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DEVELOPMENT OF A CORN AND SOYBEAN LABELING PROCEDURE FOR USE WITH PROFILE PARAMETER CLASSIFICATION 1

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16. Abstract

This document (1) provides background and documents some processes that are essential to the development of a green-number-based logic for identifying (labeling) crops in Landsat imagery and (2) records the supporting data and subsequent conclusions that resulted from development of a specific semiautomated labeling logic (i.e., for corn and soybean crops in the United States).

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DEVELOPMENT OF A CORN AND SOYBEAN LABELING PROCEDURE FOR USE WITH PROFILE PARAMETER CLASSIFICATION

Job Order 71-309

This report describes Corn and Soybean Labeling activities under the Small Grain Pattern Recognition job order of the Supporting Research project of the AgRISTARS program.

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LYNDON B. JOHNSON SPACE CENTER
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June 1982

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PREFACE

The research documented by this report was performed in support of the Scene Analysis Branch, Earth Resources Research Division, Space and Life Sciences Directorate of the Lyndon B. Johnson Space Center, National Aeronautics and Space Administration. All work was performed under Contract NAS 9-15800.

The following scientists and other personnel contributed to this work:

1. G. Badhwar of the Lyndon B. Johnson Space Center developed some of the techniques employed in the labeling procedure that is provided in this document. He is responsible for the multitemporal adaptation of the edge gradient technique used in eliminating impure pixels, for the greenness over brightness profile technique used in determining crops or noncrops, and for the direction of the computer adaptation of the growth stage prediction models used in predicting growth stages. Successful operation of the labeling process is highly dependent upon these techniques.
2. J. G. Carnes of Lockheed Engineering and Management Services Company, Inc., provided many constructive ideas for the preparation of this document.
3. G. L. Clouette, R. L. Fagan, C. L. Horton, J. L. Lastres, J. H. McCormac, C. A. Sivillo, and M. A. Tompkins of Lockheed Engineering and Management Services Company, Inc., provided invaluable computer programming and data processing support during the development and testing of this procedure.
4. B. A. Tolbert of Lockheed Engineering and Management Services Company, Inc., participated in testing the integrated labeling and classification system and provided many ideas for improving clarity in the procedures documentation.

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ABBREVIATIONS

AgRISTARS	Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing
ASCS	Agricultural Stabilization and Conservation Service
CPU	central processing unit
CRD	crop reporting district
GN	green number
JSC	Lyndon B. Johnson Space Center
LACIE	Large Area Crop Inventory Experiment
LARSYS	Laboratory for Applications of Remote Sensing System
NASA	National Aeronautics and Space Administration
PFC	production film converter
RMSE	root mean square error

1. INTRODUCTION

1.1 OBJECTIVES

The purposes of this report are (1) to document some essential processes for the development of a green-number-based logic for identifying (labeling) crops in Landsat imagery and (2) to record the supporting data and subsequent conclusions that resulted from development of a specific labeling logic [i.e., for corn and soybean crops in the United States (ref. 1)].

The corn and soybean labeling logic developed, while possibly being useful to other crop classification systems, was designed specifically to isolate and identify pure pixels to train a specific classifier. The classifier to be trained uses profile parameters of temporal greenness curves as the basis for separating crops of interest in Landsat data. In addition to high purity, it was desired that the labeling accuracy of crops also be high in order to keep the classification errors due to mislabeling at a low level. Earlier experimentation (ref. 2) had shown that this classifier could accurately classify both pure and mixed pixels in a Landsat scene with good accuracy when trained only with "superpure" ground truth pixels. It was now desired to see whether comparable accuracy could be attained using training pixels that were both isolated and labeled using either an automated or semiautomated labeler.

1.2 MAJOR CONSIDERATIONS

The identification of crops in Landsat imagery by Lockheed personnel supporting the Johnson Space Center (JSC) Earth Observations Division [i.e., during the Large Area Crop Inventory Experiment (LACIE), the Transition Year project, and the Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) program] has always been accomplished by the recognition of a temporal pattern of characteristics through the growing season of a particular crop of interest. If the time periods of occurrence of the recognizable characteristics can be isolated accurately year to year, and these periods do not overlap prohibitively with periods in which similar characteristics exist in other crops, the crop of interest can be consistently and accurately identified.

Since 1978, efforts to improve crop labeling have concentrated on methods for increasing objectivity and repeatability, as well as methods for improving utilization of computers. The Kauth transformations of greenness and brightness (ref. 3) have contributed much to these efforts. The temporal sequences of colors (i.e., nonred-red-nonred) signifying nonvegetation-vegetation-nonvegetation present in the false-color film products that are used in AgRISTARS are sufficiently relatable to plant greenness (as green numbers) and brightness to allow identification of the same sequences using greenness and brightness. Since greenness and brightness are numerical quantities generated from the Landsat channel values, efforts have been directed at creating computer logic using these numbers to identify the sequences in an objective and repeatable way. Reference 4 documents a labeling procedure for spring small grains that employs greenness and brightness in this context, and the research addressed in section 3 of this report provides a greenness methodology for identifying corn and soybeans as summer crops using the same basic technique. Brightness, in combination with greenness, is shown in section 3.4 to be valuable in separating corn and soybeans, both from each other and from certain other summer crops.

Of utmost importance, and perhaps the most elusive to predict, is the time frame of occurrence during a new crop year of the identifying characteristics of a crop. While the spectral characteristics of a crop, as recorded by the Landsat, seem to have a direct relationship to the phenology of the crop, accurate modeling of all the necessary phenological factors over large areas is very difficult. Section 3.7 covers the research carried out to adapt two growth stage prediction models for the purpose of predicting the key time periods necessary to the process of identifying corn and soybeans. It was desired by the National Aeronautics and Space Administration (NASA) technical monitor that these models be evaluated for use. The sensitivity of the procedure to the accuracy of the model and the compensating corrections are discussed.

The size of the area over which a crop must be identified is an important consideration both from the standpoint of predicting time of occurrence of identifiable stages of the crop and from the standpoint of the number of types of confusion crops that must be dealt with. The primary objective of this effort was to develop a labeling procedure for the designated U.S. Corn Belt States of Iowa, Illinois, and Indiana. The segments in the developmental data set were therefore chosen primarily to address the conditions in this area. But in order to increase flexibility, some peripheral areas and one area in the Deep South that grows primarily soybeans were considered. Logic was then developed for labeling these areas using the selected segments. Other areas would have been addressed if data had been available. It is felt that if growth stages can be predicted adequately and the necessary Landsat acquisitions are available segments would be processable in most areas of the United States.

Finally, the output from a labeling procedure designed to provide training information for a classification algorithm must take into account the requirements of the classifier. The Ho-Kashyap-type classifier used in profile parameter classification requires an equal number of pure dots in each crop category to be classified. The technical monitor established 90 percent or greater as the labeling accuracy goal for these dots. The steps taken during this research effort to isolate only pure dots are covered in sections 4.2.3 and 4.2.4 of this document. Numerous factors were considered in arriving at methodology to achieve the required labeling accuracy. Selection of the appropriate subset from the available pure dots for use by the classifier was accomplished with a random number generator. The number of dots required per crop category was established by separate research (ref. 2).

2. DATA SET

2.1 BASIC GUIDELINES

Guidelines from the NASA monitor were that a labeling procedure should be developed primarily for labeling 5- by 6-nautical-mile segments in the Corn Belt States of Iowa, Illinois, and Indiana; but, if possible, the procedure should also be usable in other areas of the United States that grow corn and soybean crops. Data availability for the full growing season would be assumed. Additionally, the Landsat data for the years 1978 and 1979 were designated for use in developing the labeling procedure. At least six segments for the year 1979 were also to be set aside for use in a verification test of the end-to-end labeling and proportion estimation procedure that would follow the developmental effort. These latter six segments were not to be used in developing the labeling procedure.

Additionally, ground truth data for the Iowa 1980 season were not to be used, because Iowa segments were reserved for use in a large-area demonstration of the procedure.

Because of the large-scale demonstration requirement, the procedure would therefore have to be executable using 1980 data.

2.2 DATA SET CHOSEN FOR DEVELOPMENT

Figure 2-1 is a map of states containing segments used in labeling procedure development. Counties in which the segments are located are shaded. Table 2-1 is a tabulation of the segments in increasing numerical order and shows the acquisitions used for generating spectral aids for use in the developmental techniques. This table also shows the percentage (by year) of area devoted to corn and soybean acreage that was inventoried by the ground surveyor.

Selection criteria for segments included the following factors:

1. Geographic distribution throughout Iowa, Illinois, and Indiana for the years 1978 and 1979.

TABLE 2-1.-DEVELOPMENTAL SEGMENT LIST

Seg. no.	State	CRD[a]	County	Year	Corn, %	Soybeans, %	Percentage of segment inventoried	Julian dates of selected cloud-free acquisitions
0127	Ind.	4	Montgomery	78	50.50	31.49	97.2	78152, 78161, 78197, 78207, 78243, 78252, 78269, 78306
				79	35.36	17.88	83.8	79121, 79138, 79174, 79210, 79219, 79247, 79300, 79309
0141	Iowa	8	Madison	78	24.39	19.18	98.7	78130, 78166, 78212, 78221, 78265, 78274, 78293, 78311
0185	Minn.	4	Traverse	78	6.57	8.01	85.1	78133, 78143, 78169, 78197, 78205, 78214, 78224, 78232, 78250, 78296
0195	Miss.	-	Pontotoc	78	1.38	56.88	97.8	78126, 78143, 78180, 78197, 78207 78215, 78233, 78251, 78269, 78306
				79	2.86	50.21	94.9	79121, 79166, 79184, 79220, 78247, 79265, 79273, 79300, 79309
0200	Miss.	-	Yazoo	78	0.94	27.74	99.6	78135, 78207, 78216, 78234, 78279, 78297, 78306
0205	Mo.	-	Clark	78	18.97	51.39	90.4	78137, 78155, 78218, 78246, 78272, 78290, 78308, 78318
0209	Mo.	-	Gentry	79	12.57	25.04	97.5	79144, 79162, 79234, 79270, 79288, 79306
0222	Nebr.	4	Dawson	78	49.00	0.00	98.9	78090, 78171, 78198, 78234, 78243, 78251, 78270, 78288, 78296
0809	Ill.	-	Ogle	78	57.61	13.70	92.3	78164, 78218, 78244, 78254, 78271, 78290, 78307
0828	Ill.	5	Kankakee	79	55.98	33.40	85.5	79121, 79157, 79176, 19202, 79220, 79230, 79265, 79301
0843	Ind.	6	Henry	78	32.80	31.71	98.4	78151, 78160, 78197, 78232, 78251, 78269, 78305, 78313, 78349
0893	Iowa	5	Webster	78	44.18	40.84	93.5	78131, 78221, 78266, 78267, 78311
				79	47.76	41.76	78.8	79126, 79162, 79216

[a] Crop reporting district.

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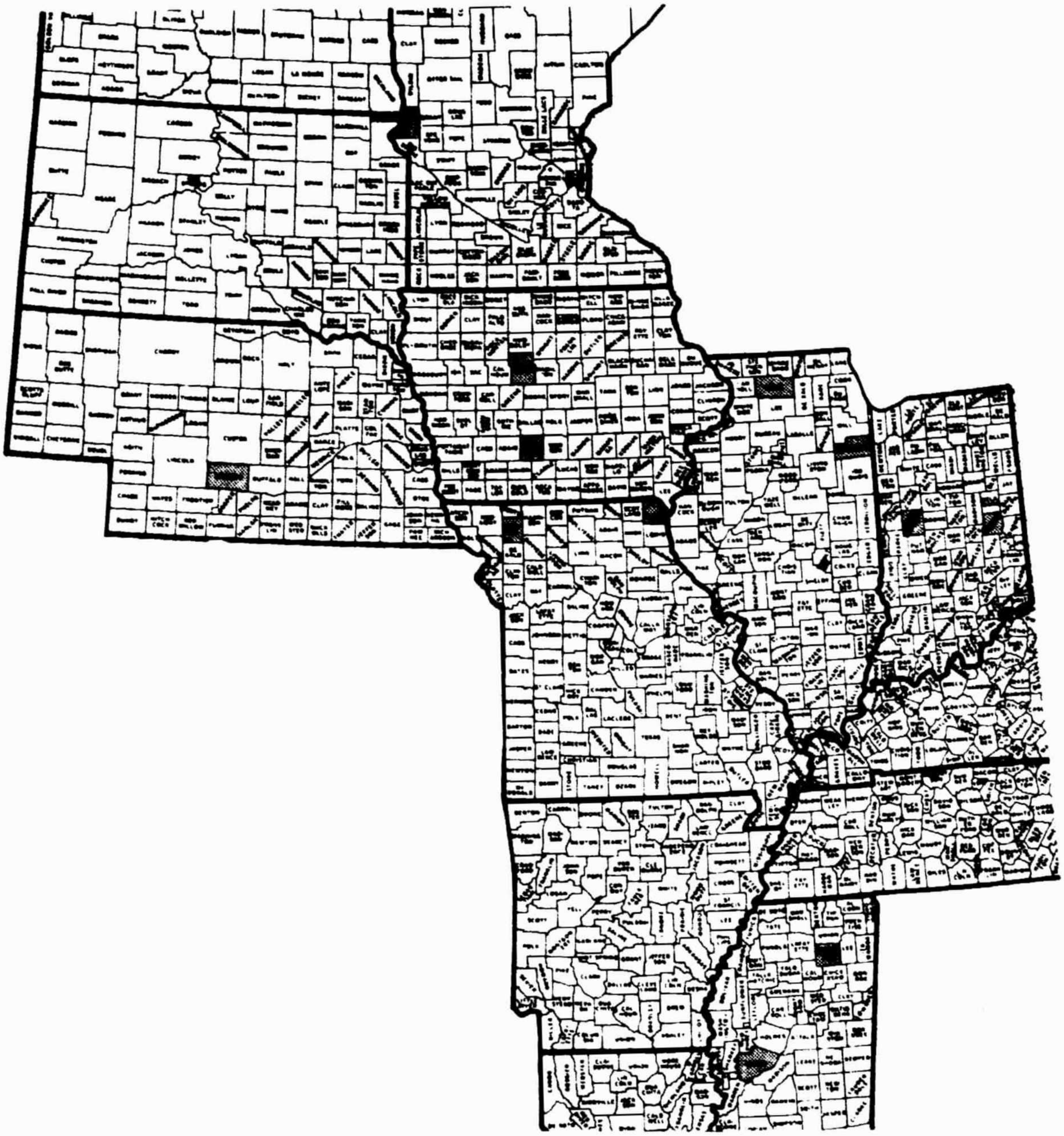


Figure. 2-1.- Counties containing developmental segments.

2. Cloud-free acquisitions for each segment to bracket the periods of planting, peak green-up, and harvest/postharvest for both corn and soybeans.

3. At least one cloud-free acquisition for each segment showing maximum interpreted color separation of color and soybeans (when both were present) in the production film converter (PFC) product 1.

4. At least one segment having corn but no soybeans.

5. At least one segment having soybeans but no corn.

6. The mix of confusion crops would be as typical as possible of the area in which the segment was located.

In addition, it was decided that segments would be included in the peripheral areas of Minnesota and Nebraska. The separability of spring small grains, sunflowers, and other possible confusion such as hay could thus be examined in the U.S. northern Great Plains.

In order to find a segment that grew soybeans but not corn, it was necessary to use Mississippi segments. The additional benefit of examining the separability of cotton accrued from using segments in that state. Segment data from both years were used in those cases where sufficient acquisitions were available.

2.3 DATA SET CHOSEN FOR VERIFICATION TEST

At the time the developmental segments were selected, nine segments in Iowa and Indiana were reserved for potential use in the verification test, in the hope that at least six of them would have sufficient acquisitions within the correct time periods for processing with the procedure. However, the procedure that resulted from the developmental research had selection criteria (see section 3.5) that eliminated all but four of the segments. Enough 1978 segments were selected at random from a listing, without regarding location, to make up the deficit. Table 2-2 lists all the segments, and figure 2-2 is a plot of the segments.

TABLE 2-2.- TEST SEGMENT LIST

Seg. no.	State	CRD	County	Year	Corn, %	Soybeans, %	Percentage of segment inventoried	Julian dates of selected cloud-free acquisitions
0144	Iowa	9	Wapello	79	19.88	21.33	96.8	79124, 79125, 79215, 79223, 79250, 79259, 79268, 79286, 79287
0145	Iowa	8	Warren	79	32.36	16.63	96.1	79125, 79134, 79197, 79215, 79224, 79242, 79251, 79260, 79287
0856	Ind.	4	Warren	79	31.42	25.77	96.9	79121, 79138, 79156, 79157, 79166, 79175, 79183, 79210, 79219, 79247, 79328
0864	Iowa	4	Crawford	78	46.21	11.95	97.7	78141, 78159, 78186, 78231, 78267
0881	Iowa	4	Monona	78	44.33	8.00	98.04	78141, 78159, 78186, 78222, 78231, 78267
0877	Iowa	4	Ida	78	48.30	24.88	79.3	78141, 78151, 78186, 78222, 78231, 78267
0883	Iowa	1	Palo Alto	79	39.17	35.39	95.4	79126, 79145, 79153, 79162, 79172, 79181, 79216, 79235, 79261, 79271, 79279, 79288

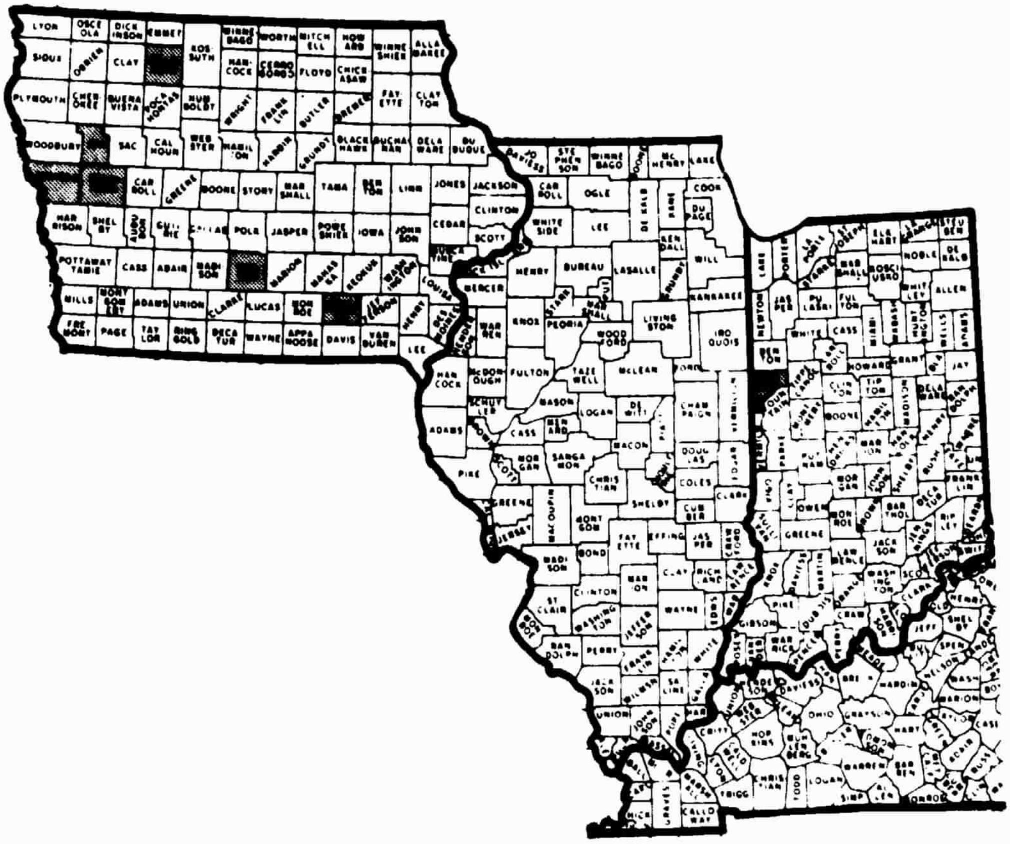


Figure 2-2.- Counties containing test segments.

2.4 DATA PREPARATION

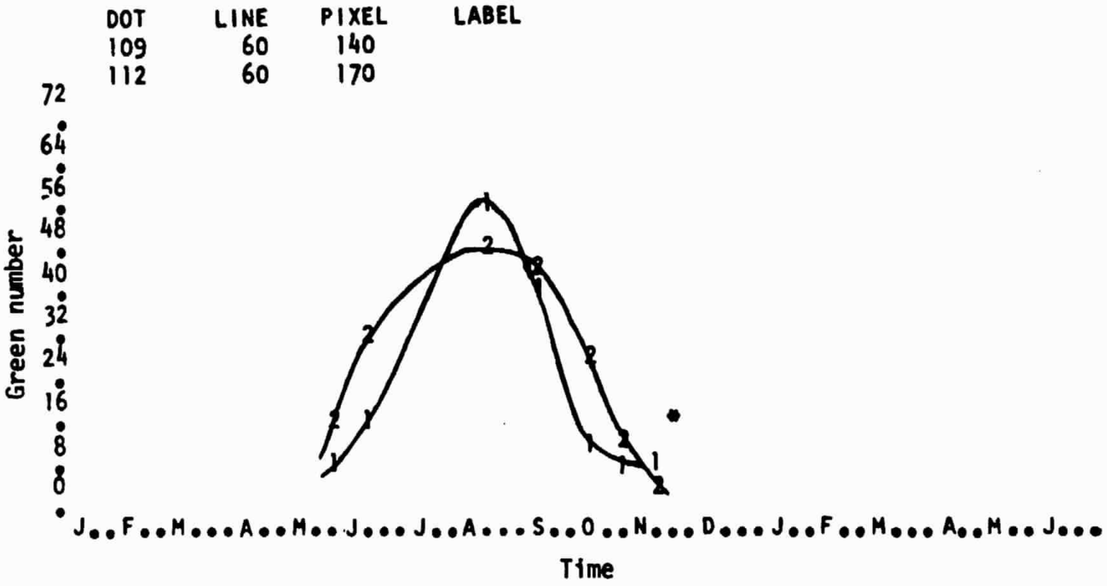
In order to establish a basis for relating the Kauth transformation values of the corn and soybean crops to identifiable characteristics of the crops in the PFC product 1 (imagery), it was necessary (1) to identify pure corn and soybean dots for use in the greenness and brightness study and (2) to generate spectral aids of the dots for studying the greenness characteristics of these crops versus confusion (pasture, other crops, and nonagriculture). Study was necessary temporally, using multiple acquisitions and single (but critical) acquisition dates.

Green number/brightness listings of pixels (dots) at the 209 grid intersections of the PFC products and also plots of green numbers through time and brightness through time of the dots were first generated. (See appendix A.) All 209 dots were then manually labeled with ground truth using ground truth annotated photographs to determine the identity of the fields or areas containing the dots. Following this, each dot was evaluated for purity using PFC products 1 and 3 and the green number through time trajectories. A pure dot was taken to be one that was located entirely within the same field (or area type) on all of the selected acquisitions. After the pure dot ground truth was determined, labeled scatter plots of corn and soybeans (C and Y) and other (N) categories were generated for use in single-date evaluation (appendix B) using only these pure dots.

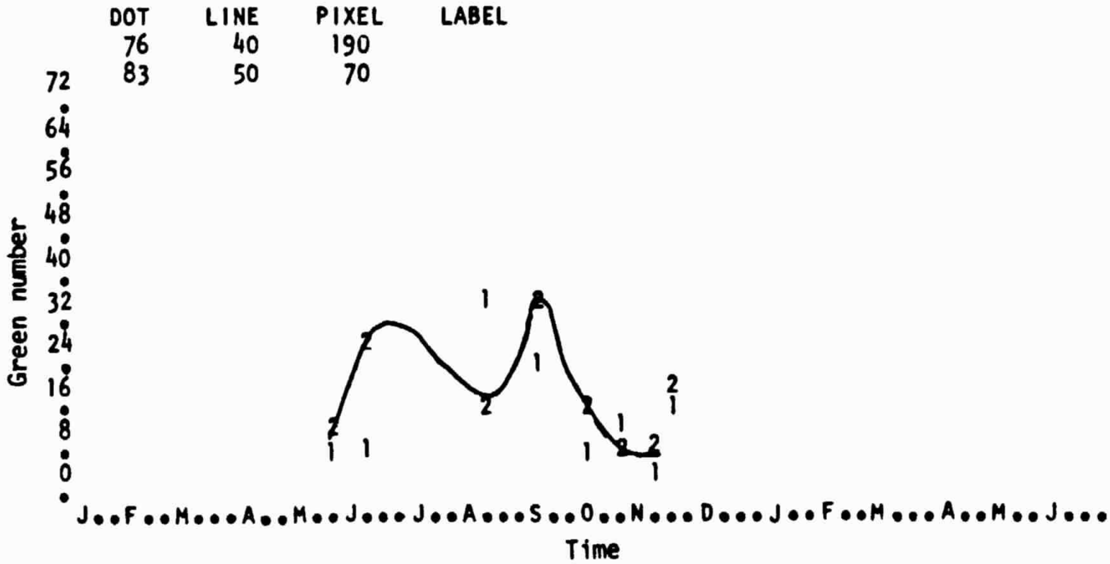
Labeling procedures presently in use at JSC employ green numbers rather than the Kauth greenness directly. Green numbers more closely approximate the greenness of the plants themselves and are generally more stable as a gauging device from acquisition to acquisition and from segment to segment. Green numbers represent total greenness minus bare soil greenness. Occasionally, there are errors in the calculation of green numbers, or nonrepresentative green numbers result from correct calculations because the formula is based on the premise that there will be at least some bare soil in the segment. In the absence of bare soil, some vegetation (of low greenness value) will be assigned bare soil greenness, and all of the calculations of green numbers will be biased to give values too low. It it therefore necessary to verify the validity of green numbers in each acquisition before basing decisions on green numbers. Before using the spectral aids described in the above paragraph to derive the labeling decision rules in section 3, the following criteria were applied to green numbers for each segment in the data set:

1. Green numbers of water or clouds should be zero or negative values.
2. Green numbers of plowed ground should be near zero or slightly negative quantities (within 0 ± 5).
3. Green numbers of greened-up crops and other solid red vegetation should be greater than or equal to 13.
4. Green numbers on the time plots of pure crop dots should form continuous normal growth curves [fig. 2-3(a) and 2-3(b)]. If summer crop dots throughout the segment show a deviation similar to the pixel in figure 2-3(b), a correction in the soil line is necessary.
5. The lower summer crop cluster should not appear to be chopped off at the bottom in the labeled scatter plot.

Soil line corrections were estimated for those acquisitions appearing to have bad green numbers, and spectral aids were then regenerated prior to using the data.



(a) Normal crop curves.



(b) Deviant crop curve.

Figure 2-3.- Growth curves for crops.

3. RESEARCH

3.1 GENERAL

Under the basic guidelines provided, the responsibility of Lockheed personnel was to arrive at an automated or semiautomated labeling logic for labeling a small number of pure (field) pixels in a Landsat scene with high accuracy. These labeled pixels would be used to train a Ho-Kashyap-type classifier that would classify pixels based on greenness profile parameters. Based on the major considerations discussed in the introduction and the experience of the author, the research would need to address the following areas in order to arrive at the basic elements of a procedure that would meet these requirements:

1. A repeatable logic for identifying corn and soybeans as summer crops, either directly or by first establishing that the fields contain crops.
2. A repeatable logic for discretely identifying corn and/or soybeans, either directly or by going through the step(s) described in subparagraph 1.
3. The identification of specific acquisitions required for identifying the crops and a method for selecting them (analyst, normal crop calendar, models, or other method).
4. Screening of acquisitions to eliminate possible errors caused by clouds, excessive misregistration, or bad data (banding, skip, etc.).

The following subsections address the above essential topics. Although acquisition screening and selection steps would precede crop logic execution in a procedure, the derivation of crop identification logic is documented first because acquisition requirements are necessarily based on this logic.

3.2 SELF-IMPOSED ACCURACY GUIDELINES

Following labeling logic development, it would be necessary to integrate this logic first with any accepted machine programs for pure pixel isolation; and, second, with the existing programs for generating profile parameters (e.g., CLASFYG; ref. 5) in order to execute a complete labeling and classification system. However, because of the constraints of the resources allocated and the short period scheduled for research and integration, there would be little time available for making trial runs of the completed classification system prior to formal testing. It was necessary, therefore, to establish some basic accuracy criteria for each labeling step to be researched in order to reasonably assure a high degree of labeling success during initial shakedown of the integrated system:

1. Acquisitions with more than 5 percent cloud cover, cloud shadows, or other bad data would not be used.
2. Segments with more than 5 percent confusion crops with unpredictable spectral characteristics should not be used (i.e., no more than 5 percent of the corn and soybean labels could in reality be other crops of nonseparability).
3. No more than 10 percent of a category of interest could be mislabeled because of acquisition selection. This takes into account the effects of executing all of the labeling logic using all labeling acquisitions selected.

It was hoped that cumulative errors from all of the above causes would be under 10 percent in the majority of the developmental segments. If this occurred, the overall guidelines for labeling accuracy established by NASA could be met.

3.3 LOGIC FOR IDENTIFYING CORN AND SOYBEANS AS SUMMER CROPS

The procedure used during the Transition Year project first separated cropland from noncropland by using a color sequence logic executed in a manual mode (ref. 6). While this was considered as a viable possibility for use in the procedure being developed, it was desired to see whether a green number logic could be developed that would identify corn and soybeans directly as summer crops without first identifying the fields as cropland. This logic, to be successful, would have to exclude noncropland from being called summer crops.

3.3.1 GREEN NUMBER LOGIC FOR IDENTIFYING CORN

First, a sequence of green numbers (GN's) for identifying corn was somewhat arbitrarily established in each of three time periods. The author's experience with spring small grain identification and some study of the imagery resulted in the following:

1. GN $\leq$ 10 during the planting period; this period would extend from the time natural vegetation reached GN > 10 until the time when no more than 5 percent of corn had reached GN > 10.
2. GN $\geq$ 13 during the period of maximum greenness; this period could begin when 95 percent of corn reached a green number of 13 and ideally would be past the time when 95 percent of spring small grains have peaked and dropped to a green number less than 13; and it could extend to the point at which no more than 5 percent of corn (while maturing) had dropped in greenness to GN < 13. Corn with green numbers less than 13 can give the spectral appearance of being trees.
3. GN $\leq$ 10 during harvest/postharvest; at least 95 percent of corn must have dropped to GN < 10 at the end of the season.

3.3.2 GREEN NUMBER LOGIC FOR IDENTIFYING SOYBEANS

Second, a sequence of green numbers for identifying soybeans was arbitrarily established:

1. GN $\leq$ 10 during the planting period; this period would extend from the time natural vegetation had reached GN > 10 until the time when no more than 5 percent of soybeans had reached GN > 10.
2. GN $\geq$ 13 during the period of maximum greenness; this period could begin at a point where at least 95 percent of the soybeans had reached GN $\geq$ 13, and it could extend to the point at which no more than 5 percent of soybeans had again dropped to GN < 13.
3. GN $\leq$ 10 during harvest/postharvest; at least 95 percent of soybeans would have dropped to GN < 10 at the end of the season.

The green number thresholds established were subject to adjustment at a later point in procedure development, if necessary. Some basis was needed at this point for examining the data at critical time periods, to obtain an estimate of the length of the critical periods and to make some correlations with other data, as explained in section 3.3.4.

3.3.3 DETERMINATION OF LENGTH OF CRITICAL PERIODS

The maximum duration of the critical periods for the two crops was determined using the following methods:

1. Planting periods: With a random selection of ground truth dots for each crop, the percentage accuracy of crop identification was determined using each acquisition that bracketed the period and during the period (using a green number threshold of 10). Particular attention was paid to acquisitions giving marginal accuracy in order to determine approximate limits of the period. Evaluation of the data for both 1978 and 1979 indicated that a period of 45 days for corn and a period of 30 days for soybeans met the specified conditions.
2. Period of maximum greenness: For each of the randomly selected dots (15 where possible), the greenness through time plot for the segment was used to approximate the date of maximum greenness. The date of occurrence of maximum greenness for each crop in each segment was taken to be the mean of the dates determined for the 15 dots. The accuracy of identification of corn (using the green number threshold of 13) was determined for each acquisition that bracketed the period of peak greenness and during the period of peak greenness. The same accuracies were determined for soybeans using the appropriate acquisitions. Particular note was taken of acquisitions with marginal accuracies in order to approximate the limits of this critical period for each crop. Evaluation of the dots for both 1978 and 1979 indicated that a period of about 30 days for corn and a period of about 25 days for soybeans met the specified conditions.
3. Harvest/postharvest period: For each acquisition after crop maturity, and using the 15 random dots of each crop, the accuracy of crop identification was determined using the green number threshold of 10. The length of this

period is of indefinite length after harvest, but a length of 35 days was arbitrarily chosen to illustrate the advantages and disadvantages of using this time period in a temporal identification logic.

3.3.4 GRAPHIC DISPLAY AND EVALUATION OF THE DATA

As part of the evaluation of whether the defined periods could be used in an automated or semiautomated procedure for identifying corn and soybeans as summer crops, it was necessary (1) to determine in which order to apply the green number criteria of the periods in order to minimize omission and commission errors, (2) to determine the relationships of the time periods for the two crops to each other and decide whether there were conditions under which the periods for one crop could be used to identify both crops, and (3) to determine how the periods could be related to standard growth stages on a year-to-year basis in order to help predict and determine the time of occurrence of the periods during each new crop year.

3.3.4.1 The Order in Which to Apply the Green Number Thresholds for the Time Periods

It was desired to keep the number of required acquisitions for labeling as low as possible and still meet the labeling accuracy requirement. This serves to minimize the number of segments that will be declared unprocessable, because certain required labeling acquisitions are missing.

Applying the green number thresholds in two periods and in the following order generally will result in the least omission of corn and soybeans as summer crops when using one acquisition per period:

Harvest → Maximum green

However, because most confusion crops and some trees and pasture will have a green number of 10 or less during the harvest period, a large number of these categories will be called summer crops (committed) and will not be eliminated by the acquisition in the maximum green period for corn and soybeans. One or more preemergence acquisitions will be required to eliminate the nonsummer dots thus committed, requiring a total of three labeling acquisitions as a minimum. Two examples of this are segments 0141 and 0809 for 1978:

Segment	Harv. acq. commission	After max. green acq.	After preemerg. acq.	Omission
0141	31 dots	22 dots	2 dots	1 dot
0809	27 dots	17 dots	---	1 dot

In the case of segment 0141, the available preemergence acquisition largely corrected for the high commission rate, whereas in segment 0809 none was available. Use of a harvest acquisition (although minimizing omission) has the additional disadvantage of not allowing the labeling and classification system to be utilized until the crops have been harvested.

Use of the following combination with a single acquisition in each period results in the highest omission, but results in low commission of nonsummer crops:

Maximum green → Preemergence

The maximum greenness acquisition picks up almost all of the corn and soybeans as summer crops and also eliminates a high percentage of nonsummer crops as "N". The preemergence acquisition then eliminates virtually all of the remaining nonsummer dots, but also calls some corn and soybean dots nonsummer crops. The omission problem was found to be particularly true in states other than Nebraska, Iowa, and Illinois. Using two or three preemergence acquisitions and applying the logic "is the green number 10 or less than 10 on any acquisition" was found to reduce omission to acceptable levels, because this increases the chance of detecting the planting signature of the crops. Segment 0843 for 1978 (in Indiana) is an example of the two-acquisition case:

Segment	Omission after max. green acq.	Omission after one preemerg. acq.	Omission combining two preemerg. acqs.
0843	1 dot	7 dots	2 dots

It was decided that the best order for combining acquisitions in the logic was maximum greenness acquisitions followed by preemergence acquisitions, because a total of two acquisitions in Nebraska, Iowa, and Illinois would be sufficient to minimize omission and commission; and three or more acquisitions would only be required in areas outside these states.

3.3.4.2 Relationships of the Time Periods for Corn and Soybeans to Each Other; Common Application

In order to display the data used to define the critical time period lengths, to show the relationships of the times of occurrence (overlap, gap, etc.) of the periods for the two crops, and to establish a basis for relating the periods to standard growth stages, the graphics in appendix C were prepared. These graphics are for corn and soybeans for 1978 and 1979. Each basic graphic has recorded on it:

1. The segment number and location (county, state).
2. The crop growth stages nearest the time of occurrence of the critical periods defined earlier. Dates of these stages are to be taken as points of reference for plotting the segment acquisitions on a relative time scale. The reference stages are from the best available CRD or state nominal crop calendar for the applicable year that most nearly applied to each segment. Reference stages for the periods were:

Crop	Period	Reference stage(s)
Corn	Preemergence	50% planted
Corn	Maximum greenness	50% tasseled, 50% dented
Corn	Harvest	50% mature
Soybeans	Preemergence	50% planted
Soybeans	Maximum greenness	50% podded, 50% turned
Soybeans	Harvest	50% mature

3. Each acquisition date for each segment plotted in relation to the reference growth stages.

4. The date of occurrence of growth stages recorded by the Agricultural Stabilization and Conservation Service (ASCS) enumerator during the ground data surveys. These dates were not always available.
5. Comments addressing the adequacy of acquisitions at early and late extremes of the critical periods.
6. Approximations of the limits of the critical periods.
7. References to the crop calendars used.

Information was added to the graphics incrementally as research progressed. Reference is made to them in later sections of this paper when they apply.

Inspection of the reference nominal crop calendars and the green number behavior of the two crops shows that in all areas where segments were selected soybeans were planted later than corn and peaked in greenness later than corn. Corn, however, remained in the field later than soybeans. There was significant overlap of the critical periods in the U.S. Corn Belt states and Minnesota. The approximate limits of the critical corn periods were duplicated on the soybean graphics, and the limits of the critical soybean periods were duplicated on the corn graphics in order to depict this overlap.

Tables 3-1 through 3-4 were compiled to show the relative times of occurrence of peak greenness and to determine the stability of the reference growth stages to peak greenness in the years 1978 and 1979. On the average, corn peaked 29 days earlier than soybeans. In view of the time duration of the critical maximum greenness periods of 30 days for corn and 25 days for soybeans, there would be an average overlap of 12.5 days between the periods for the two crops if the midpoint of each period were placed at exactly peak greenness. There were other factors, however, related to separation (or discrete identification) of corn and soybeans that needed to be taken into account for establishing relative locations of labeling windows (heretofore known as critical periods); these factors are discussed in section 4.4. This relative closeness of peak greenness showed, nevertheless, that a common logic could be used for identifying corn and soybeans as summer crops in the U.S. Corn Belt states and Minnesota. Farther south (at least in Mississippi), the

TABLE 3-1.- RELATIONSHIPS OF CORN PEAK GREENNESS TO STANDARD GROWTH STAGES FOR YEAR 1978

State	Seg. no.	Type calendar	CRD	Length of[a] planting to harvest	50-percent[b] planting	Prop. to tassel	Calandar[a] tassel date	Peak greenness	Prop. to denting	Calendar[a] denting date	Prop. to maturity	Calendar[a] maturity date	Begin[c] harv. (calc.)	Comment
Ind.	0127	CRD (1978)	4	151	149	0.38	206		0.60	240	0.76	265	(295)	Peak not determinable
Iowa	0141	CRD (1978)	8	142	153	0.37	206	214	0.65	246	0.79	261	(290)	
Minn.	C185	CRD nom.	4	158	138	0.37	206	211	0.70	248	0.78	260	(283)	
Miss.	0195													Corn insignificant
Miss.	02[illegible]													Corn insignificant
Mo.	0205	Iowa State		158	135	0.41	199	217	0.72	248	0.77	256	(299)	
Nebr.	0222	CRD nom. (1978)	4	128	145	0.51	212	213				263	(284)	Denting date not depicted
Ill.	0809	CRD nom.	1	171	132	0.39	198	205	0.61	237		257	(292)	
Ind.	0843	CRD (1978)	6	159	148	0.38	209	200	0.61	245	0.76	269	(282)	
Iowa	0893	Incomplete		158	135		199			248		256	(286)	Peak not determinable
				Means:	142	0.40	204	210	0.65	245	0.77			
							6 days		35 days					
						68 days								

[a] 50-percent stages, as shown on the crop calendar.

[b] Median date taken from observation of special fields, when available.

[c] Beginning of window C3 or Y3.

TABLE 3-2.- RELATIONSHIPS OF CORN PEAK GREENNESS TO STANDARD GROWTH STAGES FOR YEAR 1979

State	Seg. no.	Type calendar	CRD	Length of[a] planting to harvest	50-percent[b] planting	Prop. to tassel	Calandar[a] tassel date	Peak greenness	Prop. to denting	Calendar[a] denting date	Prop. to maturity	Calendar[a] maturity date	Begin[c] harv. (calc.)	Comment
Ind.	0127	CRD (1979)	4	165	128	0.42	206	209	0.65	244	0.79	266	(295)	
Mo.	0209	Iowa (1979)		174	132	0.39	203	218	0.66	250	0.72	260	(306)	
Ill.	0828	Ill. (1979)	5	157	132	0.42	202	199	0.66	239		253	(281)	
			Means:	165	131	0.41	204	209	0.66	244	0.76			
							5 days		35 days					
							73 days							
Miss.	0195	State nom.												Corn negligible
Iowa	0893	CRD (1979)	5	163	130		(197)			(238)			(286)	Peak not determinable

[a] 50-percent stages, as shown on the crop calendar.

[b] Median date taken from observation of special fields, when available.

[c] Beginning of window C3 or Y3.

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TABLE 3-3.- RELATIONSHIPS OF SOYBEAN PEAK GREENNESS TO STANDARD GROWTH STAGES FOR YEAR 1978

State	Seg. no.	Type calendar	CRD	Length of[a] planting to harvest	50-percent[b] planting	Prop. to podding	Calandar[a] podding date	Peak greenness	Prop. to turning	Calendar[a] turning date	Prop. to maturity	Calendar[a] maturity date	Begin[c] harv. (calc.)	Comment
Ind.	0127	CRD (1978)	4	145	(151)		(227)	237		(255)		(279)	(301)	
Iowa	0141	CRD (1978)	8	141	154	0.46	219	232	0.72	256	0.81	270	(294)	
Minn.	0185	CRD nom.	4	135	145	0.56	219	220	0.74	244	0.90	265	(280)	
Miss.	0195	State nom.		155	153	0.49	229	229			0.95	290	(296)	
Miss.	0200	State nom.		155	153	0.49	229	243			0.95	290	(309)	
Mo.	0205	Iowa (1978)		141	145	0.46	210	228	0.74	251	0.82	261	(290)	
Ill.	0809	Incomplete		132	(139)		210	220		(240)		(260)	(281)	
Ind.	0843	CRD (1978)	6	141	157	0.50	228	238	0.71	258	0.84	276	(300)	
Iowa	0893	Incomplete		141	154	0.46	219	(222)	0.72	(242)	0.81	270	(290)	
				Means:	151	0.49	222	232	0.72	252	0.88			

10 days

20 days

81 days

[a] 50-percent stages, as shown on the crop calendar.

[b] Median date taken from observation of special fields, when available.

[c] Beginning of window C3 or Y3.

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TABLE 3-4.- RELATIONSHIPS OF SOYBEAN PEAK GREENNESS TO STANDARD GROWTH STAGES FOR YEAR 1979

State	Seg. no.	Type calendar	CRD	Length of[a] planting to harvest	50-percent[b] planting	Prop. to podding	Calandar[a] podding date	Peak greenness	Prop. to turning	Calendar[a] turning date	Prop. to maturity	Calendar[a] maturity date	Begin[c] harv. (calc.)	Comment
Ind.	0127	CRD (1979)	4	139	142	0.53	220	226	0.78	255	0.89	266	(287)	
Mo.	0209	Iowa (1979)		136	146	0.52	214	229	0.82	254	0.87	264	(289)	
Ill.	0828	Ill. (1979)	5	136	144	0.53	220	218	0.80	255	0.85	266	(278)	
Miss.	0195	State nom.		155	162	0.41	226	242		(286)		(297)	(309)	
				Means:	149	0.50	220	229		(260)				
							80 days	9 days	31 days					
Iowa	0893	CRD (1979)	5	135	141		210			250		(258)	(278)	Peak not determinable

[a] 50-percent stages, as shown on the crop calendar.

[b] Median date taken from observation of special fields, when available.

[c] Beginning of window C3 or Y3.

crop calendars indicated a much wider separation in peak greenness, which would require execution of separate logic steps for the two crops where significant acreages are grown.

3.3.4.3 Relationships of Critical Periods to Standard Growth Stages

Tables 3-1 and 3-2 showed that there was relative stability during the two crop years between the times of occurrence of corn tasseling and denting as related to peak greenness. Fifty-percent tasseling occurred each year about 5 days earlier than peak greenness, and denting occurred about 35 days later than peak greenness. Crop calendar data for the two crop years also showed that 50 percent tasseling occurred approximately 41 percent of the way through the growing season; that denting occurred about 66 percent of the way through; and that maturity occurred about 77 percent of the way through. Provided that the length of the growing season is known, additional knowledge of either the planting date or the peak greenness date (determined spectrally) could enable one to make good approximations of the time of occurrence of the growth stages.

Tables 3-3 and 3-4 showed a relative existence of stability during the two crop years between the times of occurrence of soybean podding and soybean peak greenness. Fifty-percent podding occurred approximately 10 days before peak greenness. The relative time of occurrence of turning was not as stable. Some other relationships observed were that podding occurred about 50 percent of the way through the growing season and that maturity occurred about 87 percent of the way through. Using these relationships, some valuable approximations regarding occurrence of soybean growth stages can be made, provided that the length of the growing season is known and either the planting date or the peak greenness date is known.

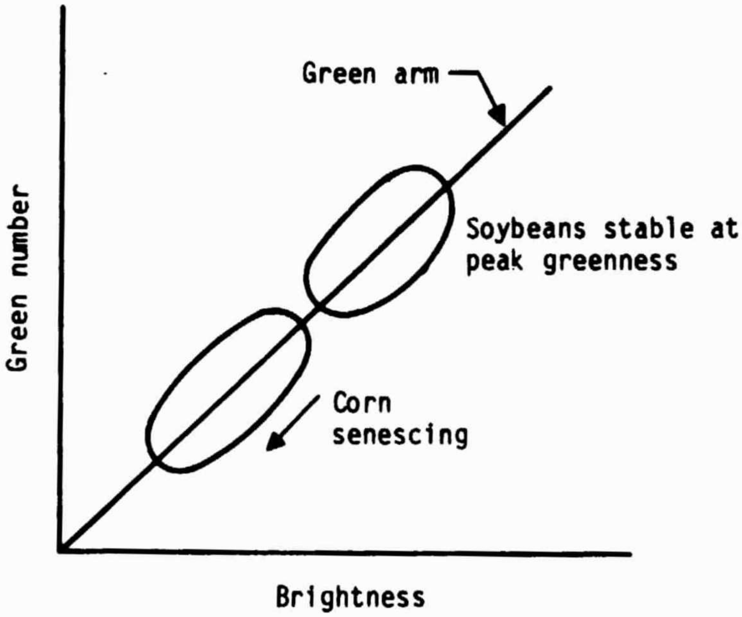
Based on the known dates for peak greenness for corn and soybeans and the seasonal tasseling, podding, and maturity relationships described in the last two paragraphs, the midpoints and time spans of critical periods were calculated for those critical periods not having acquisitions near the period extremes (and allowing interpretative approximations). Calculations of the postharvest period were made for all segments, based on maturity dates, and confirmed by interpretation, where possible. Real dates determined either by ground observation (planting and harvest) or by nominal crop calendar are unbracketed in tables 3-1 through 3-4. Those dates determined by calculations are bracketed. Fifty-percent planted dates in the tables were based on special fields observations, where possible.

