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AN EARLY ESTIMATE OF SMALL GRAINS ACREAGE

Large Area Crop Inventory Experiment (LACIE)

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AN EARLY ESTIMATE OF SMALL GRAINS ACREAGE

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CONTENTS

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TABLES

FIGURES

AN EARLY ESTIMATE OF SMALL GRAINS ACREAGE

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SUMMARY

This internal note describes a transformation which reduces four dimensional agricultural data obtained from a satellite to two dimensions. A classification scheme to provide an early estimate for winter small grains is then presented. The classifier is then evaluated using ground truth. The results indicate a reasonable job can be done.

INTRODUCTION

The problem being addressed is the inventory of the small grains crop. The primary tool to be used in this effort is multispectral data obtained from scanners onboard the Earth Resources Technology Satellite (ERTS). The problems arising from an attempt to do a full inventory are such that estimation of the inventory is a more realistic goal. This report will be concerned only with an attempt to estimate the total acreage of winter small grains.

Since estimation is the major concern, only a sample of the data available will be required. Only the data from the 4-by-5-mile sample segments are maintained. The data consists of measurements taken at four different wavelengths, and are, therefore, four-dimensional in nature. The data for each sample segment are nominally available every 18 days throughout the growing season. In practice, the acquisition rate is considerabley less due to various factors such as haze and cloud cover.

Two general approaches may be taken. First, one may assume a theoretical model for the data and then use the data to estimate the parameters needed to make a decision within this theoretical framework. The second approach, and the one taken here, is simply to analyze the data for features that may be used for the desired purpose.

Here the concern is to separate small grains from other agricultural crops, and the feature used is the growth trend. Other efforts using growth trends include the delta classifier (ref. 1) and the IBM classifier (ref. 2). One of the advantages of the growth trend analysis is the natural incorporation of the temporal aspect for multiple acquisitions.

The growth of a small grains crop can be divided into four phases or biostages. Although the effort here is centered on making an acreage estimate in biostage 2, it is reasonable to believe that the technique could be extended for use in later biostages.

The following discussion deals with wheat versus non-wheat because wheat is the predominant small grains crop. Other studies and the results of this study indicate that the small grains as a whole exhibit the characteristic growth trend. This study is concentrated on winter small grains only, and as a result all spring small grains will be grouped with non-small grains.

TRANSFORMATION

When the problem of analyzing multidimensional data is considered, it is natural to attempt to map the data to some lower dimensional space in such a way that a minimum of information is lost. In this study, such a transformation is presented and it is shown that an excessive amount of information is not lost.

The chosen transformation is constructed as a composition of mappings. The first maps the four-channel Landsat data into the standard three-dimensional simplex; that is,

$$f(x_1, x_2, x_3, x_4) = (z_1, z_2, z_3, z_4)$$

where (1)

$$z_i = x_i/(x_1 + x_2 + x_3 + x_4)$$

thus reducing the dimension from four to three.

Munday and Alfoldi (ref. 3) have shown that for three-band isoluminous transformations the transformation of this type is theoretically optimal because it is strictly isoluminous and chromaticity invariant. Their development easily extends to four bands, as in the case of Landsat data. Thus, at this stage, channel values are available that represent the percent of total reflected radiation contributed by each wavelength interval. It seems reasonable to expect that this is a more stable quantity than the total reflected energy, which is a function of many variables such as haze, Sun angle, shade, and probably many atmospheric conditions.

Reflectance spectra have been experimentally determined for mature leaves of certain agriculture crops. The information shown in figure 1 is taken from Wiegand, Gausman, and Allen (ref. 4).

The reflectance data for wheat is not included in the chart, but it is clear from the given data that reflectance properties for leaves of agricultural crops are quite similar, at least in the wavelength interval from .5 to 1.1, which corresponds to the Landsat data interval. They reflect strongly in the near-infrared and infrared band, .7 to 1.1, and very little in the visible band from .5 to .7. Therefore, it would be difficult to distinguish between two crops that have identical growth patterns if they are normally planted at the same time of the year. However, crops with different growth patterns should be distinguishable at some point during their biological development. For this reason, it would be desirable to know spectral response curves as a function of time in the growing season for wheat.

In order to construct graphs from Landsat data that are comparable to the preceding spectral response curves, the data must first be normalized in order to obtain the total reflectance percentage for the four channels. The data obtained from equation (1) is not precisely what is given in the figure 1. To construct a graph from the data in figure 1 giving percent of total reflectance, one must compute $\alpha_i = \beta_i / \Sigma \beta_j$ where β_i is the percent of total incident energy reflected in channel i.

The following graphs in figure 2 show percent of total reflectance for wheat in each channel because the information necessary to construct percent of incident radiation that is reflected in each channel is not available. A typical temporal pattern for a wheat field is shown in figure 3 where the label $t_i = n$ means the information is from data collected n days into biophase i. There are 18 calendar days between each graph. All data were taken from Landsat 2.

Figure 3 also shows charts for two subclasses of wheat and four subclasses of non-wheat taken from a sample segment in Kansas (1975 Landsat 2 data) on five different dates. On examination of the charts, one can see the possibilities for separating wheat from non-wheat crops. Notice in particular that at time $t_2 = 25$ and $t_3 = 7$ (late biophase 2 and early biophase 3) that channel 1, 3, and 4 values are all greater than channel 2 for the wheat subclasses and that this property does not hold for any of the non-wheat subclasses.

The second transformation to be applied is a one-to-one mapping which transforms the three-dimensional simplex in four-dimensional space into a three-dimensional simplex embedded in a three-dimensional space by taking the differences of each channel with respect to channel 2; that is,

$$g(z_1, z_2, z_3, z_4) = (z_1 - z_2, z_3 - z_2, z_4 - z_2) \tag{2}$$

On projecting Landsat 2 data from five sample segments taken from well separated areas of the United states into the plane of $z_3 - z_2$ and $z_4 - z_2$, it was discovered that the agricultural data as identified by the analyst interpreters (AI's) all lie essentially on the same straight line. These projected points are illustrated in figure 4. (Landsat 1 data projects onto a different line -- see figure 5 -- having the same slope.) This observation implies that the transformed agricultural data lies in a plane parallel to the $z_1 - z_2$ axis that cuts the $z_3 - z_2$, $z_4 - z_2$ plane on the above line.

In addition to studying the original radiance normalized data, the motion or behavior of the transformed data in this plane can be studied further as a function of time into the growing season of wheat in order to find optimum times for separating wheat from non-wheat. The transformation into the plane can be made using the following equations.

$$x = z_1 - z_2$$
$$y = .7071 \, (z_3 + z_4 - 2z_2 + 21) \qquad (3)$$

Two additional variables were also maintained by the computer program that processed the data. These are distance from the point to the plane and the sum of the original four channels of data, or the total reflectance. Having seen the tightness of the fit about the line in the plane, figure 6 shows the scatter of the data in the x,y plane of data variability. Once the data was reduced from four dimensions to a plane, the next step was to analyze the data for the features that could be used to separate small grains from other crops.

CLASSIFICATION SCHEME

As mentioned earlier, the feature used is the trend exhibited by the data over the growing season. Figures 7 and 8 show the y "green" values as a function of day of the year for AI-labeled fields. Both wheat and non-wheat fields are included. The figures also show the mean y value for the entire scene, μ_y, and the mean plus one standard deviation, $\mu_y + \sigma$. Figures 7 and 8 also show that $\mu_y + \sigma$ separates the wheat and non-wheat.

Some early results using a classification scheme based on graphs similar to figures 7 and 8 are contained in Lea (ref. 5). After these results were analyzed and the data was examined further, a typical growth trend, as illustrated in figure 9, was discovered. Figures 10 to 13 show the mean x and y values for the AI-labeled fields used in figures 7 and 8. The numerical sequence (i.e. 1, 2, etc.) represents successive acquisition dates throughout the growing season. The following acquisition dates were used: day 349 of 1975 and days 38, 73, 109, 127, and 164 of 1976. It can easily be seen that the growth trend involves changes in both x and y values.

Figures 14 and 15 are similar to figures 7 and 8 but involve the mean x value for AI-labeled fields and the mean value of x for the scene. These quantities are again plotted against day of year to indicate the trend through the growing season. Note that wheat and non-wheat can be separated by the scene mean, so that x also contains information useful in separating crops. the x values were incorporated into the classification rule and an early version of the scheme was compared to AI-labeled fields from 13 sample segments yielding .851 and .969 as the probabilities of correct classification for wheat and non-wheat, respectively.

In examining the behavior of x, it was noted that water corresponded to unusually large x values. Because this is the case, the scene mean is shifted from its normal location when a scene contains a large body of water. When segments with large bodies of water are processed, a histogram of the x values yields a second peak at a high positive x value. Thus, the problem segments are easily spotted and a trimmed mean (i.e., mean of the scene excluding the water) may be used in place of the scene mean.

After some experimentation, the following decision rule involving both x and y was chosen. Classify a pixel as small grain if, on the day C nearest to but not before the beginning of biophase 2,

$$\text{i)} \quad y > \min\{\max\{\mu_y + \sigma/2, 20\}, 25\} \tag{4}$$

where μ_y is the scene mean of the y values on day C and σ is the associated standard deviation and

$$\text{ii)} \quad \bar{x} > \bar{\mu}_x, \text{ where } \bar{x} = (\Sigma x_i)/N \text{ and } \bar{\mu}_x = (\Sigma \mu_{x_i})/N \tag{5}$$

where x_i is the pixel value of x for the pixel on day i and μ_{x_i} is the scene mean for x on day i and the summation is over the N acquisitions

This is the form of the rule that was used to generate the test results presented in section 6.

The computer program was written to use two, three, or four acquisitions, but it was decided not to use less than three and four, if possible. When there was a choice of data available for use in the classification, they were picked to give a "spread" over biophase 1. If possible, the first date was picked after day 300 to minimize the chance of observing last year's crop. Also a mid-winter date was sought.

Note that the classification uses only spectral data and that no use was made of the spatial information; that is, field patterns. This spatial information was used, however, in evaluating the resulting class map. An example showing the field patterns for sample segment 1978 is shown in figure 16.

THE GROUND TRUTH DATA SET

For this study, the data from nine intensive test sites (ITS) were available. Each ITS covered only a portion of the corresponding sample segment. Table I gives the location, numbering scheme, and acquisition dates used for each ITS.

