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CROP IDENTIFICATION USING LANDSAT TEMPORAL-SPECTRAL PROFILES

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I. ABSTRACT

The temporal-spectral profile is a detailed indicator of the physical state of a field through time. Characteristic profiles have been observed for a variety of crops and other cover classes from Landsat data in the United States Corn Belt. These profiles contain information to support crop identification at various levels.

II. INTRODUCTION

Through the use of multitemporal sequences of observations, a valuable dimension is added to remote sensing based procedures related to agricultural feature detection and identification. This is particularly true when ground-derived observations cannot be incorporated into the crop identification process. Multitemporal coverage, such as that provided by Landsat, allows a field to be sampled several times during the growing season. The resulting pattern of spectral values over time represents the phenological development (i.e., the progression of a crop toward maturity) in the field. By relating the observed temporal-spectral pattern to the expected phenological development patterns associated with different crops, a crop identity, or label, can be assigned to the field.

Until recently, temporal-spectral patterns have been evaluated primarily using multitemporal image products. An image analyst tracks a field through time over available acquisitions, identifying it based on the sequence and timing (relative to the overall growing season) of colors observed from the imagery. However, this approach has its limitations, particularly when the image product is generated from digital data. Compression of the initial range of digital values into a limited number of color levels results in a reduction of the information that can be extracted from the data. Furthermore, color renditions on image products tend to vary from image to image due to photo processing and to the specific mapping function that is used to create the image. This means that subtle, perhaps critical, spectral differences may not be detectable on image products, and features that are in fact spectrally similar may appear completely different on different images.

The original information content of the Landsat data is better preserved if digital data are analyzed in numeric, rather than image, format. The temporal-spectral profile is a particularly informative way of organizing the data for analysis. It consists of a Landsat signal viewed through time and represents a specific labeling target (field, pixel, etc.). Any Landsat band or Landsat-derived transformation may be evaluated in this form. For crop identification purposes, however, it is most appropriate to use a vegetation indicator, such as the 2xMSS7 to MSS5 ratio or the Tasselled Cap Greenness component[1], which measures infrared reflectance relative to that in the visual bands.

The Landsat temporal-spectral profile is an indicator of the physical properties of the field or other landscape feature from which it was derived. The exact profile appearance is determined by a variety of interrelated factors, including crop calendar, plant morphology, canopy structure, and associated cultural practices. Although these factors vary from field to field, individual fields that contain the same crop tend to resemble one another more closely than they resemble fields containing different crops. Hence, the profiles that represent a specific crop are usually more similar to one another than to profiles that represent other crops. Profile-based crop identification techniques capitalize on these differences and similarities.

In 1980 personnel from the Environmental Research Institute of Michigan and the University of California at Berkeley combined efforts to develop a U.S. Baseline Corn and Soybean Segment Classification Procedure under the auspices of the Foreign Commodity Production Forecasting Project (currently, the Inventory Technology Development Project) of the AgRISTARS program.[2] The labeling component of this procedure draws heavily from the detailed spectral information conveyed by the temporal-spectral profile. During the development, evaluation, and revision of the analysis logic, ample opportunity was provided to examine the profiles of a variety of crops and other cover classes in both the central and marginal areas of the United States Corn Belt. In this paper we present some of the characteristic profiles that have been observed and describe the information contained in them that enable us to identify the labeling targets they represent.

III. PROFILE ANALYSIS AND IDENTIFICATION

The discussion that follows parallels the content and hierarchical organization of the analysis logic in the baseline procedure. Three crop identification levels are considered, each of which focuses on the further refinement of a label: (1) Annual Crop vs. Other, (2) Crop Group, and (3) Crop Type. Representative profiles, drawn from AgRISTARS Corn Belt and Corn Belt fringe sample segments, are introduced at appropriate points in the discussion. The profiles are presented against a time axis that extends from May through November, which is the most active part of the growing season in this region. The vegetation indicator is GRABS (Greenness Above Bare Soil), which is equivalent to the Greenness component of the Tasselled Cap Transformation minus a discriminant placed at the top of the bare soil distribution.[3] In order to minimize the effect of external factors such as haze, sun angle and sensor, the data were normalized using the XSTAR algorithm before GRABS was computed.[1] Theoretically, the green vegetation detection threshold is equal to a GRABS value of zero. However, some variability occurs around this line, and non-vegetated landscape features have been observed to have positive values. As a conservative measure, we will refer to a slightly higher threshold of six in order to increase the probability that only values indicative of green vegetation will be above the threshold.

