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E81-10167

CR-160983

2. # AgRISTARS

7. SR-L1-04054
JSC-17128

APR 15 1981

NASA CR-160983

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

Supporting Research.

5. NAS 9-15800

6. March 1981

A TEMPORAL/SPECTRAL ANALYSIS OF SMALL GRAIN CROPS AND CONFUSION CROPS

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(E81-10167) A TEMPORAL/SPECTRAL ANALYSIS OF SMALL GRAIN CROPS AND CONFUSION CROPS (Lockheed Engineering and Management) 76 p HC A05/MF A01 CSCL 02C

N81-28498

Unclas

G3/43 00167

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SR-L1-04054
JSC-17128

A TEMPORAL/SPECTRAL ANALYSIS OF SMALL GRAIN CROPS AND CONFUSION CROPS

Job Order 71-318

This report describes Field Research Data Analysis activities of the Supporting Research project of the AgRISTARS program.

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LOCKHEED ENGINEERING AND MANAGEMENT SERVICES COMPANY, INC.

Under Contract NAS 9-15800

For

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

March 1981

LEMSCO-15676

PREFACE

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

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

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FIGURES

1. INTRODUCTION

The potential importance of trajectory plots or temporal spectral plots has developed since Kauth and Thomas (ref. 1) discussed the "tasselled cap" and methods for using all four Landsat multispectral scanner (MSS) channels to describe vegetation growth cycles in terms of greenness, brightness, yellowness, and "none-such" spectral properties. In this paper, only greenness and brightness are used in generating trajectory plots. Throughout this report, the greenness-brightness position (a vector) on the trajectory plot is referred to as the GB.

This report consists of case studies of temporal spectral plots which characterize the growth cycle of specified forms of vegetation and is a summary of the analyses of Landsat MSS data on field crops and land use classes for three test sites in southeast North Dakota. (See appendix A.) The MSS data were processed using ground-truth inventories in a way that each field crop and land use class in the blind sites could be related to the MSS picture elements (pixels). Thus, each field's mean pixel value which was representative of a crop or land use could be determined at each Landsat acquisition time. The analyses were performed by transforming the mean values of the four channels of the MSS data into greenness and brightness. The transformations were performed on data from 12 different field crops as well as on pasture, hay, grass, trees, and fallow ground. (See appendix B.)

Since these data were acquired within a specified area and time period, it is emphasized that the results herein are related to the particular growing season (April to August 1977) and climate. During this period, the wheat crop development in this region was considered by agriculture agents to be 10 days ahead of normal due to early warm weather followed by extremely hot weather and below normal precipitation.

These analyses were resumed and aborted using data acquired during the 1978 growing season, at which time the climate was characterized by a wet spring that delayed planting. The Landsat data acquisition histories were poor throughout this region due to excessive cloudiness during the growing season; therefore, relatively few spectral data sets were available for a temporal analysis.

This study was undertaken to (1) examine crop signatures as determined by the trajectory plots of GB, (2) determine signature means and variances for crops within the test site, (3) compare crop signatures in nearby test sites, (4) associate spring wheat signatures with the ground truth, and (5) associate anomalous data with episodal events. Primarily, wheat and barley crops were designated for the case studies, but as data for other small-grain crops, field crops, and vegetative land cover became accessible, the studies were expanded to include a spectral analysis of these data. (Spectrally, some of these crops are easily confused with wheat and barley.) Some ground-truth data for 15 wheat fields were logged on days near the day of the Landsat-2 data acquisitions. This ground truth consisted of wheat plant height in inches and the percentage of ground cover by the wheat canopy. Neither the planting date nor the crop stage of growth was recorded during this particular crop year.

The test sites were completely inventoried by agriculture agents once during the year near the wheat harvest time. The agents identified each crop in all fields and outlined the areas of pasture, hay, grasses, trees, and other uses of the land in the test sites. These inventories were converted to a digitally processed form so that each acre in the test site could be related to a Landsat pixel. Thus, data specifying growth and development of wheat crops could be related to the spectral response of each of the four channels of the MSS. However, only the seasonal growth cycle of all other crops and land use could be related to the MSS data.

2. BACKGROUND OF THE ANALYSIS PROCEDURES

In order to see the Landsat-2 data in all four channels better, a linear transformation [based on the Kauth transform (ref. 1)] of the data presents the four channels as GB. These transforms are listed in appendix C.

Operationally, one of the analyst aids consists of GB trajectory plots of a single pixel at specified locations in the scene. For interpretation, the analyst associates the sequence of GB plots with the expected temporal growth stages of small grains (refs. 2 and 3). In the case of wheat, a maximum in greenness and brightness usually occurs near the booting stage, with greenness decreasing into the harvest period and brightness decreasing until about the ripening period, at which time brightness remains relatively constant until harvest. This latter characterization of brightness varies, showing sometimes a slight increase and sometimes a decrease during the period near harvest.

On each of the Landsat acquisition dates, all the pixels within any field or area are isolated and the means and standard deviations of pixels are determined for each channel. Each of these sets of channel means are used to compute a GB representative of this field or land use. Thus, from the series of acquisitions, the pairs of computations provide GB plots. The characteristic forms of these trajectory plots are the basis for discussion in the following case studies.

The software used in performing the functions described in the preceding paragraph was developed by G. Badhwar of the NASA Johnson Space Center. The IMADAT$ routine combines all the acquisitions for a segment with its ground-truth file. The SCANA$ routine extracts channel data for a specified crop code within an area specified. The FSDEV$ routine converts channel data to means and standard deviation. The PLOT15$ is a plot routine capable of plotting temporal channel data, ratio data, transformations, and trajectory plots.

3. CASE STUDY NO. 1: SPRING WHEAT

3.1 DISCUSSION

During the crop year 1976-77 [Large Area Crop Inventory Experiment (LACIE), Phase III], the agriculture agent did not record the crop stage of the growth of wheat during periodic visits to the special wheat fields; however, he did record the plant height and crop coverage. This record gives a reasonable indicator by which spectral data can be compared to a crop stage of growth.

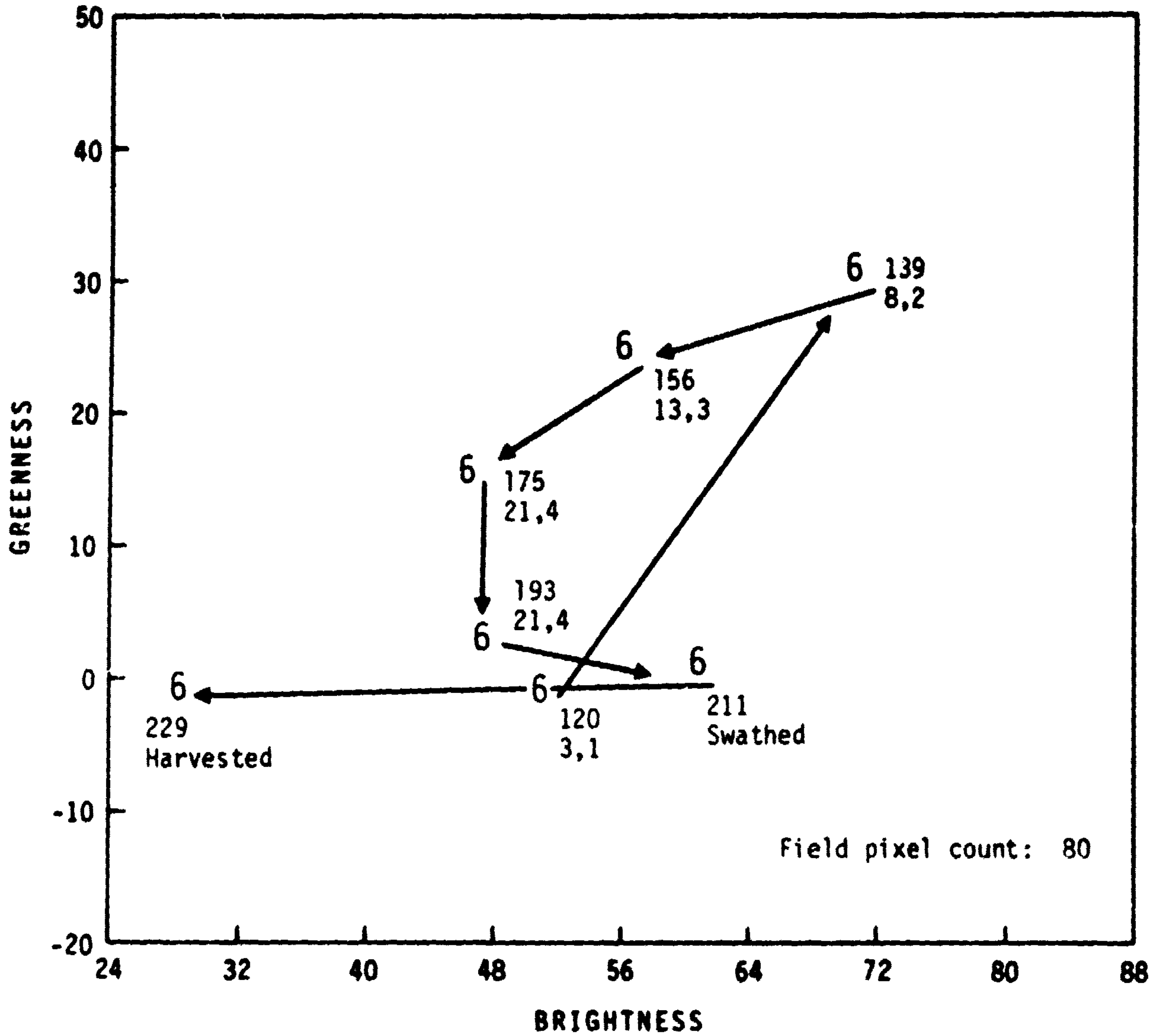
In most cases, comparative values of the plant height indicate which fields were planted earlier or later than the average.

Figures 1 and 2 are the GB plots for fields 6 and 8, respectively, in test site 1663. Field 6 was recorded as having a 3-inch growth on day 120, whereas the wheat in field 8 had not emerged yet. Thus, field 6 was considered early planted, and field 8 was considered late planted. The difference in the profiles is quite marked as the GB of field 6 peaked on day 139, whereas the GB of field 8 peaked on day 156. It is interesting to note that both field 6 and field 8 were harvested about the same time and both fields were reported as swathed on day 211. Thus, the plant height data are used to categorize the wheatfields as an early or late planted field. The results obtained here are compatible with those referred to in the report by Badhwar (ref. 4) in which the crop-emergence date is determined from the spectral profile.

When the GB values of each set of the early- and late-planted fields are averaged and a standard deviation is calculated, an average GB profile for wheat in the segment is established. Figure 3 shows the average GB profile for wheat fields in segment 1663. The GB plot positions of the early planted fields precede the plots of the late planted fields in a very predictable fashion through all stages of crop growth development. The standard deviation data are listed on figure 3 and indicate considerable variability of GB among the fields. The variability can be attributed to multiple causes: differences in planting dates, types of soil, moisture availability, crop stress differences, wheat genus, and fertilization programs.

A few scattered clouds occurred on day 193. Figure 4 illustrates the effect of cloud cover over field 11 where the brightness value of 74 is recorded.

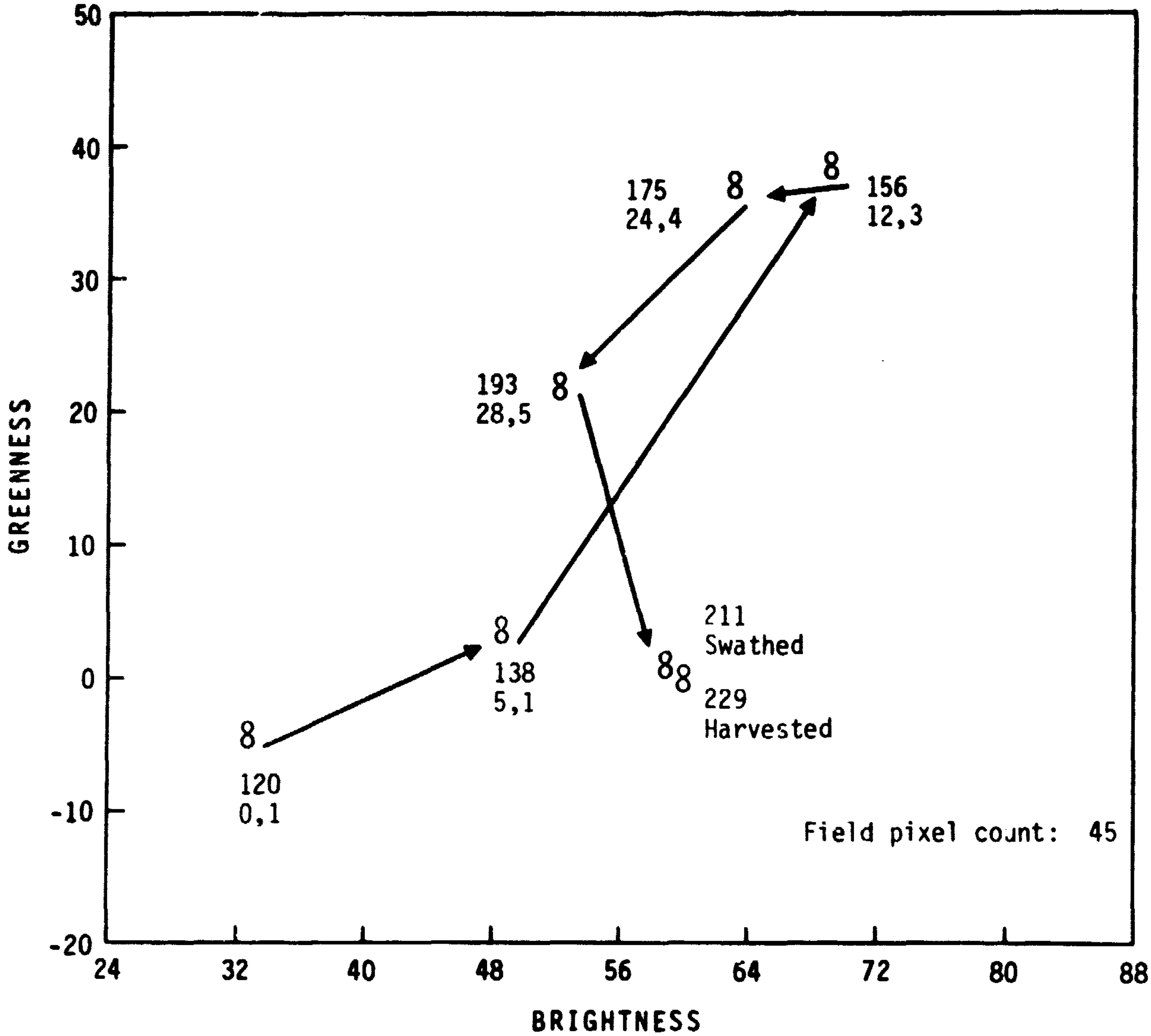
In figure 5, anomalous data are seen in the plot of field 5 on day 139. The study of the imagery does not indicate a cause for a shift of brightness to higher values (i.e., no apparent clouds). An examination of the channel data indicates that channels 1 and 2 have unusually high values while channels 3 and 4 have expected values. This is shown in figures 6 and 7, temporal plots of



PLOT LEGEND

X Field number
ddd Day of year in 1977
H,C Plant height (inches), coverage code = C × 20 = %

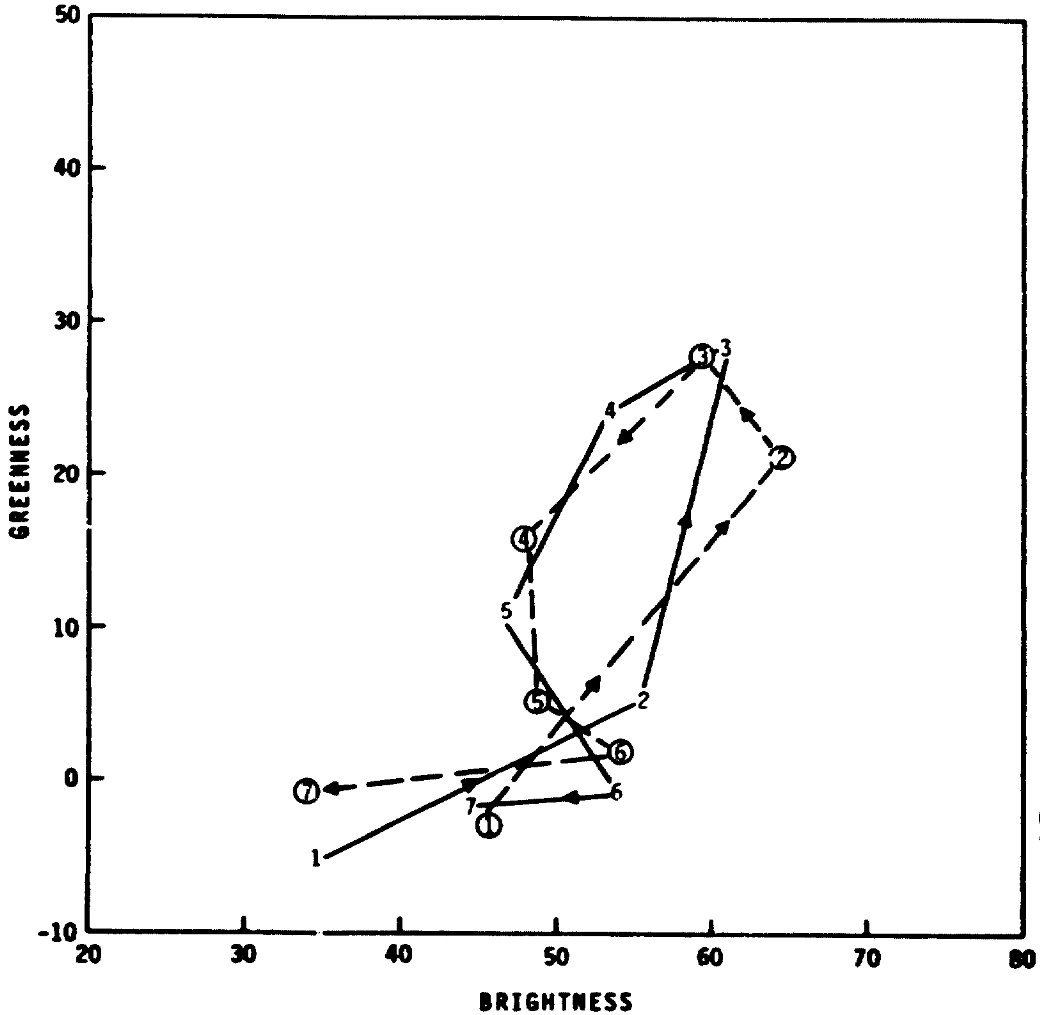
Figure 1.- Greenness-brightness plot for wheat field 6 in segment 1663; an example of an early plant.



<u>PLOT LEGEND</u>

X Field number
ddd Day of year in 1977
H,C Plant height (inches), coverage code = C × 20 = %

Figure 2.- Greenness-brightness plot for wheat field 8 in segment 1663; an example of a late plant.



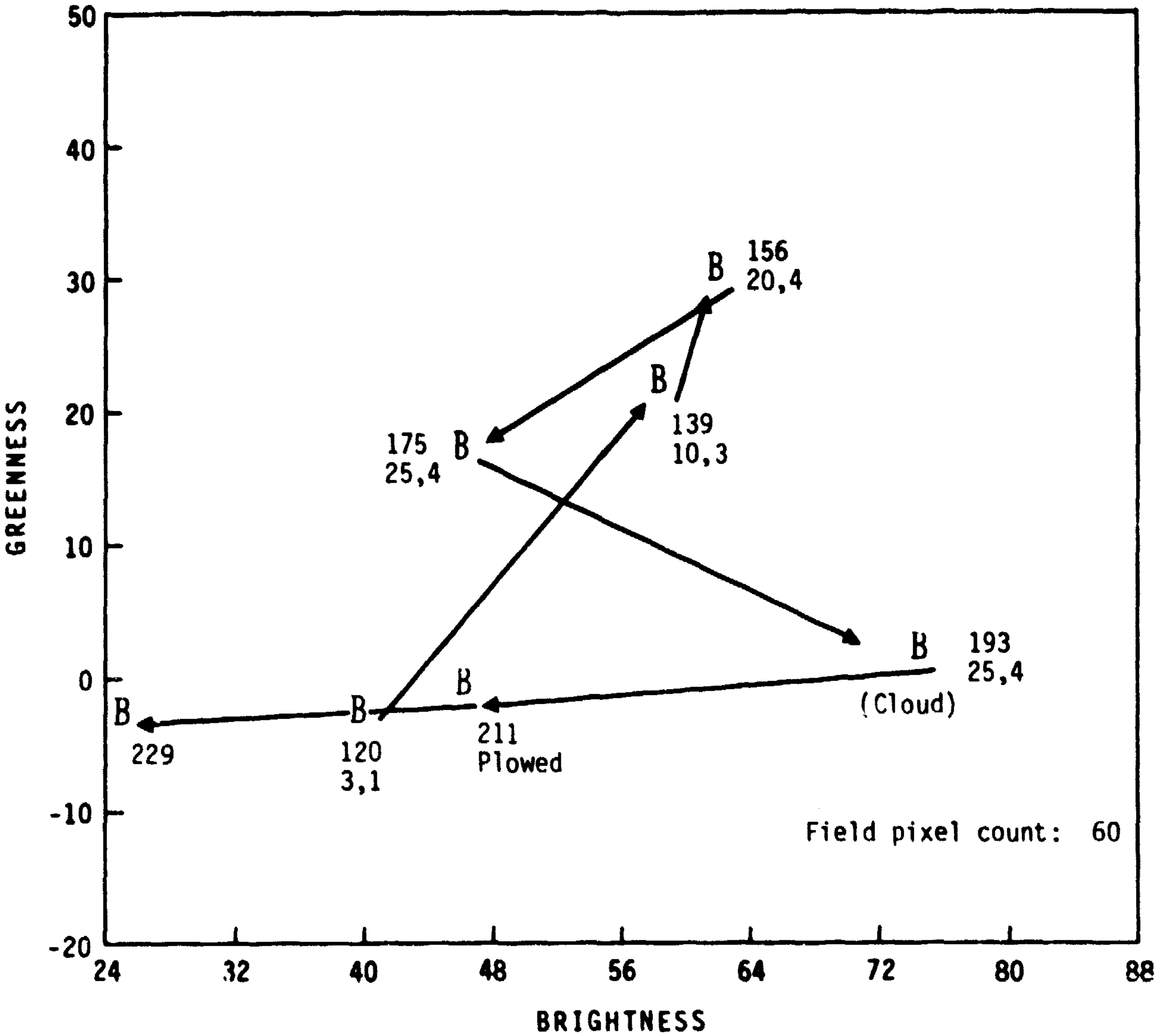
Plot	Day	Standard deviation			
		Early plant (6 fields)		Late plant (9 fields)	
		Gr.	Br.	Gr.	Br.
1	120	1.8	4.3	0.9	3.0
2	139	8.6	5.2	4.1	8.4
3	156	5.0	3.3	4.8	4.6
4	175	4.7	2.8	5.7	5.2
5	193	2.5	2.2	4.9	8.2
6	211	0.3	7.6	0.9	10.5
7	229	5.3	9.2	1.3	12.5

Note: Most wheat fields had been or were being harvested on day 211, plot 6.

Field pixel count: 81, 32, 90, 39, 53, 80, 52, 45, 24, 37, 60, 100, 122, 57, 22

6 cases: average early SW ---O---O---
3 cases: average late SW ——— ——— ———

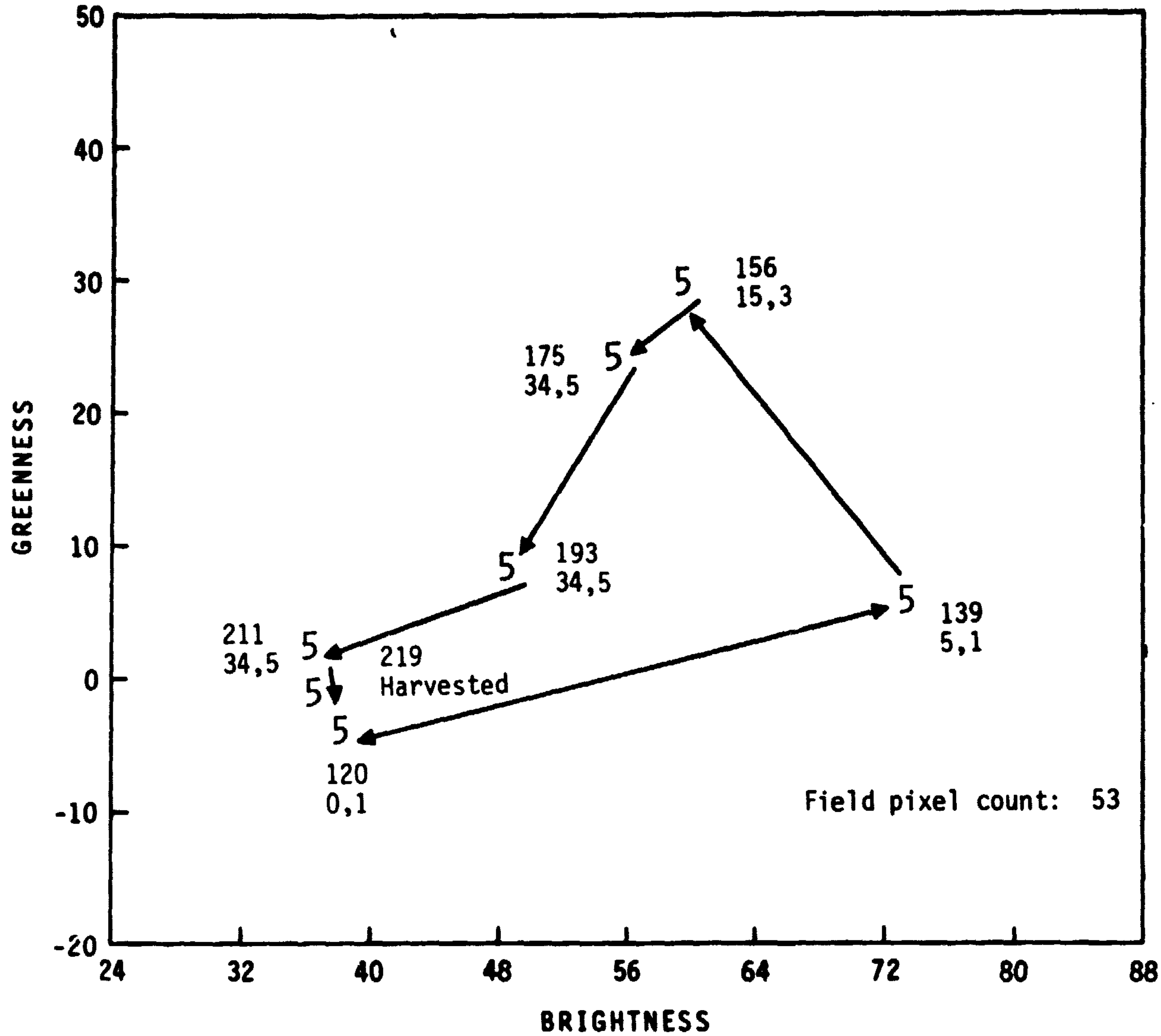
Figure 3.- Average greenness-brightness profiles of early and late planted wheat fields in segment 1663.