Each ITS was divided according to the fields on the ground. The type and amount of information available on a particular field were quite varied. Most of the fields in the ITS were listed in a crop inventory report. This report included acreage, land use code, use of irrigation and fertilizer, and planting date. Many of the small grains fields also had yield data available. Certain fields within each ITS had been preselected for periodic observation. These fields were reported on approximately every 18 days throughout the growing season. The reports included information on acreage, land use, growth stage, ground cover, plant height, surface moisture, weed growth, field operation, growth/yield detractants, and stand-quality.

For each ITS, line and pixel boundary information from a number of fields that had been registered with the satellite multispectral scanner data were available. These fields were also labelled as wheat or non-wheat. These labels generally referred to the crop planted in the fall. In several cases, the periodic information showed that the fields had not been harvested; that is, plowed under or replanted. For these cases, the label on the field was changed. Also since classification groups oats with wheat, the oats fields were changed from non-wheat to small grains. The data used here contains some of the data discussed in Kern (ref.6).

THE RESULTS

Of the nine sample segments listed in table 1, only five have acquisition dates during biophase 2: 1962, 1975, 1978, 1982, and 1988. The other four have acquisitions fairly late in biophase 1, so that these, too, are processed. Table 2 gives percents misclassified and classified correctly.

The results for two sample segments were poor, so these were singled out for study. Sample segment 1988 is in a drought region, and it is believed that the drought caused unusually low x and y values in the wheat, which, in turn, caused poor results for wheat. It is noted that all non-wheat fields were correctly classified.

Sample segment 1973 remains the enigma of the study. It is located in the same county as sample segment 1974. The ground truth indicates that the same factors influencing growth were present in both, yet the results are markedly different. A possible explanation of the non-wheat results is that in sample segment 1974, all but three of the non-wheat fields were planted as a crop in the spring; whereas in sample segment 1973, many fields were left inactive from the preceeding year. This indicates the classifier may not work well in areas where the land is left idle. The classifier may, however, be finding volunteer small grains in these areas. In one field that was planted in barley, the ground truth indicates that wild oats are mixed in throughout the field. One thing is very obvious: the data itself is quite different for the two sample segments.

Table 2 gives the accumulated percentages for the sample segments in biophase 2, excluding 1988, and for the sample segments using late biophase 1, excluding 1973. The accumulated percentages for the combined group, excluding 1973 and 1988, are also given there. Tables 3 to 11 give the counts for each of the fields used in the sample segments.

CONCLUDING REMARKS

A major advantage of a scheme such as the one presented here is that it needs minimal human intervention. This entire scheme, with the exception of the choice of dates, can be computerized and the results obtained in minutes. The decision to limit the number of acquisitions processed to four was made to facilitate operation on the particular computer being used. Some earlier runs on another computer system were based on as may as seven biophase-1 acquisitions.

Although the results for sample segments 1973 and 1988, particularly 1973, are discouraging, those presented in table 2 are good. It is felt that the results support further investigation of growth trend classifiers. A possible extension of the classifier presented here would be to make the bounds on x and y functions of the geographic location and date of the last acquisition used. Such a scheme would allow for variations in biowindows across the country and allow processing over a wide range of acquisition dates, possible at any biostage. It may also be possible to incorporate spatial data into the classifier.

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TABLE I.- THE NINE SAMPLE SEGMENTS SELECTED FOR THE STUDY

ITS number	Geographic location	Sample segment number	Acquisition dates for classification	Beginning dates for biophases 2 and 3
23	Boone County, Indiana	1983	75285,75303,76082,76100	76121,76155
24	Madison County, Indiana	1982	75303,75321,76082,76154	76121,76155
27	Finney County, Kansas	1988	75312,76001,76037,76109	76092,76148
29	Rice County, Kansas	1963	75293,75311,76018,76108	76124,76148
30	Saline County, Kansas	1962	75311,76053,76107,76125	76124,76148
33	Randall County, Texas	1978	75313,76056,76092,76110	76101,76127
38	Oneida County, Idaho	1975	76130,76137,76155,76172	76162,76182
40	Whitman County, Washington	1973	75308,76069,76087,76142	76147,76177
41	Whitman County, Washington	1974	75308,76124,76142	76147,76177

TABLE II.- ACCUMULATED AND SEGMENT LEVEL CLASSIFICATION PERCENTS

Sample segment Number	Small grains			Other		
	Percent correct	Percent wrong	Number of pixels	Percent correct	Percent wrong	Number of pixels
1962	93.87	6.13	751	85.85	14.15	106
1975	87.27	12.73	377	99.42	0.58	810
1978	67.95	32.05	468	96.33	3.67	708
1982	30.00	70.00	30	99.72	0.28	356
Total 1	83.70	16.30	1626	97.68	2.32	1980
1963	64.75	35.25	261	96.86	3.14	414
1974	89.61	10.39	635	100.00	0.00	648
1983	69.49	30.51	59	97.14	2.86	384
Total 2	81.57	18.43	955	98.34	1.66	1446
1973	38.09	61.91	1108	75.40	24.60	1297
1988	29.59	70.41	872	100.00	0.00	752
*Total	82.91	17.09	2581	97.96	2.04	3426

*Excluding 1973 and 1988

TABLE III.- FIELD COUNTS FOR SAMPLE SEGMENT 1962

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
1	sg	35	17	18
4	sg	20	18	2
5	sg	30	30	0
7	sg	77	77	0
8	sg	30	30	0
[illegible]	sg	47	46	1
11	sg	31	20	11
12	sg	24	23	1
13	sg	63	63	0
15	sg	15	15	0
16	sg	31	31	0
18	sg	27	27	0
19	sg	34	33	1
20	sg	20	19	1
21	sg	42	42	0
22	sg	24	23	1
24	sg	32	32	0
25	sg	14	14	0
26	sg	27	27	0
28	sg	21	11	10
30	sg	42	42	0

TABLE III.- FIELD COUNTS FOR SAMPLE SEGMENT 1962 - Continued

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
2	other	5	0	5
3	other	19	0	19
6	other	14	13	1
10	other	9	0	9
14	other	14	2	12
17	other	13	0	13
27	other	14	0	14
29	other	18	0	18

TABLE IV.- FIELD COUNTS FOR SAMPLE SEGMENT 1963

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
7	sg	14	2	12
8	sg	12	7	5
9	sg	13	4	9
12	sg	15	14	1
13	sg	15	1	14
15	sg	24	7	17
16	sg	21	20	1
17	sg	37	37	0
22	sg	11	0	11
23	sg	24	18	6
25	sg	14	7	7
28	sg	27	26	8
30	sg	34	26	8
1	other	32	0	32
2	other	13	0	13
3	other	28	0	28
5	other	34	0	34
6	other	27	0	27
10	other	29	0	29
11	other	18	3	15
14	other	18	2	16

TABLE IV.- FIELD COUNTS FOR SAMPLE SEGMENT 1963 - Continued

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
18	other	16	1	15
19	other	20	2	18
20	other	45	0	45
21	other	26	0	26
24	other	27	0	27
26	other	22	3	19
27	other	17	0	17
29	other	15	2	13

TABLE V.- FIELD COUNTS FOR SAMPLE SEGMENT 1973

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
1	sg	145	70	75
4	sg	69	0	69
5	sg	155	32	123
8	sg	45	34	11
9	sg	262	81	181
10	sg	49	5	44
13	sg	31	31	0
14	sg	33	21	12
18	sg	127	25	102
19	sg	141	85	56
23	sg	43	37	6
27	sg	8	1	7
2	other	87	49	38
3	other	177	7	170
6	other	89	34	55
7	other	23	15	8
11	other	163	0	163
12	other	33	16	17
15	other	46	39	7
16	other	51	4	47
17	other	46	2	44

TABLE V.- FIELD COUNTS FOR SAMPLE SEGMENT 1973 - Continued

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed otner
20	other	121	75	46
21	other	168	44	124
22	other	119	10	109
24	other	135	5	130
25	other	30	14	16
26	other	9	5	4

TABLE VI.- FIELD COUNTS FOR SAMPLE SEGMENT 1974

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
1	sg	22	21	1
3	sg	51	45	6
4	sg	20	17	3
5	sg	77	69	8
7	sg	44	43	1
9	sg	33	33	0
12	sg	24	21	3
13	sg	29	27	2
15	sg	114	99	15
16	sg	55	52	3
18	sg	37	37	0
20	sg	18	18	0
22	sg	52	37	15
24	sg	23	23	0
25	sg	18	9	9
28	sg	18	18	0
2	other	25	0	25
6	other	25	0	25
8	other	25	0	25
10	other	28	0	28
11	other	13	0	13

TABLE VI.- FIELD COUNTS FOR SAMPLE SEGMENT 1974 - Continued

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
14	other	55	0	55
17	other	37	0	37
19	other	15	0	15
21	other	185	0	185
23	other	117	0	117
26	other	32	0	32
27	other	62	0	62
29	other	12	0	12
30	other	17	0	17

TABLE VII.- FIELD COUNTS FOR SAMPLE SEGMENT 1975

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
2	sg	40	27	13
4	sg	61	47	14
6	sg	18	18	0
10	sg	200	200	0
13	sg	32	32	0
23	sg	26	5	21
7	other	84	0	84
8	other	84	0	84
9	other	33	0	33
11	other	27	1	26
12	other	75	0	75
14	other	31	0	31
15	other	32	0	32
16	other	33	0	33
17	other	26	0	26
18	other	26	1	25
19	other	33	0	33
20	other	37	0	37
22	other	28	0	28
25	other	39	2	37
26	other	34	0	34

TABLE VII.- FIELD COUNTS FOR SAMPLE SEGMENT 1975 - Continued

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
27	other	38	0	38
28	other	35	0	35
1	other	15	0	15
3	other	20	0	20
5	other	20	0	20
21	other	28	0	28
24	other	32	0	32
29	other	23	0	23
30	other	56	0	56

TABLE VIII.- FIELD COUNTS FOR SAMPLE SEGMENT 1978

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
3	sg	21	21	0
4	sg	42	41	1
5	sg	18	12	6
6	sg	23	0	23
7	sg	27	0	27
8	sg	29	28	1
13	sg	60	30	30
15	sg	26	0	26
16	sg	36	35	1
17	sg	24	24	0
19	sg	30	0	30
21	sg	53	53	0
25	sg	57	52	5
30	sg	22	22	0
1	other	88	0	88
2	other	140	26	114
9	other	23	0	23
10	other	30	0	30
11	other	40	0	40
12	other	16	0	16
14	other	38	0	38

