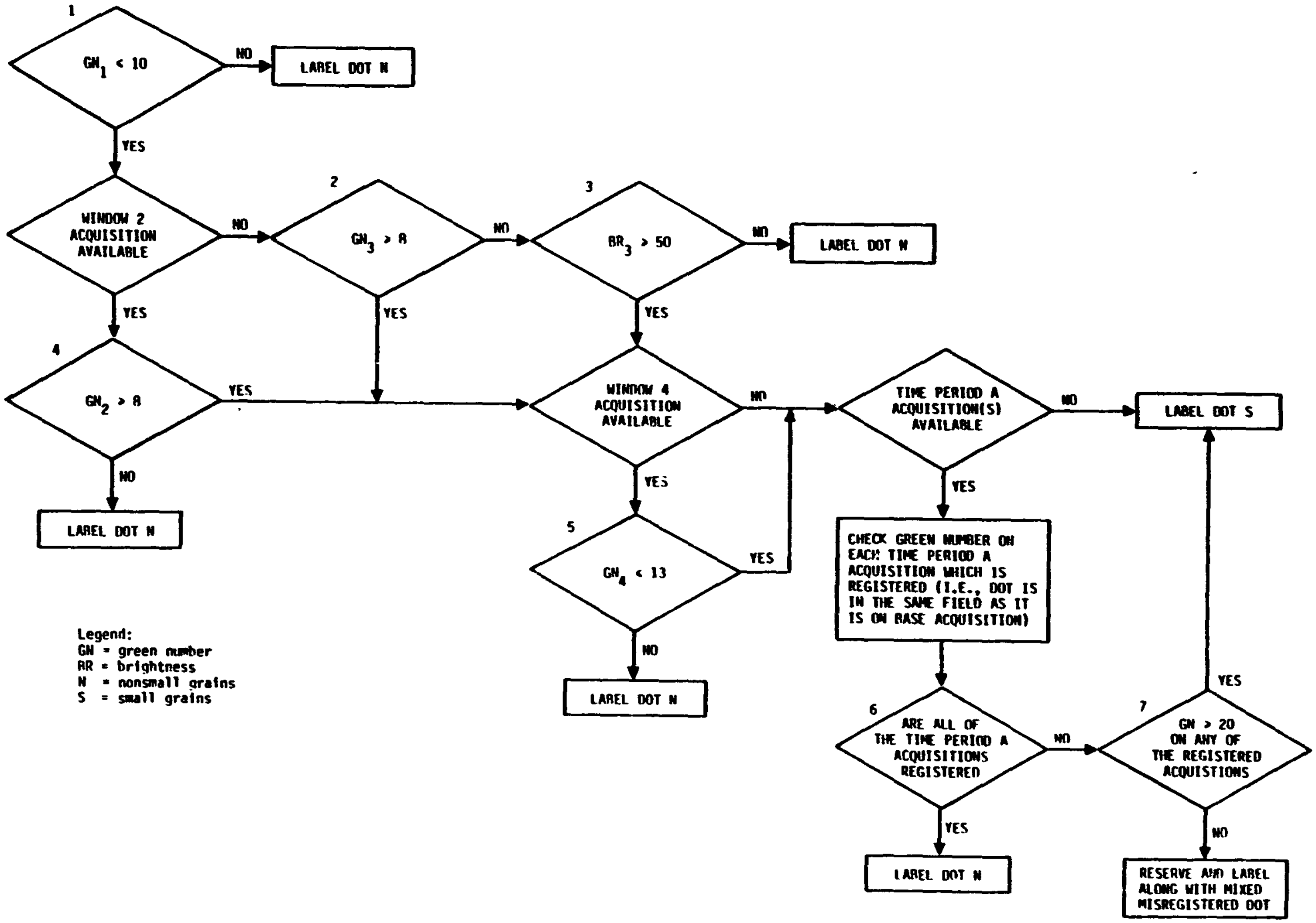

Figure 3-2.- Labeling logic for small grains/nonsmall grains.

4. CONCLUSION

The results from the Shakedown Test indicated that there were no major problems with the Reformatted Labeling Procedure as it was applied to the segments involved. The labeling accuracies were comparable with the accuracies for the Integrated Labeling Procedure. Though this performance needs to be verified through more extensive testing, the reformatted procedure does represent a substantial automation of the labeling process. With the recommended changes to the procedure, the Reformatted Labeling Procedure should be ready for testing on 1979 data.

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APPENDIX A

DEVELOPMENT OF AN ENHANCED BASELINE SPRING SMALL GRAINS PROCEDURE

A SUBSIDIARY OF
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Company, Inc.

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December 20, 1979
Ref: 644-1472
Job Order 74-413
NAS9-15800

Mr. R. M. Bizzell, SF4
National Aeronautics and Space Administration
Johnson Space Center
Houston, Texas 77058

Dear Mr. Bizzell:

Subject: Development of Enhanced Baseline Spring Small Grains Procedure
AD 63-2137-4413-01

The attached document describes the development of the procedure which was produced under action document 63-2137-4413-01. The final revision of this procedure is included as the appendix.

Copies of the preliminary draft were delivered to the task monitor on November 19, 1979. Copies of the first revision, which incorporated reviewers' comments, were delivered to the NASA analysts on December 3, 1979, before the start of the shakedown test. Additional changes for clarification have been included in this final revision.

All work on this task has been completed.

Concurrence:

B L Carroll
for J. G. Baron, Project Manager
TY SF4 Project Office

Sincerely,

W. F. Palmer
W. F. Palmer

Approval:

Luis M Flores
L. M. Flores, Supervisor
Design Integration Section

Attachment
cc: JSC/L. F. Childs, SF2 (w/o attach.)
J. L. Dragg, SF4
G. Gutschewski, SF3
R. O. Hill, SF4
A. G. Houston, SF4
L. C. Wade, SF4
LEC/B. L. Carroll
J. J. Vaccaro (w/o attachment)
Job Order File

DEVELOPMENT OF THE
REFORMATTED SPRING SMALL GRAINS LABELING PROCEDURE

Objective

The objective of this effort was to develop a procedure for labeling small grains and barley in the northern U.S. Great Plains segments by converting the U.S. spring small grains and barley separation procedure used during the Transition Project to a format similar to the corn/soybeans decision logic (Ref.). The techniques that were used in the Transition Project were to be enhanced whenever possible.

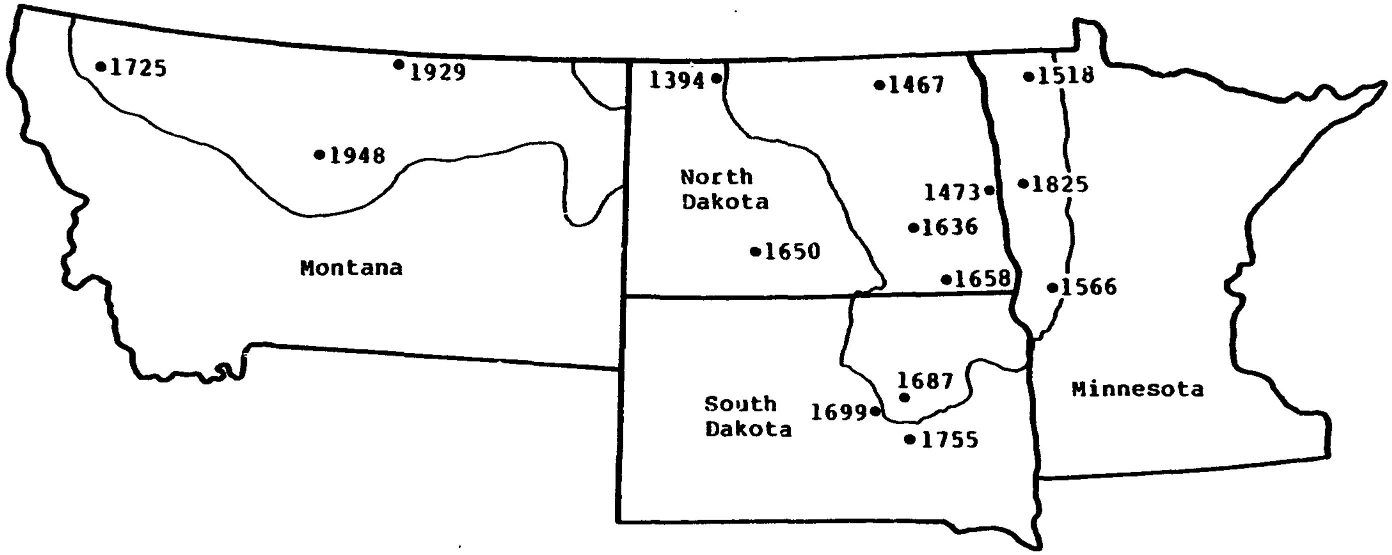
Approach

Following a comprehensive review of the Transition Project labeling procedures, alternative methods for performing some of the steps were identified. These alternatives were designed to leave fewer subjective analyst decisions in the labeling process.

The new techniques were tested using segments from the developmental data set. Necessary modifications and revisions were made before incorporating them into the overall labeling procedure.

Developmental Data Set

The labeling procedure is based primarily on analysis/ observations of the segments shown in figure 1 which comprised



North Dakota	1394 1467 1636 1473 1650 1658	1978 Blind site 1978 Blind site 1978 Blind site 1978 Blind site 1978 Blind site 1978 Blind site
Minnesota	1518 1825 1566	1978 Blind site 1977 and 1978 Blind site 1978 Blind site
South Dakota	1687 1755 1699	Intensive test site 1978 Blind site 1977 Blind site
Montana	1725 1948 1929	1977 and 1978 Blind site 1977 and 1978 Blind site 1977 Blind site

Figure 1.- Developmental data set.

the developmental data set. Shaded areas on the map represent the major barley producing regions of each state.

Criteria for selection of the segments were based upon having a sufficient number of acquisitions to adequately describe the growth cycle of spring small grains and having a reasonably large proportion of spring small grains, particularly barley.

In South Dakota and Montana, an Intensive Test Site and two phase two blind sites were used in order to obtain segments which were suitable for labeling procedure development.

Discussion of the Procedure

There are essentially three major divisions within the labeling procedure (appendix A1). These are 1) the separation of dots into either cropland or non-cropland, 2) the separation of cropland dots into spring small grains or non-spring small grains, and 3) the separation of spring small grains dots into barley or other spring small grains.

For the cropland/non-cropland separation, the procedure relies on a slightly modified portion of the Decision Logic for Major Land-Use Categories which was developed as part of the corn/soybeans procedure.

TABLE 1.- EXPECTED CHARACTERISTICS OF ACQUISITIONS AS A FUNCTION OF WINDOW

Window	Description of spring small grains	Product 1 appearance of spring small grains
1	Plowing/planting for spring small grains All spring small grains appear to be bare soil Spring wheat Robertson stage 0.8 - 2.4	Light to dark green, light to dark gray, black
2	All spring small grains appear to be green vegetation. (Most of the summer crops appear to be bare soil.) Spring wheat Robertson stage 3.8 - 4.5	Red, pink, brown orange
3	Spring barley is turned/harvested and spring wheat, oats, and flax appear to be green vegetation	Deep red, reddish brown, brown, orange, pink, yellow, gold, olive, white, gray, green
4	Spring wheat Robertson stage 4.7 to beginning of harvest All spring small grains appear to be turned/harvested.	Light to dark green, light to dark gray, white, yellow, gold, olive, black

window should allow accurate separation of spring small grains from non-spring small grains. In an attempt to provide a more objective description of appearance, green numbers and brightness were used in lieu of color descriptions for this procedure.

Observation of the behavior of the green number/brightness of spring small grains on segments from the developmental data set was used to establish the green number/brightness criteria for spring small grains as a function of acquisition/window. These cutoffs were utilized in the decision logic for spring small grains.

For the separation of barley and other spring small grains, much of the transition project labeling procedure was retained. However, there are several important modifications including the following:

1) The separation acquisition is selected using an objective procedure. This is the window 3 acquisition.

2) The decision boundary on the green number versus brightness scatter plot is a straight line with fixed slope.

3) The concept of dot drift is introduced to assist in determining the location of the decision boundary. Dot drift is the direction of movement in the green number-brightness plane from the window 2 acquisition to the window 3 acquisition.

Minimum Acquisition/Window Requirements

The definition of a minimum data set for processing segments with this labeling procedure reflects extensive LACIE experience in addition to observations of the segments from the developmental data set.

A window 1 acquisition was known to be a requirement in mixed wheat areas to provide separation between winter and spring small grains. This requirement was extended to all of the areas of interest because of its additional value for separating natural vegetation.

An acquisition in window 2 or window 3 is required to provide a date when spring small grains are growing. Since the barley separation technique relies on observing barley turning/harvested while the other spring small grains are pre-turning, a window 3 acquisition is required to execute that portion of the procedure.

An acquisition in window 4 is essential in areas such as South Dakota and Minnesota to avoid confusion between summer crops such as corn and spring small grains.

APPENDIX A1

REFORMATTED SPRING SMALL GRAINS LABELING PROCEDURE

The reformatted spring small grains labeling procedure is designed to be used for assigning labels to a pre-determined/selected number of dots. Spectral data or statistics from these dot labels may be used as input to a machine classification/clustering algorithm.

The general flow of the steps involved in the procedure is detailed in the diagram in figure 1. Following acquisition selection (step 1), the combination of acquisitions/windows available are considered to determine the type of labeling, if any, that can be performed using the procedure.

If the available acquisitions/windows are sufficient for barley separation, the entire procedure can be executed. If an acquisition from window 3 is not available, only the spring small grains portion (steps 4 through 7) of the procedure can be used.

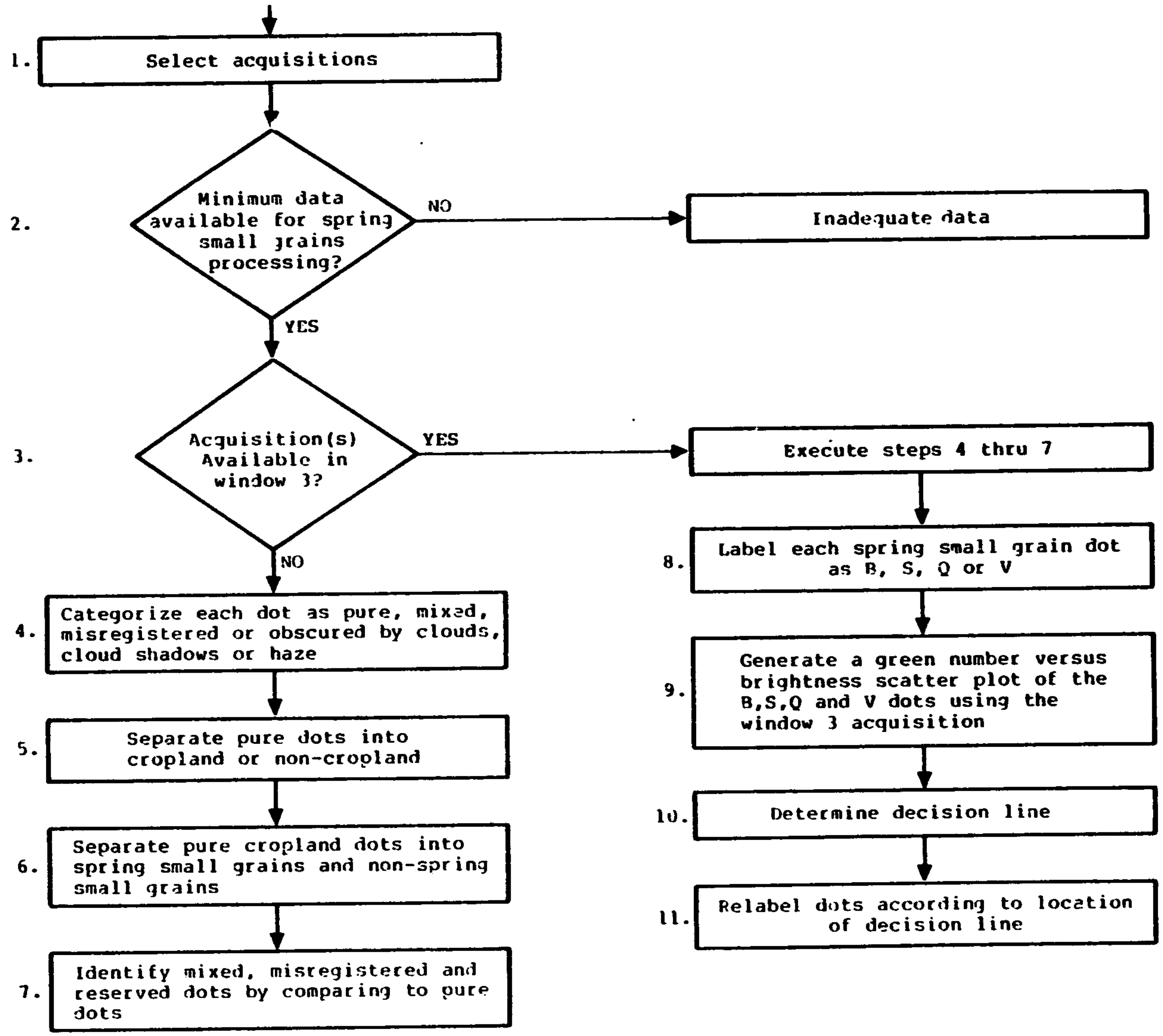


Figure 1.- Flow Diagram of Reformatted Spring Small Grains Labeling procedure.

1. Select Acquisitions

Using the historical crop calendars for spring wheat and spring barley, determine the opening and closing dates for each of the following four windows:

Window	Open	Close
1	Spring Wheat 50% Planted-5 days	Spring Wheat 50% Planted +18 days
2	Spring Wheat 50% Headed -10 days	Spring Wheat 50% Headed + 10 days
3	Spring Barley 50% Turning to Ripe - 6 days	Spring Barley 50% Turning to Ripe + 6 days
4	Spring Wheat 50% Harvested + 15 days	Spring Wheat 50% Harvested + 30 days

Sort all available acquisitions covering the growing season for spring small grains (beginning of planting to one month after the completion of harvest) into these windows.

Select one acquisition per window. If more than one acquisition falls within a window, select the one closest to the middle of the window. If two acquisitions are equidistant from the middle, select the latest one.

If a window does not contain an acquisition but one falls within three days of the opening or closing of the window, refer to the adjusted crop calendar, meteorological summaries and location of the segment within the crop reporting district to determine whether or not the acquisition should be included in the window.

For example, if an acquisition falls three days after the close of a window and the adjusted crop calendar/meteorological summaries indicate that in the area of the segment spring small grains are late developing or the segment is in the northernmost part of a large crop reporting district, include the acquisition in the window.

In a similar manner, acquisitions falling within three days of the start or end of a window may be excluded from the window. Suppose an acquisition is collected two days before the close of window 1 and the adjusted crop calendar/meteorological summaries indicate that spring small grains development is considerably ahead of normal in the area of the segment. The analyst should select another acquisition or if there are no other candidates, conclude that no window 1 acquisition exists.

If available, the window 3 acquisition is to be used as the base acquisition for labeling. If there is no window 3 acquisition, use the window 2 acquisition. If neither of these windows contain an acquisition, the segment is unprocessable.

Screen the base acquisition for data quality. If the acquisition contains excessive (>40%) clouds, cloud shadows, haze or snow or other problems such as data dropouts, banding, etc., revert to the second choice for the base acquisition. If data quality on the second choice is unacceptable, revert to the third choice. Continue until a base acquisition with

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with acceptable data quality has been selected or the list of candidates has been exhausted.

Screen each of the other selected acquisitions for data quality using the same criteria plus registration to the base acquisition to ± one pixel. In each case, if the acquisition fails the data quality test, revert to the second choice, third choice, etc.until an acceptable acquisition has been found or the candidates have been exhausted.

The decision logic for spring small grains requires the use of acquisition(s) in addition to those previously selected if available. Acquisitions collected within the time period beginning with the close of window 3 plus 40% of the distance between the close of window 3 and the opening of window 4 and ending with the opening of window 4 are described as being in time period A. This period is graphically described in Figure 2.

The acquisitions selected and the time period A acquisitions should be recorded on the acquisition form as shown in Figure 3. The format of year, day should be used. 8124 indicates the 124th day of 1978.

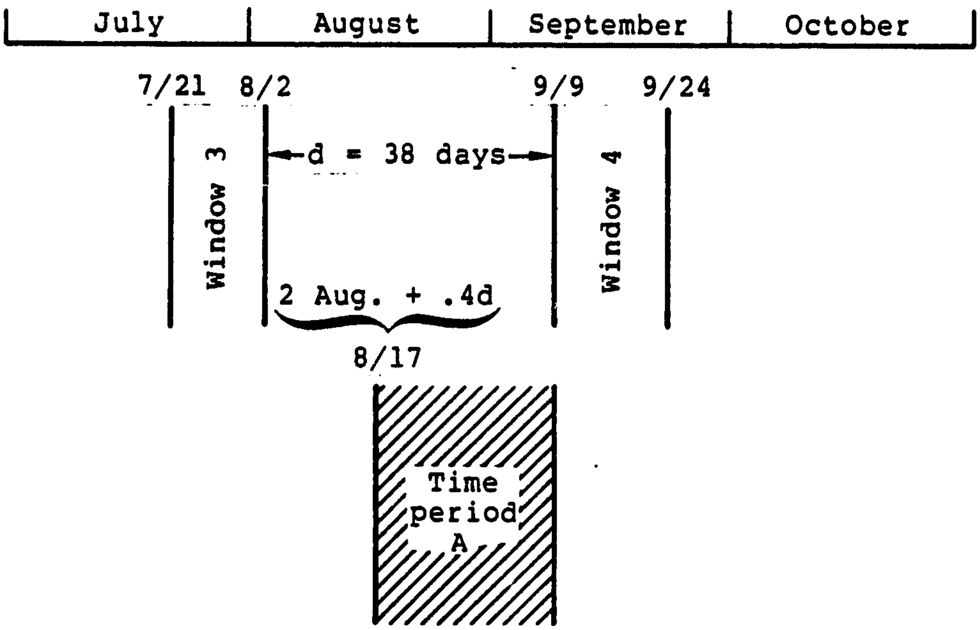

Figure 2.- Graphical description of the determination of time period A.

	ACQUISITIONS SELECTED FROM WINDOWS					ACQUISITIONS COLLECTED DURING TIME PERIOD A			
	SEGMENT NUMBER (1–4)	WINDOW 1 (6–9)	WINDOW 2 (11–14)	WINDOW 3 (16–19)	WINDOW 4 (21–24)	ACQ. 1 (26–29)	ACQ. 2 (31–34)	ACQ. 3 (36–39)	40–42
1	1825	8124	8187	8206	8251	8223	8224	8232	
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									

Figure 3.- Acquisition Recording Form.