3.4 LOGIC FOR DISCRETE IDENTIFICATION OF CORN AND SOYBEANS

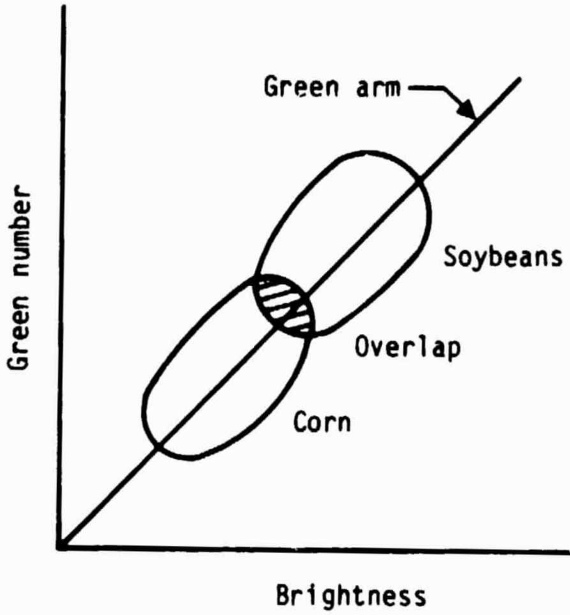
The ground-truth-labeled scatter plots were examined for all dates before, within, and after the periods identified in section 3.3.3 for maximum greenness of the two crops, to determine whether separation of corn and soybeans (when they occurred together) could be accomplished using the same acquisition used to identify the two crops as summer crops. The separability of the crops in each acquisition examined is recorded on the graphics in appendix C. The separability of other summer crops such as alfalfa, sunflowers, and cotton was also studied. Green number versus brightness scatter plots of the acquisition best illustrating separation are shown in appendix D for the various summer crop combinations. The following paragraphs explain the processes necessary to achieve separation (identification) of corn and soybeans in each case.

3.4.1 CORN AND SOYBEANS IN THE U.S. CORN BELT STATES

Acquisitions that fall in the maximum greenness period for identifying soybeans as summer crops serve best for separating corn from soybeans. However, an acquisition in which corn has senesced sufficiently to be past the bright red stage is best. If the peak greenness points of the corn and soybean crops are too close, this condition will not occur before soybeans begin to senesce, and overlap between the spectral distributions will then prohibit separation (fig. 3-1). If the correct acquisition is available (and selected), the bright red colors of soybeans and the dark reds and browns of the corn will be easily distinguishable in the PFC product 1; and a line separating the two crop distributions (colors) can be placed in the scatter plot for the acquisition.



(a) Ideal separation acquisition.



(b) Corn peak too near soybean peak (or soybeans not yet peaked).

Figure 3-1.- Good separation versus overlapping distributions.

Figures 3-2 and 3-3 further illustrate how greenness and brightness combine to give ideal separation. Note that greenness is the predominant separator early in the separation period (window) but that brightness may predominate late in the window. Dots plotted are typical pixels taken from segment 0943 for 1978.

As stated in the introduction, only pure dots could be labeled for training the classifier. While pure dots were defined as being those that were entirely within a field on all acquisitions used in labeling, some additional pixels in the best separation acquisitions looked like impure pixels or were atypical of corn and soybeans. These pixels were always lying outside the main dot clusters in the plots. After examining several plots, it was concluded that a width of 13 brightness counts spanning a line lying along the green arm would include all of the main cluster pixels and would exclude less than 5 percent of the total corn and soybean dots that were otherwise pure. It was therefore decided to put limiters in the plots to eliminate these atypical pixels from consideration in labeling, in the hope that this would enhance classifier training.

It was also noted that most of the corn dots that would be labeled "N" by the green number threshold of 13 were also below the limits of the main corn cluster and that they looked very much like trees in the PFC product 1; this confirmed that the earlier decision to use 13 as the threshold between crop and noncrop was appropriate.

3.4.2 CORN, CORN AND HAY, OR CORN AND SUNFLOWERS

These combinations of corn and other crops can be present in those acquisitions which best identify corn as a summer crop. Winter or spring grains may also be grown in areas bordering the U.S. Corn Belt where these combinations occur; but, by using logic already described, these latter crops should separate readily as being nonsummer crops. In areas where soybeans are not grown or in areas where the time separation between peak greenness of corn is too great to allow identification of corn (as a summer crop) using a green-up acquisition for soybeans, it is necessary to use the optimal green-up acquisition for corn (selected in accordance with section 3.3.1). Alfalfa

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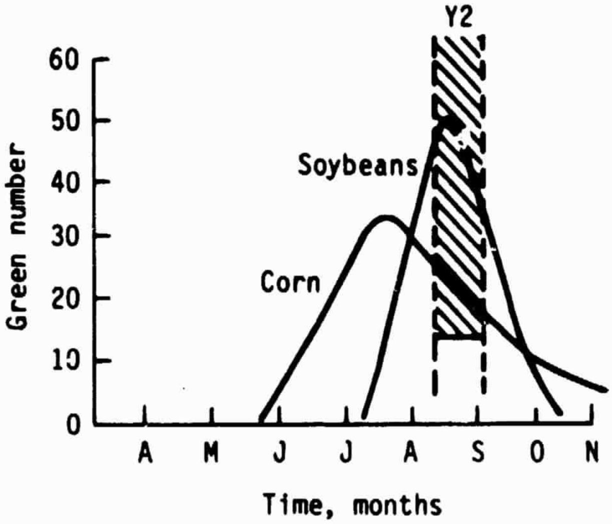
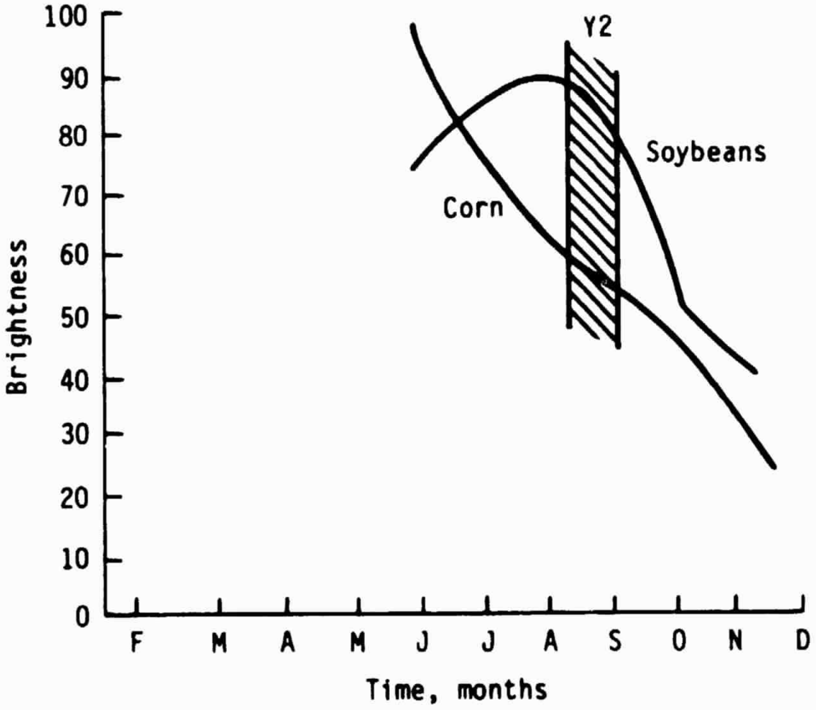


(a) Greenness through time.



(b) Brightness through time.

Figure 3-2.- Corn and soybean separation window duration.

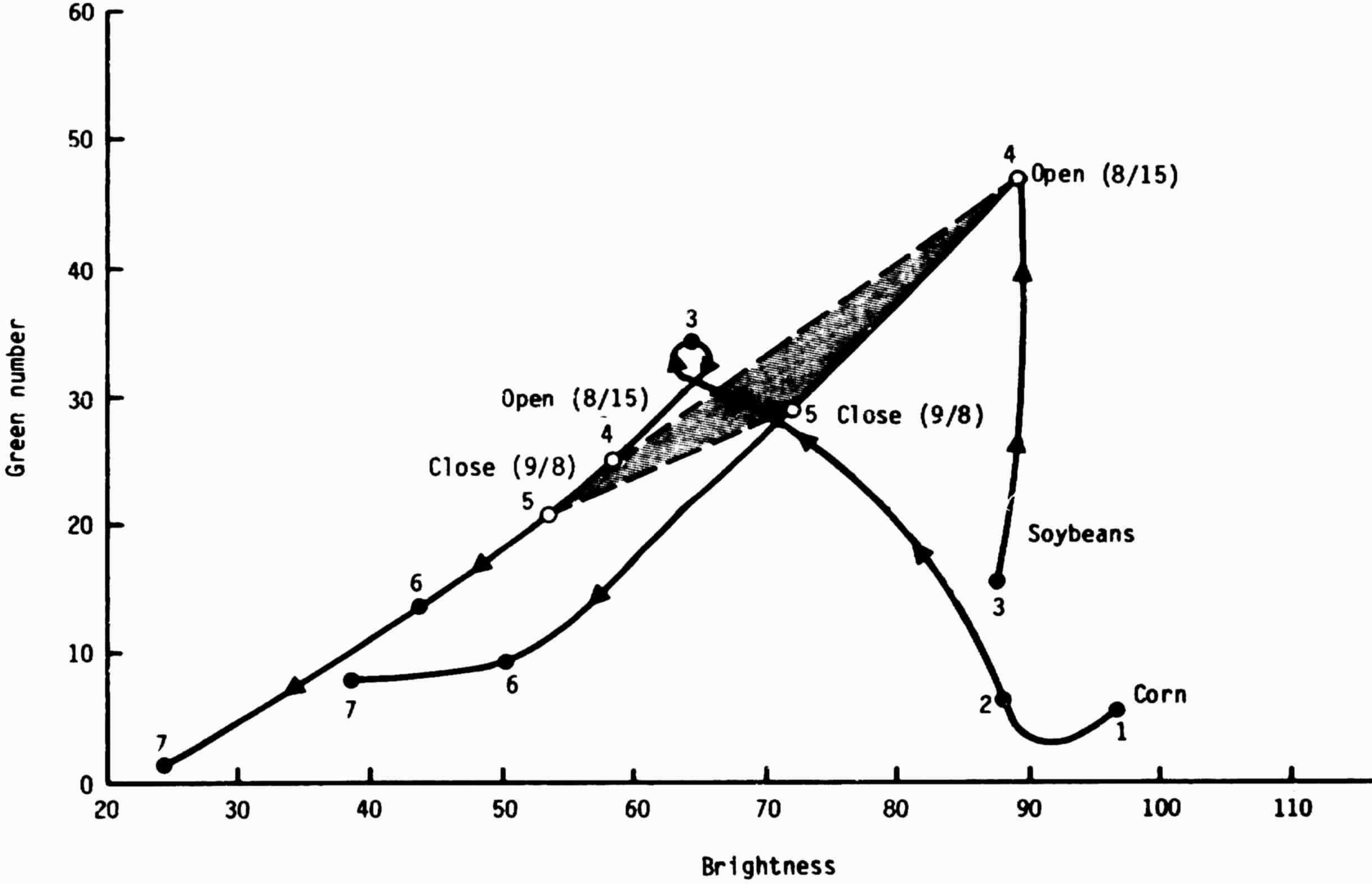


Figure 3-3.- Corn and soybean separation window duration illustrated by trajectories through time.

hay, which is the hay most likely to be confused as a summer crop, will be much greener and brighter than corn. This will also be true of sunflowers. In these scatter plots, or in plots where there is corn alone, the color of corn is dark red, and a boundary can be placed above the corn in the plots, separating its cluster from any confusion.

3.4.3 CORN AND SPRING GRAINS

Another possibility in and north of the U.S. Corn Belt states is for corn and spring grains to be grown without soybeans being present. When this is true, the optimal green-up acquisitions for identifying corn may also contain spring small grains with green numbers higher than the corn threshold of 13; this will identify the spring small grains as being a summer crop. However, it was shown using segment 0185 in Minnesota that in acquisitions late in the critical corn period the green numbers of spring small grains tend to drop below 13. The logic "is the green number greater than or equal to 13 on all acquisitions?" will retain most corn as a summer crop but eliminate most of the spring small grains, provided that one early acquisition and one late acquisition are picked within the critical period. The corn can then be isolated in the scatter plot of the late acquisition in the same way as in section 3.4.2.

South of the U.S. Corn Belt, two acquisitions should not be required because spring small grains in more southerly states are earlier maturing varieties.

3.4.4 SOYBEANS OR SOYBEANS AND SPRING GRAINS

Segments have not been found in the U.S. Corn Belt states where soybeans are present without corn, although Missouri has some segments where the percentage of corn is low (e.g., segment 0209 has about 12.6 percent corn). In the critical maximum green acquisitions for soybeans (as selected in sections 3.3.2 and 3.4.1), the spring small grains will be below the summer crop green number threshold of 13. The soybean cluster will be easy to isolate by viewing the bright red color of soybean dots in the PFC product 1 and placing a line in the summer crop scatter plot just below their lower limit.

3.4.5 CORN, SOYBEANS, SPRING GRAINS, AND SUNFLOWERS

Landsat segments containing corn, soybeans, spring small grains, and sunflowers are not known to exist south of latitude 43° N. in the United States. One segment was found north of latitude 43° N. in Minnesota (segment 0185) that had sufficient acquisitions at the right times to illustrate the separation of corn and soybeans when this combination of crops is present.

As shown in section 3.4.3, use of both an early acquisition and a late acquisition in the maximum greenness period for corn will separate corn from spring small grains. This is accomplished by applying the logic "is the green number greater than or equal to 13 on all acquisitions?" to the two acquisitions. The logic holds true for corn, but not for the soybeans because they will not be sufficiently emerged in these acquisitions.

In order to retrieve the soybean dots after identifying corn, it is necessary to use an acquisition late in the soybean maximum greenness time period and generate another scatter plot. All dots not previously called corn are subjected to the logic "is the green number greater than or equal to 13?", and only the dots meeting this criterion are plotted on the scatter plot.

While the corn is gone, sunflowers as well as soybeans are now identified as summer crops. Inspection of the plot shows, however, that the sunflowers occupy the normal position of corn on the plot and are separated (in greenness and brightness) from the soybeans. The soybeans will be bright red in the PFC product 1, and the sunflowers will be dark red. Placement of a line in the scatter plot immediately below the last dot that is bright red in the scatter plot correctly separates 100 percent of the soybeans with no sunflower confusion remaining.

Although requiring three acquisitions in the maximum greenness periods for corn and soybeans and application of summer crop logic twice, separation of corn and soybeans in this rather confusing mix of spring crops and sunflowers is possible. This is an example in which usage of temporal information on both greenness and brightness is shown to be an effective method for labeling crops that peak in greenness at about the same time.

3.4.6 SOYBEANS AND COTTON

The only available blind sites growing soybeans but not corn were located in Mississippi. Application of the same logic, "is the green number greater than or equal to 13?", to the maximum greenness acquisition for soybeans resulted in effective identification of soybeans as a summer crop in the Mississippi segments (numbers 0195 and 0200). However, cotton also was called a summer crop. Trial and error placement of limiters in the scatter plot showed that 80 percent of soybeans would be called summer crops, committing only two cotton dots in segments 0195 and 0200 (1978), if the distance between the limiters was widened to 15 counts. Only 69 percent was called summer crops using a lesser width of 13 counts. The necessity for the increased width between the limiters could be due to brighter soil or to existence of a different sun angle. Soils south of the U.S. Corn Belt generally contain more sand (ref. 7).

It was noted that soybeans in Mississippi were not as bright red in PFC product 1 as they were in the U.S. Corn Belt and other more northerly states. It was not possible to place a line perpendicular to the green arm in these segments that would clearly separate soybeans as a separate distribution along the green arm. The amount of corn, however, was insignificant (<2 percent) and had senesced to the point that it was no longer identified as a summer crop using the acquisition suited to soybeans. Therefore, there was no confusion with corn.

3.4.7 HAZE PRECAUTION

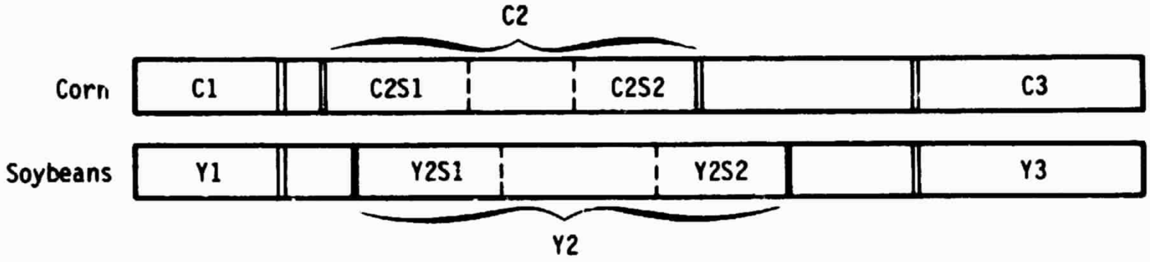
Available hazy acquisitions in the development data set that fell in separation windows for any option were examined to determine the effect of haze on the amount of brightness spread in the crop clusters.

It was evident that in some separation acquisitions haze caused some crop dots to be outside the boundary of the second limiter because of increased brightness width of the crop clusters. The plot for acquisition 230, segment 0828, is an example of this. As a general rule, if more than 10 percent of the pure dots for either corn or soybeans are lost to labeling in this manner, the acquisition is too hazy for use.

3.5 USE OF LABELING WINDOWS FOR DESIGNATING CRITICAL ACQUISITIONS

Section 3.3 showed that the green numbers could be used in the periods of preemergence, maximum greenness, and harvest and postharvest to identify corn and soybeans as summer crops. There is sufficient overlap in some areas between the periods for the two crops to allow common acquisitions to be used for this purpose. Additionally, section 3.4 showed that acquisitions in the maximum greenness period can be used to make discrete identification of corn and soybeans (after they are known to be summer crops) using green number versus brightness scatter plots. The times of occurrence of the critical periods were shown in section 3.3.4 to be rather stable when related to crop growth stages reported in historical crop calendars. It was decided, because of this year-to-year stability, to establish labeling windows at the times of the critical periods.

The establishment of labeling windows would provide a simplified terminology for designating the time periods in which acquisitions must occur. Based on the study of the dots, the following approximate window relationships should be established. (Note: C = corn; Y = soybeans.)



The alphanumeric codes appearing in this diagram represent the following windows and subwindows:

Planting windows: C1 and Y1

Green-up windows: C2 and Y2 (subwindows C2S1, C2S2, Y2S1, and Y2S2)

Postharvest windows: C3 and Y3

The diagram illustrates that the planting and postharvest windows for corn and soybeans almost coincide and that the green-up window for soybeans is later than the corresponding one for corn. These windows are based on the critical time periods plotted in the appendix C graphics. Appendix E defines each window in terms of a specific number of days. The amount of overlap between the C2 and Y2 windows will vary according to location. Two independent sets of windows were established in order to increase flexibility of their use, depending upon geographic location and the crop mix. Subwindows were established in order to facilitate designation of early or late acquisitions within windows.

Figure 3-4 illustrates the location of these windows in relation to greenness through time profiles of typical crops in and near the U.S. Corn Belt states. Note that window C1/Y1 greenness threshold of 10 separates summer crops from pasture and winter wheat (or winter grains). Window C2/Y2 threshold of 13 identifies corn and soybeans as summer crops. Window C3/Y3 is seen as not being very critical, but occasionally it is effective in separating out trees not called "N" by the other logic. Cotton, the only other summer crop addressed but not shown in the figure, peaks in greenness a little earlier than soybeans and separates using window Y2 brightness as described in section 3.4.6.

Based on the window definitions and their possible applications, as explained in sections 3.3 and 3.4, it was now possible to establish a series of labeling options. Table 3-5 lists the possible crop mixes of major crops observed in the development segments and establishes an appropriate labeling option for each mix. The option designates particular logic and combinations of windows

TABLE 3-5.- OPTION SELECTION TABLE

Major crops present (>5% of pseudocounty)	General area of the United States		
	Between lat. 37° N. and 43° N.	North of lat. 43° N.	South of lat. 37° N.
Corn and soybeans	1	1	
Corn, soybeans, and spring grains	1	1	
Corn	2	2	
Corn and hay	2		
Corn and sunflowers		2	
Corn and spring grains	2S	2S	2
Soybeans	3	3	5
Soybeans and spring grains	3	3	
Corn, soybeans, and sunflowers	3S	3S	
Corn, soybeans, spring grains, and sunflowers		3S	
Soybeans and sunflowers		4S	
Soybeans and cotton			5
Summer crop (general)	0	0	0
Winter grains	Included in all options	Included in all options	Included in all options

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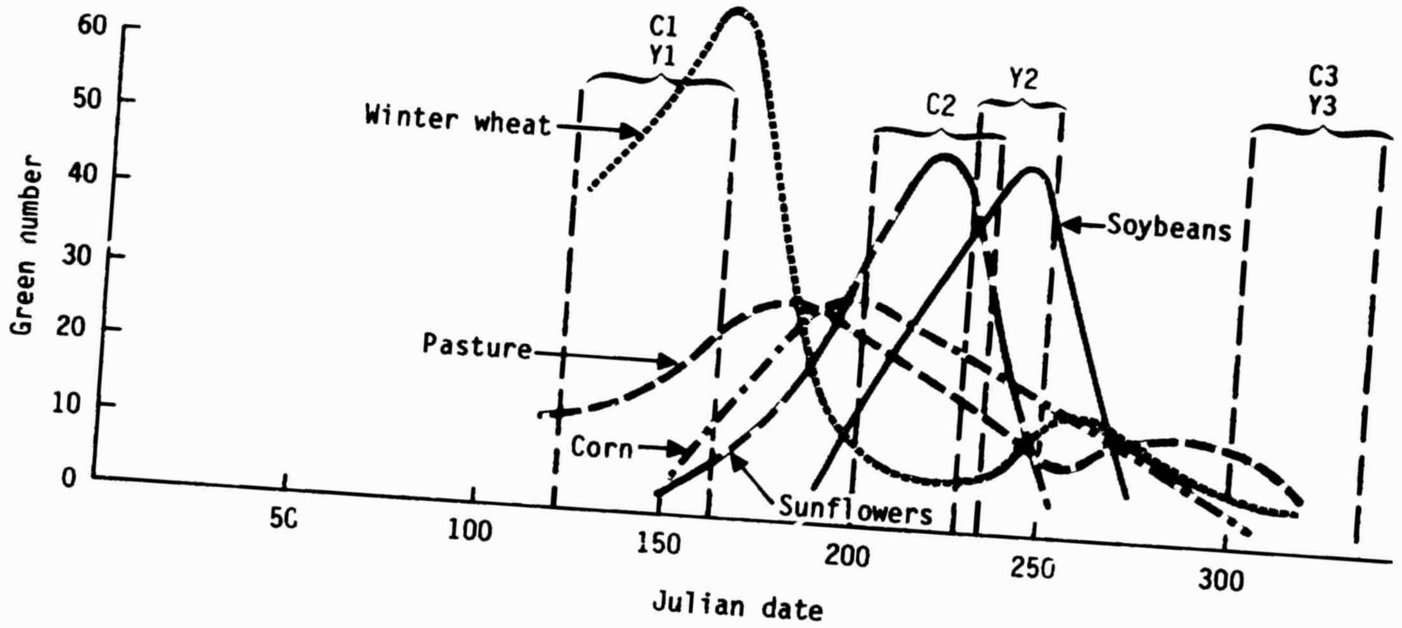

Figure 3-4.- Window relationships to greenness curves.

to be used in each case. Options that use subwindows are designated with an "S" and are called split options. Blank spaces in the table indicate that either (1) the crop combination listed is not known to be grown at the particular latitude or (2) no segments were available to confirm the effectiveness of the option. For example, an option for processing corn and sunflowers south of latitude 37° N. was not provided because this combination of crops was not observed in any developmental segments at these latitudes; and no segments were available for corn south of latitude 37° N., although it was probably processable using option 2. Further study would be required to establish option effectiveness for the blank spaces.

The latitude dividing lines of 37° and 43° N. were established to roughly enclose the states comprising the U.S. Corn Belt. It was also noted that, partly because of soil factors and crop types and varieties being grown, crops north and south of this latitude envelope needed slightly different labeling rules (options) to separate them from corn or soybeans when compared to rules for the U.S. Corn Belt.

Options are designed strictly for labeling corn and/or soybeans, with or without the presence of other crops. Although some options might prove useful as tools in labeling other crops, further testing is advised prior to making such a usage (e.g., for sunflowers).

Because of sampling techniques used in the United States, which place segments primarily on cropland (pseudocounty), a lower limit of 5 percent was used as a cutoff for categorizing crops in the major (or significant) category. In an area where sampling is not as precise or in areas outside the United States where statistics are not as accurate (historical for region, province, etc.), a lower limit of 2 percent is recommended because large fluctuations may occur. Such fluctuations may cause acreages in individual segments to be quite large.

Table 3-6 specifies the number of acquisitions to be used in each window when applying a specific labeling option. Footnotes to the table explain that

TABLE 3-6.- WINDOW ACQUISITION[a] REQUIREMENTS FOR EACH LABELING OPTION

Window or subwindow	Labeling option									
	0	[b]1	[b]1C	[b]1Y	2	2S	3	3S	4S	5
C1[c]					1 to 3	1 to 3		1 to 3		
Y1[c]	1 to 3	1 to 3	1 to 3	1 to 3			1 to 3		2 to 3	2 to 3
C2					1					
C2S1						1		1		
C2S2						1		1		
Y2	1	1	1	1			1			1
Y2S1				[d]1				[d]1		
Y2S2								1	1	
C3					[e]0 to 2	[e]0 to 2		[e]0 to 2		
Y3	[e]0 to 2	[e]0 to 2	[e]0 to 2	[e]0 to 2			[e]0 to 2		[e]0 to 2	[e]0 to 2

[a] Consecutive days will not be counted in determining minimum numbers of acquisitions or for establishing any maximum limitations.

[b] The overlap between windows C2 and Y2 must be <15 days, and the gap between these windows must be <5 days in order for option 1 or 1C to be a valid option. If gap ≥5 days, option 1Y may be used but 1C may not.

[c] A minimum of one acquisition is required in window C1 or Y1 in all options. In areas where potential corn and/or soybean fields green up prior to spring plowing, a minimum of two acquisitions is required in order to increase the probability of detecting the planting signature. A minimum of two acquisitions is required in all corn and soybean states except Iowa, Illinois, and Nebraska.

[d] Optional; may replace an acquisition in another window or subwindow under certain conditions (to be exercised by analyst only; see expanded option definitions in appendix F).

[e] One or two acquisitions are desirable but are not required.

consecutive-day acquisitions are not to be used when totaling the acquisition requirements. Footnotes also key in certain restrictions already explained in an earlier section. This table capsulizes the information in appendix F, which additionally provides alternative option selections (for some options).

Options that use corn windows are for areas that grow corn but no soybeans, or areas where there is low overlap between corn and soybeans.

3.6 LABELING OPTIONS AND DEVELOPMENT SEGMENTS; ACCURACIES ATTAINED IN THE MANUAL MODE

For each labeling option previously defined, logic diagrams were constructed (appendix G). Using the green numbers in the necessary acquisitions, each diagram shows the steps necessary to arrive at identification of summer crops for the option. Note that a single diagram may apply to more than one option. Summer crop dots (Z) from these options are then identified as either corn or soybeans by applying the appropriate scatter plot technique from appendix D. An option was selected for each development segment, and the summer crop logic was executed manually for each pure dot in the segment. Table 3-7 shows the results obtained. Separation accuracy of the dots was then evaluated using the acquisitions giving the best separation and placing the decision boundary as described in section 3.4. See table 3-8 for these results.

Note that accuracies of both summer crop identification and final corn and soybean separation for 1978 are less than for 1979. The reason for this is unknown, but the procedure may not compensate for such factors as wide variations in moisture or episodic events. The accuracies attained outside the U.S. Corn Belt compared well with accuracies in the U.S. Corn Belt states (the Missouri segment is in a marginal location). The least accurate result was obtained for the segment in the spring small grains area (73 percent), and the majority of the error was caused by low corn accuracy. However, there were only seven pure corn and eight pure soybean dots to be labeled in this segment.

TABLE 3-7.- LABELING ACCURACY OF THOSE PURE DOTS CONSIDERED

Area	Seg. no. (year)	Z:Z,[a] %	N:N,[b] %
U.S. Corn Belt			
Ind.	0127 (1978)	93	100
	0843 (1978)	87	100
Ill.	0809 (1978)	(c)	(c)
Iowa	0141 (1978)	94	96
	0893 (1978)	97	100
Mo.	0205 (1978)	68	91
	Average	89	91
Spring small grains			
Minn.	0185 (1978)	73	93
Pure corn			
Nebr.	0222 (1978)	96	98
Pure soybeans			
Miss.	0195 (1978)	94	94
	0200 (1978)	77	97
	Average	88	97
U.S. Corn Belt			
Ind.	0127 (1979)	95	80
Mo.	0209 (1979)	89	100
Ill.	0828 (1979)	97	100
Iowa	0893 (1979)	97	90
	Average	96	98
Pure soybeans			
Miss.	0195 (1979)	94	97

[a] Z:Z = Z called Z.

[b] N:N = N called N.

[c] No planting date.

TABLE 3-8.- SEPARATION OF CROPS CALLED SUMMER CROPS

(a) 1978 separation of crops within limiters

Area	Seg. no.	Corn, %	Soybeans, %
U.S. Corn Belt	0127	100	95.5
	0843	100	100
	0809	93.5	87.5
	0141	100	100
	0893	100	96
	0205	89	60
Average		97	89
Spring small grains	0185	100	87.8
1978 Average		97	89

(b) 1979 separation of crops within limiters

Area	Seg. no.	Corn, %	Soybeans, %
U.S. Corn Belt	0127	98.4	100
	0209	100	100
	0828	100	100
	0893	100	100
1979 Average		100	100

3.7 PREDICTION OF TIME OF OCCURRENCE OF LABELING WINDOWS; ACQUISITION SELECTION

The goal of acquisition selection has always been to select those acquisitions which give the best spectral separation of the crop of interest. For labeling purposes, this translates into those acquisitions having the necessary characteristics for crop identification. Features recognizable in the imagery using imagery interpretation methods may be "gauged" using green numbers or other indices of vegetation in order to make this identification using the key acquisitions. Some methods available for selecting these acquisitions, with pros and cons, are as follows.

3.7.1 HISTORICAL CROP CALENDARS ADJUSTED BY INTERPRETATION

In this method, growth stages are assumed to relate directly to labeling windows. Historical crop calendars, showing key growth stages on one or more years of data, are compared to the PFC imagery products to determine whether the crop of interest appears to be at the correct historical growth stage on the date of a given Landsat image. The interpreter uses his experience (using one or all available acquisitions) to identify the crop of interest and to interpret the approximate growth stage of the crop of interest in each acquisition. Selections of the acquisitions most nearly having the necessary crop characteristics are then made.

This method, although giving the analyst the satisfaction of feeling that he is exerting direct influence on the outcome of labeling and classification, is very prone to error. Reference 8, which addresses some of the weaknesses of the procedure used during the Transition Year, attributes much of the labeling error to using this method of acquisition selection. The main weakness is the average analyst's inability to recognize all of the growth stage variability in the crops. Also, inaccuracies in the historical crop calendars often confuse the analyst.

3.7.2 HISTORICAL AVERAGES OF GROWTH STAGE OCCURRENCE

This method uses mean historical averages of growth stage occurrence as the basis for window establishment. A statistic for past years, such as 50-percent planted, is taken as the reference for locating a window. This statistic may be taken either from a crop calendar or from reliable statistical tables. This approach works well for years in which the crop of interest is planted in a normal time frame and no abnormal events occur affecting the growth cycle of the crop.

A small test of the probable success of using this approach for 1980 was made. The average date of occurrence of midpoints of the two most critical crop windows, C1/C2 and Y1/Y2, was calculated for segment 0893 corn and soybeans, using 1978 and 1979 crop calendars. The average dates obtained and compared to dates taken from 1980 calendars were as follows:

Window	Midpoint average date	1980 calendar date	Difference
C1	135	118	-17 days
C2	196	188	-8 days
Y1	139	136	-3 days
Y2	221	224	+3 days

In option 1 segments, such as segment 0893 where the windows for both crops are based on the latest crop planted (i.e., soybeans), the statistical average method might work well. However, in an option 2 segment, windows based on this example might have resulted in omission of a considerable amount of corn. If segment 0893 had a window C1 midpoint of 135 for 1980, this would mean the limits of the window would range from day 115 to day 156. If some corn were planted as early as day 115 and the real window ranged from day 098 to 138, as indicated by a midpoint of 118 on the 1980 crop calendar, an acquisition acquired between days 139 and 156 could result in much of the corn that had already emerged being thrown out as natural vegetation (using the established green number threshold of 10). The window for planting would, in fact, be overlapping onto emerged corn.

3.7.3 USE OF THERMAL AND PHOTOTHERMAL PHENOLOGICAL MODELS

The Cross-Zuber thermal model for predicting corn growth stages (ref. 9) and the Majors-Johnson photothermal model for predicting soybean growth stages (ref. 10) were scheduled for evaluation as part of this developmental task for labeling corn and soybeans. If it was possible to use or adapt the growth stages from these models for selecting acquisitions, it was desired to do so.

Certain nominal, year-specific crop calendar growth stages were shown in section 3.3.4 to be rather stable from year to year with respect to peak greenness. Windows calculated using peak greenness adequately encompassed the necessary acquisitions. Taking window midpoints based on these windows as the reference for determining the accuracy of stages determined using the Cross-Zuber and Majors-Johnson models will, in effect, give an indication of the stability of the model with respect to peak greenness (i.e., peak greenness becomes a common denominator for growth stage determination, window limits, and model evaluation).

All of the developmental segments for which weather data were readily available were run using the two models. Tables 3-9 and 3-10 show the results of the Cross-Zuber model predictions and, also, the resulting bias when comparing the predictions to the stable crop-calendar-derived windows. The Cross-Zuber stages used as the basis for window midpoint prediction were:

Window C1 = 50 percent planted (+1 day)

Window C2 = 50 percent silked (comparable to 50 percent tasseling) (+5 days)

Window C3 = 50 percent mature (+45 days)

The mean error in predicting the two most critical windows, C1 and C2, for 1978 was 7 to 8 days and for 1979 it was 4 to 8 days. For window C3, the mean error for 1978 was 13 days and for 1979 it was 8 days. On the average, the model was early for 1978 and late for 1979.

Tables 3-10 and 3-11 show the results of running all of the segments with the Majors-Johnson prediction model, for which weather data were on line. Also

TABLE 3-9.- COMPARISON OF CROSS-ZUBER MODELED GROWTH STAGES TO MANUALLY DETERMINED WINDOW MIDPOINTS FOR YEAR 1978

State	Seg. no.	Window C1			Window C2			Window C3		
		Man.	Mod.	Bias	Man.	Mod.	Bias	Man.	Mod.	Bias
Ind.	0127	152	139	-13	215	205	-10	310	292	-18
	0843	151	140	-11	217	210	-7	315	300	-15
Ill.	0809	135	138	+3	205	210	+5	309	301	-8
Iowa	0141	156	135	-21	214	205	-9	307	291	-16
	0893	138	133	-5	213	202	-11	302	288	-14
Mo.	0205	138	139	+1	217	206	-11	302	293	-9
		Mean: -7.7 RMSE: 11.3			Mean: -7.2 RMSE: 8.9			Mean: -13.3 RMSE: 13.8		

TABLE 3-10.- COMPARISON OF CROSS-ZUBER MODELED GROWTH STAGES TO MANUALLY DETERMINED WINDOW MIDPOINTS FOR YEAR 1979

State	Seg. no.	Window C1			Window C2			Window C3		
		Man.	Mod.	Bias	Man.	Mod.	Bias	Man.	Mod.	Bias
Ind.	0127	131	138	+8	209	214	+5	300	311	+11
Mo.	0209	135	140	+5	218	214	-4	311	305	-6
Ill.	0828	135	138	+3	199	212	+13	298	305	+7
Iowa	0893	134	143	-1	202	218	+16	303	320	+17
		Mean: +3.75 RMSE: 5.0			Mean: +7.5 RMSE: 10.8			Mean: +7.25 RMSE: 11.1		

TABLE 3-11.- COMPARISON OF MAJORS-JOHNSON MODELED GROWTH STAGES TO MANUALLY DETERMINED WINDOW MIDPOINTS FOR YEAR 1978

State	Seg. no.	Window Y1			Window Y2			Window Y3		
		Man.	Mod.	Bias	Man.	Mod.	Bias	Man.	Mod.	Bias
Ind.	0127	151	150	-1	239	231	-8	319	293	-26
	0843	152	151	-1	240	233	-7	298	294	-25
Ill.	0809	134	147	-13	222	232	+10	298	294	-4
Iowa	0141	149	145	-4	234	228	-6	316	290	-26
	0893	149	141	-8	228	225	-3	316	286	-30
Mo.	0205	140	149	+9	230	230	0	307	293	-14
		Mean: +1.33			Mean: -2.33			Mean: -20.8		
		RMSE: 7.4			RMSE: 6.55			RMSE: 22.7		

TABLE 3-12.- COMPARISON OF MAJORS-JOHNSON MODELED GROWTH STAGES TO MANUALLY DETERMINED WINDOW MIDPOINTS FOR YEAR 1979

State	Seg. no.	Window Y1			Window Y2			Window Y3		
		Man.	Mod.	Bias	Man.	Mod.	Bias	Man.	Mod.	Bias
Ind.	0127	137	150	+13	228	234	+6	301	299	-1
Mo.	0209	141	151	+10	231	234	+3	301	300	-1
Ill.	0828	139	148	+9	220	233	+13	299	297	-2
Iowa	0893	136	151	+15	224	236	+12	295	304	+9
		Mean: +11.8			Mean: +8.5			Mean: +1.25		
		RMSE: 12.0			RMSE: 9.5			RMSE: 4.7		

shown is the resulting bias when comparing the results to the stable crop-calendar-derived windows. The Majors-Johnson model stages used as the basis for midpoint calculation were as follows:

Window Y1 = 50 percent planted

Window Y2 = 50 percent pod beginning to fill (+12 days)

Window Y3 = 50 percent mature (+38 days)

The error in predicting the window Y1 and Y2 midpoints for 1978 was about 1 to 2 days and for 1979 it was 8 to 12 days. For window Y3, the error was on the order of 1 and 21 days, respectively, for the 2 years.

The mean error for windows 1 and 2, for both corn and soybeans, was not surprisingly high; but the root mean square error (RMSE) for six out of eight of the window determinations was above seven. This led to further examination of the error in the individual segments. Some bias in the individual segments was 2 weeks or more. Bias in three out of four of the window 3 determinations was also exceptionally high.

The effect on labeling accuracy for two of the segments with the highest soybean window (Y1, Y2, and Y3) midpoint bias was determined. Segments 0809 for 1978 and 0127 for 1979 were selected (both option 1). Comparison of the window limits to the data showed the following:

Segment 0809 (1978): Window Y1 limits of 122 through 163 (bias of 13) makes no selection of a window Y1 acquisition and the segment remains unprocessable. Note: If an acquisition had been available on day 163, there would have been some omission because an omission of 12 percent corn and 15 percent soybeans is indicated for day 164, which is 1 day later than the cutoff. (See pages C-5 and C-11.)

Window Y2 limits of 231 through 255 (bias of 10) would cause the acquisition for day 244 to be selected for separating corn and soybeans. There is an additional loss of corn of 16 percent with the threshold of 13, but no additional loss of soybeans when the acquisition is selected. Separation of the remaining corn is 96.6 percent and of the remaining soybeans is 94.1 percent.

Window Y3 limits of 276 through 311 (bias of -4) would select no bad acquisitions.

Segment 0127 (1979): Window Y1 limits of 125 through 165 (bias of 13) will cause this segment to become unprocessable, since two acquisitions in the window are not available. Day 138 taken alone results in green number loss of about 8 percent of the soybeans, but no corn is lost.

Window Y2 limits of 233 through 257 (bias of 6) would result in selection of the day 247 acquisition. Green number loss of corn of 16 percent would result using this acquisition. Separation of the remaining crop dots was 100 percent.

Window Y3 limits of 281 through 316 (bias of -1) would not result in the selection of any bad acquisitions.

After evaluating these and other similar segment results, it was concluded that acquisitions selected using the models alone were unsatisfactory.

When using the models, the amount of variation from segment to segment within a given crop year did not differ greatly from the variation observed when using the peak greenness (manual) method, as shown in table 3-13.

The within-year variation of window midpoints in the U.S. Corn Belt states is sufficiently close that either a manual method, using maximum greenness and fractional season relationships, or the two phenological models should serve equally well if a seasonal correction could be applied to each window selected

TABLE 3-13.- AVERAGE DEVIATION FROM THE MEAN OF WINDOW MIDPOINTS

Window	1978		1979	
	Manual	Model	Manual	Model
C1	8	3	1	2
C2	3	2	7	2
C3	4	4	4	5
Y1	6	3	2	1
Y2	6	2	3	1
Y3	7	2	3	2

by the models. The low variation shown in table 3-13 indicates that a single seasonal correction for all segments would be sufficient.

3.7.4 USE OF PEAK GREENNESS TO CORRECT PHENOLOGICAL MODEL OUTPUT

A method using peak greenness, while requiring no type of adjustment, would be limited to those segments having good acquisitions throughout the growing season. Numerous acquisitions are necessary to enable construction of accurate greenness curves for all of the selected dots used in the methodology.

Segments can be labeled with fewer acquisitions than are needed to construct accurate greenness curves. In order to extend the accuracy of a peak greenness method of window determination to these additional segments, it was decided to see whether a seasonal correction applied to the output of the two phenological models could do this. This correction would be based on window midpoint dates of segments having acquisition histories sufficient to determine and apply peak greenness. As a test of this method, the sign on each mean bias determined in tables 3-9 through 3-12 was changed, and the quantity obtained was then applied as a correction to each model-determined midpoint in the appropriate table. (Remember that section 3.3.4 showed a direct relationship between crop calendar stages and peak greenness.) New window limits for each segment were then calculated, and the charts in appendix C were checked to determine whether any undesirable acquisitions would be selected by using these new windows. No bad acquisitions resulted.

Appendix H documents the details of a technique for determining windows using peak greenness and for applying the results of this technique in order to correct phenological models.

3.7.5 CURRENT-YEAR CROP CALENDAR ADJUSTED BY INTERPRETATION

This method is similar to the method using historical crop calendars, and it has the same weaknesses when applied on a segment-by-segment basis. It has an additional weakness in that considerable resources are required to build current-year crop calendars in order to process the Landsat data for that year; this means that no segments can be processed until after these calendars have been constructed.

4. PROCEDURE ASSEMBLY

4.1 MAN/MACHINE RELATIONSHIPS

The procedure was supposed to be assembled in such a way that the objective of labeling a few pure pixels with high accuracy could be accomplished with the minimum number of manual operations and with the maximum utilization of the computer being made. Also, any analyst decisions to be made would be easy ones having objective decision rules, and they would be computer supported whenever possible.

Assembly of the major procedural functions in modular form would make it easier to insert major improvements at a later date; for example, replacement of a manual step with a fully computerized one.

In order to make use of available computer programs, to establish the desired man and machine relationships, and to combine groups of manual and machine functions into modular form, figure 4-1 was constructed. Figure 4-1 depicts two machine-processing sessions that produce reports to be utilized by the analyst during two subsequent imagery contact sessions. These four sessions result in data and training labels, which are used in the final classification session.

4.2 PROCESSING FUNCTIONAL FLOW

The following subsections explain the purposes of each processing session, the rationale for use and integration of existing methodology, and the factors affecting the decision to create new methodology or software.