TABLE VIII.- FIELD COUNTS FOR SAMPLE SEGMENT 1978 - Continued

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
18	other	38	0	38
20	other	12	0	12
22	other	113	0	113
23	other	19	0	19
24	other	32	0	32
26	other	21	0	21
27	other	44	0	44
28	other	27	0	27
29	other	27	0	27

TABLE IX.- FIELD COUNTS FOR SAMPLE SEGMENT 1982

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
5	sg	14	0	14
6	sg	12	[illegible]	6
19	sg	4	3	1
1	other	19	0	19
2	other	22	0	22
3	other	10	0	10
4	other	18	0	18
7	other	18	0	18
8	other	20	0	20
9	other	19	0	19
10	other	20	1	19
11	other	18	0	18
12	other	23	0	23
13	other	19	0	19
14	other	33	0	33
15	other	26	0	26
16	other	22	0	22
17	other	33	0	33
18	other	18	0	18
20	other	18	0	18

TABLE X.- FIELD COUNTS FOR SAMPLE SEGMENT 1983

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
3	sg	18	16	2
6	sg	10	10	0
16	sg	10	9	1
22	sg	11	6	5
27	sg	10	0	10
1	other	71	0	71
2	other	28	0	28
4	other	19	0	19
5	other	14	0	14
7	other	10	0	10
8	other	12	0	12
9	other	14	0	14
10	other	23	0	23
11	other	7	0	7
12	other	43	0	43
13	other	13	0	13
14	other	13	0	13
15	other	9	0	9
17	other	9	0	9
18	other	13	0	13
19	other	13	0	13

TABLE X.- FIELD COUNTS FOR SAMPLE SEGMENT 1983 - Continued

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
20	other	6	0	6
21	other	12	0	12
23	other	9	0	9
24	other	8	0	8
25	other	11	0	11
26	other	18	0	18
28	other	9	2	7
29	other	13	0	13
30	other	8	0	8

TABLE XI.- FIELD COUNTS FOR SAMPLE SEGMENT 1983

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
1	sg	61	10	51
2	sg	79	6	73
4	sg	61	3	58
5	sg	62	58	4
6	sg	34	29	5
7	sg	80	58	22
9	sg	38	13	25
13	sg	34	3	31
21	sg	24	10	14
22	sg	18	11	7
25	sg	71	14	57
27	sg	34	23	11
28	sg	101	20	81
3	sg	49	0	49
8	other	48	0	48
10	other	127	0	127
11	other	122	0	122
12	other	58	0	58
14	other	24	0	24
15	other	25	0	25
16	other	45	0	45

TABLE XI.- FIELD COUNTS FOR SAMPLE SEGMENT 1983 - Continued

Field number	Type of crop	Number of pixels	Number classed small grains	Number classed other
17	other	25	0	25
18	other	58	0	58
19	other	36	0	36
20	other	35	0	35
23	other	43	0	43
24	other	37	0	37
26	other	34	0	34
29	other	132	0	132
30	other	29	0	29

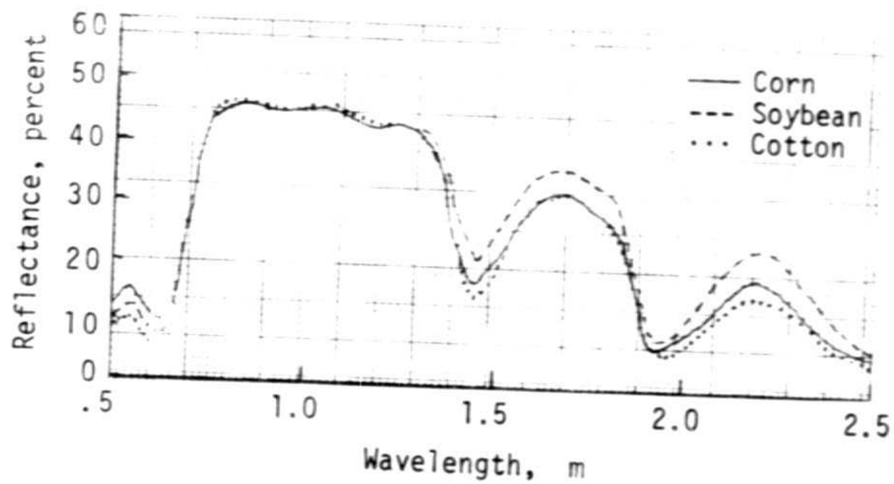


Figure 1.- Percent of incident radiation reflected versus wavelength.

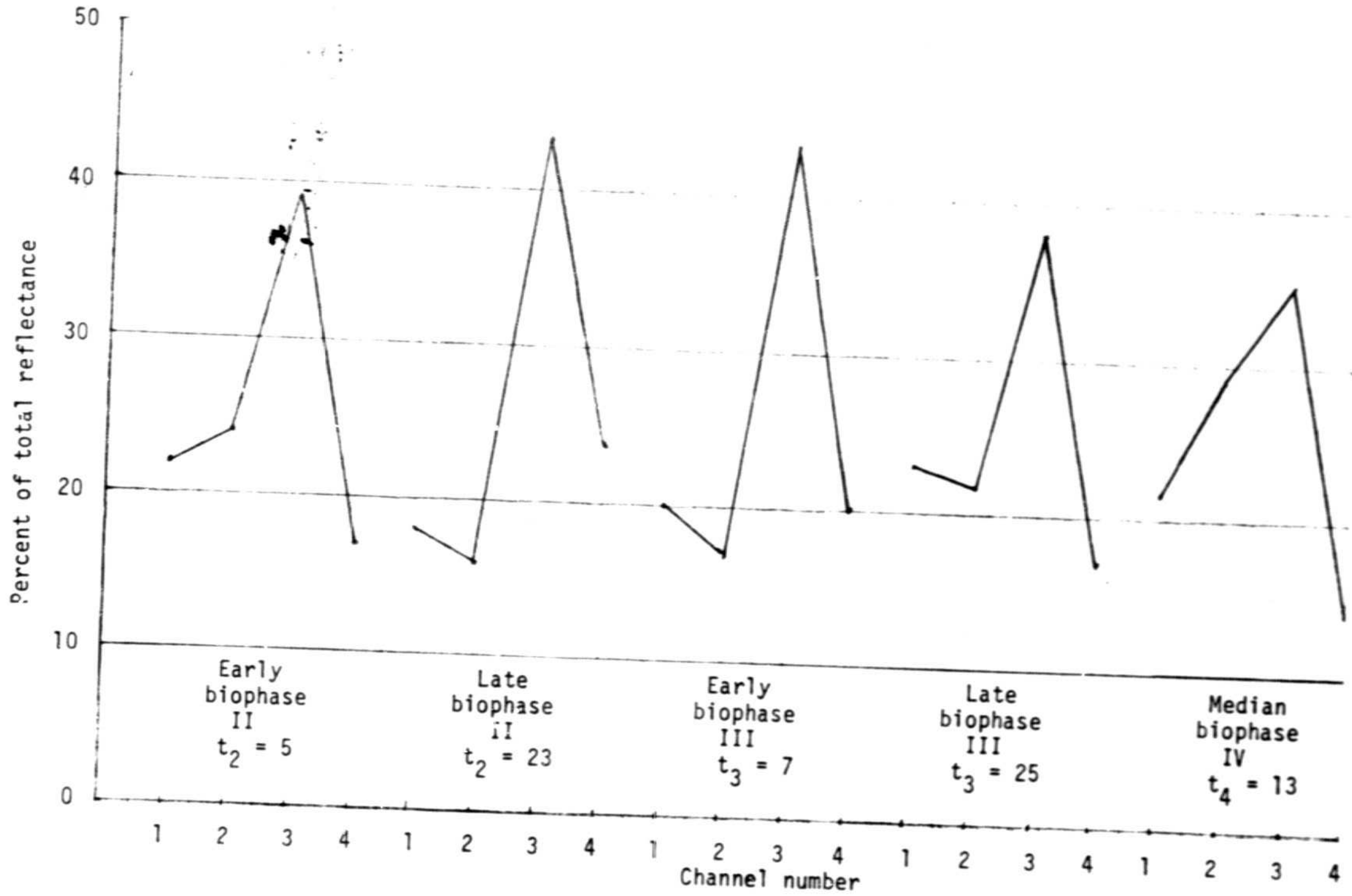


Figure 2.- Fercent of total reflectance from each channel.