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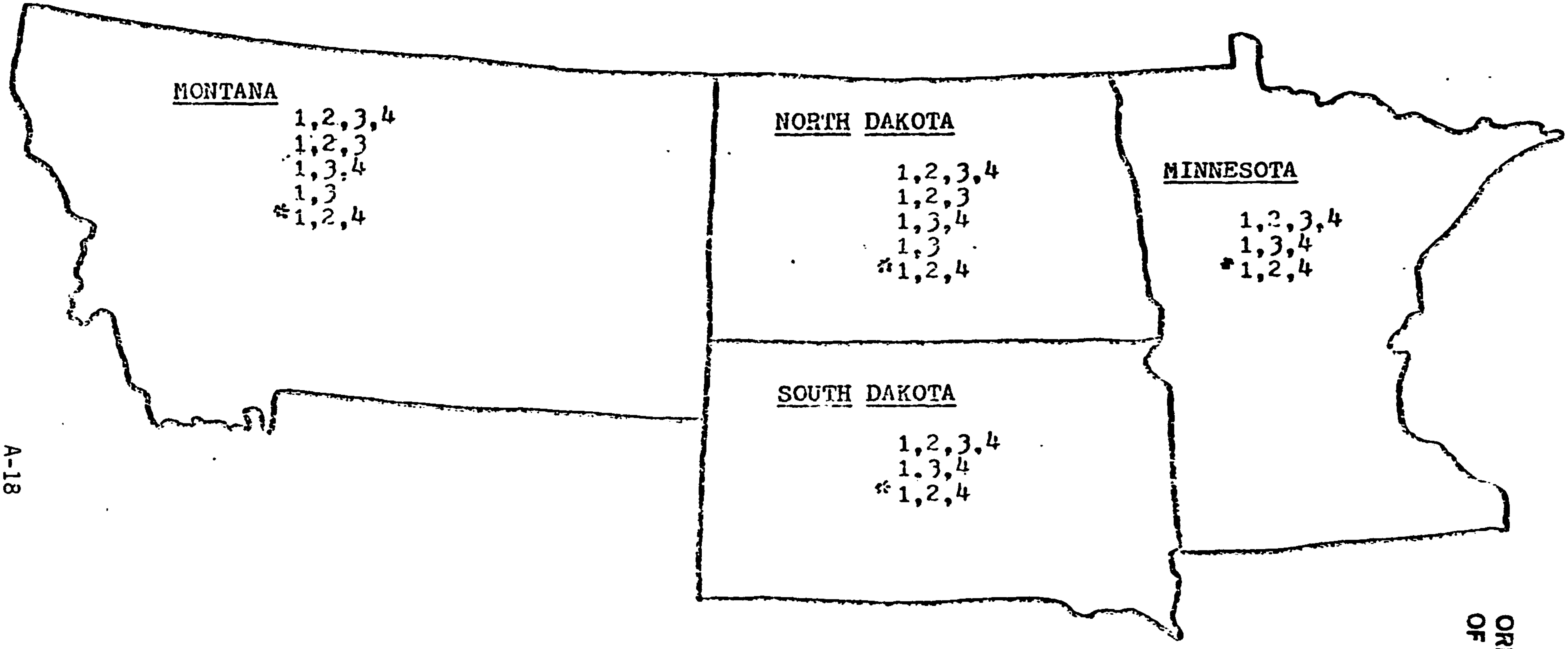
2. Check for Minimum Data

Refer to the map in Figure 4 to determine if the combination of windows/acquisitions available meet the minimum requirements for processing. If the combination available is not listed as a processable data set, there is inadequate data for spring small grains labeling using this procedure.

3. Check for minimum data for barley separation

The barley separation procedure is based on the assumption that barley ripens and is harvested before spring wheat, oats and flax. The acquisition selection process for selecting the window 3 acquisition is intended to isolate the acquisition where this difference is maximized. Therefore, an acquisition in window 3 is required for this procedure.



* Inadequate for barley separation. Spring small grains labeling only.

Figure 4. Processable Data Sets.

4. Categorize each dot as pure, mixed, misregistered or obscured by clouds, cloud shadows or haze.

The following definitions are used in this step:

Pure dot - A dot which is completely within the same field/area on each of the selected acquisitions.

Mixed dot - A dot which is only partially within a field/area on the base acquisition.

Misregistered dot - A dot which is completely within a field/area on the base acquisition but shifts either partially or completely out of the field/area on one or more of the selected acquisitions.

Using the base acquisition, locate the field/area associated with the dot of interest. If the pixel is not the same color as the field/area it is associated with, the dot should be considered mixed. For example, in Figure 5, the dot of interest is associated with field A, a white field. If the pixel at this location appears pink rather than approximately the same color as the other pixels in field A, the dot should be considered mixed.

If the dot is not mixed, the same test should be applied to the pixel at this location on each of the remaining selected acquisitions. If the dot shifts partially or completely to another field, it should be considered misregistered. If the dot remains completely within the same field/area on all of the selected acquisitions, it should be considered pure.

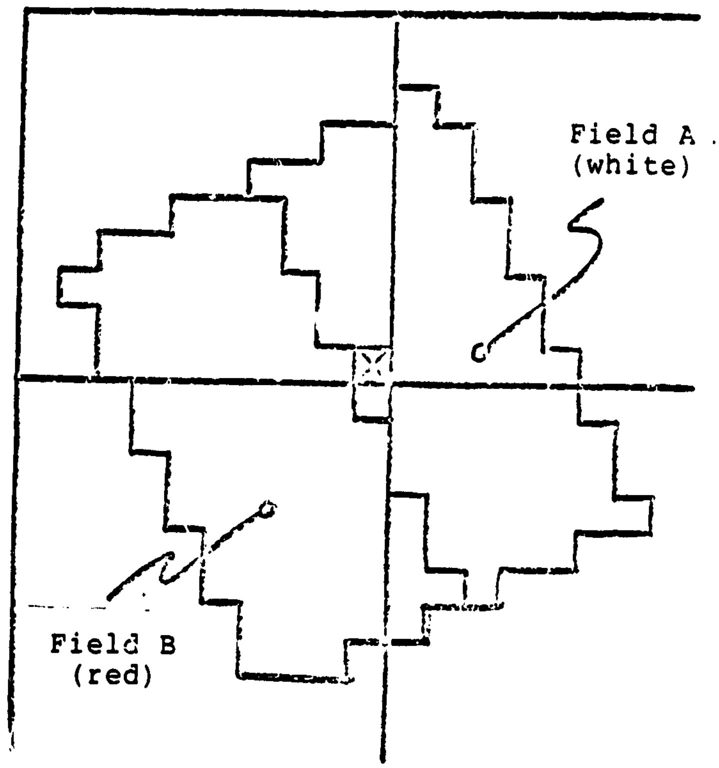


Figure 5.- Relationship between a dot and a field.

The determination of pure, mixed or misregistered should be recorded on the labeling form as shown in Figure 6. (P-pure, M-mixed, R-misregistered) If a dot is found to be mixed, record the coordinates of an interior pixel from the field with which the dot is associated.

If a dot is obscured by clouds, cloud shadows or haze on any of the selected acquisitions, leave the pure, mixed, misregistered column (column 13) blank and record a U in the final label column (column 47).

	Dot no.	Line	Pixel	P M or R	1a	1b	1c	2	3 or 4	GN1	GN2	GN3	BR3	GN4	Green numbers from time period A acquisitions: 1	2	3	Label: BR or S	BS G or V	Final	Coordinates of interior pixel from field/area associated with mixed dot: Line	Pixel	Segment number
1	1	10	10	P																			1825
2	2	10	20	M																	9	18	
3	3	10	30	R																			
4	4	10	40	P																			
5	5	10	50	P																			
6	6	10	60	P																			
7	7	10	70	R																			
8	8	10	80	R																			
9	9	10	90	M																	11	93	
10	10	10	100	M																	9	101	
11	11	10	110	P																			
12	12	10	120	P																			
13	13	10	130	P																			
14	14	10	140	R																			
15	15	10	150																	U			
16	16	10	160	R																			
17	17	10	170	R																			
18	18	10	180	P																			
19	19	10	190	P																			

Figure 6.- Recording of pure, mixed, and misregistered dots.

5. Separate pure dots into cropland or non-cropland Using the acquisitions selected from windows,

execute the decision logic shown in Figure 7 for each pure dot recording your responses in columns 15 thru 19 of the labeling form as shown in Figure 8 (Y-yes, N-no).

If the decision logic indicates that the dot is non-cropland, a D should be entered in the first label column (column 45). If the dot is cropland, column 45 should be left blank at this point.

The decision logic in Figure 7 is a portion of the Decision Logic for Major Land-Use Categories (Figure 9) which has been slightly modified for this procedure. The complete Decision Logic for Major Land-Use Categories can be found in Appendix B of the Detailed Analysis Procedures for Transition Project (FY79).

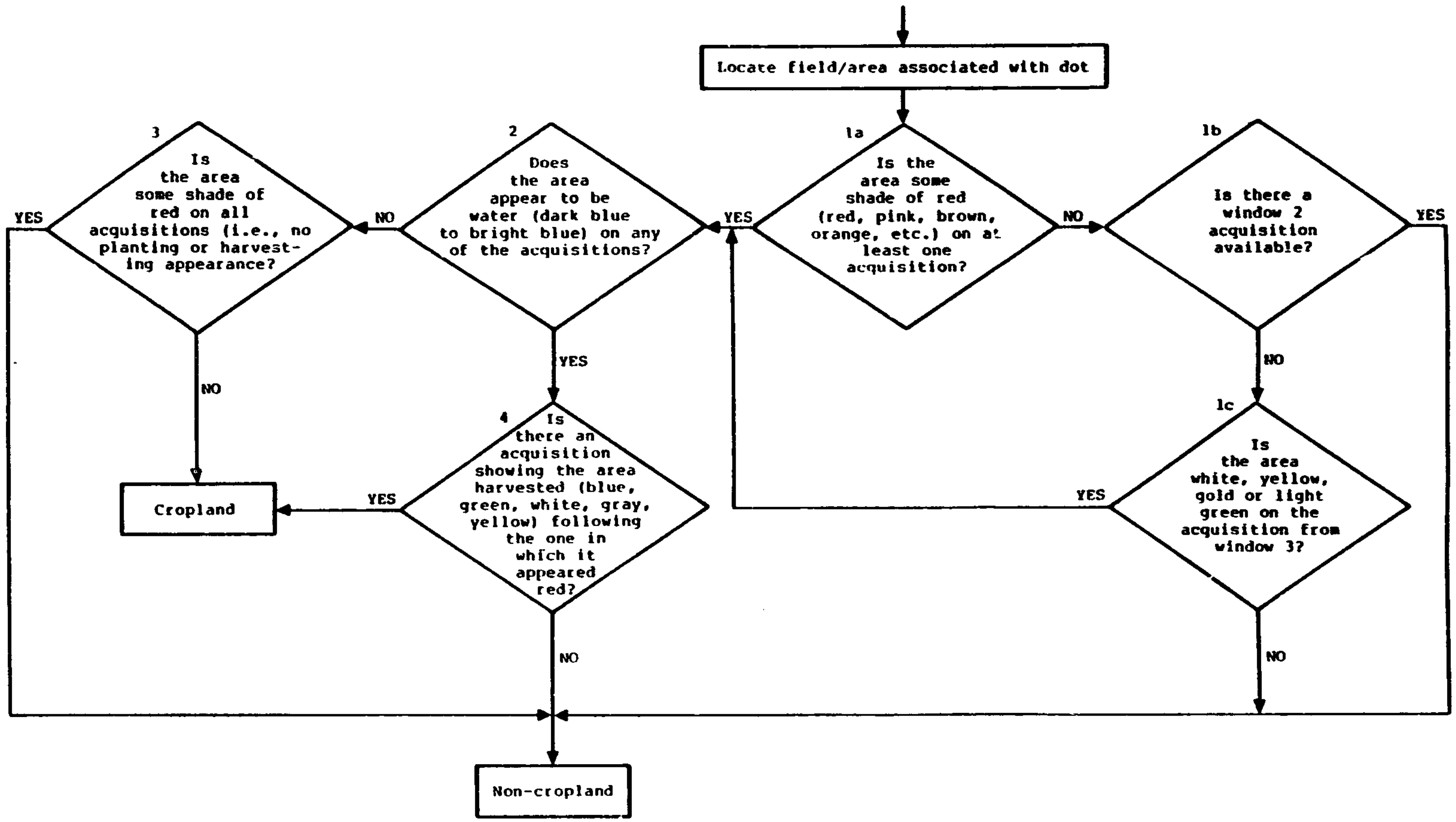


Figure 7.- Decision Logic for Cropland - Non-cropland.

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	Dot no.	Line	Pixel	P M or R	Responses to questions from decision logic for major landuse categories: 1a	1b	1c	2	3 or 4	GN_1	GN_2	GN_3	BR_3	GN_4	Green numbers from time period A acquisitions: 1	2	3	Label: D R or S	B S Q or V	Final	Coordinates of interior pixel from field/area associated with mixed dot: Line	Pixel	Segment number
1	1	10	10	P	Y			Y	Y														1825
2	2	10	20	M																	8	18	
3	3	10	30	R																			
4	4	10	40	P	N	Y												D					
5	5	10	50	P	Y			N	M														
6	6	10	60	P	Y			Y	Y														
7	7	10	70	R																			
8	8	10	80	R																			
9	9	10	90	M																	11	93	
10	10	10	100	M																	9	101	
11	11	10	110	P	Y			N	Y									D					
12	12	10	120	P	Y			N	Y									D					
13	13	10	130	P	Y			N	M														
14	14	10	140	R																			
15	15	10	150																	U			
16	16	10	160	R																			
17	17	10	170	R																			
18	18	10	180	P	Y			N	N														
19	19	10	190	P	Y			Y	Y														

Figure 8.- Recording of responses from Cropland Decision Logic.

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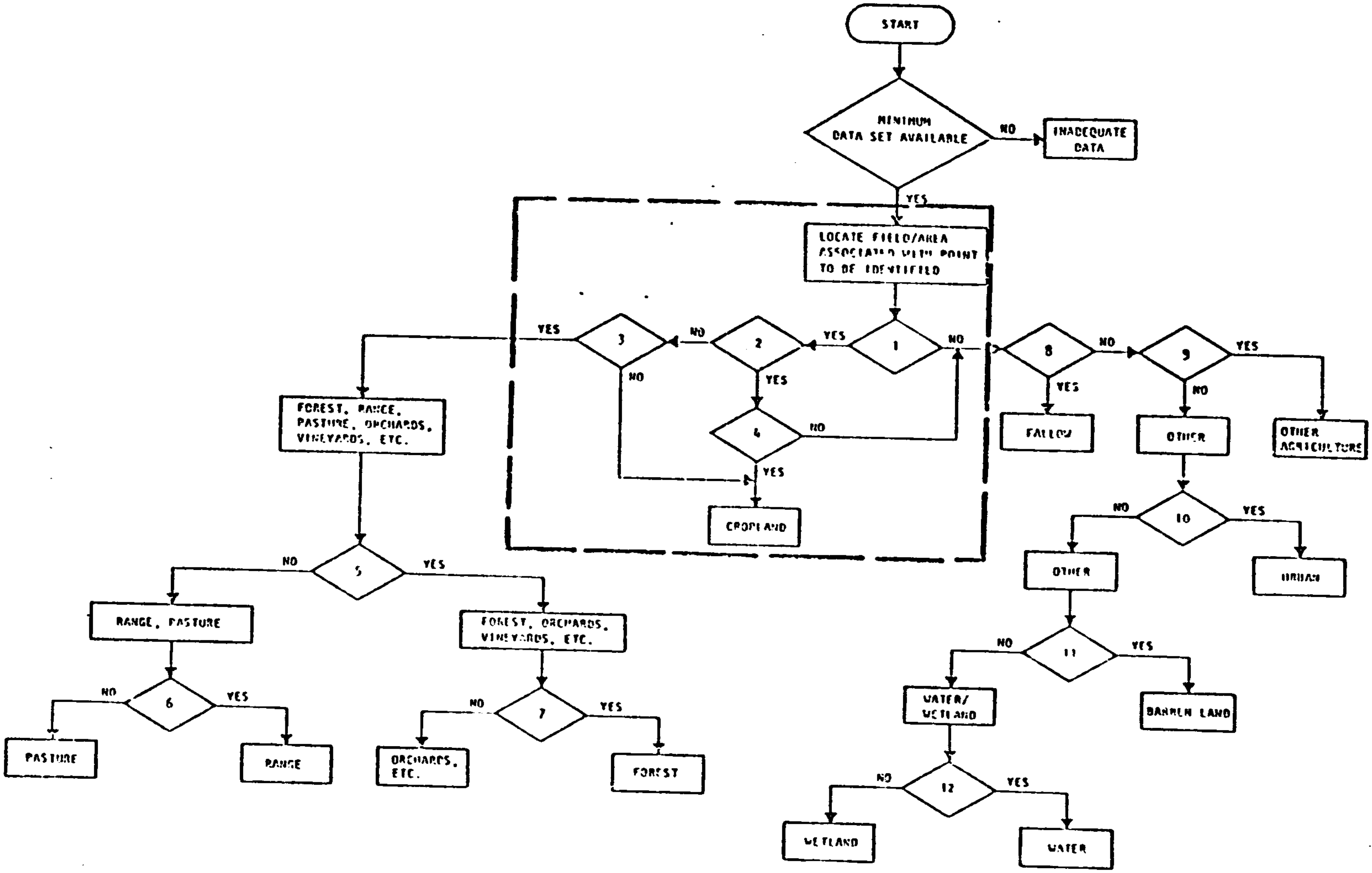

Figure 9. Diagram of decision tree for major land-use categories.

6. Separate pure cropland dots into spring small grains and non-spring small grains.

For those pure dots determined to be cropland, execute the decision logic in Figure 10.

Those pure cropland dots which meet the green number/brightness criteria for spring small grains on the acquisitions selected from windows are subjected to a final test by requiring that the green number be less than 20 on all acquisitions collected during time period A. If the green number is not usable on these acquisitions due to misregistration, the dot should be reserved for labeling along with the mixed and misregistered dots.

The green numbers/brightness values which are used in making the decisions should be recorded in columns 20 thru 43 of the labeling form as shown in Figure 11. The labels of S for spring small grains and N for non-spring small grains should be recorded in column 45.

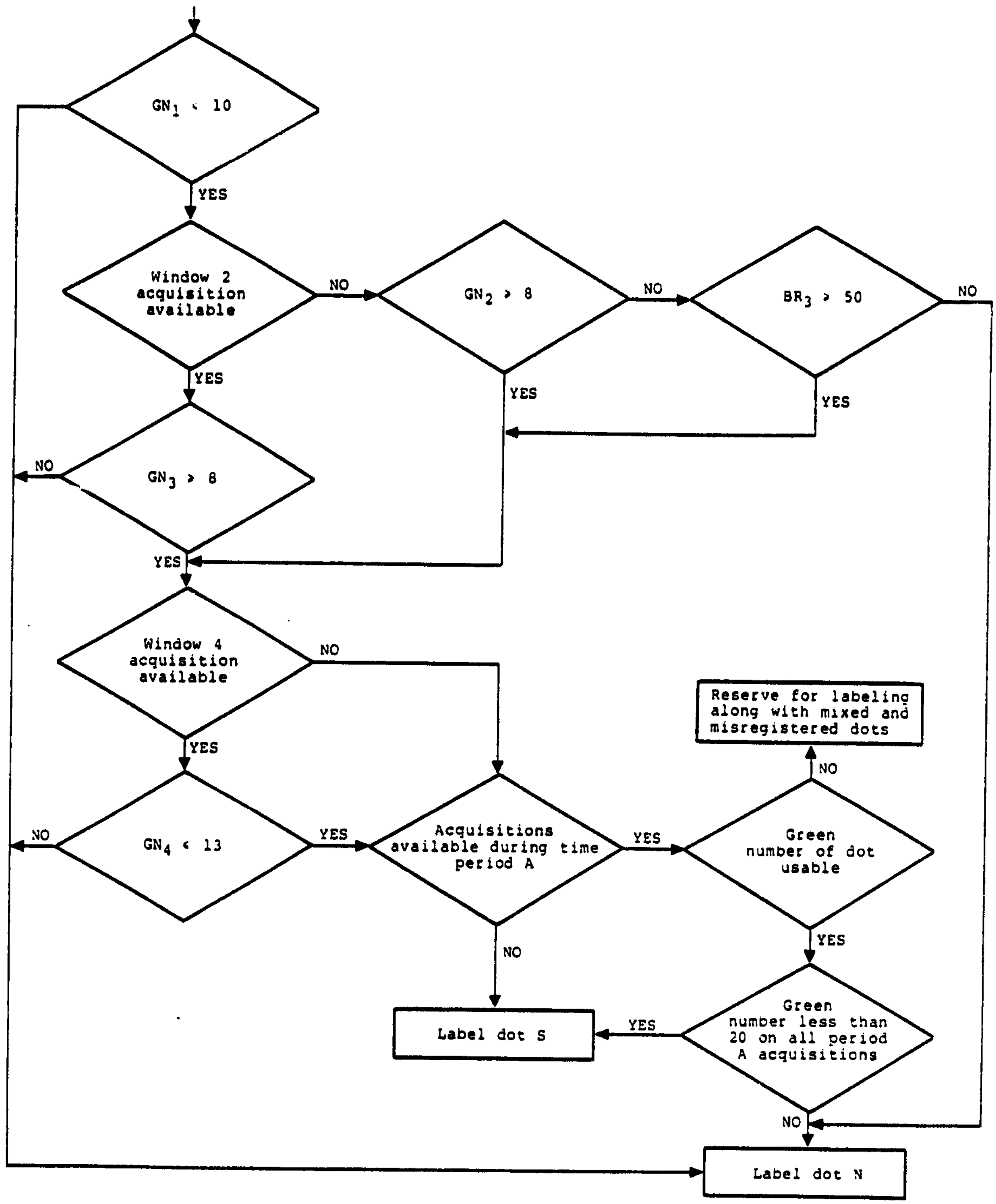

Figure 10.- Decision Logic for pure cropland dots.

	Dot no. (1–3)	Line (5–7)	Pixel (9–11)	P, M or R (13)	1a (15)	1b (16)	1c (17)	2 (18)	3 or 4 (19)	GN₁ (20–22)	GN₂ (23–25)	GN₃ (26–28)	BR₃ (29–31)	GN₄ (32–34)	Green numbers from time period A acquisitions: 1 (35–37)	2 (38–40)	3 (41–43)	Label: D N or S (45)	B S Q or V (46)	Final (47)	Coordinates of interior pixel from field/area associated with mixed dot: Line (49–51)	Pixel (53–55)	Segment number (57–60)
1	1	10	10	P	Y			Y	Y	- 1	22			5	17	17	9	S					1825
2	2	10	20	M																	8	18	
3	3	10	30	R																			
4	4	10	40	P	N	Y												D					
5	5	10	50	P	Y			N	N									N					
6	6	10	60	P	Y			Y	Y	6	14			10	25			N					
7	7	10	70	R																			
8	8	10	80	R																			
9	9	10	90	M																	11	93	
10	10	10	100	M																	9	101	
11	11	10	110	P	Y			N	Y									D					
12	12	10	120	P	Y			N	Y									D					
13	13	10	130	P	Y			N	N	7	18			12	19	22		N					
14	14	10	140	R																			
15	15	10	150																	U			
16	16	10	160	R																			
17	17	10	170	R																			
18	18	10	180	P	Y			N	N	8	28			3	16	16	10	S					
19	19	10	190	P	Y			Y	Y	0	30			8	12	11	9	S					

Figure 11.- Recording of pure cropland dots as spring small grains or non-spring small grains.

7. Label Mixed, Misregistered and Reserved Dots by comparing to Pure Dots.

Delineate and annotate enough of the fields/areas associated with dots which have been labeled D, N or S to provide a representative cross section of each class. Compare the imagery appearance (Product 1)* of each field/area associated with a mixed, misregistered or reserved dot to the annotated fields/areas and select the field/area which is most similar in appearance. Record the label of the selected field/area for the mixed, misregistered or reserved dot. Record the labels in column 45 of the labeling form as shown in Figure 12.

* For instructions on the use of Product 3, refer to the Detailed Analysis Procedures for Transition Project (FY79).