PLOT LEGEND

X	Field number
ddd	Day of year in 1977
h,C	Plant height (inches), coverage code = C × 20 = %

Figure 4.- Greenness-brightness plot for wheat field 11 in segment 1663; an example of cloud effect.



PLOT LEGEND

X Field number
ddd Day of year in 1977
H,C Plant height (inches), coverage code = C × 20 = %

Figure 5.- Greenness-brightness plot for wheat field 5 in segment 1663; an example with anomalous data.

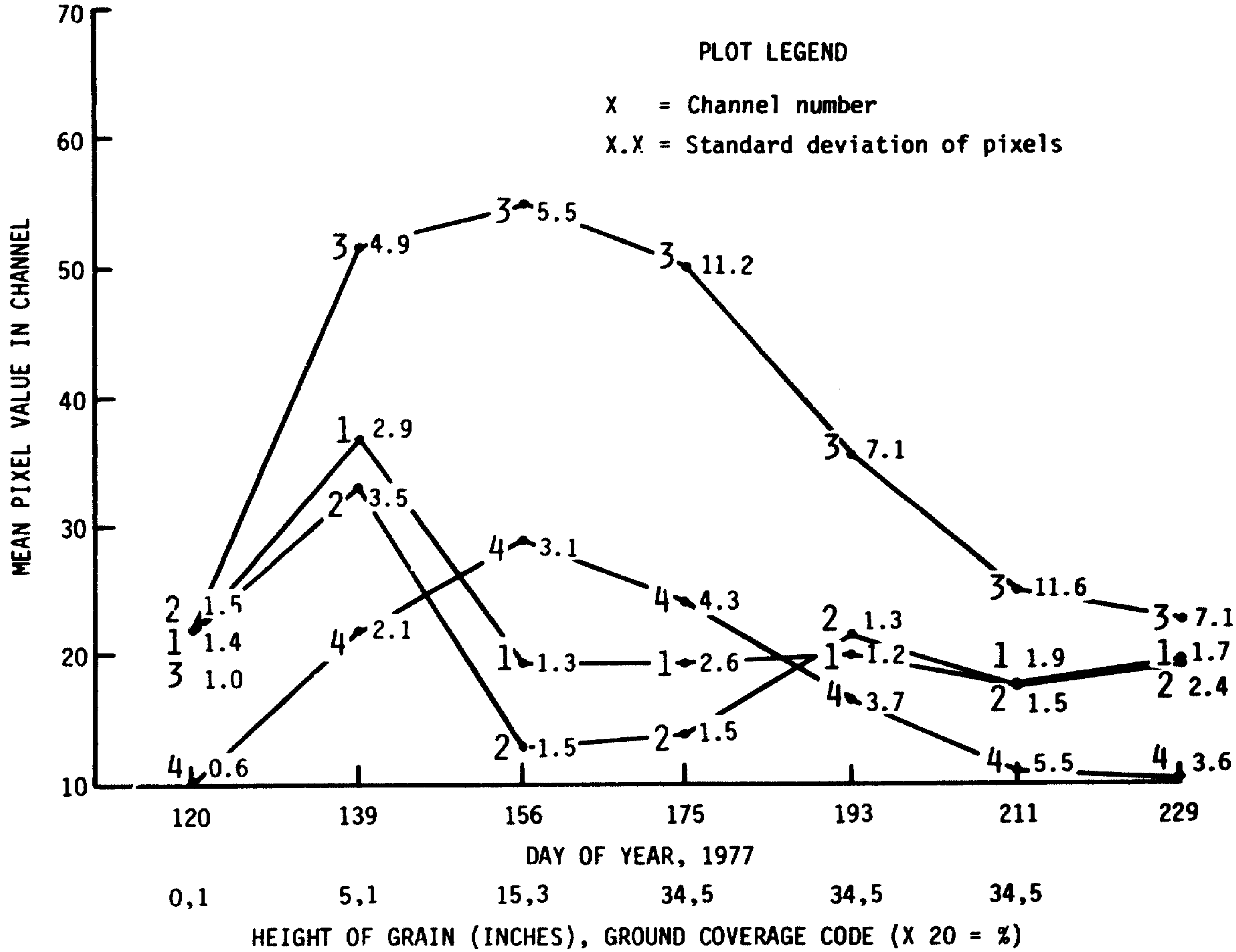


Figure 6.- Temporal plots of channel mean pixel data for wheat field 5 in segment 1663 (53 pixels); anomalous data in channels 1 and 2 on day 130.

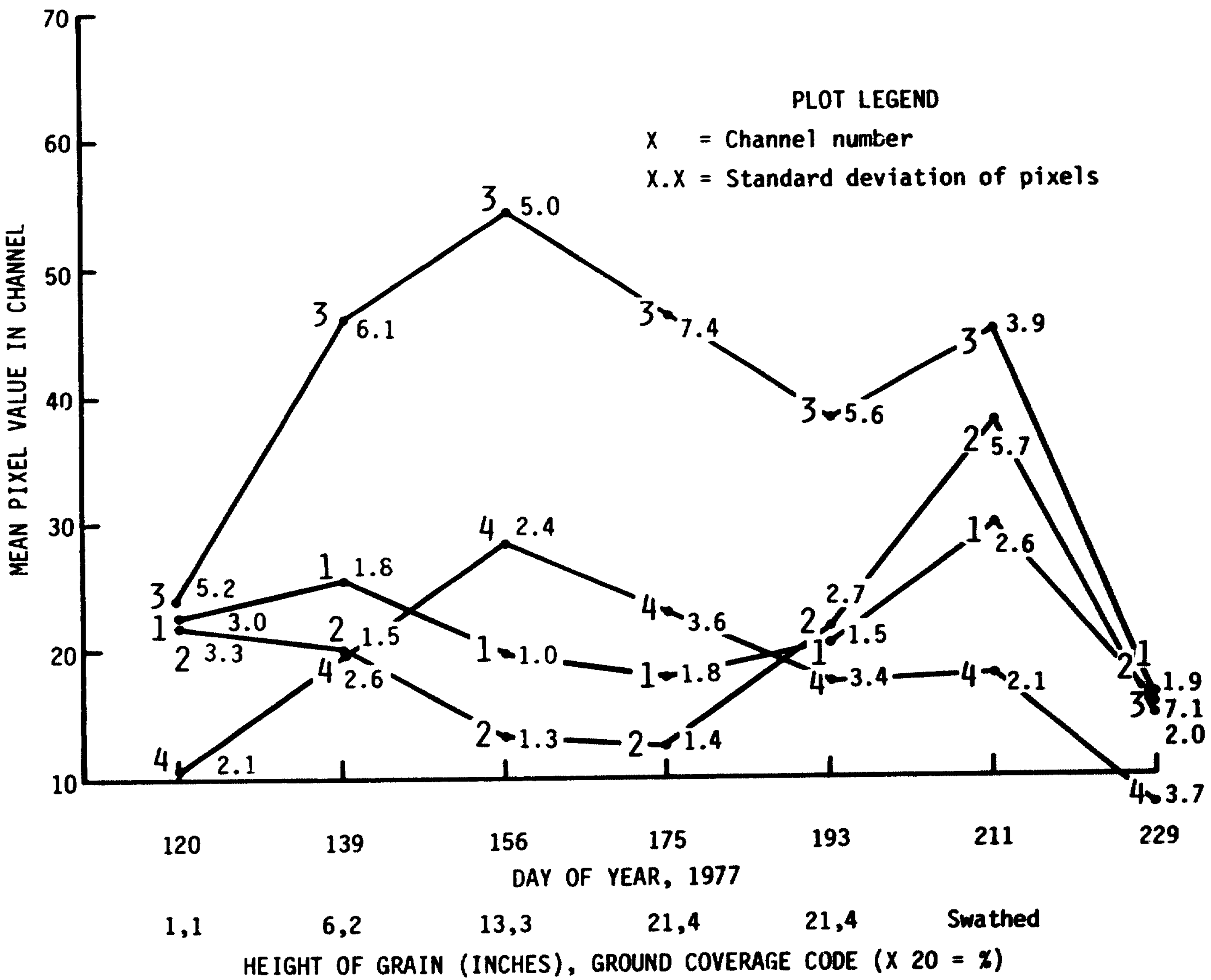
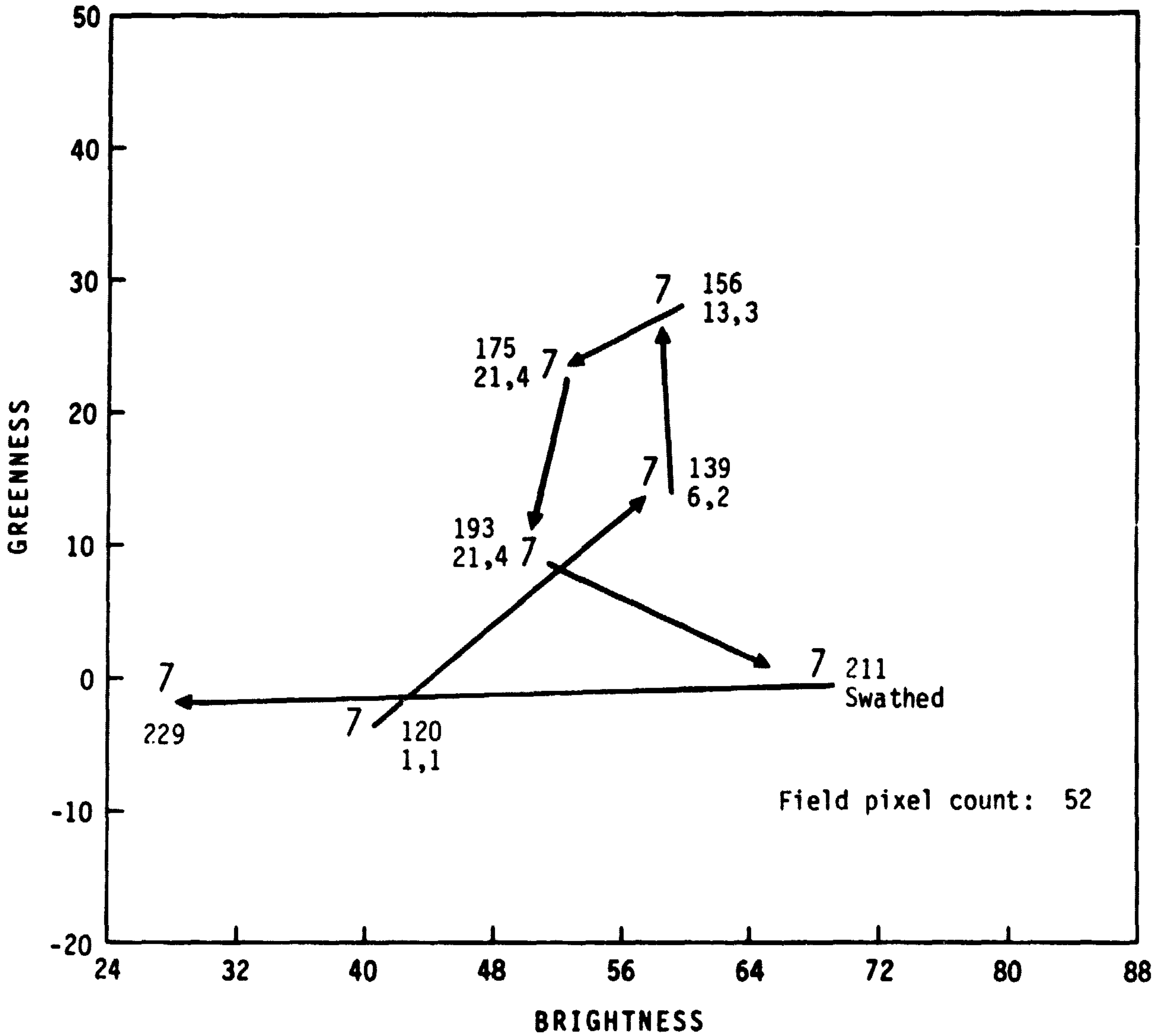


Figure 7.- Temporal plots of channel mean pixel data for wheat field 7 in segment 1663 (52 pixels).

the channel mean pixel values for fields 5 and 7, respectively. Representative of the wheat fields in test site 1663, the GB plot for field 7 is shown in figure 8.

In segment 1927, the GB plots of the wheat fields appear to be quite normal until day 193 when five of the 12 fields display anomalous profiles. Until this date, the GB maximum occurs on day 157, a date near the wheat's heading stage; the GB maximum starts its decrease by day 175. A GB plot for field 2, shown in figure 9, is representative of seven of the wheat fields and is considered a normal GB plot. Figure 10, a GB plot of field 3, is representative of five wheat fields where an anomaly occurs on day 193. The GB values are both too high, displaced from the normal GB plot. These five fields are well scattered in the test site. This displacement of GB has been noted when wheat fields were destroyed by hail; however, the periodic observation record of the fields did not reflect that such an event happened. Nevertheless, these five fields are suspected to have been damaged by hail. One other support for the hail theory is that an examination of the channel data shows that data channels 1 and 2 were not affected, whereas data in channels 3 and 4 were greatly affected. This same effect on the channel data has been noted in reported hail cases. (This perturbation of the channels should be noted to be the opposite of the atmospheric effect, where aerosol scattering and gaseous absorption significantly affect radiation transfer in the lower wave length channels). For these five fields exhibiting anomalous profiles, the hail damage must not have been severe enough to interrupt the growth cycle such that the crop could not be harvested. Because harvest yield data are not available for the individual fields, the effects of the anomaly are not known.

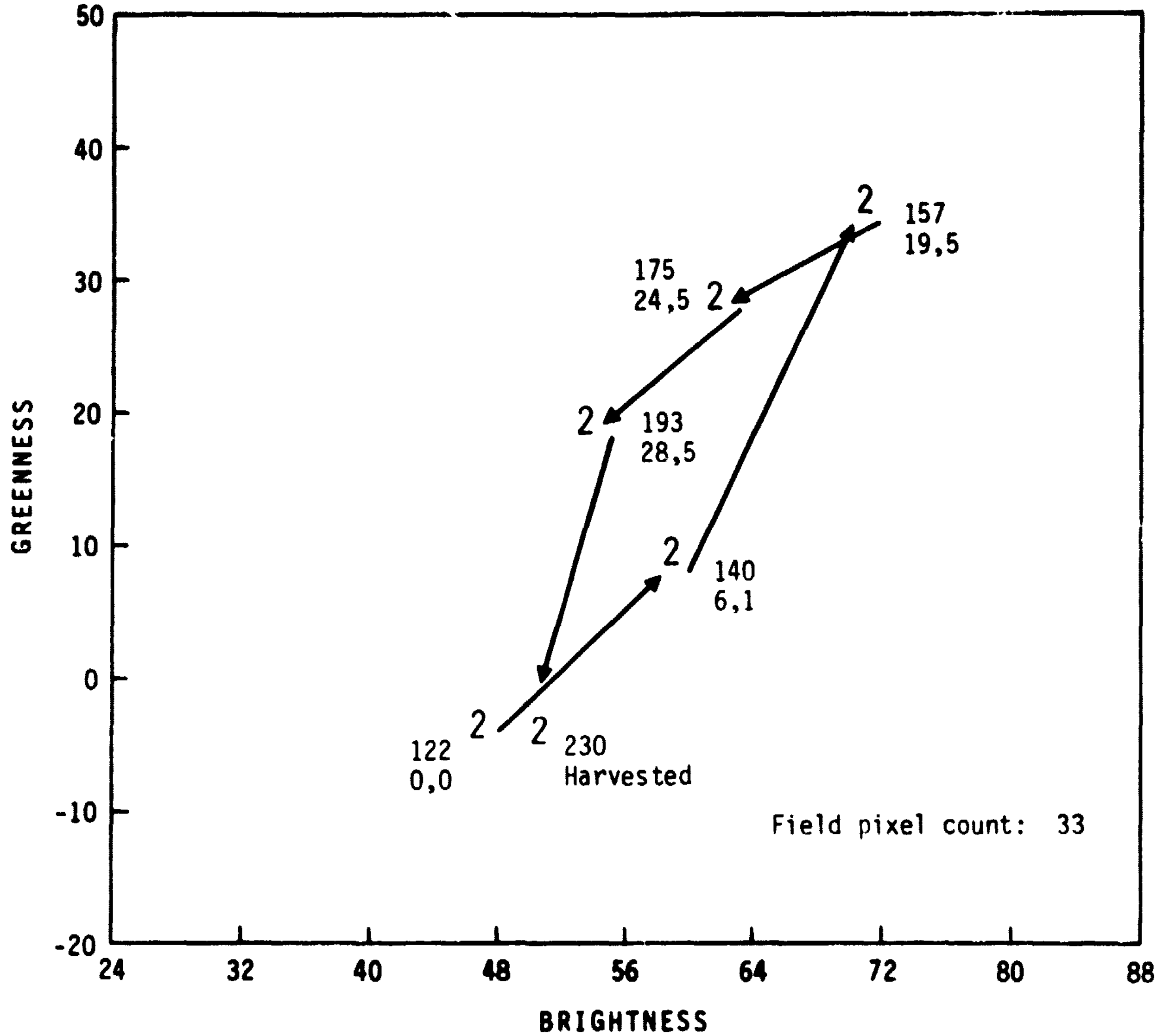
There were 12 special fields in segment 1927 which were available for study. Three were located outside the limits of Landsat image. Six of the fields could be categorized as early planted and four as late planted. The GB profile of the averages for the early planted fields differs from the GB profile of the averages for the late planted fields. (See figure 11.) The plots do not overlap very well and do not indic a common profile. The major differences occur from day 175 to day 193 when the GB values change from 25,61 to 10,50 on



PLOT LEGEND

X Field number
ddd Day of year in 1977
H,C Plant height (inches), coverage code = C × 20 = %

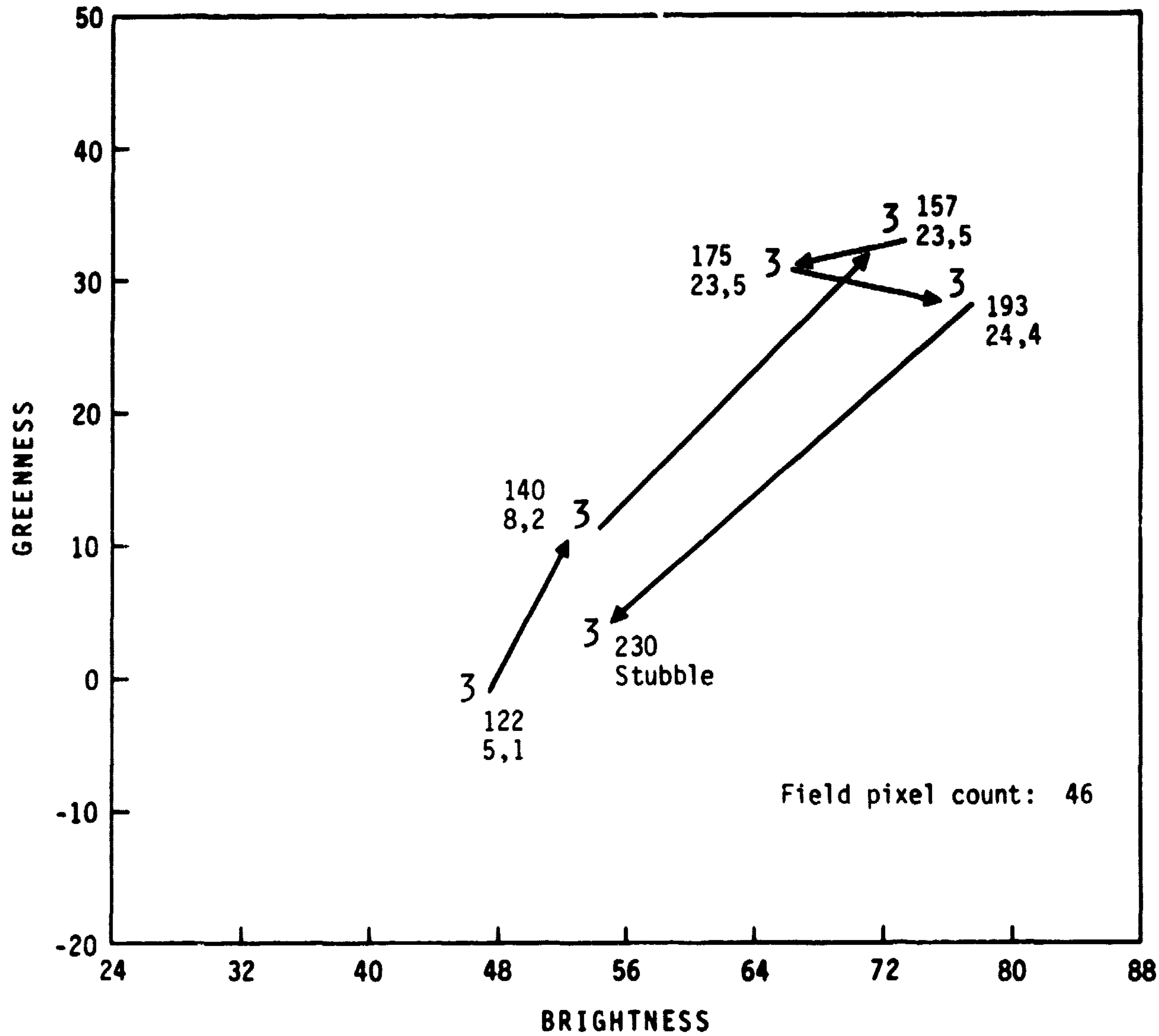
Figure 8.- Greenness-brightness plot for wheat field 7 in segment 1663.



PLOT LEGEND

X Field number
ddd Day of year in 1977
H,C Plant height (inches), coverage code = C × 20 = %

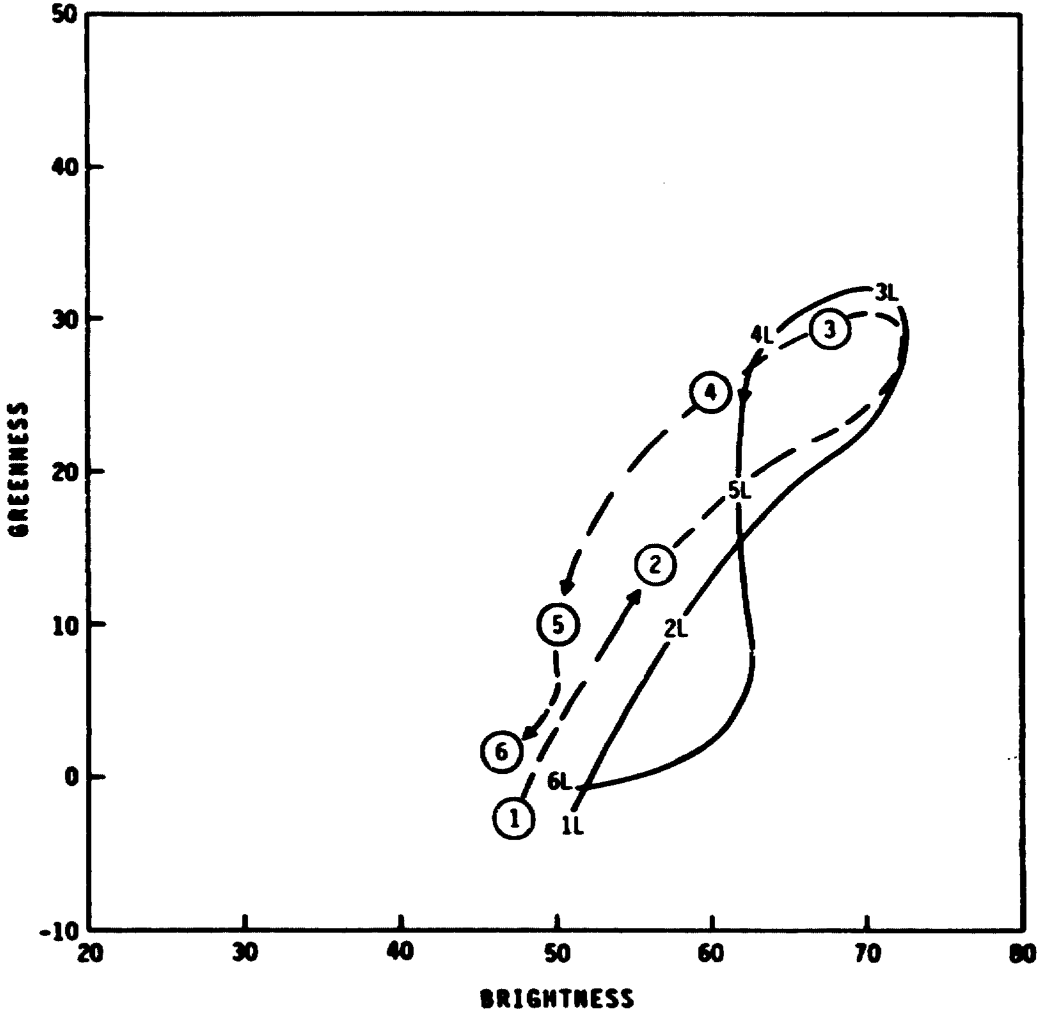
Figure 9.- Greenness-brightness plot for wheat field 2 in segment 1927.