4.2.1 SESSION 1: INITIAL ACQUISITION SELECTION

This session, a computer processing step, uses the Cross-Zuber and Majors-Johnson model growth stage predictions as the basis for determining the optimal time periods for use in the pure-pixel isolation and profile parameter creation software and for establishing labeling windows. Model growth stages are used directly for determining the pure-pixel isolation period and the

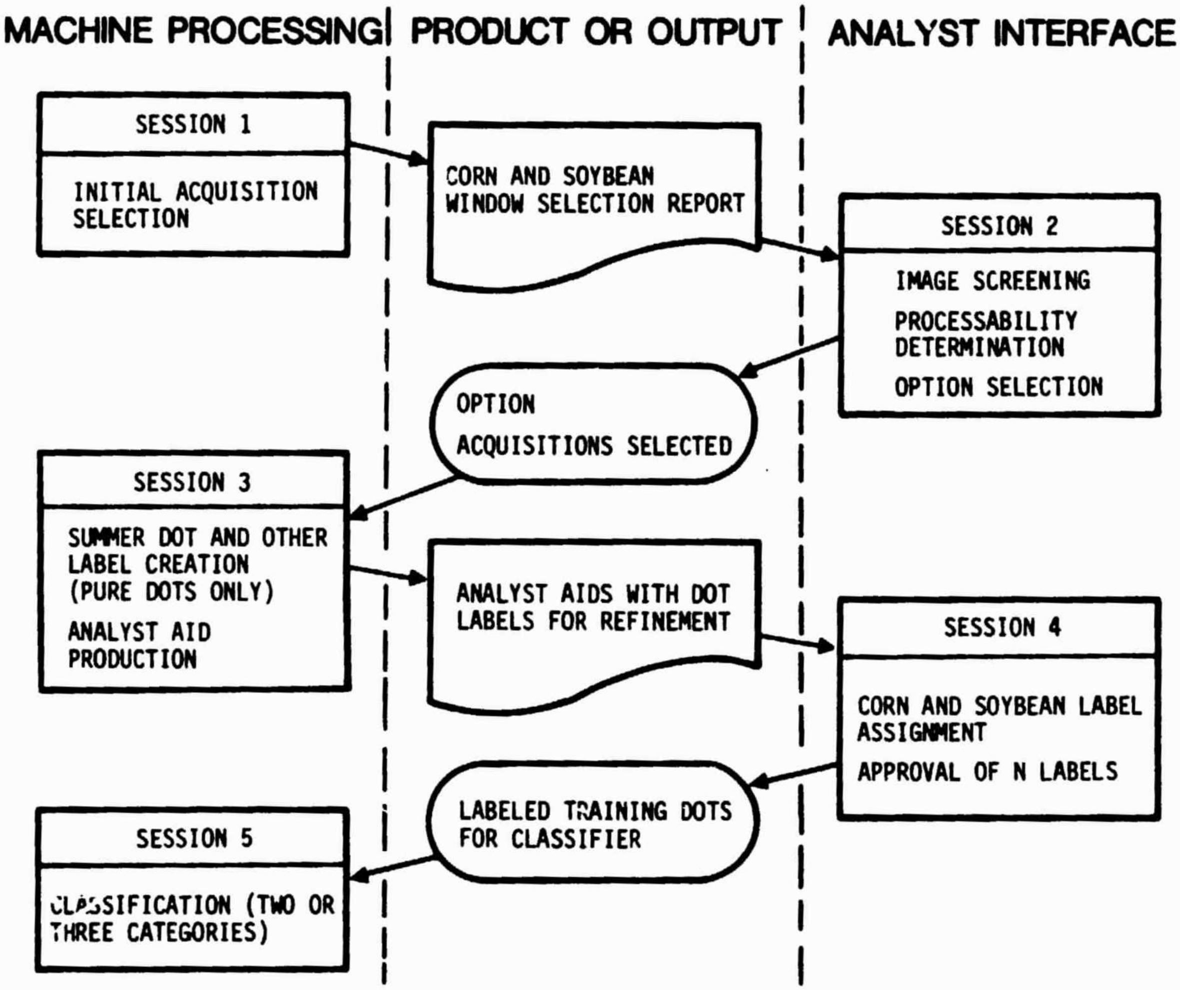

Figure 4-1.- Functional flow chart.

profile parameter periods; a correction (appendix H) is applied to the modeled growth stage in order to determine limits for the labeling windows.

The program for running the phenological models, available on Laboratory for Applications of Remote Sensing System (LARSYS), was utilized by personnel of the Design and Integration Section to create a data base of growth stages based on data from the primary weather reporting stations. The data base is now available for use on JSC computers and includes the States of Iowa, Illinois, and Indiana. The software for running session 1, AIREPORT, accesses this data base and creates two reports: the Crop Report and the Corn and Soybean Window Selection Report. Examples of these products are contained in appendix I.

The Crop Report shows the growth stages predicted by the two models. For the Corn and Soybean Window Selection Report, the corrections shown in table 4-1 are applied to the appropriate model growth stages to arrive at procedure labeling window midpoints for 1978, 1979, and 1980:

TABLE 4-1.- CORRECTIONS TO BE APPLIED TO MODEL GROWTH STAGES

Year	Corn			Soybeans		
	50% planted	50% silked	50% mature	50% planted	50% podding	50% mature
1978	+7 days	+7 days	+13 days	-2 days	+2 days	+2 days
1979	-4 days	-8 days	-8 days	-11 days	-8 days	0 days
[a]1980	-16 days	-4 days	+6 days	-8 days	-10 days	+4 days

[a]The corrections for 1980 growth stages are not based on the technique described in appendix H; but current-year crop calendars were used and adjusted by imagery interpretation (by the procedure developer), because of system problems in generating green numbers.

Based on the corrected windows, the amounts of overlap and gap between windows are applied in order to determine which corn or soybean options can be applied; and based on the latitude of a segment, the report gives a complete listing of the options executable for a segment.

4.2.2 SESSION 2: IMAGE SCREENING, PROCESSABILITY DETERMINATION, AND OPTION SELECTION

Error messages in the Corn and Soybean Window Selection Report will indicate when segments are nonprocessable based on location, window overlap, or unscreened acquisition availability. If the segment is still processable after session 1, the analyst proceeds with session 2.

Images are screened in this session for usability. Based on the availability of usable acquisitions to fulfill requirements of later procedural sessions, a labeling option is selected and certain key acquisitions are designated for use in running these later sessions.

Based on the good labeling results obtained using the experimental logic (table 3-7), it was decided to maintain the 5-percent criterion for clouds, cloud shadows, or bad data. The analyst screens each of the acquisitions that are flagged by program AIREPORT (for potential use) to omit any acquisitions not meeting these data quality standards and to omit any acquisitions having misregistration of greater than two pixels. The acquisitions remaining after screening are inventoried to determine whether the following requirements are met:

- A minimum of two and a maximum of five acquisitions for use in program AUTOFLD, which selects pure field pixels.
- A minimum of one preemerged and three emerged acquisitions, or a maximum of two preemerged and six emerged acquisitions, for use in programs AUTOCLS COEFGB and AUTOCLS COEFGBTR (session 4). These programs create a file of profile parameters that is used in cropland and noncropland determination and in classification.
- Acquisitions to meet the minimum labeling requirements determined using table 3-6.

If the above acquisitions are available, the segment is processable. A maximum of 12 acquisitions may be used because of spectral aid program limitations. Care must be taken to assure that there are no more than two preemerged and six emerged acquisitions for use in AUTOCLS COEFGBTR. Because this program will automatically eliminate excessive acquisitions, key acquisitions used in labeling may be eliminated. It is essential that as many labeling acquisitions as possible also be used in program AUTOCLS, because the labels are used to label those profile parameters obtained from AUTOCLS COEFGBTR for use in classification. Rules were devised whereby excess acquisitions that met the image quality standards would be eliminated by the analyst rather than by the computer.

In order to select a labeling option, it is necessary to know the geographic latitude of the segment and the major crops being grown in the area (see section 3.5). In the United States where historical data bases are readily available at the county level, it is recommended that the data bases be used to determine crop percentages. When processing data on other countries, it may be necessary to use information that is in fragmentary and incomplete form. In each case, the source and quality of the information will need to be evaluated prior to its use. The purpose in using this information is, of course, to enable the analyst to select the option that will best identify corn and soybeans as summer crops and eliminate (label N) any confusion crops. High concentrations of crops that are not separable can cause highly erratic labeling and classification results. The best information available should therefore be used in order to make the option selection.

When a suitable cloud-screening algorithm can be designed and automated, and if temporal registration of acquisitions can be improved, much of this manual session can then be combined with session 1, thus increasing efficiency.

4.2.3 SESSION 3: SUMMER CROP AND OTHER LABEL CREATION; ANALYST AID PRODUCTION

Acquisitions selected in session 2 and information on the worksheet from that session are used to create the necessary files for use in the session 3 computer programs.

Program AUTOFLD (FLDPROC) is run to isolate pure pixels and create a file of dots (PURPIX file) to be labeled; program AUTOCLS COEFGB creates greenness profiles through time and determines the α, β, and t_0 parameters in the following equation and creates a file:

$$G(t) = G_0(t/t_0)^{\alpha}e^{\beta\left(t^2-t_0^2\right)}$$

where

G_0 = the soil line greenness
t_0 = the calculated spectral emergence date
α, β = constants

The FLDPROC program uses the edge gradient enhancement technique described in appendix J. This program and the AUTOCLS COEFGB program were adapted for multitemporal use in corn and soybean areas under the technical direction of Dr. G. Badhwar of NASA/JSC. Appendix M shows a flow chart of these programs.

The remaining programs for session 3 process the pure pixels to determine which are summer crops, and then the summer crops labels are printed out on a spectral scatter plot and on green number versus brightness listings, as follows:

1. Using the acquisitions indicated on the session 2 worksheet, the appropriate logic for the selected summer crop labeling option (appendix G) is executed in the CROP program. A file (LISTCROP) is created containing crop definitions (Z or N).
2. The file of parameters from COEFGB is then used in a program called PEAKGB to determine crop/noncrop by a profile parameter method (see appendix K) that uses a length of season parameter (σ). Only the pixels in the PURPIX file that have survived the CROP program as summer crops are passed through this screen. The PEAKGB program is run in series to the CROP program as a greenness curve screen that does not depend on soil lines (as does the CROP logic with green numbers). Usually, CROP is slightly more accurate; but in those cases where soil lines are inaccurate, the PEAKGB

program is superior for detecting trees. A file (PURECROP) of summer crop (Z) and nonsummer crop (N) dots is created for later editing (at the beginning of session 5).

3. The summer crop labels from step 2 are also used as input for the following programs that create spectral aids and listings. The labeling aids are output for use by the analyst in session 4.
    - SRCSTBLA - produces table A (example in appendix L, page L-2)
    - SRCSTBLB - produces table B (example in appendix L, page L-3)
    - SRCSTBLC - produces table C (example in appendix L, page L-4)
    - SRCSSPA - produces an unlabeled scatter plot of all 418 grid dots used in labeling dot selection or a scatter plot with only the pure summer crop dots (examples in appendix L, pages L-5 and L-6)
    - SRCSTPA - creates green number through time and brightness through time trajectory plots (example in appendix L, page L-7)

All of the programs to be executed in this session, except AUTOCLS COEFGB, were designed specifically to support this labeling procedure and the profile parameter classification system. The listings and plots, adapted from Procedure P1A, enable the analyst to quickly find a scatter plot dot in the imagery, or vice versa, and to go from one listing to another for making various comparisons. Instructions for executing these programs either individually or as combined runs are contained in reference 11. Shortcuts for the creation of the necessary files will be readily apparent to the computer-oriented analyst after becoming familiar with the profile parameter system.

4.2.4 SESSION 4: CORN AND SOYBEAN LABEL ASSIGNMENT; APPROVAL OF N LABELS

Prior to proceeding with final labeling, it is necessary at this point to check the accuracy of the soil lines because the green numbers based on them affect accuracy of the automated summer crop logic used in the programs for session 3. The same checks as those used in the development research (see section 2.4) were inserted into the procedure at this point, with instructions for making soil line corrections, if necessary. If a reliable, error-free method for generating soil lines can be devised that will work in segments having very small amounts of bare soil, this step may then be eliminated.

The final (discrete) identification of corn and soybean crops is accomplished using the scatter plot of summer crop dots. Limiters are placed in this plot to identify the zones containing the crop dot clusters, and a decision boundary is placed between the corn and soybean cluster distributions. Since the labeled scatter plots may not always have sufficient dots within both the corn and soybean distributions (e.g., option 2 or 5) to clearly define the slope of the green arm in the C2 or Y2 window acquisitions, rules for use of the unlabeled plot were devised to assist in establishing the first limiter (the second limiter is automatic upon establishment of the first one). The steps described in sections 3.4.1 through 3.4.6 were used for final placement of the line distinguishing the corn and soybean distributions; a few simple rules were found to apply to multiple combinations of crops.

Rules were devised for editing (checking purity) dots of all categories, C, Y, or N, prior to accepting them. In order to ensure that the proper spectral training would be provided for the classifier, C or Y dots needed to be on the same field in the window 1 and window 2 acquisitions. Since the value of the window 3 acquisition is found in the occasional labeling of an N dot, N dots had to be registered to the same field in windows 1, 2, and 3 in order to be accepted.

After purity is checked, the analyst checks which crop distribution the dot is in to make final categorization of the dot. Between 15 and 20 dots from categories C, Y, and N are required for classifier training.

A final action to be performed in this session is to select a pure blob of at least 10 pure contiguous corn pixels to act as a starter for program COEFGBTR. A blob should be picked and coordinates of its vertices should be recorded in line-pixel format.

Various methods have been tried in order to automate the discrete identification of corn and soybeans. However, the manual method of separating distributions described here has been shown to give the best results so far when using profile parameter classification. One means of further automation would be through the use of a cathode-ray tube display of the separation scatter plot. If dots in the displayed plot were colored the same color as in the PFC product 1, then cursoring of a decision boundary could be made to be very fast and accurate. Software could then sort (and record) the dots according to crop category depending upon placement of the cursored line, and the resulting labels could be transferred to the classifier automatically. This method would give less accurate classification results, unless pure dots were always isolated and plotted. (At present, purity is manually confirmed.)

4.2.5 SESSION 5: CLASSIFICATION (TWO OR THREE CATEGORIES)

The labels accepted during session 4 are final edited by the execution of the PPIXEDIT program. The analyst enters the dot number and crop symbol for each of the pure labels. The program transforms all dot symbols into the required numeric labels for program PPIXGT. This results in a new file PURECROP. This file may be printed if evaluation of the labels is desired at a later date.

Before classification can be run, profile parameters for classification must be run using program AUTOCLS COEFGBTR. The flow chart in appendix M shows the flow of this program. The blob of starter corn pixels and other control cards are input from file USERGBTR. Because of the length of time necessary to run this program, it is desirable to begin running it as early as possible; and it can be run as soon as the procedure has identified the corn distribution in session 4 (in order to obtain a valid corn blob).

Classification (program PARCLS) may be run after the necessary files are available. The labels, profile parameters, some control cards, and symbol definitions are input. See appendix M, page M-6, for an illustrative flow chart. Details of the control cards are contained in reference 11. Either the three categories C, Y, and N or a combination of any two of the categories may be classified, depending upon the availability of category dots. If a category is determined to be insignificant (<7 dots), it may be disregarded. If there are between 7 and 14 of either C or Y dots, this category may be combined with category N. If both categories C and Y have between 7 and 14 dots, the segment is nonprocessable.

A report of classification and a classification map are printed as final products. The percentage of a crop in the scene may be determined by dividing the number of pixels classified in each category by 22,932.

5. TEST RESULTS

5.1 GENERAL

The procedure was tested in the semiautomated mode to verify that satisfactory results could be obtained using an independent set of segments for the years 1978 and 1979 in the U.S. Corn Belt states. For this test, the segments in table 2-2 were used. Personnel used for this test had the following qualifications:

1. One Landsat analyst with no previous contact during procedure development for labeling
2. One programmer used in procedure programming for computer processing
3. The author (a Landsat analyst) for quality assurance

The average time required to process a segment, executing sessions 1 through 5, was 85 minutes analyst time, 70 minutes central processing unit (CPU) time, 70 minutes operator time, and 22 minutes quality assurance time. See figure 5-1.

5.2 TEST RESULTS

Appendix N contains an overall evaluation and individual evaluations for the seven segments. The aspects evaluated were classification accuracy, dot labeling accuracy (with general characterization of errors), and purity of labels sent to the classifier. The highlights of the results were as follows:

1. Proportion estimation accuracy (area of seven segments)
    - Corn: 99.38 percent of ground truth (-0.62 percent relative error)
    - Soybeans: 95.57 percent of ground truth (-4.43 percent relative error)
    - Other: 102.7 percent of ground truth (+2.73 percent relative error)

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TEST NO.	TEST TYPE	CROP PROCEDURE/NAME	PROC. TYPE	TEST LEVEL	TEST REGION	DATA SET		DATE	TEST PERIOD	
						SEGS.	ACQS.		FROM	TO
	DEVELOPMENT	CS-4/PROFILE PARAMETER ESTIMATION	AREA ESTIMATION	SUBSYSTEM	U.S. CORN BELT	78-3 79-4	17 53	10/21/81	8/81	10/81

PROCEDURES EFFICIENCY DATA

GROUP	FUNCTION		MANUAL OPERATIONS						COMPUTER OPERATIONS				THROUGH-PUT TIME (DAYS)
			ANALYST					TECHNICIAN	BATCH		INTERACTIVE		
	NO.	NAME	CONTACT	CLER.	QA	DATA HANDLING	STATUS & TRACKING		CPU	CONNECT	CPU	OPR.	
			MIN	MIN	MIN	MIN	MIN	MIN	MIN:SEC	MIN:SEC	MIN:SEC	MIN:SEC	
DATA PREP. FOR ANALYSIS	1	SOIL LINE PROGRAM							2:30	15:00	0:.0006	5:00	0.5
	2	ACQUISITION SELECTION									1:20	5:00	
	3	IMAGERY SCREENING	15		2								
LABELING	1	ANALYSIS									8:00	30:00	0.5
	2	SOIL LINE VERIFICATION	10										
	3	FINAL LABELS	60		20								
PROPORTION ESTIMATION	1	LABEL INPUT									0:06	5:00	0.5
	2	PROFILE PARAMETER ESTIMATION									60:00	10:00	
	3	CLASSIFICATION									1:22	15:00	
		TOTAL	85		22				2:30	15:00	70:4706	70:00	1.5

Figure 5-1.- Segment processing time.

2. Labeling accuracy (all dots in seven segments)

   - Corn called corn: 86 percent
   - Soybeans called soybeans: 90 percent
   - Other called other: 98 percent

3. Purity of labels after analyst acceptance: 95.8 percent

Classification yielded relatively clean classification maps with an average percentage (of the area inventoried) of 68.45 percent of the pixels being correctly classified.

Although a detailed characterization of classification errors was not made, the segments with higher errors seemed to show some correlation with labeling error causes. The majority of the labeling error was procedurally inherent (i.e., error from factors that the labeling procedure, in the interest of simplicity, is not designed to handle). These errors appeared to be associated with moisture fluctuations, as evidenced by early and late fields or by episodic events such as hailstorms.

5.3 LABELING ERROR CHARACTERIZATION

Errors made in labeling the 152 corn (C), 143 soybean (Y), and 125 nonsummer crop (N) dots were as follows:

1. C called Y = 10 dots

   5 - wrong distribution; possible late planting

   2 - incorrect decision boundary placement

   1 - clerical error

   2 - questionable ground truth

2. C called N = 11 dots

    2 - planting signature not detected

    5 - low green number (<13) in separation acquisition; probable early planting

    2 - sigma error

    1 - clerical error

    1 - questionable ground truth

3. Y called C = 13 dots

    8 - wrong distribution; hail damage, moisture variations; possible poor stands

    2 - impure pixels

    3 - questionable ground truth

4. Y called N = 2 dots

    1 - planting signature not detected

    1 - impure pixel

5. N called Y = 2 dots

    1 - volunteer growth

    1 - mixed cropping

6. EXTENDABILITY

Aside from such factors as soil differences, drought, pests, and plant disease effects that can affect light reflectance from crops, there appear to be some factors that could be considered common to all countries when adapting this procedure (or another) for identifying crops and determining crop proportions using Landsat imagery. Generally, these factors seem to be as follows:

1. The crop has unique colors or geometry in the imagery products that permit visual (manual) identification of the crop, either in a data acquisition for a single date or in data acquisitions from multiple dates. All variations or varieties of the crop must be visually identifiable.
2. In order to develop automatic methods, some means (e.g., Kauth greenness, brightness) must be available for gauging the intensity of the identifying characteristic(s) in a manner that will identify the crop but exclude other crops or noncropland. It appears that automation accuracy can only be as good as manually executable accuracy (step 1), excluding clerical error.
3. The time and duration of occurrence of the unique identifying characteristics are relatable to the plants' growth cycle.
4. A method must be available for accurately predicting the time of occurrence of the characteristics during each new crop year.
5. Sufficient data acquisitions (at the right times) must be acquired in order to execute the desired logic for each segment.

Because of the difficulty in identifying all variations of a crop, ground truth should be studied carefully when initially adapting the procedure and establishing decision rules. It was noted, for example, when developing the procedure, that soybeans in Mississippi did not look like soybeans in Iowa. Because of the greenness-brightness differences, part of the Iowa logic was executable in Mississippi, but not all of it. Since the differences were known, however, the procedure logic was adaptable.

The relative times of occurrence of peak greenness were used in determining the logic for identifying corn and soybeans in this procedure. If peak greenness of a confusion crop occurs at a time very near that of the target crop, then greenness cannot be used to discretely identify the target crop unless there are other unique features (e.g., brightness) that occur consistently and with sufficient, quantifiable intensity. The two transformations of greenness and brightness do have considerable flexibility of application in the multitemporal sense. Adaptability of this procedure will depend upon relative times of greenness and brightness of various crops.

Prediction of the time of occurrence of peak greenness (or other characteristics) using phenological models as in this procedure will depend largely upon availability of an appropriate means of starting the model at the right time, the amount of variability in planting date, or the variations of the target crop.

7. CONCLUSIONS

The labeling accuracy of summer crops and the separation of corn and soybeans as individual crops, when applying the logic to the research segments (section 3.6), indicated a potential for procedural labeling accuracy slightly less than 90 percent for corn and soybeans for 1978, but slightly over 90 percent for 1979. This, plus a potential of greater than 90 percent accuracy for nonsummer crops, indicated that an assembled semiautomated procedure could provide the required training for a classifier.

Testing of the assembled semiautomated labeling procedure on seven independent segments for 1978 and 1979 verified that sufficiently high classification accuracy (on the average) could be obtained using the labels. The average classification bias for the total area of the seven segments was -0.62 percent relative for corn and -4.43 percent relative for soybeans; inputting labels with a labeling accuracy of 86 percent for corn, 90 percent for soybeans, and 98 percent for other.

The major part of both labeling and classification error seemed to be caused by precipitation variations and episodal events. Labeling error attributable to the semiautomated procedure was approximately 6 percent, based on the test, and 4.3 percent was due to these two factors.

The phenological growth stage models that were evaluated, with a spectrally determined seasonal correction, worked well at determining the correct labeling windows. The semiautomated labeling logic, when applied to the window acquisitions, was then effective in arriving at correct labels.

The requirement for high labeling accuracy slightly reduces the number of segments that can be classified because high labeling accuracy requires higher precision in acquisition selection.

The more complexity there is in numbers of crops grown, the greater the number of acquisitions and the more complex the green number logic required (see section 4.4). Greater precision in acquisition selection (window width) is also required.

Provided that the following conditions can be met, the principles of this labeling procedure (and use of the profile parameter classification system) should be extendable to other countries:

1. Stable time periods (windows) based on growth stages can be established for application of a semiautomated green number logic to discretely identify corn and soybeans.
2. Additional logic can be devised for separating out any other summer crops (or confusion) and identifying them as other.
3. A phenological model is available for predicting the times of occurrence of the essential growth stages in new crop years. The model may or may not be seasonally adjusted, depending on the nature of the model.

8. REFERENCES

1. Magness, E. R.: Semiautomated Procedure for Producing High-Purity Labels for Corn and Soybean Crops. JSC-17786, LEMSCO-17105, NASA/JSC (Houston), Nov. 1981.

2. Badhwar, G. D.; Carnes, J. G.; and Austin, W. W.: Use of Landsat-Derived Temporal Profiles for Corn-Soybeans Feature Extraction and Classification. Remote Sensing of Environment, vol. 12, 1982, pp. 57-79.

3. Austin, W. W.: Landsat Data Transformations Used in CAMS; The Kauth Data Transformation and the Wehmanen Implementation Used to Generate Spectral Aids for CAMS. LEC IDC 644-797, Jan. 18, 1978.

4. Palmer, W. F.; and Magness, E. R.: A Description of the Reformatted Spring Small Grains Labeling Procedure Used in Test 2, Part 2 of the U.S./Canada Wheat and Barley Exploratory Experiment. JSC-16827, LEMSCO-15404, NASA/JSC (Houston), Feb. 1981.

5. Horton, C. L.: "As-Built" Design Specification for the CLASFYG Program. JSC-17369, LEMSCO-16649, NASA/JSC (Houston), June 1981.

6. Detailed Analysis Procedures for Transition Project (FY79). JSC-13756, LEC-13222, NASA/JSC (Houston), May 1979.

7. USDA Economic Research Service, Agriculture Handbook Series (By State).

8. Dailey, C. L.; and Abotteen, K. M.: Corn/Soybean Decision Logic Development and Testing. JSC-16380, LEMSCO-14811, NASA/JSC (Houston), Oct. 1980.

9. Cross, H. Z.; and Zuber, M. S.: Prediction of Flowering Dates in Maize Based on Different Models of Estimating Thermal Units. Agronomy J., vol. 64, May-June 1972, p. 351.

10. Majors, J.; Johnson, D. R.; and Lueddens, V. D.: Evaluation of Eleven Thermal Unit Methods for Predicting Soybean Development. Crop Science, vol. 15, 1975, pp. 172-174.

11. Tompkins, M. A.; and Sivillo, C. A.: User's Guide for the Profile Parameter Classification System. JSC-17655, LEMSCO-17272, NASA/JSC (Houston), Aug. 1981.

APPENDIX A

UNLABELED SPECTRAL AIDS

APPENDIX A

UNLABELED SPECTRAL AIDS

This appendix contains examples of unlabeled spectral aids used in procedure development. The following examples are given for segment 0843, located in Henry County, Indiana.

1. First page of 209-dot green number listings for acquisition dates selected
2. Unlabeled green number versus brightness scatter plot
3. Example pages of greenness through time and brightness through time spectral plots

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TABLE III

ORDERED BY GRID

SEGMENT = [illegible]   DATE GENERATED = 6/15/81

GRID 1

DOT NO.	LINE/ PIXEL		ANALYST LABEL	AC01 78151		AC02 78160		AC03 78197		AC04 78232		AC05 78251		AC06 78269	
				G	B	G	H	G	H	G	B	G	H	G	B
1	10	10		7	98	-2	104	11	81	25	64	19	57	21	51
2	10	20		14	97	25	92	23	71	22	62	14	60	20	56
3	10	30		25	101	6	85	28	73	23	59	18	58	15	[illegible]
4	10	40		9	91	27	74	26	65	20	54	12	[illegible]	18	42
5	10	50		5	89	6	73	26	65	15	68	17	55	21	59
6	10	60		31	90	41	72	10	59	43	83	22	67	[illegible]	55
7	10	70		11	86	5	68	17	76	48	89	42	85	19	62
8	10	80		20	88	6	66	13	70	40	81	23	70	23	59
9	10	90		40	83	54	85	23	62	15	64	11	59	20	49
10	10	100		27	77	33	68	23	69	22	65	15	64	21	48
11	10	110		4	79	7	69	17	62	44	81	35	79	19	50
12	10	120		2	87	7	53	22	63	24	60	24	65	8	48
13	10	130		14	95	19	63	26	64	21	72	14	65	27	50
14	10	140		[illegible]	96	34	87	31	74	29	74	16	72	21	47
15	10	150		38	85	43	84	24	62	20	61	10	60	25	46
16	10	160		23	88	17	80	23	73	44	82	32	77	29	64
17	10	170		28	93	6	56	33	76	39	80	14	70	13	50
18	10	180		36	79	48	76	29	61	17	57	12	51	21	41
19	10	190		6	78	11	46	42	77	25	64	28	68	15	43
20	20	10		38	79	56	88	36	66	24	60	17	57	25	44
21	20	20		30	81	10	96	24	86	19	64	25	67	15	[illegible]
22	20	30		13	91	24	77	18	61	19	55	20	62	7	[illegible]
23	20	40		8	103	1	86	1	102	36	73	25	72	19	52
24	20	50		26	76	32	73	26	54	15	49	10	49	21	35
25	20	60		11	101	1	92	19	91	35	75	35	77	13	47
26	20	70		2	126	2	95	10	79	46	83	35	[illegible]	12	48
27	20	80		3	99	3	69	24	62	21	57	21	62	18	45
28	20	90		2	80	7	66	35	66	21	61	17	63	15	44
29	20	100		3	72	7	59	32	65	20	57	16	57	15	41
30	20	110		27	84	35	75	20	57	24	70	27	70	12	53
31	20	120		14	108	4	71	26	68	23	59	16	60	24	50
32	20	130		20	95	7	64	18	70	13	53	11	56	17	43
33	20	140		9	76	14	54	8	49	18	56	15	56	15	41
34	20	150		31	89	40	82	26	72	14	65	14	63	29	55
35	20	160		5	117	34	75	15	87	46	88	29	72	9	50
36	20	170		22	114	15	75	13	81	40	81	31	80	14	54
37	20	180		25	83	34	69	34	65	24	56	17	57	19	36
38	20	190		38	85	56	84	22	59	15	60	9	54	19	41
39	30	10		4	103	14	77	12	76	17	57	9	60	21	53
40	30	20		15	112	14	91	19	79	14	52	17	60	22	52
41	30	30		25	95	24	79	23	63	17	57	13	57	18	44
42	30	40		3	97	6	88	33	63	23	57	17	59	14	43
43	30	50		31	99	38	89	30	54	49	78	24	64	25	44
44	30	60		37	87	30	75	10	63	16	70	23	67	-2	71
45	30	70		39	78	34	76	7	61	28	62	16	55	2	52
46	30	80		2	84	7	45	31	60	23	61	13	55	5	33
47	30	90		5	91	14	43	29	64	17	57	10	54	4	[illegible]
48	30	100		3	85	6	73	36	68	25	64	17	56	18	50
49	30	110		13	92	8	75	14	64	35	72	24	67	10	53
50	30	120		25	95	27	70	19	69	21	58	16	60	18	46
51	30	130		32	[illegible]	8	41	23	56	24	60	17	59	26	52
52	30	140		18	72	12	51	9	49	15	57	12	55	23	50
53	30	150		7	61	5	27	20	56	21	58	15	59	17	45
54	30	160			82	20	70	25	61	20	63	15	60	18	45
55	30	170		44	87	40	82	22	75	31	71	14	54	32	55
56	30	180		36	91	13	101	23	77	21	62	18	63	22	49
57	30	190		37	79	55	76	33	58	26	58	16	52	22	37
58	40	10		38	81	51	82	31	62	15	56	16	54	20	46
59	40	20		14	76	3	84	24	65	24	61	18	59	23	47

TABLE III

ORDERED BY GRID

SEGMENT = 0P43　　DATE GENERATED = 6/15/81

GRID 1

DOT NO.	LINE/	PIXEL	ANALYST LABEL	AC07 78305		AC28 78313		AC09 78349	
				G	R	G	H	G	H
1	10	10		12	37	12	46	6	34
2	10	20		4	35	3	35	4	35
3	10	30		2	33	1	37	1	28
4	10	40		3	27	4	29	3	35
5	10	50		5	39	5	41	5	35
6	10	60		5	43	6	39	8	35
7	10	70		2	46	3	43	4	25
8	10	80		2	46	5	45	4	31
9	10	90		12	40	15	41	11	31
10	10	100		9	38	10	36	9	30
11	10	110		0	31	4	32	5	24
12	10	120		2	47	1	55	4	25
13	10	130		6	46	5	52	5	34
14	10	140		10	40	11	46	9	37
15	10	150		11	39	8	32	9	33
16	10	160		5	33	6	46	2	30
17	10	170		10	33	3	29	4	31
18	10	180		10	31	8	28	6	22
19	10	190		4	36	3	37	3	31
20	20	10		9	30	9	32	9	27
21	20	20		7	28	7	27	4	20
22	20	30		2	25	2	55	2	27
23	20	40		4	47	2	46	4	29
24	20	50		10	31	9	29	4	20
25	20	60		1	42	2	40	4	31
26	20	70		3	44	2	43	3	31
27	20	80		5	39	3	36	2	32
28	20	90		1	25	2	56	5	34
29	20	100		2	26	4	50	5	28
30	20	110		11	49	9	46	7	31
31	20	120		4	33	1	33	4	39
32	20	130		5	32	4	38	3	33
33	20	140		4	28	2	36	3	36
34	20	150		11	38	13	36	10	30
35	20	160		8	38	6	42	7	28
36	20	170		5	47	9	43	8	30
37	20	180		6	23	6	33	4	24
38	20	190		14	36	9	36	8	29
39	30	10		3	32	4	31	3	38
40	30	20		3	36	5	53	2	31
41	30	30		4	32	7	31	7	31
42	30	40		1	24	2	25	1	42
43	30	50		1	37	4	34	3	31
44	30	60		6	44	11	45	6	33
45	30	70		3	27	7	31	4	30
46	30	80		4	23	2	24	1	23
47	30	90		0	36	1	44	4	27
48	30	100		4	41	3	32	2	26
49	30	110		3	42	6	44	1	25
50	30	120		2	33	5	55	5	27
51	30	130		5	34	3	34	6	34
52	30	140		6	34	4	32	2	31
53	30	150		3	36	4	48	5	42
54	30	160		12	29	8	41	5	31
55	30	170		7	31	5	42	3	26
56	30	180		8	31	6	30	3	26
57	30	190		11	34	10	30	3	21
58	40	10		10	41	11	36	8	31
59	40	20		4	35	6	60	4	35

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TABLE IV

ORDERED BY GREEN NUMBER

SEGMENT = 08.3 DATE GENERATED = 6/15/81

AC01 78151				AC02 78160				AC03 78197				AC04 78232			
GREEN NO.	BRIGHT NESS	DOT NO.	LINE/ PIXEL	GREEN NO.	BRIGHT NESS	DOT NO.	LINE/ PIXEL	GREEN NO.	BRIGHT NESS	DOT NO.	LINE/ PIXEL	GREEN NO.	BRIGHT NESS	DOT NO.	LINE/ PIXEL
0	104	156	90 40	-4	105	119	70 50	-9	88	170	90 180	-17	77	170	90 180
0	139	66	40 90	-2	104	1	10 10	1	92	164	90 170	-8	71	199	110 90
0	145	44	50 120	0	81	118	70 40	1	102	23	20 40	0	72	93	50 170
1	91	136	80 30	1	34	116	70 20	3	90	159	90 70	2	60	158	90 60
1	95	103	60 80	1	85	23	20 40	4	92	171	90 190	7	53	166	90 140
1	94	113	70 40	1	92	25	20 60	4	93	207	110 170	7	59	121	70 70
1	111	162	90 100	2	75	135	80 20	5	57	62	40 50	8	55	68	40 110
1	117	78	50 20	2	79	64	40 70	5	69	183	100 120	9	54	179	100 80
1	124	140	80 70	2	44	139	80 60	5	76	143	80 100	9	60	141	80 80
2	76	137	80 40	2	95	26	20 70	5	84	114	60 190	10	50	182	100 110
2	80	24	20 90	2	97	60	40 30	5	85	151	80 180	10	64	129	70 150
2	86	46	30 90	3	49	185	100 140	5	90	76	40 190	10	65	96	60 10
2	87	12	10 120	3	62	85	50 90	5	94	74	40 170	10	75	198	110 80
2	93	122	70 30	3	63	176	100 50	6	96	206	110 160	12	50	152	80 190
2	90	147	90 50	3	64	194	110 40	7	44	146	80 130	12	54	190	100 190
2	96	112	50 170	3	67	136	80 30	7	61	45	30 70	12	60	151	80 180
2	126	26	20 70	3	69	27	20 80	7	62	158	90 60	12	66	187	100 160
3	72	29	20 100	3	76	175	100 40	7	73	199	110 90	12	74	63	40 60
3	85	44	30 130	3	84	59	40 20	7	79	203	110 130	13	53	32	20 130
3	93	163	80 110	4	49	178	100 70	7	91	208	110 180	13	64	169	90 170
3	97	42	30 40	4	60	149	80 160	8	49	33	20 140	14	50	122	70 80
3	99	27	20 80	4	61	161	90 90	8	67	145	80 120	14	51	185	100 140
3	99	135	80 20	4	64	126	70 120	8	80	93	50 170	14	52	40	30 20
3	121	[illegible]	90 60	4	65	132	70 190	8	80	142	80 90	14	62	71	40 140
3	124	[illegible]	60 120	4	71	31	20 120	8	99	101	60 60	14	62	109	60 140
3	132	162	80 30	4	78	79	50 30	9	49	52	30 140	14	64	153	90 10
3	141	126	70 120	4	85	78	50 20	9	76	202	110 120	14	65	34	20 150
4	74	11	10 110	4	94	100	60 50	9	110	178	70 140	15	49	24	20 50
4	92	120	70 60	4	95	115	70 10	10	49	166	90 140	15	54	163	90 110
4	103	34	30 10	5	27	53	30 150	10	59	6	10 60	15	54	165	90 130
4	120	131	110 10	5	46	122	70 80	10	63	44	30 60	15	56	58	40 10
4	123	67	40 100	5	55	137	80 40	10	77	186	100 150	15	57	52	30 140
5	66	145	100 140	5	56	182	100 110	11	75	84	50 80	15	57	168	90 160
5	82	54	30 150	5	63	88	50 120	11	81	1	10 10	15	59	130	70 160
5	89	5	10 50	5	64	7	10 70	11	86	194	100 130	15	60	38	20 140
5	91	47	30 30	5	79	199	110 90	11	88	139	80 60	15	60	148	80 150
5	91	161	80 30	5	81	206	110 150	12	49	168	90 160	15	60	189	100 180
5	93	200	110 100	5	81	207	110 170	12	67	86	50 100	15	64	9	10 90
5	96	176	100 50	5	91	66	40 90	12	76	39	30 10	15	67	188	100 170
5	97	159	80 160	5	101	117	70 30	13	70	8	10 80	15	68	5	10 50
5	93	123	70 30	6	53	120	70 60	13	70	94	50 180	16	58	201	110 110
5	101	76	40 130	6	55	157	40 50	13	81	36	20 170	16	59	181	100 100
5	112	66	40 70	6	56	17	10 170	13	90	175	100 40	16	62	91	50 150
5	124	159	90 70	6	56	74	40 170	13	93	172	100 10	16	62	94	50 180
5	127	123	70 140	6	59	155	90 30	14	64	49	30 110	16	63	177	100 60
6	74	19	10 190	6	64	124	70 100	14	65	185	100 140	16	68	173	100 20
6	84	147	80 70	6	66	8	10 80	15	72	197	110 70	16	70	44	30 60
6	94	[illegible]	60 50	6	73	5	10 50	15	77	187	100 160	17	52	112	60 170
6	96	[illegible]	80 150	6	73	48	30 100	15	83	140	80 70	17	56	167	90 150
6	96	178	100 70	6	73	47	60 20	16	67	204	110 140	17	57	18	10 180
6	96	72	50 30	6	84	184	100 130	16	83	98	60 30	17	57	39	30 10
6	105	144	80 110	6	85	3	10 30	16	87	35	20 160	17	57	41	30 30
6	106	124	70 130	6	88	42	30 40	17	60	71	40 140	17	57	47	30 90
6	117	35	20 160	6	90	82	50 60	17	62	11	10 110	17	58	160	90 80
6	119	82	50 60	6	91	170	90 180	17	66	141	80 80	17	58	176	100 50
7	61	53	30 150	7	45	46	30 80	17	70	72	40 150	17	66	204	110 140
7	82	74	40 170	7	53	12	10 120	17	70	47	60 20	17	67	138	80 50
7	83	97	60 20	7	55	163	90 110	17	76	7	10 70	18	52	120	70 60
7	98	1	10 10	7	56	87	50 110	17	76	120	70 60	18	54	65	40 80

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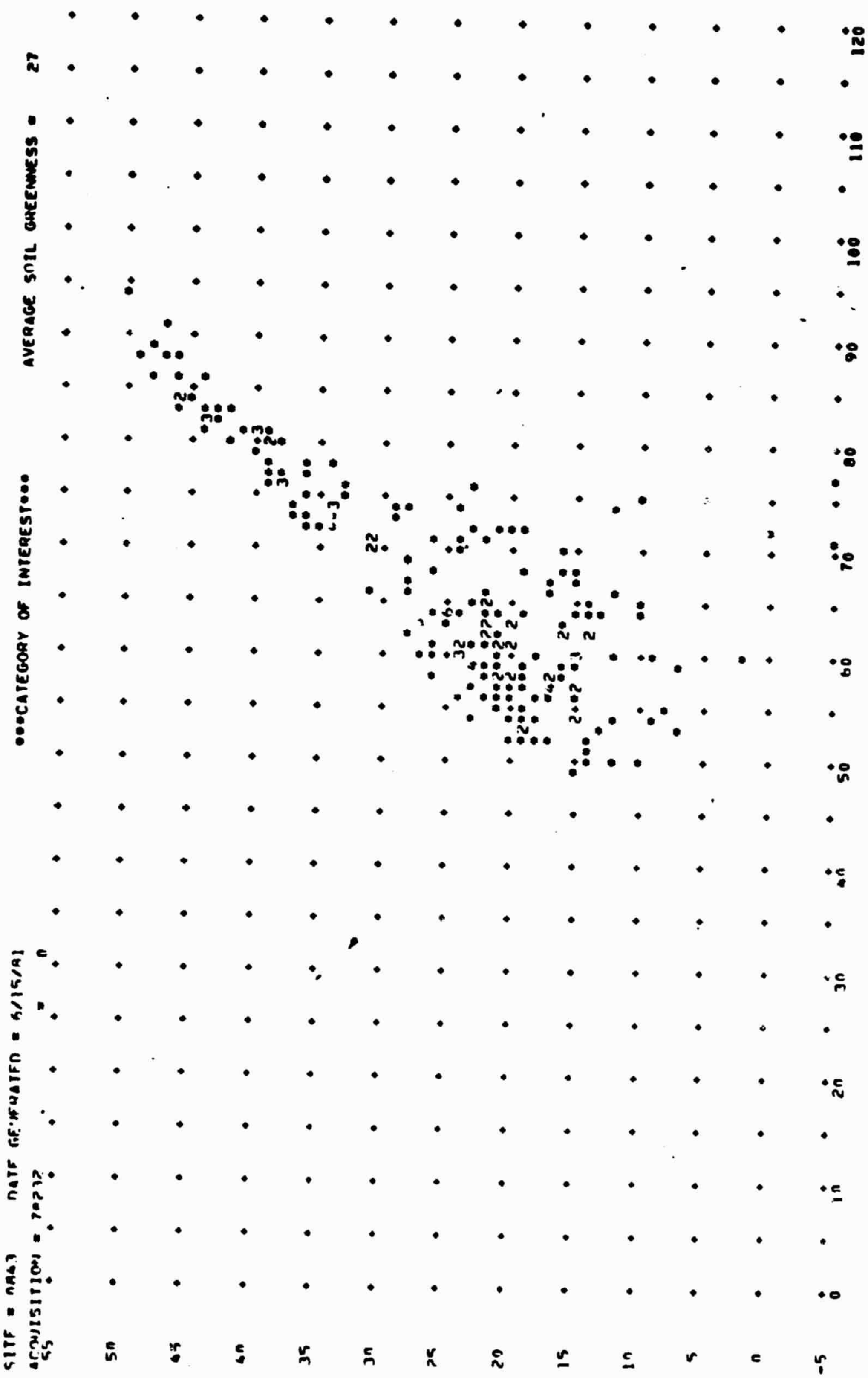
SITE = 0843 DATE GENERATED = 6/15/81

ACQUISITION = 78232

CATEGORY OF INTEREST

AVERAGE SOIL GREENNESS = 27



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SITE = 0943   4  DATE GENERATED = 6/15/81                    CATEGORIES PLOTTED   •
ACQUISITION = 78151     78160     78197     78232     78251     78269     78305     78313     78349
  SOIL LINES =   8        7        19        27        23        14        10        11        11

    DOT   LINE  PIXEL   LABEL                                  DOT   LINE  PIXEL   LABEL
     17    10    170                                            19    10    190
     18    10    180                                            20    20     10
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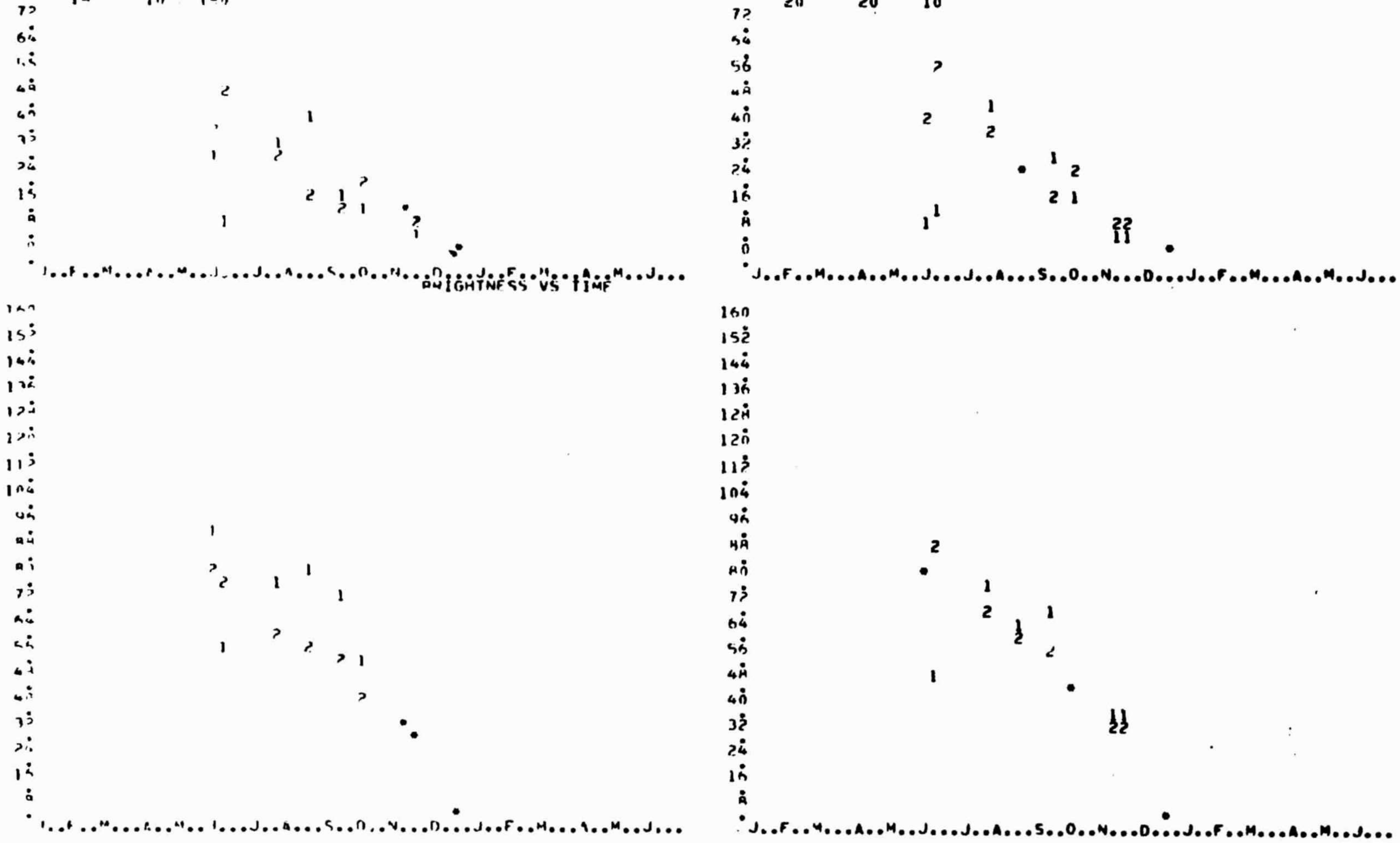

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APPENDIX B

LABELED SPECTRAL AIDS

..PENDIX B

LABELED SPECTRAL AIDS

This appendix contains examples of labeled spectral aids used in procedure development. The following examples are given for segment 0843, located in Henry County, Indiana.