	Dot no.	Line	Pixel	P, M, or R	1a	1b	1c	2	3 or 4	GN₁	GN₂	GN₃	BR₃	GN₄	Green numbers from time period A acquisitions: 1	2	3	Label: B, N, or S	B, S, Q, or V	Final	Coordinates of interior pixel from field/area associated with mixed dot: Line	Pixel	Segment number
1	1	10	10	P	Y			Y	Y	– 1	22			5	17	17	9	S					1825
2	2	10	20	M														S			8	18	
3	3	10	30	R														D					
4	4	10	40	P	N	Y												D					
5	5	10	50	P	Y			N	N	15								N					
6	6	10	60	P	Y			Y	Y	6	14			10	25			N					
7	7	10	70	R														N					
8	8	10	80	R														S					
9	9	10	90	M														S			11	93	
10	10	10	100	M														N			9	101	
11	11	10	110	P	Y			N	Y									D					
12	12	10	120	P	Y			N	Y									D					
13	13	10	130	P	Y			N	N	7	18			12	19	22		N					
14	14	10	140	R														D					
15	15	10	150																	U			
16	16	10	160	R														S					
17	17	10	170	R														N					
18	18	10	180	P	Y			N	N	8	28			3	16	16	10	S					
19	19	10	190	P	Y			Y	Y	0	30			8	12	11	9	S					

Figure 12.- Recording of mixed, registered, and reserved dots as D, S, or N.

8. Label each spring small grain dot as B,S,Q or V.

In column 46 of the labeling form, record one of the following labels for each spring small grain dot. (The recording is illustrated in Figure 13.)

B - (barley) - spring small grains in the more advanced growth stages. (bright pink, yellow, bright gold, tan, white, light gray, light green on Product 1 from window 3)*

S - (spring wheat, oats, flax) - spring small grains in the least advanced stages. (red, brown, reddish brown on Product 1 from window 3)*

Q - spring small grains which appear to be between the groups labeled B and S. Some spring wheat/ oats fields may be at the soft dough or ripe stages as illustrated in Figure 14. They will not have a bright appearance but otherwise may be confused with barley. Dots which fall into fields such as this should be labeled Q.

V - spring small grains dots which were determined to be mixed unless they are associated with a field containing a dot labeled B or S. If they are, they should receive the same label as the pure dot.

* For instructions on the use of Product 3, refer to the Detailed Analysis Procedures for Transition Project (FY79).

	Dot no.	Line	Pixel	P M or R	1a	1b	1c	2	3 or 4	GN_1	LN_2	GN_3	BR_3	GN_4	Green numbers from time period A acquisitions: 1	2	3	Label: D NNS or S	Label: BSQ or V	Label: Final	Coordinates of interior pixel from field/area associated with mixed dot: Line	Pixel	Segment number
1	1	10	10	P	Y			Y	Y	- 1	22			5	17	17	9	S	B				1825
2	2	10	20	M														S	V		8	18	
3	3	10	30	R														D					
4	4	10	40	P	N	Y												D					
5	5	10	50	P	Y			N	M	115								N					
6	6	10	60	P						6	14			10	25			N					
7	7	10	70	R														N					
8	8	10	80															S	Q				
9	9	10	90															S	V		11	93	
10	10	10	100															N			9	101	
11	11	10	110															D					
12	12	10	120															D					
13	13	10	130							7	18			12	19	22		N					
14	14	10	140															D					
15	15	10	150																	U			
16	16	10	160															S	S				
17	17	10	170															N					
18	18	10	180							8	28			3	16	16	10	S	Q				
19	19	10	190							0	30			8	12	11	9	S	B				

Figure 13.- Recording of labels for scatter plot generation.

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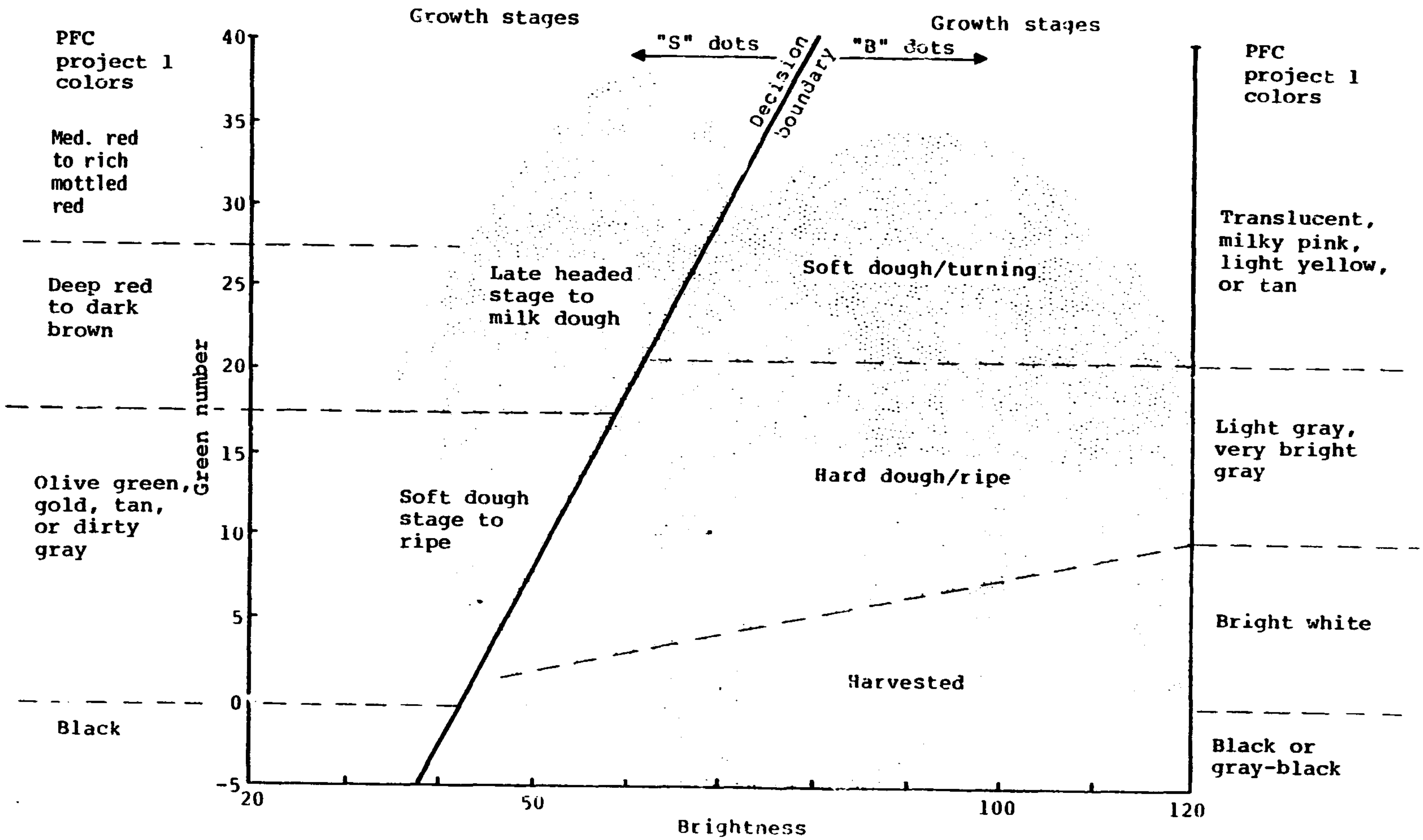

Figure 14.- General relationship between image appearance/growth stage and location on scatterplot generated from window 3 acquisition.

9. <u>Generate a green number versus brightness scatter plot of the B,S,2 and V dots using the window 3 acquisition.</u>

Transfer the labels from column 46 of the labeling form to a Process Request Form and generate a green number versus brightness scatter plot using the window 3 acquisition. If a window 2 acquisition is available, request green number versus brightness trajectory plots using the acquisitions from windows 2 and 3. (Additional acquisitions up to a total of eight may be included.)

The relationship between the location of a dot on the scatter plot and imagery color/growth stage is generally as shown in Figure 14. The barley dots will fall to the right of the decision line and be widely scattered. The other spring small grains will form a relatively tight cluster in the region noted as late headed to milk dough.

10. <u>Determine Decision Line</u>.

If there are B and S dots, construct a line on the scatter plot of the form GN = 1.1 BR + constant through the S dot where the constant is a minimum and no pure B dots fall to the left of the line (Line A). Construct a line of the form GN = 1.1 BR + constant through the B dot where the constant is a maximum and no pure S dots fall to the right of the line (Line B). (A template is provided to assist in constructing these lines.)

If the location of the dots is such that a line cannot be constructed, reexamine the image appearance of the dot(s) which prevent construction of the line. If the original label(s) were in error, change the label(s) and continue. If the original label(s) are confirmed, place the line just to the right of the rightmost S dot in the case of Line B or just to the left of the leftmost B dot in the case of Line A.

If a window 2 acquisition is available, green number versus brightness trajectory plots will be used to assist in determining the decision line. Generally in the time period from window 2 to window 3, barley dots become less green but brighter. The dot drift or direction of movement on the trajectory plot will be down and to the right. During this same period, spring wheat and oats dots become less green and less bright. The dot drift will be down and to the left.

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If a window 2 acquisition is available, transfer the dot drift from the green number versus brightness trajectory plots to the scatter plot for each dot between lines A and B. Place the decision line parallel to and between lines A and B such that dots having different drift characteristics are separated. An example of this is shown in Figure 15.

If a window 2 acquisition is not available, place the decision line between and parallel to lines A and B such that 1) No dots to the right of the line appear to group with the S dots and 2) Dots to the right of the line are widely scattered as opposed to the closer knit group to the left of the line. This technique is illustrated in Figure 16.

If no dots were labeled B, construct Line A. If window 2 acquisition is available, check the dot drift of dots which fall to the right of the line to determine if they behave more like barley (increase in brightness with decrease in green number) or spring wheat(decrease in brightness with decrease in green number). Use the dot drift, scatter as opposed to clustering and Figure 14 to determine if Line A should be the decision line or it should be to the right of and parallel to Line A.

If no dots were labeled S, construct Line B. Use the same technique described above to determine if Line B should be the decision line or whether it should be placed to the left of and parallel to Line B.

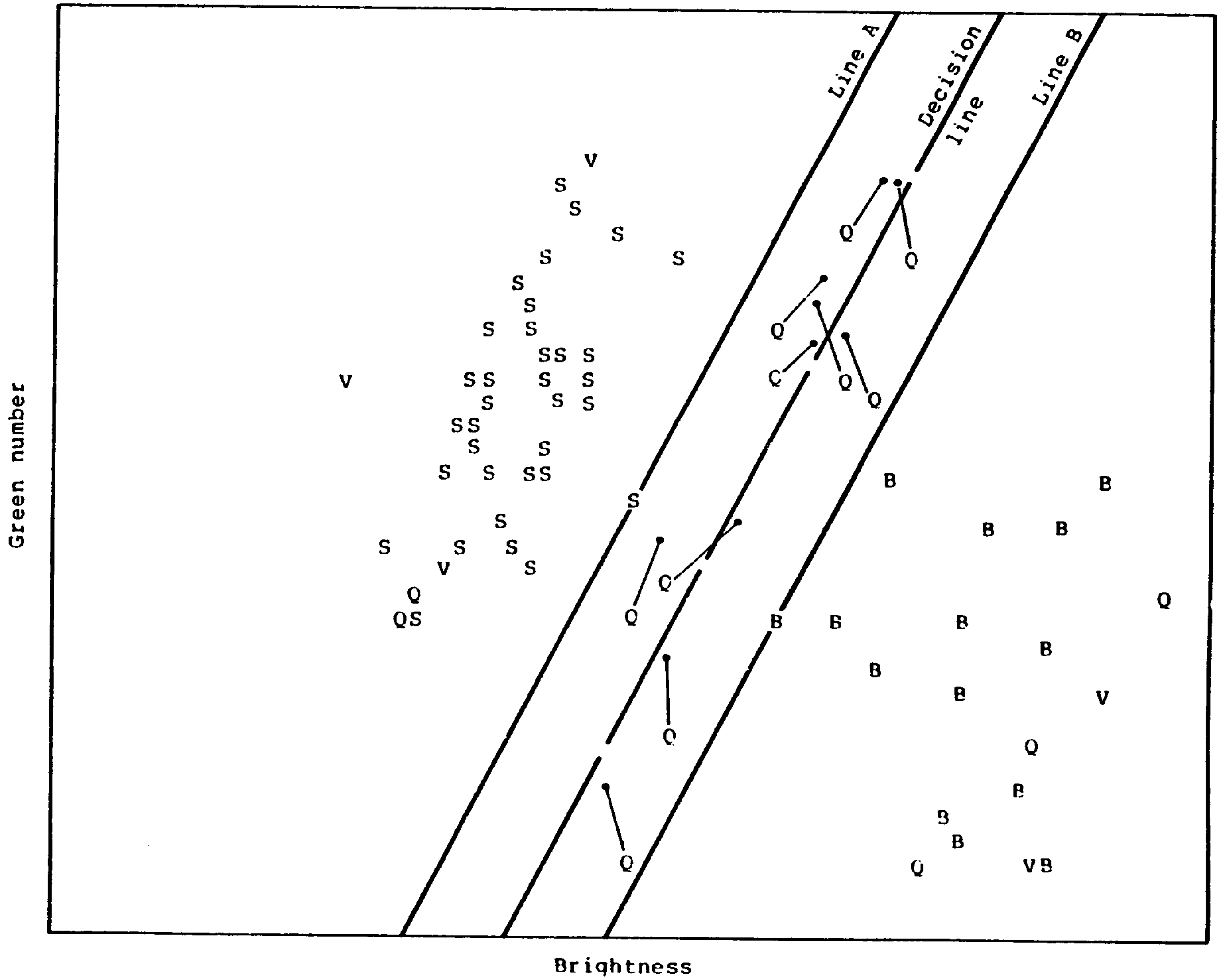

Figure 15.- Illustration of the use of dot drift characteristics to determine decision line.

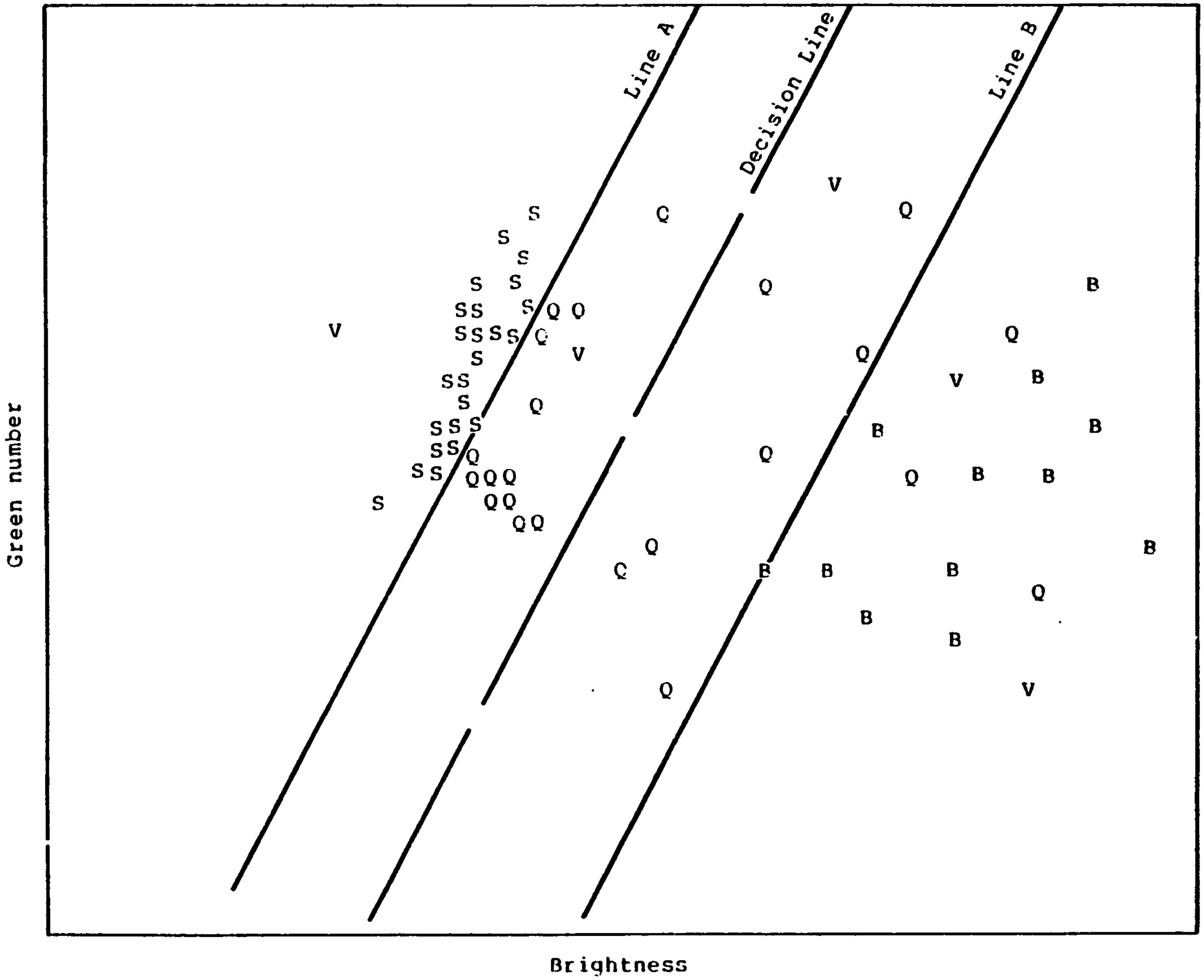

Figure 16.- Illustration of the determination of decision line without a window 2 acquisition.

11. Relabel Dots according to location of decision line.

All Q and V dots which fall to the right of the decision line should be labeled B in the final label column.

All Q and V dots which fall to the left of the decision line should be labeled S in the final label column.

The original interpretation should be confirmed for any pure B dots which fall to the left of the line and any pure S dots which fall to the right of the line.

Final labels should be recorded on the labeling form in column 47 as shown in Figure 17.

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	Dot no.	Line	Pixel	P, M or R	Responses to questions from decision logic for major landuse categories: 1a	1b	1c	2	3 or 4	GN_1	GN_2	GN_3	BR_3	GN_4	Green numbers from time period A acquisitions: 1	2	3	Label: D, M or S	B, S, Q or V	Final	Coordinates of interior pixel from field/area associated with mixed dot: Line	Pixel	Segment number
1	1	10	10	P	Y			Y	Y	- 1	22			5	17	17	9	S	B	B			1825
2	2	10	20	M														S	V	S	8	18	
3	3	10	30	R														D					
4	4	10	40	P	N	Y												D					
5	5	10	50	P	Y			N	N	15								N					
6	6	10	60	P	Y			Y	Y	6	14			10	25			N					
7	7	10	70	R														N					
8	8	10	80	R														S	Q	B	11	93	
9	9	10	90	M														S	V	B	9	101	
10	10	10	100	M														N					
11	11	10	110	P	Y			N	Y									D					
12	12	10	120	P	Y			N	Y									D					
13	13	10	130	P	Y			N	N	7	18			12	19	22		N					
14	14	10	140	R														D					
15	15	10	150																	U			
16	16	10	160	R														S	S	S			
17	17	10	170	R														N					
18	18	10	180	P	Y			N	N	8	28			3	16	16	10	S	Q	S			
19	19	10	190	P	Y			Y	Y	0	30			8	12	11	9	S	B	B			

Figure 17.- Recording of final labels.

ADDENDUM 2

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AgRISTARS

FC-L1-04219
JSC-17806

A Joint Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing

Foreign Commodity Production Forecasting

December 1981

EVALUATION OF THE PROCEDURE 1A COMPONENT OF THE 1980 U.S./CANADA WHEAT AND BARLEY EXPLORATORY EXPERIMENT

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15. Supplementary Notes

The Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing is a joint program of the U.S. Department of Agriculture, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration (U.S. Department of Commerce), the Agency for International Development (U.S. Department of State), and the U.S. Department of the Interior.

16. Abstract

During the FY80 U.S./Canada Wheat and Barley Exploratory Experiment, proportion estimation technology was a concern. Until this time, no techniques had provided estimates any better than those obtainable by random sampling. Several techniques which used clusters generated by a new clustering algorithm, CLASSY, were proposed as alternatives to random sampling to obtain greater precision in estimation: (1) PA/RCE used proportional allocation of dots to clusters on the basis of cluster size and a relative count cluster-level estimate; (2) PA/BE used proportional allocation of dots to clusters and a Bayesian cluster-level estimate; and (3) BSA/BE used sequential allocation of dots to clusters (in an attempt to minimize an internal mean-squared-error estimate) and a Bayesian cluster-level estimate. For the first time in foreign commodity production forecasting testing, clustering has been an effective method in making proportion estimates. It was estimated that, in order to obtain the same precision with random sampling as obtained by the proportional sampling of 50 dots with an unbiased estimator, samples of 85 or 166 would need to be taken if dot sets with AI labels (integrated procedure) or ground-truth labels, respectively were input. Another important result is that dot reallocation by analysts provided dot sets that were unbiased. It is recommended that these proportion estimation techniques be maintained, particularly the PA/BE because it provided the greatest precision.

17. Key Words (Suggested by Author(s))		18. Distribution Statement
Bayes Sequential Allocation/ Bayesian Estimator (BSA/BE) CLASSY Clusters Integrated procedure Procedure 1A	Proportion Allocation/ Bayes Estimator (PA/BE) Proportional Allocation/ Relative Count Estimator (PA/RCE) Reformatted procedure Sequential Allocation/ Bayesian Estimator	

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EVALUATION OF THE PROCEDURE 1A COMPONENT OF THE 1980 U.S./CANADA WHEAT AND BARLEY EXPLORATORY EXPERIMENT

Job Order 72-422

This report describes the 1980 Exploratory Experiments activities of the Foreign Commodity Production Forecasting project of the AgRISTARS program.

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LOCKHEED ENGINEERING AND MANAGEMENT SERVICES COMPANY, INC.

Under Contract NAS 9-15800

For

Earth Resources Applications Division

Space and Life Sciences Directorate

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

December 1981

LEMSCO-16311

PREFACE

The Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing is a multiyear program of research, development, evaluation, and application of aerospace remote sensing for agricultural resources, which began in fiscal year 1980. This program is a cooperative effort of the U.S. Department of Agriculture, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration (U.S. Department of Commerce), the Agency for International Development (U.S. Department of State), and the U.S. Department of the Interior.

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 Lockheed Engineering and Management Services Company, Inc. The tasks performed by Lockheed Engineering and Management Services Company, Inc., were accomplished under Contract NAS 9-15800.

CONTENTS

TABLES

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FIGURES

Figure | Page

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1. BACKGROUND

The Foreign Commodity Production Forecasting project of the Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) program was responsible for developing and testing procedures for using aerospace remote sensing technology to provide more objective, timely, and reliable crop production forecasts. One of the components of production estimation is segment area estimation. Since large-area acreage estimates for small grains depend upon segment-level proportion estimates, it is important that those proportion estimates be as accurate and precise as possible. Prior to the AgRISTARS program, several procedures were tested in an attempt to find an accurate and efficient method for estimating small-grain proportions. In the resultant method, Procedure 1 (P1), labels were used in the random selection of training pixels to start a clustering algorithm. Then, cluster statistics were used to produce a maximum likelihood classification of the scene into 2- or 3-class strata. Finally, stratified proportion estimates were made using a second random set of labeled dots. However, this classification component provided no better results than those which could have been produced through simple random sampling. Thus, clustering had not been an effective method.

Consequently, a new clustering algorithm was developed (refs. 1 and 2). Previously, clusters were used to define distributions in the data. The new algorithm used clusters to generate strata within which crop proportions could be estimated. One advantage of this algorithm was that, as an unsupervised routine, a first set of training dots was not needed (as in P1).

In addition, a proportion estimation technique (ref. 3) which used the clusters of this algorithm was developed. This technique involved Bayesian estimation of cluster-level proportions based on historical information concerning cluster purities. The cluster-level estimates were then weighted by their relative cluster sizes and aggregated to produce the segment-level estimate. Use of this technique was expected to provide better proportion estimates. The technique also implemented sequential sampling in an attempt to sample the segment clusters more effectively and further reduce the expected mean squared error (MSE) of the proportion estimation.