PLOT LEGEND

X Field number
ddd Day of year in 1977
H,C Plant height (inches), coverage code = C × 20 = %

Figure 10.- Greenness-brightness plot for wheat field 3 in segment 1927; anomalous data on day 193.



Plot	Day	Standard deviation			
		Early plant (6 fields)		Late plant (4 fields)	
		Gr.	Br.	Gr.	Br.
1	122	5.5	2.2	2.5	5.2
2	140	3.2	5.2	6.3	8.6
3	157	3.3	2.8	3.0	1.7
4	175	4.0	2.3	3.1	2.5
5	193	4.4	10.4	5.9	6.8
6	230	1.8	3.0	2.2	4.5

Inventory: day 210

Note: On day 210, all fields were harvested or were being harvested.

Field pixel count: 16, 33, 46, 48, 13, 24, 10, 21, 17, 71

6 early fields O---O---O
4 late fields ——— ———

Agriculture agent comment: Crop 10 days ahead due to lack of moisture; early warm, then extremely hot weather.

Figure 11.- Average greenness-brightness profiles of early and late planted wheat fields in segment 1927.

the early profile and change from 28,63 to 18,61 on the late profile. Since the two categories of fields contain the anomalous data from fields allegedly damaged by hail, the day 193 plots should be ignored.

Examination of the periodic crop height data for the 13 fields[1] of segment 1640 provided the following: three fields could be categorized as late planted and four fields as early planted. The averaged GB plots of both early and late planted are shown in figure 12. The profiles of the two plots do not overlay exactly, but the position around the loop is consistent with the wheat growth profile. Note that satellite data on a critical time plot, day 157, are missing; these data would have established a maximum GB position of the profile. Significant differences can be seen when comparing the segment 1640 profile (fig. 12), the segment 1663 profile (fig. 3), and the segment 1927 profile (fig. 11). For instance, on day 175 the early and late greenness values are 29 and 28, respectively, for segment 1640; 25 and 28 for segment 1927; and 16 and 24 for segment 1663. The maximum GB values for the 1640 profile is near 38 and 73; for the 1927 profile, near 32 and 72; and for the 1663 profile, near 30 and 66. These three segments fall within a 100-mile circle; therefore, it is surprising to see such a dramatic difference in GB values. It is evident that more detailed information for the segment as well as for each special wheat field is required to be related to the spectral data.

3.2 SUMMARY

The four channels of spectral data from Landsat at the 18-day interval of observation are adequate to provide a GB profile representative of the spring wheat growth cycle within a specified segment. By comparing the GB plots within a segment, it can be established which field has the more advanced growth stage on a particular date.

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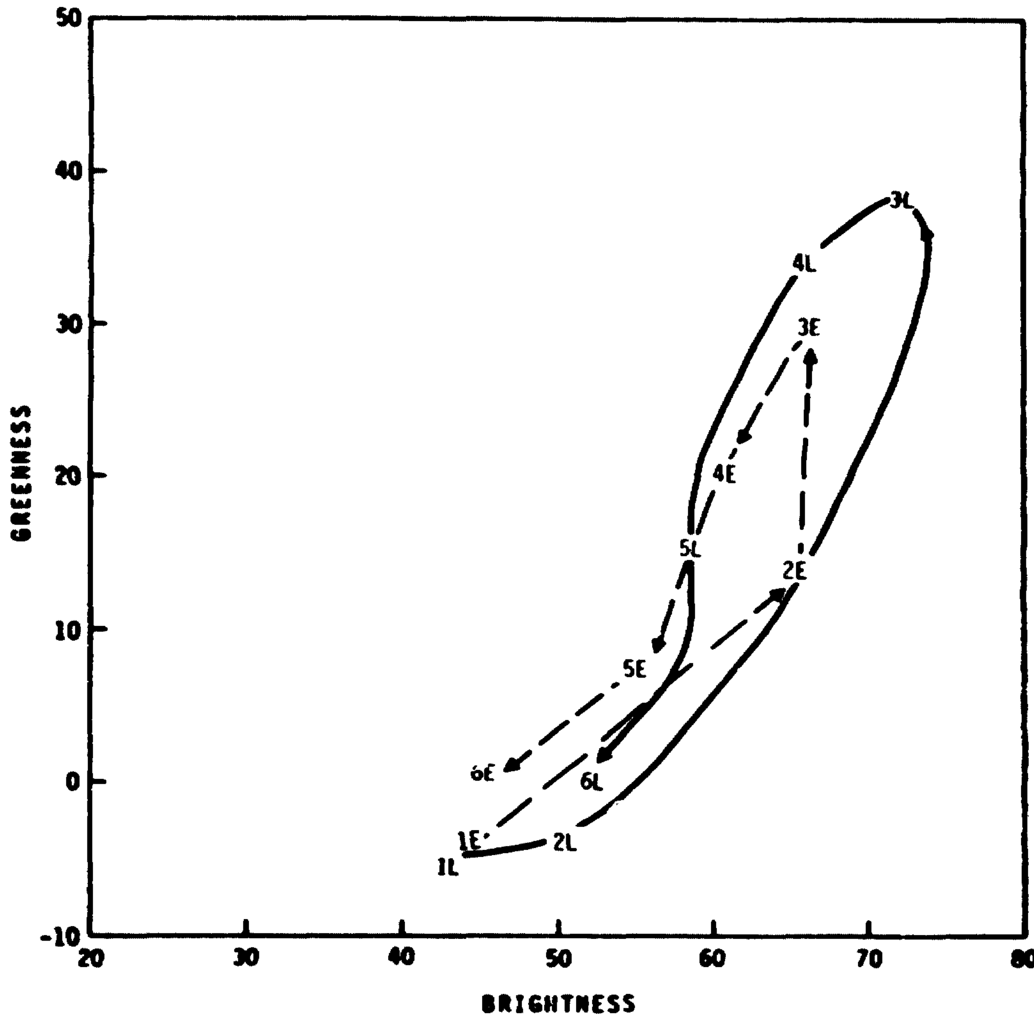
[1]During ground-truth processing, field 13 was encoded wrong, and field 12 was delineated to encompass land use other than wheat.



Plot	Day	Standard deviation			
		Early plant (4 fields)		Late plant (3 fields)	
		Gr.	Br.	Gr.	Br.
1	121	0.4	4.8	0.4	2.7
2	139	3.7	2.5	0.6	2.6
3	175	4.7	0.6	3.6	2.5
4	193	6.3	2.4	3.5	4.3
5	211	5.4	1.2	5.3	2.7
6	229	3.2	10.8	2.4	3.2

Inventory: day 213

Note: On day 213, all fields were ripe and being harvested.

Field pixel count: 112, 144, 91, 30, 70, 27, 119, 33, 28, 29, 23, 78, 46

Agriculture agent comment: Crop development 10 days ahead of normal due to early warm weather.

Figure 12.- Average greenness-brightness profiles of early and late planted wheat fields in segment 1640.

The major conclusions from this case study are as follows:

a. The growth cycle of spring wheat can be characterized by a trajectory GB profile.

b. Early in the growth cycle, plant height is an indicator of position in the GB profile.

c. During the period immediately before harvesting, the segment 1663 profile indicated an increase in brightness and the segment 1640 profile indicated a decrease in brightness (the 1927 profile missed critical acquisition). Therefore, the trend of brightness during ripening into harvest is inconclusive.

d. At harvest or swathing, brightness values increase significantly. If tilling occurs immediately after harvest, brightness values decrease significantly.

e. Clouds increase brightness considerably but have little effect on greenness.

f. The purported hail damage indicates that the profile is affected as an increase in brightness and little change in greenness. Examination of the channel data can assist in determining this episodial event.

g. The standard deviation of the GB values of the fields (see figures 3, 11, 12) indicates a variability of those factors which influence crop development. These factors consist of planting date, soil type, moisture availability, degree days, crop stress, wheat genus, and fertilization program. It is not surprising to see large standard deviation values when differences in these factors in the fields can supplement or cancel the effect of one another during crop development.

4. CASE STUDY NO. 2, BARLEY

4.1 DISCUSSION

There were no periodic visits to the barley fields during the growth cycle to record plant height or ground coverages during the 1966-67 season. However, the inventory of the segments was taken during the barley harvest. The inventory established the crop and its field condition: harvested, unharvested, or abandoned. In this case, the harvested barley fields were categorized as early planted and the unharvested barley fields were categorized as late planted. In segment 1663, 15 barley fields, were selected for study. In segments 1640 and 1927, six and nine barley fields, respectively, were used in the analyses.

The GB plots for these two categories of fields reveal the same profile characteristics as the wheat fields. That is, on any of the acquisition dates, the GB position was further along the growth profile for the early planted category than the GB position for the late planted category.

In segment 1663, barley field 129 was unharvested on day 201. The GB plot of the spectral data for this field is shown in figure 13 with a maximum GB occurring on day 156. Barley field 146 had already been harvested on day 201. The GB plot (figure 14) of this harvested field shows that the maximum GB occurred soon after day 139. Both figures show standard deviation of the GB of the within-field pixels.

Data from seven harvested barley fields and eight unharvested barley fields were used to compute average GB plots for each category. The results are shown in figure 15. The profiles overlap quite well through day 175. On day 193, the average brightness for the late planted fields is higher than that of the early planted fields; however, the standard deviation of both sets of data indicate a wide distribution. Since clouds were scattered over this segment on this date, the effect of nearby clouds and cloud shadows is expected in the data. This effect persists even when image analysis locates the clouds and cloud shadows, and the data are purged to eliminate direct effect on the fields. That is, when the remainder of the fields not directly affected by the clouds are analyzed, the data remain widely distributed. This can be ascribed to (a) the indirect effect of clouds (i.e., each cloud becomes a reflector, another source of energy) and/or (b) the effects of an unstable atmosphere in which clouds are in a constant state of development and dissipation, thus providing large areas of invisible moisture concentrations and areas of moisture deficiencies. Spectral

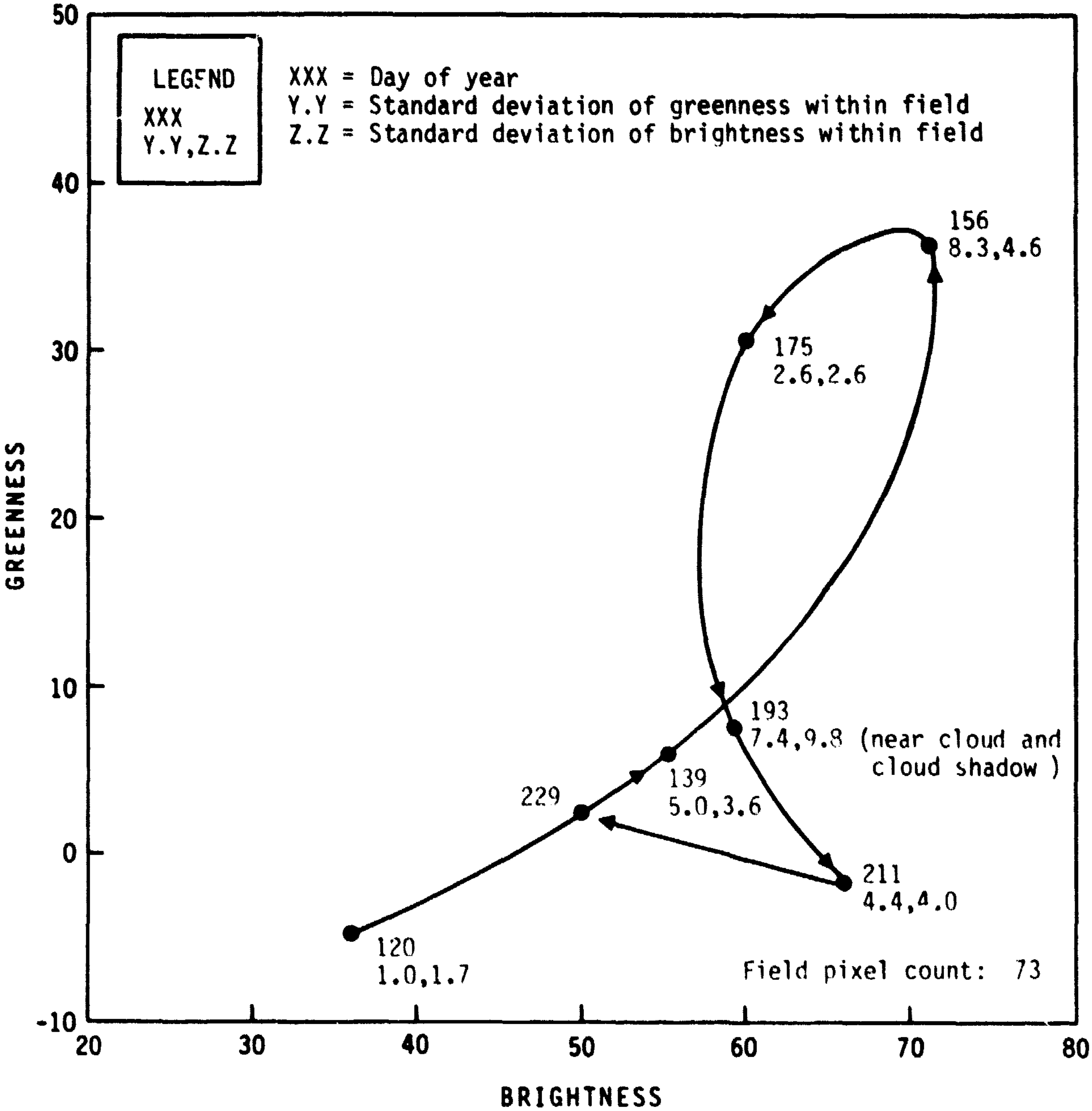


Figure 13.- Greenness-brightness plot for barley field 129 in segment 1663; an example of late plant.

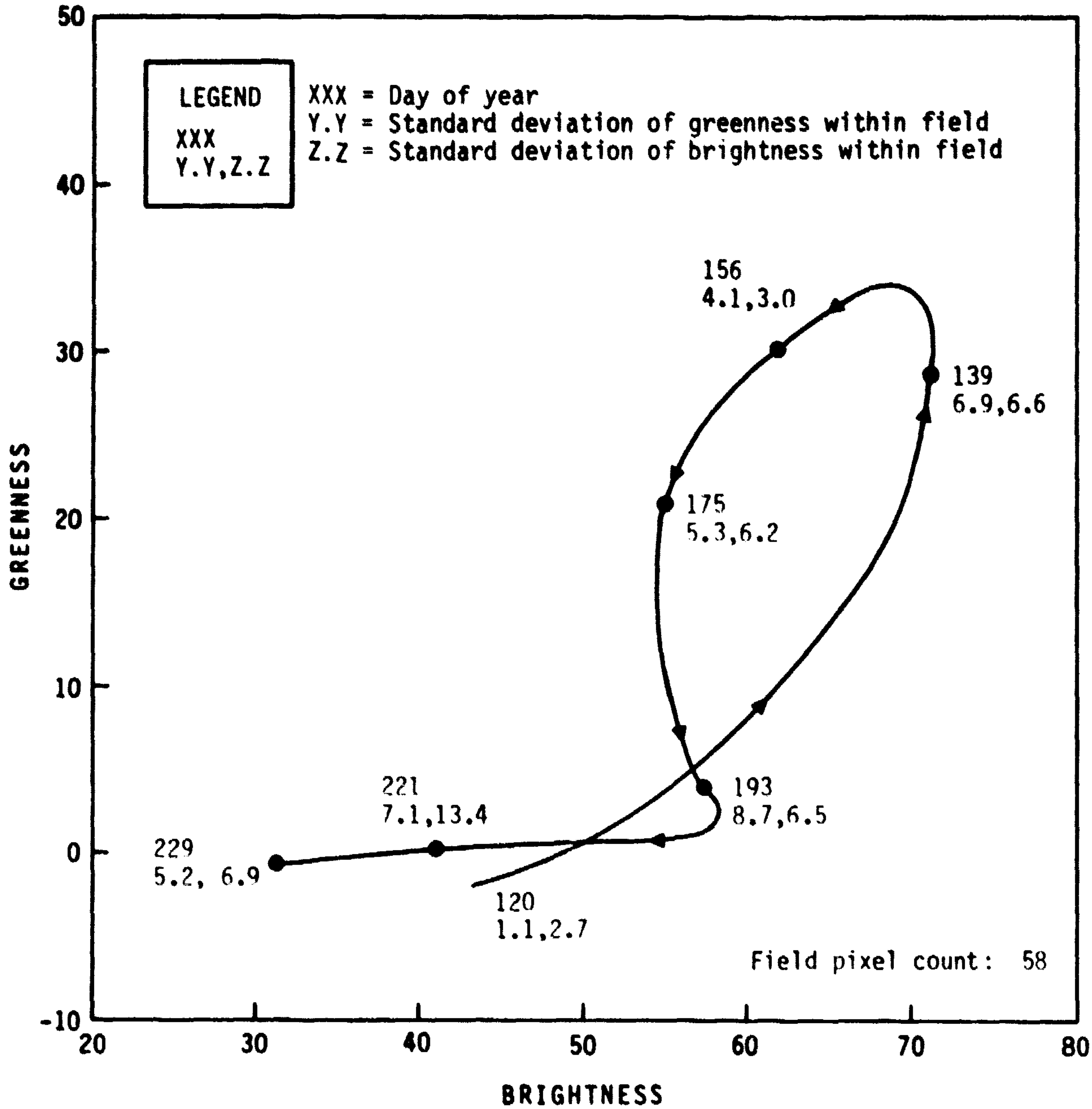
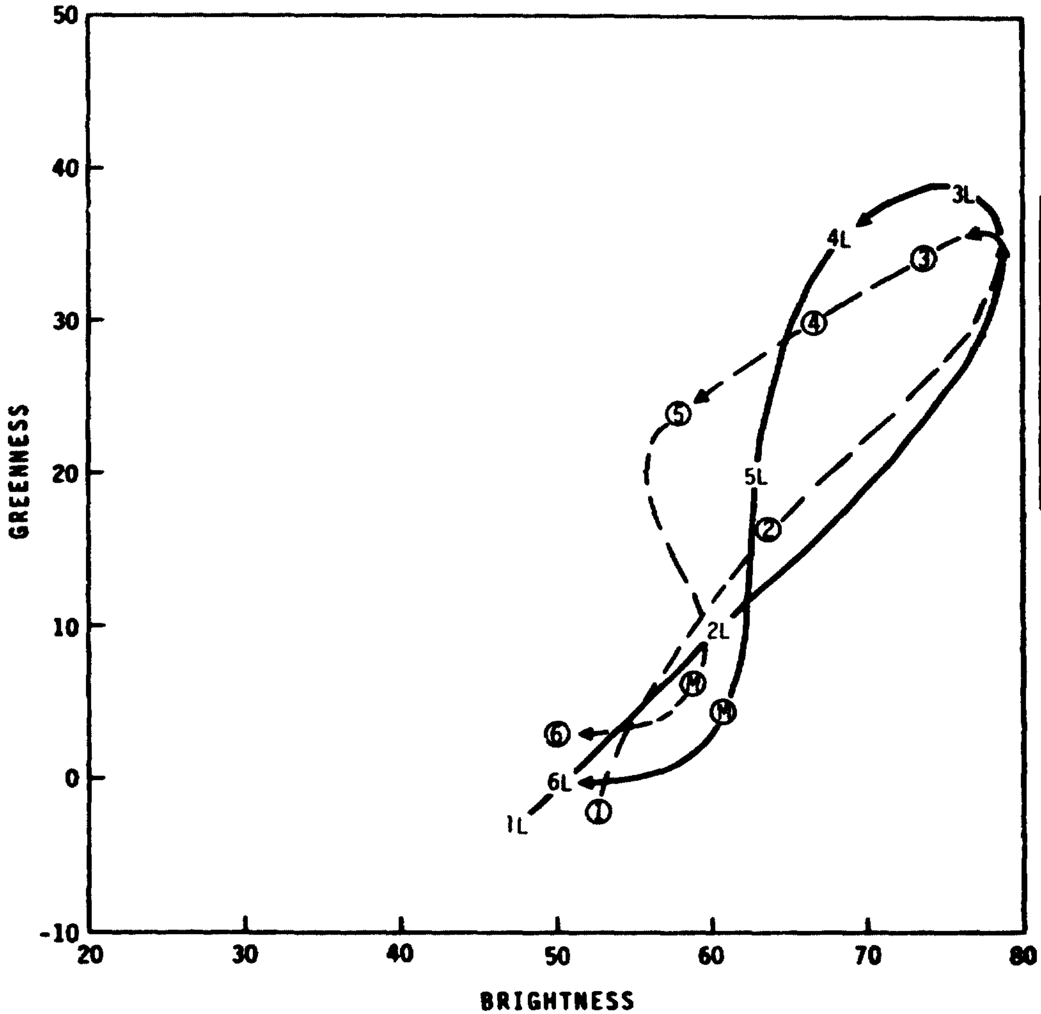


Figure 14.- Greenness-brightness plot for barley field 146 in segment 1663; an example of an early plant.



Plot	Day	Standard deviation			
		Early plant (5 fields)		Late plant (4 fields)	
		Gr.	Br.	Gr.	Br.
1	122	2.2	4.0	0.5	1.3
2	140	9.3	6.3	3.4	3.5
3	157	1.9	3.6	3.8	2.1
4	175	4.2	3.3	3.8	2.4
5	193	5.0	3.2	4.7	4.6
6	230	3.9	1.6	3.2	7.7

Note: 5 barley fields assumed early if harvested by day 210; circled plots. 4 barley fields assumed late when not harvested by day 210.

Field pixel count: 136, 133, 21, 60, 16, 133, 105, 134, 100

Figure 15.- Average greenness-brightness profiles for early and late planted barley fields in segment 1663.

data from the MSS are changed by absorption due to water vapor (Pitts, et al., ref. 6) and by scattering in areas of incipient clouds (sub visible concentrations of water droplets) (Wilkins, ref. 7). Atmospheric correction programs are being developed to evaluate this effect on the channels of the MSS.

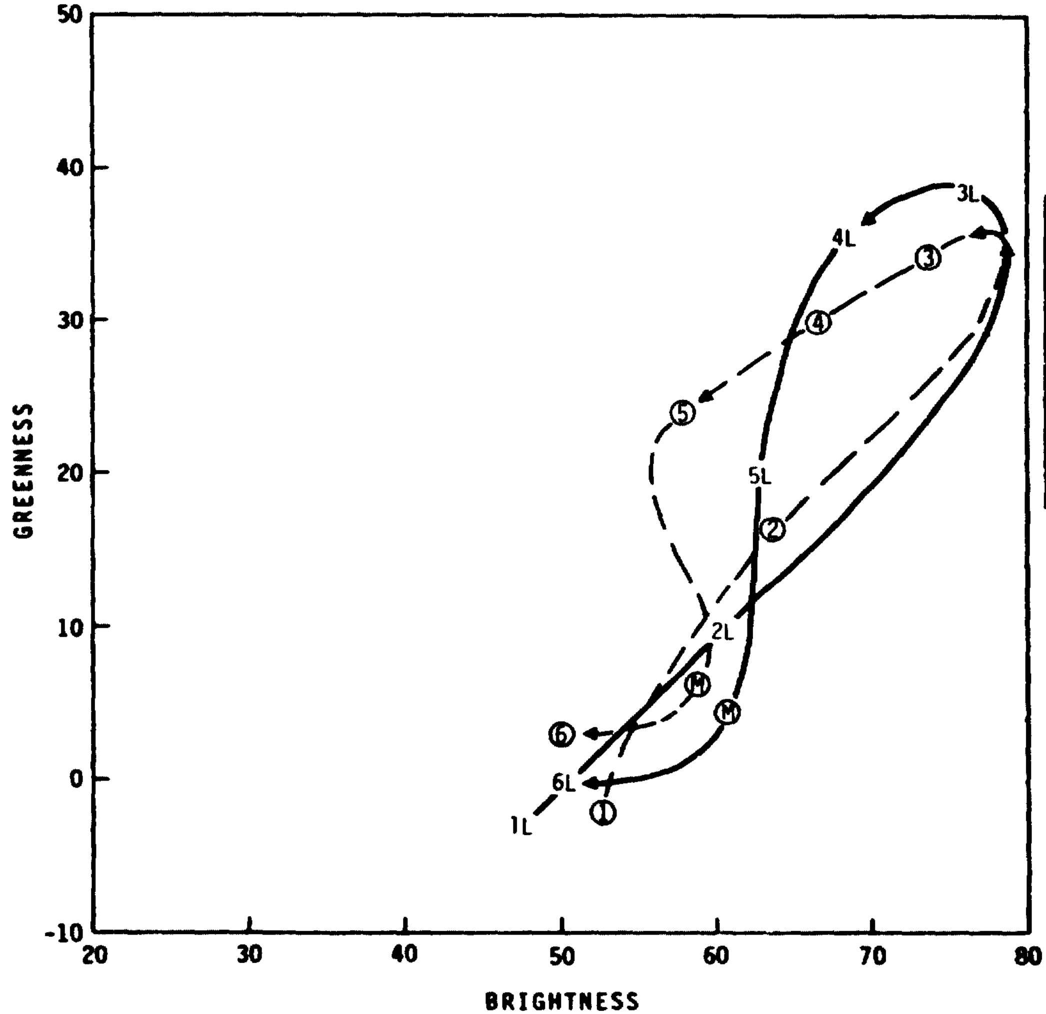
Two interesting features begin to emerge when the wheat profile is compared with the barley profile. They are described as follows:

a. Most of the time the peak GB of barley is slightly higher than that of spring wheat.

b. On the average, during the period immediately before harvest, the barley profile shows more brightness and less greenness than the wheat profile. This is believed to portray the yellowing stage of barley as it ripens. This feature is not always seen, however, probably because of data acquisition times which are not coincident with the period of maximum yellowing. The yellowing is seen mainly in larger increases for values in channels 1 and 2 when compared to those in spring wheat data.