A. LEVEL ONE: ANNUAL CROP VS. OTHER

In this section we present the general profile form that is characteristic of annual field crops such as corn, soybeans and the small grains. This is accomplished through the progressive elimination of profile forms that clearly do not belong to the category of interest. For the purpose of this discussion, hay crops that have an annual life cycle are included in this latter group.

No Vegetation. A field in which a crop is grown must, by definition, contain vegetation at some time during the growing season. Accordingly, a crop profile should exceed the green vegetation detection threshold on at least one date. If a profile remains below the threshold during the entire season, there is no evidence to indicate the presence of vegetation. We must assume that the profile represents a non-vegetated class, such as fallow, water, barren land, and man-made features. Note, however, that in order to distinguish a crop profile from one in this category, at least one acquisition must be available from the period during which the crop is green.

A typical profile from one non-vegetated class, fallow, is illustrated in Figure 1. Actual Landsat observations are represented by stars. The overall form of the profile is irrelevant. The key identifying feature is its location relative to the detection threshold.

Continuous Vegetation. A field in which an annual crop is grown contains bare soil or non-green crop residue at some time during the growing season. The correspond-

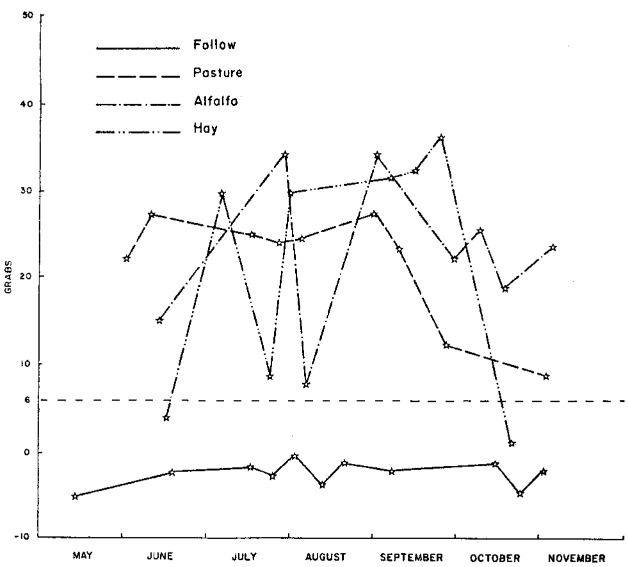

Figure 1. Fallow, Pasture, Alfalfa and Hay (Miscellaneous Sample Segments).

ing profile falls below the detection threshold at that time. If a profile remains above the threshold, planting and harvesting of the vegetation cannot be confirmed. We must assume that the profile represents a continuously green cover class. Note, however, that in order to distinguish an annual crop profile from one in this category, at least one acquisition must be available from the period during which the crop is not green.

This category potentially includes vegetation types that occupy the same site for more than a single growing season, such as range and other unimproved grasslands, brush, pasture, alfalfa and trees. However, such factors as winter dormancy and hay mowing, if they occur during the time period covered by the profile, may result in GRABS values below the detection threshold. If so, the profile will not be eliminated at this point.

Figure 1 illustrates two representative profiles: pasture and alfalfa. They are substantially different in overall form. The feature common to both is their location relative to the detection threshold.

More Than One Vegetated Period. An annual crop is planted and harvested during a single growing season. If a field contains only one such crop in a season, the corresponding profile should be above the detection threshold during a single continuous time period when the crop is green. This period should be preceded and followed by periods during which the profile is below the threshold, corresponding to the pre-emergence and post-harvest stages when the field contains only bare soil or residue.