Characteristic of this new estimation technique, the Bayesian Sequential Allocation/Bayesian Estimator (BSA/BE), was the selection of dots, one at a time. The sampling technique was an attempt to minimize the MSE of the proportion estimate. Before each sampling of a dot, expected effects to MSE estimates were made for each cluster; and, on the basis of these estimates, a sample was taken from the cluster that was expected to most reduce the MSE. This manner of sampling provided an additional feature: the option of sampling with a fixed sample size or varying the sample size from segment to segment. Varying the sample size could be managed by halting the sampling when a predetermined threshold was obtained for the internal MSE estimate. Varying sample sizes in this manner was to provide uniform accuracy across segments by sampling more frequently from more "difficult" segments.

A 10-segment development test of the BSA/BE (ref. 4) showed that there was at least a 2-to-1 reduction in the MSE from that observed from P1, a reduction in proportion estimation error, and improved analyst labeling accuracy.

2. APPROACH

Flow diagrams of the BSA/BE technique and P1 are presented in figures 2-1 and 2-2, respectively. Table 2-1 shows the four steps involved in stratified areal estimation and a comparison of the BSA/BE to P1 at each level. The BSA/BE differs from P1 at three of the four steps; whereas P1 makes use of approximately proportional allocation of sample dots to Iterative Self-Organizing Clustering System (ISOCLS) clusters and a relative count estimator of cluster-level proportions, the BSA/BE technique makes use of sequential allocation of sample dots to CLASSY clusters and a Bayesian estimator of cluster-level proportions. By incorporating only step 1 of the BSA/BE into P1 (that is, by substituting CLASSY clustering for ISOCLS clustering) and proportionally allocating sample dots to clusters based on cluster sizes, a new estimation technique, the Proportional Allocation/Relative Count Estimator (PA/RCE) is defined. By additionally incorporating step 3 of the BSA/BE, the Proportional Allocation/Bayesian Estimator (PA/BE) technique is defined. Both of these techniques were included for testing in this experiment. A fourth technique, the Random Sampling/Relative Count Estimator (RS/RCE), was also included in the experiment. The RS/RCE, which randomly samples the entire scene without regard to clusters and employs a relative count estimator of segment-level proportions, was included since P1 had not proved to be significantly better than the RS/RCE. The PA/RCE was included to determine the effectiveness of CLASSY clustering. The PA/BE was included to determine the effect of the cluster-level Bayesian estimator with proportional allocation.

For each of these four techniques, the dot sets that were input had labels from one of three possible sources: the integrated labeling procedure (ref. 5), the reformatted labeling procedure (ref. 6), or ground-truth data. Combining the four techniques with the three sources of dot labels and the two sample size requirements (fixed or variable), 24 estimates were made for each segment. The effect of these three factors on the estimates was to be determined.

TABLE 2-1.- PROCEDURE 1 COMPARED TO THE BAYESIAN SEQUENTIAL ALLOCATION/BAYESIAN ESTIMATOR (BSA/BE) TECHNIQUE

Step	Procedure 1	Bayesian Sequential Allocation/ Bayesian Estimator	Proposed advantage
1. Stratification	ISOCLS Use Type 1 labeled dots to collapse clusters into two strata	CLASSY	No need to label dots to create a small number of strata for sampling; thus more efficient.
2. Allocation of dots to be labeled	Approximately proportional to size of strata (post-stratification)	Sequential to minimize mean squared error	Requires less dots for same accuracy by incorporation of 1. Prior information of the distribution of cluster purity. 2. Knowledge of previously labeled samples. More accurate labeling for selected dots.
3. Strata-level estimation	Relative count	Bayes	Reduction in mean squared error for equivalent number of dots by including prior information of distribution of cluster purity.
4. Segment-level estimation	Weighted average over strata	Weighted average over strata	None (same)

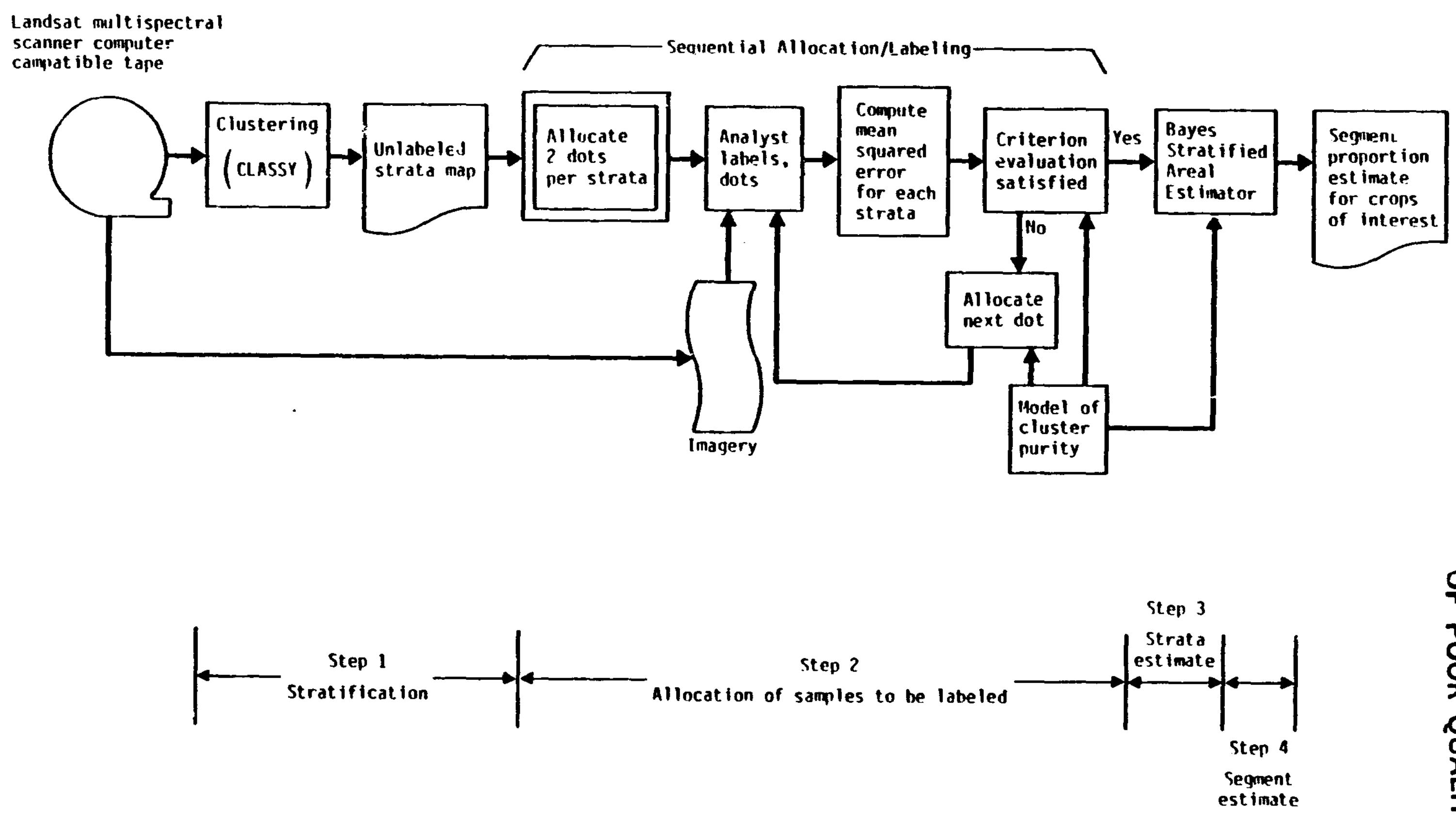

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Figure 2-1.- Segment analysis using Bayes Sequential Allocation procedure.

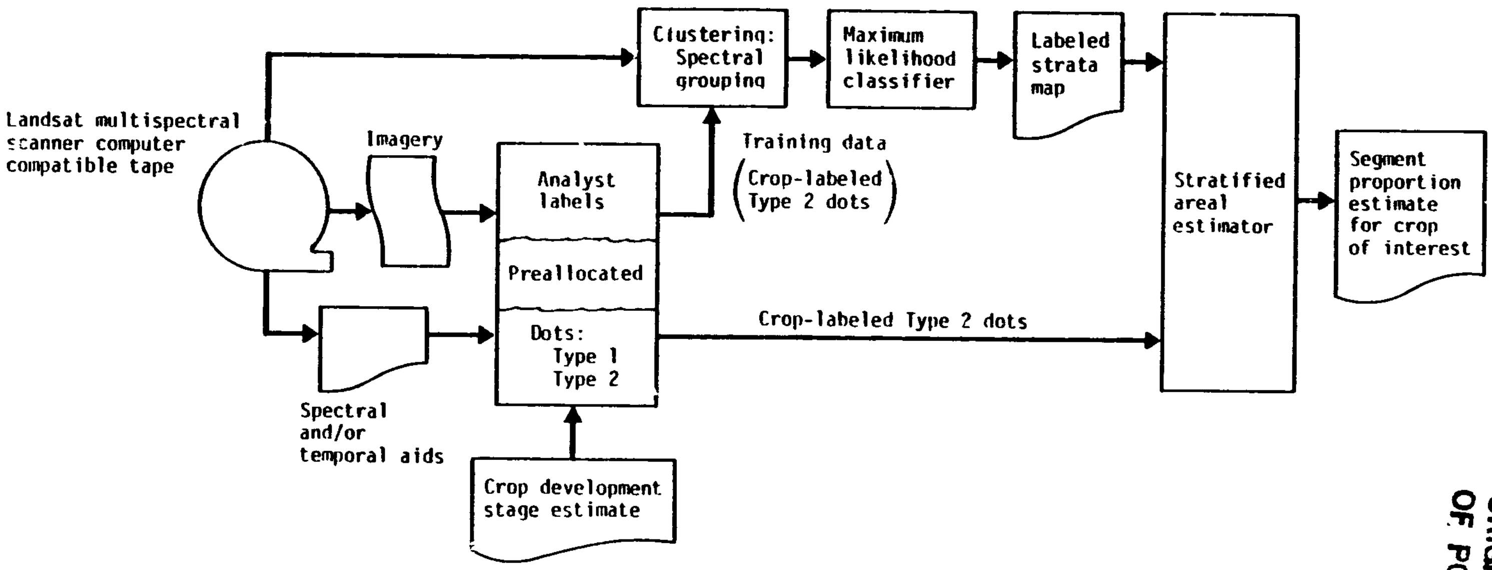

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Figure 2-2.- Segment analysis, Procedure 1.

Examination of the effects of the different techniques will, in essence, measure (a) the effect of using stratified random sampling of CLASSY clusters, which are proportional to cluster size, in estimating spring small-grain proportions rather than randomly sampling the entire scene; (b) the effect of Bayesian procedures rather than relative frequency in estimating proportions at the cluster level proportions; and (c) the effect of Bayesian Sequential Allocation rather than proportional allocation in estimating spring small-grain proportions (ref. 7).

3. METHOD

The dot sets from which samples were taken contained dots on one of the four major grids or alternates for grid dots. Enough dots were labeled from each segment so that 75 dots were allocated proportionally to the clusters; this was usually the 209 dots from the first grid plus a few (1 to 10) from grid 2. This was to insure that each cluster would have enough dots for sequential allocations. If it was determined that a grid dot was a boundary dot, an alternate dot was substituted for labeling purposes since boundary dots present special labeling problems; pure dots have been found to have higher labeling accuracies than do boundary dots, but to ignore them by using only pure grid dots in proportion estimation could bias results (refs. 8 and 9). From these dot sets, sample dots were taken for proportion estimation.

Two separate estimation processings were made for 35 spring wheat segments: for one, a fixed sample size of 50 dots was used; and for the other, varying sampling sizes from segment to segment were allowed.

To permit variable sample sizes, two dots were automatically allocated to each cluster so that MSE estimates could be obtained. Then, a threshold was set on the internal segment MSE estimate ($MSE = E(\hat{p} - p)^2 < .0020$). When this threshold was reached, sampling was halted. To achieve comparable results using other techniques, this same sample size was applied to them to obtain proportion estimates. Thus, while the sample size could vary from segment to segment, it was constant among the techniques by which estimates were made for any particular segment.

4. RESULTS

Because there were insufficient data (only nine segments were processible using the reformatted procedure) on which to base an evaluation when the reformatted labeling procedure was used, the part of the evaluation which would include that procedure will not be considered. In appendix A, however, the results are presented for the four estimation techniques for which labels were obtained from the reformatted procedure. Only those results which were obtained when the integrated procedure labels or ground-truth labels were input were considered in the evaluation.

Although estimates were made with fixed and variable sample sizes, emphasis during the evaluation was placed on the fixed sample case. Results of the variable sample case were comparable to those of the fixed sample case; these results, which include biases, MSE's, and plots of proportion estimation errors, are presented in appendix B. Further discussion of the analysis and results will concern only the fixed sample case for input dot sets with labels from the integrated procedure or ground-truth data.

Tables 4-1 and 4-2 present biases of proportion estimates, standard deviations of estimate errors, and MSE's for all 35 segments when dot labels from the integrated procedure were input. The errors are shown in figure 4-1 (ground-truth proportions for these segments are presented in appendix C).

On the basis of analyst-interpreter (AI) labels, the PA/RCE technique provided a significantly less biased estimate and produced less variable errors than did random sampling. The fact that the errors were less variable showed that the clustering algorithm had been effective.

When ground-truth labels were input, the errors produced using the PA/RCE were less variable than those of random sampling (table 4-1 and figure 4-2); but, the disturbing result was the significant bias produced by random sampling. With ground-truth labels input, random sampling was expected to provide an unbiased estimate. Ground-truth labels were input to determine the effect of

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TABLE 4-1.- ACCURACY AND PRECISION OF THE INTEGRATED PROCEDURE WITH AI LABELS AND GROUND-TRUTH LABELS

Technique	AI labels			Ground-truth labels		
	Bias	Standard deviation	MSE	Bias	Standard deviation	MSE
Random Sampling/ Relative Count Estimator	-5.7	7.7	90	-2.5	6.9	53
Proportional/ Relative Count Estimator	-4.0	6.2	53	0.0	4.0	16
Proportional Allocation/ Bayesian Estimator	-3.5	6.0	47	0.5	3.8	14
Bayesian Sequential Allocation/ Bayesian Estimator	-2.7	6.8	52	0.4	4.7	22

TABLE 4-2.- RELATIVE ACCURACY AND PRECISION OF THE INTEGRATED PROCEDURE WITH AT LABELS AND GROUND-TRUTH LABELS

Technique	AI labels			Ground-truth labels		
	$\bar{\hat{p}}$ (a)	Relative bias, % (b)	RV (c)	$\bar{\hat{p}}$ (a)	Relative bias, % (b)	RV (c)
Random Sampling/ Relative Count Estimator	23.4	-24.4	32.9	26.6	9.4	25.9
Proportional/ Relative Count Estimator	25.1	-15.9	24.7	29.1	0.0	13.7
Proportional Allocation/ Bayesian Estimator	25.6	-13.7	23.4	29.6	1.7	12.8
Bayesian Sequential Allocation/ Bayesian Estimator	26.4	-10.2	25.8	29.5	1.4	15.9

[a]Average proportion estimate = $\bar{\hat{p}}$

[b]Relative bias = $\dfrac{\bar{\hat{p}} - \bar{p}}{\bar{\hat{p}}} \times 100\%$

[c]RV = $100 \times \dfrac{\hat{\sigma}_e}{\bar{\hat{p}}}$ = relative variation

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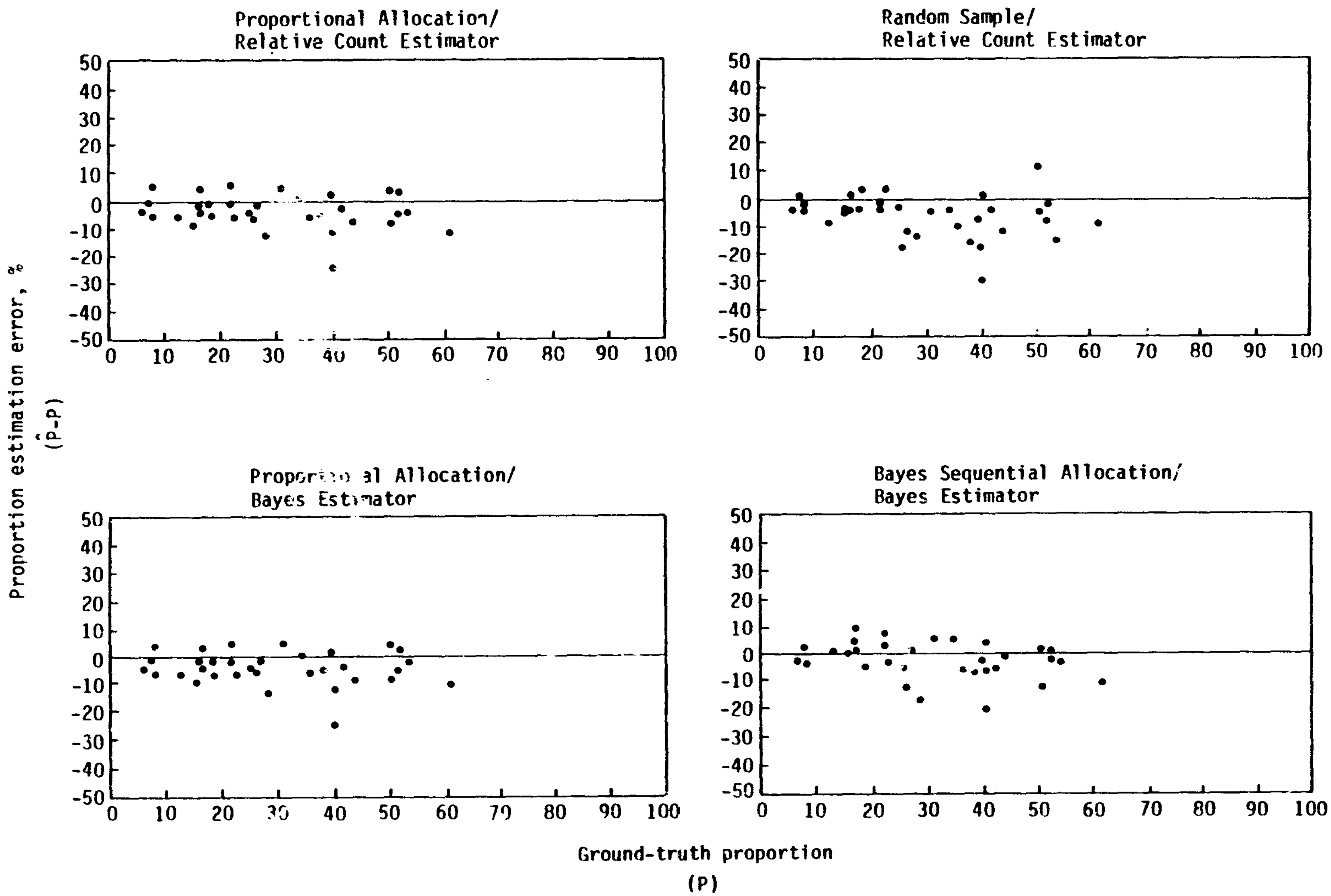

Figure 4-1.- Proportion estimation results with analyst labels.

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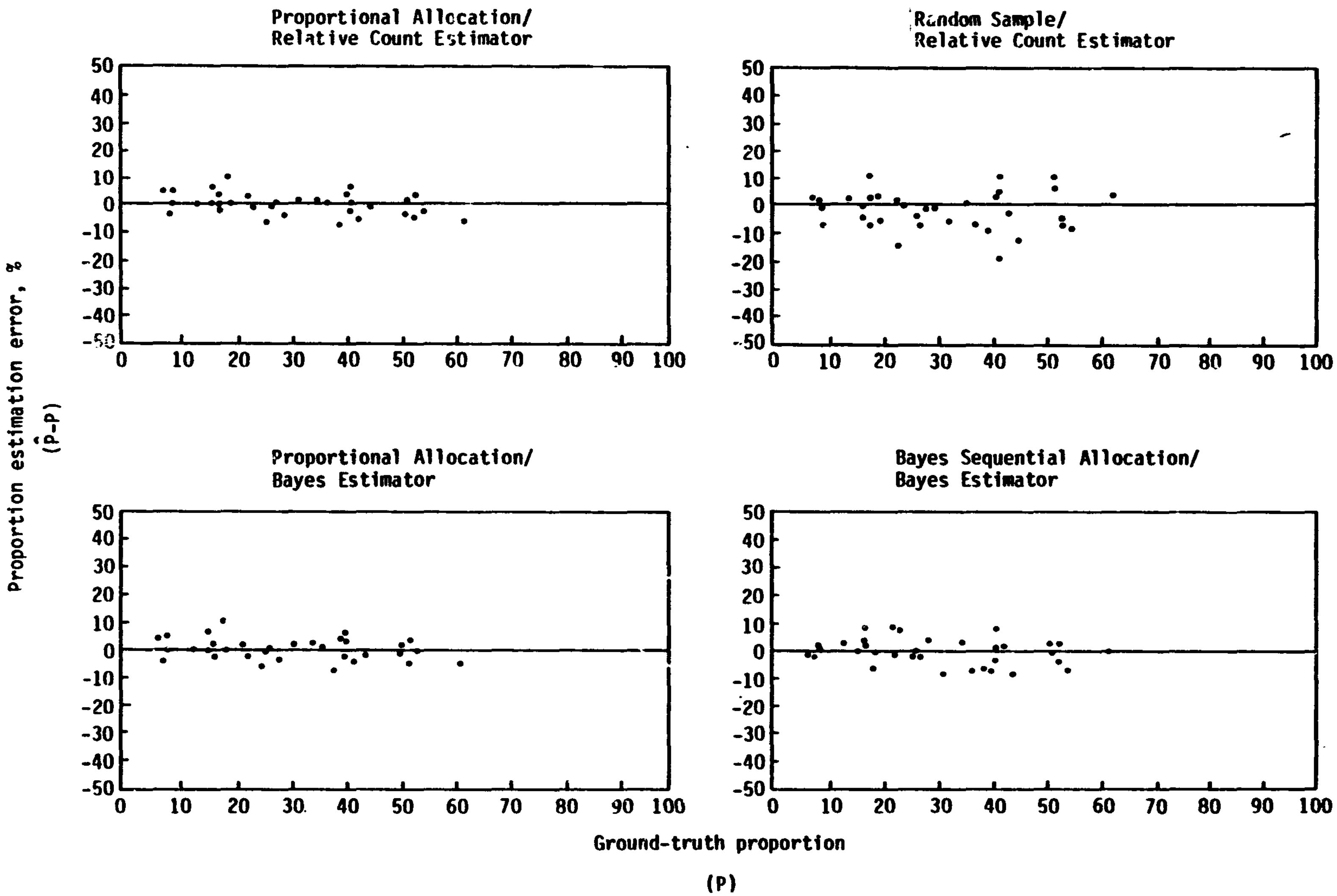

Figure 4-2.- Proportion estimation results with ground-truth labels.

C-2

techniques with unbiased estimators on the variability of errors and the effect of techniques with biased estimators on both the proportion estimates and the variability of errors. However, random sampling as an unbiased technique, produced a significant underestimate even when ground-truth labels were input. To determine the reason for this result, the biases of the 209-plus pixel input dot sets were examined since these were the sets from which the 50-dot samples were taken. The bias (over all 35 segments) was found to be -0.8 percent, and the estimate produced by random sampling was not really significantly biased with respect to this. This indicates that the use of the PA/RCE technique resulted in the overestimation of the 209-plus dot proportion estimates by 0.8 percent. While this was not a significant overestimate, it should be noted. The important result achieved was the reduction of error variability produced by the PA/RCE from random sampling when AI labels and ground-truth labels were input. This reduction was attributed to CLASSY clustering. Cluster purities are further discussed in appendix D.