The GB average plot of segment 1927 barley fields, figure 16, is surprisingly similar to the wheat fields in this segment (fig. 11). The profiles indicate that the peak GB of the barley fields again are higher than those of the wheat fields.

The profile of both the early wheat and early barley (as categoried) have the unique characteristic of decreasing brightness from day 157 to day 193. An examination of the individual field profiles confirm that this characteristic prevailed. It can only be assumed that brightness increased between day 193 and harvest. This is just another case in which the data within a segment can vary considerably from that of its neighboring fields. In this case, the variation is assumed to be due to different planting dates. The information for the early categories in segment 1927 does not provide an explanation for the low brightness values on day 193. Obviously, the yellowness which was seen in the analysis for segment 1663 is not seen with these early barley fields. However, most of the late categories of barley did show some of the yellowing features.



Plot	Day	Standard deviation			
		Early plant (5 fields)		Late plant (4 fields)	
		Gr.	Br.	Gr.	Br.
1	122	2.2	4.0	0.5	1.3
2	140	9.3	6.3	3.4	3.5
3	157	1.9	3.6	3.8	2.1
4	175	4.2	3.3	3.8	2.4
5	193	5.0	3.2	4.7	4.6
6	230	3.9	1.6	3.2	7.7

Note: 5 barley fields assumed early if harvested by day 210; circled plots. 4 barley fields assumed late when not harvested by day 210.

Field pixel count: 136, 133, 21, 60, 16, 133, 105, 134, 100

Figure 16.- Average greenness-brightness profiles for early and late planted barley fields in segment 1927.

In segment 1640 on inventory day 213, only one barley field had been harvested. When comparing barley development in this segment with that of segment 1663 (60 miles southeast) and that of segment 1927 (60 miles south), the differences in crop development appear to be great. For instance, inventories were made on days 201, 210, and 213 for segments 1663, 1927, and 1640, respectively. The development of barley in segment 1640 is estimated to be about 2 weeks later than that in segment 1663. A review of yearly crop calendar data indicates that a 14-day difference does occur in some years; however, the average difference is nearer 5 days.

The GB average plot for five unharvested barley fields is shown in figure 17. Note that Landsat data were not acquired on day 157, for which the profile is annotated with a circled M (for missing). The yellowing feature as discussed in the field 1663 data analysis is again seen here.

4.2 SUMMARY

The major conclusions from this case study are as follows.

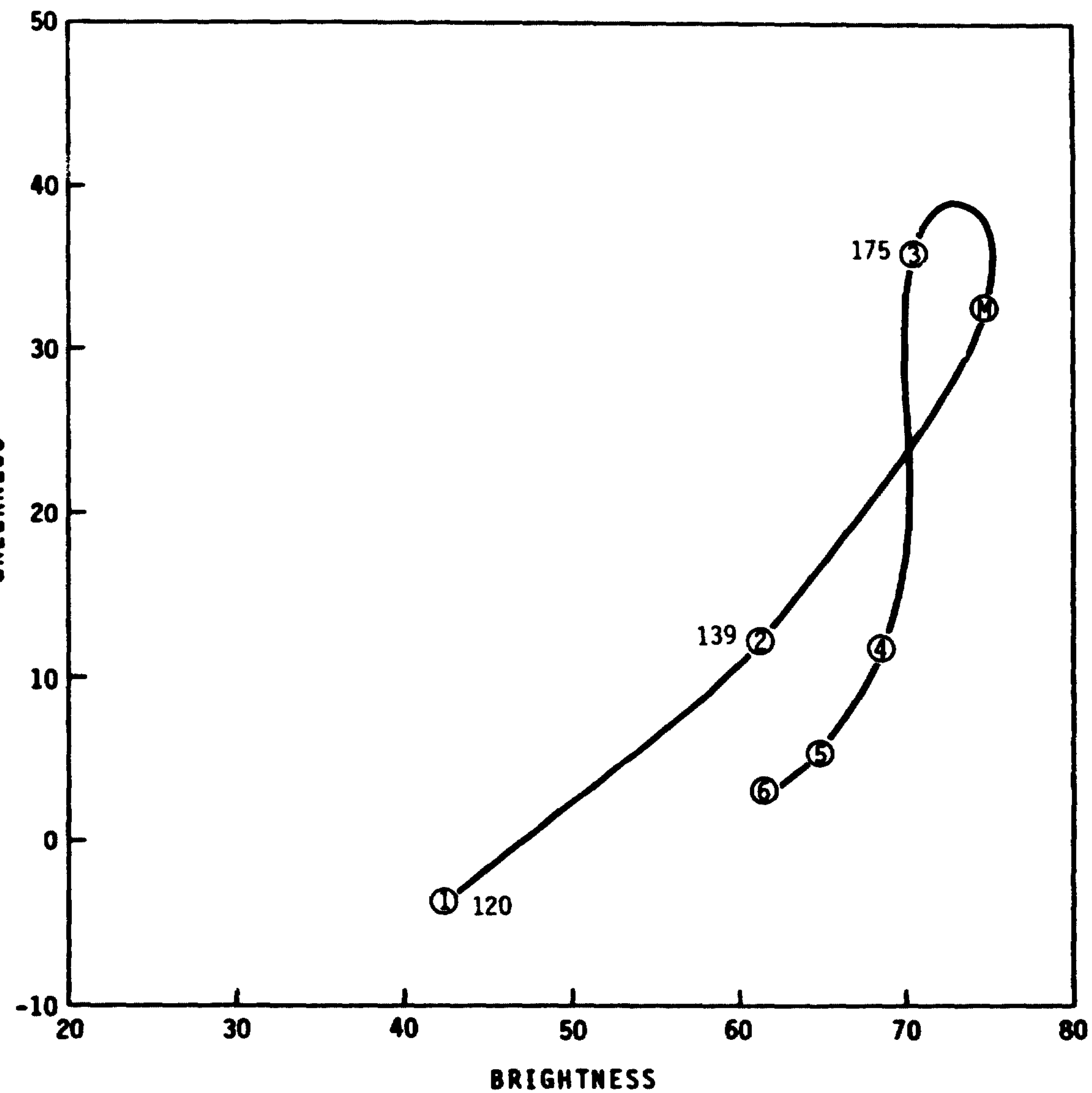
a. The trajectory profile is similar (not coincident) to that of spring wheat. The maximum of the GB in the profiles is greater for barley than for wheat.

b. The yellowing effect shown for barley near harvest is usually seen as increased brightness and decreased greenness. This is due to higher values in channels 1 and 2.

c. Atmospheric effects are speculated to be the cause of some of the large variances in the data.

5. CASE STUDY NO. 3, WINTER WHEAT

Segment 1640 was the only segment having a winter wheat crop. The GB profile of this crop, figure 18, is similar to that of early planted spring wheat (fig. 12) in segment 1640 through day 175. The brightness value on day 193 is somewhat lower than the early wheat brightness. It is not known if this is characteristic for winter wheat. Because this is a single case for comparison, no specific conclusions should be made.



Plot	Day	Standard deviation Early plant (5 fields, unharvested)	
		Gr.	Br.
1	121	0.9	5.6
2	139	3.1	3.0
3	175	6.8	4.9
4	193	7.3	8.8
5	211	4.2	14.3
6	229	5.8	10.3

Inventory: day 213

Field pixel count: 31, 124, 72, 284, 81

Figure 17.- Average greenness-brightness profile for barley fields in segment 1640.

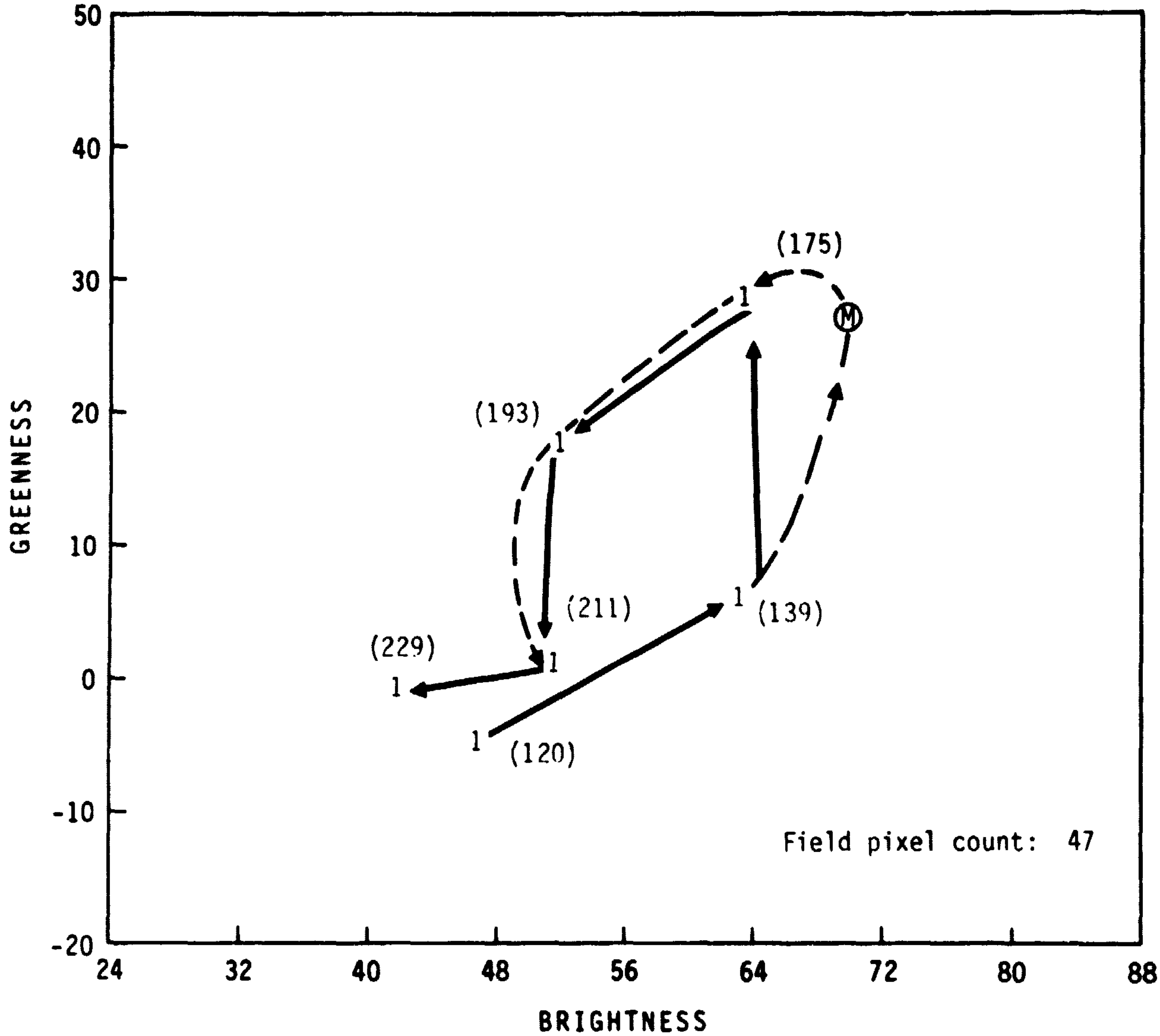


Figure 18.- Greenness-brightness plot for a winter wheat field in segment 1640.

6. CASE STUDY NO. 4, OATS

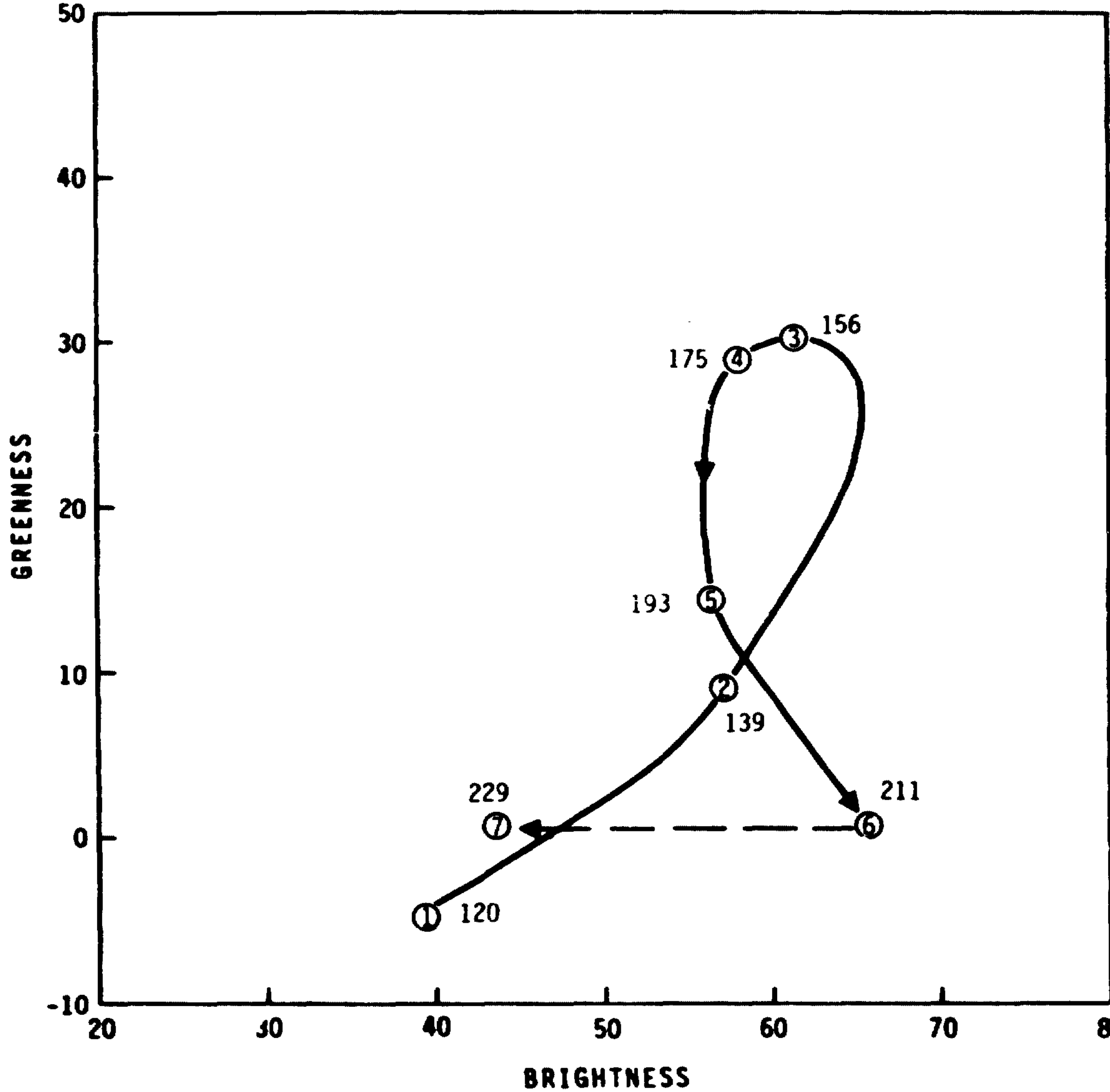
Six oat fields were randomly selected in each of the three segments (1663, 1640, and 1927), and mean channel spectral values were determined for each field for each Landsat acquisition. The GB plots derived from these means are strikingly similar to those for wheat and barley. The mean GB values and the standard deviations for each set of six fields within each segment are computed. The plotted results are shown in figures 19, 20, and 21 for segments 1663, 1927, and 1640, respectively. These three profiles are in good agreement with one another. The standard deviations are listed on each figure.

7. CASE STUDY NO. 5, FLAX

Five flax fields were randomly selected in each of the three segments (1663, 1927, and 1640). The GB plots of these flax fields show a completely different profile from the profiles of wheat and/or barley. The crop development cycle occurs much later than that of wheat or barley, with peak GB occurring about 3 weeks after wheat and barley have reached their peak GB and harvest occurring 3 to 4 weeks after the wheat and barley harvest. The average GB profiles for the flax fields in segments 1663, 1927, and 1940 are provided in figures 22, 23, and 24, respectively. It can be seen that the flax profile characteristic is quite different from that of wheat or barley.

8. CASE STUDY NO. 6, WINTER RYE

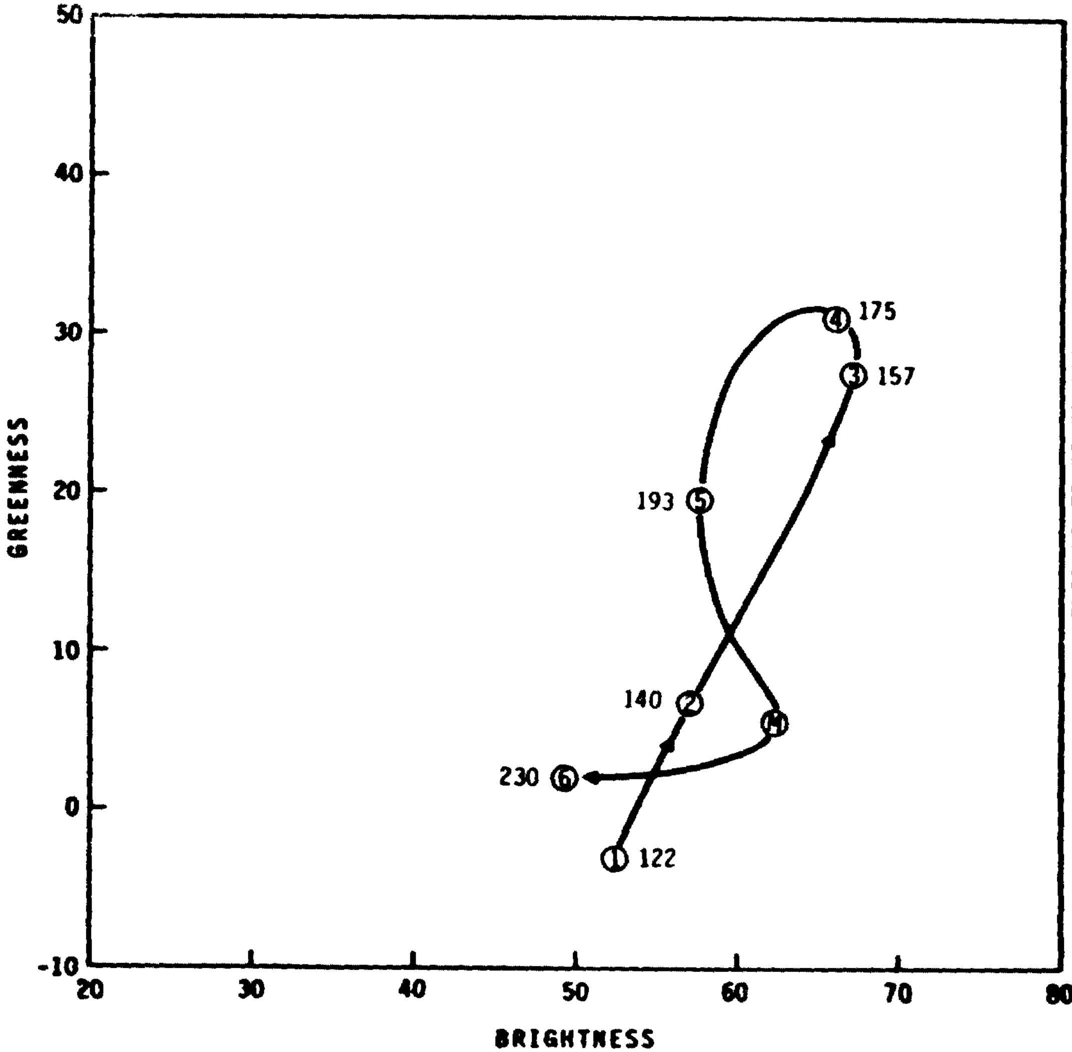
Three winter rye fields were located in segment 1927; none were located in the other two segments. The channel data were reduced to GB values, and the average profile was plotted (fig. 25). The GB data values do not show much of a trend from day 140 to day 193. More winter rye fields in North and South Dakota were analyzed in the following year's (1978) data. In this case, acquisitions before day 197 were lacking but were abundant after that date. The analysis showed that the average profiles at the end of the rye growing season increased in brightness to day 211 and then decreased to near harvest. This characteristic is indicated on the profile in figure 25.



Plot	Day	Standard deviation Oats (6 fields) Gr.	Br.
1	120	2.2	6.3
2	139	10.2	9.6
3	156	3.6	3.6
4	175	4.5	4.2
5	193	7.2	4.0
6	211	2.7	16.5
7	229	2.9	8.0

Field pixel count: 34, 235, 28, 17, 79

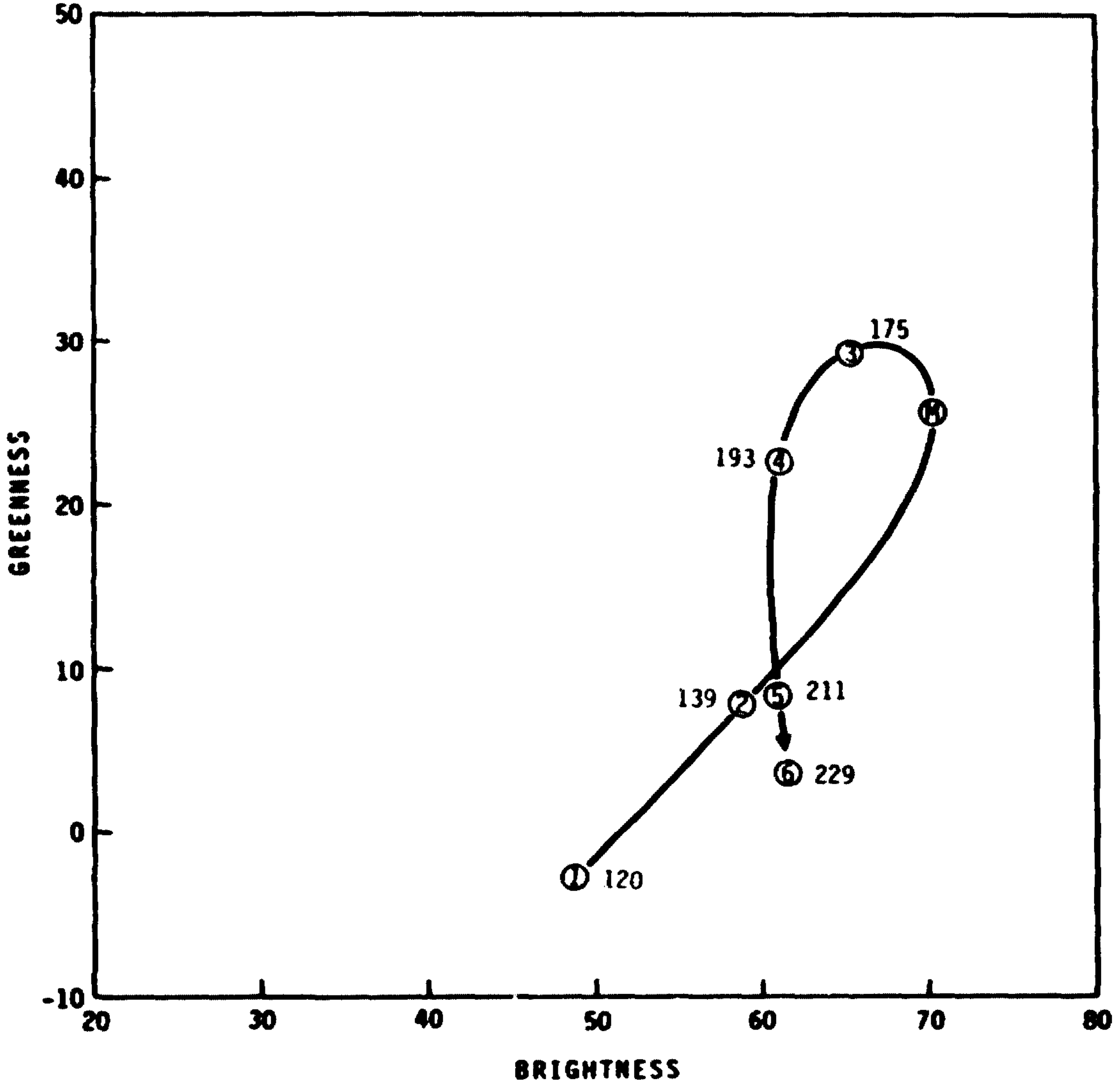
Figure 19.- Average greenness-brightness profile for oat fields in segment 1663.