1. First page of 209-dot green number listings for acquisition dates selected
2. Scatter plots of planting (window C1 and Y1) acquisitions (dates 78151 and 78160) with corn (C) and soybean (Y) dots plotted
3. Scatter plots of window C1 and Y1 acquisitions (dates 78151 and 78160) with _other_ categories of dots plotted
4. Scatter plot of green-up and separation (window Y2) acquisition (date 78232) with C and Y category dots plotted
5. Scatter plot of window Y2 acquisition (date 78232) with _other_ categories of dots plotted
6. Scatter plots of postharvest (window C3 and Y3) acquisitions (dates 78305 and 78313) with C and Y category dots plotted
7. Scatter plots of window C3 and Y3 acquisitions (dates 78305 and 78313) with _other_ categories of dots plotted

The procedure processes the acquisitions in designated windows using a multitemporal logic that separates the corn and soybeans from _other_ categories of crops and noncropland.

TABLE III
ORDERED BY GRID

SEGMENT = 0843   DATE GENERATED = 7/14/81

GRID 1

DOT NO.	LINE/	PIXEL	ANALYST LABEL	ACU1 78151		ACU2 78160		ACU3 78197		ACU4 78232		ACU5 78251		ACU6 78269	
				G	B	G	B	G	B	G	B	G	B	G	B
1	10	10		7	98	-2	104	11	81	25	64	19	57	21	51
2	10	20	C	14	97	25	92	23	71	22	62	14	60	20	56
3	10	30	C	25	101	6	85	28	73	23	59	18	58	15	45
4	10	40		9	91	27	74	26	65	20	54	12	57	18	42
5	10	50		5	89	6	73	26	65	15	68	17	55	21	54
6	10	60		31	90	41	72	10	59	43	83	22	67	17	55
7	10	70	Y	11	86	5	68	17	76	48	79	42	85	19	62
8	10	80	Y	20	88	6	66	13	70	40	81	23	70	23	59
9	10	90	P	40	83	54	85	23	62	15	64	11	59	20	49
10	10	100	H	27	77	33	68	23	69	22	65	15	64	21	48
11	10	110	Y	4	79	7	9	17	62	44	81	35	79	19	50
12	10	120	C	2	87	7	53	22	63	24	80	24	65	4	48
13	10	130		14	85	19	63	26	64	21	72	14	65	27	58
14	10	140		52	96	34	87	31	74	29	74	16	72	21	47
15	10	150	P	38	85	43	84	24	62	20	61	10	60	25	46
16	10	160	Y	23	58	17	80	23	73	44	82	32	77	29	64
17	10	170	Y	28	93	6	50	33	76	39	80	14	70	13	50
18	10	180	P	30	79	48	76	29	81	17	57	12	51	21	41
19	10	190		6	78	11	46	42	77	25	64	28	68	15	43
20	20	10	P	38	79	50	88	35	66	24	60	17	57	25	44
21	20	20		30	81	10	96	24	80	19	64	25	67	17	43
22	20	30		13	91	24	77	18	81	19	55	20	62	7	44
23	20	40		8	108	1	86	1	102	36	73	25	72	19	52
24	20	50	T	26	76	32	73	26	54	15	49	10	49	21	35
25	20	60	T	11	101	1	92	19	91	30	75	35	77	13	47
26	20	70	Y	2	126	2	95	19	79	46	83	35	78	12	48
27	20	80	C	3	94	3	69	24	62	21	57	21	62	18	45
28	20	90	C	2	80	7	66	35	66	21	61	17	63	15	44
29	20	100	C	3	72	7	59	32	65	20	57	16	57	15	41
30	20	110		27	84	35	75	20	57	4	70	27	70	12	53
31	20	120	C	14	108	4	71	26	68	23	59	16	60	24	50
32	20	130		20	95	7	64	18	70	13	53	11	55	17	43
33	20	140	C	9	76	14	54	8	49	18	56	15	56	15	41
34	20	150	H	31	89	40	82	26	72	14	65	14	63	29	55
35	20	160	Y	6	117	34	75	16	87	40	88	29	72	9	50
36	20	170		22	114	15	75	13	81	40	81	33	80	14	54
37	20	180	P	25	83	34	69	34	65	24	56	17	57	19	36
38	20	190	P	38	85	56	84	22	59	15	60	9	54	19	41
39	30	10		4	103	14	77	12	76	17	57	9	60	21	53
40	30	20	C	15	112	14	91	19	79	14	52	17	60	22	52
41	30	30		25	85	24	79	23	63	17	57	13	57	18	44
42	30	40	C	3	97	6	88	33	63	23	57	17	59	14	43
43	30	50		31	99	38	89	30	58	49	88	24	64	25	44
44	30	60	H	37	87	50	75	10	63	16	70	23	67	-2	71
45	30	70		39	78	34	76	7	61	28	62	16	55	2	52
46	30	80	C	2	84	7	45	31	60	23	61	13	55	5	33
47	30	90	C	5	91	14	83	29	64	17	57	10	54	4	41
48	30	100	C	3	85	6	73	36	68	25	64	17	56	18	50
49	30	110	Y	13	92	8	75	14	64	35	72	24	67	10	53
50	30	120	C	25	96	27	70	19	69	21	58	16	60	18	46
51	30	130	C	32	84	8	41	23	56	24	60	17	59	26	52
52	30	140		18	72	12	31	9	49	15	57	12	55	21	50
53	30	150	C	7	61	5	27	20	56	21	58	15	59	17	45
54	30	160		5	82	20	70	25	61	20	63	15	60	18	45
55	30	170		49	87	40	82	22	75	31	71	14	54	32	55
56	30	180		36	91	13	101	23	77	21	62	18	63	22	49
57	30	190	Y	37	79	55	78	33	58	20	58	16	52	22	37
58	40	10	P	38	81	51	82	31	82	15	56	16	54	20	46
59	40	20	C	14	76	3	84	24	66	24	61	18	59	23	47

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TABLE III
ORDERED BY GRID

SEGMENT = 0R43 DATE GENERATED = 7/14/81

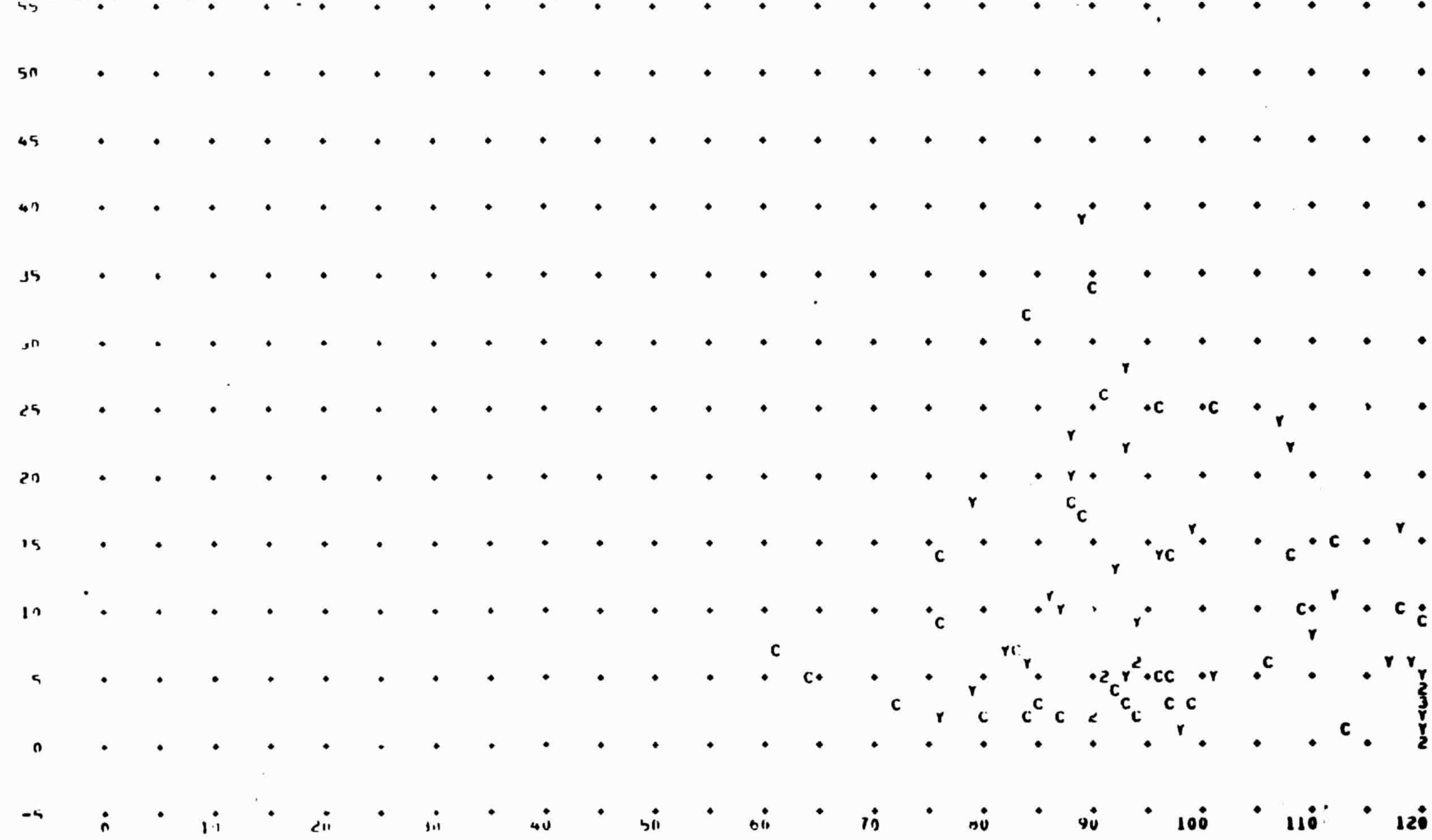
GRID 1

DOT NO.	LINE/	PIXEL	ANALYST LABEL	AC07 78305 G	B	AC28 78313 G	B	AC09 78349 G	B
1	10	10		12	37	12	46	6	34
2	10	20	C	4	35	3	35	4	35
3	10	30	C	2	33	1	37	1	28
4	10	40		3	27	4	29	3	35
5	10	50		5	39	5	41	5	35
6	10	60		5	43	6	39	8	35
7	10	70	Y	2	46	3	43	4	25
8	10	80	Y	2	46	5	45	4	31
9	10	90	P	12	40	15	41	11	31
10	10	100	T	9	38	10	36	9	30
11	10	110	Y	0	31	4	32	5	24
12	10	120	C	2	47	1	55	4	25
13	10	130		6	46	5	52	5	34
14	10	140		10	40	11	46	9	37
15	10	150	P	11	39	8	32	6	33
16	10	160	[illegible]	5	33	6	40	2	30
17	10	170	Y	10	33	3	29	4	31
18	10	180	P	10	31	8	28	6	22
19	10	190		4	36	3	37	3	31
20	20	10	P	9	30	9	32	9	27
21	20	20		7	28	7	27	4	20
22	20	30		2	26	2	55	2	37
23	20	40		4	47	8	46	4	29
24	20	50	T	10	31	9	29	4	20
25	20	60	T	1	42	2	40	4	31
26	20	70	Y	3	44	2	43	3	31
27	20	80	C	5	39	3	35	2	32
28	20	90	C	1	25	2	56	3	34
29	20	100	C	2	26	4	50	3	28
30	20	110		11	49	9	46	7	31
31	20	120	C	4	33	1	33	4	39
32	20	130		5	32	4	38	3	33
33	20	140	C	4	28	2	36	2	30
34	20	150	H	11	38	13	36	10	30
35	20	160	Y	8	38	6	42	7	28
36	20	170		5	47	9	43	8	30
37	20	180	P	6	23	6	33	4	24
38	20	190	P	14	36	9	30	8	29
39	30	10		3	32	4	31	3	38
40	30	20	C	3	36	5	53	2	31
41	30	30		8	32	7	31	7	31
42	30	40	C	1	24	2	25	1	42
43	30	50		1	37	4	34	3	31
44	30	60	[illegible]	6	49	11	45	6	33
45	30	70		3	27	7	31	4	20
46	30	80	C	4	23	2	24	1	23
47	30	90	C	0	36	1	44	4	27
48	30	100	C	4	41	3	32	2	26
49	30	110	Y	3	42	6	44	1	25
50	30	120	C	2	33	5	56	5	27
51	30	130	C	5	34	3	34	6	34
52	30	140		6	34	4	32	2	31
53	30	150	C	3	32	4	48	5	42
54	30	160		12	29	8	41	2	31
55	30	170		7	31	5	42	5	24
56	30	180		8	31	6	[illegible]	3	26
57	30	190	T	11	34	10	30	3	21
58	40	10	P	10	41	11	36	3	31
59	40	20	C	4	35	6	60	4	35

PLANTING ACQUISITION NO. 1, CORN AND SOYBEAN CATEGORIES

SITE = 0843   DATE GENERATED = 7/06/81   ***CATEGORY OF INTEREST***   AVERAGE SOIL GREENNESS = 8

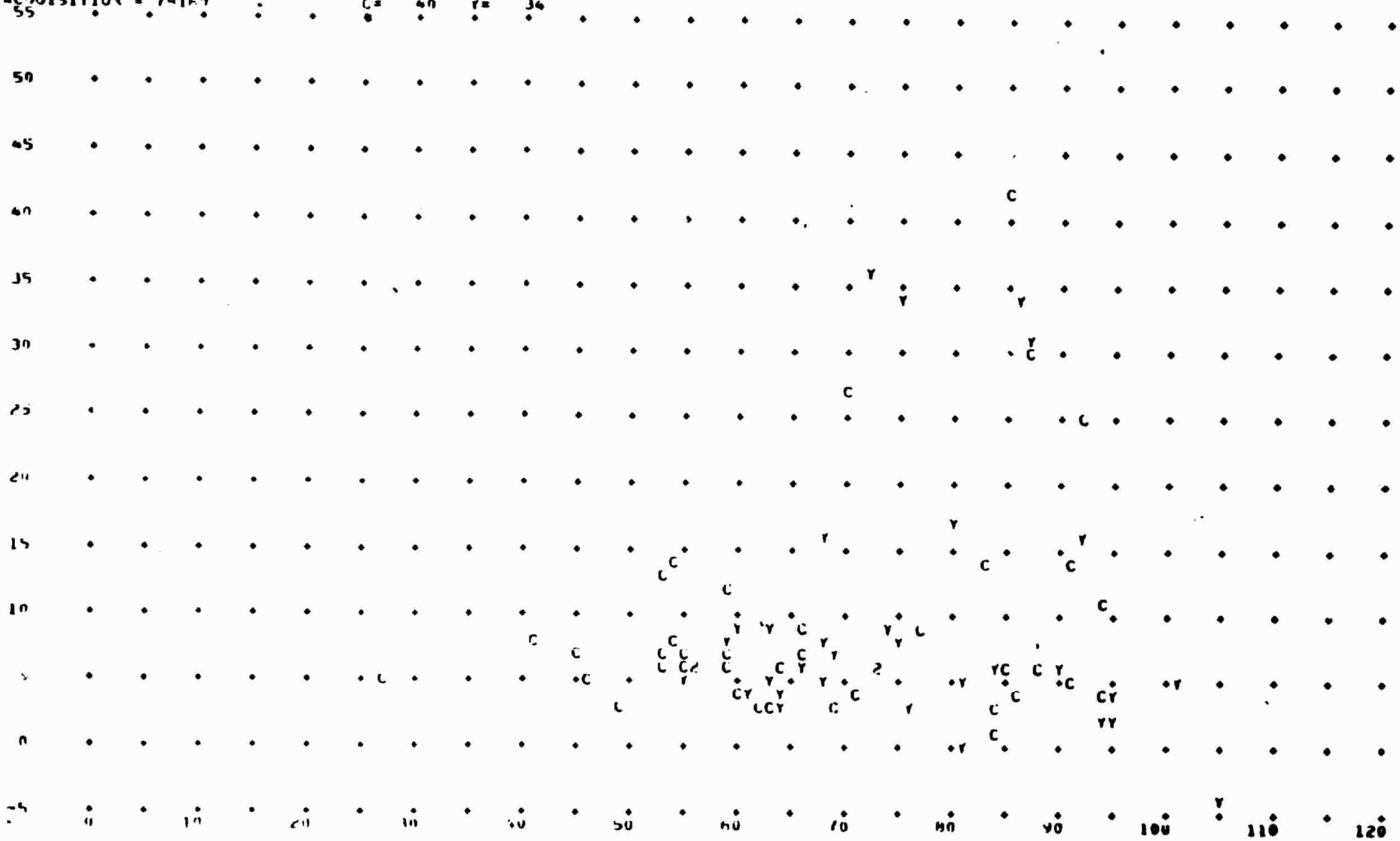
ACQUISITION = 78151   C= 40   Y= 34



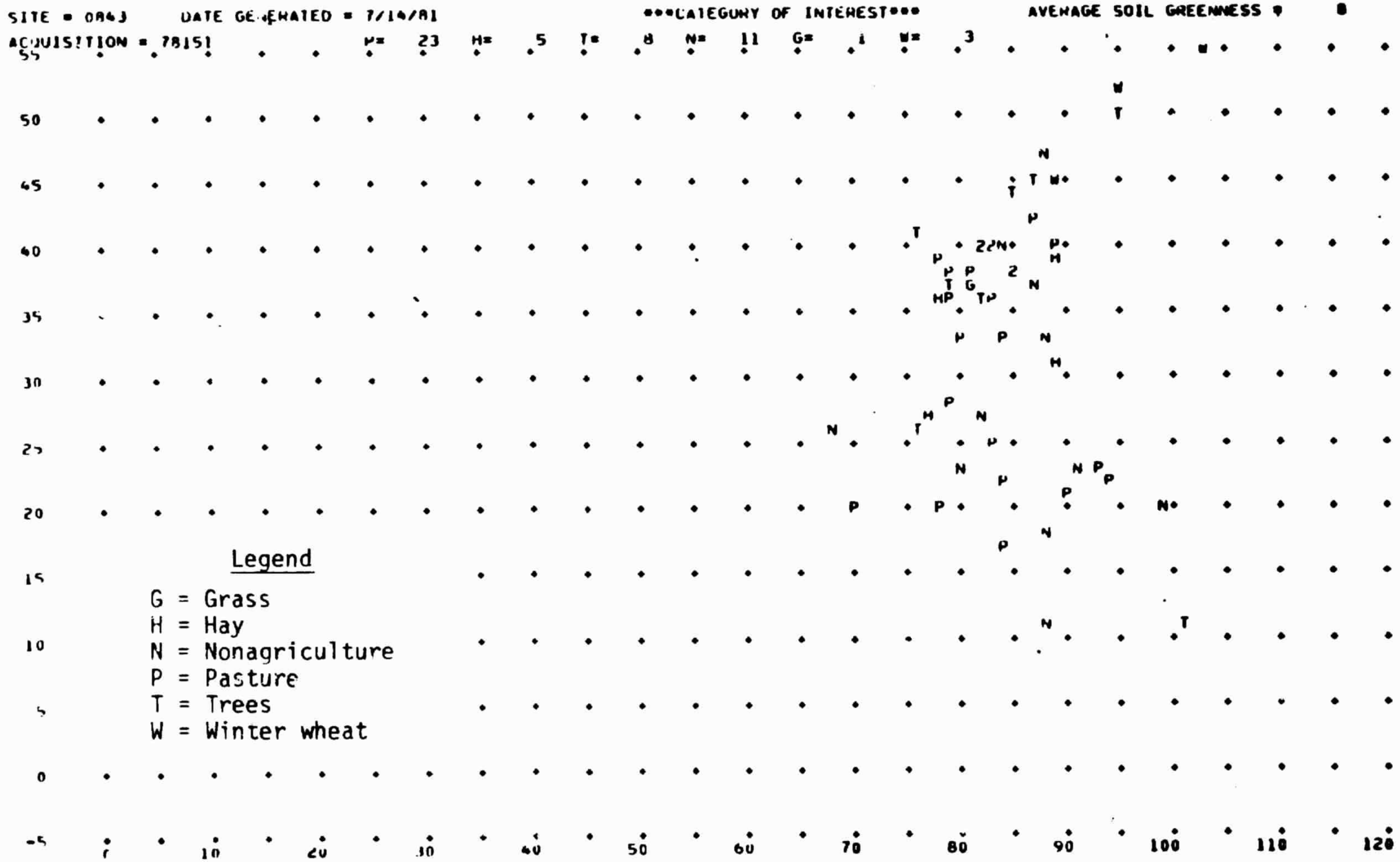
PLANTING ACQUISITION NO. 2, CORN AND SOYBEAN CATEGORIES

SITE = 0843 DATE GENERATED = 7/08/81 ***CATEGORY OF INTEREST*** AVERAGE SOIL GREENNESS = 7

ACQUISITION = 79163 C= 40 Y= 34



PLANTING ACQUISITION NO. 1, OTHER CATEGORIES



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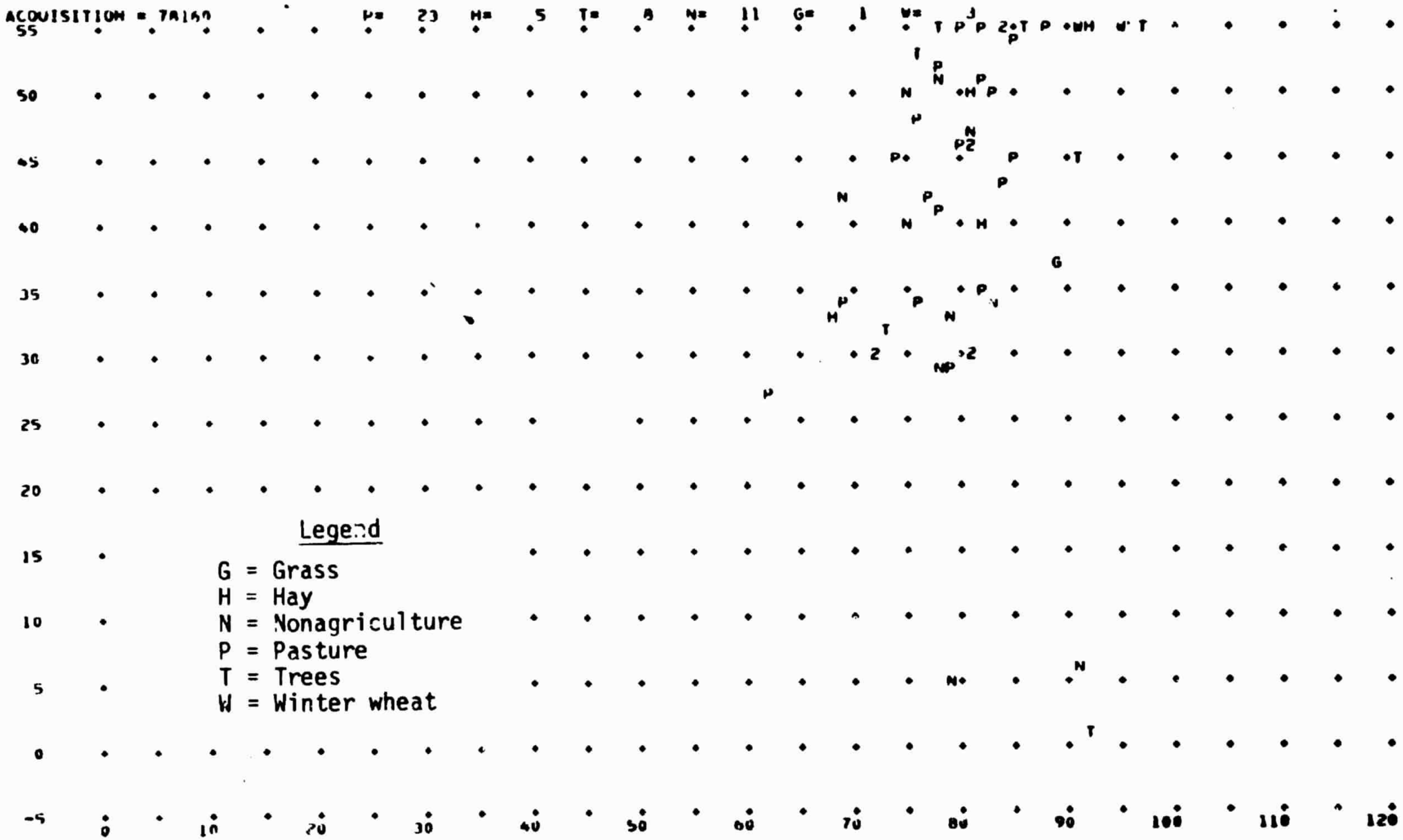
SITE = 0843      DATE GENERATED = 7/14/81                ***CATEGORY OF INTEREST***          AVERAGE SOIL GREENNESS =    8
ACQUISITION = 78151            P=  23  H=   5  T=   8  N=  11  G=   1  W=   3
```

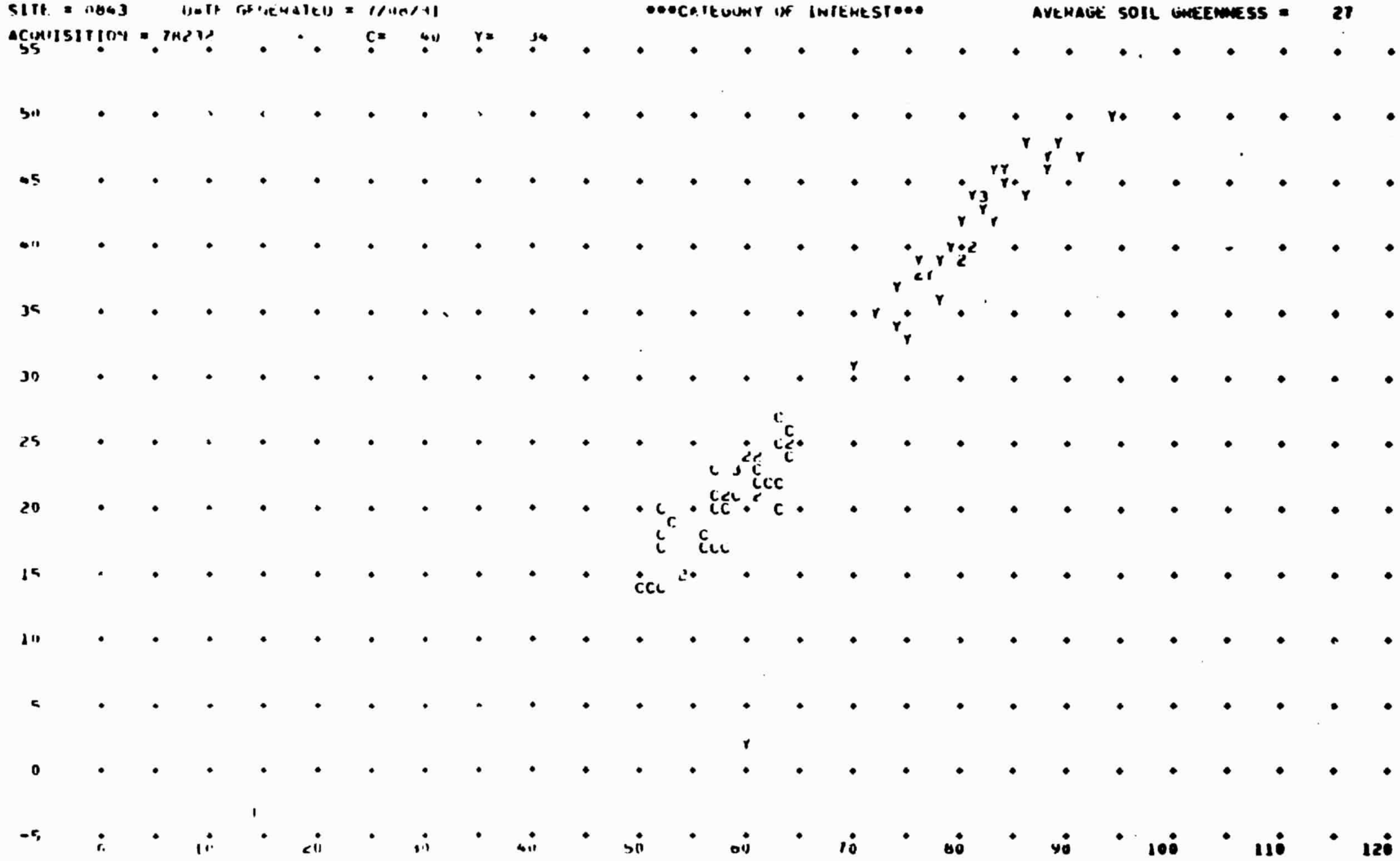
PLANTING ACQUISITION NO. 2, OTHER CATEGORIES

SITE = 0843 DATE GENERATED = 7/14/81 ***CATEGORY OF INTEREST*** AVERAGE SOIL GREENNESS = 7

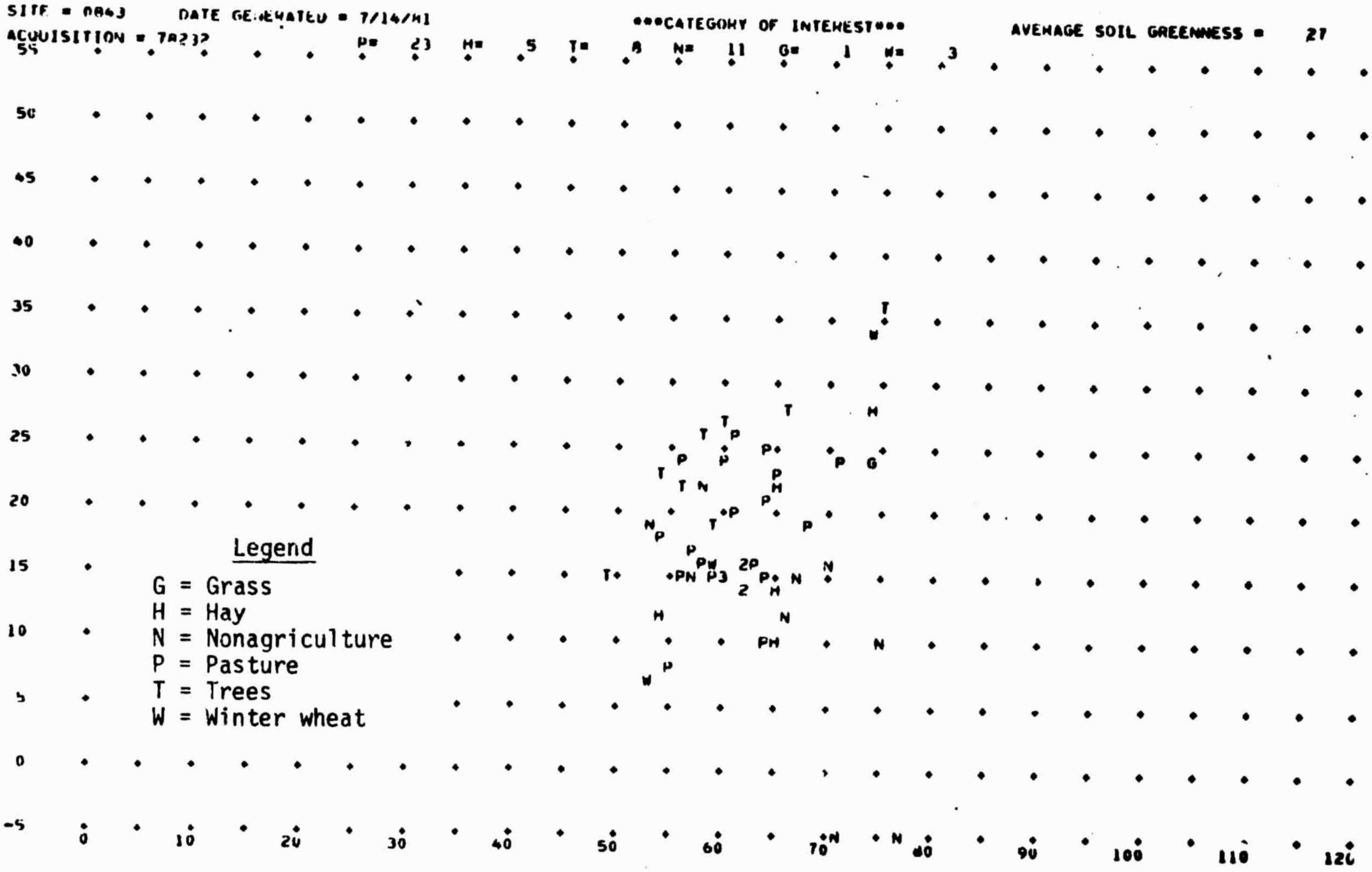
ACQUISITION = 78160 P= 23 H= 5 T= 8 N= 11 G= 1 W= 3



GREEN-UP AND SEPARATION ACQUISITION, CORN AND SOYBEAN CATEGORIES



GREEN-UP AND SEPARATION ACQUISITION, OTHER CATEGORIES



C-2

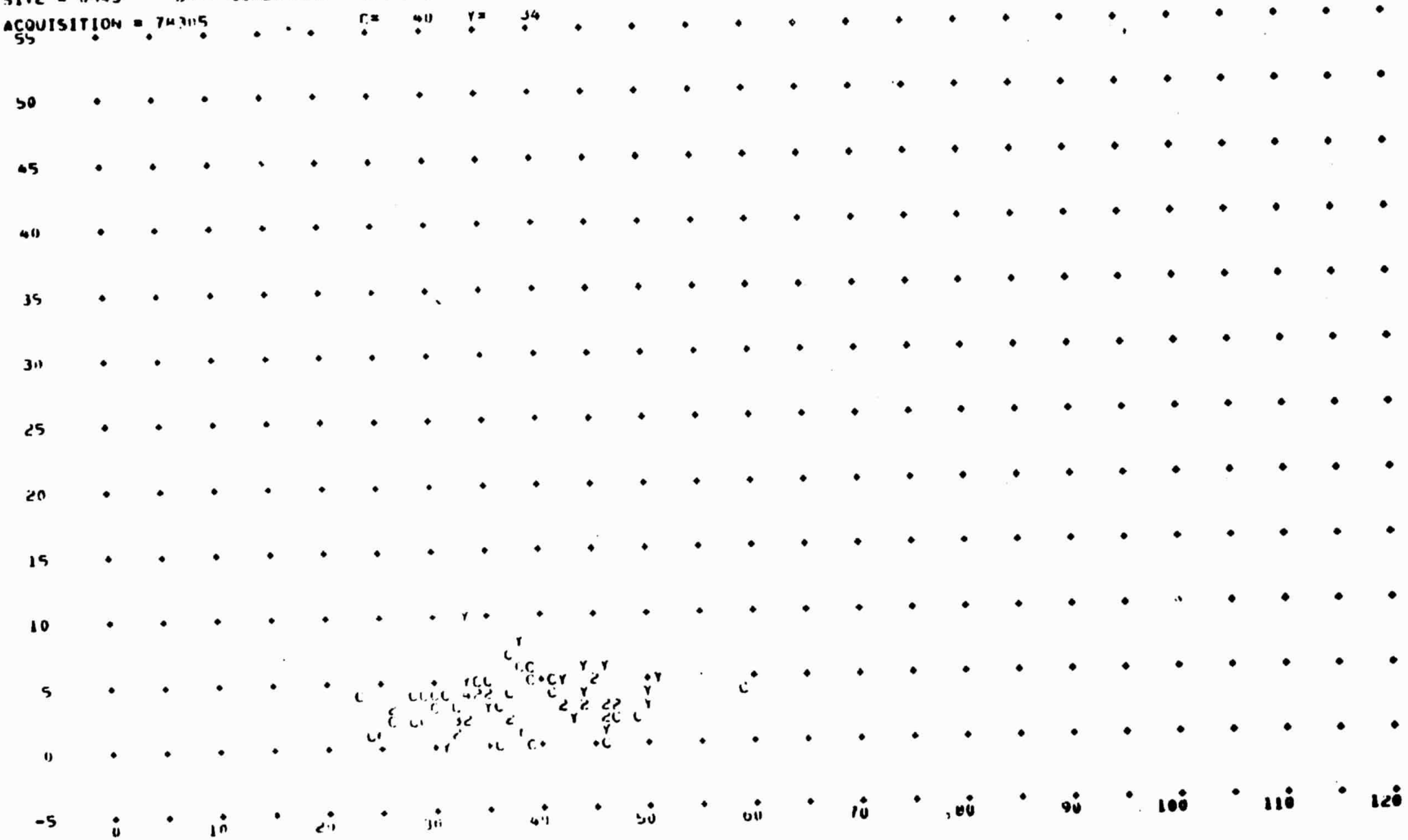
POSTHARVEST ACQUISITION NO. 1, CORN AND SOYBEAN CATEGORIES

SITE = 0843 DATE GENERATED = 7/08/81

ACQUISITION = 78305

CATEGORY OF INTEREST

AVERAGE SOIL GREENNESS = 10



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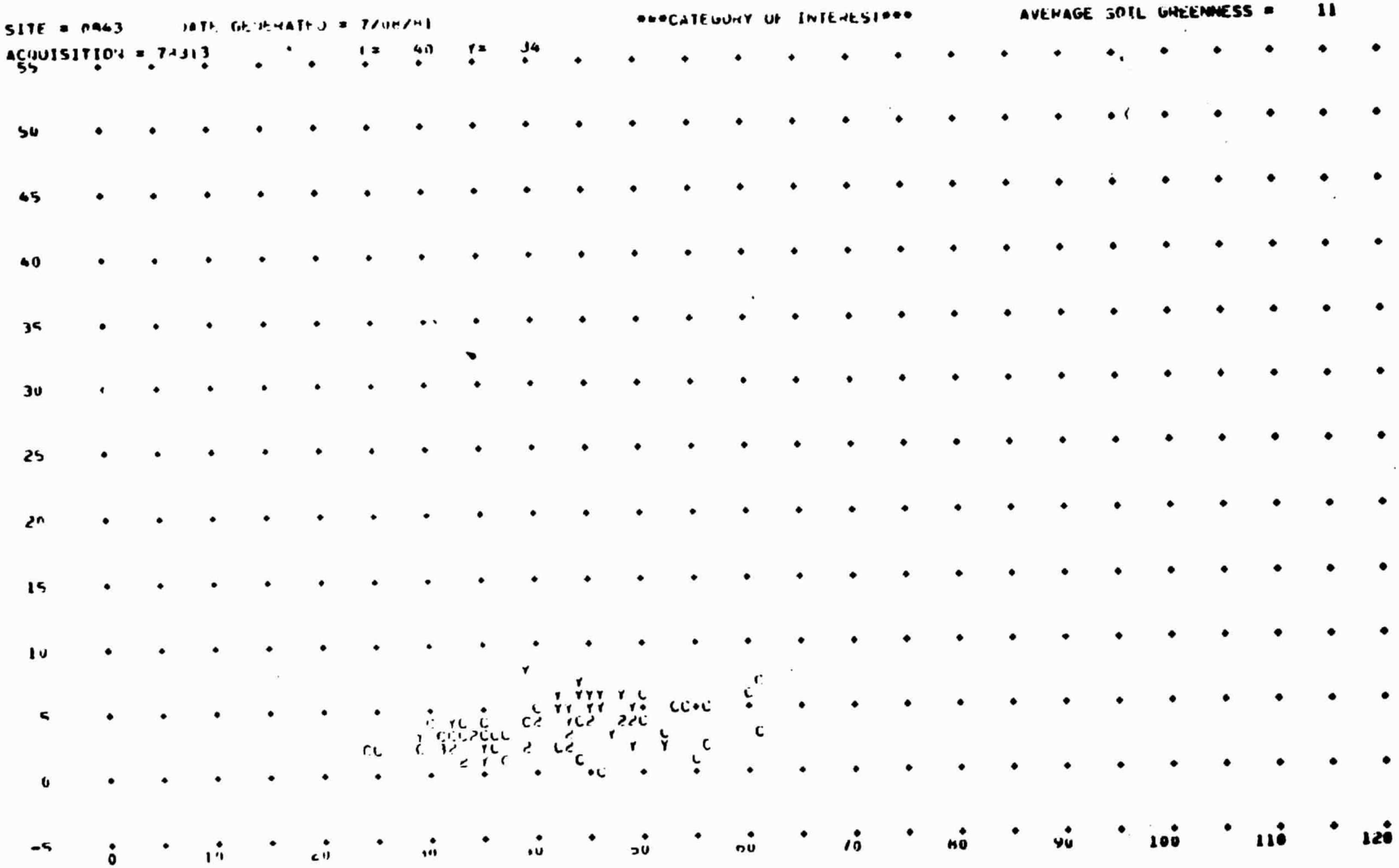
POSTHARVEST ACQUISITION NO. 2, CORN AND SOYBEAN CATEGORIES

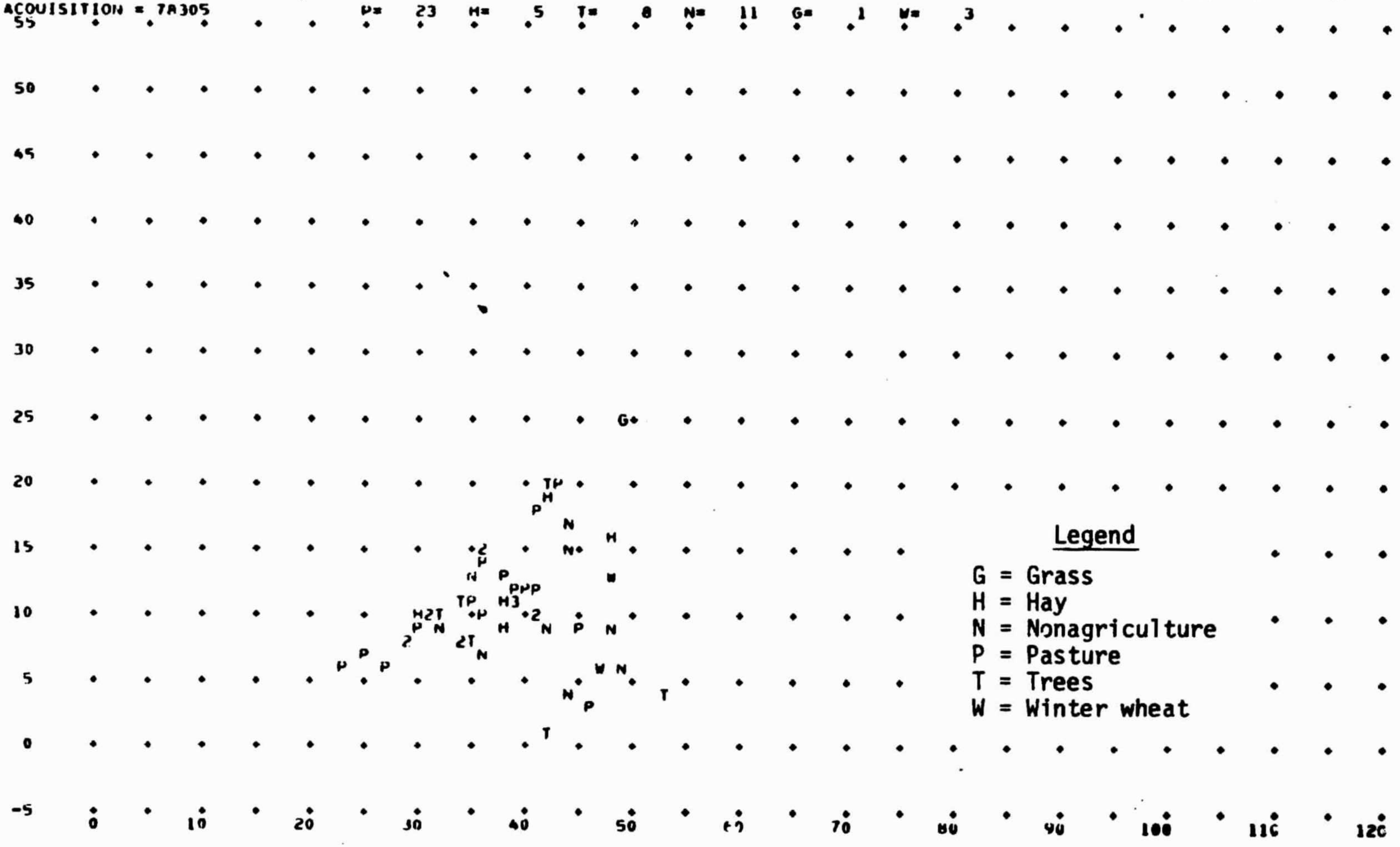


SITE = 0843 DATE GENERATED = 7/08/81 ***CATEGORY OF INTEREST*** AVERAGE SOIL GREENNESS = 11

ACQUISITION = 74313 I= 40 Y= 34

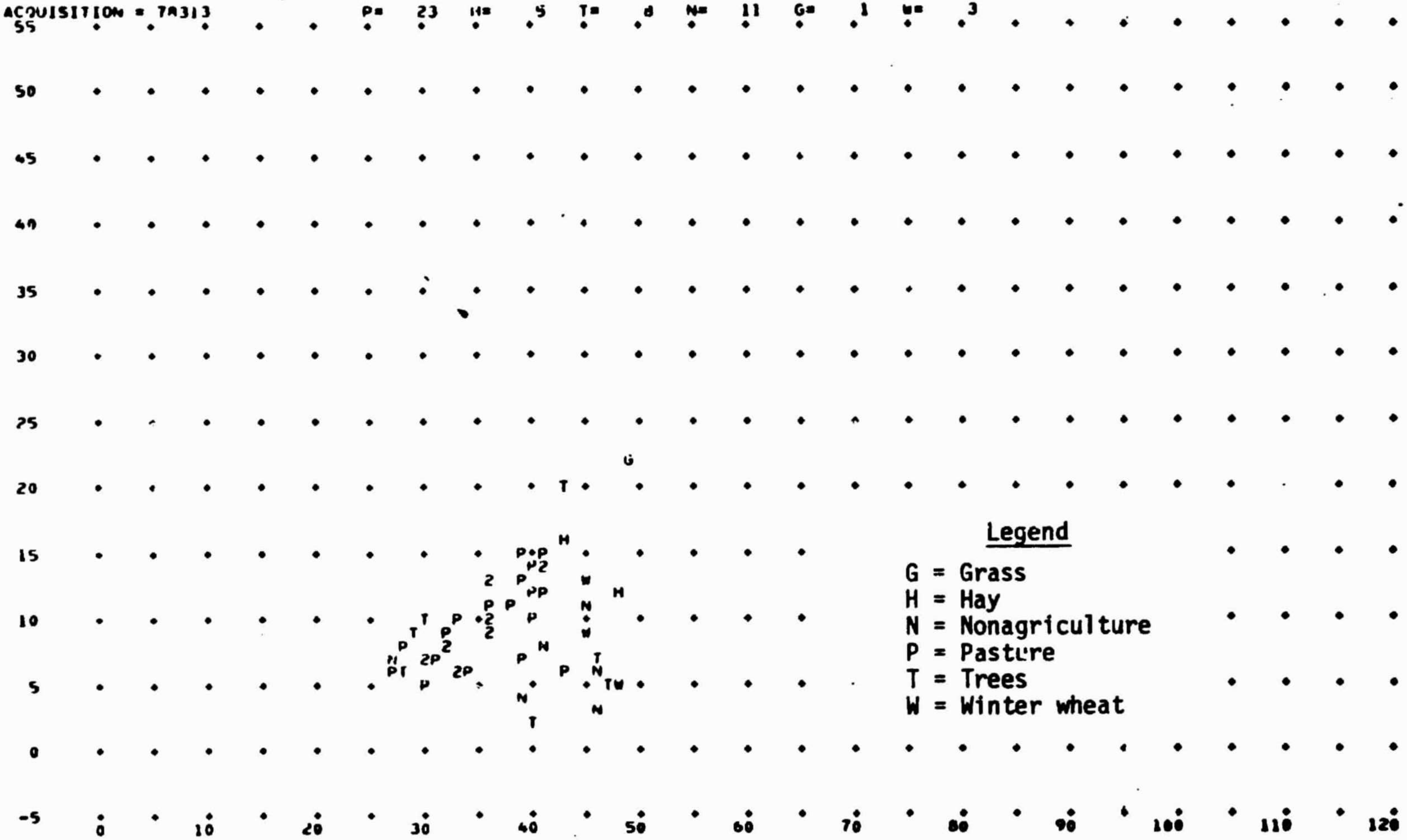
POSTHARVEST ACQUISITION NO. 1, OTHER CATEGORIES