If a profile is above the detection threshold during more than one discontinuous time period, any one of a number of situations may be responsible. The first that should be investigated is the possibility of acquisition-to-acquisition misregistration. In order for a profile to be valid for crop identification purposes, the multidate sample from which it is generated must be drawn from a pure target that is precisely registered across all acquisitions. Otherwise, the profile will be a meaningless composite of two or more crops. Similarly, atmospheric phenomena that are not removed through normalization, e.g., clouds and accompanying shadow, will confound the form of the profile. The existence of these conditions can be verified from imagery.

Assuming that external factors are not involved, the profile may represent alfalfa or another hay crop that has been cut at least once in midseason. In this case, the discontinuity of the vegetated periods would be a result of mowing, which severely reduces the green vegetation canopy and leaves dry residue on the surface of the field. To determine whether a profile is alfalfa, we must compare the time period(s) during which the profile drops below the threshold to the time period(s) during which we expect mowing to take place (a crop calendar can be used to make this comparison). If there is no correspondence, other potential explanations must be investigated. These will be considered under Variant Annual Crop Profiles below.

Alfalfa and hay profiles are illustrated in Figure 1. Had the profiles fallen a few counts lower in the late July/early August time frame, both would have belonged to this category.

Probable Annual Crop Profiles (Other Than Hay). In addition to following the non-vegetated/vegetated/non-vegetated sequence described above, most annual crop profiles have a characteristic overall form that is related to the sequence of crop development stages through which most crops pass: (1) the profile rises above the threshold as the crop emerges and becomes spectrally detectable; (2) the vegetation indicator values increase continuously as the soil background is increasingly obscured by the expanding green canopy; (3) a maximum value, or peak, is reached as the crop reaches maximum green canopy development and the onset of reproduction; (4) the values decrease gradually to rapidly during seed filling as the crop progresses toward maturity; and (5) the profile falls below the threshold at harvest maturity or harvest. Although the exact form may vary depending on the crop and the acquisition history, the profile is generally a single "smooth" curve with a single peak. A profile that fluctuates sharply (more than a few counts) up and down, such as the hay profile in Figure 1, must be evaluated against the possibilities that are considered in the preceding category.

The profiles that appear in Figures 2 and 3 follow the general trajectory described above. The values in between actual observations have been manually interpolated to represent more accurately the specific shape of each profile. Note that although all of these profiles have the general form that is characteristic of annual crops, not all of them represent cover classes that belong to the annual crop category. This problem is addressed in Level Two.

Variant Annual Crop Profiles. In humid areas like the central Corn Belt, a

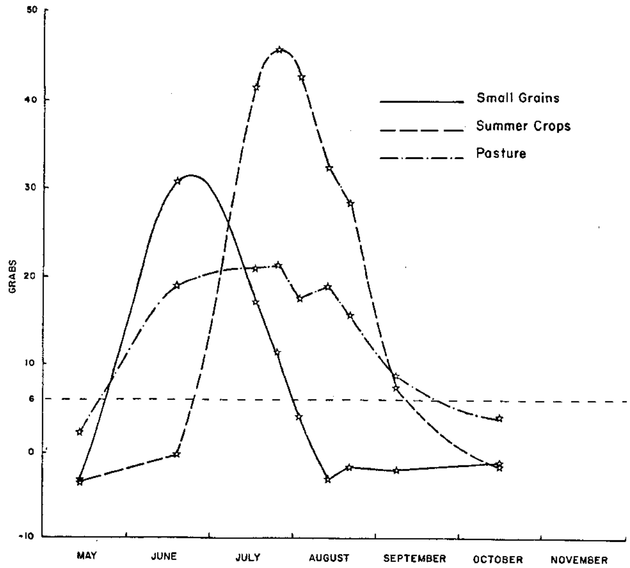

Figure 2. Small Grains, Summer Crops and Pasture (185, Traverse, Minnesota).