Plot	Day	Standard deviation Oats (6 fields)	
		Gr.	Br.
1	122	2.6	6.1
2	140	5.8	3.8
3	157	6.9	3.7
4	175	4.0	2.9
5	193	8.7	8.5
6	230	3.4	7.2

Field pixel count: 68, 132, 56, 102, 37, 54

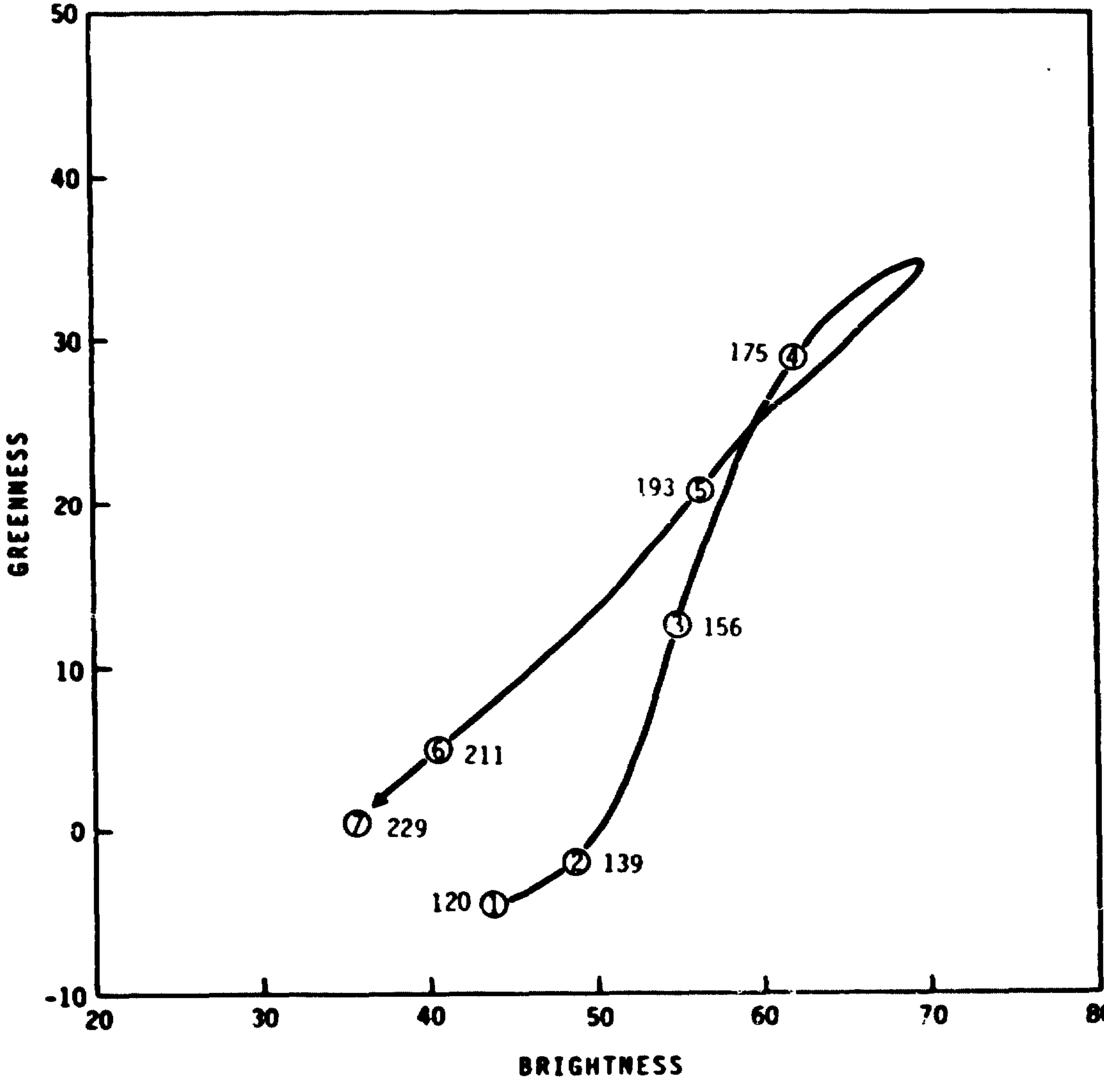
Figure 20.- Average greenness-brightness profile for oat fields in segment 1927.



Plot	Day	Standard deviation Oats (6 fields)	
		Gr.	Br.
1	120	1.1	3.3
2	139	6.3	7.0
3	175	6.1	4.2
4	193	3.4	3.0
5	211	2.4	5.1
6	229	2.6	9.6

Field pixel count: 31, 20, 65, 57, 53, 53

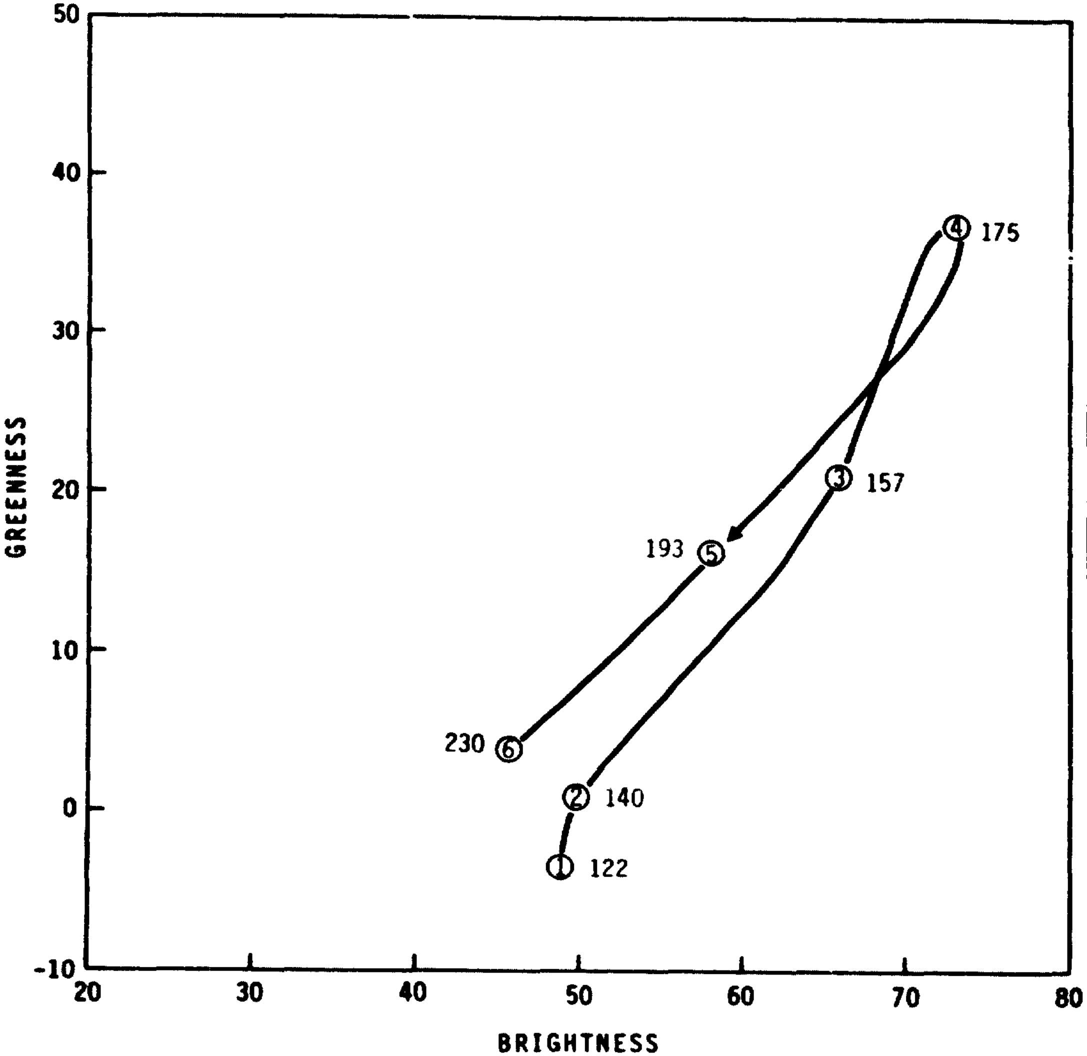
Figure 21.- Average greenness-brightness profile for oat fields in segment 1640.



Plot	Day	Standard deviation Flax (4 fields)	
		Gr.	Br.
1	120	0.6	5.5
2	139	2.1	3.0
3	156	9.1	5.0
4	175	7.5	7.[illegible]
5	193	4.4	3.7
6	211	5.6	5.2
7	229	4.7	13.7

Field pixel count: 29, 48, 32, 121

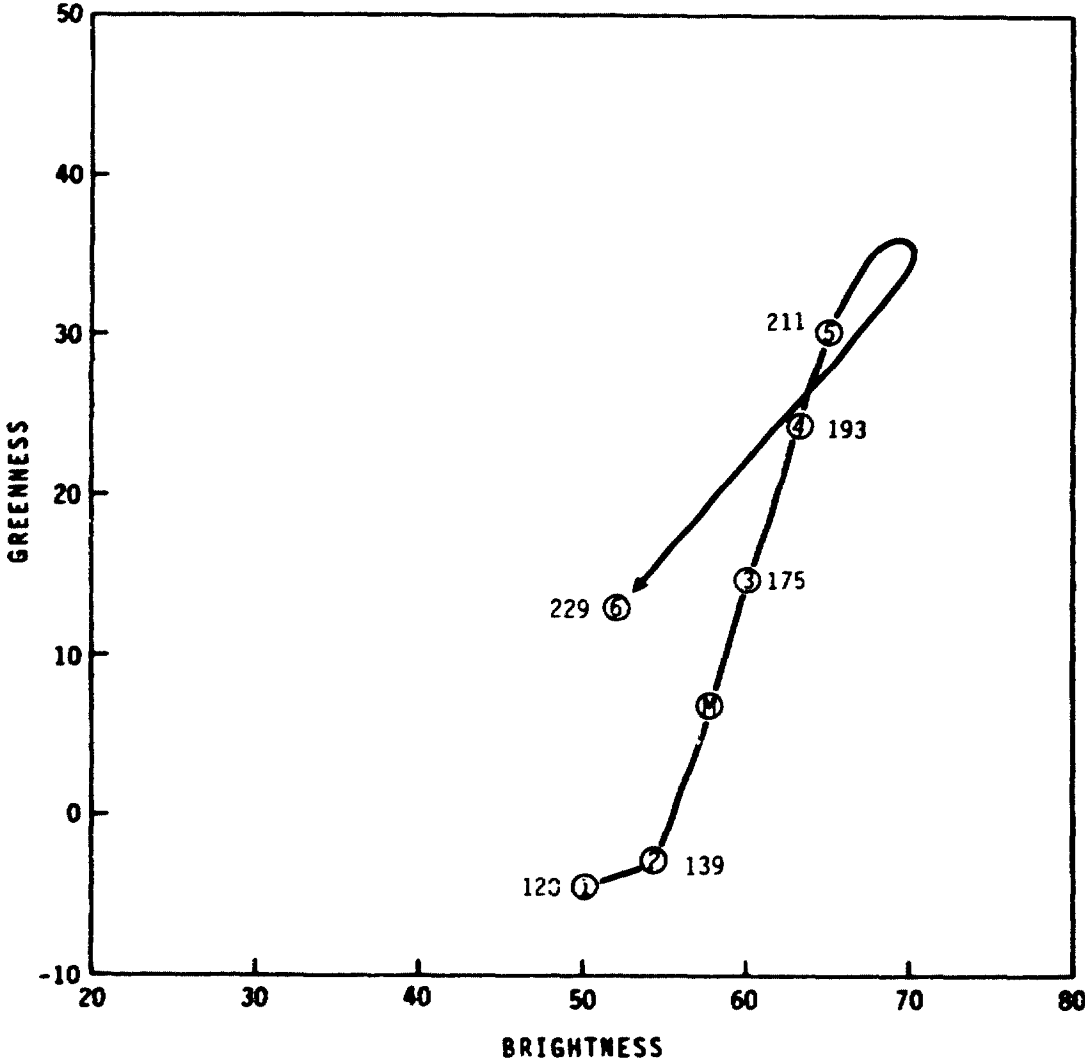
Figure 22.- Average greenness-brightness profile for flax fields in segment 1663.



Plot	Day	Standard deviation Flax (5 fields) Gr.	Br.
1	122	0.9	6.2
2	140	1.7	2.0
3	157	4.4	2.8
4	175	4.1	3.6
5	193	13.9	9.1
6	230	2.1	4.0

Field pixel count: 23, 46, 16, 62, 32

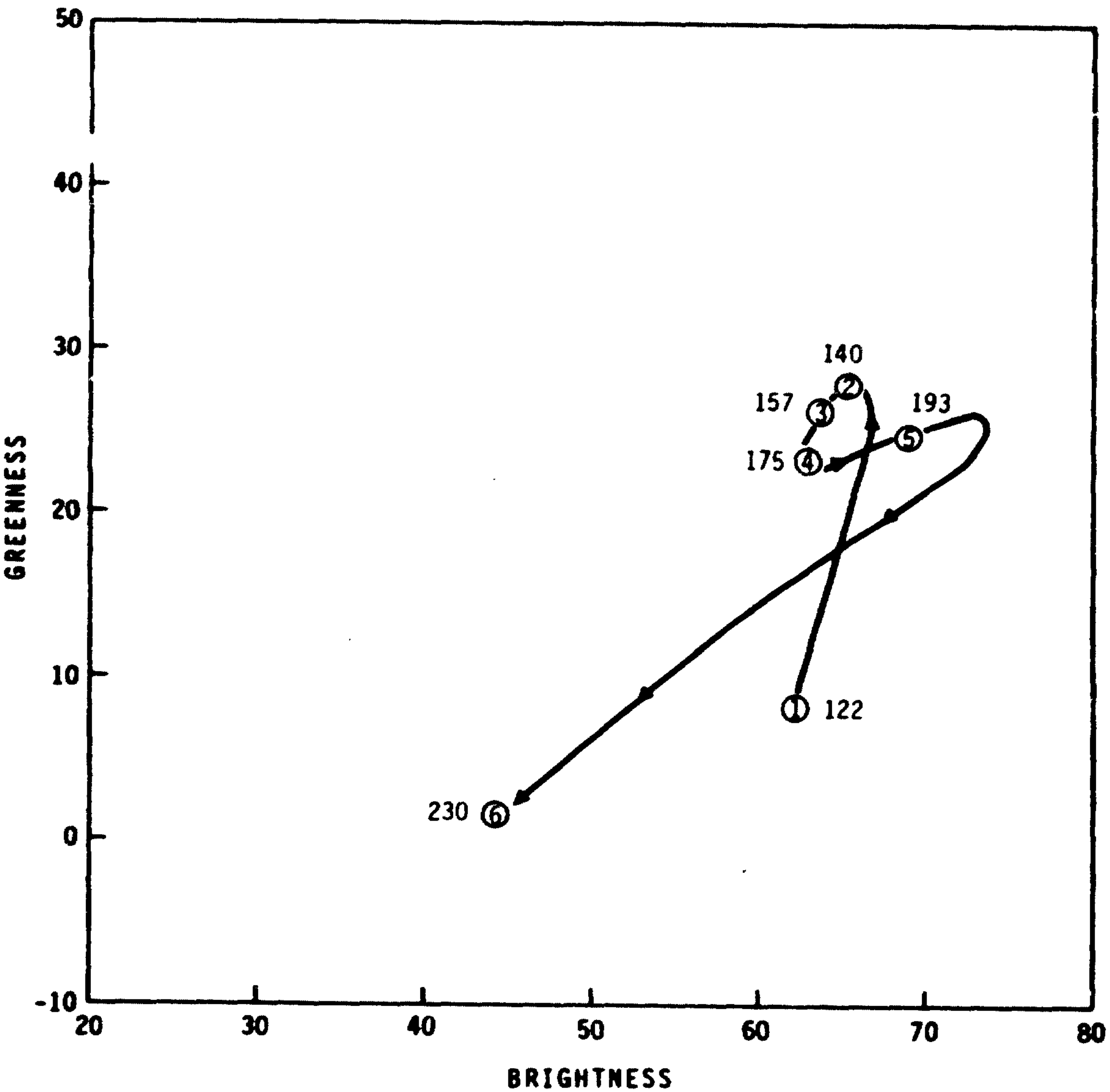
Figure 23.- Average greenness-brightness profile for flax fields in segment 1927.



Plot	Day	Standard deviation Flax (5 fields)	
		Gr.	Br.
1	120	1.0	6.3
2	139	2.1	4.4
3	175	11.8	8.0
4	193	8.2	1.1
5	211	8.6	7.4
6	229	8.9	5.4

Field pixel count: 65, 20, 46, 73, 16

Figure 24.- Average greenness-brightness profile for flax fields in segment 1640.



Plot	Day	Standard deviation Rye (3 fields) Gr.	Br.
1	122	4.2	0.5
2	140	4.2	1.6
3	157	1.3	3.8
4	175	3.5	1.9
5	193	13.2	7.5
6	230	2.2	0.6

Field pixel count: 18, 12, 9

Figure 25.- Average greenness-brightness profile of winter rye fields in segment 1927.

9. CASE STUDY NO. 7, CORN

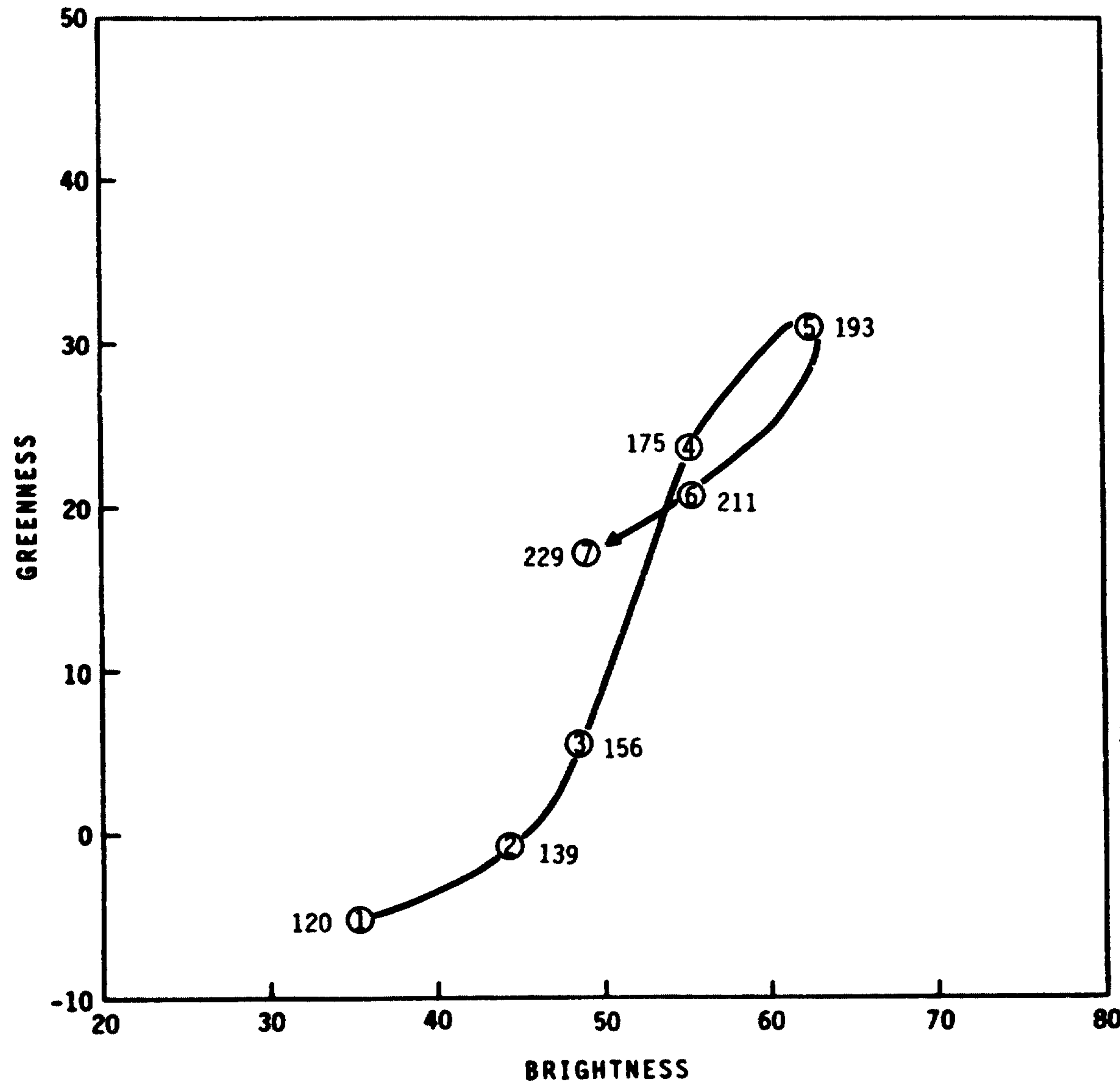
Four, five, and six corn fields were randomly selected from segments 1663, 1927, and 1640, respectively. The GB plots of these corn fields show a profile different from those of wheat or barley; but the GB plots for corn are not unlike those of flax fields except the corn profiles remain near the maximum GB for a longer period. The average GB profiles for the corn fields in segments 1663, 1927, and 1640 are provided in figures 26, 27, and 28, respectively.

10. CASE STUDY NO. 8, SOYBEANS

In the three segments considered in this study, only segment 1663 had soybean fields. Channel data from five of these fields were reduced to GB values, and the average profile was plotted (fig. 29). It is apparent that day 229 does not encompass the end of the crop development cycle and additional acquisitions are required to complete the profile through harvest. However, the average profile does indicate that the maximum GB occurs near day 211. It is probable that this crop is easily confused with corn.

11. CASE STUDY NO. 9, SUNFLOWERS

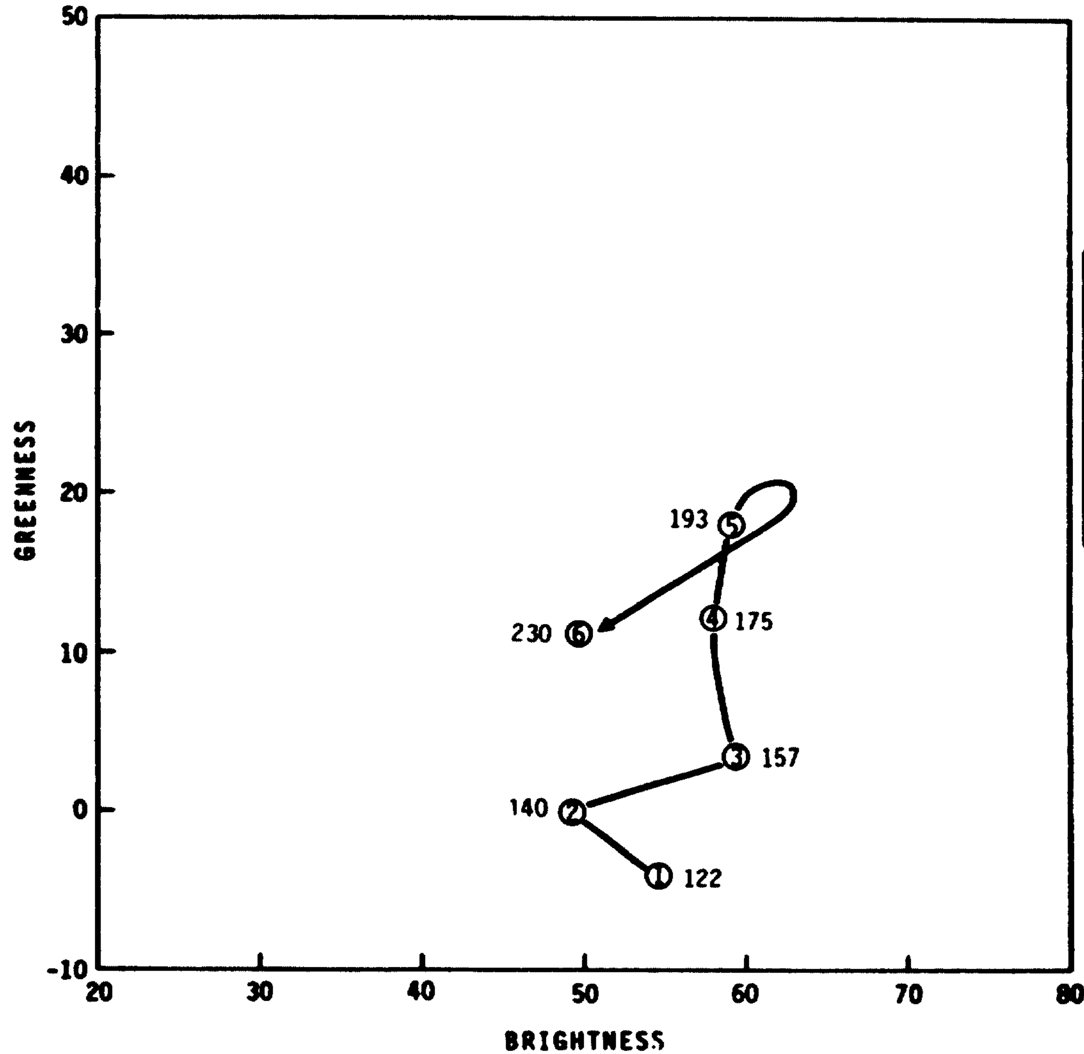
Sunflowers cover the second largest acreage of crops in the three segments in this part of North Dakota; only spring wheat acreage is larger. Ten fields of sunflowers from segment 1663, five from segment 1927, and five from segment 1640 were selected for this study. The channel data were reduced to GB values, and the average GB profiles for the sunflower fields were prepared (figs. 30, 31, and 32). These profiles indicate that sunflower crops can be easily confused with corn and/or soybean crops since GB peak for sunflowers occurs near day 193 and since subsequent decreases in GB are not well revealed because the last acquisition near day 230 is obtained before the harvest season. In general, the decrease in GB is similar to that of the corn/soybeans profile.



Plot	Day	Standard deviation Corn (4 fields) Gr.	Br.
1	120	0.4	0.7
2	139	4.3	5.2
3	156	4.5	2.0
4	175	7.8	5.0
5	193	1.4	1.4
6	211	2.6	2.8
7	229	2.4	2.5

Field pixel count: 25, 35, 29, 35

Figure 26.- Average greenness-brightness profile for corn fields in segment 1663.