```
SITE = 0843      DATE GENERATED = 7/14/81                    ***CATEGORY OF INTEREST***          AVERAGE SOIL GREENNESS =    10
ACQUISITION = 7A305                 P=  23   H=   5   T=   8   N=   11   G=   1   W=   3
```



POSTHARVEST ACQUISITION NO. 2, OTHER CATEGORIES

```
SITE = 0843     DATE GENERATED = 7/14/81                    ***CATEGORY OF INTEREST***          AVERAGE SOIL GREENNESS =    11
ACQUISITION = 78313                P=  23   H=   5   T=   8   N=  11   G=   1   W=   3
```



APPENDIX C

CRITICAL TIME PERIOD (WINDOW) CHARTS

APPENDIX C

CRITICAL TIME PERIOD (WINDOW) CHARTS

This appendix contains charts depicting the data relevant to determining critical time periods (windows) for labeling corn and soybeans in the United States. The charts have the following captions:

Figure C-1 - Critical time period (window) chart for corn for year 1978

Figure C-2 - Critical time period (window) chart for corn for year 1979

Figure C-3 - Critical time period (window) chart for soybeans for year 1978

Figure C-4 - Critical time period (window) chart for soybeans for year 1979

Data recorded on each chart are as follows:

1. For each segment, the segment number and location (county, state).
2. The growth stages nearest the time of occurrence of the critical periods defined earlier. Dates of these stages are to be taken as points of reference for plotting the segment acquisitions on a relative scale. The "reference" stages are from the best available CRD or state crop calendar for the applicable year. Reference stages for the periods are:

Crop	Period	Reference stage(s)
Corn	Preemergence	50% planted
Corn	Maximum greenness	50% tasseled, 50% dented
Corn	Harvest	50% mature
Soybeans	Preemergence	50% planted
Soybeans	Maximum greenness	50% podded, 50% turned
Soybeans	Harvest	50% mature

3. Each acquisition date for each segment plotted in relation to the reference growth stages.
4. The date of occurrence of growth stages recorded by the ASCS enumerator during the ground data surveys. Median dates were calculated whenever possible, but planting data were not always available.

5. Comments addressing the adequacy of acquisitions at early and late extremes of the critical periods.

6. Approximations of the limits of the critical periods. These limits are empirically derived. The final limits recorded are based on calculations described in appendix H, which are based on the relationships shown in tables 3-1 through 3-4.

The following critical period symbology is used in these figures:

1. Dotted line brackets represent the corn window limits.
2. Solid line brackets represent the soybean window limits.
3. Dashed lines represent the corn/soybean window limits coinciding on same date.

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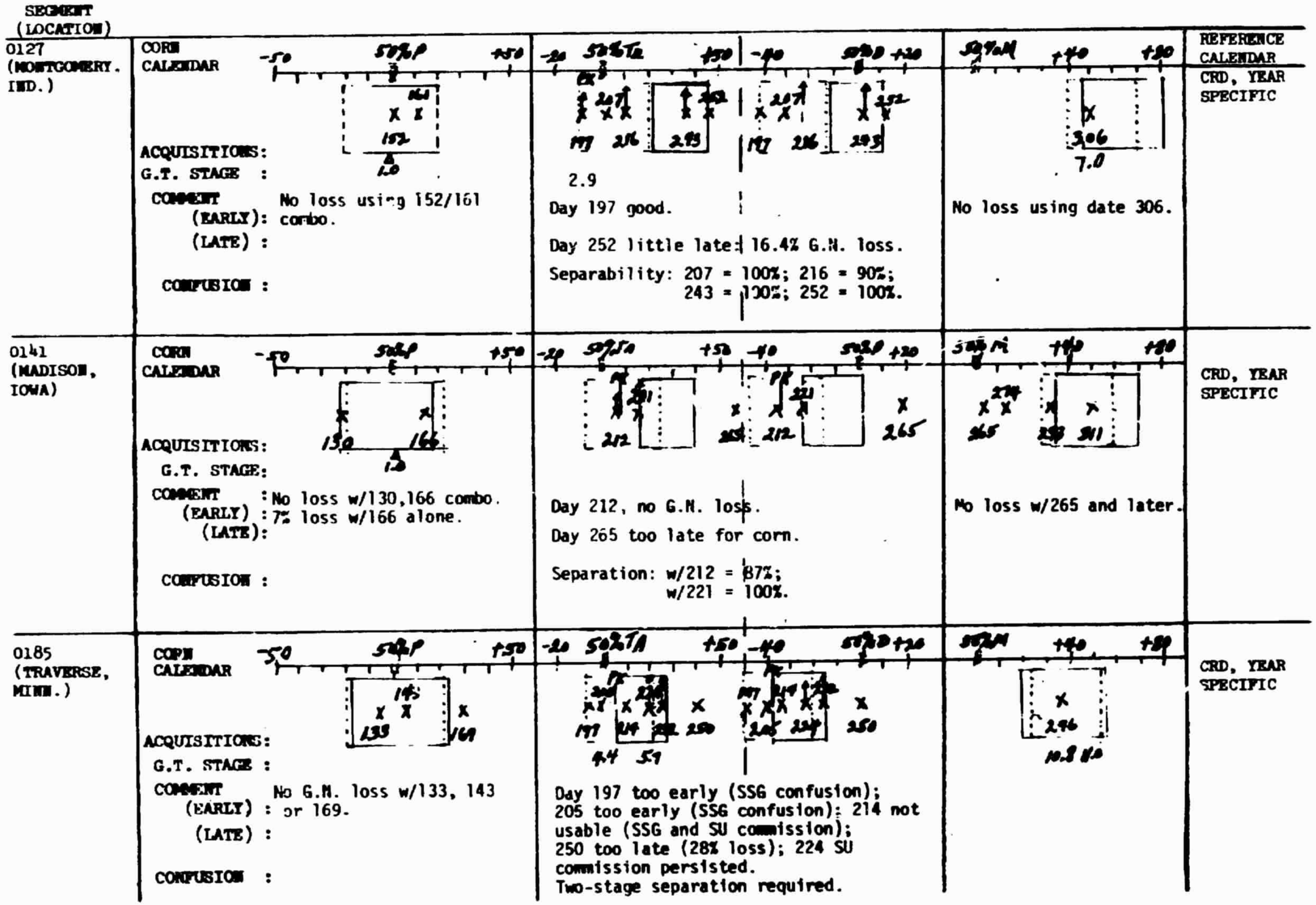


SEGMENT (LOCATION) | REFERENCE CALENDAR

0127 (MONTGOMERY, IND.) — CORN CALENDAR — CRD, YEAR SPECIFIC

ACQUISITIONS:

G.T. STAGE :

COMMENT (EARLY): No loss using 152/161 combo.

(LATE) :

CONFUSION :

2.9

Day 197 good.

Day 252 little late: 16.4% G.N. loss.

Separability: 207 = 100%; 216 = 90%;
243 = 100%; 252 = 100%.

No loss using date 306.

0141 (MADISON, IOWA) — CORN CALENDAR — CRD, YEAR SPECIFIC

ACQUISITIONS:

G.T. STAGE:

COMMENT (EARLY) : No loss w/130,166 combo.
7% loss w/166 alone.

(LATE):

CONFUSION :

Day 212, no G.N. loss.

Day 265 too late for corn.

Separation: w/212 = 87%;
w/221 = 100%.

No loss w/265 and later.

0185 (TRAVERSE, MINN.) — CORN CALENDAR — CRD, YEAR SPECIFIC

ACQUISITIONS:

G.T. STAGE :

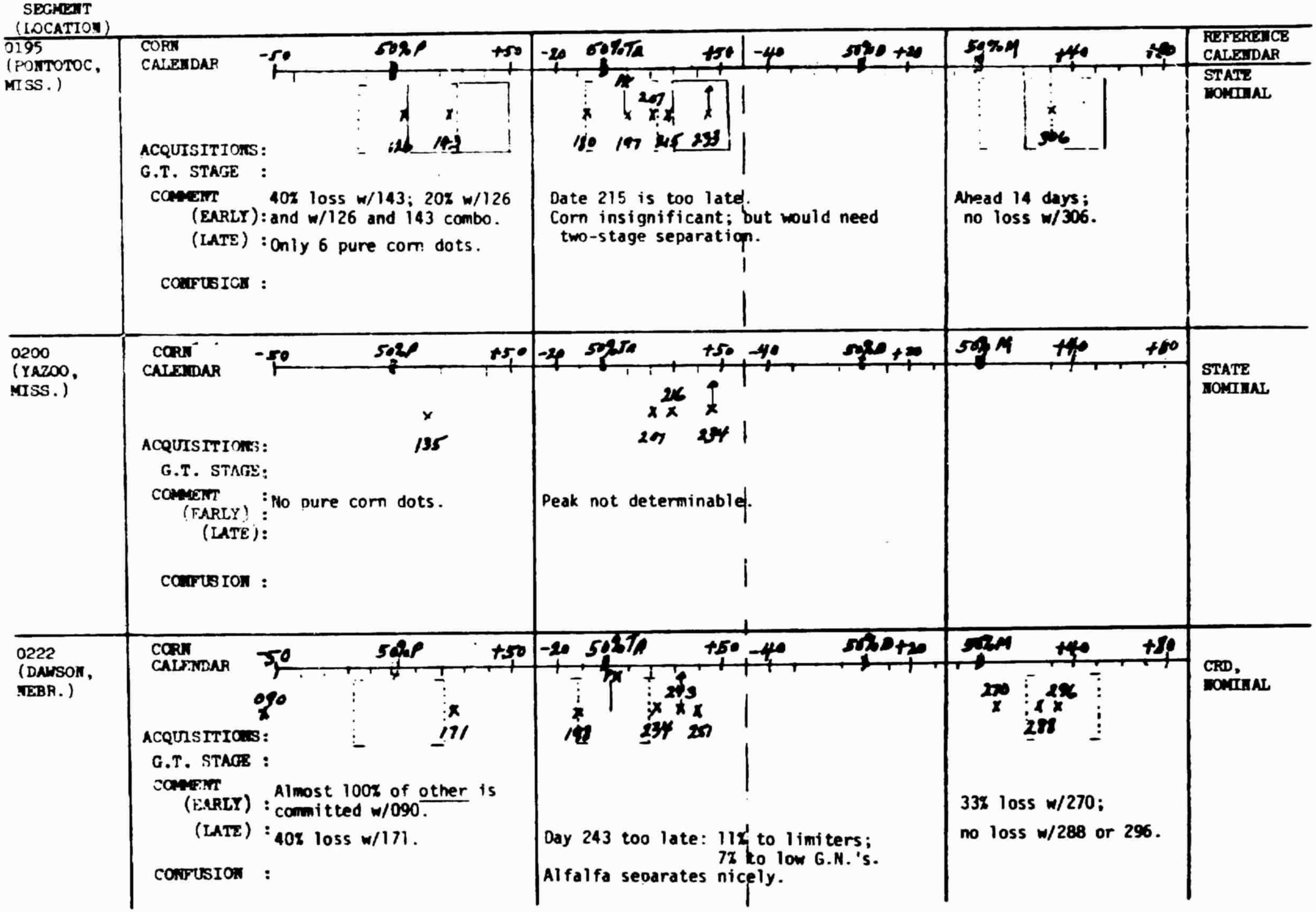
COMMENT (EARLY) : No G.N. loss w/133, 143 or 169.

(LATE) :

CONFUSION :

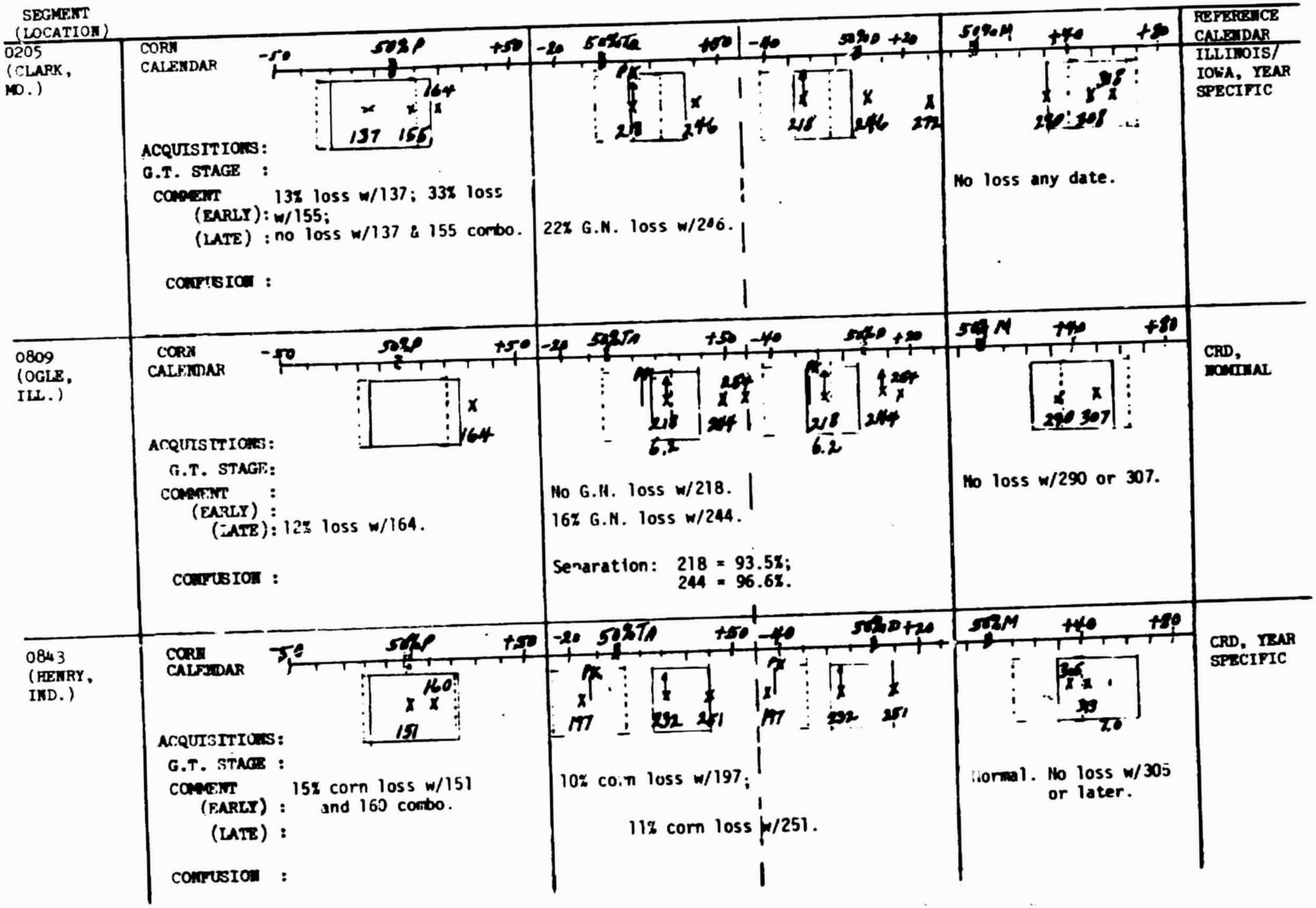
Day 197 too early (SSG confusion);
205 too early (SSG confusion); 214 not usable (SSG and SU commission);
250 too late (28% loss); 224 SU commission persisted.
Two-stage separation required.

Figure C-1.- Critical time period (window) chart for corn for year 1978.



SEGMENT (LOCATION)	CORN CALENDAR				REFERENCE CALENDAR
0195 (PONTOTOC, MISS.)	ACQUISITIONS: G.T. STAGE : COMMENT (EARLY): 40% loss w/143; 20% w/126 and w/126 and 143 combo. (LATE) : Only 6 pure corn dots. CONFUSION :	Date 215 is too late. Corn insignificant; but would need two-stage separation.		Ahead 14 days; no loss w/306.	STATE NOMINAL
0200 (YAZOO, MISS.)	ACQUISITIONS: G.T. STAGE: COMMENT (EARLY) : No pure corn dots. (LATE): CONFUSION :	Peak not determinable.			STATE NOMINAL
0222 (DAWSON, NEBR.)	ACQUISITIONS: G.T. STAGE : COMMENT (EARLY) : Almost 100% of other is committed w/090. (LATE) : 40% loss w/171. CONFUSION :	Day 243 too late: 11% to limiters; 7% to low G.N.'s. Alfalfa separates nicely.		33% loss w/270; no loss w/288 or 296.	CRD. NOMINAL

Figure C-1.- Continued.



SEGMENT (LOCATION)					REFERENCE CALENDAR
0205 (CLARK, MO.)	CORN CALENDAR ACQUISITIONS: G.T. STAGE : COMMENT (EARLY): 13% loss w/137; 33% loss w/155; (LATE) : no loss w/137 & 155 combo. CONFUSION :	22% G.N. loss w/246.		No loss any date.	ILLINOIS/ IOWA, YEAR SPECIFIC
0809 (OGLE, ILL.)	CORN CALENDAR ACQUISITIONS: G.T. STAGE: COMMENT : (EARLY) : (LATE): 12% loss w/164. CONFUSION :	No G.N. loss w/218. 16% G.N. loss w/244. Separation: 218 = 93.5%; 244 = 96.6%.		No loss w/290 or 307.	CRD, NOMINAL
0843 (HENRY, IND.)	CORN CALENDAR ACQUISITIONS: G.T. STAGE : COMMENT (EARLY) : 15% corn loss w/151 and 160 combo. (LATE) : CONFUSION :	10% corn loss w/197; 11% corn loss w/251.		Normal. No loss w/305 or later.	CRD, YEAR SPECIFIC

Figure C-1.- Continued.

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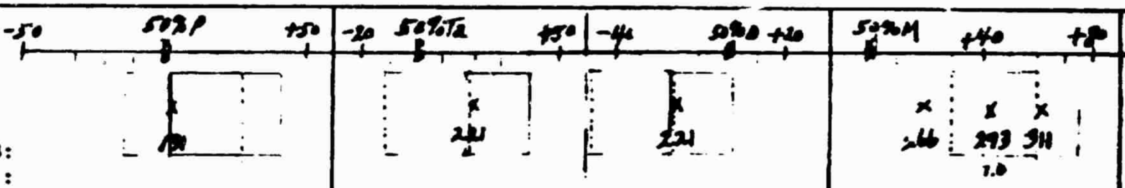
SEGMENT
(LOCATION)
0893
(WEBSTER,
IOWA)

CORN
CALENDAR



REFERENCE
CALENDAR
CRD, YEAR
SPECIFIC

ACQUISITIONS:
G.T. STAGE :
COMMENT
(EARLY): 7 days ahead.
No loss w/131.
(LATE) :

Date of peak not determinable.

7 days ahead.
No losses w/266 or later.

CONFUSION :

Separation: 100%.

Figure C-1.- Concluded.

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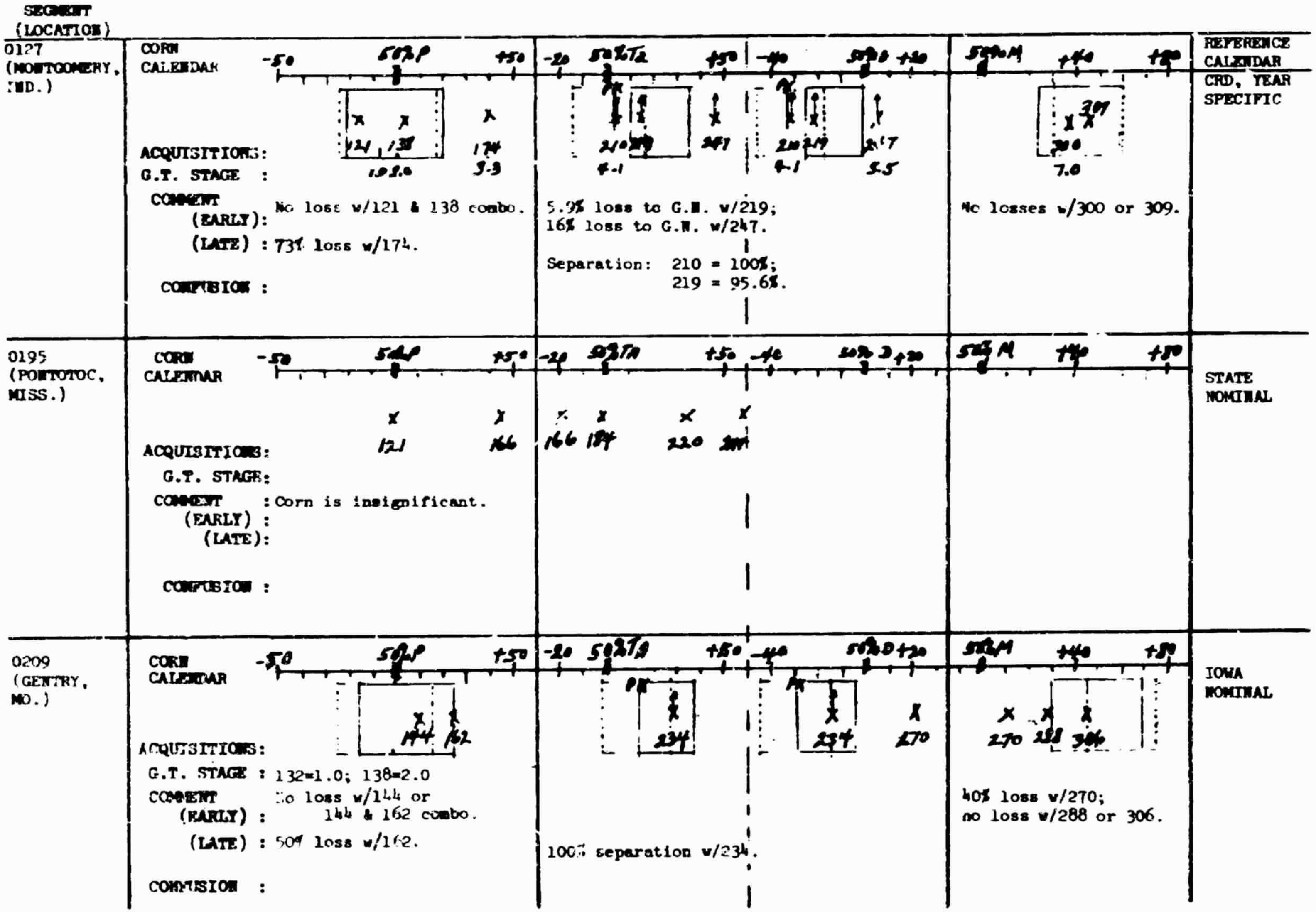


0127 (MONTGOMERY, IND.)

COMMENT (EARLY): No loss w/121 & 138 combo.

(LATE) : 73% loss w/174.

5.9% loss to G.M. w/219;
16% loss to G.M. w/247.

Separation: 210 = 100%;
219 = 95.6%.

No losses w/300 or 309.

0195 (PONTOTOC, MISS.)

COMMENT : Corn is insignificant.

0209 (GENTRY, MO.)

G.T. STAGE : 132=1.0; 138=2.0

COMMENT (EARLY) : No loss w/144 or 144 & 162 combo.

(LATE) : 50% loss w/162.

100% separation w/234.

40% loss w/270;
no loss w/288 or 306.

Figure C-2.- Critical time period (window) chart for corn for year 1979.

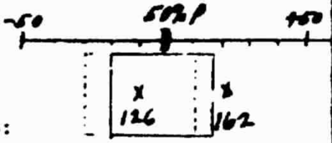
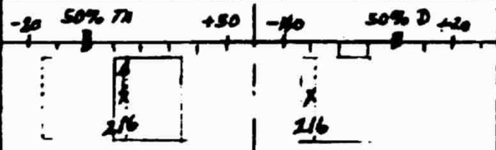
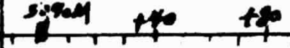
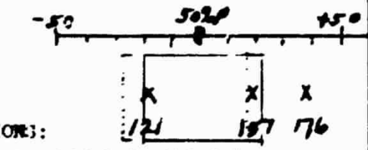
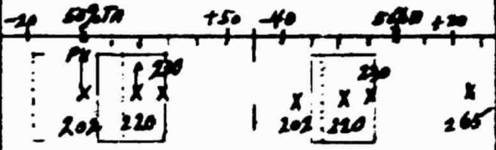
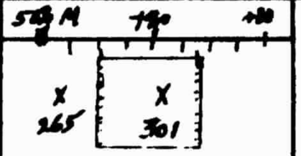
SEGMENT (LOCATION)				REFERENCE CALENDAR
0593 (WEBSTER, IOWA)	CORN CALENDAR  ACQUISITIONS: G.T. STAGE : 130=1.0; 139=2.0 COMMENT (EARLY): Loss of 1% w/126 & 162 combo. (LATE) : CONFUSION :	 Loss of 4% w/216. ·* not determinable. Separation 100%.		CRD, YEAR SPECIFIC
0828 (KANKAKEE, ILL.)	CORN CALENDAR  ACQUISITIONS: G.T. STAGE: 132=1.0; 142=2.0 COMMENT : No loss w/121 & 157 combo. (EARLY) : (LATE): 87% loss w/176. CONFUSION :	 Corn not yet dark red on 202. No G.N. loss w/202; 6% G.N. loss w/220. Separation: w/220 = 91%; w/230 = 79%. 24% loss to limiters w/230 due to haze.	 80% loss w/265; no loss w/301.	CRD, YEAR SPECIFIC (EXCEPT MATURITY)

Figure C-2.- Concluded.

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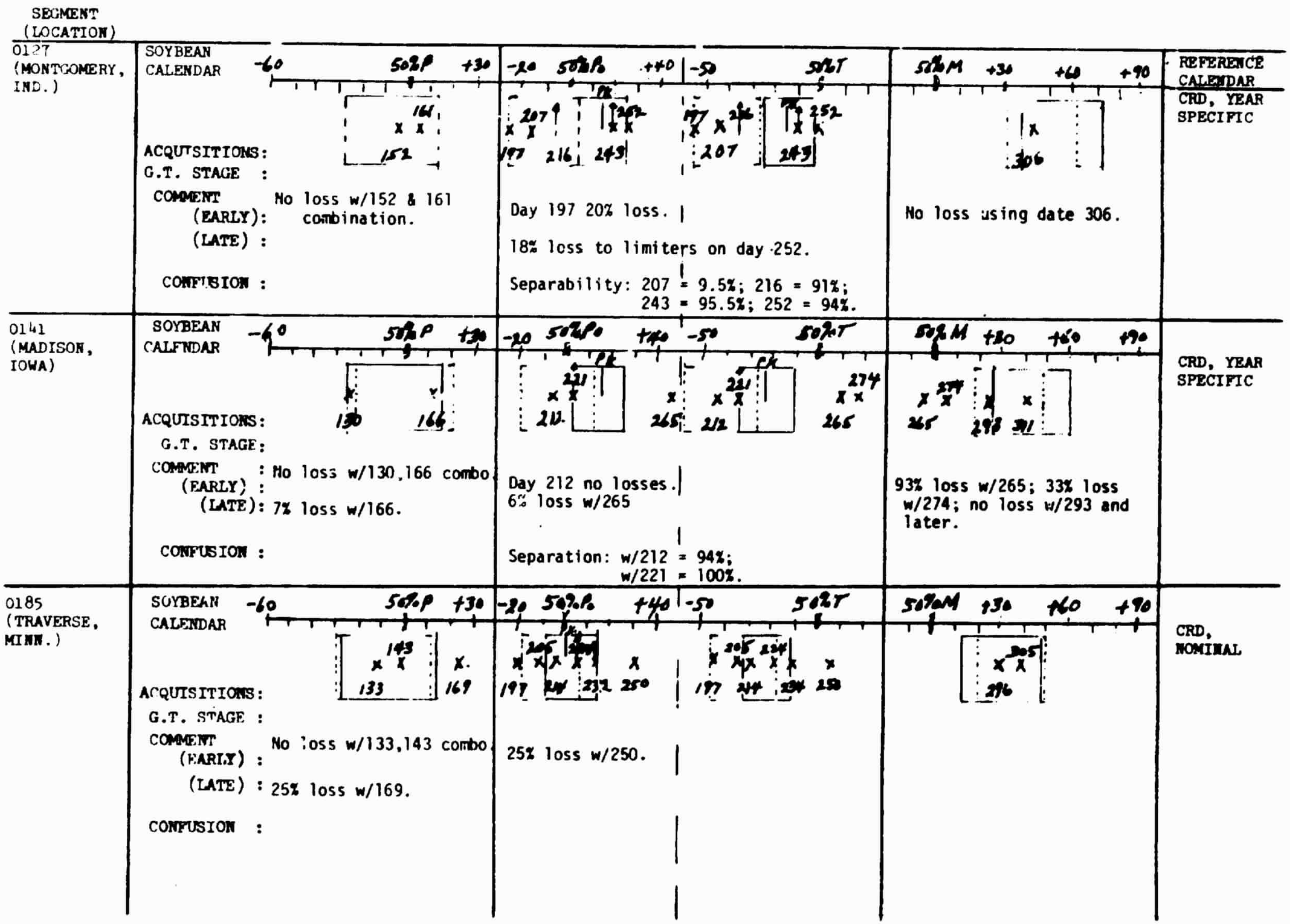
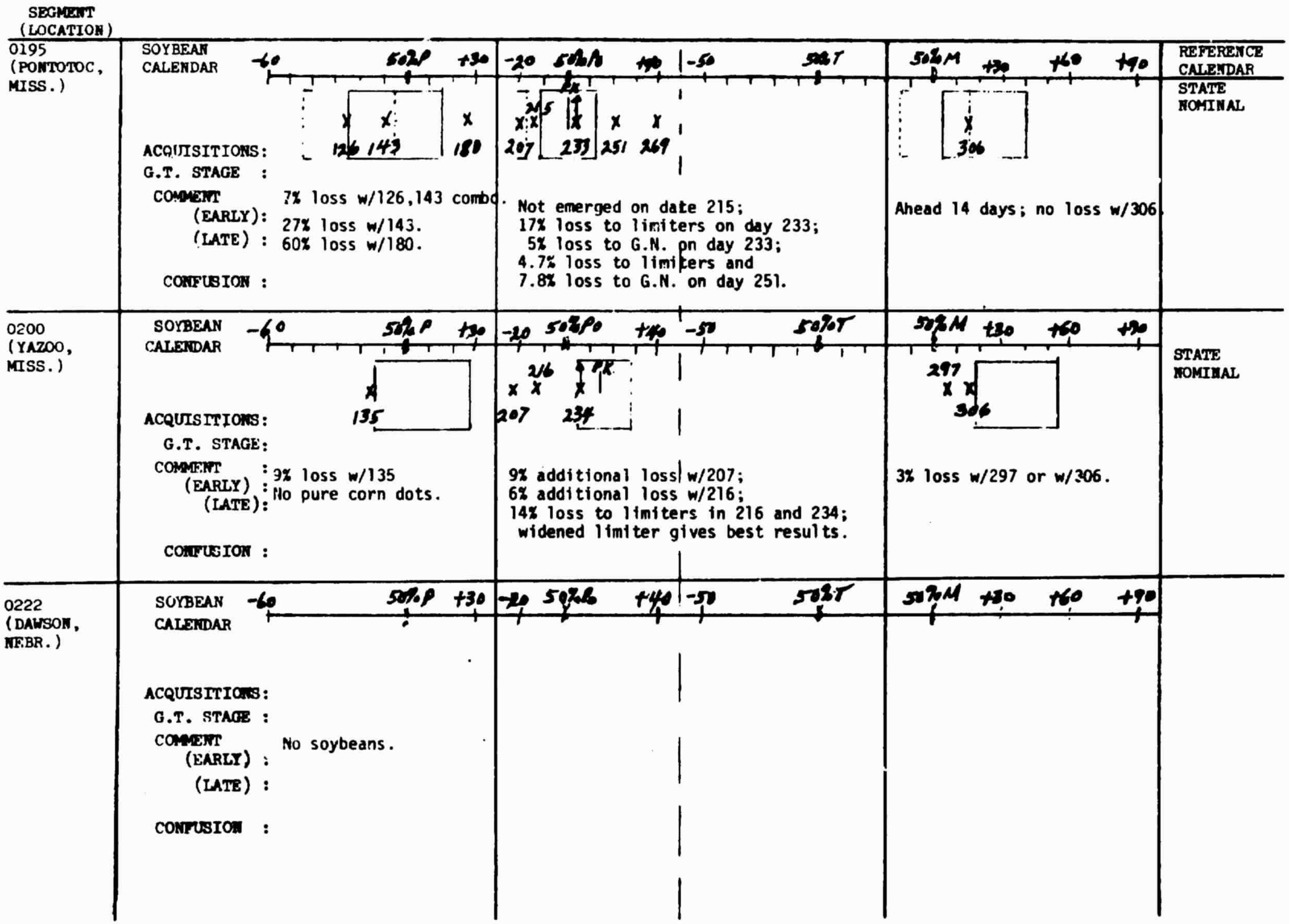


SEGMENT (LOCATION)					REFERENCE CALENDAR
0127 (MONTGOMERY, IND.)	SOYBEAN CALENDAR				
	ACQUTSITIONS:				CRD, YEAR SPECIFIC
	G.T. STAGE :				
	COMMENT (EARLY):	No loss w/152 & 161 combination.	Day 197 20% loss. 18% loss to limiters on day 252.	No loss using date 306.	
	(LATE) :				
	CONFUSION :		Separability: 207 = 9.5%; 216 = 91%; 243 = 95.5%; 252 = 94%.		
0141 (MADISON, IOWA)	SOYBEAN CALENDAR				
	ACQUISITIONS:				CRD, YEAR SPECIFIC
	G.T. STAGE:				
	COMMENT (EARLY) :	No loss w/130,166 combo	Day 212 no losses. 6% loss w/265	93% loss w/265; 33% loss w/274; no loss w/293 and later.	
	(LATE):	7% loss w/166.			
	CONFUSION :		Separation: w/212 = 94%; w/221 = 100%.		
0185 (TRAVERSE, MINN.)	SOYBEAN CALENDAR				
	ACQUISITIONS:				CRD, NOMINAL
	G.T. STAGE :				
	COMMENT (EARLY) :	No loss w/133,143 combo	25% loss w/250.		
	(LATE) :	25% loss w/169.			
	CONFUSION :				

Figure C-3.- Critical time period (window) chart for soybeans for year 1978.



0195 (PONTOTOC, MISS.)

COMMENT (EARLY): 7% loss w/126,143 combd. 27% loss w/143.

(LATE) : 60% loss w/180.

Not emerged on date 215;
17% loss to limiters on day 233;
5% loss to G.N. on day 233;
4.7% loss to limiters and
7.8% loss to G.N. on day 251.

Ahead 14 days; no loss w/306

CONFUSION :

0200 (YAZOO, MISS.)

COMMENT (EARLY) : 9% loss w/135

(LATE): No pure corn dots.

9% additional loss w/207;
6% additional loss w/216;
14% loss to limiters in 216 and 234;
widened limiter gives best results.

3% loss w/297 or w/306.

CONFUSION :

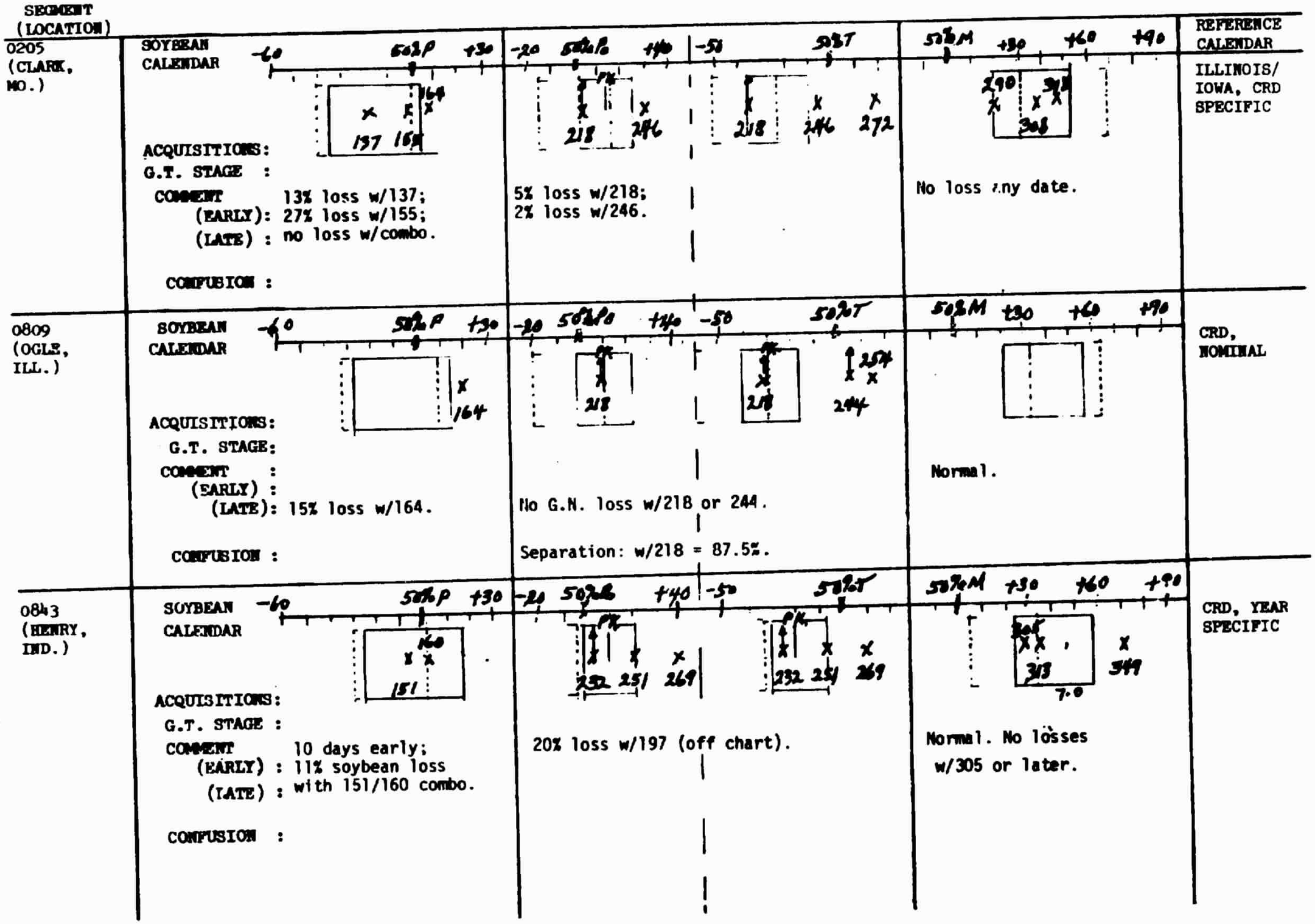
0222 (DAWSON, NEBR.)

COMMENT (EARLY) : No soybeans.

(LATE) :

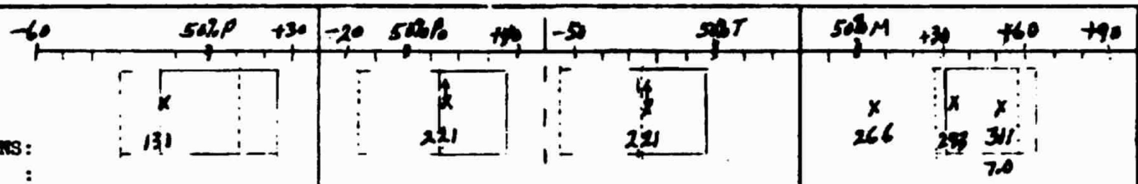
CONFUSION :

Figure C-3.- Continued.



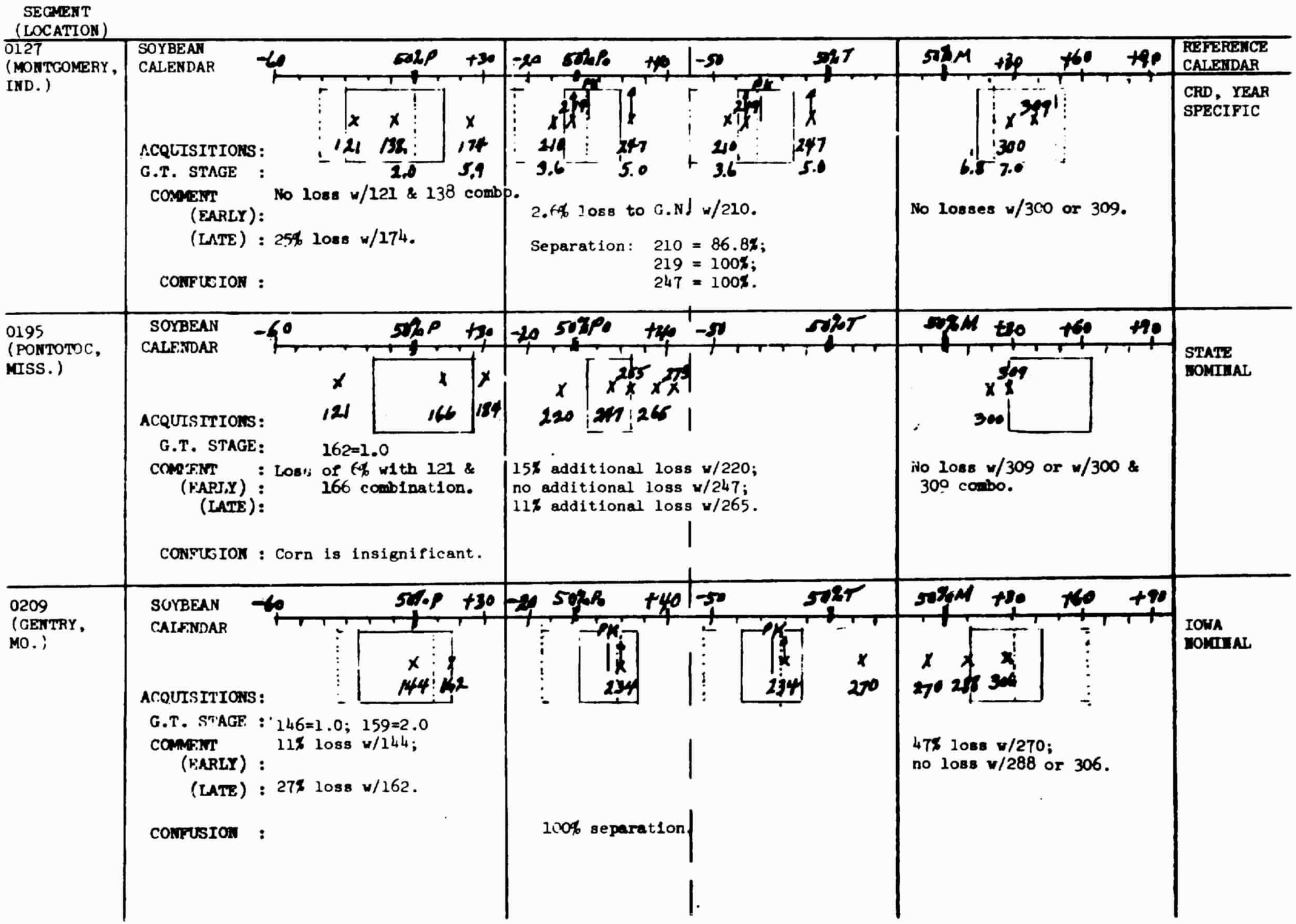
SEGMENT (LOCATION)					REFERENCE CALENDAR
0205 (CLARK, MO.)	SOYBEAN CALENDAR ACQUISITIONS: G.T. STAGE : COMMENT (EARLY): (LATE) : CONFUSION :	13% loss w/137; 27% loss w/155; no loss w/combo.	5% loss w/218; 2% loss w/246.	No loss any date.	ILLINOIS/ IOWA, CRD SPECIFIC
0809 (OGLE, ILL.)	SOYBEAN CALENDAR ACQUISITIONS: G.T. STAGE: COMMENT : (EARLY) : (LATE): CONFUSION :	15% loss w/164.	No G.N. loss w/218 or 244. Separation: w/218 = 87.5%.	Normal.	CRD, NOMINAL
0843 (HENRY, IND.)	SOYBEAN CALENDAR ACQUISITIONS: G.T. STAGE : COMMENT (EARLY) : (LATE) : CONFUSION :	10 days early; 11% soybean loss with 151/160 combo.	20% loss w/197 (off chart).	Normal. No losses w/305 or later.	CRD, YEAR SPECIFIC

Figure C-3.- Continued.



SEGMENT (LOCATION)					
0893 (WEBSTER, IOWA)	SOYBEAN CALENDAR				REFERENCE CALENDAR CRD, YEAR SPECIFIC
	ACQUISITIONS:				
	G.T. STAGE :				
	COMMENT (EARLY):	No losses w/131.	Date of peak not determinable.	No losses w/266 or later.	
	(LATE) :				
	CONFUSION :		Separation = 96%.		

Figure C-3.- Concluded.



0127 (MONTGOMERY, IND.)

ACQUISITIONS:
G.T. STAGE :
COMMENT (EARLY): No loss w/121 & 138 combo. 2.6% loss to G.N. w/210. No losses w/300 or 309.
(LATE) : 25% loss w/174.
Separation: 210 = 86.8%; 219 = 100%; 247 = 100%.
CONFUSION :

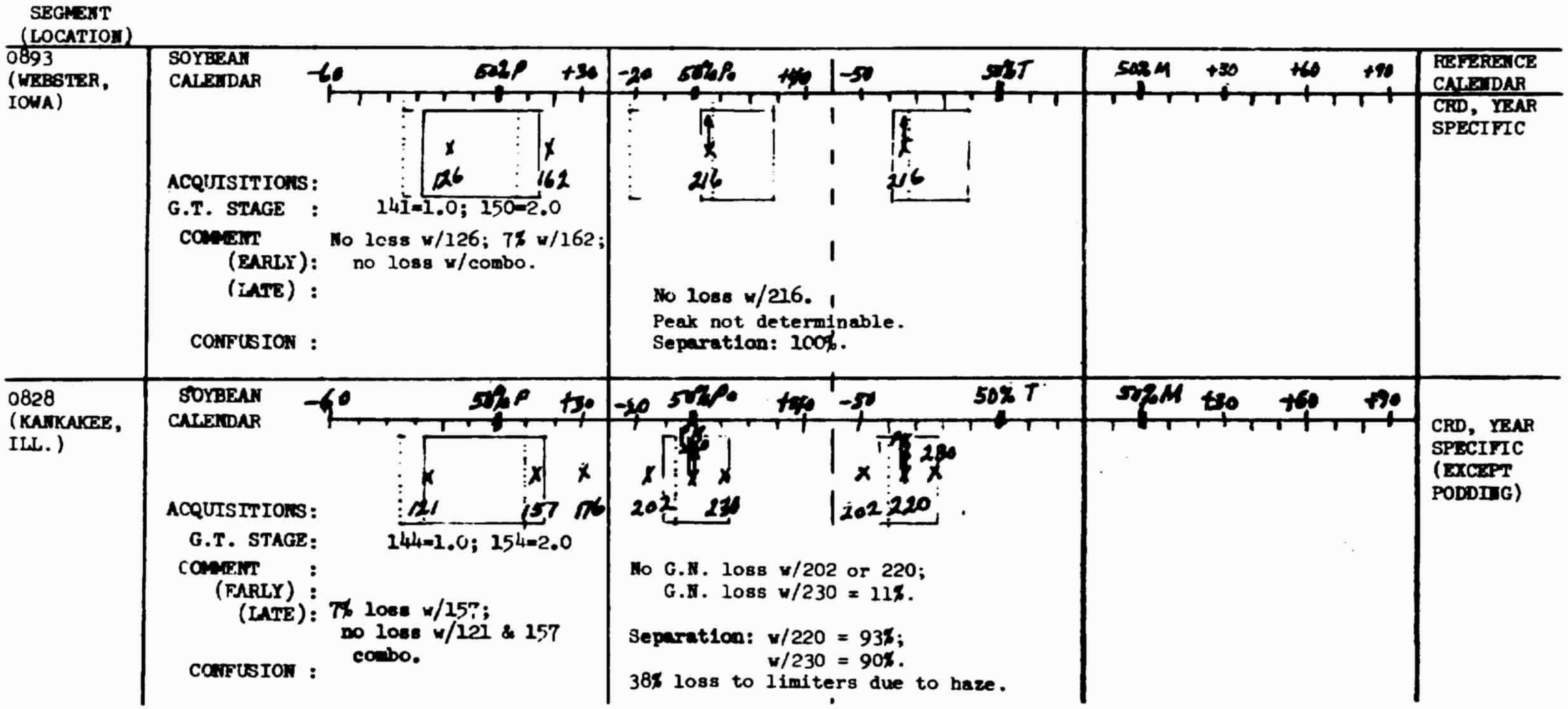
0195 (PONTOTOC, MISS.)

ACQUISITIONS:
G.T. STAGE: 162=1.0
COMMENT (EARLY) : Loss of 6% with 121 & 166 combination. 15% additional loss w/220; no additional loss w/247; 11% additional loss w/265. No loss w/309 or w/300 & 309 combo.
(LATE):
CONFUSION : Corn is insignificant.

0209 (GENTRY, MO.)

ACQUISITIONS:
G.T. STAGE : 146=1.0; 159=2.0
COMMENT (EARLY) : 11% loss w/144; 47% loss w/270; no loss w/288 or 306.
(LATE) : 27% loss w/162.
CONFUSION : 100% separation.

Figure C-4.- Critical time period (window) chart for soybeans for year 1979.



0893 (WEBSTER, IOWA)

G.T. STAGE : 141=1.0; 150=2.0

COMMENT (EARLY): No loss w/126; 7% w/162; no loss w/combo.

No loss w/216.
Peak not determinable.
Separation: 100%.

0828 (KANKAKEE, ILL.)

G.T. STAGE: 144=1.0; 154=2.0

(LATE): 7% loss w/157; no loss w/121 & 157 combo.

No G.N. loss w/202 or 220;
G.N. loss w/230 = 11%.

Separation: w/220 = 93%;
w/230 = 90%.
38% loss to limiters due to haze.

Figure C-4.- Concluded.

APPENDIX D

ILLUSTRATIVE CORN AND SOYBEAN IDENTIFICATION SCATTER PLOTS

APPENDIX D

ILLUSTRATIVE CORN AND SOYBEAN IDENTIFICATION SCATTER PLOTS

This appendix contains example scatter plots to illustrate separation of corn and soybean distributions, when various combinations of summer crops are being grown. The crop key for crops grown in each segment is recorded on each individual scatter plot. The following is a list, by figure number, of the various crop combinations shown:

Figure D-1 - Corn and soybeans in the U.S. Corn Belt states
Figure D-2 - Corn or corn and hay
Figure D-3 - Corn and spring grains or corn and sunflowers
Figure D-4 - Soybeans or soybeans and spring grains
Figure D-5 - Soybeans and sunflowers
Figure D-6 - Soybeans and cotton

In addition, an example of the effects of excessive haze on crop separation is shown in figure D-7.

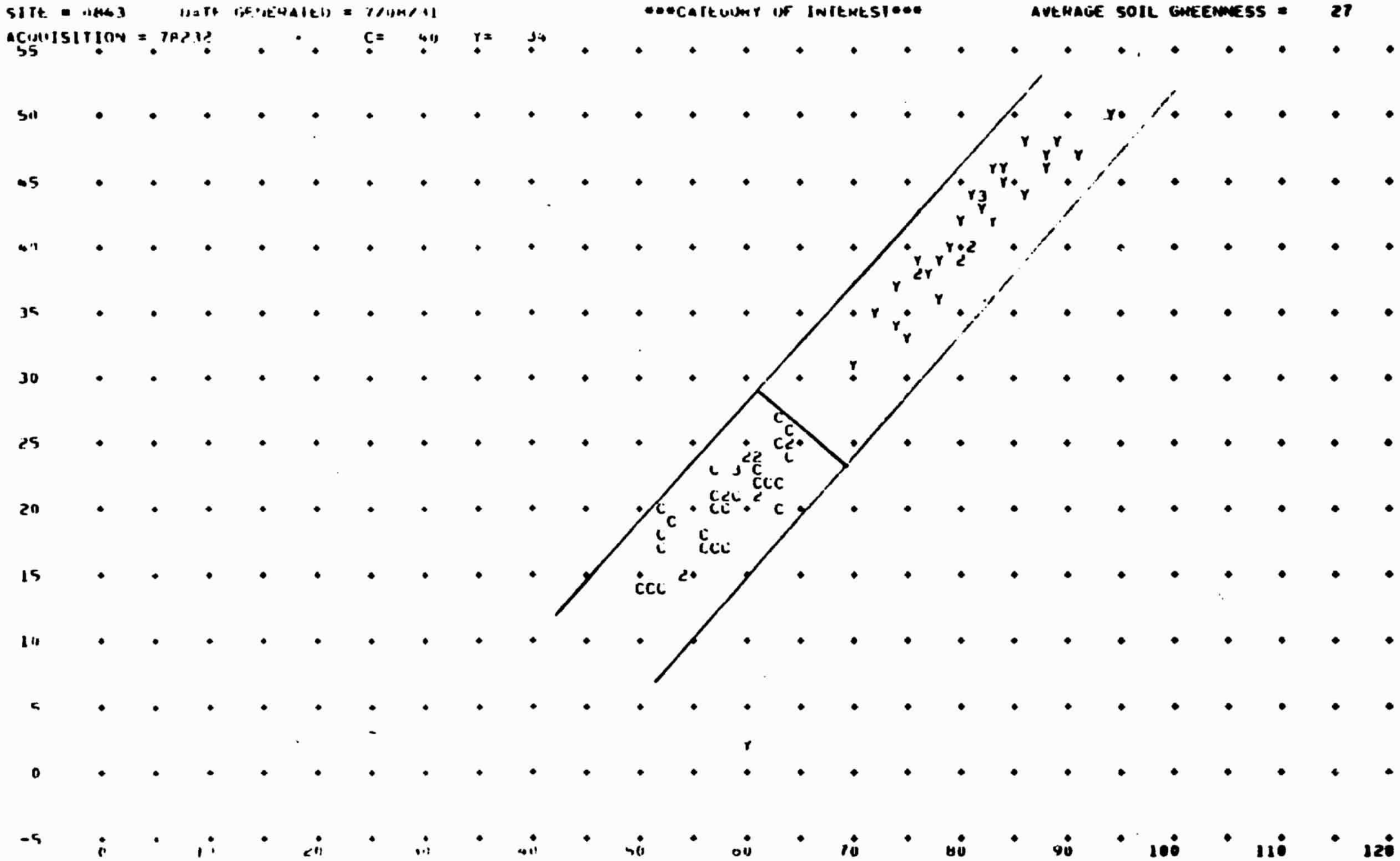


Figure D-1.- Example scatter plot illustrating the separation of corn and soybean distributions in the U.S. Corn Belt states (option 1).

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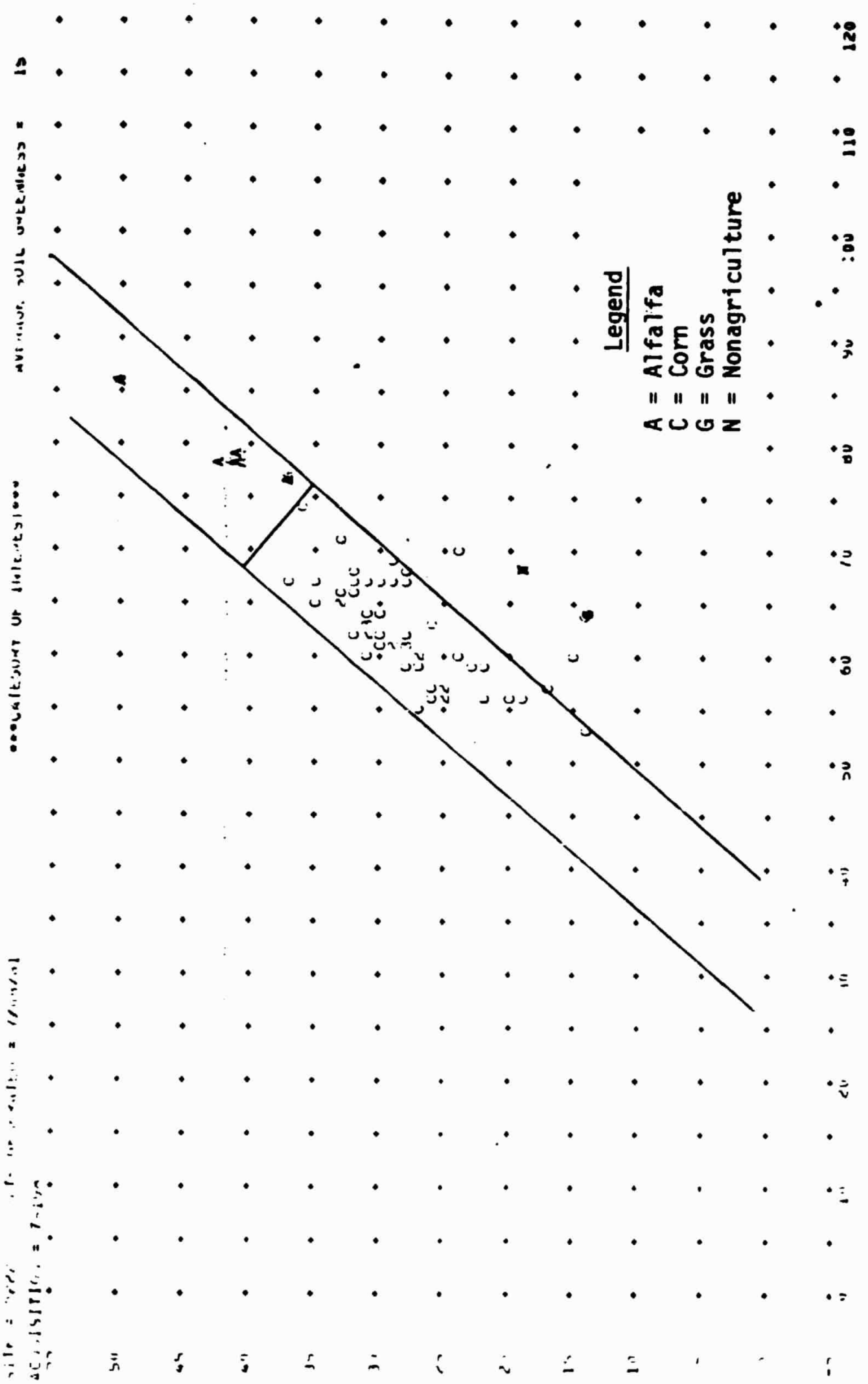

Figure D-2.- Example scatter plot illustrating the separation of corn or corn and hay (option 2).

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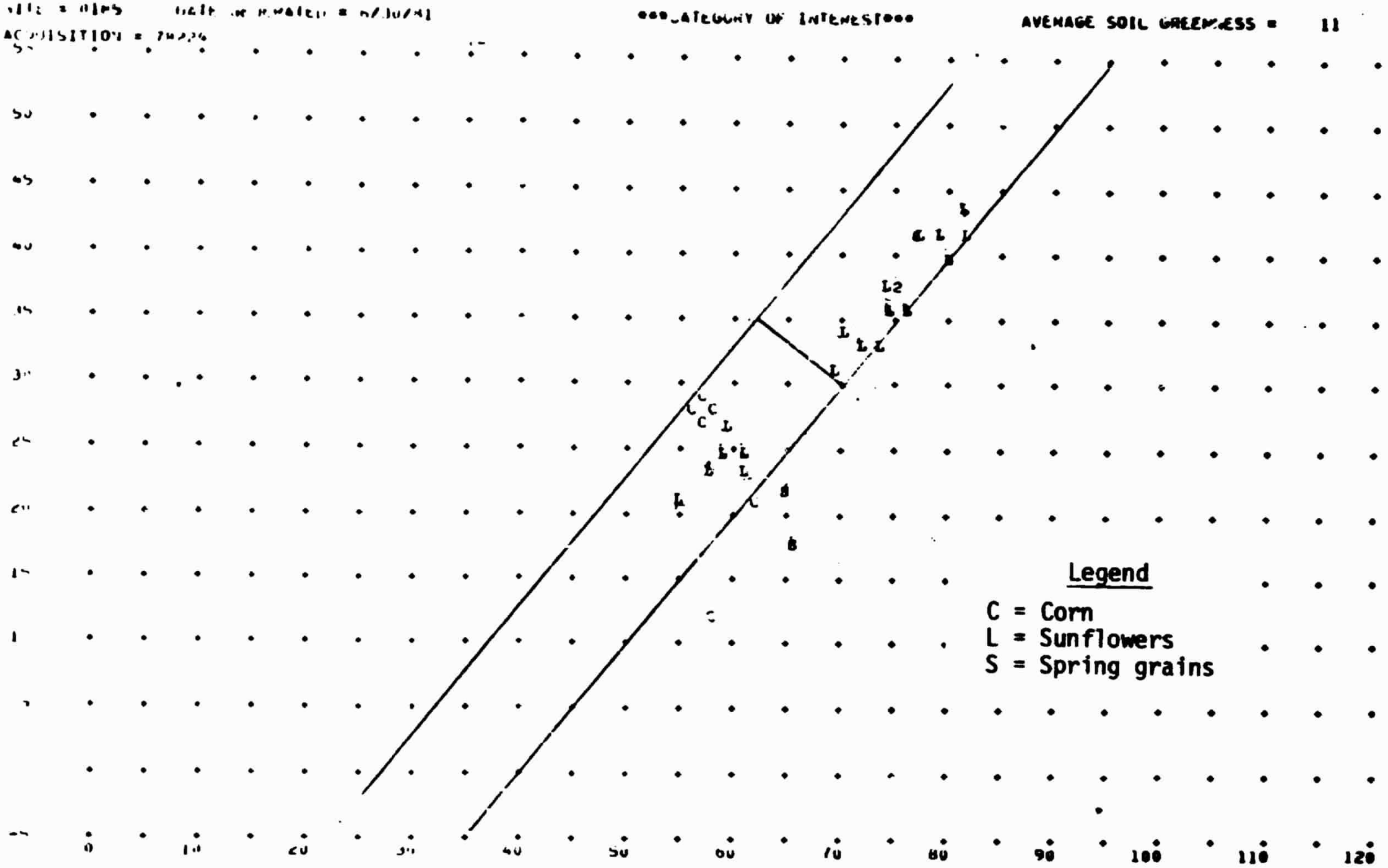


Figure D-3.- Example scatter plot illustrating the separation of corn and spring grains or corn and sunflowers (option 2S).

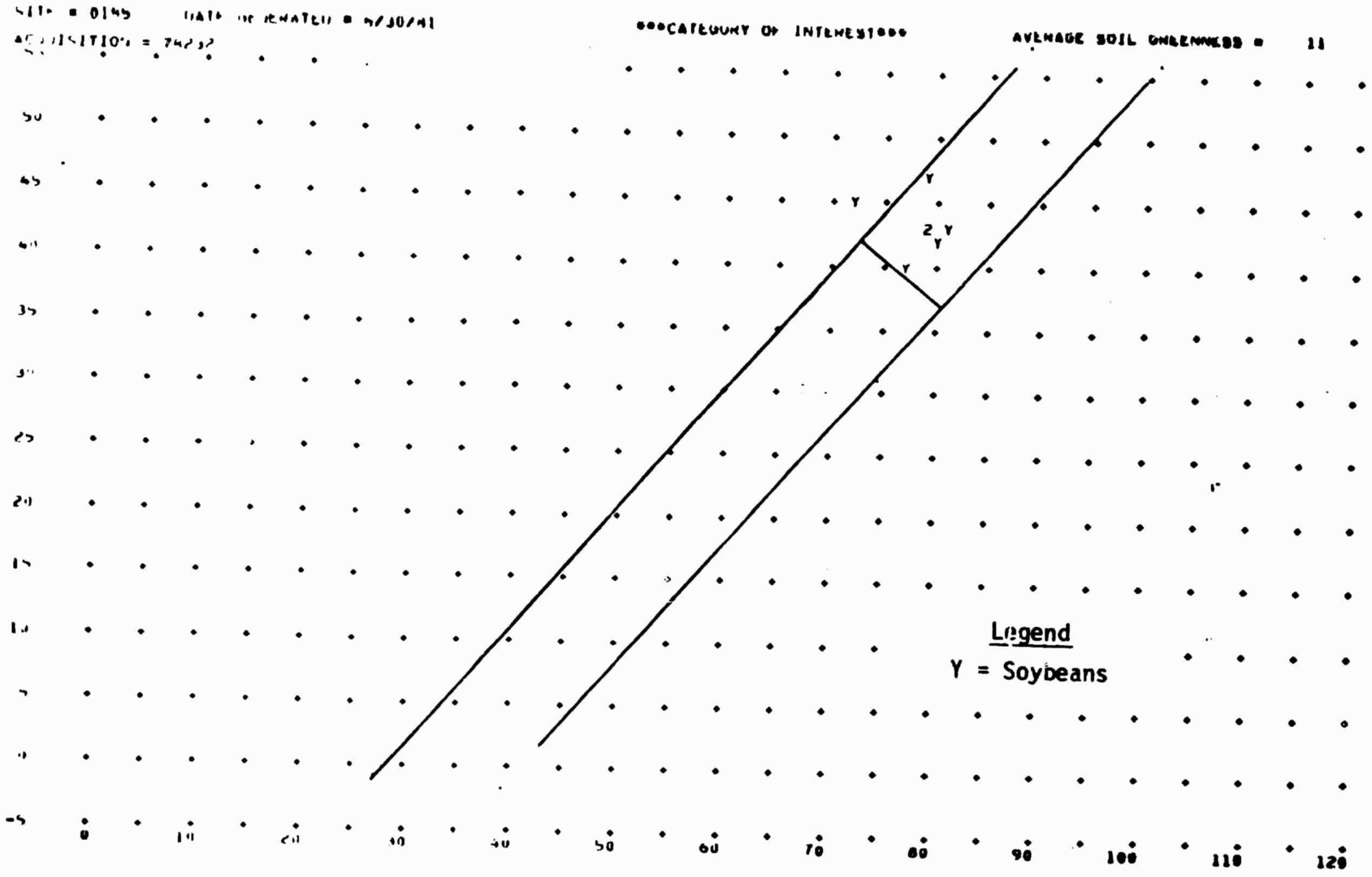
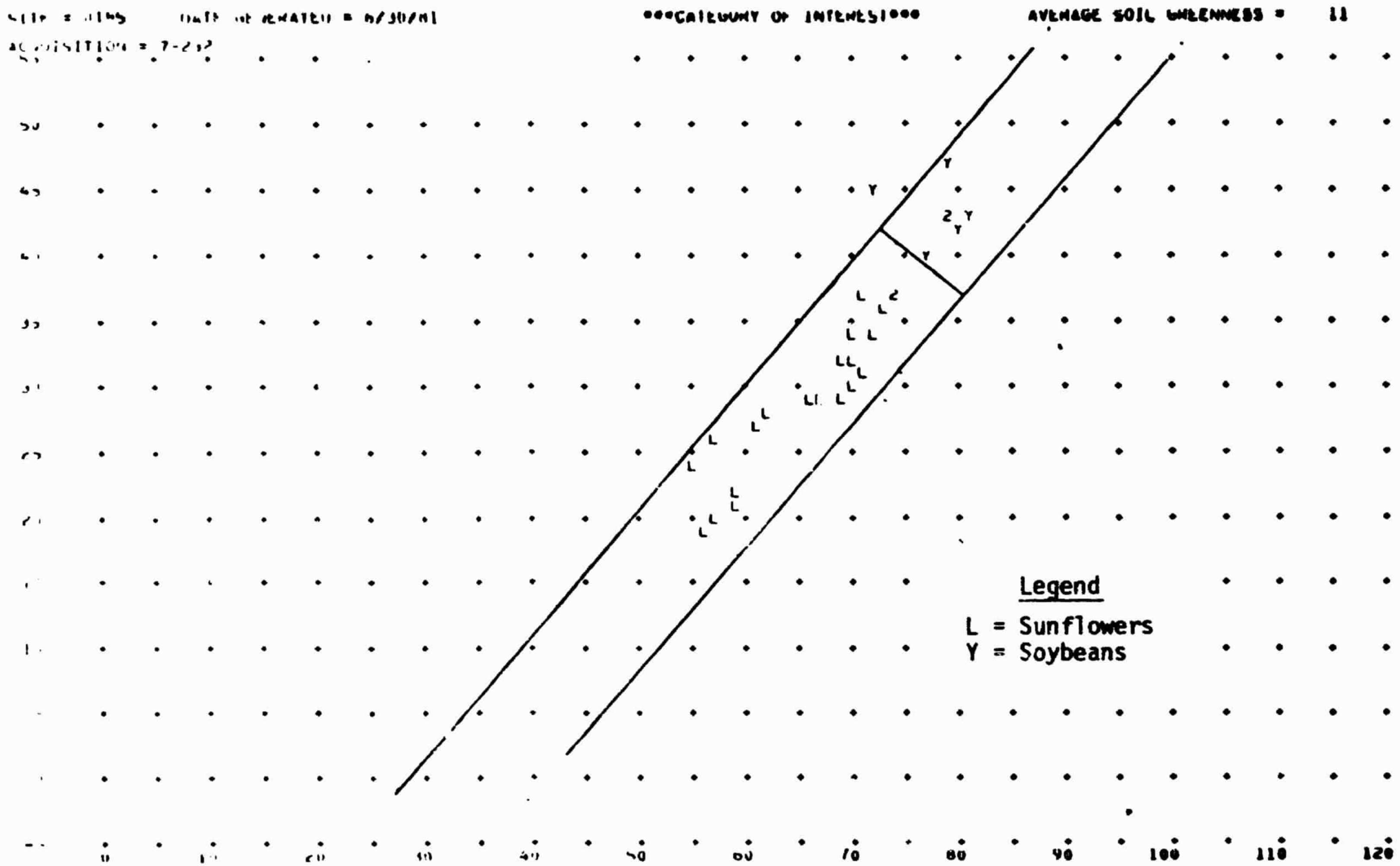


Figure D-4.- Example scatter plot illustrating the separation of soybeans or soybeans and spring grains (option 3).



Legend

L = Sunflowers
Y = Soybeans

Figure D-5.- Example scatter plot illustrating the separation of soybeans and sunflowers (option 3S or 4S).

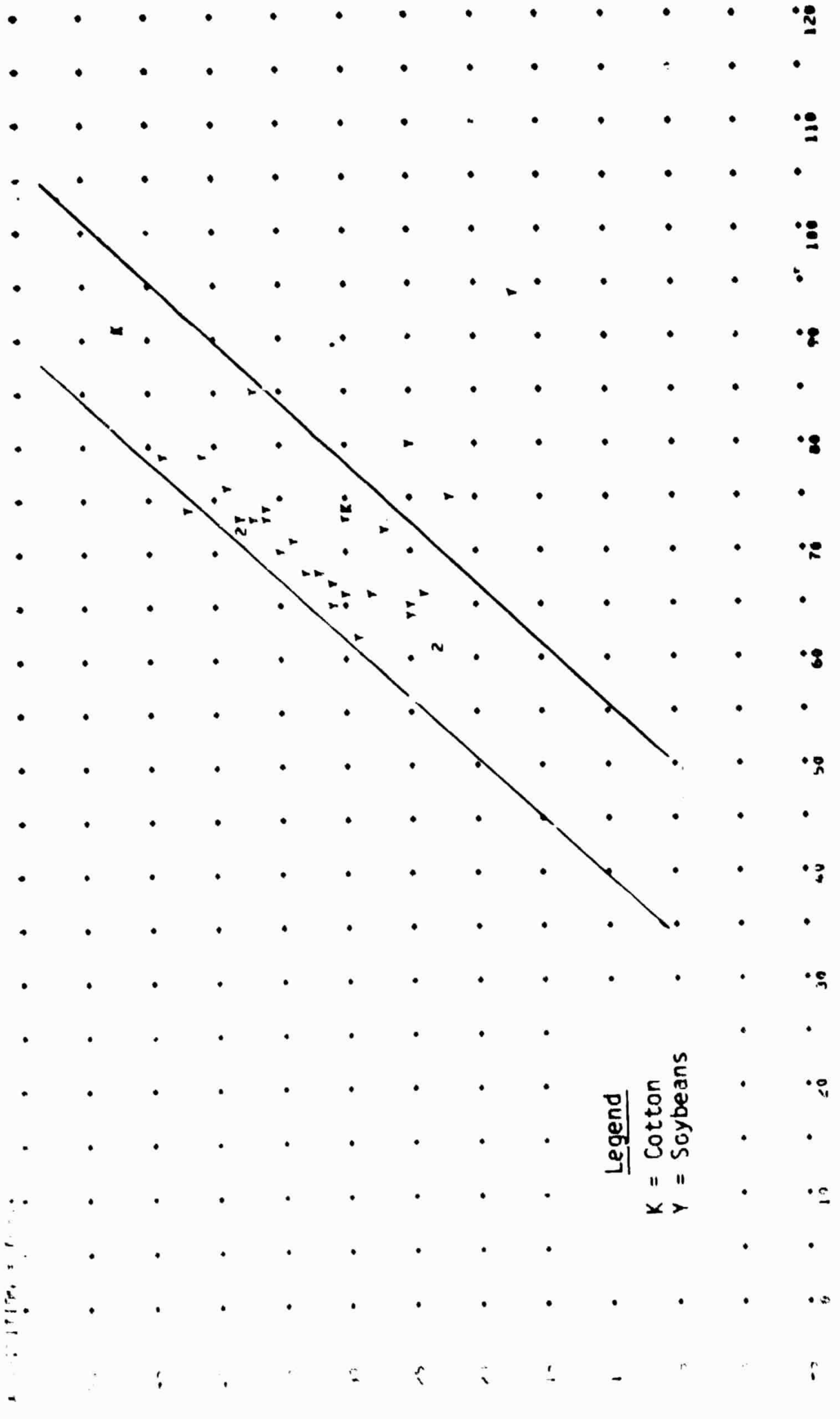


Figure D-6.-- Example scatter plot illustrating the separation of soybeans and cotton (option 5).

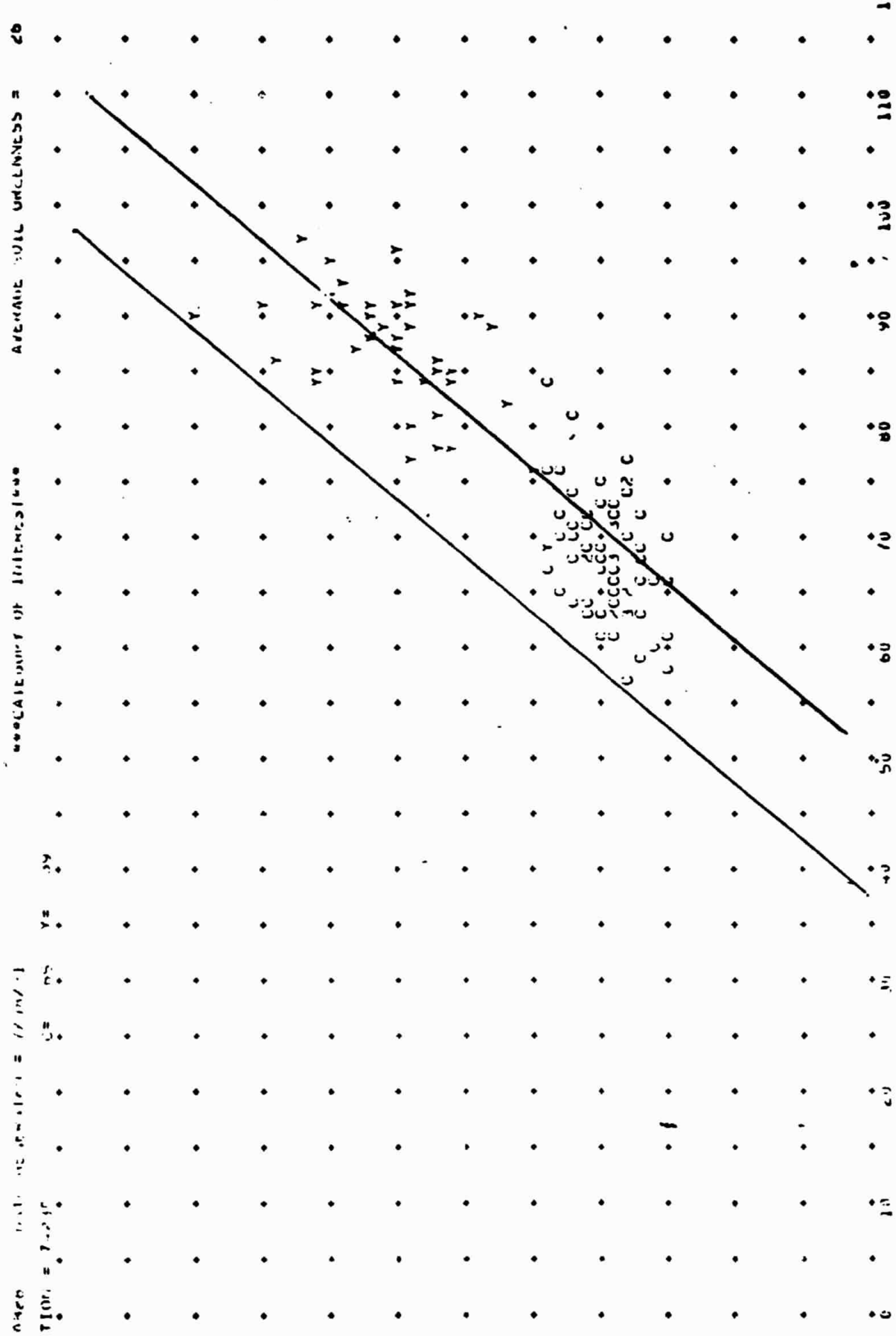


Figure D-7.- Example of the effects of excessive haze
on the separation of corn and soybeans.

APPENDIX E

CORN AND SOYBEAN LABELING WINDOWS

APPENDIX E

CORN AND SOYBEAN LABELING WINDOWS

Window Y1:

Open: Soybeans 50 percent planted minus 25 days (Opening date may not be earlier than day 110.)

Close: Soybeans 50 percent planted plus 16 days

Window Y2:

Open: Soybeans 50 percent podding minus 1 day

Close: Soybeans 50 percent podding plus 23 days

Window Y3:

Open: Soybeans 50 percent mature plus 20 days

Close: Soybeans 50 percent mature plus 55 days

Window C1:

Open: Corn 50 percent planted minus 20 days (Opening date may not be earlier than day 110.)

Close: Corn 50 percent planted plus 21 days

Window C2:

Open: Corn 50 percent tasseling minus 10 days

Close: Corn 50 percent tasseling plus 20 days

Window C3:

Open: Corn 50 percent mature plus 30 days

Close: Corn 50 percent mature plus 60 days

Subwindow C2S1:

Open: Corn 50 percent tasseling minus 10 days

Close: Corn 50 percent tasseling minus 1 day

Subwindow C2S2:

Open: Corn 50 percent tasseling plus 11 days

Close: Corn 50 percent tasseling plus 20 days

Subwindow Y2S1:

Open: Soybeans 50 percent podding minus 1 day

Close: Soybeans 50 percent podding plus 8 days

Subwindow Y2S2:

Open: Soybeans 50 percent podding plus 14 days

Close: Soybeans 50 percent podding plus 23 days

APPENDIX F

EXPANDED OPTION DEFINITIONS INCLUDING RESTRICTIONS AND ALTERNATIVES

APPENDIX F

EXPANDED OPTION DEFINITIONS INCLUDING RESTRICTIONS AND ALTERNATIVES

OPTION 0:

Acquisitions: A. One window Y1 acquisition[1] in Iowa, Illinois, or Nebraska; at least two window Y1 acquisitions in other states.

B. One window Y2 acquisition.

C. One or two window Y3 acquisitions desirable but not required.

Restriction: Two-category labeling only: Z and N. Label 15 to 20 dots in each category.

OPTION 1:

Acquisitions: A. At least one window Y1 acquisition in Iowa, Illinois, or Nebraska; at least two window Y1 acquisitions in other states.

B. One window Y2 acquisition.

C. One or two window Y3 acquisitions desirable but not required.

Restrictions: A. Overlap of windows Y2 and C2 must be <15 days. (Alternate option: zero.)

B. Gap between windows Y2 and C2 must be <5 days. (Alternate option: If gap is 5 to 14 days, use 1Y.)

C. Number of labelable corn dots must be >15. (Alternate option: 1Y.)

---

[1] An acquisition will be counted as nonconsecutive-day coverage only. Only one consecutive day may be counted in these minimum date determinations.

D. Number of labelable soybean dots must be >15. (Alternate option: 1C.)

E. Number of labelable N dots must be <7 or >15. (Alternate option: none.)

OPTION 1C:

Acquisitions: Same as for option 1.

Restriction: Two-category labeling only: C and N (combine Y labels with N).

OPTION 1Y:

Acquisitions: Same as for option 1.

Restriction: Two-category labeling only: Y and N (combine C labels with N).

OPTION 2:

Acquisitions: A. At least one window C1 acquisition in Iowa, Illinois, or Nebraska; at least two window C1 acquisitions in other states.

B. One window C2 acquisition.

C. One or two window C3 acquisitions desirable but not required.

Restrictions: A. Two-category labeling only: C and N. At least 15 dots in each category must be labeled.

B. In areas where winter wheat is planted following corn harvest (in excess of 5 percent of the pseudo-county), do not attempt this option. (Alternate option: none.)

OPTION 2S:

Acquisitions: A. At least one window C1 acquisition in Iowa, Illinois, or Nebraska; at least two window C1 acquisitions in other states.

B. One subwindow C2S1 acquisition. Select earliest acquisition available in the subwindow.

C. One subwindow C2S2 acquisition. Select latest acquisition available in the subwindow.

D. One or two window C3 acquisitions desirable but not required.

Restrictions: A. Number of labelable corn dots must be >15.

B. Number of labelable N dots must be >15. (Alternate option: none.)

OPTION 3:

Acquisitions: A. At least one window Y1 acquisition in Iowa, Illinois, or Nebraska; at least two window Y1 acquisitions in other states.

B. One window Y2 acquisition.

C. One or two window Y3 acquisitions desirable but not required.