Since clustering was effective, the next step was to determine the effect of a Bayesian estimator. For the PA/BE, the same dots that were used for the PA/RCE were again used. Thus, the only difference between the two techniques was the estimator employed; with the PA/BE, a cluster-level Bayesian estimator was used instead of a relative count estimator. It had been hypothesized that the PA/BE would provide improved proportion estimates over the PA/RCE because prior knowledge of cluster purities was being considered. Such results could be expected in the same way that the PA/RCE was expected to provide proportion estimates that were more accurate than those obtained through random sampling because of the use of clustering information. As hypothesized, there seemed to be improved precision; but, the difference was small (table 4-1). Figure 4-3 shows the difference between the PA/BE and the PA/RCE for all 35 segments. A positive difference indicates that the PA/BE produced the larger estimate. As the PA/RCE estimate increased, there was a tendency for a larger positive difference. Whether AI labels or ground-truth labels were input, the PA/BE produced a mean proportion estimate that was five-tenths of a percent larger than that of the PA/RCE. This was attributed to a tendency for positive biasing (with respect to the PA/RCE) by the Bayesian estimator (figure 4-3).

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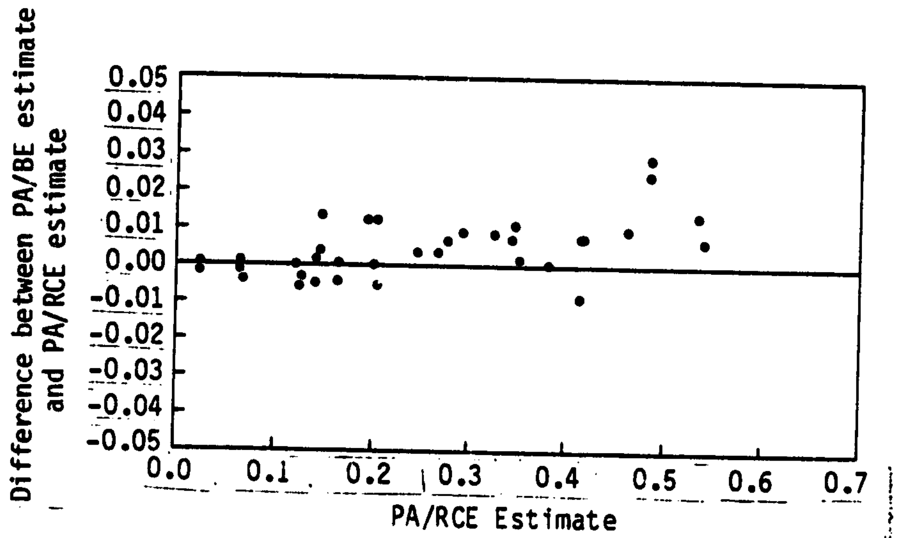

Figure 4-3.- Differences in estimates using proportional allocation with and without Bayesian estimation.

The net effect was a reduction of a negative bias when AI labels were input. With the positive biasing, however, the result was a slight reduction (0.2 percent) in error variability from that of the PA/RCE. This was the case when AI labels were input and also when ground-truth labels were input. In both cases, the MSE's of the PA/BE were slightly reduced from those of the PA/RCE. These results were encouraging because they supported the expectation that Bayesian estimation at the cluster level would provide greater precision (although producing slightly biased results) over maximum likelihood estimation.

The final technique was the BSA/BE, the results for which (as can be seen in table 4-1) showed it to be the least biased technique when AI labels were input. This had been hypothesized since the dots were allocated to clusters one at a time with the intention of minimizing the MSE. Although it produced the least biased results as hypothesized, the BSA/BE produced more variable results than did proportional allocation. This was a disturbing observation.

In an effort to further study these results, an attempt was made to separate the effects of Bayesian estimation and sequential allocation. In order to determine whether or not the results of the BSA/BE followed those of the PA/BE when compared to an unbiased estimation technique, estimates were made using the same sequentially allocated dots and cluster information with a relative count cluster-level (BSA/RCE) estimator rather than the Bayesian estimator. Using the Bayesian estimator in the proportion estimation process increased the estimates by approximately 2 percent. This was true whether input labels were from AI's or ground-truth data (table 4-3). As in proportional allocation, Bayesian estimation produced less variable results at the expense of biasing. However, with sequential allocation, this bias was not as slight as with proportional allocation. A graph comparing the two sequential estimates for each of the 35 segments is presented in figure 4-4. Notice that there was greater overestimation for segments with lesser amounts of small grain.

TABLE 4-3.- ACCURACY AND PRECISION OF SEQUENTIAL ALLOCATION

Technique	AI labels			Ground-truth labels		
	Bias	Standard deviation	MSE	Bias	Standard deviation	MSE
Sequential allocation (relative count, cluster-level estimate)	-4.9	7.1	73	-1.7	5.3	30
Sequential allocation (Bayesian cluster-level estimate)	-2.7	6.8	52	+0.4	4.7	22

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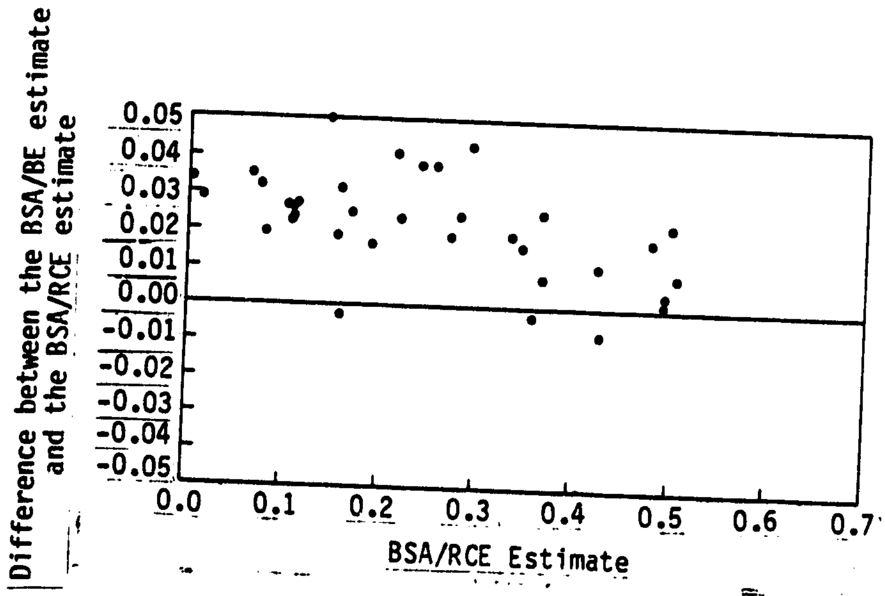

Figure 4-4.- Differences in proportion estimates using sequential allocation.

The fact that the BSA/BE produced more variable results than did the PA/BE was due, in part, to a decreased overall labeling accuracy (table 4-4). In order to determine whether or not these differences were significant, the differences between labeling accuracies of the samples for each segment from those of all labeled dots for each segment were found. The means of these differences are shown in table 4-5. While there was a significant improvement of small-grain labeling accuracy, there was a simultaneous decrease in nonsmall-grain labeling accuracy. The result was a slight decline in total labeling accuracy.

These results indicate that, with a small sample of 50 dots, proportional allocation is the sampling method that produces the most precise and reliable estimates. A slight reduction in variability can be gained at the cost of slight biasing of results by using the Bayesian estimation technique.

Although CLASSY clustering was effective (that is, proportional allocation of dots to CLASSY clusters resulted in greater precision for a given sample size), the same precision could be obtained by random sampling without the need of clustering information if a large enough sample size were taken. If dot sets with AI labels were input with the present labeling accuracy, a random sample of 85 dots would be required to obtain the precision of 50 dots proportionally sampled from CLASSY clusters. If labeling was perfect, a random sample of 166 dots would be required to obtain the same precision of 50 dots proportionally allocated to CLASSY clusters.

Therefore, the biases of proportion estimates, standard deviations of errors, and MSE's of all available labeled dots from the 209 pixels were found when dot sets with AI labels were input and when dot sets with ground-truth labels were input. Table 4-6 presents the results obtained when those dots were treated as a random sample. It was expected that these dots would provide greater precision than a 50-dot proportional sampling of CLASSY clusters because of the larger sample size. Just as we expected, when using all available labeled dots, the RS/RCE showed less variable errors than the PA/RCE when it used only 50-dot samples allocated to CLASSY clusters. Notice in table 4-6 that the use of alternate dots did not introduce a bias; the mean error was very small when ground-truth labels were used. This was important since analysts substituted alternate dots for boundary dots in both the integrated and reformatted labeling procedures to provide better labeling targets to eliminate the special labeling problems that boundary dots present.

In order to determine the effect of clustering with larger samples, cluster-level proportion estimates were made with a relative count estimator on the basis of all labeled dots and weighted by their cluster sizes to produce segment-level estimates. These results are shown in table 4-7. As can be seen, clustering had little effect on the accuracy or precision of estimates when these larger samples were taken. These results point to labeling errors as the limiting element in precision.

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TABLE 4-7.- ACCURACY AND PRECISION OF ALL LABELED DOTS WHEN WEIGHTED BY CLUSTER SIZE

Dots	AI labels			Ground truth labels		
	Bias	Standard deviation	MSE	Bias	Standard deviation	MSE
All labeled dots (weighted)	-3.9	5.7	48	-0.7	2.5	6.3
All labeled dots (random)	-3.9	5.8	48	-0.8	2.9	9
Proportional sampling	-4.0	6.2	53	0.0	4.0	16

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5. SUMMARY AND CONCLUSIONS

For the first time in Foreign Commodity Production Forecasting (FCPF) project testing, clustering has been an effective method in making proportion estimates. Proportionally allocating 50 dots to CLASSY clusters to estimate proportions resulted in greater precision than using a random sampling of 50 dots. This was observed when dot sets with AI labels from the integrated procedure were input, and it was also observed when dot sets with ground-truth labels were input.

When a cluster-level Bayesian estimator (rather than a relative count estimator) was employed with proportional allocation, errors of proportion estimates were slightly less variable at the expense of a slight positive bias with respect to the estimate of the PA/RCE technique. When dot sets with AI labels from the integrated procedure were input, the results of the PA/BE were less biased with respect to ground-truth proportions. Whether analyst-labeled dot sets or ground-truth labeled dot sets were input, the net result was a reduction in the MSE.

The BSA/BE provided the least amount of bias with respect to ground-truth proportions when analyst-labeled dot sets were input. However, this was due to positive biasing by the Bayesian estimator with respect to an unbiased estimate based on the same dots, also weighted by cluster size. The magnitude of this bias was approximately 2 percent. This same effect was observed when dot sets with ground-truth labels were input. In addition, the errors of estimates from the Sequential Bayesian technique showed greater variability than did those from proportional sampling. This was attributed, in part, to a reduced overall labeling accuracy observed for dots selected through sequential allocation.

It was estimated that in order to obtain the same precision with random sampling as obtained by the proportional sampling of 50 dots with an unbiased estimator, samples of 85 or 166 would need to be taken if dots sets with AI labels (integrated procedure) or ground-truth labels, respectively, were input. Little difference, on the other hand, was observed between random sampling and cluster-weighted estimates when all available labeled dot from the 209 were input. Another important result is that dot relocation by analysts provided dot sets that were unbiased.

6. RECOMMENDATIONS

While automatic labeling would provide large samples at relatively low costs, it is only a goal. With large samples, these clustering procedures do not seem to provide much improvement in proportion estimation. However, it is not recommended that effective clustering algorithms be discarded. Neither should efforts in proportion estimation techniques be defaulted to random sampling. An effective procedure using clustering information is available for use in testing and for future development. Automatic labeling, it should be remembered, is not yet a reality. It is therefore recommended that these proportion estimation techniques be maintained, particularly the PA/BE because it provided the greatest precision. It is recommended also that this estimation procedure be considered as the base line for the 1981-82 FCPF Spring Small Grains Pilot Experiment. Further exploratory testing needs to be conducted for other crops of interest such as corn and soybeans.

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APPENDIX A

RESULTS OF THE FOUR ESTIMATION TECHNIQUES UNDER REFORMATTED PROCEDURE

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APPENDIX A

RESULTS OF THE FOUR ESTIMATION TECHNIQUES UNDER REFORMATTED PROCEDURE

Because of biowindow restrictions, only nine segments were processible under the reformatted procedure. Biases of proportion estimates (for fixed samples) along with standard deviations and mean-squared-errors (MSE's) for these segments are presented in table A-1. The errors of the proportion estimates are shown in figures A-1 and A-2. When dot sets with labels from the reformatted procedure were input, large positive biases were produced through the use of all the techniques. Although the estimates produced by techniques using CLASSY clustering were less biased, there was no significant difference among the biases because of the great amount of variation in the errors; as can be seen, the standard deviation of the proportion estimate errors in each of the techniques was approximately 19 percent. Errors in the labeling of dots and the limited number of segments would not permit enough of a basis to warrant an evaluation of the techniques when labels result from the Reformatted procedure. But to be complete, comparable statistics are provided in table A-1 for these same segments when ground-truth labels were used. Interestingly, the standard deviations and MSE's were smaller when CLASSY clustering was used.

TABLE A-1.- ACCURACY AND PRECISION OF THE REFORMATTED PROCEDURE WITH AI LABELS AND GROUND-TRUTH LABELS

Technique	AI labels			Ground-truth labels		
	Bias	Standard deviation	MSE	Bias	Standard deviation	MSE
Random sampling/ Relative Count Estimator	9.1	19.4	436	-0.8	6.1	36
Proportional Allocation/ Relative Count Estimator	6.2	19.2	382	-1.5	3.9	17
Proportional Allocation/ Bayesian Estimator	6.0	18.8	369	-1.7	3.9	17
Bayesian Sequential Allocation/ Bayesian Estimator	6.3	19.1	381	-2.7	4.0	22

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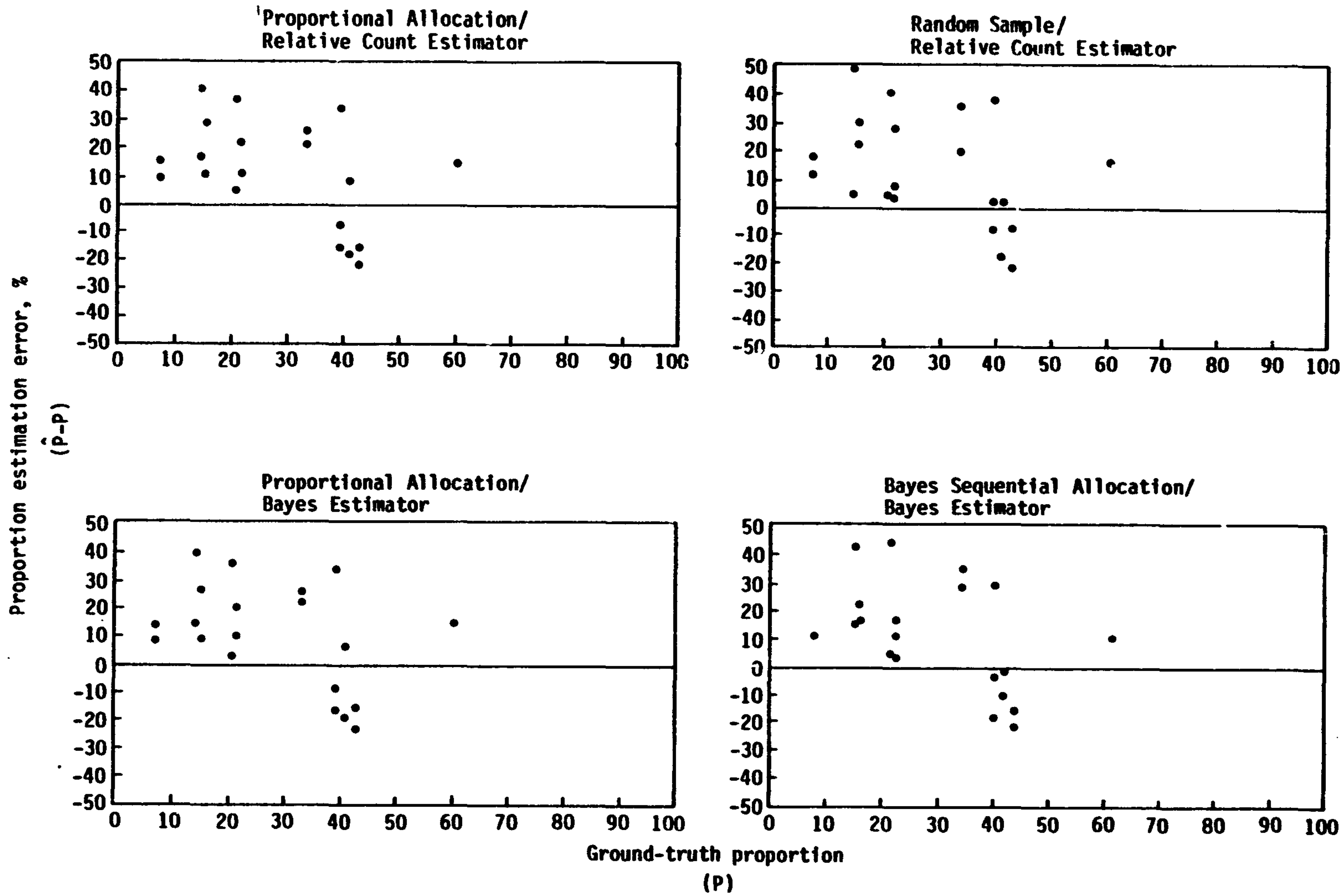

Figure A-1.- Proportion estimation results with analyst labels.

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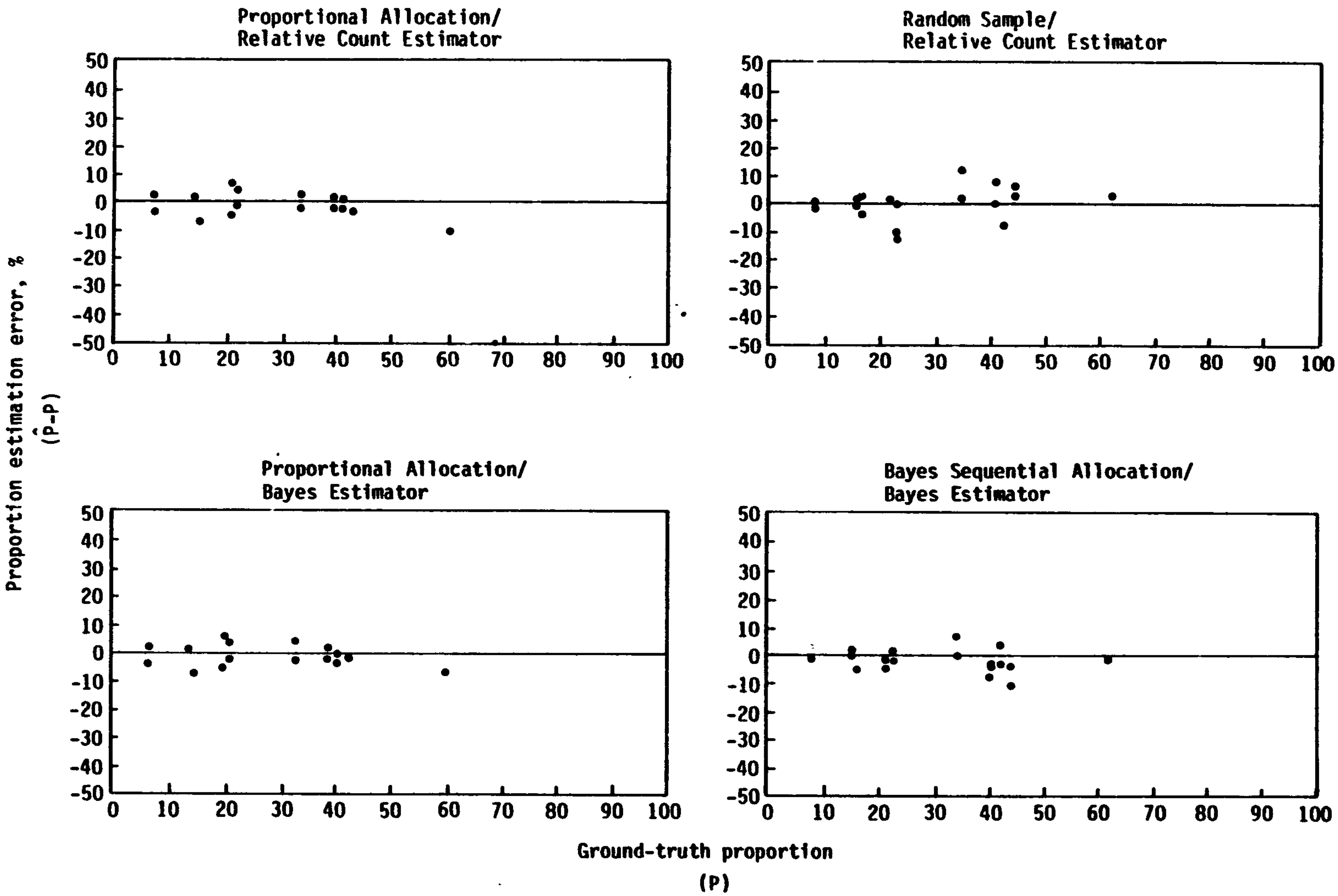

Figure A-2.- Proportion estimation results with ground-truth labels.

APPENDIX B

RESULTS OF FOUR ESTIMATION TECHNIQUES UNDER VARIABLE SAMPLING OF SEGMENTS

APPENDIX B

RESULTS OF FOUR ESTIMATION TECHNIQUES UNDER VARIABLE SAMPLING OF SEGMENTS

Proportion estimates for segments with varying sample sizes were made only when dot labels were obtained from the integrated procedure or ground-truth data. In table B-1, biases, standard deviations, and MSE's for proportion estimates made under sampling based on a threshold (set at .0020) for an internal MSE estimate are presented.

Proportion errors are shown in figures B-1 and B-2. The results were similar to those of the fixed sample size. The sample sizes averaged approximately 42 dots and ranged from 25 to 75 dots.