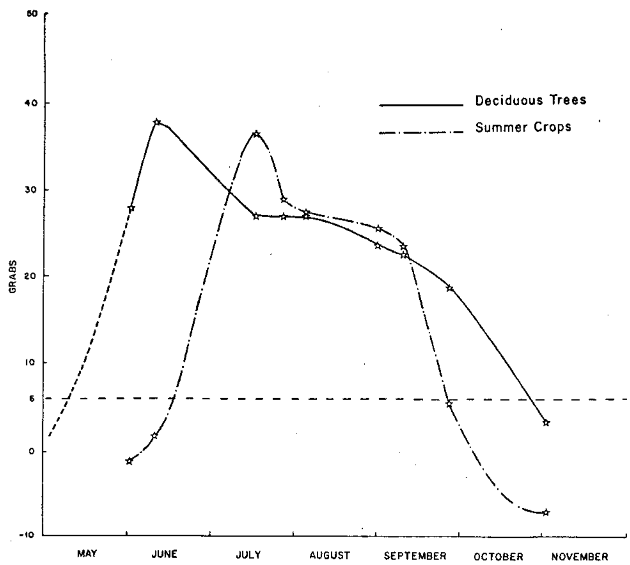

Figure 3. Summer Crops and Deciduous Trees (127, Montgomery, Indianna).

field may be occupied by more than one vegetation type during a single growing season. The possibilities include: (1) an annual crop preceded and/or followed by volunteer vegetation; (2) an annual crop following another annual crop that failed early in its development cycle; and (3) two consecutive annual crops, each of which completed a full development cycle (double-cropping). The profiles that represent these field conditions do not follow the characteristic annual crop trajectory.

Figure 4 presents two profiles that are typical of those in this category. Profile A has two vegetated periods, one major and one minor. The major vegetated period corresponds to the presence of an annual crop, and the profile during this time has the appropriate general form. The period in between, during which the profile is below the threshold, can be attributed to field preparation activities. Profile B represents a probable double-cropping situation. The profile has two local maxima separated by values that approach the detection threshold. Each of the two major portions of the profile resembles an annual crop curve, and it is reasonable to assume that two crops could be grown during the time periods indicated.

B. LEVEL TWO: CROP GROUP

In the Corn Belt, each annual crop is associated with a specific part of the growing season. Actual planting and harvest dates vary from year to year as well as from field to field. However, general temporal relationships among crops tend to remain constant. Certain crops grow during such similar periods of time that they are often grouped together for analysis purposes. Winter wheat and rye form the winter small grains group; spring wheat, barley and oats make up the spring small grains group; and corn, soybeans, sunflowers and sorghum, among others, fall into the summer crops group.

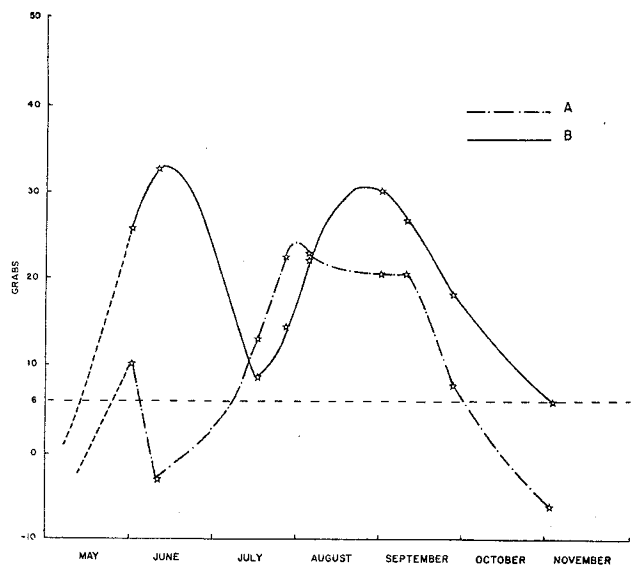

Figure 4. Variant Annual Crop Profiles (127, Montgomery, Indiana).

In this section we discuss the features that distinguish crop group profiles from one another. Only profiles that have the characteristic annual crop form (or variant form) are considered at this level. Included are profiles that do not belong to the annual crop category but could not be identified as such on the basis of general curve form.