Restriction: Two-category labeling only: Y and N; 15 to 20 dots of each category required.

OPTION 3S:

Acquisitions: A. At least one window C1 acquisition in Iowa, Illinois, or Nebraska; at least two window C1 acquisitions in other states.

B. One subwindow C2S1 acquisition and one subwindow C2S2 acquisition as in option 2S. (Subwindow Y2S1 acquisition may replace subwindow C2S2 acquisition if gap between windows C2 and Y2 is <5 days.)

C. One subwindow Y2S2 acquisition.

D. One or two window C3 acquisitions desirable but not required.

Restrictions: A. Spring grains and sunflowers will be labeled N.

B. If the requirement for 15 to 20 dots cannot be met for three categories, combine the dots into two categories and proceed as in less complex options.

OPTION 4S:

Acquisitions: A. At least two window Y1 acquisitions.

B. One subwindow Y2S2 acquisition.

C. One or two window Y3 acquisitions desirable but not required.

Restrictions: Label as categories Y and N; at least 15 dots must be labeled in each category.

OPTION 5:

Acquisitions: A. At least two window Y1 acquisitions.

B. One window Y2 acquisition.

C. One or two window Y3 acquisitions desirable but not required.

Restrictions: The minimum of 15 Y and 15 N dots must be met.

APPENDIX G

SUMMER CROP LOGIC FLOW CHARTS

APPENDIX G

SUMMER CROP LOGIC FLOW CHARTS

The decision logic for labeling summer crops using the various labeling options is shown in figures G-1 through G-5. An explanation of the terminology used in these flow charts is provided below.

1. When a single window acquisition is referenced, the acquisition nearest the center of the window will be looked at first; the later acquisition will be meant in case of a tie. (For exceptions, see note 3 below.)
2. When first, second, and third acquisitions are referenced, these should be taken to mean the acquisition nearest the center of the window, a later acquisition, and an earlier acquisition, respectively.
3. In options 2S and 3S, reference to a subwindow C2S1 acquisition will be taken to mean the earliest acquisition available in the subwindow; reference to a subwindow C2S2 acquisition will be taken to mean the latest available acquisition, all other considerations being equal. The green number threshold of 13 on the C2S2 acquisition is tentative; further research is required to establish a relationship to the appropriate spring small grain growth stage and a corresponding corn growth stage.
4. Option 3S includes option 2S in its entirety and requires manual input of Z dots (minus all corn dots) and N dots resulting from the option 2S spectral aids evaluation. Software to support processing of option 3S is not yet available; this option will be available at a later date.

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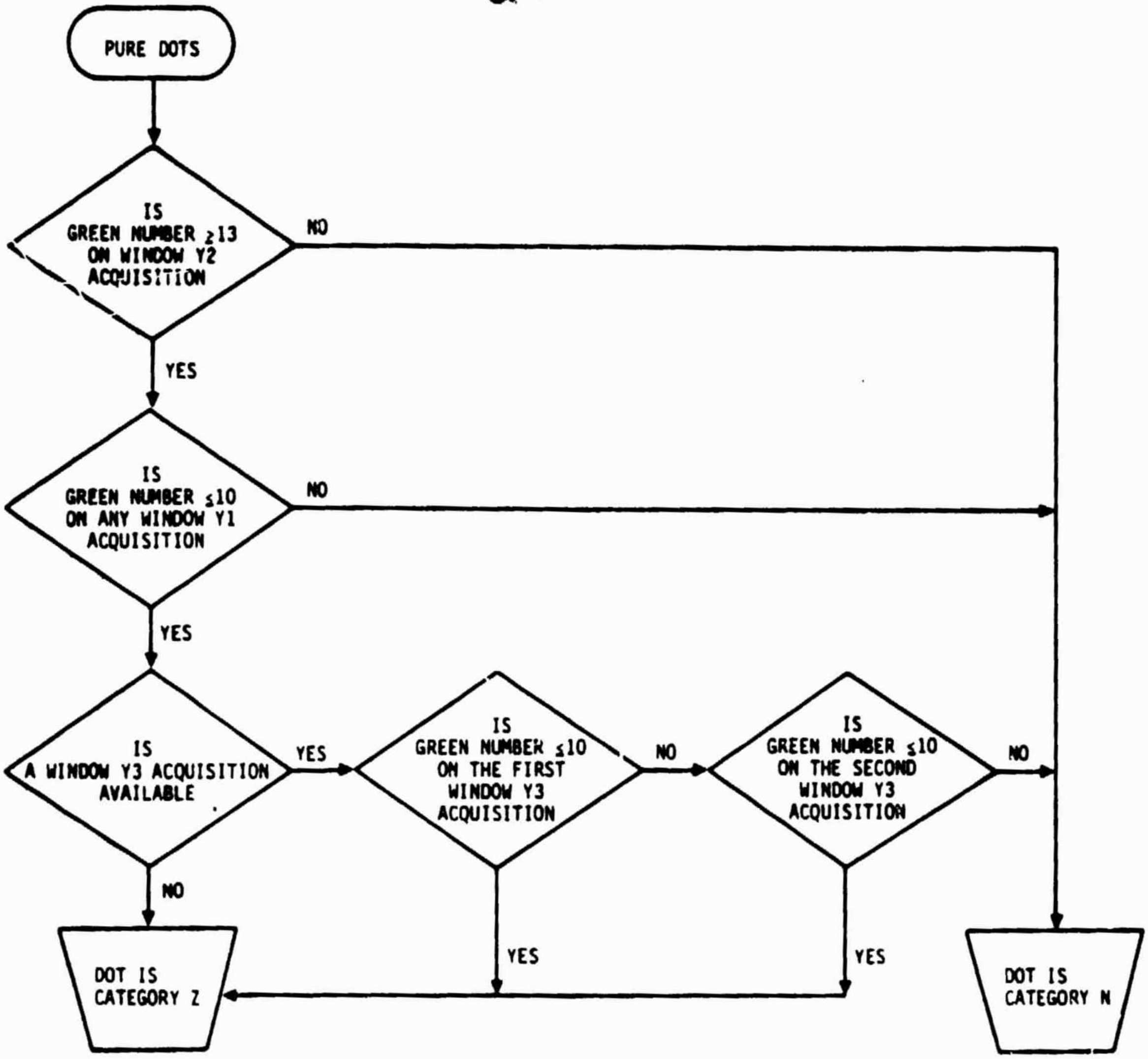

Figure G-1.- Labeling logic for options 0, 1, 1C, 1Y, 3, and 5. An explanation of the terminology used in this flow chart is provided in notes 1 and 2 on page G-1.

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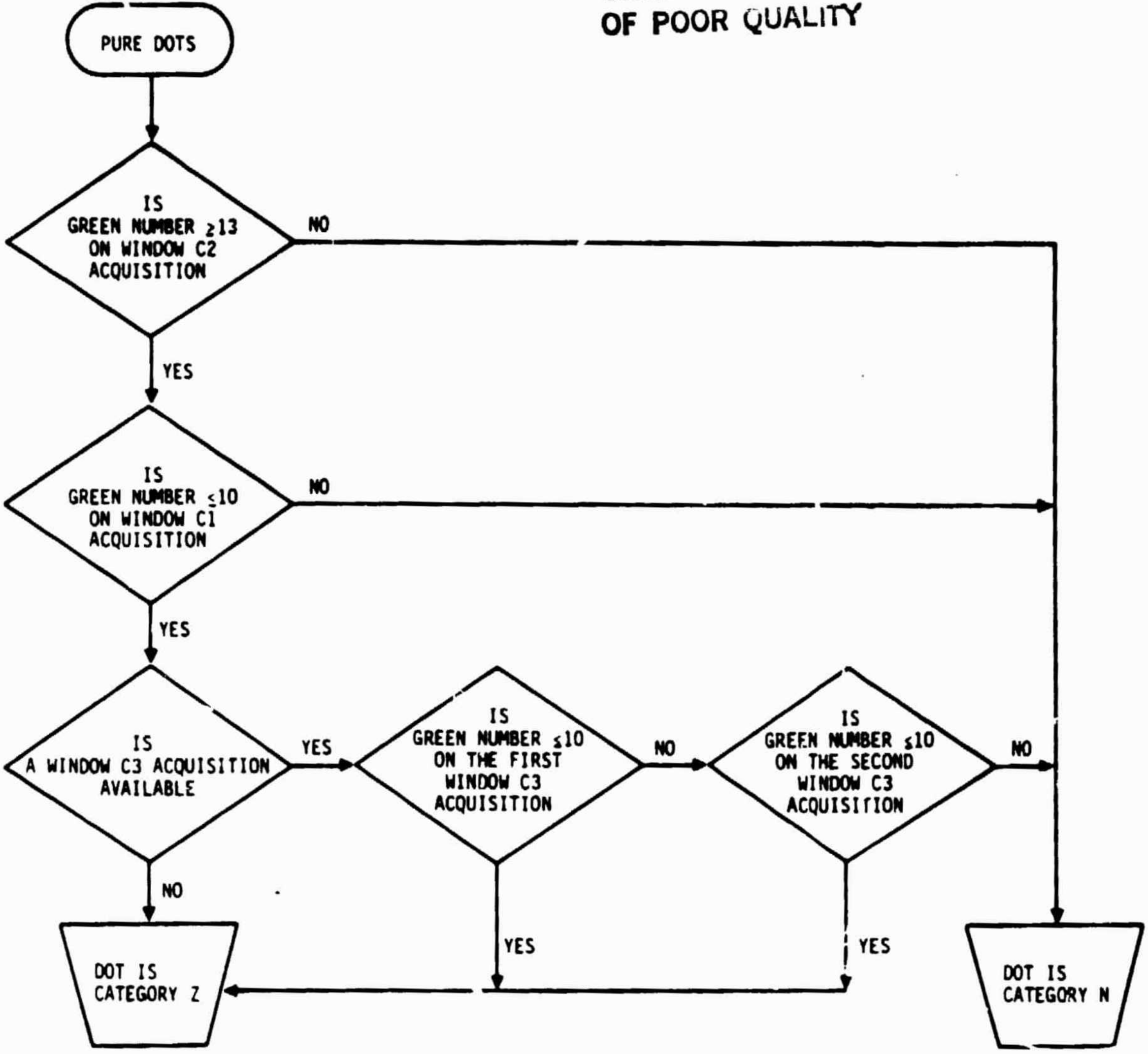

Figure G-2.- Labeling logic for option 2. An explanation of the terminology used in this flow chart is provided in notes 1 and 2 on page G-1.

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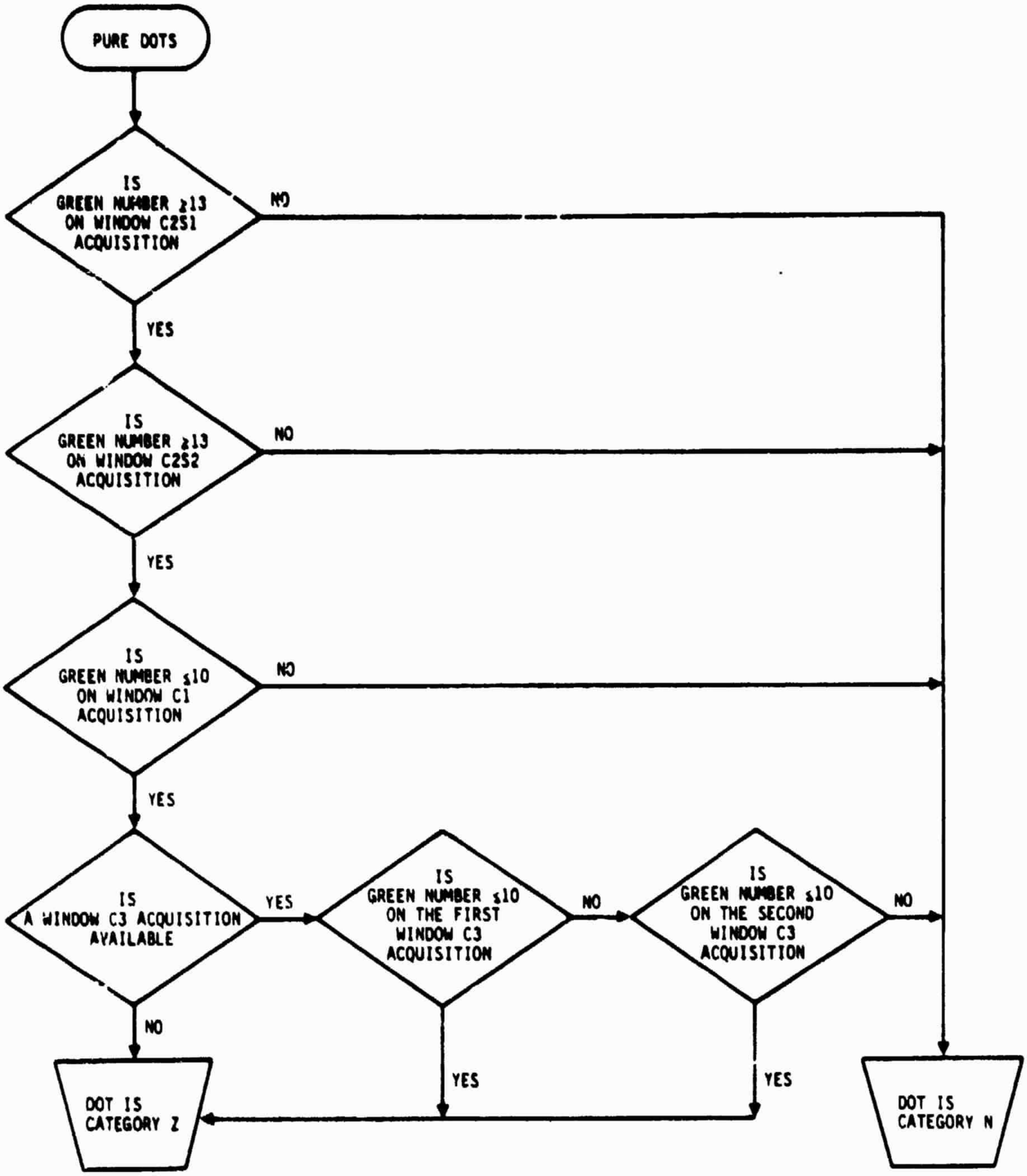

Figure G-3.- Labeling logic for option 2S. An explanation of the terminology used in this flow chart is provided in note 1, 2, and 3 on page G-1.

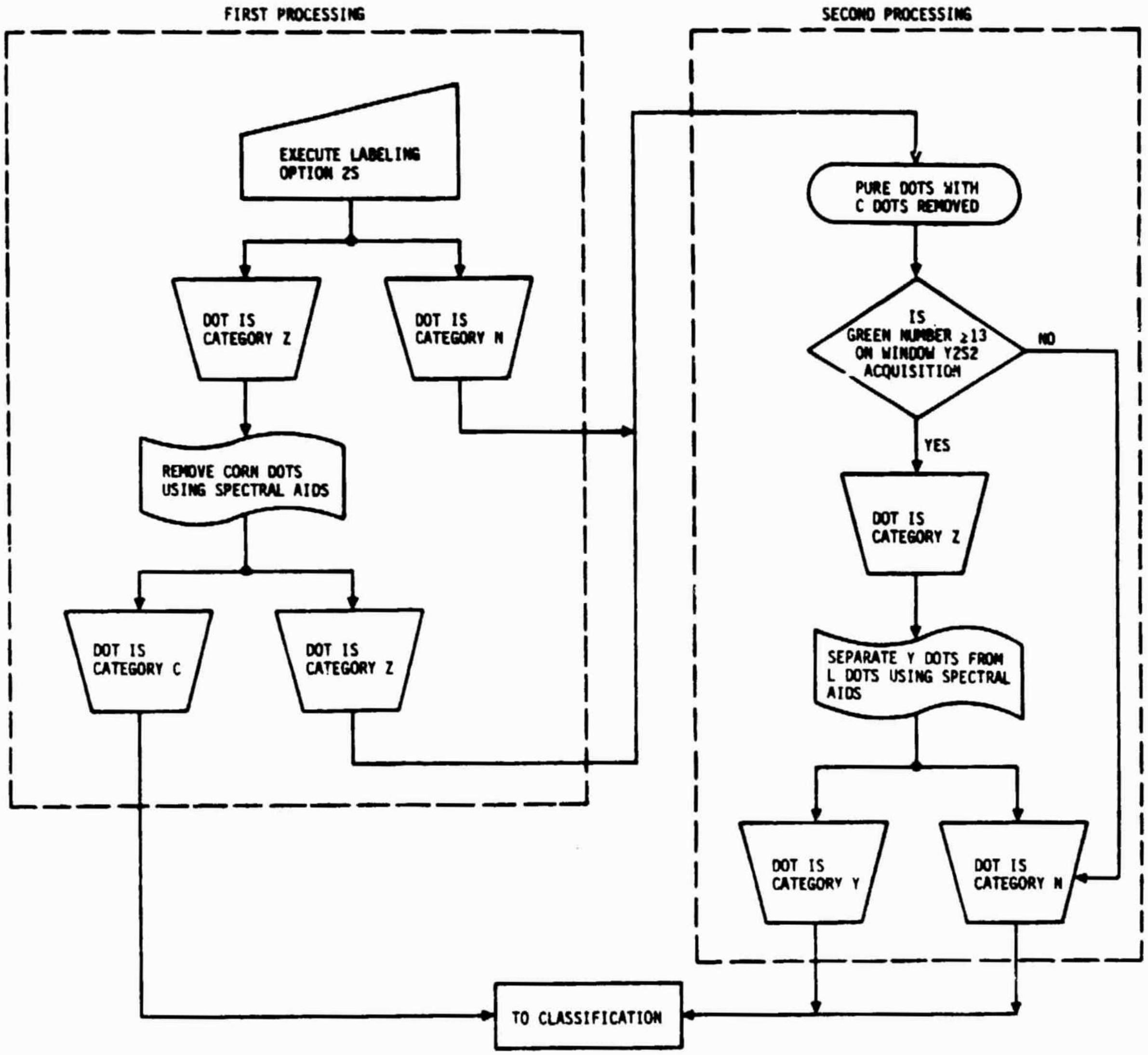

Figure G-4.- Labeling logic for option 3S. An explanation of the terminology used in this flow chart is provided in notes 1 through 4 on page G-1.

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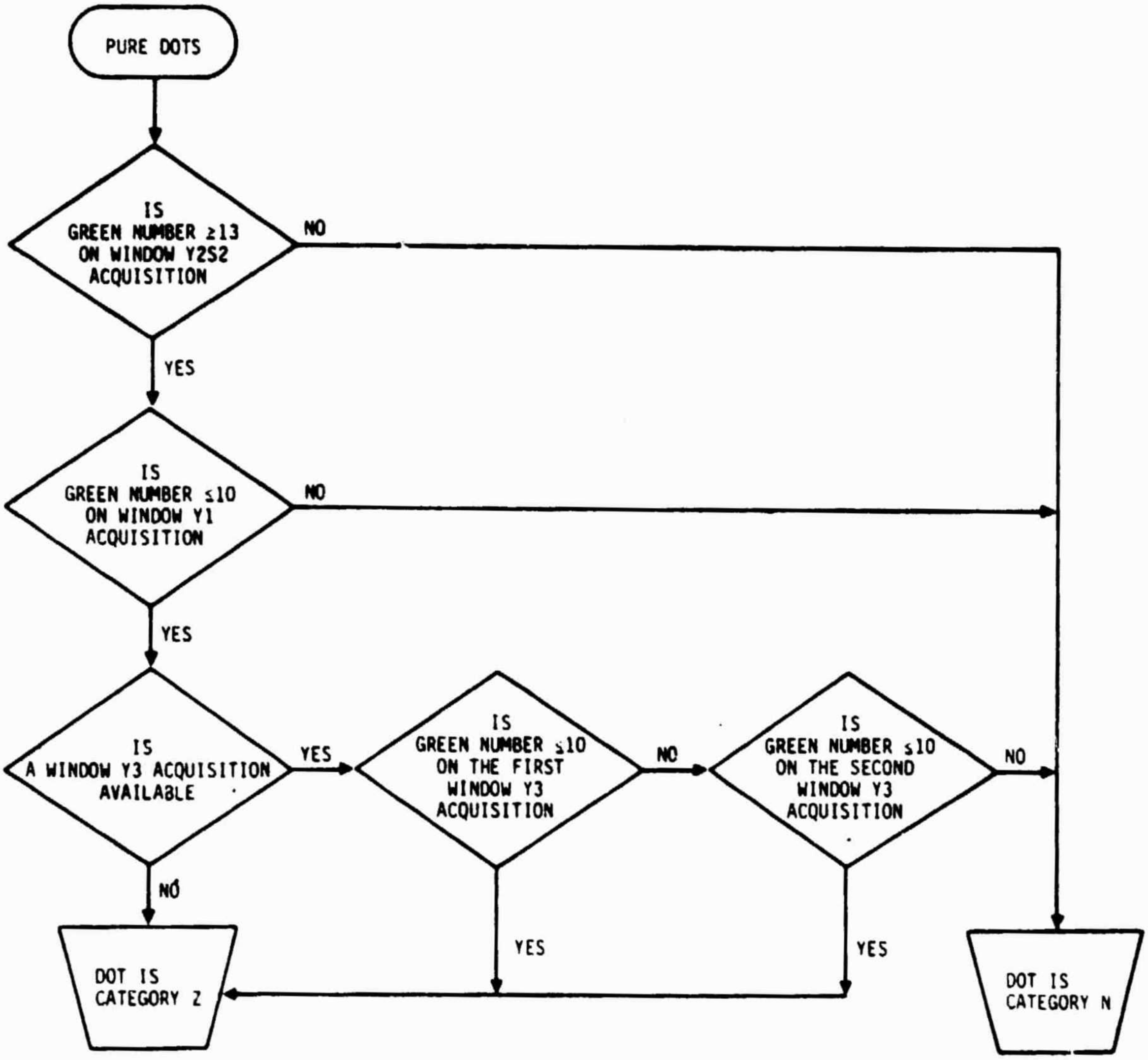

Figure G-5.- Labeling logic for option 4S. An explanation of the terminology used in this flow chart is provided in notes 1 and 2 on page G-1.

APPENDIX H

TECHNIQUE FOR USING PEAK GREENNESS TO DETERMINE PHENOLOGICAL MODEL CORRECTIONS

APPENDIX H

TECHNIQUE FOR USING PEAK GREENNESS TO DETERMINE PHENOLOGICAL MODEL CORRECTIONS

Prior methods available for determining the dates of labeling window occurrence (in order to select labeling acquisitions) have the following advantages and disadvantages:

1. Analyst interpretation

   Advantage: Allows the analyst processing the segments to exert the most direct influence on the selection of acquisitions.

   Disadvantages:
   - Requires several through-the-season acquisitions to allow the analyst to track the growth stages of each crop of interest and of other crops and confusion.
   - Depends on the analyst's prior training to identify the crop; poor acquisition selection will result from the analysts with lesser training.
   - Very time consuming.
   - Usually requires historical or current-year crop calendars (as an aid) for the geographic region being analyzed.

2. Historical averages of growth stage occurrence

   Advantage: Allows complete automation of window limit determination.

   Disadvantages:
   - Requires historical crop calendar data base.
   - Will not perform well in years having large deviations from the normal in growth stage occurrence, or in segments having large deviations.

3. Thermal and photothermal phenological models

   Advantages:
   - Allows growth stage predictions (and windows) to be completely automated.

- Adequately handles segment-to-segment variations for corn and soybeans.

Disadvantages:

- Depends on accurate temperature data from a sufficiently large network of reporting stations.
- Needs an accurate phenological model.
- Does not adequately handle early and late seasons caused by rainfall fluctuations.

The method of using peak greenness to determine labeling window midpoints, which are then used to correct phenological models, has the following advantages and disadvantages:

Advantages:

- Allows results of skilled interpretation of a few segments to be applied to many segments in an automated mode.
- Same accuracy attainable with numerous acquisitions is attained in segments with minimal acquisitions.
- Adequately handles segment-to-segment and season-to-season variations.
- Complete crop calendar data base not essential.

Disadvantages:

- Depends on accurate temperature data from a network of reporting stations.
- Interpretation of the crops and peak greenness determination of the few segments used to correct the models must be very accurate, since any errors made may be proliferated to other segments.
- No segments can be processed until after the peak greenness stage of crops has been reached.
- Either the 50-percent-planted date or the length of the growing season must be known.

Segments selected for using this technique must have several cloud-free acquisitions through the crop-growing season. This requirement is necessary in order that curves of greenness through time can be constructed accurately enough to determine the peak greenness date for each selected crop pixel (dot) and to permit accurate temporal crop interpretation. A planting acquisition and at least one acquisition before and after peak greenness are essential. Sufficient acquisitions must be present to allow construction of a curve for the earliest and latest fields. See figures H-1 and H-2 for example curves of early and late developing crop dots.

This technique also requires prior training in imagery interpretation of the crop of interest. This training is essential, since the accuracy attained in window determination for a few segments will, in effect, be extended to many segments, because windows using this technique are used to adjust and train the models.

After generating greenness through time plots for the segment, do the following:

1. Using all of the cloud-free acquisitions for the segment, any available historical crop calendars, ground reports of conditions, and any other crop information for the segment year, make an accurate interpretation of a representative selection of as many pure corn and soybean dots as possible (15 is the desired minimum).
2. Construct greenness through time curves of each dot and record the approximate date of occurrence of maximum greenness for each dot. This may be interpolated as a fraction of distance between two plotted dates.
3. Calculate the mean of the peak greenness dates for each crop.
4. Determine window limits as follows:
   - If both the 50-percent-planted date and the length of season are known:

$$C1 = P_o - 20 \text{ through } P_o + 21$$

$$C2 = T_p - 15 \text{ through } T_p + 15$$

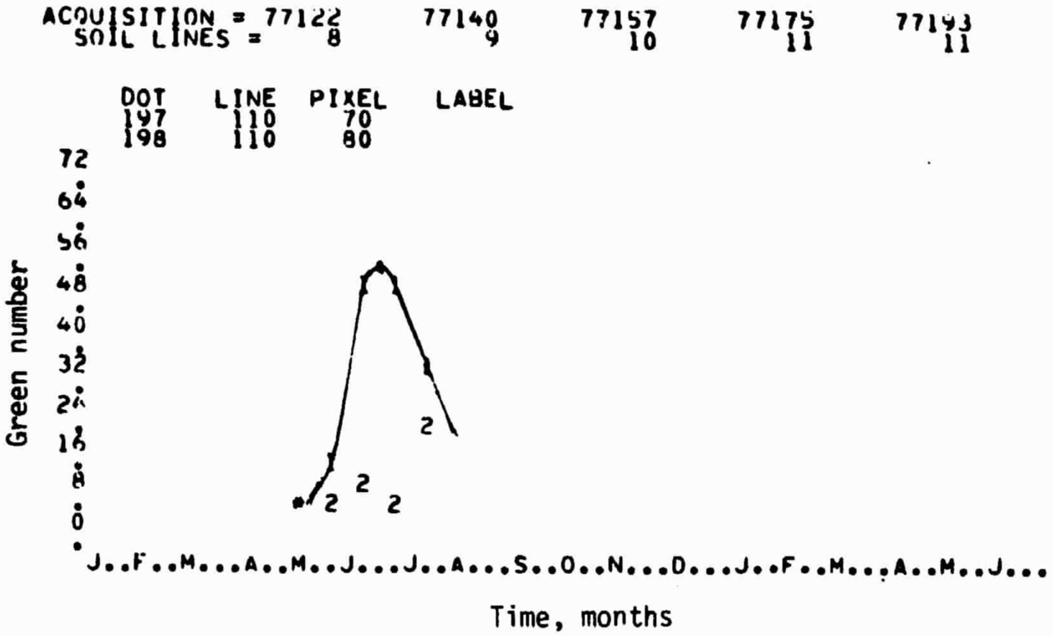

Figure H-1.- Curve of early dot.

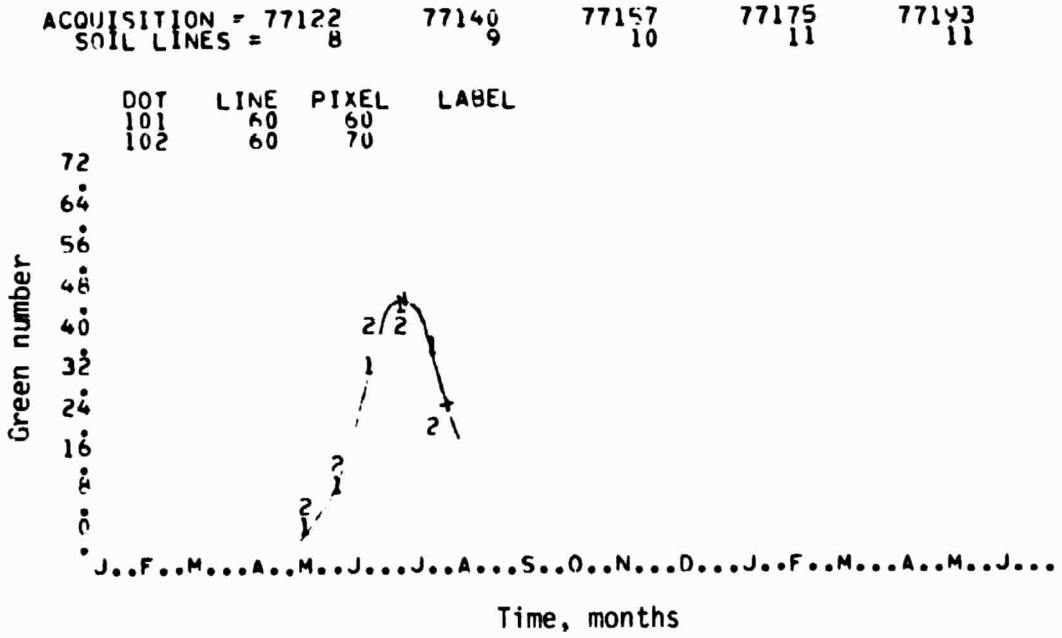

Figure H-2.- Curve of late dot.

$$C3 = T_p + 0.36L_s + 25 \text{ through } T_p + 0.36L_s + 55$$

$$Y1 = P_o - 25 \text{ through } P_o + 16$$

$$Y2 = T_p - 11 \text{ through } T_p + 13$$

$$Y3 = T_p + 0.37L_s + 10 \text{ through } T_p + 0.37L_s + 45$$

where

P_o = date of 50 percent planted

T_p = date of peak greenness

L_s = length of season (i.e., number of days from 50 percent planted to 50 percent harvested)

NOTE: Neither window C1 nor window Y1 may open earlier than day 110.

- The alternate method to use when the length of season is known but the 50-percent-planted date is not known is as follows:

$$C1 = T_p - 0.41L_s - 25 \text{ through } T_p - 0.41L_s + 16$$

$$C2 = T_p - 15 \text{ through } T_p + 15$$

$$C3 = T_p + 0.36L_s + 25 \text{ through } T_p + 0.36L_s + 55$$

$$Y1 = T_p - 0.5L_s - 35 \text{ through } T_p - 0.5L_s + 6$$

$$Y2 = T_p - 11 \text{ through } T_p + 13$$

$$Y3 = T_p + 0.37L_s + 10 \text{ through } T_p + 0.37L_s + 45$$

where definitions of T_p and L_s remain the same.

NOTE: Neither window C1 nor window Y1 may open earlier than day 110.

- The alternative method to use when the planting date, but not the length of season, is known, is as follows:

$$C1 = P_o - 20 \text{ through } P_o + 21$$

$$C2 = T_p - 15 \text{ through } T_p + 15$$

$$C3 = 0.77\left(\frac{T_p - P_o - 5}{0.41}\right) + P_o + 30 \text{ through } 0.77\left(\frac{T_p - P_o - 5}{0.41}\right) + P_o + 60$$

$$Y1 = P_o - 25 \text{ through } P_o + 16$$

$$Y2 = T_p - 11 \text{ through } T_p + 13$$

$$Y3 = 0.87\left(\frac{T_p - P_o - 11}{0.5}\right) + P_o + 20 \text{ through } 0.87\left(\frac{T_p - P_o - 11}{0.5}\right) + P_o + 55$$

where the definitions of P_o and T_p remain the same.

NOTE: Neither window C1 nor window Y1 may open earlier than day 110.

The second operation required in the technique is to use the manually determined windows to correct the windows determined with the phenological models. The necessary steps are as follows:

1. Run the Cross-Zuber model and the Majors-Johnson model to determine the model window midpoints:

   C1 = 50% planted

   C2 = 50% silked

   C3 = 50% mature

   Y1 = 50% planted

   Y2 = 50% beginning pod fill

   Y3 = 50% mature

2. Determine the midpoints of the windows determined using peak greenness.

3. Determine the window midpoint bias of each segment. Subtract the midpoint dates determined using peak greenness from the midpoint dates determined using the phenological models.
4. Determine the mean bias of each modeled window using the results of step 3.
5. Change the sign of each window bias determined in step 4 and apply this number (of days) as a correction to each window output of the models.

APPENDIX I

OUTPUT OF PROGRAM AIREPORT
(SESSION 1)

APPENDIX I

OUTPUT OF PROGRAM AIREPORT

(SESSION 1)

The semiautomated procedure presented in this document utilizes the Majors-Johnson and Cross-Zuber growth stage prediction models to establish the opening and closing dates of the time periods in which acquisitions are necessary for labeling corn and soybean crops. A sample printout of the Crop Report generated by this model is shown on page I-2.

The Corn and Soybean Window Selection Report is used by the analyst in the imagery screening session. This report contains the initial acquisition selections within each window made by the computer. In addition, the options available for use at a particular latitude of a segment are printed in the report. These windows and subwindows, which are based on the time periods predicted by the Majors-Johnson and Cross-Zubers growth stage prediction models, have been seasonally adjusted.

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```
                                        CROP REPORT
                                        -----------

AVAILABLE ACQUISITION AND LANDSAT NUMBERS
SEGMENT:   144      YEAR:  79

LATITUDE:        40.97
LONGITUDE:       92.30

ACQUISITIONS:  79097   79124   79125   79215   79223   79232   79241   79250   79251   79259   79268   79286   79287   79314
LANDSAT NO.      3       2       2       2       3       2       3       2       2       3       2       2       2       3

                                      CORN CROP CALENDAR

                                 DATES OF HANWAY SCALE STAGES

                   -1.0      0.0       1.0        5.0      7.0     8.5     10.5
                 PLANTED   EMERGED   4 LEAVES   SILKED    DOUGH    DENT   MATURE
                 -------   -------   --------   ------    -----    ----   ------

           25%     132       142       163        203      229     241     252

           50%     136       145       164        204      230     242     254

           75%     143       152       169        209      235     247     261

                                    SOYBEAN CROP CALENDAR

                                              BEGINNING    TERMINATION
                 PLANTED   EMERGED   FLOWER   POD FILL     OF FLOWERING    MATURE
                 -------   -------   ------   ---------    ------------    ------

           25%     148       156       194       219           235           255

           50%     152       160       197       222           236           259

           75%     157       165       202       225           239           262
```

```
                         CORN AND SOYBEAN WINDOW SELECTION REPORT
                         ---- --- ------- ------ --------- ------

SEGMENT:   144     YEAR:  79

LATITUDE:        40.97
LONGITUDE:       92.30

ALLOWABLE LABELING OPTIONS: 0 1 1C 1Y 2 2S 3 3S

                    WINDOW/SUBWINDOW    CENTER DATE    OPENING DATE    CLOSING DATE
                    ----------------    -----------    ------------    ------------
                          C1                133            112             153
                          Y1                137            116             157
                          C2                201            186             216
                          C2S1              191            186             195
                          C2S2              212            207             216
                          Y2                225            213             237
                          Y2S1              218            213             222
                          Y2S2              233            228             237
                          C3                291            276             306
                          Y3                297            279             314

THE AMOUNT OF OVERLAP BETWEEN WINDOWS Y2 AND C2 =   4 DAYS AND THE DISTANCE BETWEEN THE WINDOWS =   0 DAYS.
```

```
SEGMENT:   144     YEAR:  79

LATITUDE:        40.97
LONGITUDE:       92.30


                ACQUISITION DATE    SATELLITE NO    CROP/NON CROP     FIELD PIXEL    WINDOW(S)
                                                    CLASSIFICATION
                ----------------    ------------    --------------    -----------    ---------
                     79124                2               *                          C1 Y1
                     79125                2               *                          C1 Y1
                     79215                2               *                 *        C2 C2S2 Y2 Y2S1
                     79223                3               *                 *        Y2
                     79232                2               *                 *        Y2 Y2S2
                     79241                3               *                 *
                     79250                2               *
                     79251                2               *
                     79259                3               *
                     79268                2               *
                     79286                2                                          C3 Y3
                     79287                2                                          C3 Y3
                     79314                3                                          Y3

THERE ARE  10 POTENTIAL CROP/NON CROP OR CLASSIFICATION ACQUISITIONS IN THE RANGE OF 100 DAYS TO 279 DAYS.
CROP/NON CROP OR CLASSIFICATION ACQUISITIONS ARE:
     PRE-EMERGENCE: 79124   79125
     GREEN UP: 79215   79223   79232   79241   79250   79251   79259   79268

THERE ARE   4 FIELD PIXEL ACQUISITIONS IN THE RANGE OF 169 DAYS TO 247 DAYS.
THE FIELD PIXEL ACQUISITIONS ARE:
     79215   79223   79232   79241
```

```
SEGMENT:   144     YEAR:  79

LATITUDE:        40.97
LONGITUDE:       92.30

BASED ON POST SCREENING CRITERIA, THE SEGMENT IS PROCESSABLE / NON PROCESSABLE .


THE EMERGENCE IS 145 AND THE INITIAL TO GUESS FOR PROGRAMS COEFGB AND COEFGBTR IS 145/100.

THE SEPARATION DATE TO BE USED FOR PROGRAM COEFGB IS 225.

THE SEGMENT IS LOCATED IN THE STATE OF: --------------------

PROCESS WITH THE FOLLOWING LABELING OPTION: -------------------

TIME PLOT SKIP FACTOR (CIRCLE ONE):  2   4

ACQUISITIONS FOR SUMMER CROP LOGIC AND TABLE C:

                                        WINDOW        ACQUISITIONS
                                        ------        ------------









ACQUISITION FOR SCATTER PLOTS: ---------.
```