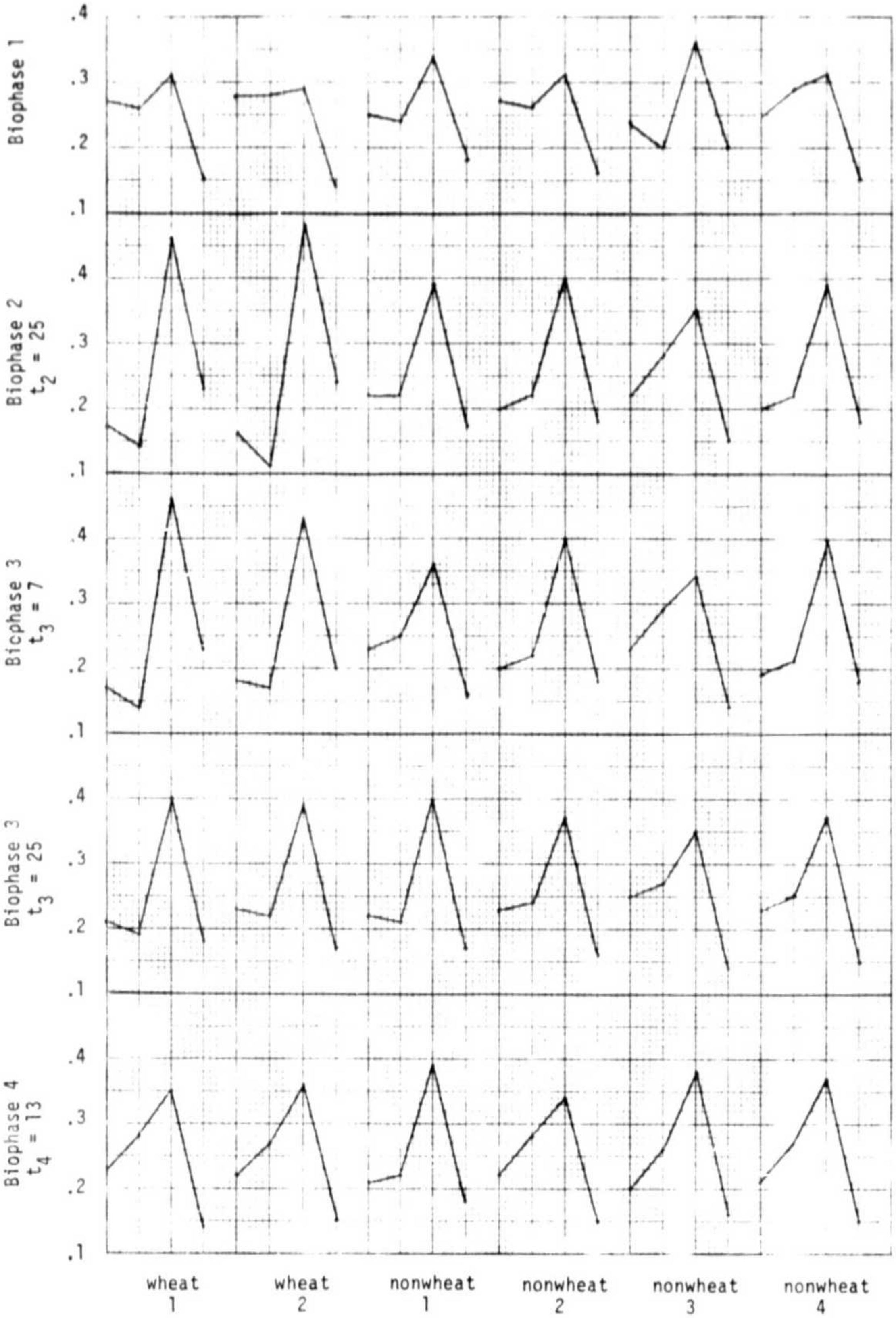


Figure 3.- Percent of total reflectance per channel for AI-defined wheat and non-wheat.

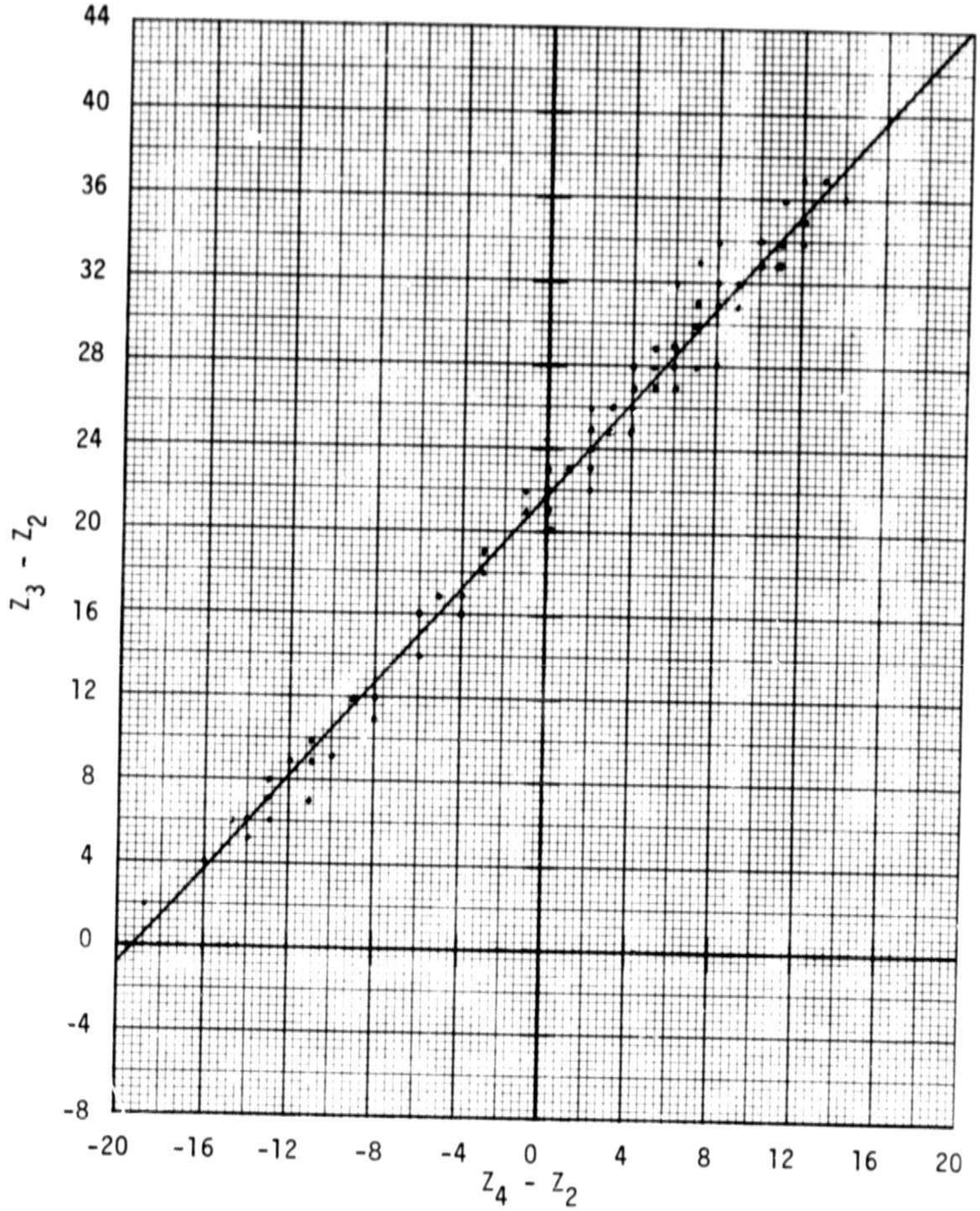


Figure 4.- Landsat 2 agricultural data.

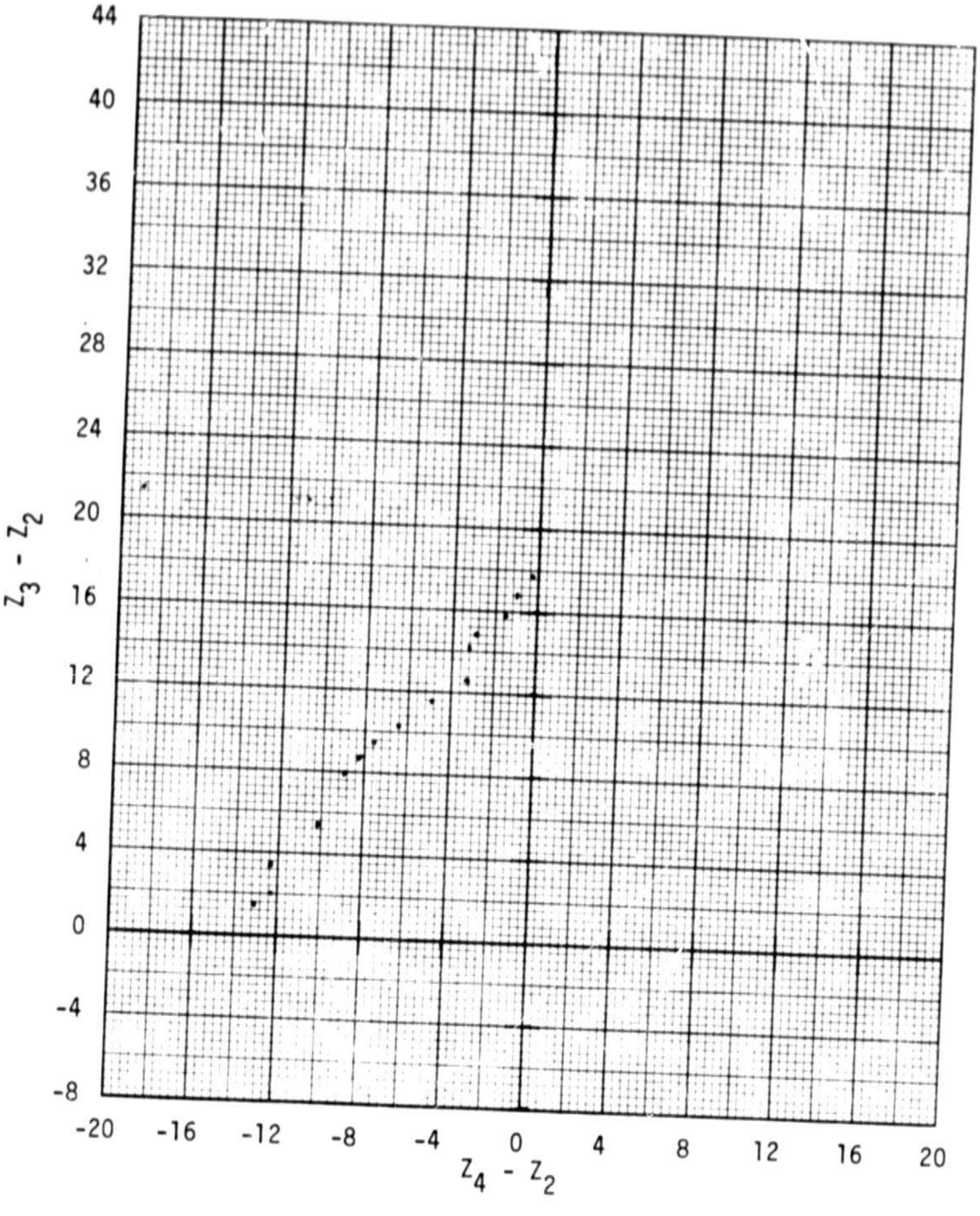


Figure 5.- Landsat 1 agricultural data.