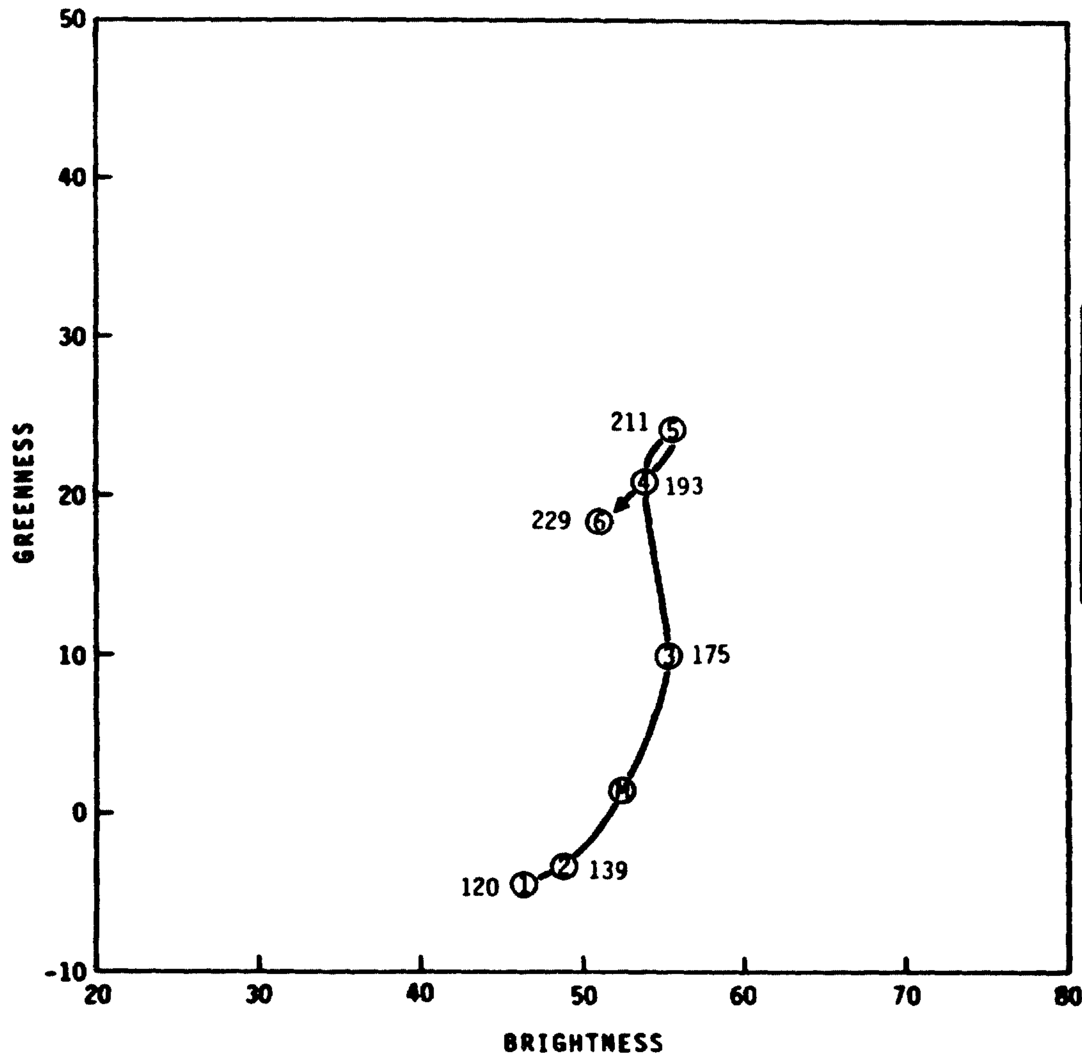


Plot	Day	Standard deviation Corn (6 fields) Gr.	Br.
1	122	0.5	5.8
2	140	3.9	4.4
3	157	3.7	4.6
4	175	4.3	4.2
5	193	5.1	3.9
6	230	4.8	0.9

6 corn fields, average

Field pixel count: 22, 40, 67, 173, 44, 172

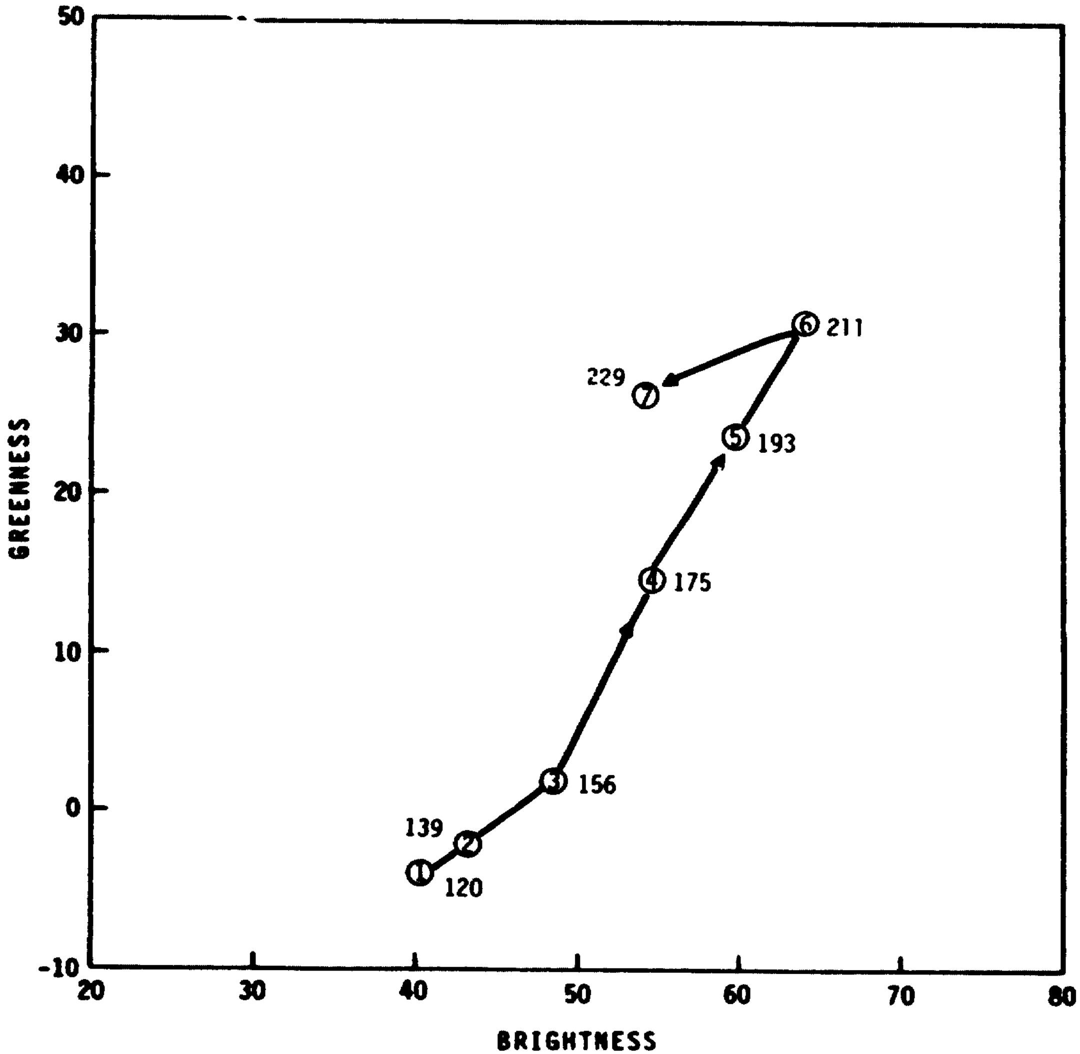
Figure 27.- Average greenness-brightness profile for corn fields in segment 1927.



Plot	Day	Standard deviation Corn (5 fields) Gr.	Br.
1	120	0.4	2.4
2	139	1.1	4.0
3	175	5.5	3.8
4	193	5.4	1.4
5	211	1.7	2.2
6	229	3.6	3.2

Field pixel count: 108, 115, 106, 99, 36

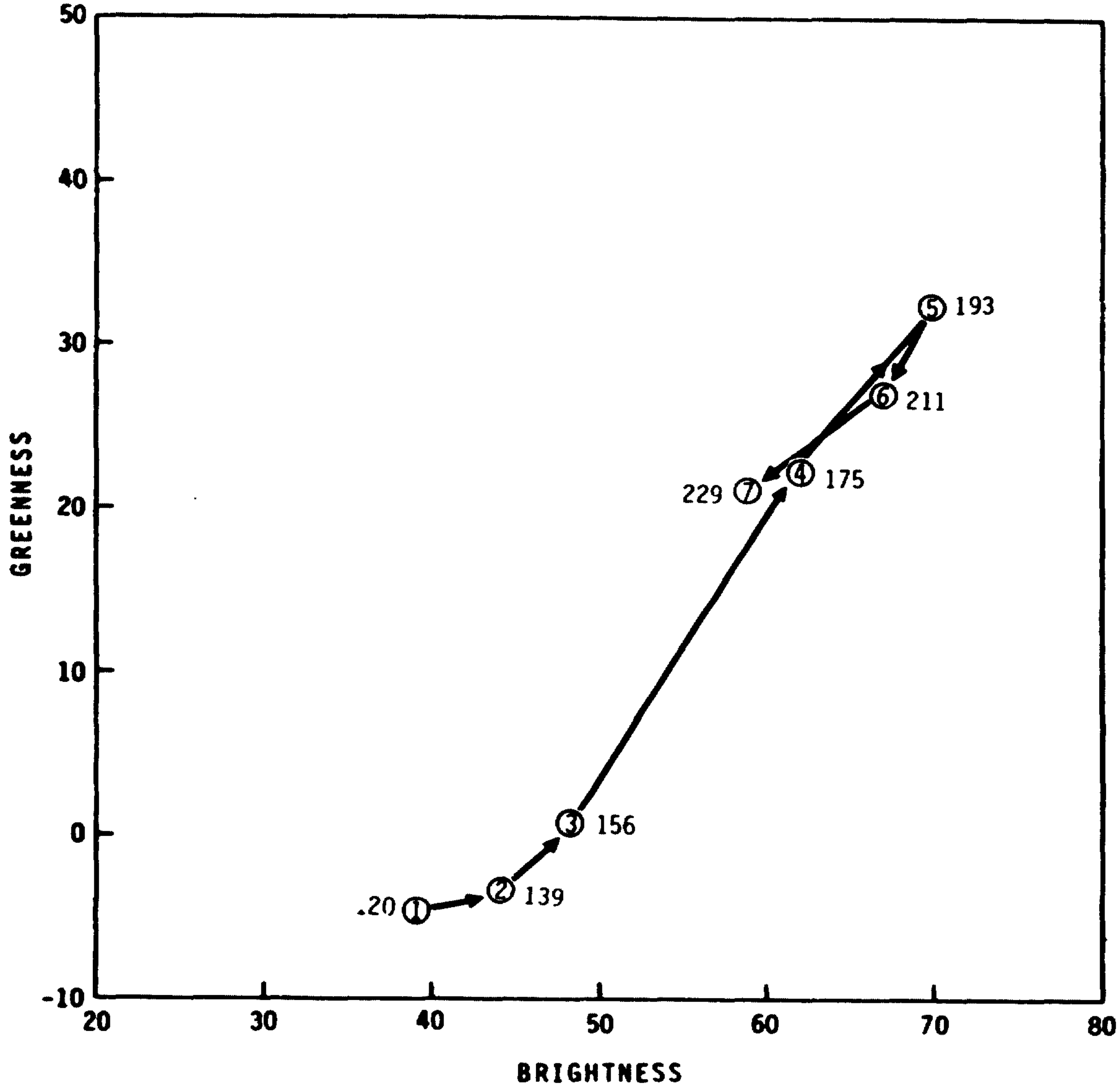
Figure 28.- Average greenness-brightness profile for corn fields in segment 1640.



Plot	Day	Standard deviation Soybeans (5 fields)	
		Gr.	Br.
1	120	4.8	5.5
2	139	1.2	5.0
3	156	2.1	3.9
4	175	4.9	5.2
5	193	3.0	3.4
6	211	4.6	4.9
7	229	6.2	5.6

Field pixel count: 111, 48, 54, 137, 49

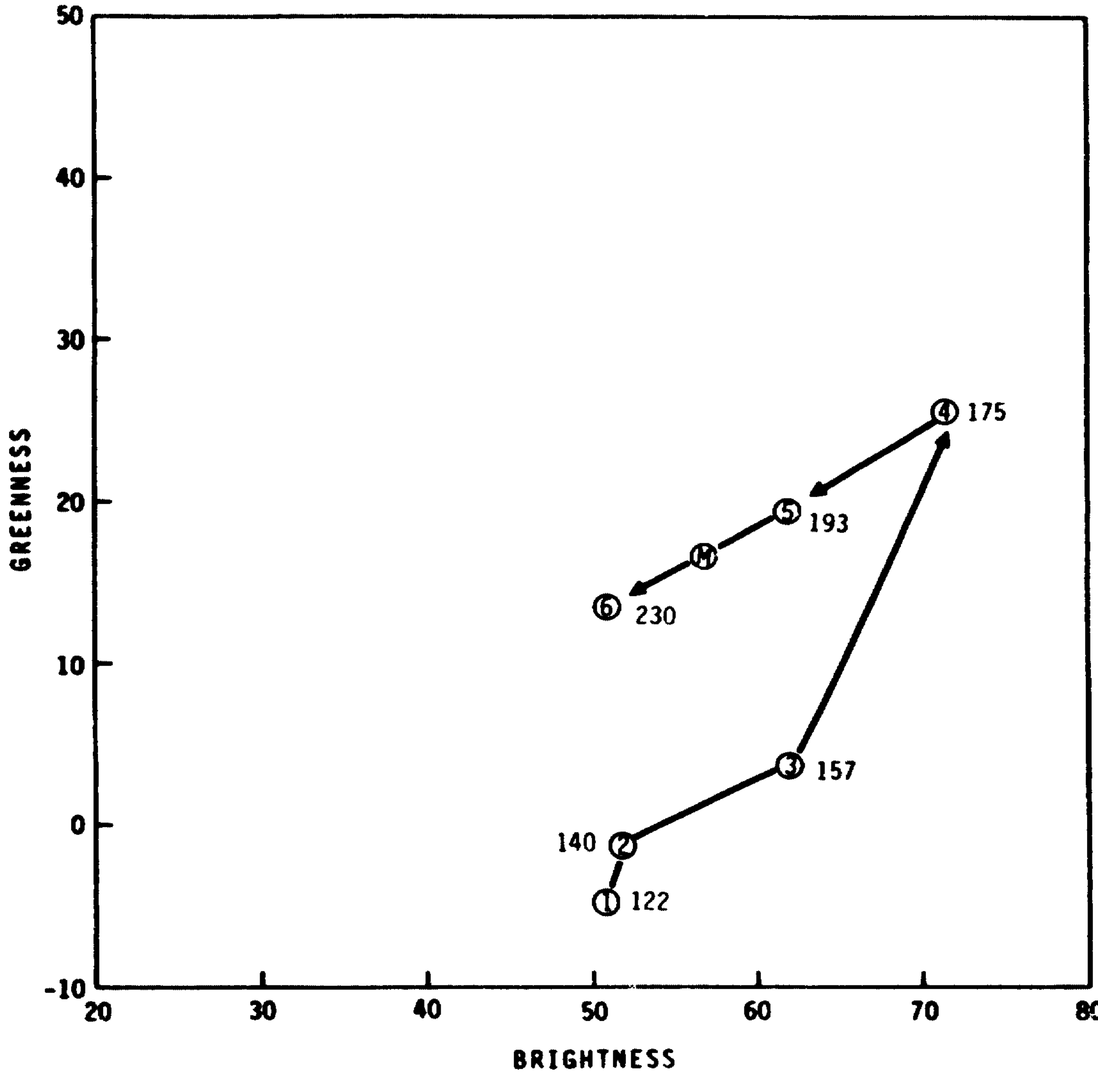
Figure 29.- Average greenness-brightness profile for soybean fields in segment 1663.



Plot	Day	Standard deviation Sunflower (10 fields) Gr.	Br.
1	120	4.7	6.0
2	139	0.9	3.9
3	156	1.6	3.4
4	175	7.4	8.4
5	193	5.9	7.4
6	211	3.8	4.8
7	229	4.5	5.3

Field pixel count: 49, 232, 246, 287, 173, 300, 300, 68, 241, 157

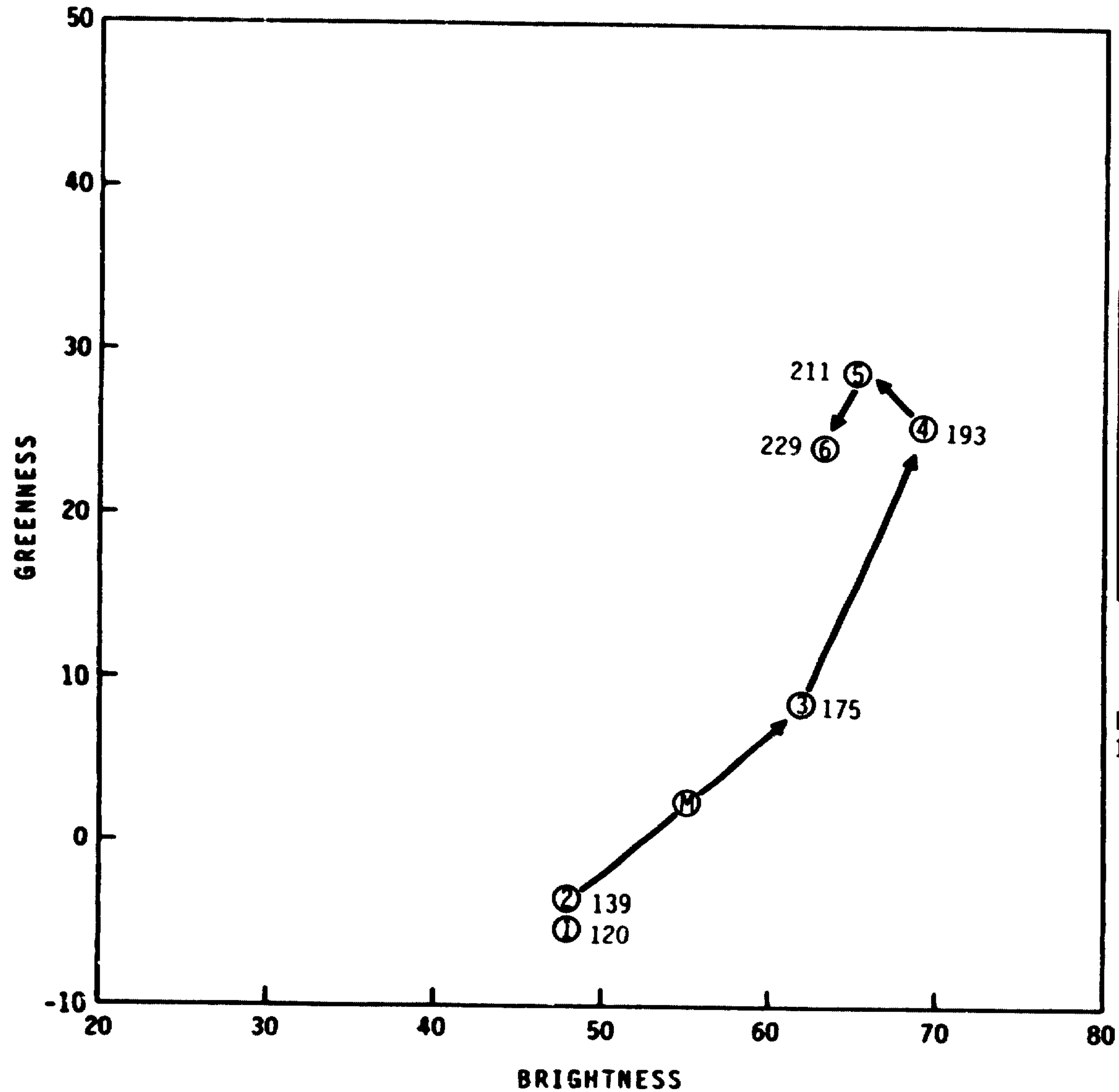
Figure 30.- Average greenness-brightness profiles for sunflower fields in segment 1663.



Plot	Day	Standard deviation Sunflower (5 fields) Gr.	Br.
1	122	1.2	5.6
2	140	4.1	3.3
3	157	4.3	7.0
4	175	8.7	6.0
5	193	4.7	8.3
6	230	5.2	5.3

Field pixel count: 278, 106, 148, 183, 115

Figure 31.- Average greenness-brightness profile for sunflower fields in segment 1927.



Plot	Day	Standard deviation Sunflower (5 fields) Gr.	Br.
1	120	2.3	3.4
2	139	1.1	2.9
3	175	4.3	7.8
4	193	9.1	5.6
5	211	5.5	6.1
6	229	5.5	4.8

Field pixel count: 109, 118, 188, 164, 198

Figure 32.- Average greenness-brightness profile for sunflower fields in segment 1640.

12. CASE STUDY NO. 10, PASTURE

Five pastures in segments 1927 and 1640 were selected and their Landsat channel data were reduced to GB values. The average GB profiles of pasture (figs. 33 and 34) show the characteristic gradual greenup into midsummer followed by gradual decrease in GB into the fall season. A separate study of data in another central North Dakota site (segment 1461) in the next year (1978) showed the pasture profile to have a similar greenness trend. However, due to a different rainfall regime, the brightness curve began near a value of 53 and increased into August (day 217) before decreasing.

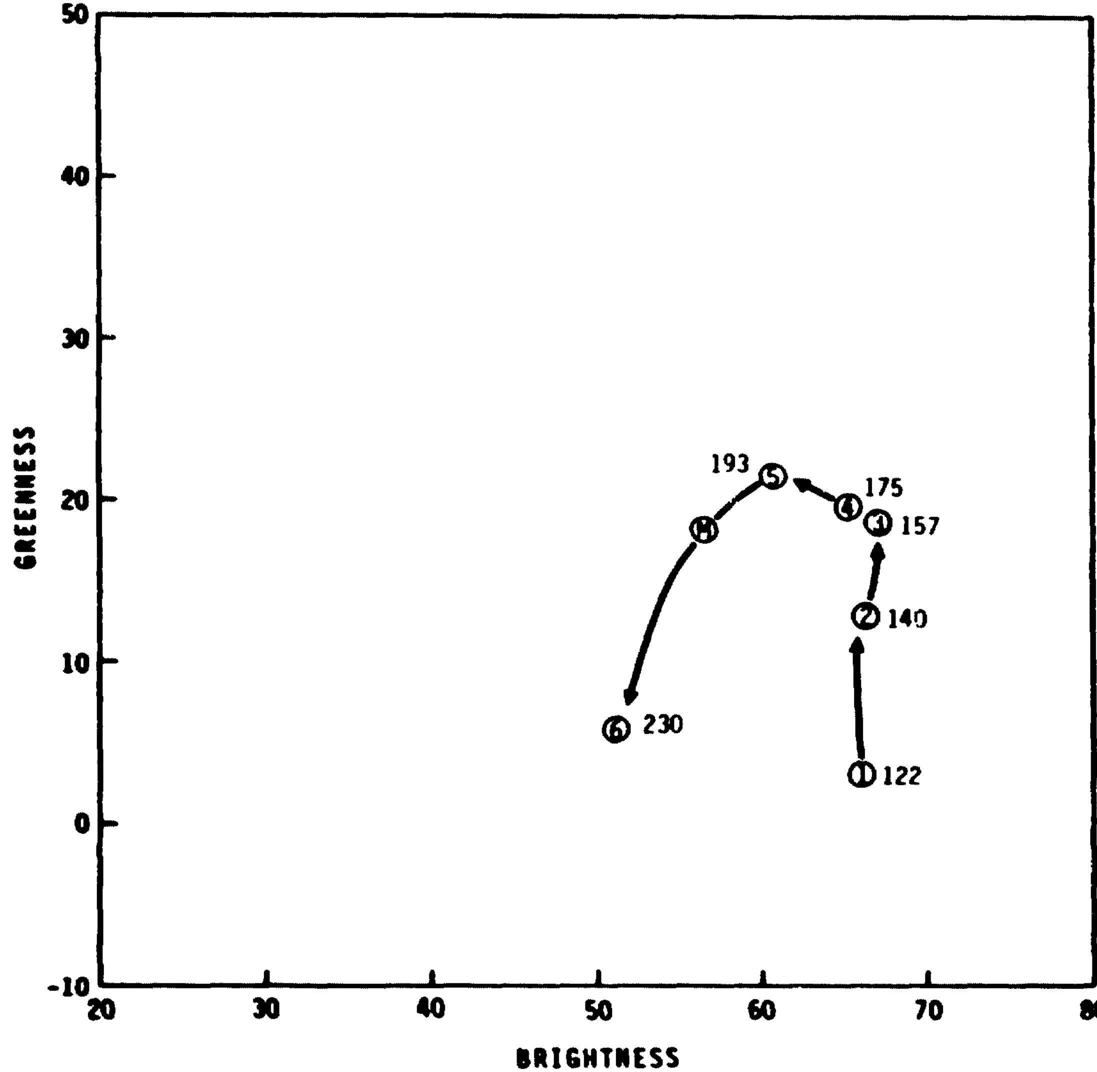
It is not expected that the pasture profile will be confused with the wheat or barley profile because of the extended time that greenness stays in the high values.

13. CASE STUDY NO. 11, GRASS-HAY

Grass crops were located in segments 1927 and 1640; hay fields were found only in segment 1927. The Landsat channel data from these fields were reduced to GB values. The average GB profiles of these fields (figs. 35, 36, and 37) are not too different from those of pasture.