Winter Small Grains, Spring Small Grains, Summer Crops. Profiles in these groups are largely separable from one another based on the timing of the non-vegetated/vegetated/non-vegetated sequence described in Level One. Although a crop calendar is required to determine precise local relationships, the following patterns may be used as a rule of thumb.

A small grain greens up and is harvested earlier in the season than a summer crop. Accordingly, the period during which a small grain profile is above the detection threshold begins earlier than that of a summer crop profile, and it ends while the summer crop profile is still above the threshold.

A winter small grain is planted in the previous fall and goes through a period of vegetative growth before winter dormancy. This will not be detected from the profile using the time axis that we have selected for this paper. However, the winter small grain greens up again in early spring. The time at which this occurs, along with the time of harvest, may be sufficiently ahead of that of a spring small grain to permit the separation of the two categories on this basis.

The profiles in Figure 2 were all obtained from the same sample segment; hence, the temporal relationships that are illustrated represent actual crop calendar differences in one locality. In order to separate the small grain and summer crop based on temporal pattern alone, we would require, at the minimum, one acquisition from each time period during which one crop is green and the other is not. In this example, the requirement would be filled by the mid-June acquisition and one of those in mid-August.

Perennial Vegetation. Perennial vegetation classes, such as pasture, are green throughout both the small grain and summer crop growing periods. Green-up takes place in the spring as the vegetation comes out of winter dormancy, and senescence takes place in the fall. Hence, the duration of the vegetated period is much greater than that of an annual crop. Accordingly, a perennial vegetation profile rises above the detection threshold as early as, or earlier than, a small grain profile and falls below the threshold as late as, or later than, a summer crop profile.

The pasture profile in Figure 2 illustrates this relationship. If we look at the two time periods from which acquisitions are required to separate the small grain and summer crop profiles, we see that the pasture profile is above the threshold during both.

Deciduous Trees. The summer crop and deciduous tree profiles in Figure 3 bear a superficial resemblance to one another based on overall form. Trees are perennial vegetation, however, and as such they have a longer vegetated period than that of the average annual crop. In addition, a tree profile has a very definite peak that is apparently correlated with the emergence of the new leaves. This peak occurs earlier than that of the earliest summer crop.

C. LEVEL THREE: CROP TYPE

In Level One it was established that vegetation indicator values vary as crops pass through a series of development stages, creating an overall profile form that is characteristic of annual crops in general. In this section we discuss how these values vary from crop to crop as well, resulting in specific profile forms that are characteristic of individual crops. Only profiles in the summer crop group are considered from this point on.

Corn, Soybeans. Corn has a very distinctive profile form, which is illustrated in Figure 5. The profile reaches a peak relatively early in the crop's development cycle, approximately two weeks prior to tassel emergence according to recent work by E. Crist.[4] Contrary to expectations, this occurs before the maximum green canopy development has been achieved. Following the peak, the profile drops slightly and then levels off during seed filling, creating a "plateau". The profile falls toward the detection threshold once again at physiological maturity as the foliage turns. The maximum amplitude of the corn profile is variable, but it rarely exceeds a value of approximately 35.

The soybean profile generally has a sharper, steeper appearance than that of corn (see Figure 5). Unlike corn, the peak appears to coincide with maximum canopy closure.[4] Since vegetative growth in indeterminate Corn Belt soybeans continues until flowering is completed, the peak occurs well into the crop's development cycle. The soybean profile tends to reach a higher maximum amplitude than corn, which has a less dense, more highly shadowed canopy.