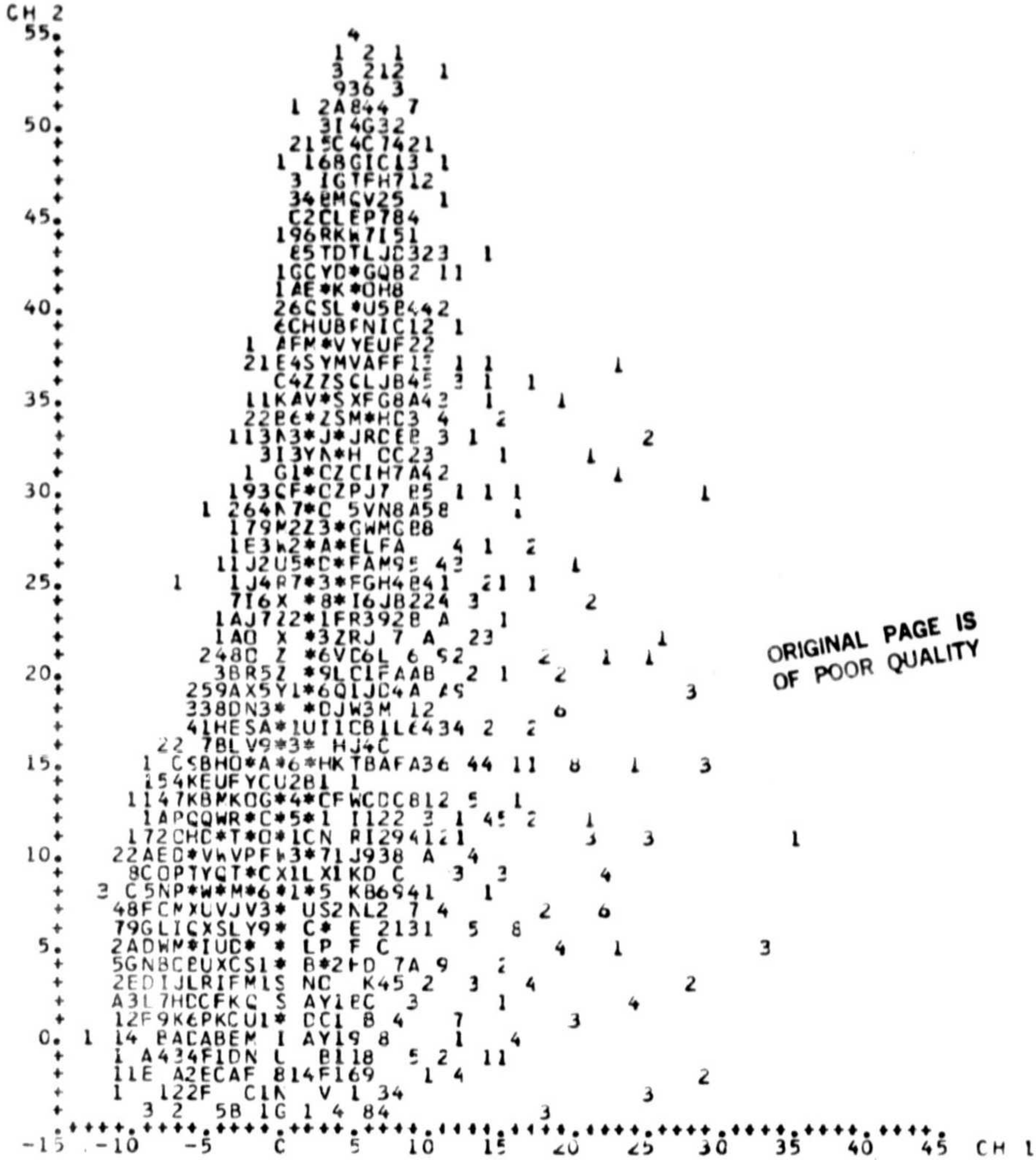


Figure 6.- Scattergram of data in the plane of data variability.

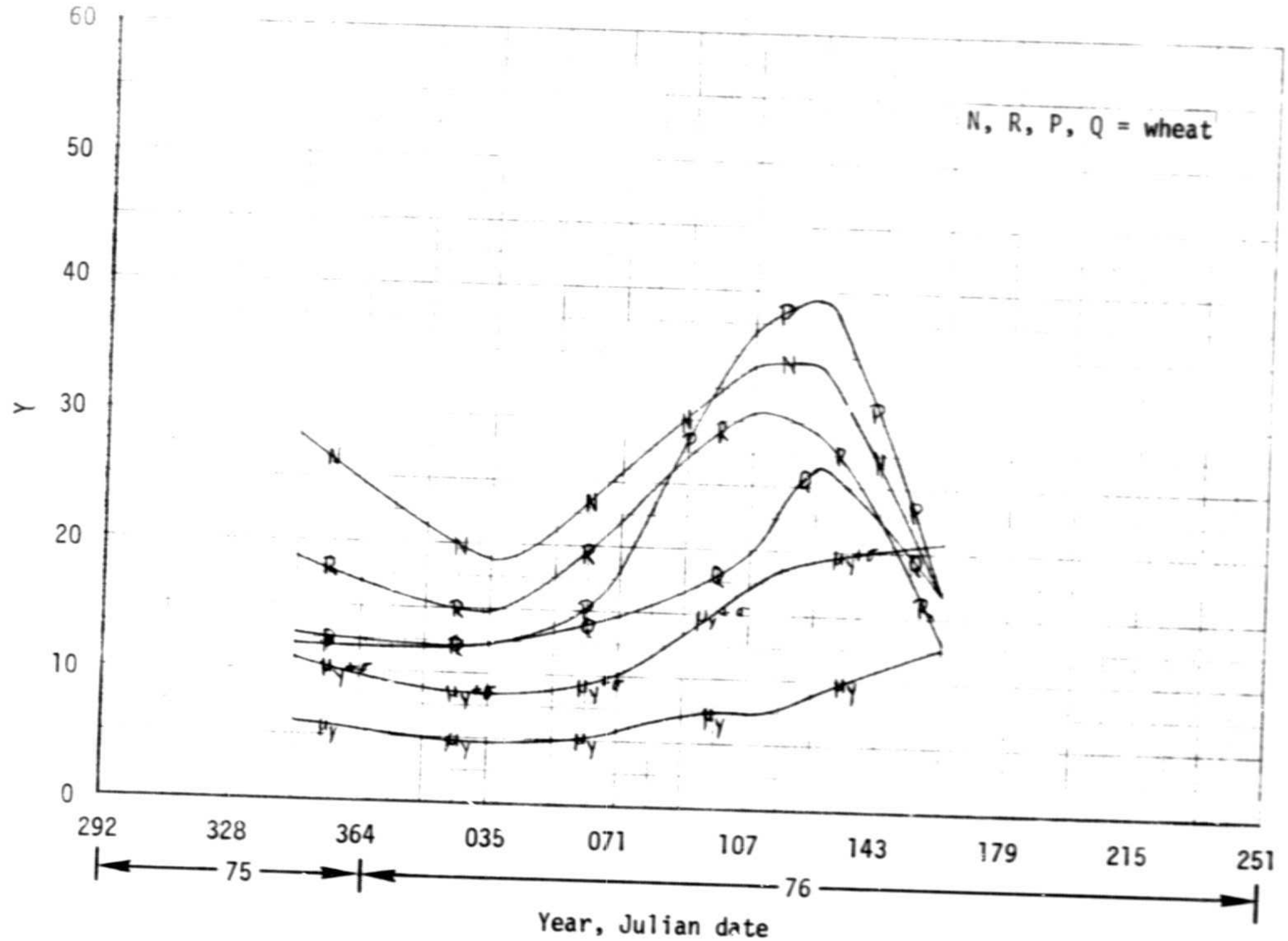


Figure 7.- Segment 1865 means for wheat fields, scene mean and scene mean plus one standard deviation.

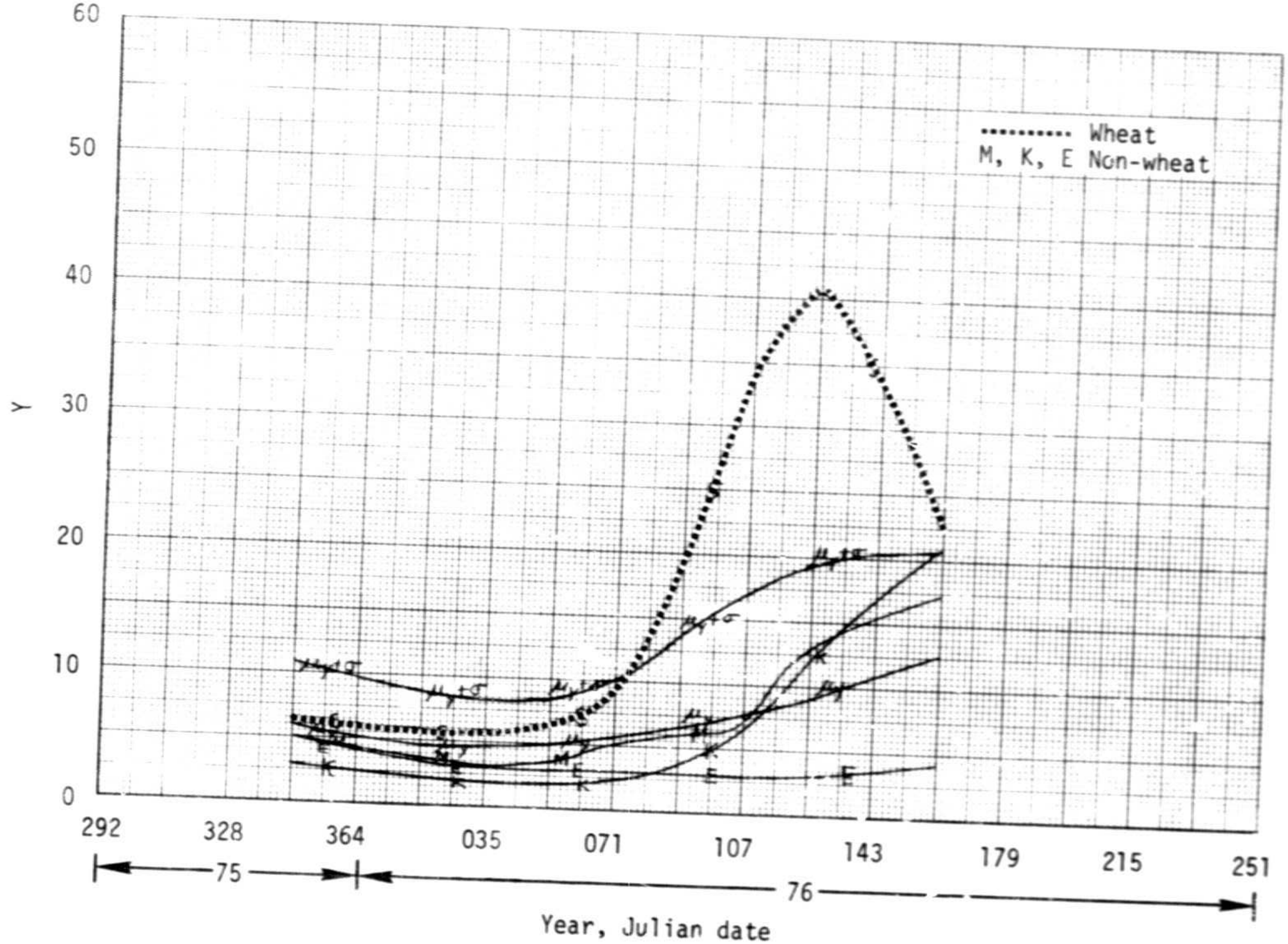


Figure 8.- Segment 1865 non-wheat field means, scene mean and scene mean plus one standard deviation.