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TABLE B-1.- BIASES AND VARIANCES

Technique	AI labels				Ground-truth labels			
	Bias	Standard deviation	MSE	Internal MSE estimate	Bias	Standard deviation	MSE	Internal MSE estimate
Random sampling/ Relative Count Estimator	-4.4	8.1	83	42	-2.3	6.8	50	42
Proportional Allocation/ Relative Count Estimator	-3.5	6.1	48	45	-0.4	5.8	33	43
Proportional Allocation/ Bayesian Estimator	+2.9	5.9	43	18	+0.1	5.7	32	17
Bayesian Sequential Allocation/ Bayesian Estimator	-2.5	6.9	53	20	+0.3	4.9	24	20

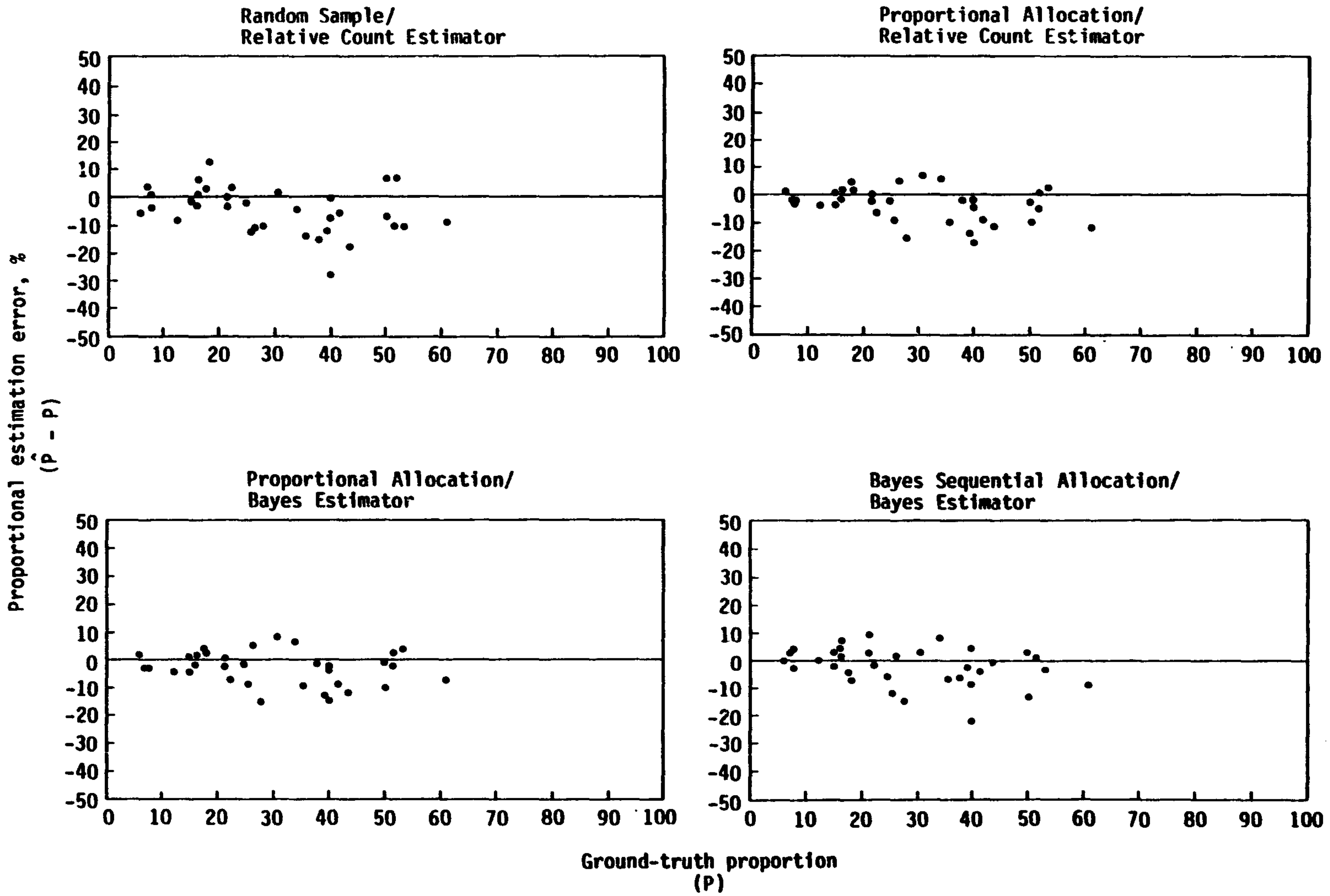

Figure B-1.- Proportion estimation results with analyst labels under varying sample sizes.

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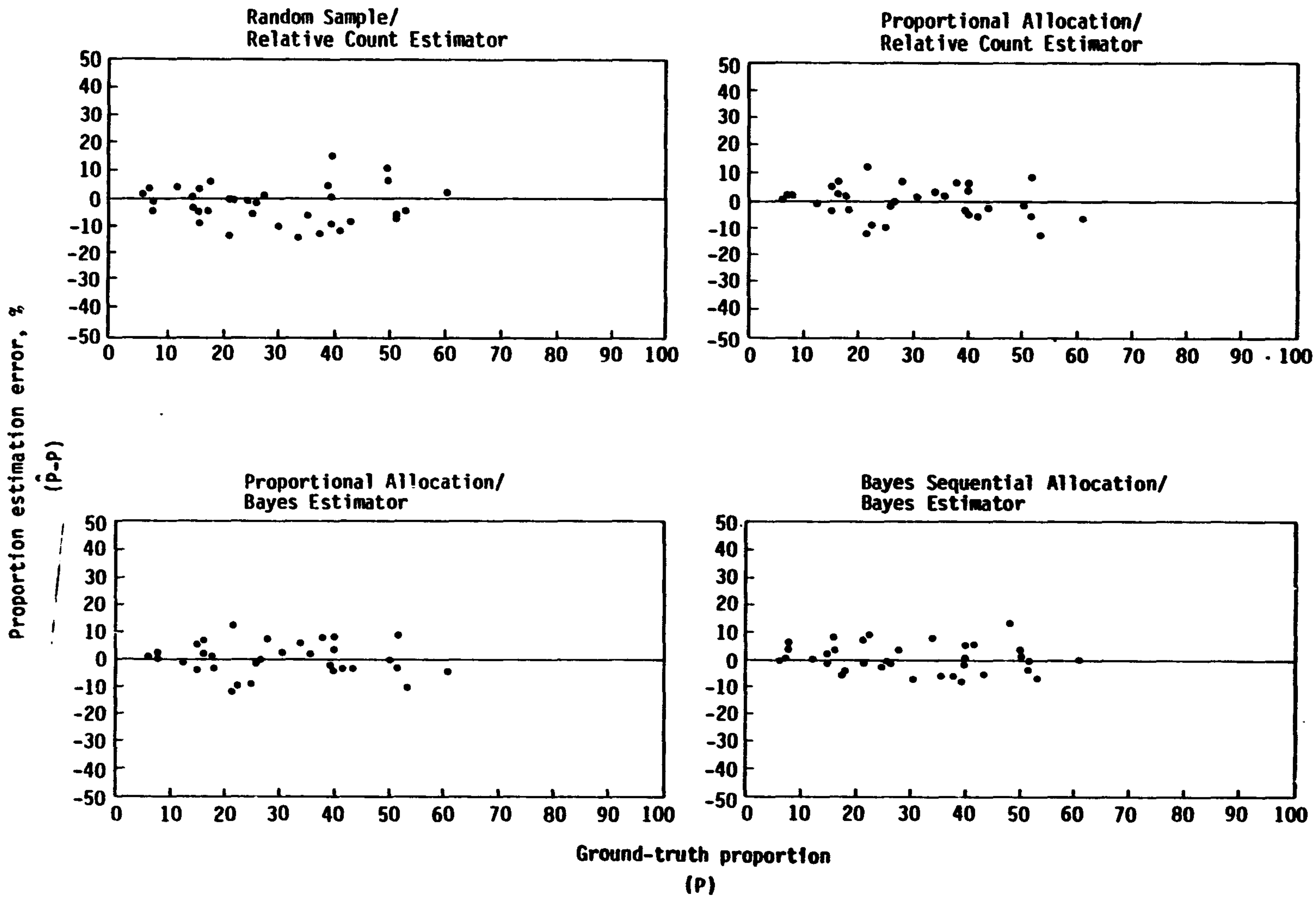

Figure B-2.- Proportion estimation results with ground-truth labels under varying sample sizes.

APPENDIX C

1979 GROUND-TRUTH PROPORTIONS

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APPENDIX C

1979 GROUND-TRUTH PROPORTIONS

Segment	Ground-truth type (a)	Barley, %	Other spring small grains, % (b)	Total spring small grains, %
1387	D	8.01	35.36	43.37
1392	D	2.02	28.28	30.30
1394	I	0.31	39.51	39.82
1457	I	3.15	38.24	41.39
1461	I	4.99	48.19	53.18
1467	D	3.09	48.46	51.55
1472	I	4.02	35.16	39.18
1473	D	11.69	39.74	51.43
1485	I	1.35	20.80	22.15
1514	D	4.92	22.77	27.69
1518	D	0.29	25.22	25.51
1524	D	0.00	6.96	6.96
1571	I	0.32	14.60	14.92
1612	I	0.00	16.03	16.03
1617	D	21.18	39.68	60.86
1619	D	10.39	39.76	50.15
1627	I	0.00	15.80	15.80
1630	I	0.67	16.80	17.47
1636	I	0.87	38.91	39.87
1653	I	0.00	16.13	16.13
1658	I	1.44	32.41	33.85
1664	D	1.94	33.50	35.44
1676	I	0.23	7.44	7.67
1755	I	6.55	5.64	12.19
1784	I	4.07	17.29	21.36
1825	D	6.20	19.95	26.15
1835	D	5.61	19.02	24.63
1843	D	0.75	5.13	5.88
1909	I	0.88	17.15	18.03
1918	I	1.14	13.80	14.94
1920	I	0.09	21.11	21.20
1924	I	1.01	36.75	37.76
1948	D	1.95	5.57	7.52
1974	I	4.48	35.25	39.73
1987	D	15.48	34.40	49.88

[a]D indicates 400 dot ground-truth proportions.
I indicates inventoried ground-truth proportions from universal ground-truth tapes.
[b]Other spring small grains include spring wheat, oats, durum wheat, and flax.

APPENDIX D

CLUSTER PURITIES

APPENDIX D

CLUSTER PURITIES

In order to determine the appropriateness of a beta prior for cluster proportion estimates, small-grain proportions for each cluster were found from ground-truth data. The percentage of all clusters having small-grain proportions within five-hundreth intervals was then found. These clusters are shown in figure D-1. The continuous line represents the shape of a beta prior with a mean equal to the mean small-grain proportion estimate for those segments (0.26). Thus the beta prior is given as follows:

$$g(\theta) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha)\Gamma(\beta)} \theta^{\alpha-1}(1 - \theta)^{\beta-1}$$

where $\alpha = 0.3513$ and $\beta = 1$.

As can be seen, the beta seems to be a reasonable prior.

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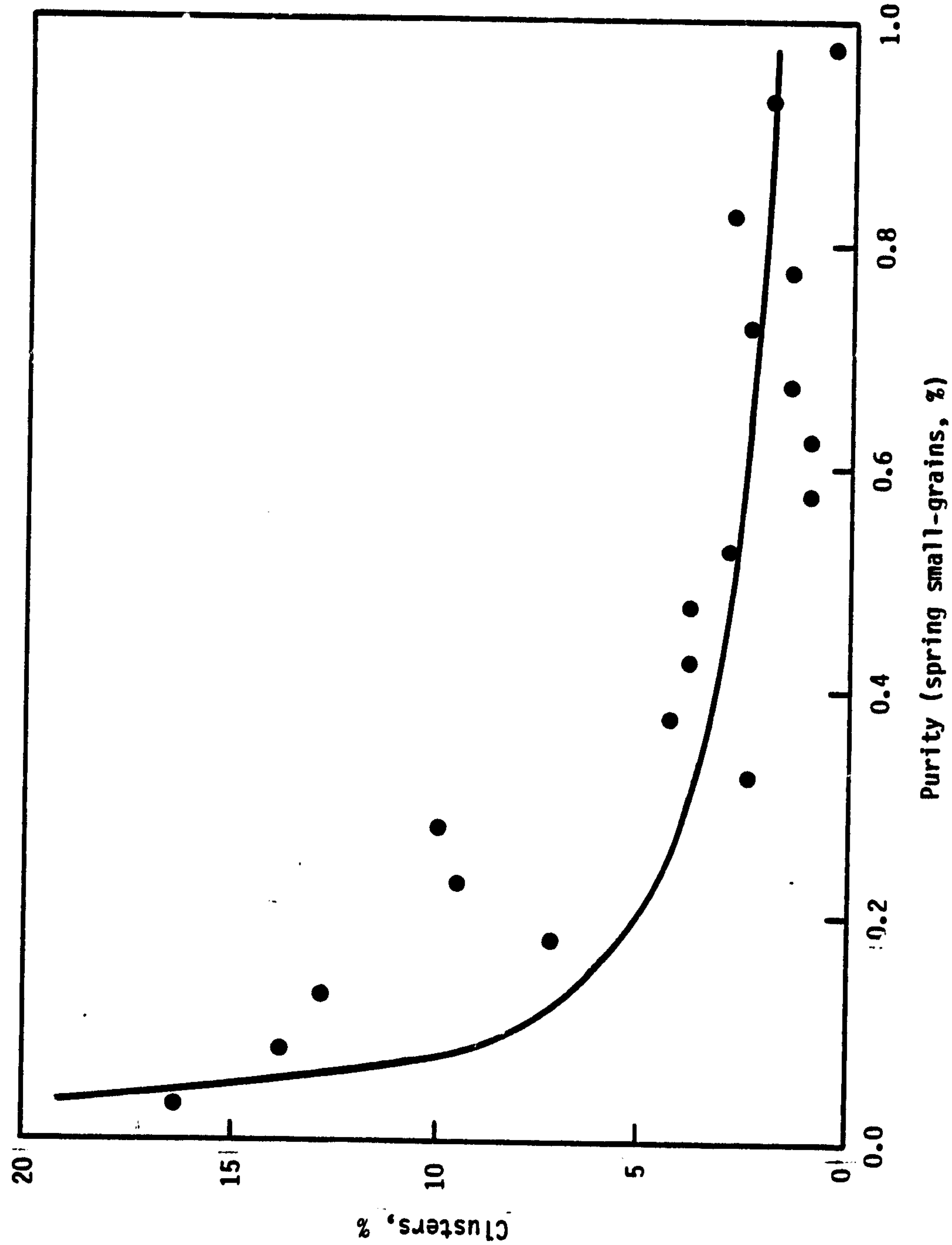

Figure D-1.- Cluster purity.

ADDENDUM 3

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AgRISTARS

FC-L1-04030
JSC-16850

A Joint Program for
Agriculture and
Resources Inventory
Surveys Through
Aerospace
Remote Sensing

Foreign Commodity Production Forecasting

February 1981

EVALUATION OF SPRING WHEAT AND BARLEY CROP CALENDAR MODELS FOR THE 1979 CROP YEAR

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15. Supplementary Notes

16. Abstract

During the Large Area Crop Inventory Experiment, spring wheat planting date and crop development stage estimates based on historical normals were improved by the use of the Feyerherm planting date and Robertson Spring Wheat Crop Calendar Models. The Supporting Research Crop Calendar Project element modified the Robertson model to reduce bias at cardinal growth stages within the growing season. These models were tested in 1980 along with a state-of-the-art barley model (Williams) against a ground-truth data set from 49 calendar year 1979 segments in the U.S. Great Plains spring wheat and barley region.

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EVALUATION OF SPRING WHEAT AND BARLEY CROP CALENDAR MODELS FOR THE 1979 CROP YEAR

Job Order 72-402

This report describes the Accuracy Assessment activities of the Foreign Commodity Production Forecasting project of the AgRISTARS Program.

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LOCKHEED ENGINEERING AND MANAGEMENT SERVICES COMPANY, INC.

Under Contract NAS 9-15800

For

Earth Resources Applications Division
Space and Life Sciences Directorate
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

February 1981

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PREFACE

The Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing is a 6-year program of research, development, evaluation, and application of aerospace remote sensing for agricultural resources which began in fiscal year 1980. This program is a cooperative effort of the National Aeronautics and Space Administration, the U.S. Agency for International Development, and the U.S. Departments of Agriculture, Commerce, and the Interior.

The research which is the subject of this document was performed within the Earth Resources Applications, Space and Life Sciences Directorate, at the Lyndon B. Johnson Space Center, National Aeronautics and Space Administration. Under Contract NAS 9-15800, personnel of Lockheed Engineering and Management Services Company, Inc., performed the tasks which contributed to the completion of this research.

The following individuals contributed to this effort: Dr. A. G. Houston, NASA, helped with his interest and suggestions. M. L. Sestak, Lockheed, put together the original data set, and Dr. P. Doraiswamy, Lockheed, was responsible for the model improvements and much of the information on the inner workings of the models.

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CONTENTS

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TABLES

FIGURES

1. BACKGROUND AND OBJECTIVES

This report describes the results of the evaluation of the performances of candidate agrometeorological crop calendar models. These models have been proposed by the Supporting Research Crop Calendar Project element for possible application to labeling procedures of the Agriculture and Resources Inventory through Aerospace Remote Sensing (AgRISTARS) program. This study is an addition to the 1980 U.S. and Canada Spring Wheat and Barley Exploratory Experiment.

During the Large Area Crop Inventory Experiment (LACIE), spring wheat planting date and crop development stage estimates based on historical normals were improved by the use of the Feyerherm planting date and Robertson Spring Wheat Crop Calendar Models. Modifications were subsequently made to the Robertson model to improve deficiencies identified in LACIE evaluations. These modifications were tested along with a state-of-the-art barley model (Williams, ref. 1) which became available for testing for the first time.

This study investigated two crop planting date (or starter) models, namely the Feyerherm (ref. 2) and the Normal models (ref. 3), and four crop growth stage models. These crop development stage models are designated the Original Robertson Model (R0), the Improved Robertson Version 1 Model (R1), the Improved Robertson Version 2 Model (R2), and the Williams Barley Model. The evaluation was based on 1979 ground-truth data consisting of 49 spring small grains blind-site segments in the U.S. Great Plains region and contains three crop categories of interest, spring wheat, durum wheat, and barley. For the purposes of this study, durum wheat is in the same category as spring wheat.

The primary objective of this study was to determine the combination of the crop planting date model and the crop development stage model which would most accurately predict the crop development stage as a function of time for spring wheat and barley. Other objectives were to determine if the Williams model predicts more accurately the barley development stages than do the Robertson models and to determine whether the models selected would produce results which are sufficiently accurate to be used in labeling and classification procedures.

2. APPROACH

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

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

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

The planting date models and the development stage models were evaluated independently so as to minimize any adverse consequences to the performances of the crop development stage models as a result of inaccurate planting date input to the models.

Certain assumptions had to be made regarding the ground-truth data used for evaluation. The 49 segments contained from 15 to 30 special fields that were distributed through the segment and observed periodically. The locations and selections of these special fields were assumed to be random, and the periodically observed stages were assumed to be truly representative of crop development at those times.

3. DATA SET

The data set used in this study comprised 49 blind-site segments in the spring wheat areas of the U.S. Great Plains and 1979 periodic observations collected by enumerators at 9- to 18-day intervals corresponding to Landsat overpass dates (ref. 4). These periodic observations contained planting dates and crop development stages for each field in the segment. The number of fields within a segment varied from 15 to 30 spring wheat or barley fields. The planting date model contained the observed planting dates and predicted planting dates for spring wheat and barley. The crop stage model data contained observed crop stages and predicted crop stages for each of the models. The crop stages were given in terms of the Robertson Phenological Crop Scale.

Figure 1 is an illustration of the Robertson Phenological Crop Scale that was used in this study, superimposed on the Feekes Scale description of identifiable crop stages (refs. 5 and 6). Figure 2 shows the geographic location of the segments that contain the data set used in this study.

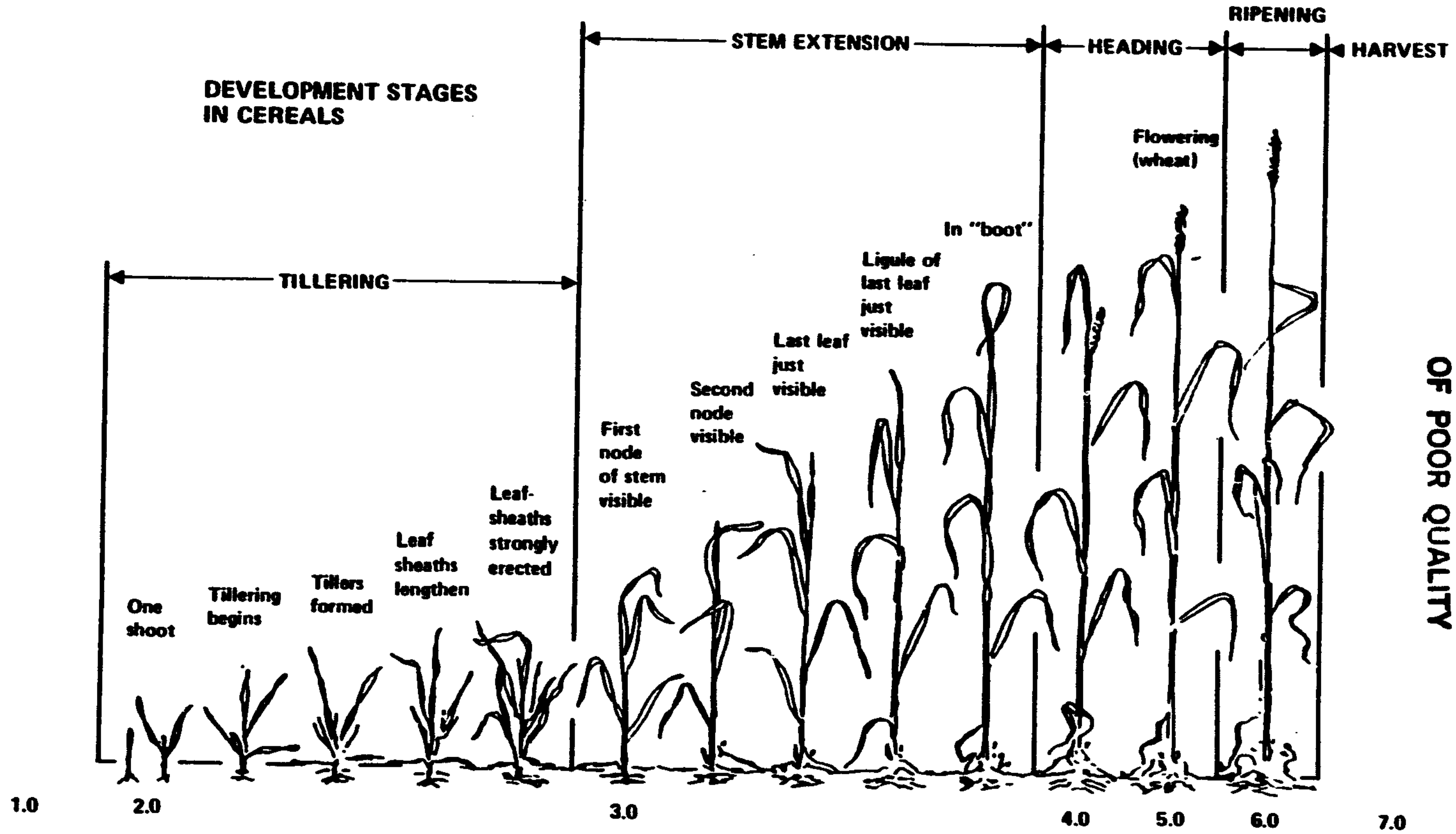

Figure 1.- Illustration of the Robertson Phenological Scale.

- 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.

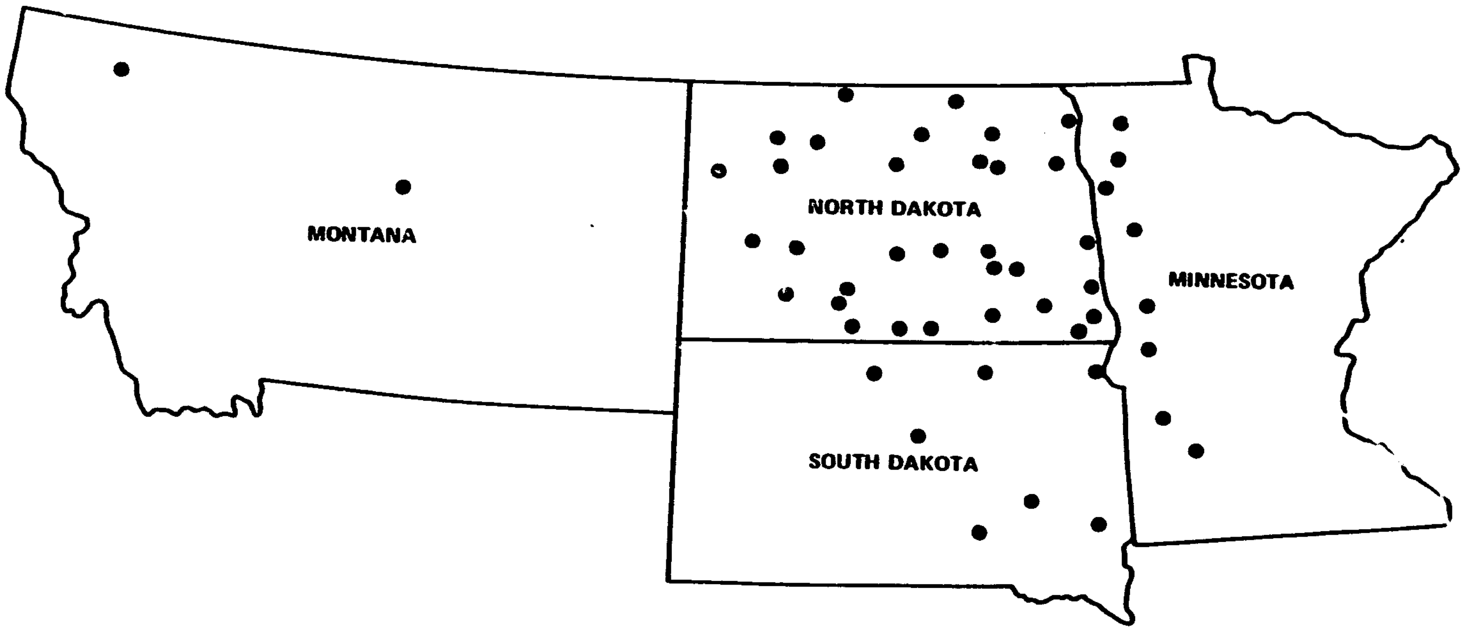

Figure 2.- Geographic locations of the segments.