14. CASE STUDY NO. 12, ALFALFA

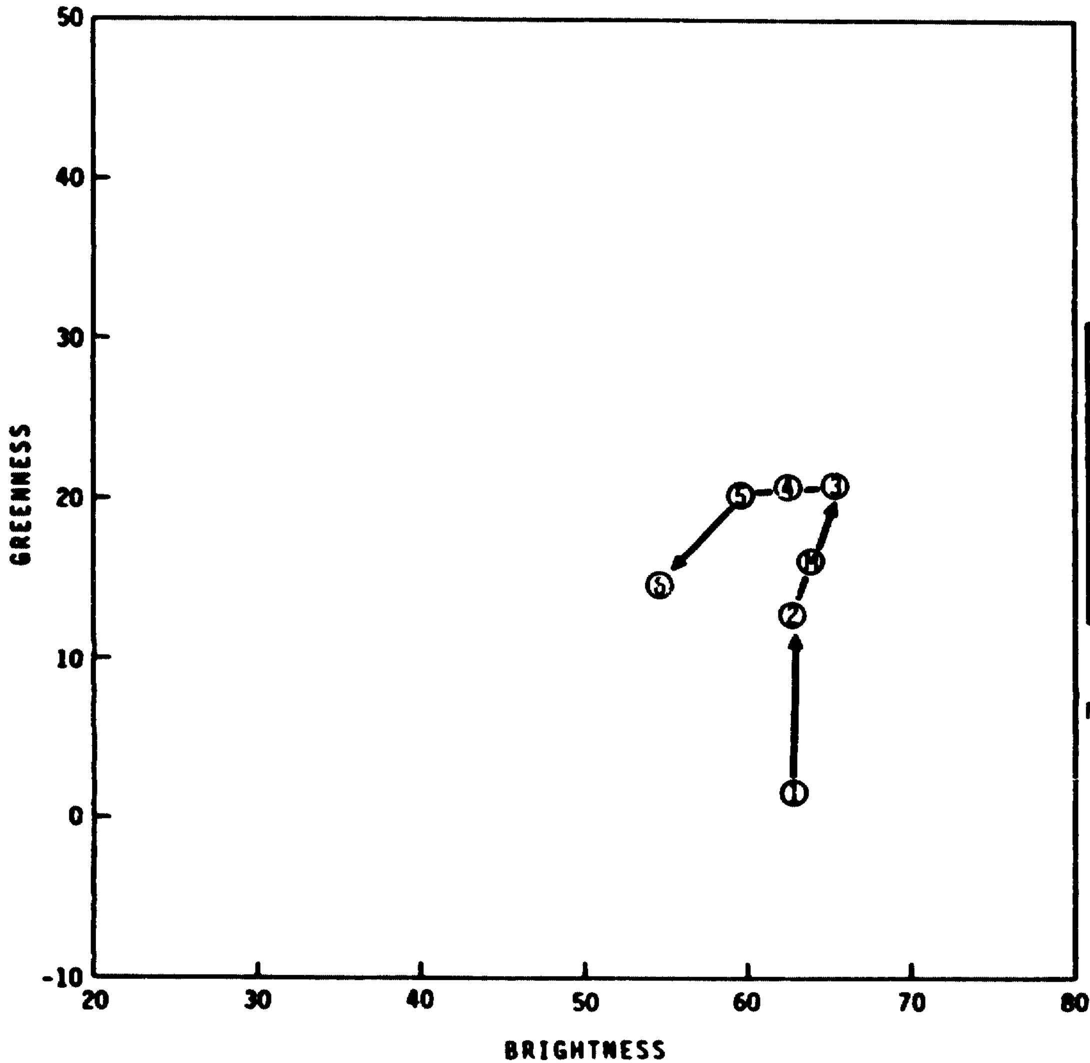
Alfalfa fields were located in segments 1663 and 1640, and five fields in each segment were analyzed. Since alfalfa is a crop which is periodically cut throughout the growing season, each growing period and harvest are easily seen in the Landsat spectral data. Examples of the spectral characteristics are shown in GB plots of two fields in segment 1663, figures 38 and 39. Figure 38 indicates that the crop begins as fallow field on day 120 with the first cutting between day 175 and 193 and the second cutting about day 229. Figure 39 indicates that the crop was well developed by day 120, had the first cutting prior to day 175, had the second cutting prior to day 221, and was developing for a third cutting soon after day 229.



Plot	Day	Standard deviation Pasture (5 fields) Gr.	Standard deviation Pasture (5 fields) Br.
1	122	2.5	3.0
2	140	2.3	2.9
3	157	2.9	2.4
4	175	2.6	2.3
5	193	4.5	4.1
6	230	2.3	0.8

Field pixel count: 244, 260, 345, 291, 511

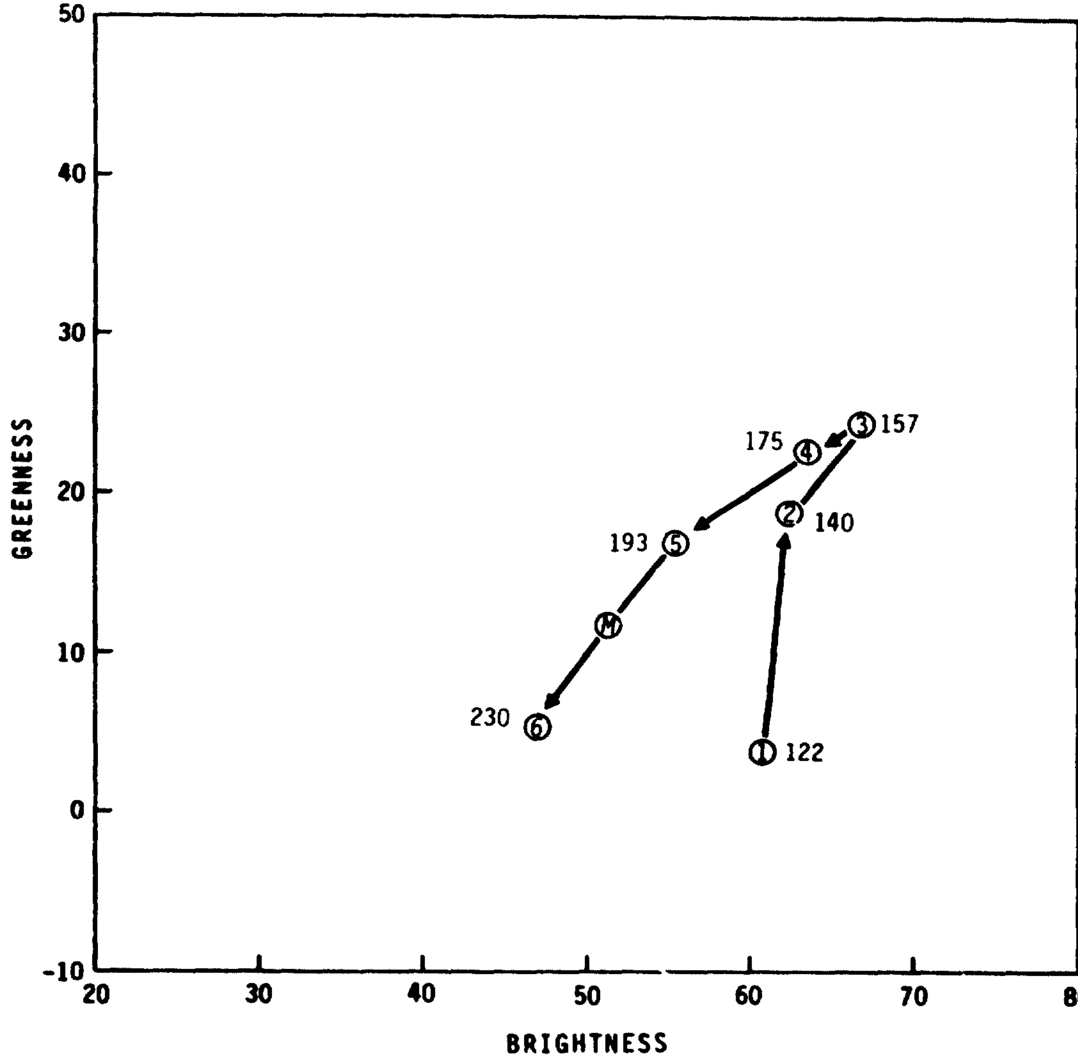
Figure 33.- Average greenness-brightness profile for pasture in segment 1927.



Plot	Day	Standard deviation Pastures (5 fields) Gr.	Br.
1	120	2.6	5.8
2	139	2.8	2.6
3	175	2.8	1.2
4	193	3.3	2.8
5	211	2.8	2.7
6	229	4.4	2.3

Field pixel count: 65, 120, 24, 10, 16

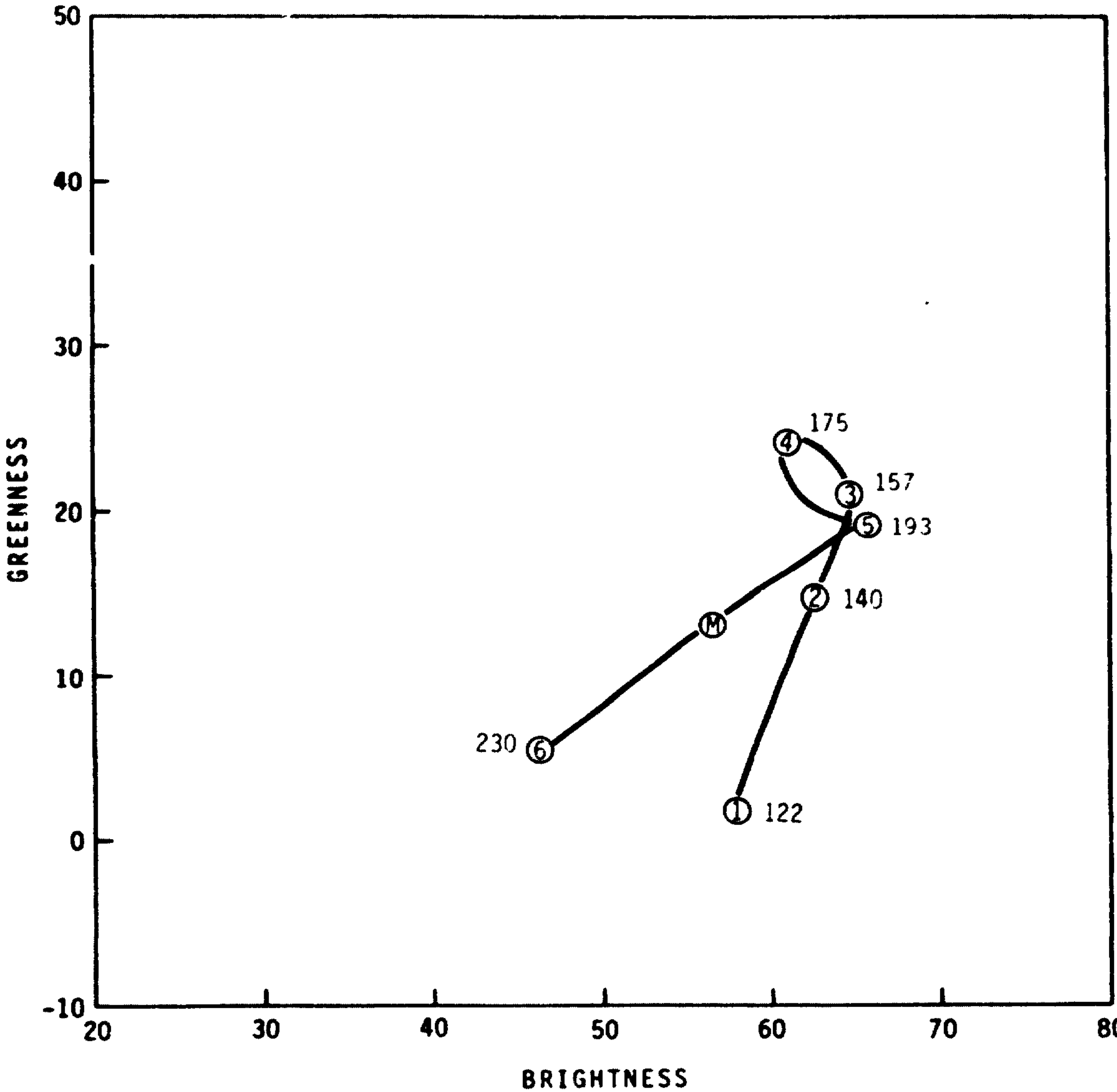
Figure 34.- Average greeness-brightness profile for pasture in segment 1640.



Plot	Day	Standard deviation Hay (6 fields)	
		Gr.	Br.
1	122	3.2	4.7
2	140	7.7	2.6
3	157	9.9	4.7
4	175	6.1	3.3
5	193	5.2	2.4
6	230	5.6	5.5

Field pixel count: 278, 63, 106, 148, 183, 115

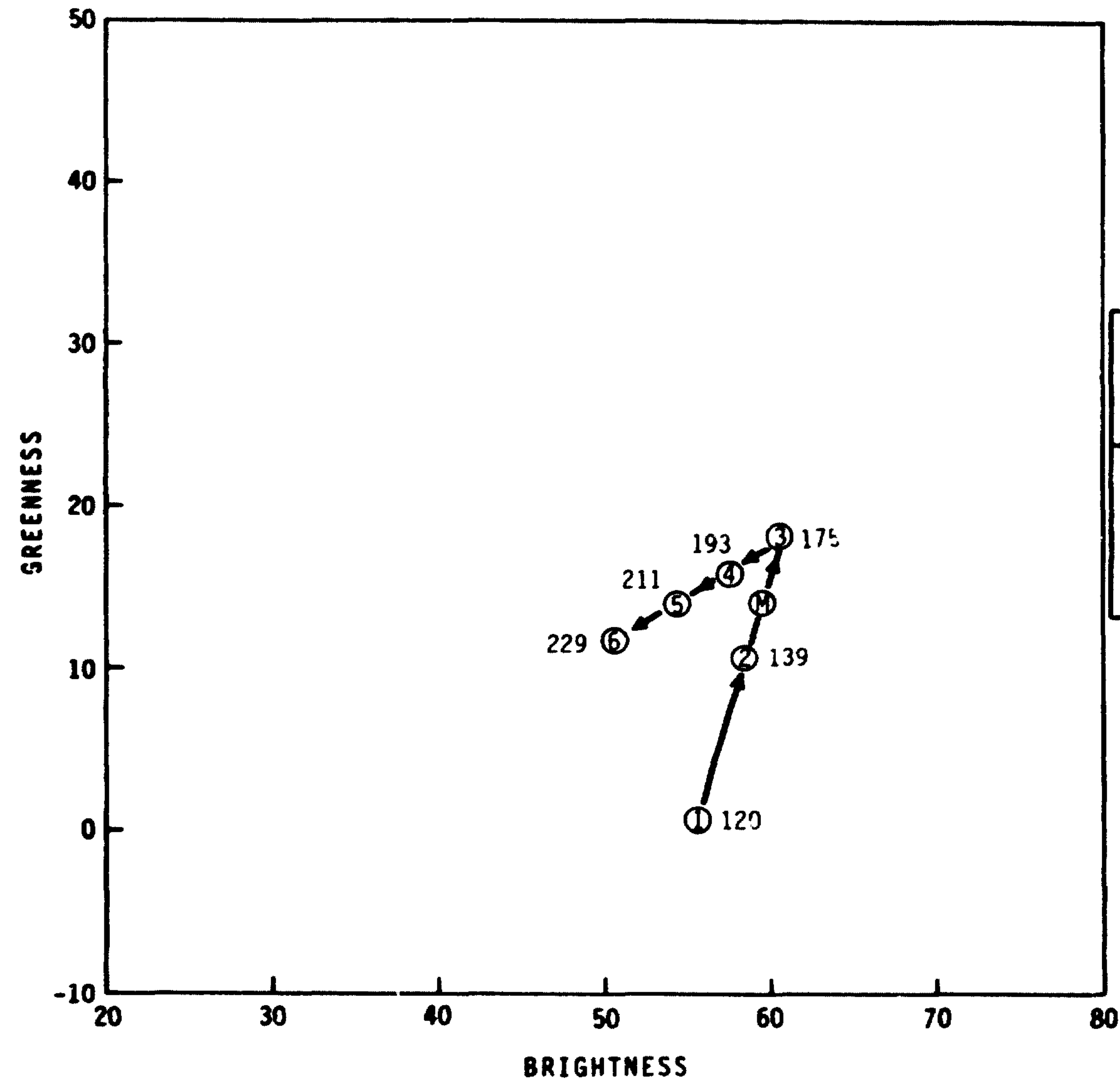
Figure 35.- Average greenness-brightness profile for hay fields in segment 1927.



Plot	Day	Standard deviation Grass (4 crops)	
		Gr.	Br.
1	122	3.4	4.1
2	140	5.1	2.8
3	157	7.7	3.9
4	175	7.6	4.8
5	193	3.0	7.1
6	230	3.9	3.3

Field pixel count: 15, 10, 83, 4

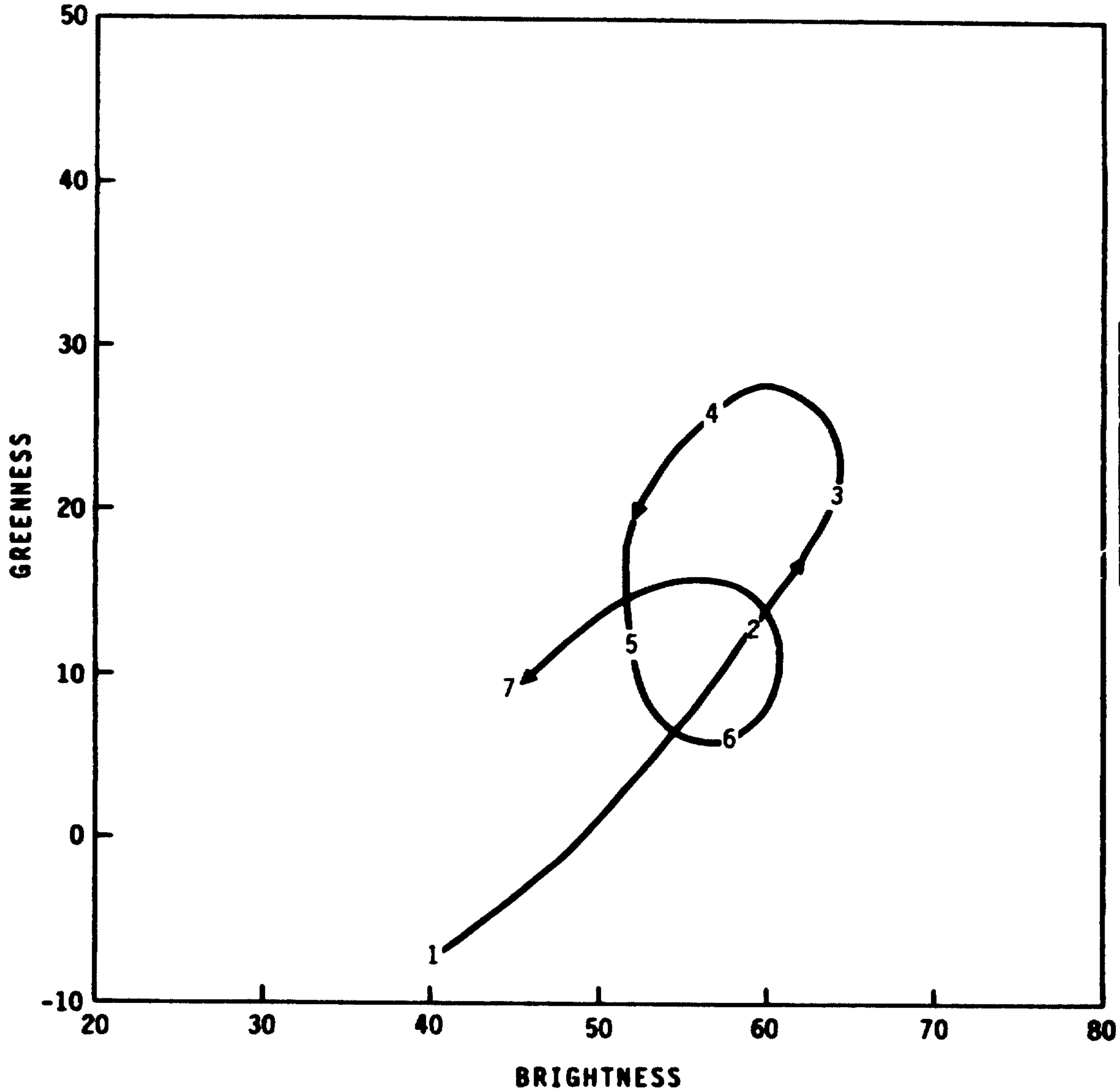
Figure 36.- Average greenness-brightness profile for grass crop in segment 1927.



Plot	Day	Standard deviation Grass (4 crops) Gr.	Br.
1	120	3.2	8.5
2	139	5.0	4.6
3	175	6.1	2.4
4	193	2.8	1.6
5	211	2.6	3.8
6	229	1.9	2.2

Field pixel count: 174, 76, 92, 39

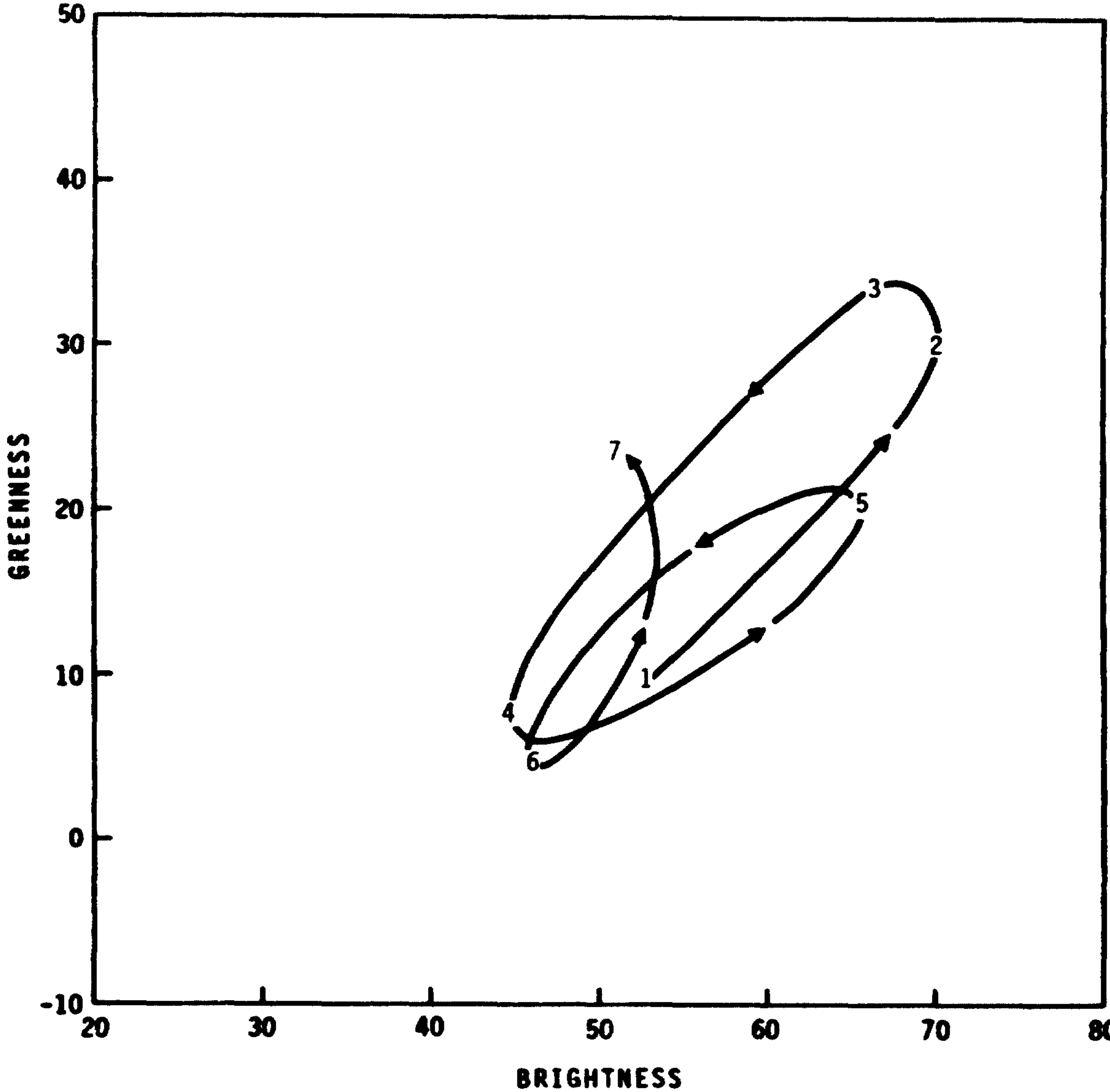
Figure 37.- Average greenness-brightness profile for grass crop in segment 1640.



Plot	Day
1	120
2	139
3	156
4	175
5	193
6	211
7	229

Field pixel count:

Figure 38.- Greenness-brightness profile of alfalfa for field 228 in segment 1663.



Plot	Day
1	120
2	139
3	157
4	175
5	193
6	211
7	229

Field pixel count: 24

Figure 39.- Greenness-brightness profile of alfalfa for field 286 in segment 1663.

15. CASE STUDY NO. 13, MILLET

Millet fields were located only in segment 1927. The GB values were generated from channel data acquired from five of these fields; the average GB plot of these fields is provided in figure 40. It is noted that the millet canopy was very slow to develop and then to blossom forth to high GB values on day 193. Unfortunately, the acquisition (day 211) after day 193 was missing and the maximum GB characteristic of this profile was not established. Later acquisitions after day 230 would have been beneficial to close out the full crop development cycle. This crop is probably a confusion crop for corn/soybeans but not for wheat or barley.