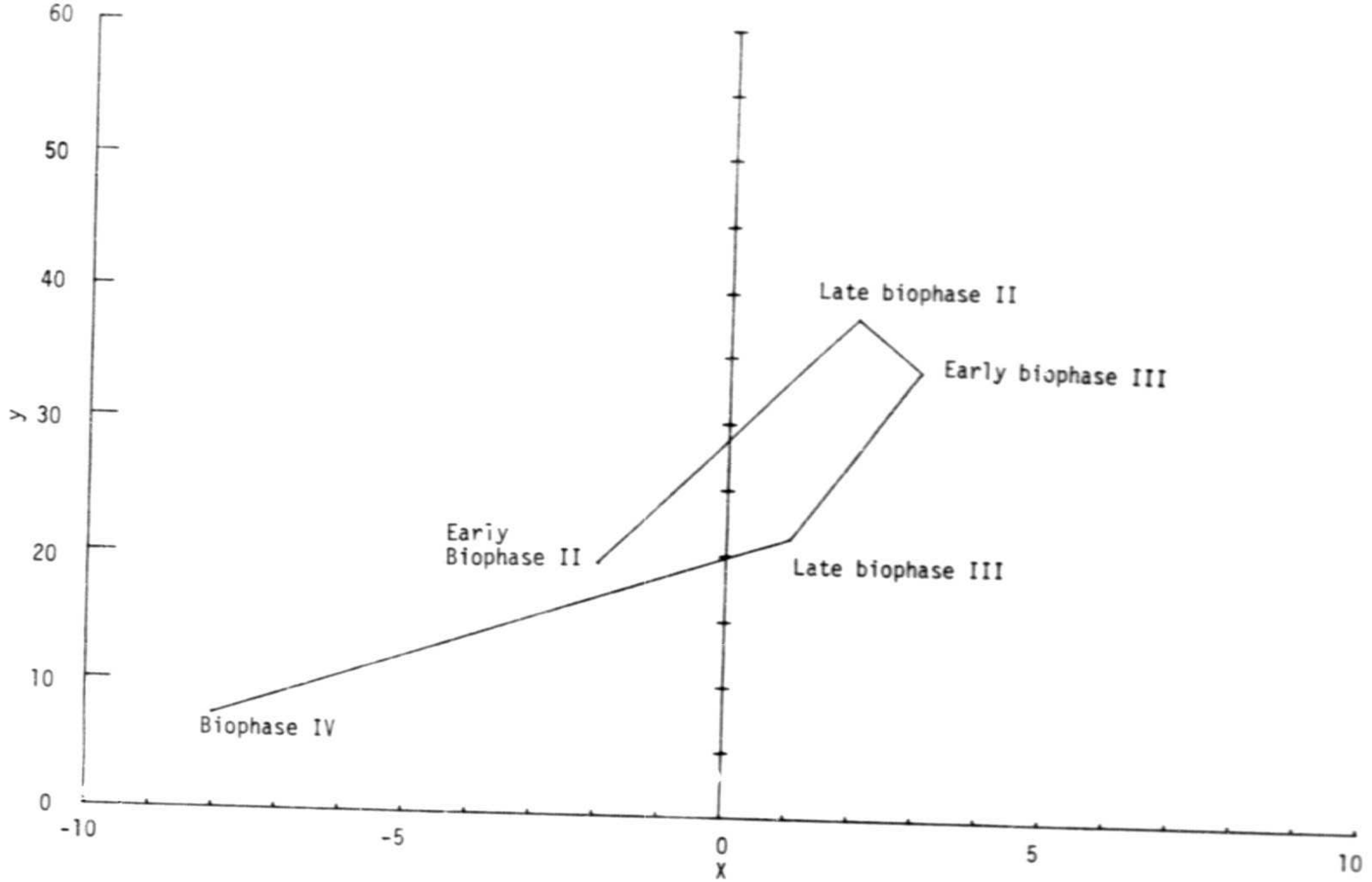
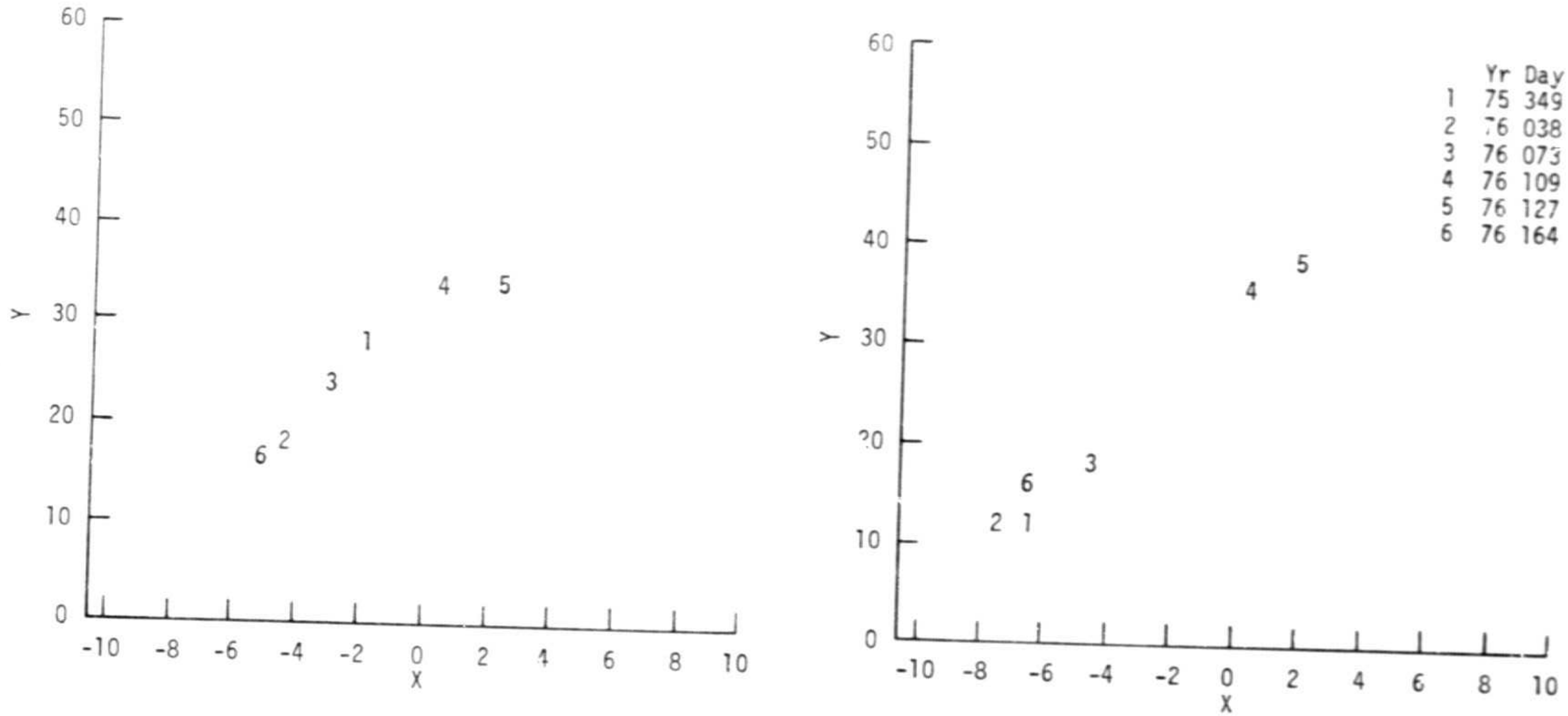


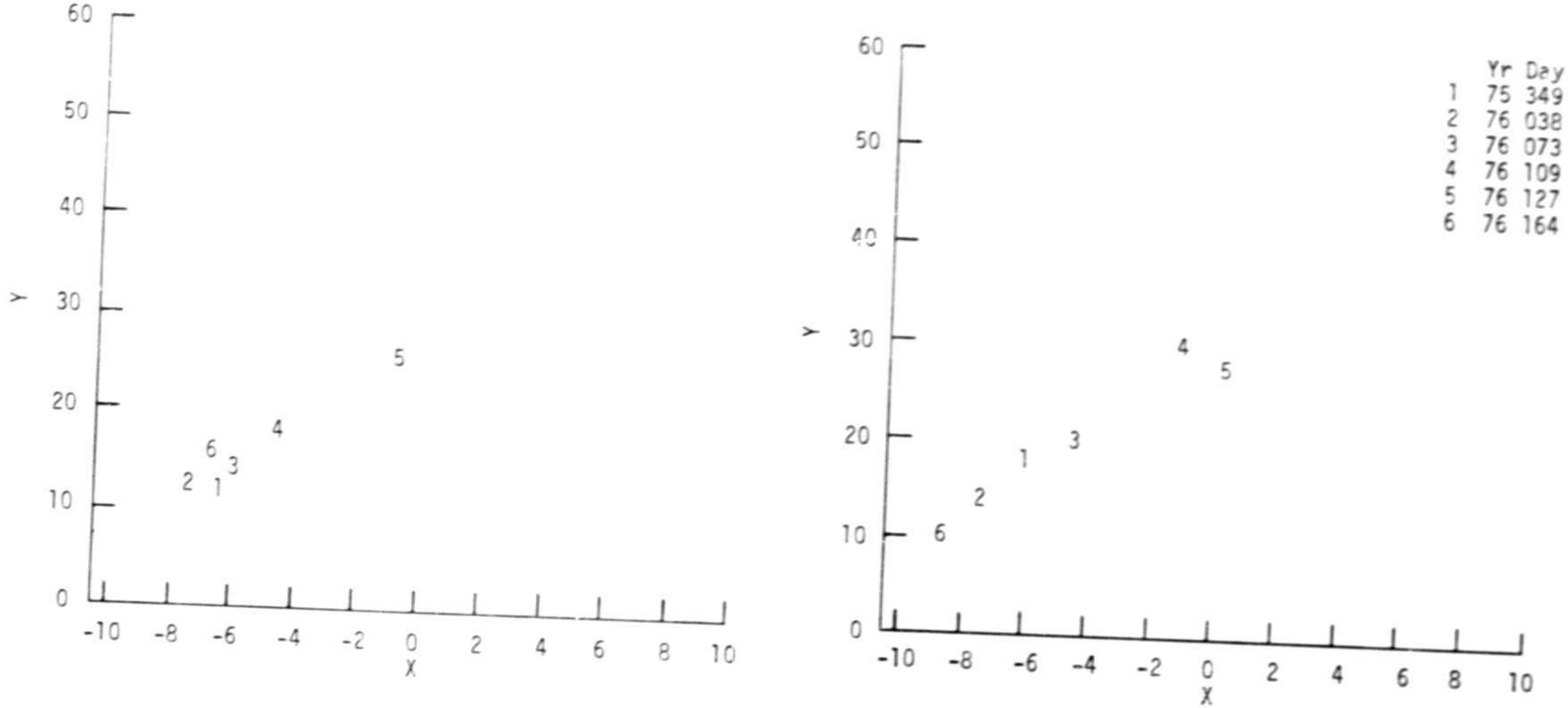
Figure 9.- Typical wheat trajectory.