APPENDIX J

PURE-PIXEL SELECTION USING MULTITEMPORAL ACQUISITIONS AND EDGE GRADIENT ENHANCEMENT

APPENDIX J

PURE-PIXEL SELECTION USING MULTITEMPORAL ACQUISITIONS AND EDGE GRADIENT ENHANCEMENT

The method of selecting pure pixels is based on changes in the recorded Landsat digital values in channels 2 and 4.

Each line of data is scanned, and the following values are recorded for each pixel:

1. The difference between the value in a channel for each pixel and the following pixel
2. The difference between the value in a channel for the same pixel and the pixel on the line below

After recording the above differences for each pixel in both channels, the differences in each channel are histogrammed and differences below a predetermined threshold value are determined to be in the same field. Conversely, if a change is above the threshold in a channel, the two pixels being compared are deemed to be in different fields. The final decision is made as follows: If a pixel is below the threshold requirement in both channels, it is determined to be in the same field; if above the threshold in either channel or there is disagreement, the two pixels are determined to be in different fields.

For multiple acquisitions, the above procedure is repeated for each acquisition. If there is disagreement on whether pixels are in the same field, either in two-channel mode or across acquisitions, a pixel under examination is determined to be impure (in a different field).

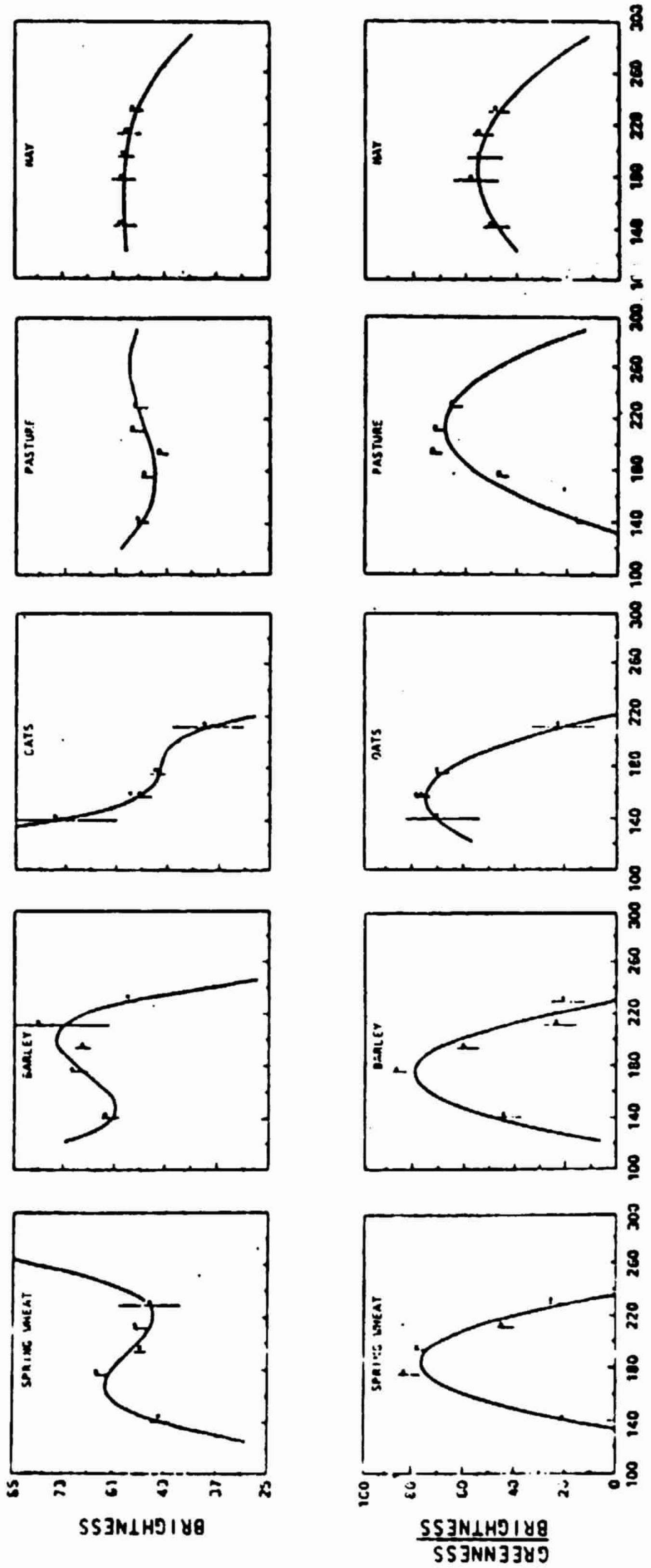
APPENDIX K

A COMPARISON OF BRIGHTNESS PROFILES AND GREENNESS-TO-BRIGHTNESS RATIO PROFILES FOR SEVERAL GRAINS AND GRASSES

APPENDIX K

A COMPARISON OF BRIGHTNESS PROFILES AND GREENNESS-TO-BRIGHTNESS RATIO PROFILES FOR SEVERAL GRAINS AND GRASSES

The graphic in this appendix illustrates how brightness, when combined with greenness as a ratio, can be a valuable aid in distinguishing between crops (such as wheat or oats) and pasture or grass hay, which can be confused with crops.


SPRING WHEAT
BARLEY
OATS
PASTURE
HAY
BRIGHTNESS
GREENNESS
BRIGHTNESS
85
73
61
49
37
25
100
80
60
40
20
0
100
140
180
220
260
300
CALENDAR DAY

APPENDIX L

EXAMPLES OF ANALYSIS AIDS

APPENDIX L

EXAMPLES OF ANALYSIS AIDS

This appendix contains examples of the spectral aids and listings used in the procedure session. The programs that produce these aids are specified in section 4.2 of this report. The examples contained in this appendix are as follows:

1. Table A, page L-2: Green number-brightness listing for all acquisitions; ordered by dot number (418 dots)
2. Table B, page L-3: Green number-brightness listing for all acquisitions; ordered by green number (418 dots)
3. Table C, page L-4: Green number-brightness listing for the labeling acquisitions; ordered by labeling sequence (pure dots only)
4. Unlabeled scatter plot, page L-5: Plot of all 418 dots
5. Labeled scatter plot, page L-6: Plot of all pure summer crop (Z) dots
6. Time trajectory plots, page L-7: Green number through time and brightness through time trajectories

For products having multiple pages, only one page has been reproduced as an example. Examples of the total products are printed in reference 11.

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TABLE A

ORDERED BY DOT NUMBER

SEGMENT = 144 DATE GENERATED = 10/27/81 PAGE 1/ 7

DOT NO.	LINE/	PIXEL	RANDOM LABELING SEQ.	SUMMER CROP LABEL	AC01 G	79124 B	AC02 G	79125 B	AC03 G	79215 B	AC04 G	79223 B	AC05 G	79250 B	AC06 G	79259 B
1	5	10	2		30	75	20	80	9	63	-3	173	14	61	8	71
2	5	20	3	N	14	57	12	63	23	58	27	64	19	51	17	55
3	5	30	9	N	18	61	13	59	19	56	26	65	28	55	21	51
4	5	40	260		13	76	15	74	17	69	18	71	17	51	17	73
5	5	50	203	N	23	67	24	68	6	55	9	61	13	54	11	59
6	5	60	4	Z	9	50	4	49	20	60	29	67	26	65	13	58
7	5	70	69		21	73	9	68	17	60	19	74	15	66	26	73
8	5	80	80	Z	4	52	2	40	28	64	39	76	44	79	32	76
9	5	90	117	N	7	52	18	55	20	59	21	62	14	49	9	58
10	5	100	132	N	25	62	8	70	16	56	13	56	20	58	17	57
11	5	110	99	Z	5	56	5	69	25	63	20	59	12	44	27	69
12	5	120	214		3	64	10	69	19	59	6	37	16	51	19	59
13	5	130	230	N	18	56	17	64	19	56	22	64	12	47	14	59
14	5	140	380	N	9	60	12	57	9	49	19	63	3	65	18	53
15	5	150	191	Z	4	66	3	61	27	66	38	76	39	74	37	81
16	5	160	52	Z	3	37	4	49	39	78	35	75	32	72	17	73
17	5	170	159		30	77	33	70	20	66	6	48	24	66	14	64
18	5	180	361	Z	4	41	5	60	18	53	23	65	18	55	15	53
19	5	190	5	Z	5	56	6	64	27	74	30	84	27	67	12	70
20	10	10	370		12	57	23	65	8	62	18	139	15	55	13	61
21	10	20	263	N	24	81	14	60	14	60	18	76	18	59	21	54
22	10	30	404		5	73	12	78	10	69	42	87	43	83	19	58
23	10	40	393	N	11	58	20	67	22	58	23	62	19	48	11	59
24	10	50	189	N	10	59	10	57	22	56	31	78	21	56	14	46
25	10	60	228	Z	8	50	4	51	31	69	23	65	16	54	33	84
26	10	70	96	Z	4	42	5	62	29	76	32	75	28	71	22	75
27	10	80	125	Z	5	55	5	61	19	56	19	57	25	62	13	55
28	10	90	318	N	13	52	22	77	-3	66	9	74	23	65	11	66
29	10	100	70	N	42	79	13	68	21	68	17	68	3	58	24	65
30	10	110	23		6	68	9	82	16	72	20	78	14	67	7	69
31	10	120	267	N	25	62	17	59	11	58	12	69	12	50	15	57
32	10	130	288		23	62	15	65	14	56	8	72	19	66	26	66
33	10	140	56	Z	4	75	5	91	30	71	29	75	21	63	18	68
34	10	150	399	Z	6	63	8	71	32	73	36	76	42	80	37	81
35	10	160	188	Z	2	47	5	53	44	83	46	88	34	77	13	67
36	10	170	334	Z	5	67	6	61	33	76	51	91	32	76	35	78
37	10	180	173		10	54	4	51	24	63	15	113	17	54	12	62
38	10	190	322		8	53	2	45	27	65	4	79	7	54	16	58
39	15	10	356		12	53	15	65	21	57	-1	166	16	51	15	51
40	15	20	256	N	24	68	14	56	18	56	20	68	13	49	11	45
41	15	30	353	N	18	68	17	66	13	51	14	66	11	53	9	53
42	15	40	42		17	65	10	64	18	54	25	64	16	47	18	51
43	15	50	285	N	14	65	9	64	20	57	26	72	9	54	11	55
44	15	60	220	N	25	63	25	63	2	50	17	61	10	52	7	60
45	15	70	18		9	49	6	57	18	65	18	57	7	47	20	63
46	15	80	72	N	34	74	32	74	15	64	20	77	20	65	18	64
47	15	90	299	N	16	53	25	69	13	62	13	73	15	49	15	61
48	15	100	336	N	19	63	3	60	31	71	29	71	23	64	24	78
49	15	110	253		13	45	7	46	-1	47	-4	53	-9	36	-2	34
50	15	120	237	N	20	59	16	64	17	58	38	78	16	53	15	52
51	15	130	354		16	65	9	73	19	71	21	75	24	65	13	78
52	15	140	111		21	75	20	78	6	67	19	77	8	60	13	66
53	15	150	149		23	59	27	66	14	58	15	73	20	61	13	63
54	15	160	314		8	40	15	59	20	64	58	91	41	80	18	72
55	15	170	138	Z	8	41	2	52	43	82	58	91	30	74	24	88
56	15	180	346	N	3	36	3	41	24	61	29	69	12	51	15	53
57	15	190	293	Z	5	40	2	36	28	68	27	70	26	62	16	55
58	20	10	396		18	76	16	71	3	58	12	82	11	58	11	51
59	20	20	360		10	46	14	53	6	57	19	62	12	42	10	49
60	20	30	415		19	68	10	83	11	52	19	65	17	52	13	56

TABLE B

ORDERED BY GREEN NUMBER

SEGMENT = 144   DATE GENERATED = 10/27/81

ACQ1 79124							ACQ2 79125							ACQ3 79215						
GREEN NO.	BRIGHTNESS	DOT NO.	LINE/	PIXEL	RANDOM LABELING SEQ.	SUMMER CROP LABEL	GREEN NO.	BRIGHTNESS	DOT NO.	LINE/	PIXEL	RANDOM LABELING SEQ.	SUMMER CROP LABEL	GREEN NO.	BRIGHTNESS	DOT NO.	LINE/	PIXEL	RANDOM LABELING SEQ.	SUMMER CROP LABEL
-2	44	336	90	130	8		-7	40	153	45	10	406		-17	30	336	90	130	8	
-2	47	292	80	70	167		-7	44	231	65	30	273		-17	32	397	105	170	54	
-1	47	276	75	100	24		-7	45	397	105	170	57		-16	32	353	95	110	290	
-1	48	397	105	170	54		-5	36	292	80	70	167		-15	31	153	45	10	406	
-1	54	297	80	120	388	Z	-5	37	354	95	120	44		-15	32	354	95	120	44	
0	36	398	105	180	218		-5	49	276	75	100	24		-14	34	292	80	70	167	
0	41	55	15	170	138	Z	-4	33	336	90	130	8		-12	34	318	85	140	394	
0	41	374	100	130	74		-4	35	215	60	60	165		-8	36	276	75	100	24	
0	46	54	15	160	314		-4	40	353	95	110	290		-7	37	231	65	30	273	
0	46	353	95	110	290		-3	39	318	85	140	394		-6	39	290	80	50	109	
0	47	153	45	10	406		-1	40	290	80	50	109		-6	85	84	25	80	134	
0	47	296	80	110	32		-1	79	119	35	50	85		-3	66	28	10	90	318	N
0	47	314	85	100	107	Z	0	50	295	80	100	249		-2	41	358	95	160	352	
0	63	172	50	10	196	Z	0	61	333	90	100	368		-1	57	49	15	110	253	
0	65	251	70	40	43		0	89	284	75	180	45		0	84	105	30	100	157	N
1	29	149	40	160	143	Z	0	91	275	75	90	280		1	94	115	35	10	199	N
1	35	76	20	190	128	Z	1	53	316	85	120	158		2	50	44	15	90	220	N
1	49	273	75	70	402		1	72	417	110	180	156	Z	2	62	83	25	70	407	
1	57	375	100	140	305		1	87	294	80	90	172	Z	2	63	88	25	40	150	
1	77	119	35	50	85		1	93	298	80	130	104		2	66	79	25	30	397	
2	33	147	40	140	144	Z	2	36	57	15	190	293	Z	3	37	215	60	60	165	
2	36	165	45	140	321		2	39	126	35	120	216		3	58	58	20	10	396	
2	38	168	45	160	225	Z	2	40	8	5	80	89	Z	5	69	284	75	180	45	
2	39	187	50	160	303		2	41	170	45	180	372	Z	5	75	187	50	160	303	
2	40	233	65	50	400	Z	2	45	38	10	190	322		6	54	365	100	40	327	N
2	42	67	20	100	244		2	48	92	25	160	166	Z	6	55	5	5	50	283	N
2	44	112	30	170	374	Z	2	48	93	25	170	411	Z	6	57	59	20	120	360	
2	44	131	35	170	316		2	49	171	45	190	250	Z	6	67	52	15	140	111	
2	47	35	10	160	188	Z	2	52	55	15	170	138	Z	6	68	179	50	80	326	
2	47	358	95	160	352		2	55	396	105	160	76		7	46	273	75	70	402	
2	48	93	25	170	411	Z	2	57	233	65	50	400	Z	7	66	344	95	20	10	
2	50	396	105	160	76		2	61	293	80	80	410	Z	7	70	96	30	10	281	
2	57	415	110	160	17	Z	2	65	415	110	160	17	Z	8	49	173	50	20	350	
2	73	351	95	90	12	Z	2	69	249	70	20	114	Z	8	59	103	30	80	154	N
2	79	272	75	60	16	Z	2	70	372	100	110	289	Z	8	62	20	10	10	370	
2	90	294	80	90	172	Z	3	39	168	45	160	225	Z	8	65	68	20	110	123	
3	33	126	35	120	216		3	41	56	15	180	346	N	9	49	14	5	140	388	N
3	34	145	40	120	119		3	43	74	20	170	258		9	56	185	50	140	275	Z
3	36	56	15	180	346	N	3	43	189	50	180	412	Z	9	56	207	55	170	88	
3	37	16	5	160	52	Z	3	44	95	25	190	405	Z	9	58	362	100	10	103	N
3	37	74	20	170	258		3	45	173	50	20	350		9	62	381	105	10	87	N
3	37	167	45	150	351	Z	3	47	112	30	170	374	Z	9	63	[illegible]	5	10	2	
3	37	188	50	170	271	Z	3	51	377	100	160	270		9	66	66	20	90	6	N
3	37	204	55	90	110	Z	3	53	314	85	100	107	Z	9	67	125	35	110	229	
3	38	108	30	130	294		3	58	357	95	150	91	Z	10	49	116	35	120	71	N
3	39	189	50	180	412	Z	3	60	48	15	100	336	N	10	53	410	110	110	235	N
3	40	[illegible]	25	180	96	Z	3	61	15	5	150	191	Z	10	56	98	30	130	146	N
3	43	376	100	150	145	Z	3	62	398	105	180	218		10	59	221	60	120	359	
3	45	92	25	160	166	Z	3	67	230	65	20	79	Z	10	60	343	95	10	222	N
3	45	111	30	160	391	Z	3	68	191	55	10	116		10	60	22	10	30	404	
3	47	255	70	80	319	Z	3	70	395	105	150	89	Z	11	52	60	20	30	415	
3	51	134	40	10	60	Z	3	72	373	100	120	68		11	57	106	30	110	131	Z
3	54	250	70	30	226		3	74	393	105	130	284	Z	11	58	31	10	120	267	N
3	57	252	70	50	221	Z	3	75	232	65	40	140		11	58	65	20	80	324	N
3	58	333	90	100	368		3	77	213	60	40	139		11	63	81	25	50	135	
3	58	395	105	150	89	Z	3	78	251	70	40	43		11	64	130	40	50	63	N
3	64	12	5	120	214		3	80	270	75	40	219	Z	11	67	85	25	90	290	
3	64	212	60	30	273		3	82	337	90	140	230		11	71	345	95	30	292	N
3	64	331	90	80	201	Z	3	82	338	90	150	355		12	54	368	100	70	140	N