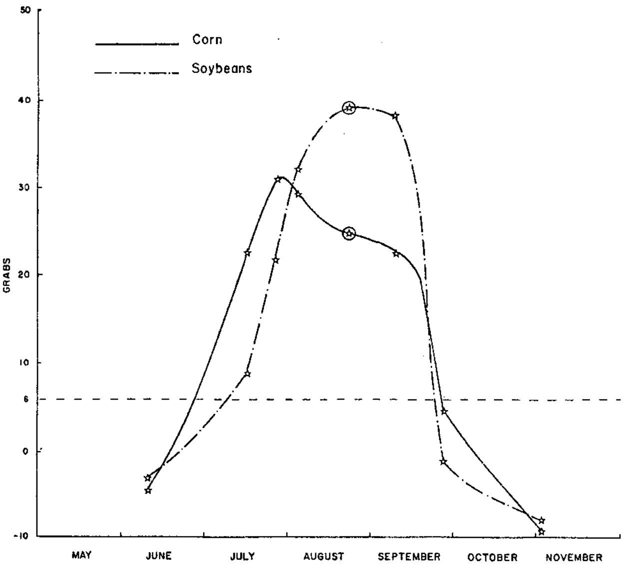

Figure 5. Corn and Soybeans (854, Tippecanoe, Indiana).

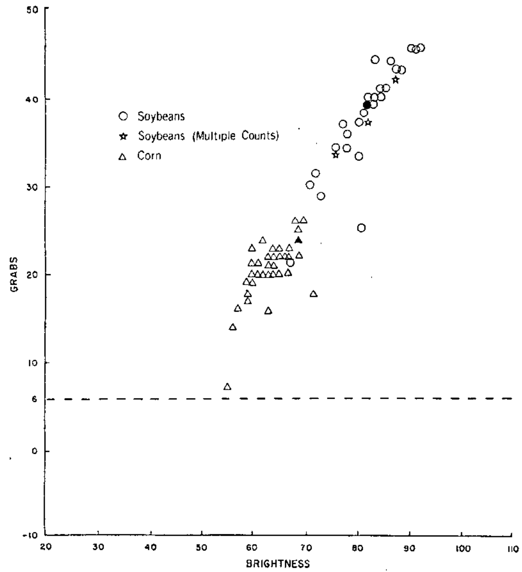

Figure 6. Corn/Soybeans Separability on August 22 (854, Tippecanoe, Indiana).

Maximum amplitude alone accounts for much of the separability between corn and soybeans. The maximum amplitude of a profile must be evaluated relative to that of other profiles, since regional variability discourages the establishment of a permanent discriminant threshold (a scatterplot, such as that in Figure 6, is a useful tool for this evaluation). Note that if a soybean profile does not reach a relatively high value, it cannot be accurately identified based on this feature.

The separation of corn from soybeans is further enhanced by the difference in the time at which the maximum amplitude occurs. Since this tends to be somewhat later for soybeans than for corn, this means that the maximum values of a soybean profile tend to coincide with the less-than-maximum values of the plateau period in a corn profile. Hence, the difference between the soybean and corn values is greater than it would be if maximum values from each were compared. This is illustrated by Figure 6, which corresponds to the date of the circled observations in Figure 5 (the location of these observations in the scatterplot is indicated by the solid symbols). Even if a soybean profile does not reach a high value, it is likely to be higher than that of corn in this later time period. Without acquisitions at this time, it is very difficult to distinguish between the two crops.

Due to a variety of factors such as plant stress, sparseness of canopy, etc., a soybean profile may not reach an amplitude that is greater than that of corn at any time. If the acquisition history is sufficient, the profile may still be identifiable based on overall form. However, if the observations that define the beginning of the corn plateau are missing, corn profiles will have a similar appearance. As a result, a soybean profile of low amplitude is likely to be labeled as corn.

Other Crops. The profiles in Figure 7 were all drawn from the same sample segment. They include two additional summer crops: sugar beets and sunflowers. The sugar beet profile is characteristic of this part of the country, where beets are harvested before flowering takes place. The profile rapidly reaches a value that remains fairly constant over the growing season, then drops abruptly as the beets are topped and lifted. Sunflower profiles, on the other hand, appear to be highly variable, even within a single locality. There is some question at the present time as to whether the information contained in the profile alone will be sufficient for the accurate identification of this crop. Two sunflower profiles are illustrated in Figure 7. One has a relatively high amplitude and bears some resemblance to the soybean profile. The other has a lower amplitude and bears a distinct resemblance to the corn profile.