16. CASE STUDY NO. 14, SUGAR BEETS

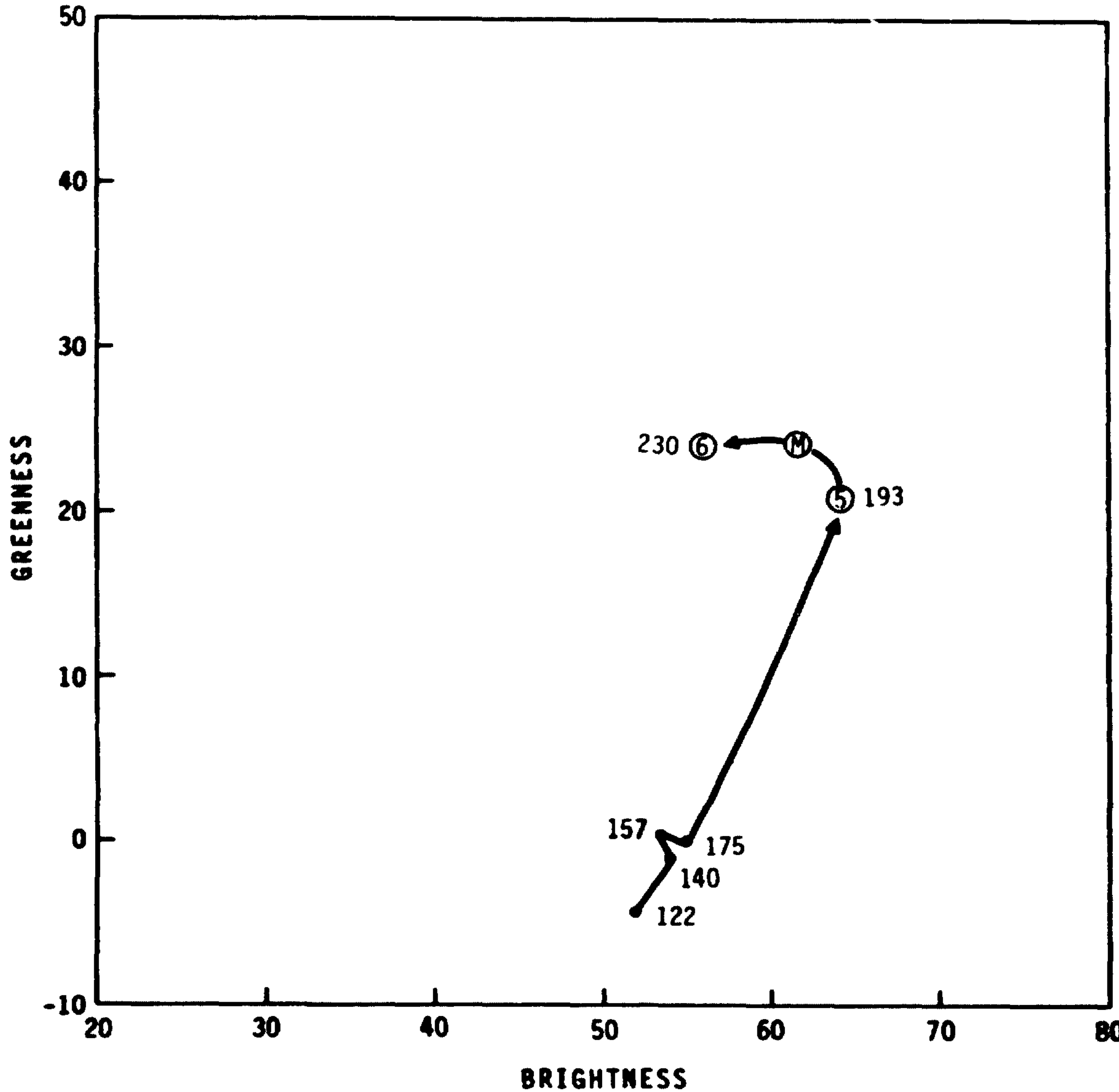
Ten sugar beet fields in segment 1663 were used to acquire channel data and GB values. The average GB profiles are provided in figure 41. Note that the sugar beet GB increases gradually to a maximum and then stabilizes for a period of time. Unfortunately, the data for the acquisition after day 229 were not available to establish the profile through harvest. The extended period of time in which the profile is near the maximum GB establishes this crop as not being a confusion crop for wheat or barley.

17. CASE STUDY NO. 15, TREES

A small sample (16 pixels) of trees in segment 1927 was used to determine a characteristic profile for trees. The average GB profile of these trees is shown in figure 42. This should not be a confusion crop profile to wheat or barley since the initial GB does not start from the soil line and the characteristic GB profile of wheat or barley varies considerably more.

18. CASE STUDY NO. 16, IDLE FALLOW FIELD

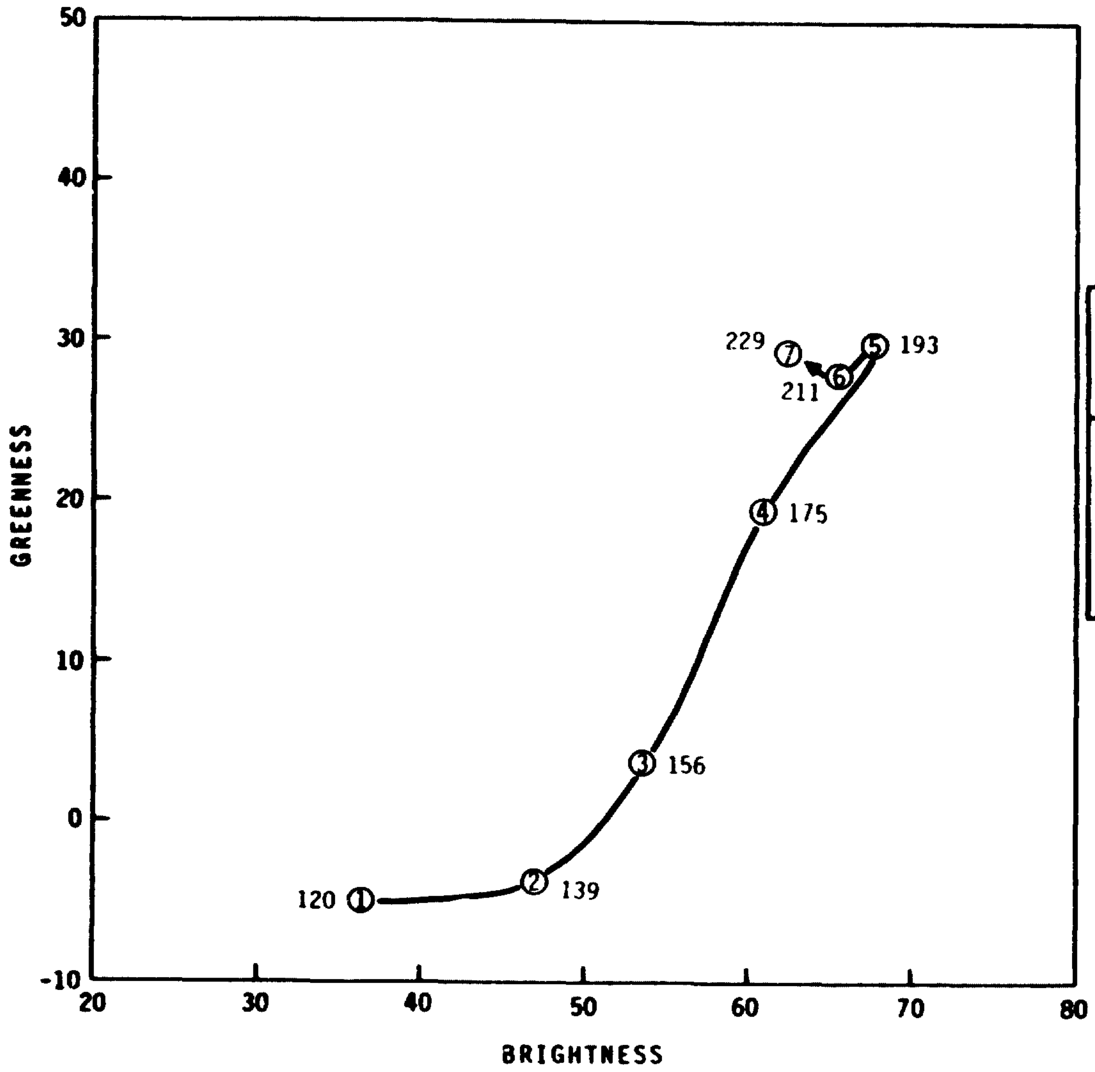
Two idle fallow fields in segment 1630 were used to acquire Landsat channel data and GB values. The profiles of these two fields are shown in figures 43



Plot	Day	Standard deviation Millet (5 fields)	
		Gr.	Br.
1	122	1.1	6.1
2	140	2.4	5.9
3	157	3.5	8.9
4	175	2.4	6.4
5	193	5.3	7.3
6	230	1.3	1.4

Field pixel count: 202, 49, 24

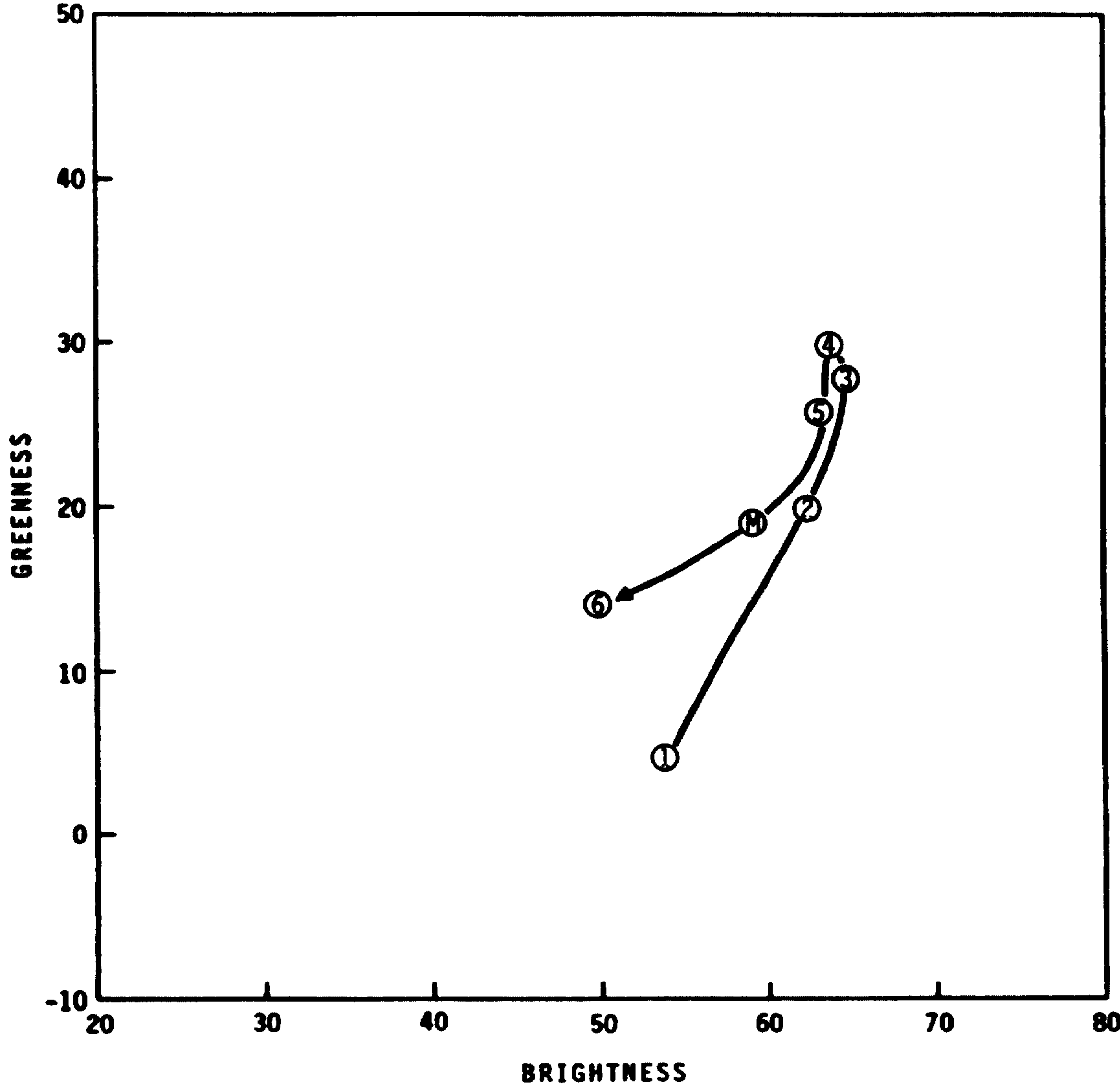
Figure 40.- Average greenness-brightness profile for millet fields in segment 1927.



Plot	Day	Standard deviation Sugar beet (10 fields) Gr.	Br.
1	120	0.5	4.9
2	139	0.7	8.2
3	156	3.9	5.0
4	175	6.3	5.8
5	193	4.4	4.8
6	211	3.7	3.8
7	229	5.4	5.8

Field pixel count: 34, 47, 74, 25, 25, 29, 76, 87, 110, 102

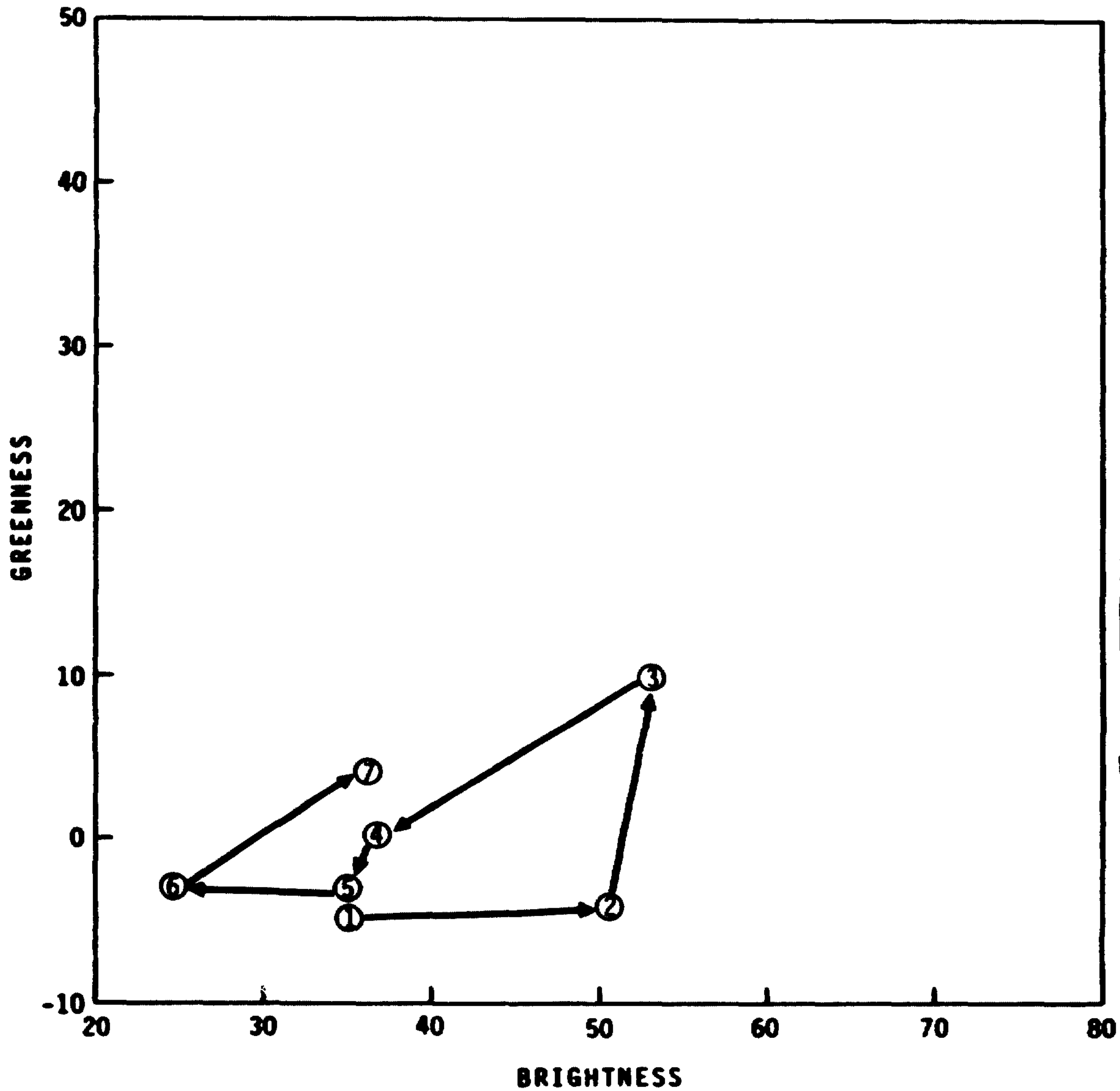
Figure 41.- Average greenness-brightness profile for sugar beet fields in segment 1663.



Plot	Day	Standard deviation Trees (3 areas)	
		Gr.	Br.
1	122	2.2	4.1
2	140	7.7	4.0
3	157	6.7	0.5
4	175	4.5	0.8
5	193	12.1	10.1
6	230	3.6	2.3

Field pixel count: 4, 3, 9

Figure 42.- Average greenness-brightness profile for trees in segment 1927.



Plot	Day
1	120
2	139
3	156
4	175
5	193
6	211
7	229

Field pixel count: 125

Figure 43.- Greenness-brightness profile of idle fallow for field 168 in segment 1663.

and 44. Figure 43 indicates some variability of GB, probably due to weeds or a volunteer crop which was eliminated before day 175. Figure 44 indicates no vegetative growth.

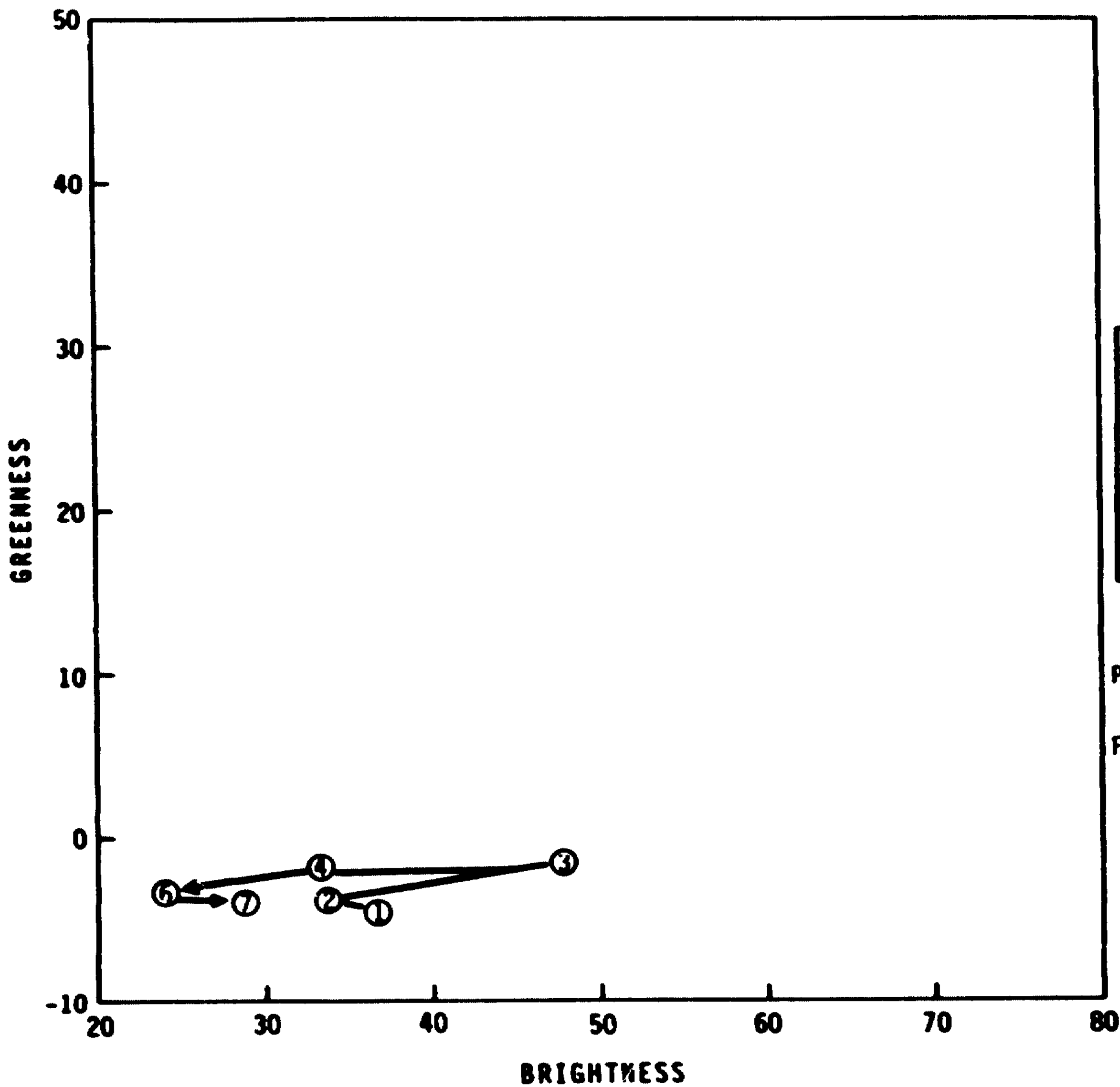
19. CONCLUSION

The purpose of this paper is to provide examples of temporal/spectral profiles (a) primarily for wheat, barley fields, and confusion crops and (b) other agricultural land uses.

The profiles themselves represent spectral data for a field or for a series of fields. Thus, a profile derived from an averaging of each channel's pixels within a field (no border pixel) is considered to be more representative of a field crop than profiles derived from individual pixels.

A profile derived from an averaging of GB values for a series of fields which can be categorized within a segment is considered to be a valid representative of that category of crop for that particular segment or test site. The attempt to categorize fields as early or late planted fields, based on spring wheat plant height early in the crop development, appears to have been a good indicator of the crop development stages. Similarly, the categorization of fields as early or late planted fields (hence, an earlier or later development stage) based on the harvest status at mid harvest appears to have been successful. These relationships can be checked further when planting date information is added to the data base.

Considerable ground-truth information can be associated with the spring wheat field profiles in case study 1. The profiles do establish that peak GB occurs when the plant height and canopy cover are about 60 percent of their season maximum. The profiles show that continued crop development lowers the GB into the ripening period. Increases in brightness during ripening into harvest have been reported (ref. 5); however, in case study no. 1, no profiles of unharvested wheat have shown that brightness increased at the end of the development cycle prior to swathing and harvesting. The profiles are good indicators to establish



Plot	Day
1	120
2	139
3	156
4	175
5	193
6	211
7	229

Plot 5: Cloud cover

Field pixel count: 61

Figure 44.- Greenness-brightness profile of idle fallow for field 174 in segment 1663.

early and late planted fields of wheat and barley. If these profiles are applied to an analytical method proposed by Badhwar (ref. 4), a crop-emergence date can be determined.

The case studies do indicate that barley, winter wheat, and oats are indeed confusion crops for spring wheat. The growing cycle of early planted spring wheat is easily confused with winter wheat.

Techniques to separate spring wheat from barley can be developed using the peak GB and the near-harvest GB as criteria. Barley generally has higher GB peaks and a higher-brightness/lower-greenness value than spring wheat near harvest.

It is conjectured that atmospheric effects account for some of the large variations in the spectral data. Indirect cloud effects and invisible moisture (water vapor) concentrations are two areas which need to be investigated.

Since ground-truth data are lacking for all crops other than for spring wheat, the case studies are provided without knowing whether they are representative of a normal or abnormal growth cycle. It is assumed that all are normal crops representative of this region with this particular year's climatic regime.

The case studies of the spectral/temporal analyses of the field crops in the three segments (1640, 1927, and 1663) point out the wide variability of GB profiles within a rather limited area of the agriculture scene.

The variability of the profiles indicates the need for performing more detailed studies to associate the variability with climatic parameters, soil parameters, crop variety, and crop stress conditions.

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APPENDIX A

THREE TEST SITES IN SOUTHEAST NORTH DAKOTA

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THREE TEST SITES IN SOUTHEAST NORTH DAKOTA

Segment or test site number	Landsat data Set, location	1977 Landsat II acquisition dates, day of year
1640	Barnes, North Dakota	120, 139, 175, 193, 211, 229
1663	Richland, North Dakota	120, 139, 156, 175, 193, 211, 229
1927	Sargent, North Dakota	122, 140, 157, 175, 193, 230

APPENDIX B

CASE STUDY INFORMATION

APPENDIX B

CASE STUDY INFORMATION

Code	Land use/crop	Segment 1640	Segment 1663	Segment 1927
90	Alfalfa	X	X	
92	Corn	X	X	X
94	Sunflowers	X	X	X
97	Soybeans	X		
98	Sugar beets	X		
99	Winter wheat		X	
100	Spring wheat	X	X	X
101	Barley	X	X	X
102	Rye			X
103	Flax	X	X	X
104	Oats	X	X	X
080	Millet			X
111	Grass		X	X
112	Hay			X
113	Pasture		X	X
114	Trees			X
115	Idle fallow	X		

APPENDIX C

LANDSAT-2 TRANSFORMATION

APPENDIX C

LANDSAT-2 TRANSFORMATIONS

LACIE Transformations

greenness: $y_1 = -0.283\ x_1$

$-0.660\ x_2$

$+0.577\ x_3$

$+0.388\ x_4$

brightness: $y_2 = 0.332\ x_1$

$+0.603\ x_2$

$+0.676\ x_3$

$+0.263\ x_4$; X_i where X is pixel value and i the channel.

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