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TABLE C

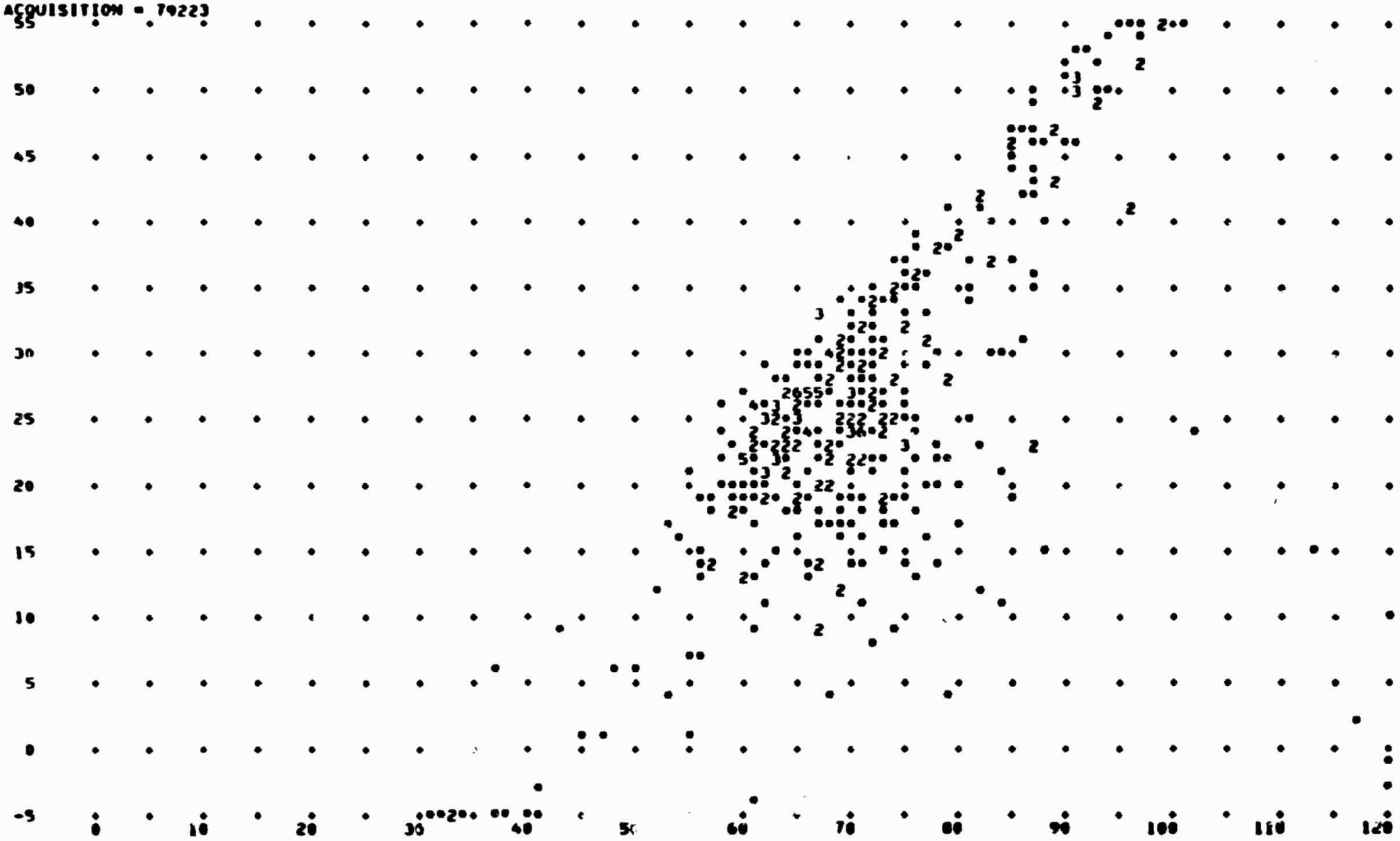
ORDERED BY LABELING SEQUENCE

SEGMENT = 144 DATE GENERATED = 10/26/81 PAGE 1/13

RANDOM LABELING SEQ.	DOT NO.	LINE/	PIXEL	WINDOW Y1 ACQ1 79124 G	B	WINDOW Y2 ACQ2 79223 G	B	WINDOW Y3 ACQ3 79286 G	B	SUMMER CROP LABEL	ANALYST LABEL C	Y	N
3	2	5	20	14	57	27	44	8	35	N	___	___	___
4	6	5	60	9	50	29	67	6	37	Z	___	___	___
5	19	5	190	5	56	30	84	2	63	Z	___	___	___
6	66	20	90	20	80	22	79	13	47	N	___	___	___
7	224	60	150	15	52	25	62	13	36	N	___	___	___
9	3	5	30	10	61	26	65	14	41	N	___	___	___
13	351	95	90	2	73	46	91	5	44	Z	___	___	___
14	200	55	100	12	55	24	64	9	31	N	___	___	___
15	135	40	20	13	46	26	63	12	34	N	___	___	___
16	272	75	60	2	89	26	72	5	53	Z	___	___	___
17	415	110	160	2	57	36	77	3	39	Z	___	___	___
19	304	80	190	14	61	24	71	10	41	N	___	___	___
22	176	50	50	11	52	24	58	19	38	N	___	___	___
25	130	35	160	5	52	27	66	5	40	Z	___	___	___
26	388	105	80	14	57	35	72	16	40	N	___	___	___
27	326	90	30	9	53	25	65	16	39	N	___	___	___
30	129	35	150	5	43	34	74	8	53	Z	___	___	___
31	174	50	30	13	46	27	64	13	38	N	___	___	___
33	216	60	70	14	57	25	63	21	42	N	___	___	___
34	305	85	10	20	60	22	61	18	39	N	___	___	___
37	265	70	180	36	77	24	71	11	41	N	___	___	___
38	349	95	70	24	63	22	72	12	47	N	___	___	___
39	133	35	190	6	44	27	66	6	50	Z	___	___	___
40	210	60	10	3	68	47	89	3	41	Z	___	___	___
41	197	55	70	15	65	28	79	16	34	N	___	___	___
42	128	35	140	6	47	46	85	7	58	Z	___	___	___
46	190	50	190	7	51	30	68	5	49	Z	___	___	___
47	261	70	140	9	59	27	66	14	39	N	___	___	___
48	271	75	50	4	82	52	97	5	62	Z	___	___	___
49	118	35	40	34	74	28	62	11	34	N	___	___	___
										TOTAL	___	___	___

SITE = 144 DATE GENERATED = 10/26/81 ***CATEGORY OF INTEREST*** AVERAGE SOIL GREENNESS = 22

ACQUISITION = 79223



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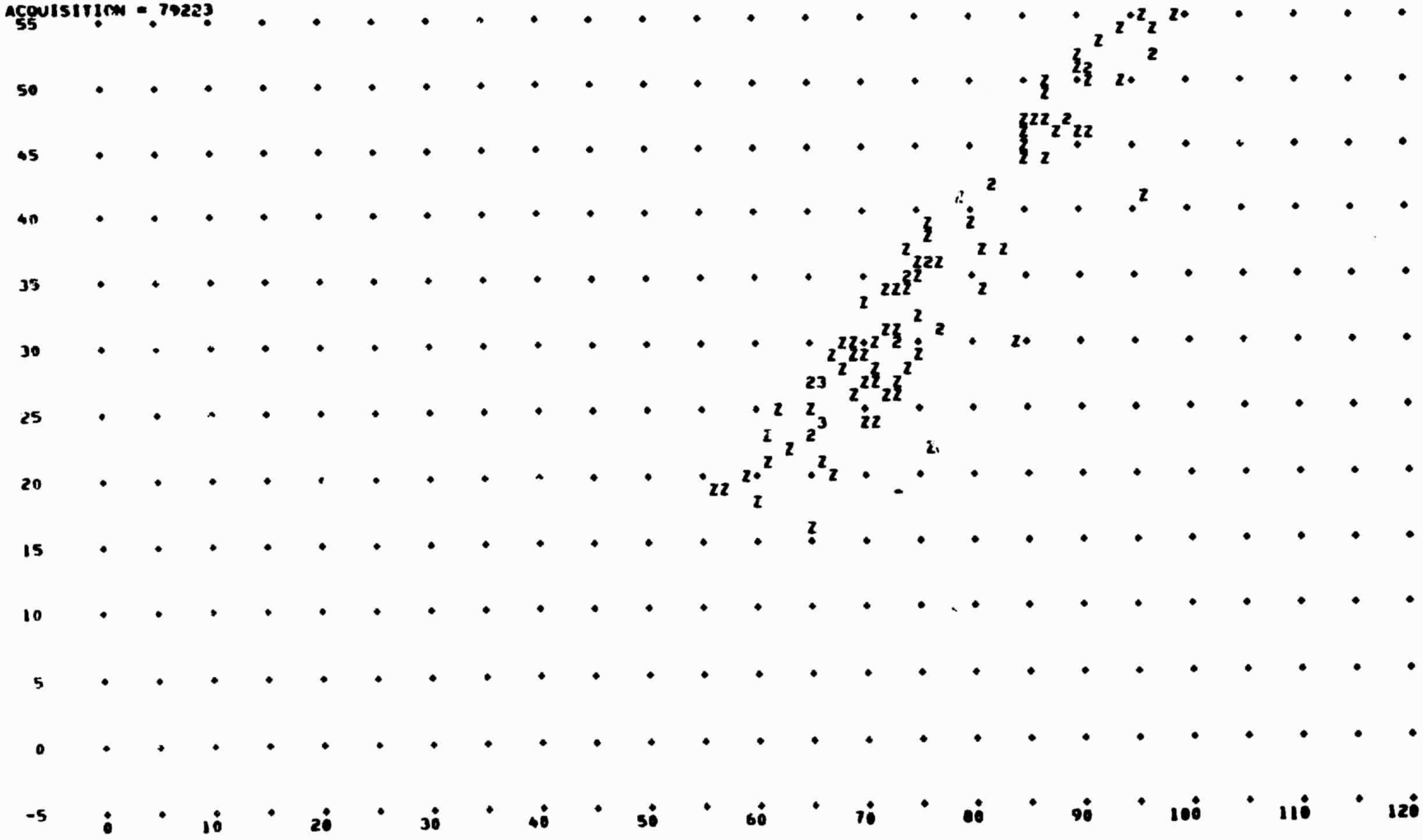
SITE = 144 DATE GENERATED = 10/26/81 ***CATEGORY OF INTEREST*** AVERAGE SOIL GREENNESS = 22

ACQUISITION = 79223



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SITE =  144      DATE GENERATED = 10/27/81          CATEGORIES PLOTTED   ,
ACQUISITION = 79124     79125     79215     79223     79250     79259     79268     79286     79287
  SOIL LINES =     10         9        24        22        24        20        18        13        12
```

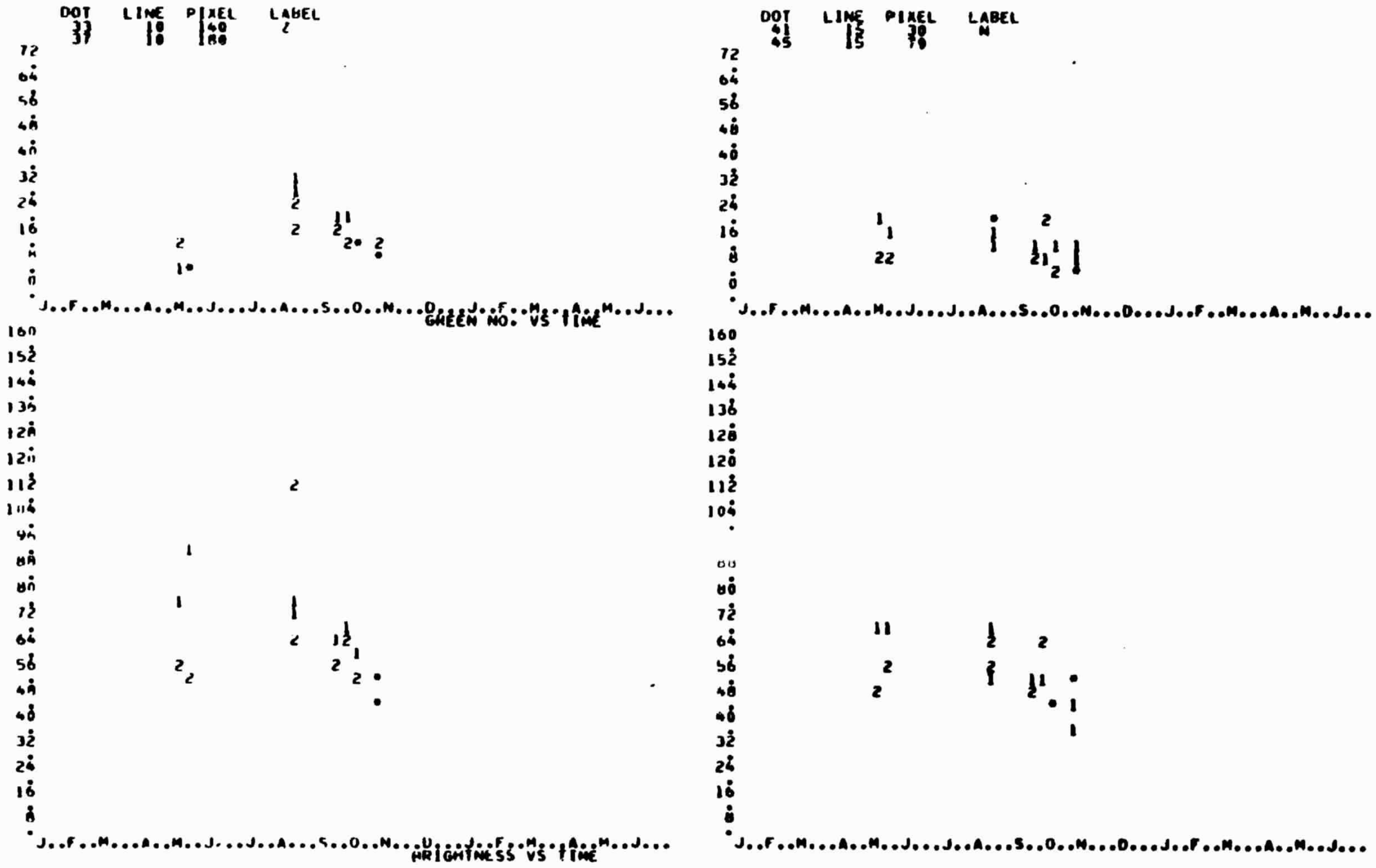

GREEN NO. VS TIME

BRIGHTNESS VS TIME

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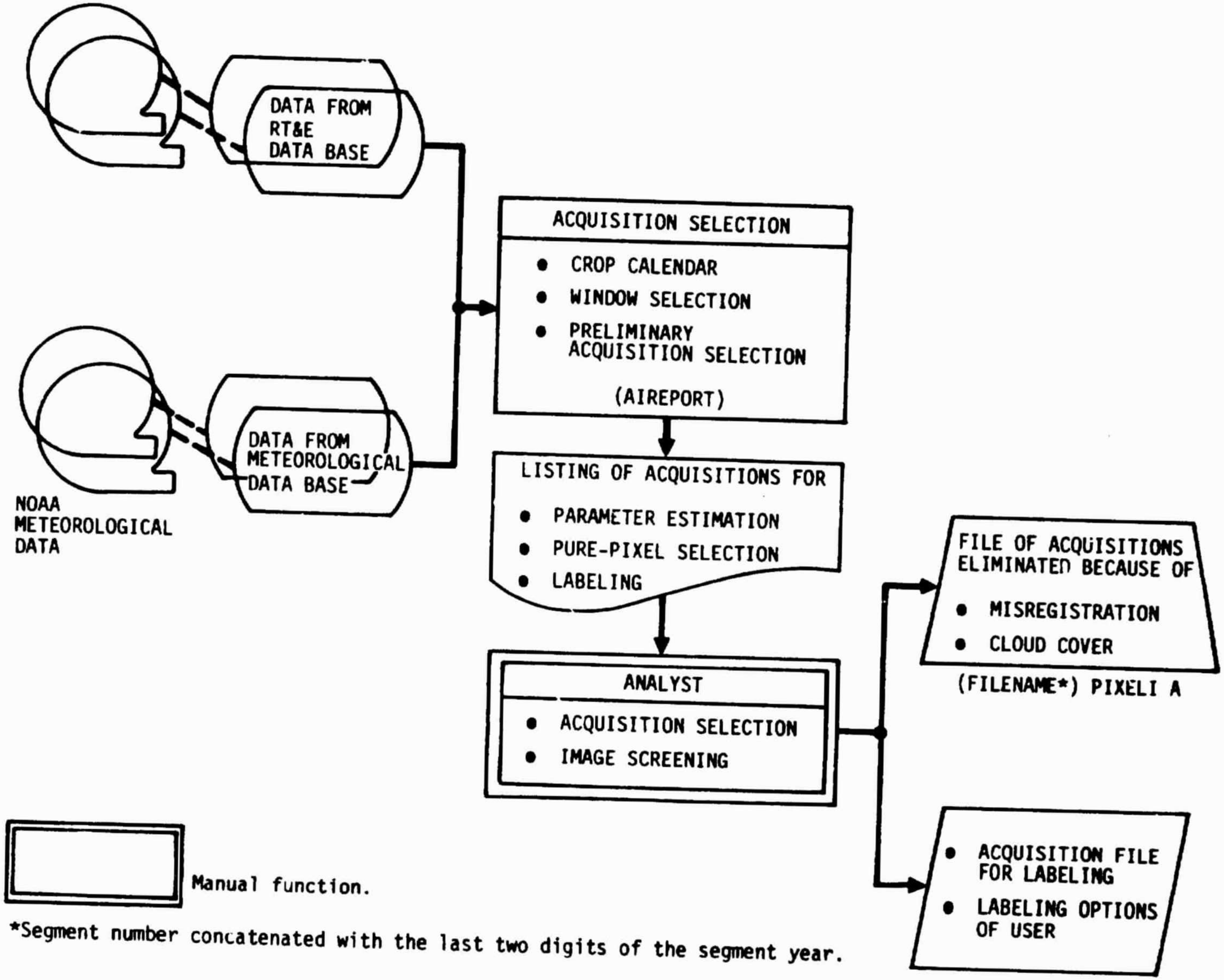
APPENDIX M

COMPUTER PROCESSING FUNCTIONS

APPENDIX M

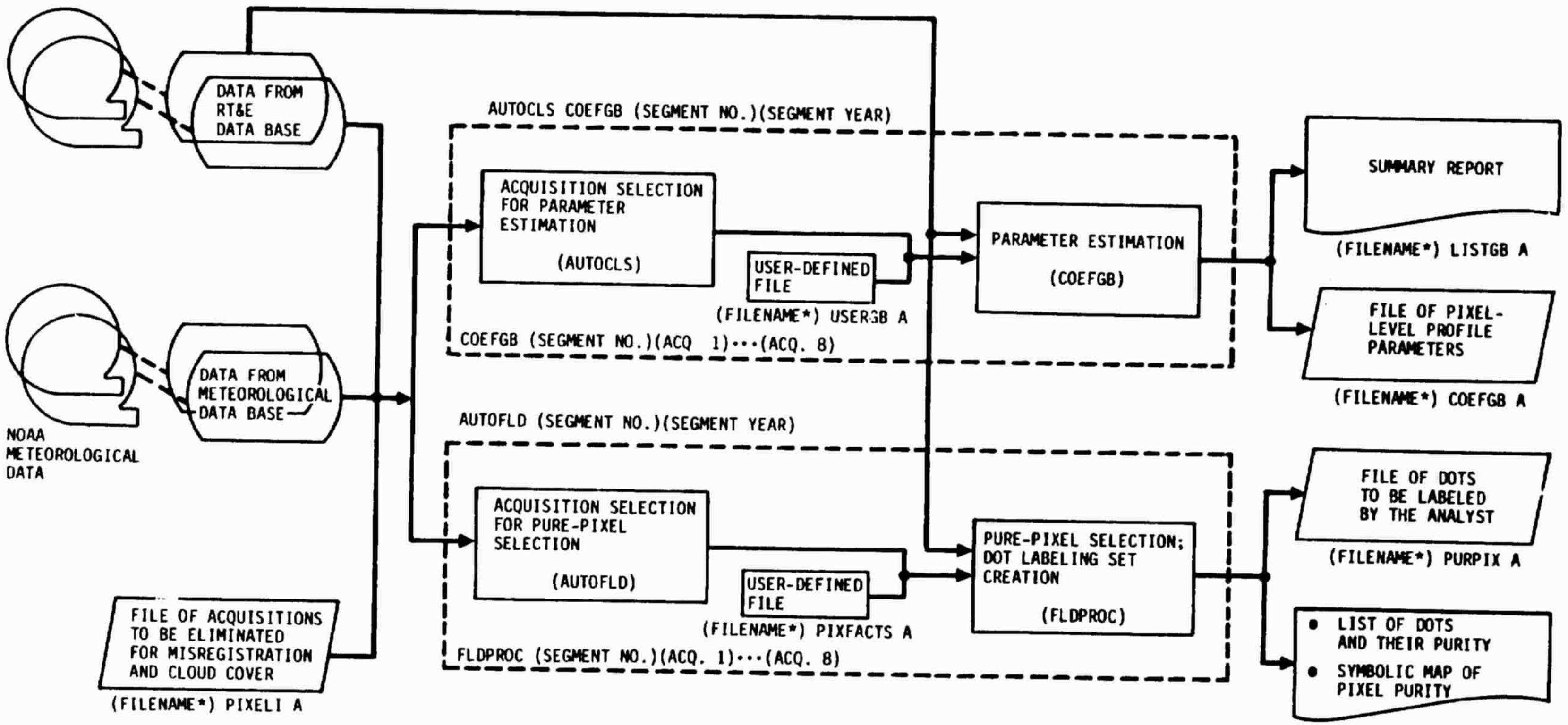
COMPUTER PROCESSING FUNCTIONS

Section 4 of this report gives an end-to-end explanation of the processing functional flow of the charts contained in this appendix and how they relate to labeling and classification. Also, see reference 11.



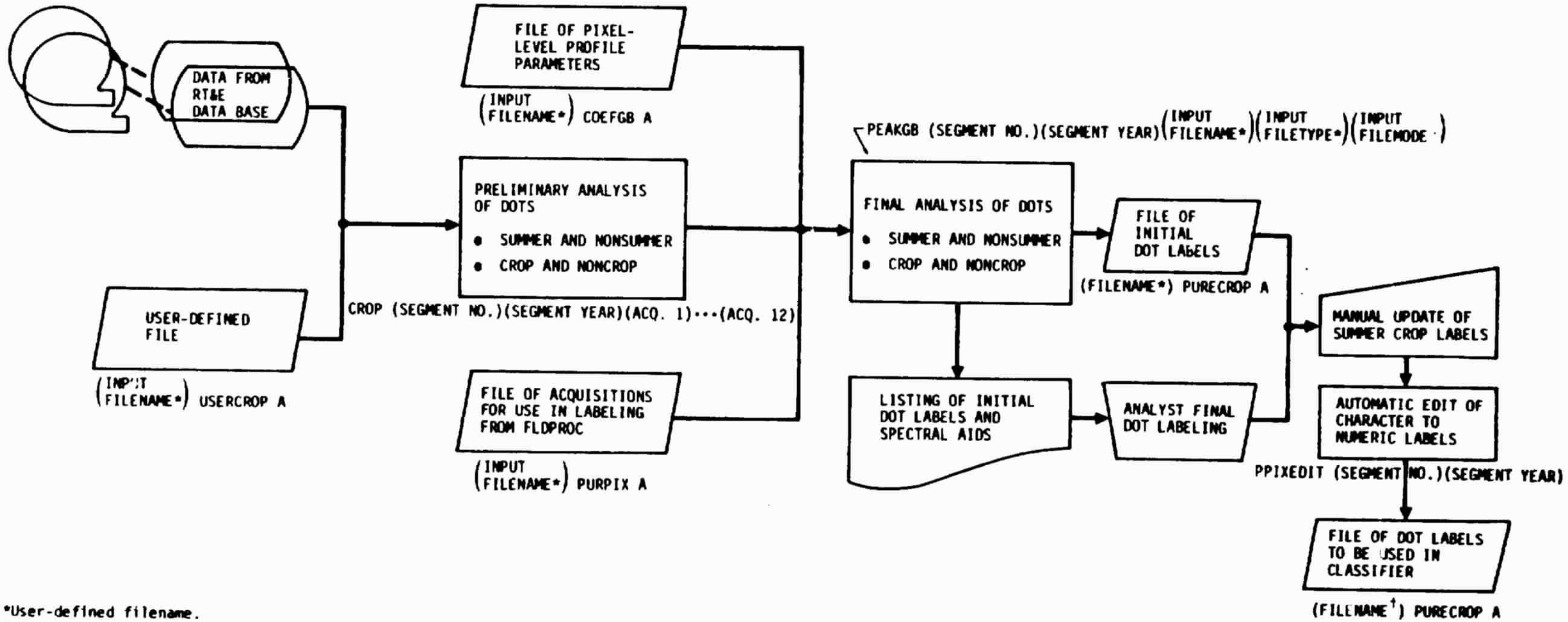
*Segment number concatenated with the last two digits of the segment year.

Figure M-1.- Initial acquisition selection.



*Segment number concatenated with the last two digits of the segment year.

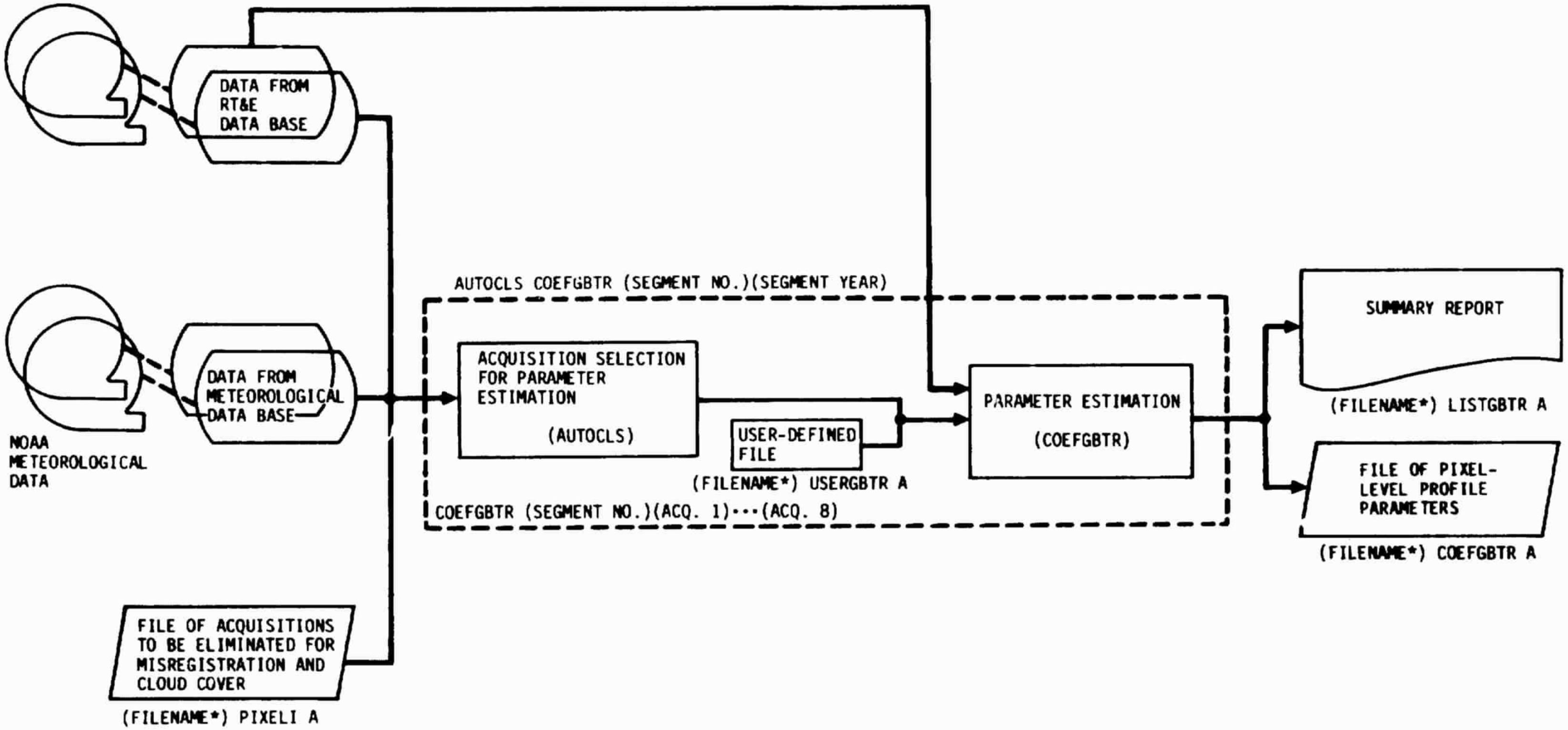
Figure M-2.- Parameter estimation and dot labeling set creation.



*User-defined filename.

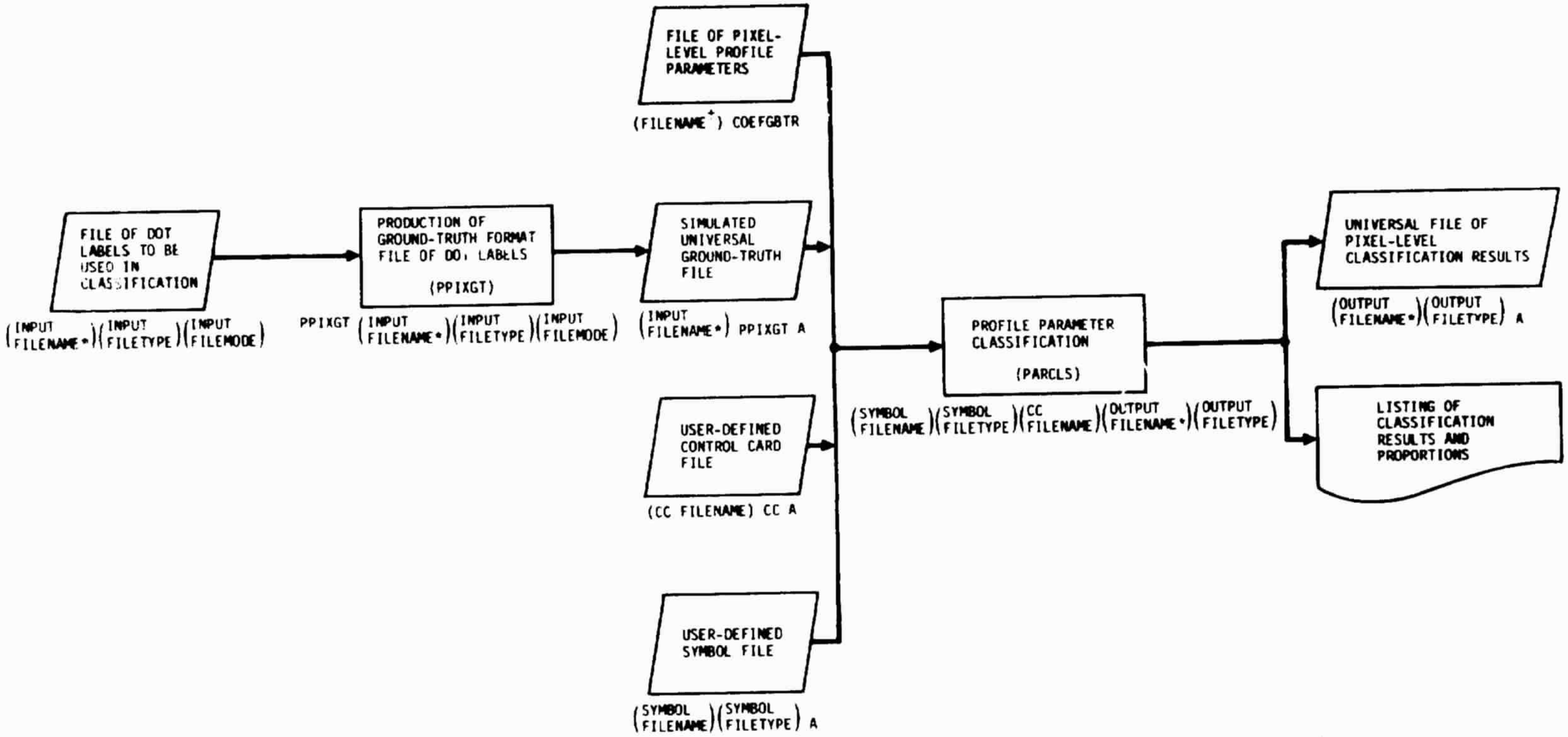
†Segment number concatenated with the last two digits of the segment year.

Figure M-3.- Analysis aid production and final dot labeling.



*Segment number concatenated with the last two digits of the segment year.

Figure M-4.- Parameter estimation for classification.



*User-defined filename.

+Segment number concatenated with the last two digits of the segment year.

Figure M-5.- Classification and proportion estimation.

APPENDIX N

TEST RESULTS

APPENDIX N

TEST RESULTS

OVERALL CS-4 VERIFICATION TEST RESULTS

[SEVEN TEST SEGMENTS]

Crop	Classified, %	Ground truth, %	Error, %	Relative error, %
Corn	37.15	37.38	-0.23	-0.61
Soybeans	19.65	20.56	-0.91	-4.43
Other	43.20	42.05	+1.15	+2.73

DOT LABELING ACCURACY, %

$$\begin{array}{cc} & \text{Label} \\ \text{Ground truth} & \left[\begin{array}{cccc} & C & Y & N \\ C & 86 & 7 & 7 \\ Y & 9 & 90 & 1 \\ N & 0 & 2 & 98 \end{array}\right] \end{array}$$

Overall accuracy: 91.04

Procedure error: 6.12

Analyst error: 1.42

Questionable ground truth: 1.42

CLASSIFICATION VS LABELS, %

$$\begin{array}{cc} & \text{Classification} \\ \text{Label} & \left[\begin{array}{cccc} & C & Y & N \\ C & 89 & 8 & 3 \\ Y & 9 & 91 & 0 \\ N & 8 & 3 & 89 \end{array}\right] \end{array}$$

CLASSIFICATION VS GROUND TRUTH, %

$$\begin{array}{cc} & \text{Classification} \\ \text{Dot ground truth} & \left[\begin{array}{cccc} & C & Y & N \\ C & 87 & 8 & 5 \\ Y & 9 & 90 & 1 \\ N & 5 & 2 & 93 \end{array}\right] \end{array}$$

Purity of dots initially selected by PURPIX program, %: 79.5

Purity of labels after analyst acceptance, %: 95.8

CS-4 VERIFICATION TEST RESULTS

Segment no.: 0144
Year: 1979
State: Iowa

Crop	Classified, %	Ground truth, %	Error, %	Relative error, %
Corn	26.82	19.88	+6.94	+34.91
Soybeans	16.41	21.33	-4.92	-23.07
Other	56.76	58.79	-2.03	-3.45

Percentage of segment inventoried: 96.8

Number of dots (labels) in each category used to train classifier: 25

DOT LABELING ACCURACY, %

Label

$$\text{Ground truth} \quad \left[\begin{array}{cccc} & C & Y & N \\ C & 100 & 0 & 0 \\ Y & 7 & 93 & 0 \\ N & 0 & 0 & 100 \end{array}\right]$$

Overall accuracy: 97.3

Procedure error: 1.35

Analyst error: 0

Questionable ground truth: 1.35

Comment: Some hail damage and possibly poor stands caused some soybeans to be classified as corn.

CLASSIFICATION VS LABELS, %

Classification

$$\text{Label} \quad \left[\begin{array}{cccc} & C & Y & N \\ C & 88 & 4 & 8 \\ Y & 12 & 88 & 0 \\ N & 4 & 4 & 92 \end{array}\right]$$

CLASSIFICATION VS GROUND TRUTH, %

Classification

$$\text{Dot ground truth} \quad \left[\begin{array}{cccc} & C & Y & N \\ C & 87 & 4 & 9 \\ Y & 12 & 88 & 0 \\ N & 4 & 4 & 92 \end{array}\right]$$

Purity of dots initially selected by PURPIX program, %: 88.9

Purity of labels after analyst acceptance, %: 92.0

CS-4 VERIFICATION TEST RESULTS

Segment no.: 0145
Year: 1979
State: Iowa

Crop	Classified, %	Ground truth, %	Error, %	Relative error, %
Corn	29.51	32.36	-2.85	-8.81
Soybeans	24.11	16.63	+7.48	+45.0
Other	46.37	51.01	-4.64	-9.00

Percentage of segment inventoried: 96.1

Number of dots (labels) in each category used to train classifier: 15

DOT LABELING ACCURACY, %

$$\begin{array}{cc} & \text{Label} \\ \text{Ground truth} & \left[\begin{array}{cccc} & C & Y & N \\ C & 100 & 0 & 0 \\ Y & 17 & 83 & 0 \\ N & 0 & 0 & 100 \end{array}\right] \end{array}$$

Overall accuracy: 93.3

Procedure error: 6.7

Analyst error: 0

Questionable ground truth: 0

Comment: Small amounts of corn classified as soybeans had a high relative effect on the total classified soybeans.

CLASSIFICATION VS LABELS, %

$$\begin{array}{cc} & \text{Classification} \\ \text{Label} & \left[\begin{array}{cccc} & C & Y & N \\ C & 73 & 27 & 0 \\ Y & 13 & 87 & 0 \\ N & 6.5 & 6.5 & 87 \end{array}\right] \end{array}$$

CLASSIFICATION VS GROUND TRUTH, %

$$\begin{array}{cc} & \text{Classification} \\ \text{Dot ground truth} & \left[\begin{array}{cccc} & C & Y & N \\ C & 92 & 8 & 0 \\ Y & 11 & 89 & 0 \\ N & 6.5 & 6.5 & 87 \end{array}\right] \end{array}$$

Purity of dots initially selected by PURPIX program, %: 73.5

Purity of labels after analyst acceptance, %: 100

CS-4 VERIFICATION TEST RESULTS

Segment no.: 0856
Year: 1979
State: Indiana

Crop	Classified, %	Ground truth, %	Error, %	Relative error, %
Corn	27.28	31.42	-4.14	-13.22
Soybeans	28.00	25.77	+2.23	-8.70
Other	44.72	42.81	+1.91	+4.50

Percentage of segment inventoried: 96.9

Number of dots (labels) in each category used to train classifier: 25

DOT LABELING ACCURACY, %

$$\begin{array}{cc|ccc|} & & \multicolumn{3}{c}{\text{Label}} \\ & & C & Y & N \\ & C & 85 & 11 & 4 \\ \text{Ground truth} & Y & 8 & 92 & 0 \\ & N & 0 & 0 & 100 \end{array}$$

Overall accuracy: 92.0

Procedure error: 4.0

Analyst error: 1.3

Questionable ground truth: 2.7

Comment: Some late corn fields had spectral characteristics of soybeans.

CLASSIFICATION VS LABELS, %

$$\begin{array}{cc|ccc|} & & \multicolumn{3}{c}{\text{Classification}} \\ & & C & Y & N \\ & C & 92 & 8 & 0 \\ \text{Label} & Y & 0 & 100 & 0 \\ & N & 4 & 0 & 96 \end{array}$$

CLASSIFICATION VS GROUND TRUTH, %

$$\begin{array}{cc|ccc|} & & \multicolumn{3}{c}{\text{Classification}} \\ & & C & Y & N \\ & C & 85 & 15 & 0 \\ \text{Dot ground truth} & Y & 8 & 92 & 0 \\ & N & 0 & 0 & 100 \end{array}$$

Purity of dots initially selected by PURPIX program, %: 78.9

Purity of labels after analyst acceptance, %: 98.7

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CS-4 VERIFICATION TEST RESULTS

Segment no.: 0864
Year: 1978
State: Iowa

Crop	Classified, %	Ground truth, %	Error, %	Relative error, %
Corn	42.47	46.21	-3.74	-8.09
Soybeans	10.61	11.95	-1.34	-11.21
Other	46.92	41.84	+5.08	+12.21

Percentage of segment inventoried: 97.7

Number of dots (labels) in each category used to train classifier: 17

DOT LABELING ACCURACY, %

$$\text{Ground truth}\quad \overset{\text{Label}}{\left[\begin{array}{cccc} & C & Y & N \\ C & 89 & 0 & 11 \\ Y & 6 & 94 & 0 \\ N & 0 & 0 & 100 \end{array}\right]}$$

Overall accuracy: 94.1

Procedure error: 3.9

Analyst error: 2.0

Questionable ground truth: 0

Comment: Some early maturing corn fields were below corn thresholds and were classified as "other"; some soybean fields were called corn (possibly poor stands).

CLASSIFICATION VS LABELS, %

$$\text{Label}\quad \overset{\text{Classification}}{\left[\begin{array}{cccc} & C & Y & N \\ C & 32 & 12 & 6 \\ Y & 6 & 94 & 0 \\ N & 6 & 0 & 94 \end{array}\right]}$$

CLASSIFICATION VS GROUND TRUTH, %

$$\text{Dot ground truth}\quad \overset{\text{Classification}}{\left[\begin{array}{cccc} & C & Y & N \\ C & 83 & 6 & 11 \\ Y & 6 & 94 & 0 \\ N & 0 & 0 & 100 \end{array}\right]}$$

Purity of dots initially selected by PURPIX program, %: 73.2

Purity of labels after analyst acceptance, %: 96.1

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CS-4 VERIFICATION TEST RESULTS

Segment no.: 0881
Year: 1978
State: Iowa

Crop	Classified, %	Ground truth, %	Error, %	Relative error, %
Corn	42.11	44.33	-2.22	-5.00
Soybeans	10.53	8.00	+2.53	+31.63
Other	47.36	47.67	-0.31	-0.65

Percentage of segment inventoried: 98.04

Number of dots (labels) in each category used to train classifier: 18

DOT LABELING ACCURACY, %

$$\underline{\text{Ground truth}} \quad \begin{array}{c} \underline{\text{Label}} \\ \left[\begin{array}{cccc} & C & Y & N \\ C & 75 & 21 & 4 \\ Y & 0 & 100 & 0 \\ N & 0 & 6 & 94 \end{array}\right] \end{array}$$

Overall accuracy: 86.8

Procedure error: 9.4

Analyst error: 3.8

Questionable ground truth: 0

Comment: Some late corn fields still had spectral characteristics of soybeans.

CLASSIFICATION VS LABELS, %

$$\underline{\text{oel}} \quad \begin{array}{c} \underline{\text{Classification}} \\ \left[\begin{array}{cccc} & C & Y & N \\ C & 94 & 6 & 0 \\ Y & 17 & 83 & 0 \\ N & 11 & 0 & 89 \end{array}\right] \end{array}$$

CLASSIFICATION VS GROUND TRUTH, %

$$\underline{\text{Dot ground truth}} \quad \begin{array}{c} \underline{\text{Classification}} \\ \left[\begin{array}{cccc} & C & Y & N \\ C & 79 & 17 & 4 \\ Y & 0 & 100 & 0 \\ N & 12 & 0 & 88 \end{array}\right] \end{array}$$

Purity of dots initially selected by PURPIX program, %: 71.2

Purity of labels after analyst acceptance, %: 92.6

CS-4 VERIFICATION TEST RESULTS

Segment no.: 0877
Year: 1978
State: Iowa

Crop	Classified, %	Ground truth, %	Error, %	Relative error, %
Corn	46.95	48.30	-1.35	-2.80
Soybeans	20.90	24.88	-3.98	-15.68
Other	32.15	26.82	+5.33	+19.87

Percentage of segment inventoried: 79.3

Number of dots (labels) in each category used to train classifier: 25

DOT LABELING ACCURACY, %

$$\begin{array}{cc} & \text{Label} \\ \text{Ground truth} & \left[\begin{array}{cccc} & C & Y & N \\ C & 78 & 6 & 16 \\ Y & 0 & 90 & 10 \\ N & 0 & 0 & 100 \end{array}\right] \end{array}$$

Overall accuracy: 86.8

Procedure error: 8.8

Analyst error: 1.5

Questionable ground truth: 2.9

Comment: Variety of factors (including early maturity) caused small amount of corn to be called "other"; some soybeans labeled "other" -- failure to detect planting.

CLASSIFICATION VS LABELS, %

$$\begin{array}{cc} & \text{Classification} \\ \text{Label} & \left[\begin{array}{cccc} & C & Y & N \\ C & 100 & 0 & 0 \\ Y & 12 & 88 & 0 \\ N & 12 & 4 & 84 \end{array}\right] \end{array}$$

CLASSIFICATION VS GROUND TRUTH, %

$$\begin{array}{cc} & \text{Classification} \\ \text{Dot ground truth} & \left[\begin{array}{cccc} & C & Y & N \\ C & 91 & 3 & 6 \\ Y & 0 & 95 & 5 \\ N & 0 & 0 & 100 \end{array}\right] \end{array}$$

Purity of dots initially selected by PURPIX program, %: 82.2

Purity of labels after analyst acceptance, %: 96.0

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CS-4 VERIFICATION TEST RESULTS

Segment no.: 0883
Year: 1979
State: Iowa

Crop	Classified, %	Ground truth, %	Error, %	Relative error, %
Corn	44.92	39.17	+5.75	+14.7
Soybeans	26.98	35.39	-8.41	-23.76
Other	28.10	25.44	+2.66	+10.5

Percentage of segment inventoried: 95.4

Number of dots (labels) in each category used to train classifier: 19

DOT LABELING ACCURACY, %

Label

Ground truth

$$\left[\begin{array}{cccc} & C & Y & N \\ C & 88 & 0 & 12 \\ Y & 22 & 78 & 0 \\ N & 0 & 6 & 94 \end{array}\right]$$

Overall accuracy: 86.0

Procedure error: 10.5

Analyst error: 3.5

Questionable ground truth: 0

Comment: Extensive hail damage caused corn to be called "other" and soybeans to be called corn.

CLASSIFICATION VS LABELS, %

Classification

Label

$$\left[\begin{array}{cccc} & C & Y & N \\ C & 84 & 11 & 5 \\ Y & 5 & 95 & 0 \\ N & 21 & 0 & 79 \end{array}\right]$$

CLASSIFICATION VS GROUND TRUTH, %

Classification

Dot ground truth

$$\left[\begin{array}{cccc} & C & Y & N \\ C & 94 & 0 & 6 \\ Y & 13 & 87 & 0 \\ N & 17 & 0 & 83 \end{array}\right]$$

Purity of dots initially selected by PURPIX program, %: 85.7

Purity of labels after analyst acceptance, %: 96.5

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