4. DESCRIPTION OF THE MODELS

Robertson's concept (ref. 5) is based on certain physiological processes that are central to the development of spring wheat. Since temperature and photoperiod are two primary environmental factors that influence the phenological development, a photothermal concept was used to compute the development of a crop over five fairly short and uniform physiological periods. The triquadratic responses of temperature and photo-period were estimated for each of the phenological stages by an interative regression technique.

The Improved Robertson Version 1 and the Improved Robertson Version 2 Models are improvements over the Original Robertson Model with respect to the photo-period and temperature responses. The photo-period response is limited to stages between emergence and flowering. The thermal responses for subsequent stages are adjusted to represent realistic physiological responses. The development rates of spring wheat immediately before and after flowering are responsive primarily to the daily maximum temperature.

The Williams Barley Model is based on approximately the same concept as the Robertson model, the difference being that the coefficients were developed specifically for barley.

Figure 3 is a schematic of the models' input requirements and resulting output data. The Normal model, although not an agrometeorological model, is included in figure 3 for the sake of completeness. It is based on historical data averaged for the crop reporting district. The daily minimum and maximum temperatures are obtained from reports of weather stations nearest the segments.

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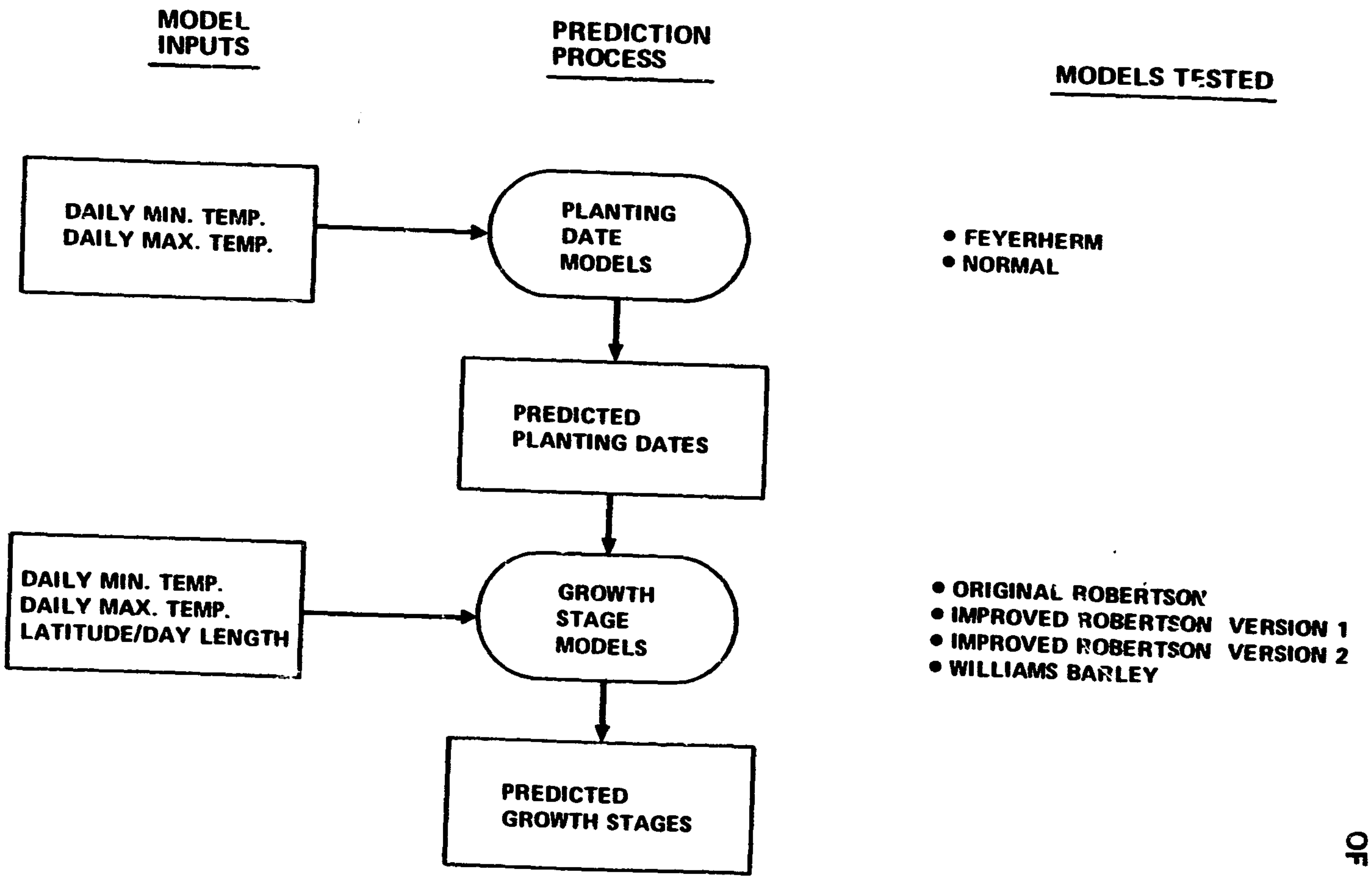

Figure 3.- Schematic of the evaluation process.

5. RESULTS FOR PLANTING DATE MODELS

Both the Feyerherm and the Normal models produce median planting date estimates at the segment level. The performances of the models for the spring wheat fields and the barley fields were evaluated separately.

Figure 4 is a histogram showing the distribution of errors measured in days for the Feyerherm versus the Normal planting date models applied to spring wheat fields. The error is the difference between the median ground-truth planting dates and the model-predicted planting dates, and the distribution of these errors should give an indication of the bias associated with the models. As can be seen from figure 4, both distributions appear normal, the differences being the locations of the midpoints of these distributions. The Feyerherm model has a positive displacement, whereas the Normal model has a negative displacement. This indicates that the Normal model is very early compared to the ground-truth median planting dates, while the Feyerherm model is slightly late. Based on reports jointly published by the U.S. Department of Agriculture and the National Oceanic and Atmospheric Administration in the Weekly Weather and Crop Bulletin, the 50 percent planting date of spring wheat in North Dakota for 1979 was 13 days late. Thus, the Normal model performed as expected.

Table 1 summarizes the statistics on the errors measured in days for the Feyerherm versus the Normal model applied to spring wheat. The sign test shown in table 1 is based on the absolute magnitude of the error and gives the percent of times one model is closer to the ground-truth than the other model.

TABLE 1.- COMPARISON OF ERRORS IN PLANTING DATE MODELS
APPLIED TO SPRING WHEAT FIELDS

	Feyerherm model	Normal model
Number of segments (n)	49	49
Mean error (in days)	+3.9	-10.4
Standard deviation (in days)	7.0	7.50
Median error (in days)	+4.0	-11.0
Sign test (%) (2% tied)	75.5	22.4

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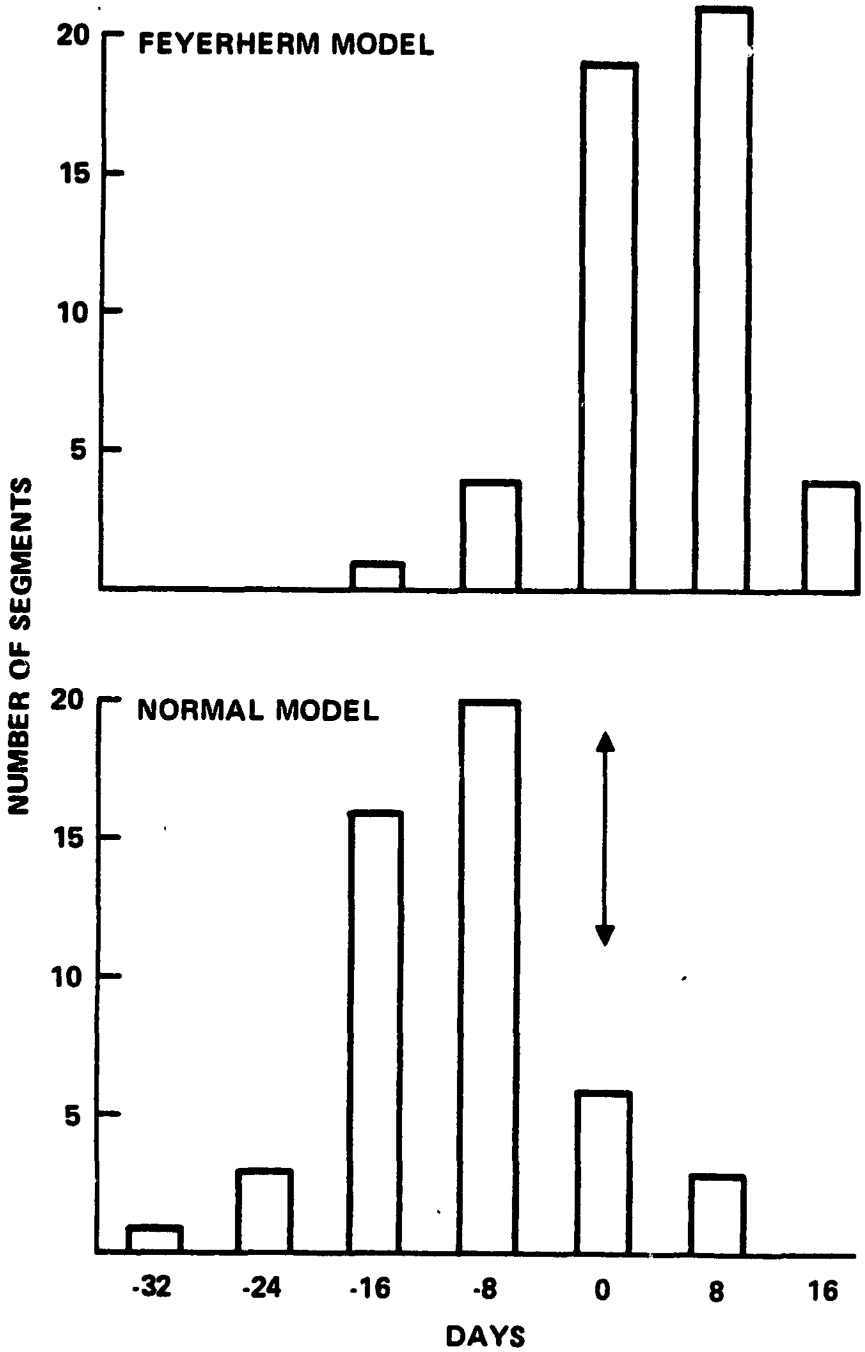

Figure 4.- Distribution of errors (in days) for the Feyerherm versus the Normal planting date models applied to barley.

From table 1 it can be seen that, on the average, the Feyerherm model is 3.9 days late compared to the observed planting date, whereas the Normal is on the average 10.4 days early compared to the observed planting date. Statistically, the sign test indicates that the Feyerherm model is significantly better than the Normal model at the 6-percent level of significance. The overall statistics indicate that the Feyerherm model is closer to the ground-truth than the Normal model in predicting spring wheat planting dates for this year.

Figure 5 is a histogram showing the distribution of error measured in days for the Feyerherm versus the Normal planting date models applied to barley fields. As can be seen from figure 5, both distributions appear normal. However, the Feyerherm model midpoint has a positive displacement, whereas the Normal model has a negative displacement. This indicates that the two models are, on the average, late and early compared to the ground-truth median planting dates as seen for barley fields.

Table 2 summarizes the statistics on the error measured in days from the Feyerherm versus the Normal model applied to barley fields. From table 2, it can be seen that, on the average, the Feyerherm model is 2.9 days later than the observed planting date, whereas the Normal is, on the average, 10.9 days earlier than the observed planting date. The sign test indicates that the Feyerherm model is better than the Normal model, though not statistically significant at the 5-percent level of significance. The overall statistics indicate that the Feyerherm model is better for this year than the Normal model is for predicting barley planting dates.

TABLE 2.- COMPARISON OF ERRORS IN PLANTING DATE MODELS
APPLIED TO BARLEY FIELDS

	Feyerherm model	Normal model
Number of segments (n)	44.0	44.0
Mean error (in days)	+2.9	-10.9
Standard Deviation (in days)	11.48	9.55
Median error (in days)	+4.5	-11.5
Sign test	63.6	36.4

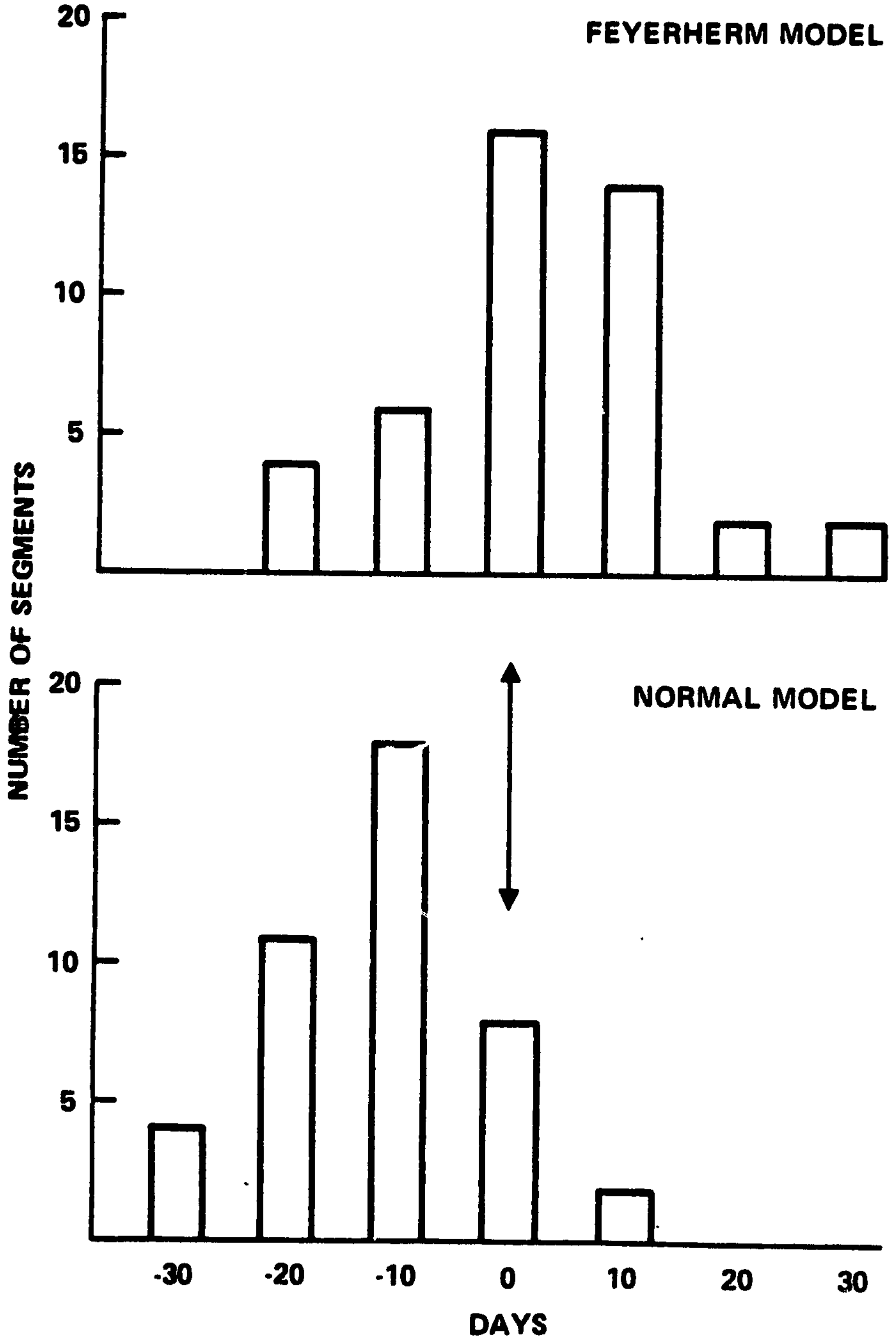

Figure 5.- Distribution of errors (in days) for the Feyerherm versus the Normal planting date models applied to barley.

6. APPROACH: CROP DEVELOPMENT STAGE MODELS

The three Robertson models and the Williams Barley Model were started using the ground-truth median planting dates for spring wheat and barley fields as input to the models. They were evaluated on their ability to accurately predict median crop development stages for spring wheat and barley between stages 2.0 and 6.0, which are the emergence through ripe stages.

In an attempt to determine if the models performed differently during different parts of the growing season, the models were evaluated at five ranges of stages as shown below.

1. Stage 2.0 to 2.9: emergence to prejointing
2. Stage 3.0 to 3.9: jointing to preheading
3. Stage 4.0 to 4.9: heading to presoft dough
4. Stage 5.0 to 5.9: soft-dough to preripening
5. Stage 6.0: ripe

In addition, the overall performance was tested for the entire growing season from stage 2.0 to stage 6.0.

7. CROP DEVELOPMENT STAGE MODEL RESULTS APPLIED TO SPRING WHEAT FIELDS

Figure 6 contains scatter plots of the median predicted development stages versus the observed median development stages for models R0, R1, and R2. The letters represent the number of data points falling on the character (A = 1, B = 2, etc.). The common trend on all three plots is for the predicted growth stage to converge on the 1-1 line, indicating that the performance of all three models is improving with time through the growing season. It can also be seen from figure 6 that model R0 is progressing faster than models R1 and R2 by noting that 13 ground truth observations are off scale and greater than stage 6.0 (i.e., swathed and harvested).

Table 3 summarizes the statistics on the errors between the observed stages and the predicted stages that were applied to spring wheat at various intervals throughout the growing season. The errors are the differences between the predicted stages and the observed stages and should give an indication of the amount of bias associated with each of the models. An average positive error would indicate that the model is ahead of the ground-truth, while an average negative error would indicate that the model was behind the ground-truth. In addition, the absolute value of the error was ranked on a scale of 1 to k, where k is the number of models being compared with each other (in table 3, k = 3). The sum of the various ranks associated with each model was then utilized in a Friedman nonparametric test of ranks (ref. 7) to determine if any one model produced better results consistently.

Table 3 shows that there were no significant differences between any of the three models when evaluating the overall performance from ground-truth stages 2.0 to 6.0. The range of the mean error for the three models was two-tenths of a stage, and the Friedman T-statistic also indicates that there is no significant difference between the models at the 95-percent confidence level.

For stages 2.0 to 2.9, there was a marginal difference between the three models. It is apparent that R1 is the worst performer of the three models at this stage interval, as indicated by the statistics on the errors and the

TABLE 3.- COMPARISON OF ROBERTSON MODELS APPLIED TO SPRING WHEAT

Ground-truth range	Statistic	Robertson 0	Robertson 1	Robertson 2
2.0 - 6.0 Entire growing season	Mean error	0.0	0.2	0.2
	STD	0.53	0.48	0.46
	Median error	0.0	0.1	0.2
	ΣRank observed	100.21	97.08	96.71
	Friedman's T-statistic: 0.15 (not significant)			
2.0 - 2.9	Mean error	0.9	1.0	0.9
	STD	0.25	0.28	0.25
	Median error	0.9	1.0	0.9
	ΣRank observed	25.00	37.75	27.25
	Friedman's T-statistic: 6.17 (significant)			
3.0 - 3.9	Mean error	0.3	0.7	0.4
	STD	0.26	0.32	0.26
	Median error	0.3	0.7	0.4
	ΣRank observed	42.42	95.25	66.33
	Friedman's T-statistic: 41.17 (significant)			
4.0 - 4.9	Mean error	-0.2	0.1	0.1
	STD	0.26	0.27	0.31
	Median error	-0.2	0.1	0.0
	ΣRank observed	89.67	70.75	79.58
	Friedman's T-statistic: 4.48 (not significant)			
5.0 - 5.9	Mean error	-9.2	0.0	0.1
	STD	0.42	0.27	0.33
	Median error	-0.2	0.0	0.2
	ΣRank observed	109.45	66.00	93.95
	Friedman's T-statistic: 20.92 (significant)			
6.0	Mean error	--	--	--
	STD	--	--	--
	Median error	-0.5	-0.4	-0.3
	ΣRank observed	50.0	48.4	33.5
	Friedman's T-statistic: 24.07 (significant)			

At 95-percent confidence level, Friedman's T-statistic critical value = 5.99.
At 99-percent confidence level, Friedman's T-statistic critical value = 9.21.

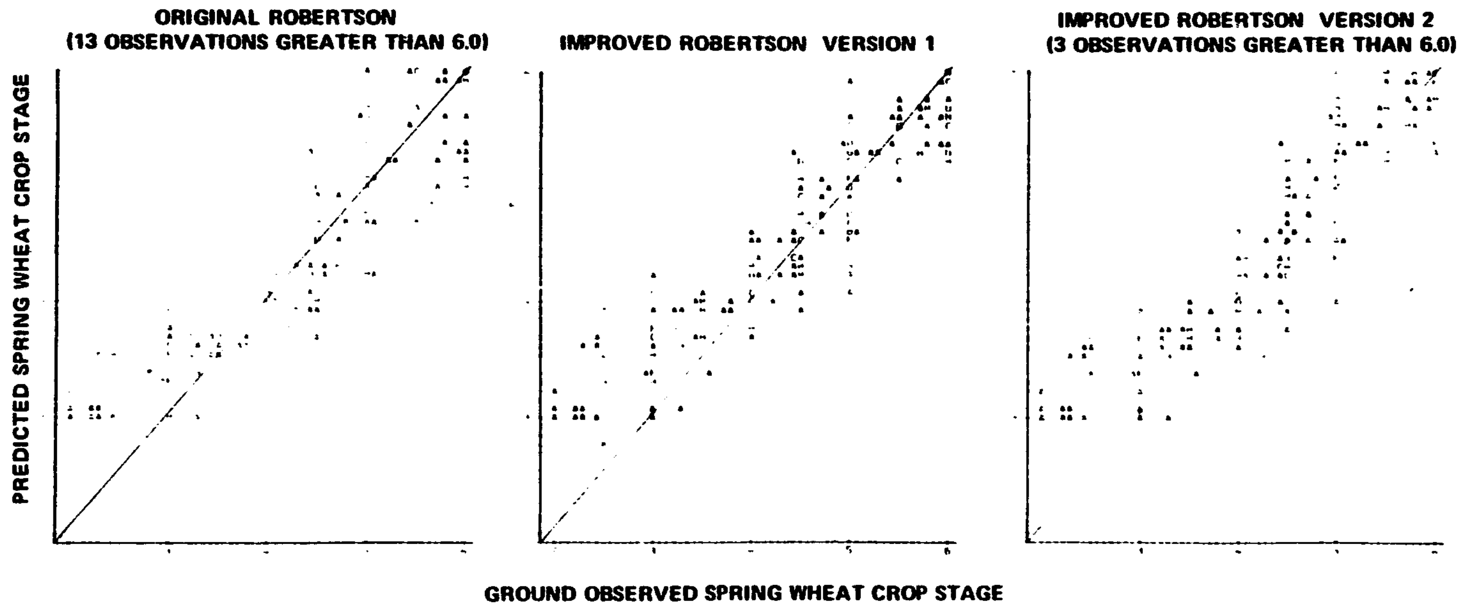

Figure 6.- Scatter plots of predicted versus ground-observed spring wheat crop stages for the three spring wheat crop stage models.

observed sum of the ranks. From stages 3.0 to 3.9, there was a significant difference between the models. R0 appeared to be the best at this stage interval. From stages 4.0 to 4.9, there was no significant difference between the models.