(a) Wheat field N.

(b) Wheat field P.

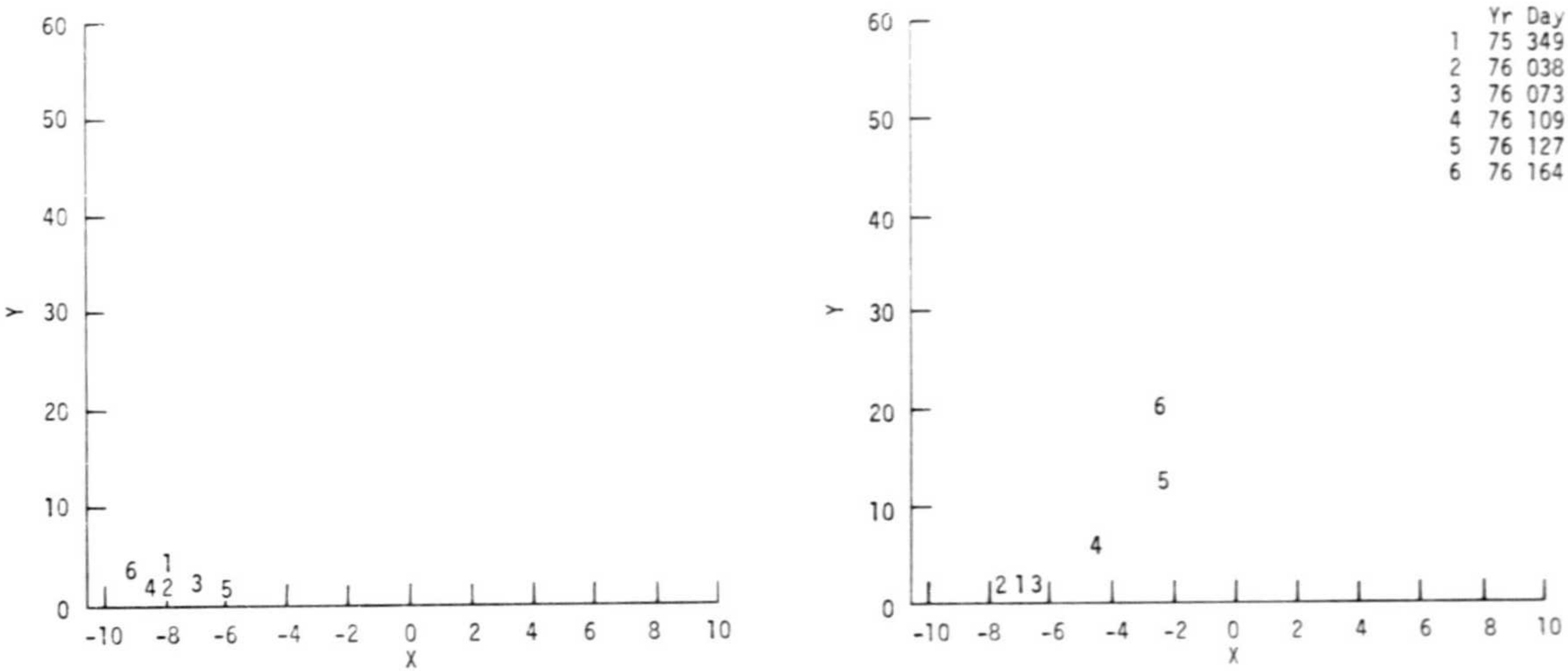
Figure 10.- Field N and P trajectories for sample segment 1865.



(a) Wheat field Q.

(b) Wheat field R.

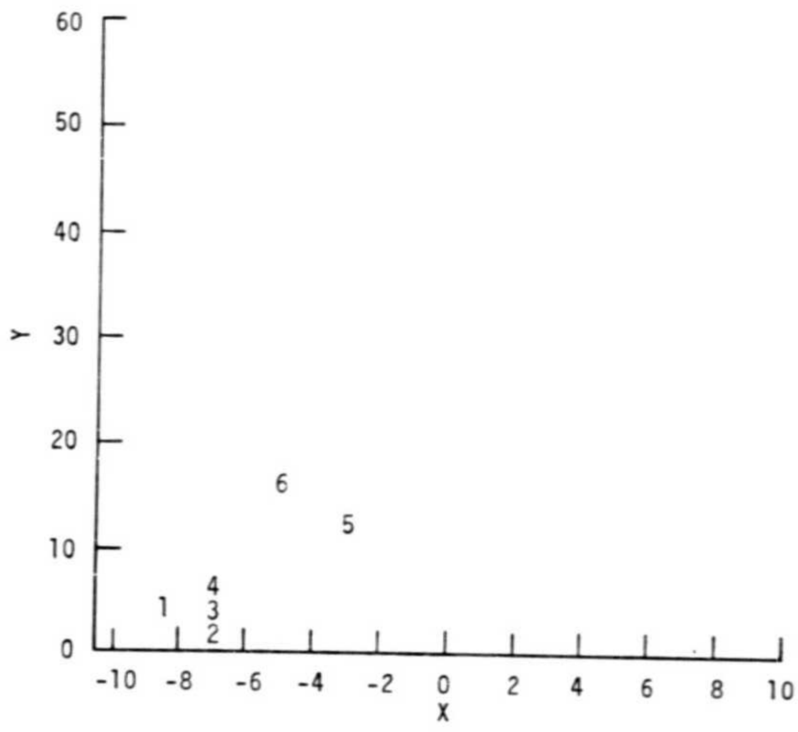
Figure 11.- Field Q and R trajectories for sample segment 1865.



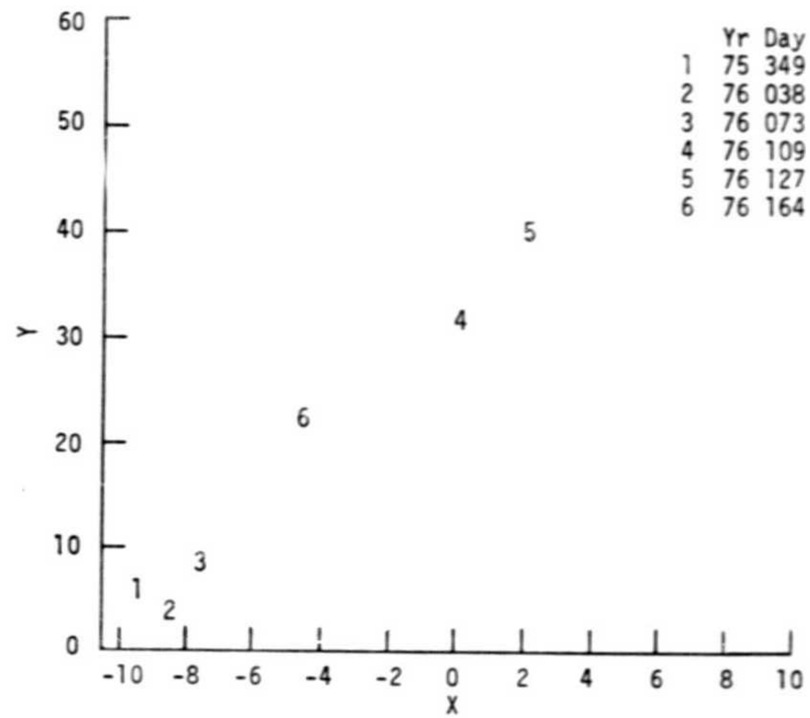
(a) Nonwheat field E.

(b) Nonwheat field K.

Figure 12.- Field E and K trajectories for sample segment 1865.



(a) Nonwheat field M.



(b) Wheat field S.

Figure 13.- Field M and S trajectories for sample segment 1865.