IV. SUMMARY

The temporal-spectral profile contains information to support crop identification at various levels. Annual crop profiles have a characteristic general form that is related to the sequence of development stages through which most crops pass. Profiles with this form can be sorted into crop groups based on temporal relationships that reflect crop calendar differences. Finally, the amplitude and specific form of the profile provide the key for refining a label to the crop type level.

Some caveats must be attached to the use of profiles. As we have seen, the overall appearance of a profile is highly dependent upon acquisition history. If key observations are missing, discriminating features may not be detected. Furthermore, if the labeling target is misregistered on any acquisition, the resulting profile will be inaccurate. These are generic difficulties related to multitemporal Landsat data, regardless of the form.

On the positive side, profiles enable us to analyze the data in its original form. The profile can be represented graphically for the human analyst, or it can be evaluated directly by the computer using objective, pre-determined criteria. Revised versions of the baseline procedure employ both methods.[5,6] Alternative approaches use mathematical techniques to describe and compare curve forms. All are based on the underlying patterns and principles that have been described in this paper.

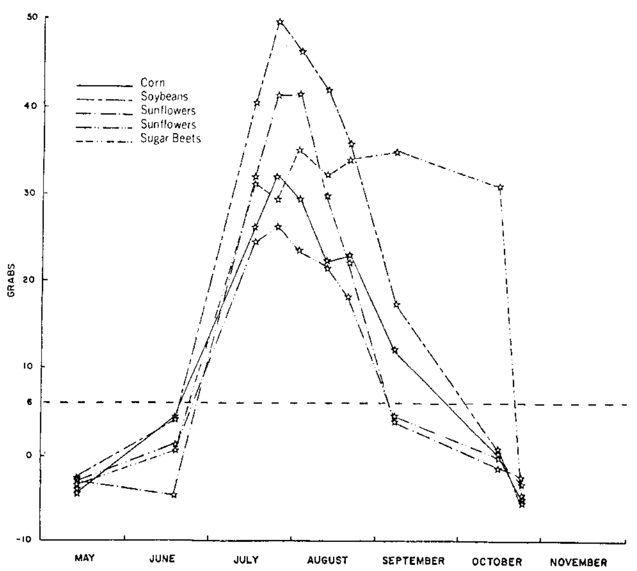

Figure 7. Corn, Soybeans, Sunflowers and Sugar Beets (185, Traverse, Minnesota).

V. ACKNOWLEDGMENTS

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VI. REFERENCES

1. Kauth, R., P. Lambeck, W. Richardson, G. Thomas, and A. Pentland, 1979. "Feature Extraction Applied to Agricultural Crops as Seen by Landsat", in The LACIE Symposium, JSC-16015, Johnson Space Center, Houston, Texas.

2. Cicone, R., C. Hay, R. Horvath, M. Metzler, O. Mykolenko, J. Odenweller, and D. Rice, 1981. Users Manual for the U.S. Baseline Corn and Soybean Segment Classification Procedure, FC-E1-00712, Ann Arbor, Michigan.

3. Hay, C., C. Kuretz, J. Odenweller, E. Sheffner, and B. Wood, 1979. Development of AI Procedures for Dealing with the Effects of Episodal Events on Crop Temporal Spectral Response and Development of AI Guidelines for Corn and Soybean Labeling, Final Report for NASA Contract NAS9-14565, SSL Series 20, Issue 44, Berkeley, California.

4. Crist, E., 1982. "Field Measurement Data Analysis", presentation at the AgRISTARS March ITD Quarterly Technical Interchange Meeting, Johnson Space Center, Houston, Texas.

5. Roller, N., K. Johnson, J. Odenweller, and C. Hay, 1981. Analyst Handbook for the Augmented U.S. Baseline Corn and Soybean Segment Classification Procedure, FC-E1-00723, Ann Arbor, Michigan.

6. Metzler, M., 1982. "Investigation of Automatic Area Estimation with Landsat", presentation at the AgRISTARS March ITD Quarterly Technical Interchange Meeting, Johnson Space Center, Houston, Texas.

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