For stages 5.0 to 5.9, there was a significant difference between the models, and R1 appeared to perform the best within this stage interval. Finally, at stage 6.0, there was a significant difference between the three models, and R2 appeared to perform the best of the three models. At ground-truth stage 6.0, the mean and standard deviation have not been displayed, as they are not valid. The observations obtained beyond stage 6.0 were beyond the range of the model's abilities of prediction and, therefore, were not valid.

8. CROP DEVELOPMENT STAGE MODEL RESULTS APPLIED TO BARLEY FIELDS

Figure 7 contains scatter plots of tne median predicted development stage for model R2 and the Williams Barley Model versus the observed median development stage. The letters represent the number of data points falling on that character. At first glance, there is no apparent difference between the two models, although the barley model appears to be more dispersed about the 1-1 line than R2 (figure 10). More significant is the fact that 33 observations are beyond 6.0, indicating that the barley model is progressing faster than the spring wheat model.

Table 4 gives the statistics on the errors between the median ground-truth stage and the model predicted median stage applied to barley at various stage intervals through the growing season. It can be seen from table 4 that there was a significant difference between the models for the overall performances from stages 2.0 to 6.0. The barley model is significantly worse than at least one of the spring wheat models.

From stage 2.0 to 2.9, there were marginal differences between the models. R0 appeared to perform the best of the four models as indicated by the error statistics and the observed sum of the ranks. For stages 3.0 to 3.9, there was a significant difference between the models. R0 appeared to be the best of the four models. From stages 4.0 to 4.9, there were no significant differences between the models. They appeared to be nearly identical at this stage interval. For stages 5.0 to 5.9, there was a significant difference between the models. Model R1 appeared to perform the best. At stage 6.0, there were no significant differences between the models, and R2 appeared to perform the best.

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TABLE 4.- COMPARISON OF ROBERTSON AND WILLIAMS MODELS APPLIED TO BARLEY

Ground-truth range	Statistic	Robertson 0	Robertson 1	Robertson 2	Williams barley
2.0 - 6.0 Entire growing season	Mean error	-0.2	0.0	0.0	0.4
	STD	0.67	0.60	0.61	0.60
	Median error	-0.2	0.0	0.0	0.0
	ΣRank observed	117.67	96.96	98.58	126.79
	Friedman's T-statistic: 8.74 (significant)				
2.0 - 2.9	Mean error	1.0	1.1	1.0	1.2
	STD	0.32	0.37	0.33	0.35
	Median error	1.1	1.2	1.1	1.2
	ΣRank observed	22.33	33.50	24.67	39.50
	Friedman's T-statistic: 9.49 (significant)				
3.0 - 3.9	Mean error	0.3	0.4	0.4	0.6
	STD	0.32	0.38	0.36	0.42
	Median error	0.2	0.4	0.3	0.5
	ΣRank observed	50.58	90.67	65.08	113.67
	Friedman's T-statistic: 43.79 (significant)				
4.0 - 4.9	Mean error	-0.3	-0.1	-0.2	0.1
	STD	0.32	0.34	0.38	0.52
	Median error	-0.3	0.0	-0.1	0.2
	ΣRank observed	89.42	62.67	74.92	79.0
	Friedman's T-statistic: 7.18 (not significant)				
5.0 - 5.9	Mean error	-0.5	-0.3	-0.2	0.1
	STD	0.57	0.45	0.54	0.59
	Median error	-0.6	-0.2	-0.2	0.3
	ΣRank observed	129.93	70.67	95.10	114.30
	Friedman's T-statistic: 28.68 (significant)				
6.0	Mean error	--	--	--	--
	STD	--	--	--	--
	Median error	-0.9	-0.7	-0.6	>0.0
	ΣRank observed	48.0	35.0	26.5	50.5
	Friedman's T-statistic: 14.31 (significant)				

At 95-percent confidence level, Friedman's T-statistic critical value = 7.82.
At 99-percent confidence level, Friedman's T-statistic critical value = 11.34.

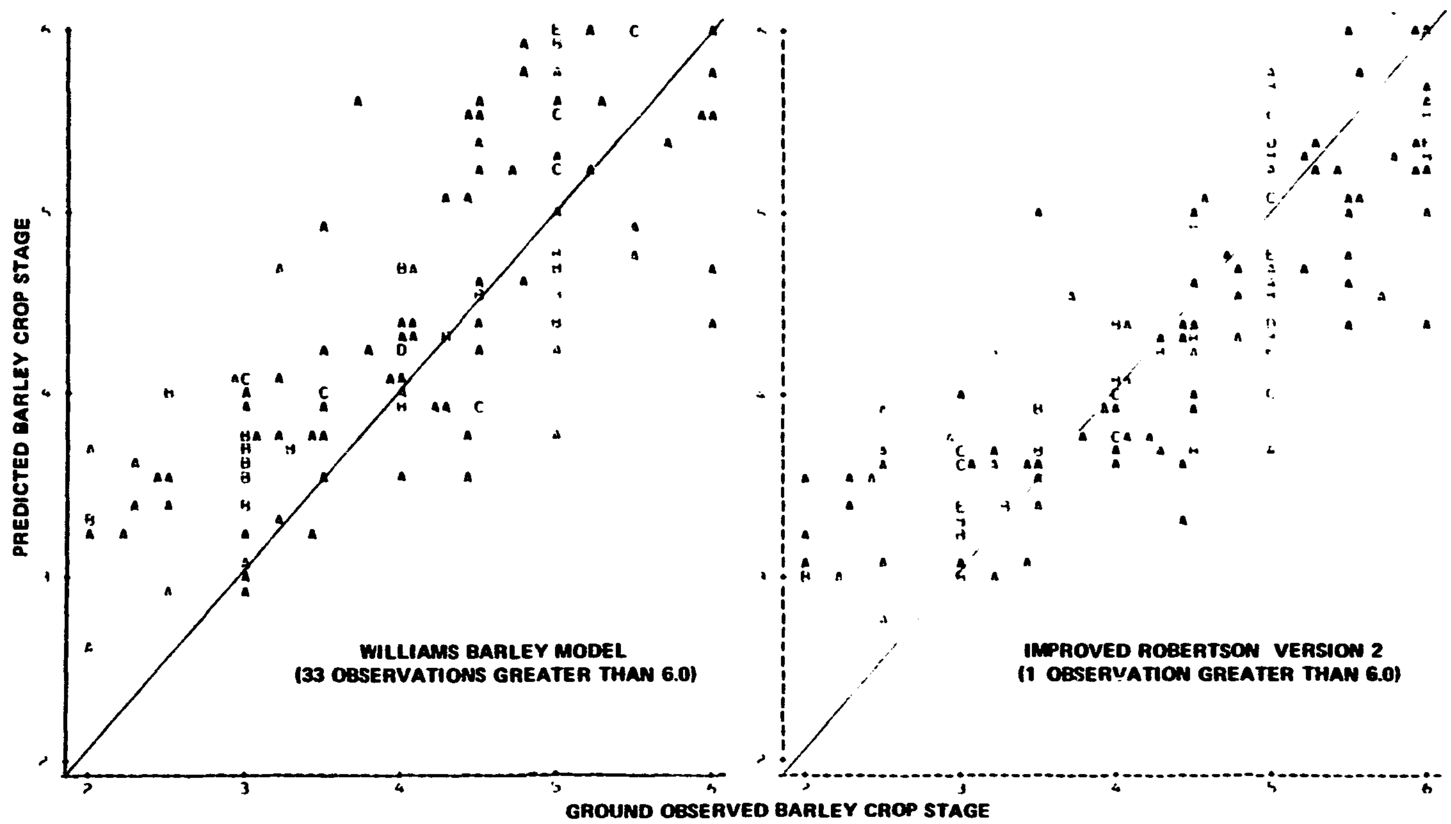

Figure 7.- Scatter plots of predicted versus ground-observed barley crop stages for the Williams Barley Model and the Improved Robertson Version 2 Spring Wheat Model.

9. APPLICATION TO LABELING PROCEDURES

The results shown in the preceding discussion indicate that the Feyerherm planting date model is more accurate than the Normal model. However, with respect to the growth-stage models, it is not readily apparent that any one model produces consistently better results through the growing season. The Improved Robertson Version 2 Model was selected on the basis of its being the most physiologically realistic model for application to the labeling procedures in AgRISTARS (ref. 8). In order that the models be useful for the spring small grains labeling procedure, it is necessary that they be able to predict crop growth stages at particular points of time with reasonable accuracy. The Reformatted procedure (ref. 9) prescribes and identifies four Landsat acquisition biowindows that are necessary for accurate labeling as shown in table 5.

TABLE 5.- BIOWINDOWS FOR REFORMATTEL PROCEDURE

Window	Open	Close
1	Spring wheat 50% Planted minus 5 days	Spring wheat 50% Planted plus 18 days
2	Spring wheat 50% Headed minus 10 days	Spring wheat 50% Headed plus 10 days
3	Spring barley 50% Turning to ripe minus 5 days	Spring barley 50% Turning to ripe plus 6 days
4	Spring wheat 50% Harvested plus 15 days	Spring wheat 50% Harvested plus 30 days

Using the criteria described in table 5, the predicted growth stages for the Improved Robertson Version 2 Model were converted to days of development to reach each of three crop stages described in the Reformatted procedure. Biowindow 4 was not calculated because it was out of the ranges of stages in which the models are effective.

Table 6 lists the median ground-truth dates and the median predicted dates for three biowindows. Biowindow 1 used the Feyerherm planting date model and biowindows 2 and 3 used the Improved Robertson Version 2 model for spring wheat and barley with the Feyerherm planting date model as the starter model.

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TABLE 6.- OBSERVED VERSUS PREDICTED BIOWINDOWS
ACCORDING TO THE REFORMATTED PROCEDURE

OBS	STATE	APU	CRD	County	Seg. no.	Biowindow 1 (SW) OBSPLT	FPLT	Biowindow 2 (SW) OBSHEAD	R2HEAD	Biowindow 3 (Barley) OBSRIPE	R2RIPE
1	27	15	70	Redwood	1380	126	136	183	190	.	.
2	27	19	40	Grant	1566	138	140	188	191	232	236
3	27	19	40	Utter Tail	1836	139	145	194	196	221	240
4	27	19	40	Yellow Medicine	1842	123	134	191	184	.	.
5	27	20	10	Marshall	1514	158	148	211	198	236	239
6	27	20	10	Roseau	1518	148	148	201	197	246	246
7	27	20	10	Norman	1825	142	144	196	197	219	246
8	27	20	10	Polk	1987	133	145	191	196	214	238
9	30	23	50	Fergus	1948	136	123	188	188	219	220
10	30	104	10	Flathead	1725	120	115	192	175	223	223
11	38	19	20	Benson	1392	153	148	198	197	226	239
12	38	19	20	Pierce	1461	147	155	204	202	226	249
13	38	19	20	Bottineau	1611	155	155	204	202	223	241
14	38	19	20	McHenry	1612	146	150	195	196	.	.
15	38	19	30	Ramsey	1387	152	153	202	202	220	242
16	38	19	30	Towner	1467	155	159	197	209	223	257
17	38	19	30	Cavalier	1617	155	154	214	202	247	242
18	38	19	50	Stutsman	1636	143	144	202	193	229	237
19	38	19	60	Barnes	1472	145	148	196	200	212	241
20	38	19	90	Dickey	1658	133	142	193	195	217	233
21	38	19	90	Sargent	1664	141	145	191	194	207	236
22	38	19	90	La Moure	1924	143	144	196	194	226	238
23	38	20	30	Pembina	1584	159	147	213	197	226	240
24	38	20	30	Grand Fork	1619	135	146	201	196	219	238
25	38	20	60	Cass	1473	141	142	200	192	228	237
26	38	20	60	Traill	1645	143	142	196	192	228	237
27	38	20	90	Richland	1399	136	144	183	196	205	.
28	38	20	90	Ransom	1974	140	145	198	197	220	.
29	38	21	10	Burke	1394	154	156	201	199	225	241
30	38	21	10	Ward	1457	156	159	202	209	232	246
31	38	21	10	Mountrail	1602	152	158	204	207	247	246
32	38	21	40	Dunn	1571	136	145	187	193	232	241
33	38	21	40	McKenzie	1627	141	138	187	185	.	.
34	38	21	40	Mercer	1630	149	145	198	188	240	226
35	38	21	50	Kidder	1909	140	148	198	198	214	240
36	38	21	70	Hettinger	1650	136	141	186	190	.	.
37	38	21	80	Burleigh	1653	142	152	197	201	.	.
38	38	21	80	Morton	1656	143	149	195	199	204	242
39	38	21	80	Emmons	1917	138	136	186	188	222	226
40	38	21	80	Grant	1918	131	149	191	199	217	.
41	38	21	80	Sioux	1920	134	136	186	188	.	.
42	38	21	90	McIntosh	1661	137	147	193	199	220	238
43	46	15	60	Minnehaha	1784	123	134	173	189	210	228
44	46	16	50	Brule	1676	118	121	183	.	201	219
45	46	16	50	Sully	1689	110	127	180	184	220	222
46	46	16	50	Jerauld	1755	109	128	175	183	198	223
47	46	17	10	Dewey	1485	123	134	185	187	212	230
48	46	19	20	Edmunds	1599	140	136	184	189	214	226
49	46	19	30	Roberts	1960	132	140	188	189	209	236

OBSPLT = Observed planting date (ground-truth).

FPLT = Feyerherm planting date (predicted).

OBSHEAD = Observed heading date (predicted).

R2HEAD = Improved Robertson Version 2 Model heading date (predicted).

OBSRIPE = Observed ripening date (ground-truth).

R2RIPE = Improved Robertson Version 2 Model ripening date (predicted).

Figure 8 shows how the models would perform in biowindow 1 (planting stage), 2 (heading stage), and 3 (ripening stage for barley) if the criteria described in table 5 for the reformatted procedure were applied to the Feyerherm and Improved Robertson Version 2 Models. For example, in figure 8 the vertical lines are the limits of the biowindow prescribed in the procedure. The vertical distance between these two lines is the width of the window in days for the biowindow (in this case, the window is 23 days). Each horizontal bar represents the location of the biowindow predicted by the model for each of the 49 segments.

In figure 8 for biowindow 1, it can be seen that there is a fair amount of overlap with the prescribed biowindow with a bias towards the positive side (i.e., the model is progressing faster than the observed stage). For biowindow 2, there is a fair amount of overlap with little apparent bias. For biowindow 3, there is poor overlap with a bias on the positive side. Table 7 gives the probability that the model prediction will be within the prescribed biowindow. This was achieved by dividing the total number of days predicted inside the ground-truth window by the total number of days within the window for all the segments. It can be seen from table 7 that the Feyerherm model is accurate in predicting the planting data for biowindow 1 (spring wheat planting) 73 percent of the time, the Improved Robertson Version 2 Model selects days in biowindow 2 (spring wheat heading) 73 percent of the time and in biowindow 3 (barley ripening) only 21 percent of the time.

TABLE 7.- REFORMATTED PROCEDURE BIOWINDOW SELECTION RESULTS

	Biowindow 1 (spring wheat, plant)	Biowindow 2 (spring wheat, head)	Biowindow 3 (barley, ripe)
Total percent outside window	27.0	27.0	79.0
Percent days past the window (model late)	22.0	15.0	75.0
Percent days before the window (model early)	5.0	12.0	4.0
Probability of being inside window	73.0	73.0	21.0

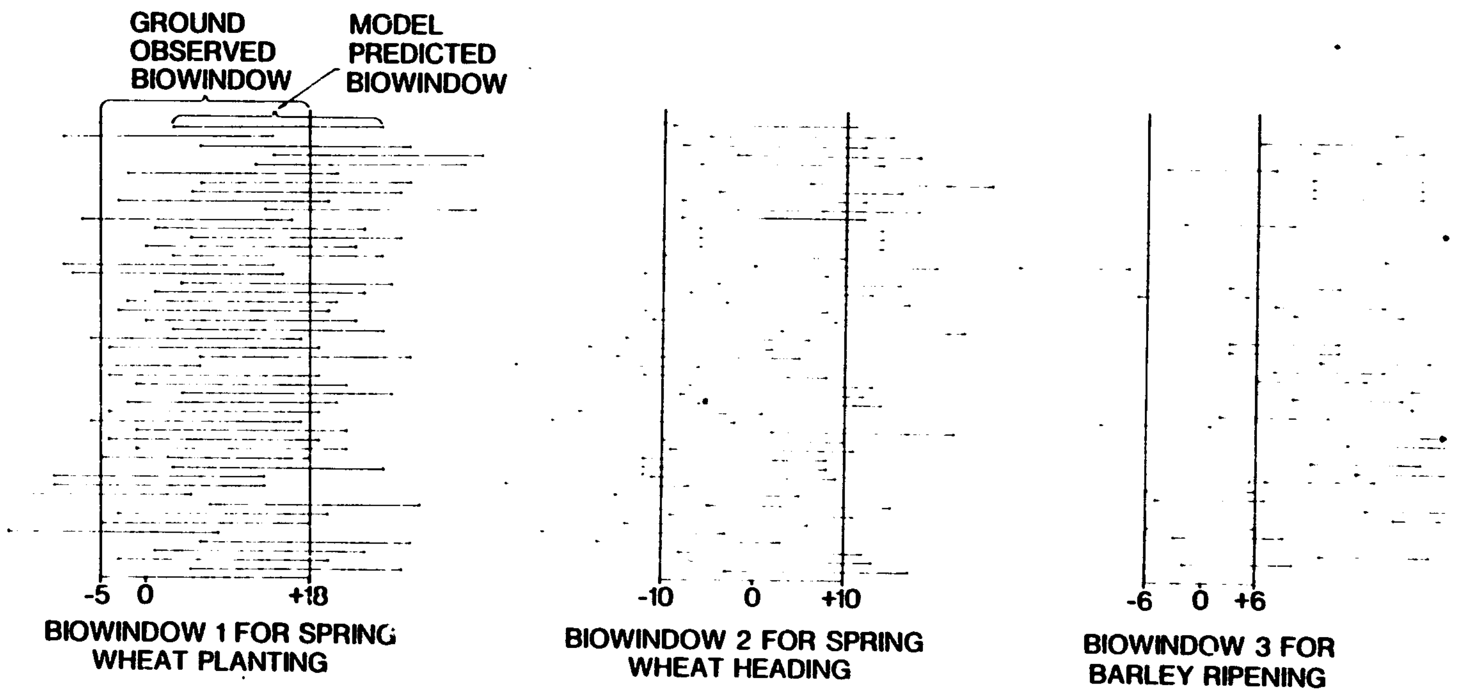

Figure 8.- Comparison of predicted biowindows versus the ground-observed biowindows for the Reformatted procedure.

10. DISCUSSION OF RESULTS AND CONCLUSIONS

It should be noted that the analysis described is based on only 1 year of ground-truth data. It is possible that the scale utilized for the ground-truth data may be too coarse (± half a stage) to be used in this type of analysis. This is evident from tables 3 and 4 where the errors are, on the average, one-tenth to seven-tenths of a stage off. A small shift in the ground truth could conceivably shift the results to yield a different set of conclusions.

As far as the Feyerherm and Normal planting date models are concerned, the Feyerherm model is closer to the true planting date, as can be seen from the results. It is the more realistic of the two models because it compensates for unusual spring planting conditions whereas the Normal model does not. The 1979 crop year was unusual in that both spring wheat and barley were planted later than usual (ref. 7).

There appeared to be no difference between any of the spring wheat models (i.e., R0, R1, and R2) applied to spring wheat, based on the ground-truth data available for evaluation. The differences in the magnitudes of the errors between the three models are so small as to be insignificant from a physical standpoint, as can be seen from tables 3 and 4. This is true for almost all the stage intervals within which the models were evaluated. Since the ground-truth data are no more accurate than a one-half stage, any differences in the models could probably be attributed to "noise." The same may be said of the Robertson and Williams models when they are applied to barley so far as the magnitudes of the errors are concerned. It can be seen from figure 7 that the Williams model is progressing too fast for barley.

So far as application to the Reformatted procedure is concerned, the Feyerherm model performs adequately for the planting stage while the Improved Robertson Version 2 Model performs adequately for the heading stage but not for the ripening stage.

Modifications to the Original Robertson Model yielded more accurate results at the later stages of spring wheat growth than the earlier stages. An example of the improvement in performance can be seen in figure 9 which shows the distribution of the errors for stages 5.0 to 5.9. Both the improved versions show a smaller amount of variability than the Original Robertson Model.

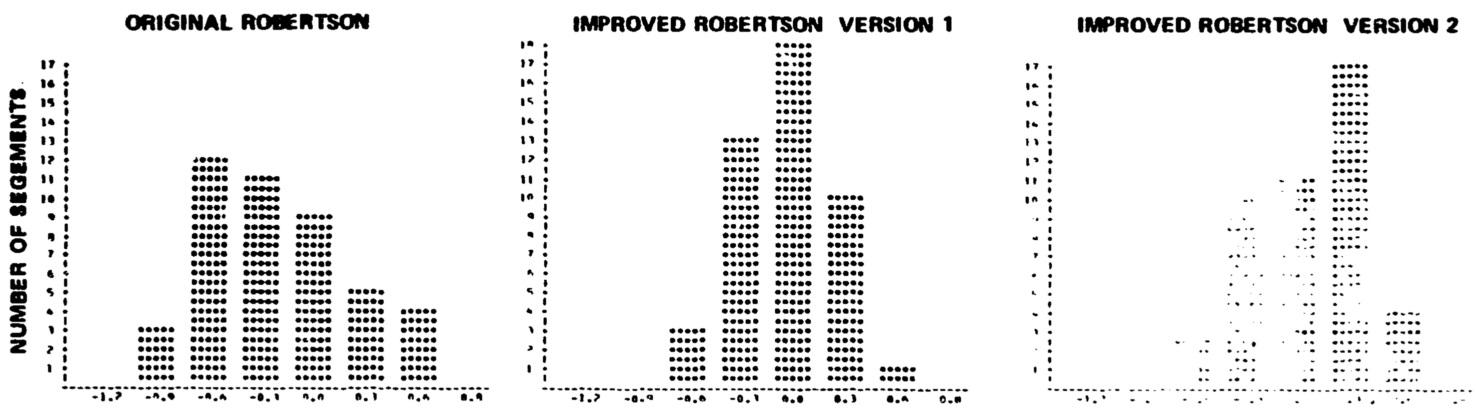

Figure 9.- Distribution of crop stage prediction errors for spring wheat stages 5.0 - 5.9.

11. RECOMMENDATIONS

Based on the results to date, it is recommended that the Feyerherm planting date model be utilized for both spring wheat and barley. It appears that the Improved Robertson Version 2 Model is the more useful for predicting spring wheat and barley development stages. However, the model is not adequate to determine window 3 of the Reformatted procedure, which is used to separate barley from spring wheat. Further research on biowindow 3 is required if accurate results are to be obtained for identifying this window.

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