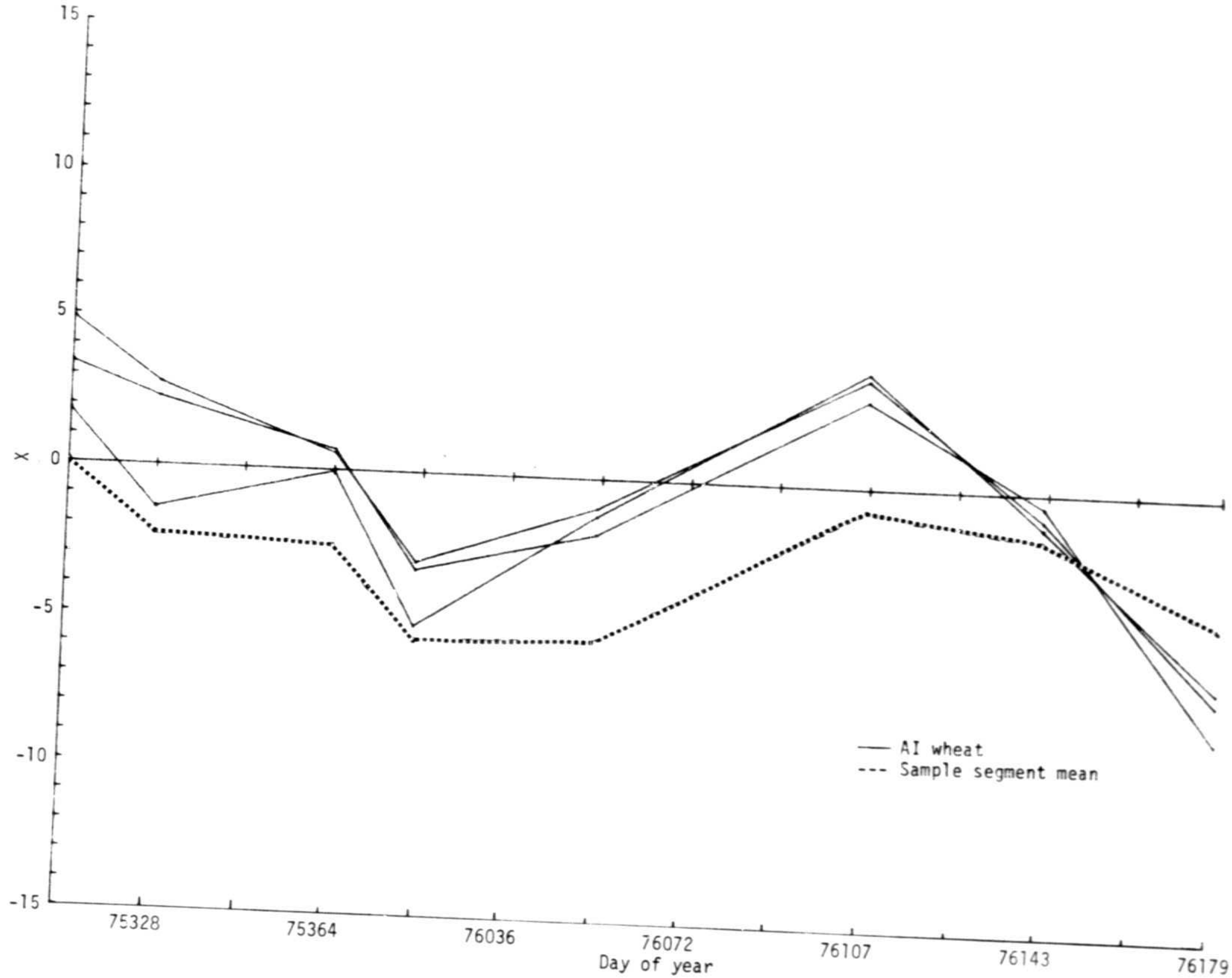


Figure 14.- Wheat-field means versus day of year.

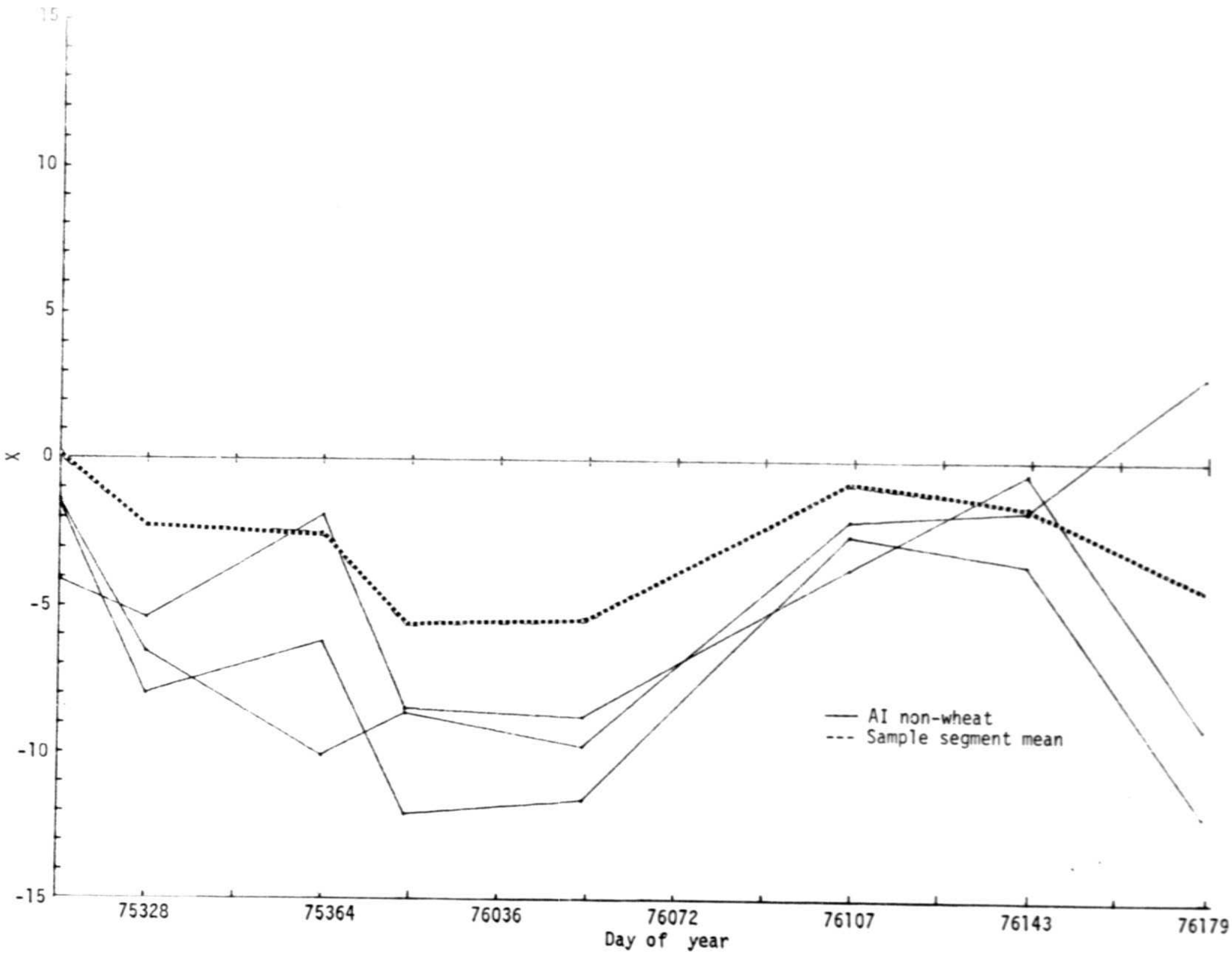


Figure 15.- Non-wheat field means versus day of year.

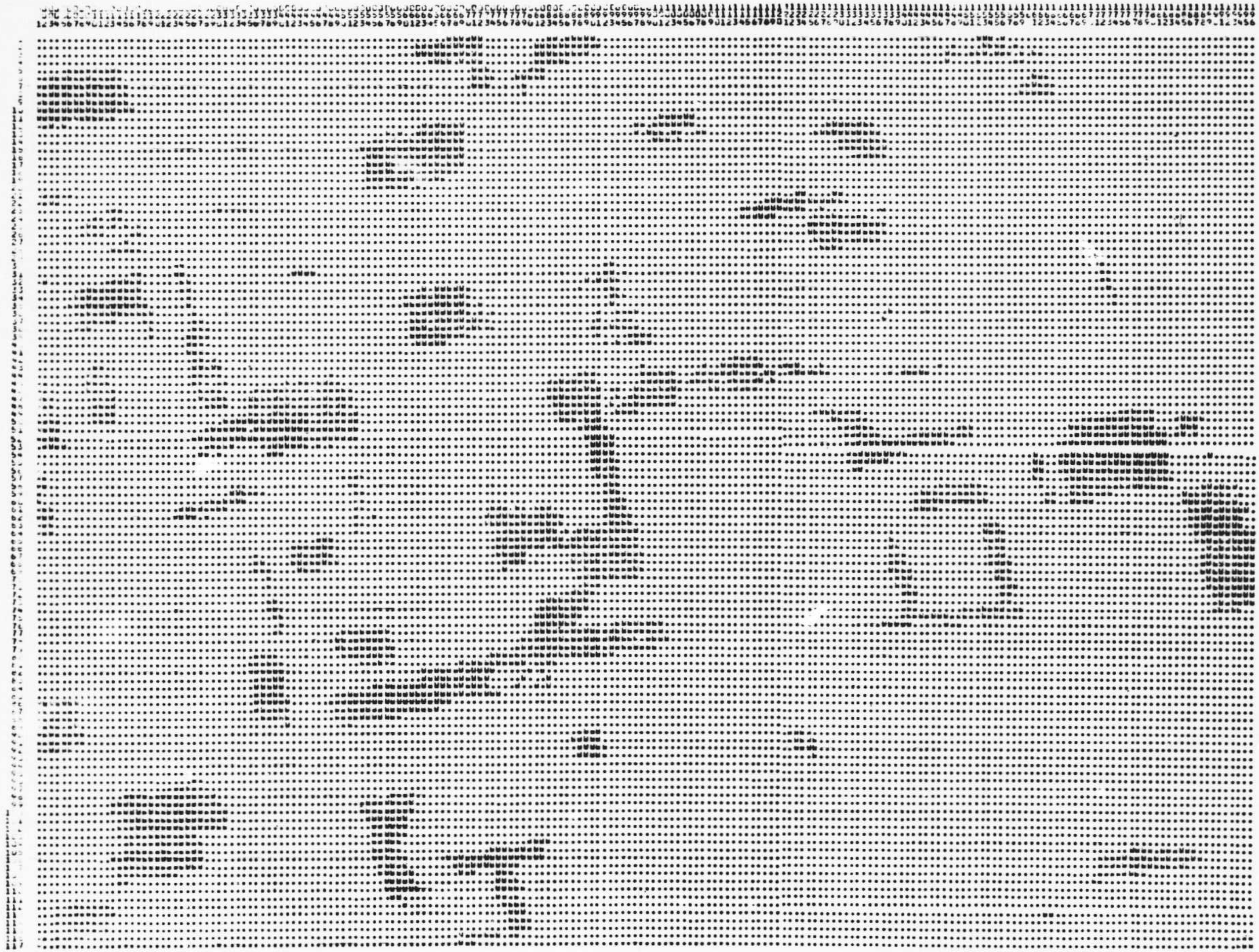


FIGURE 16.- CLASS MAP FOR SAMPLE SEGMENT 1978.