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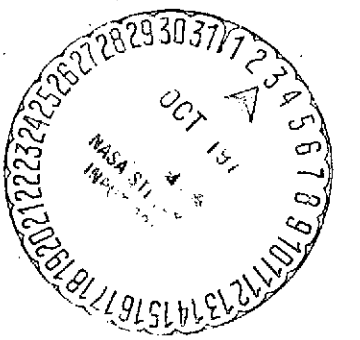
Technical Memorandum

# Feasibility for Identification of Wheat in Hill County, Montana

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# 1.0 INTRODUCTION

This study was undertaken to determine the feasibility for wheat identification using ERTS-1 data with presently available computerized techniques. Specifically, it was undertaken to find out if wheat is separable from other crops which are typically grown in wheat producing areas.

The site for which this study was undertaken was a selected area in Hill County, Montana. This particular site is representative of typical growing practices in northwestern United States. Wheat is grown along with other crops that might be spectrally confused with wheat such as barley, oats and different types of grasses. Both winter and spring wheat are grown. Strip-follow practices are followed in a large portion of the fields in this region. The strips are usually about eighty to three-hundred meters wide.

## 2.0 TECHNICAL BACKGROUND

This study was accomplished utilizing software presently available at the Lyndon B. Johnson Space Center. The data consisted of system corrected ERTS-1 4-channel MSS data generated at three different dates during the wheat growing season. Ground truth was obtained via ASCS channels.

### 2.1 Data

Data from the three dates were correlated and registered together to form a single data set with twelve channels. The correlation and registration were done on the Earth Resources Interactive Processing System (ERIPS) using a first degree polynomial for the registration process with approximately thirty common points over the area. The nearest neighbor technique was used for interpolation on the rotated (registered) image. Registration accuracy appears to be better than one pixel.

The following table describes some of the characteristics of the three data sets used:

| Scene Number | Date | State of the Crop: Winter Wheat | State of the Crop: Spring Wheat |
|---|---|---|---|
| 1304-17461 | 5/23/73 | Early growth to lush growth - varying amounts of bare soil showing between plants. | Early growth - thin growth with bare soil showing between plants. |
| 1339-17400 | 6/27/73 | Dough or milk stage - headed and green. | Lush growth - heavy green growth with little bare soil showing between plants. |
| 1358-17453 | 7/16/73 | Mature growth - ripening, headed - changing color from green. | Dough or milk stage - headed and green. |

## 2.2 Ground Truth

Ground truth was known for the 1973 growing season as follows:

- Detailed ground truth for twelve winter wheat fields 100 to 300 acres in size located south of Fresno reservoir.
- Species only ground truth for eight spring wheat, seven barley, six oats and four grass fields 70 to 150 acres in size.
- Wall to wall ground truth over a two by six (twelve square mile) area north of Fresno reservoir.

## 2.3 Analysis Approach

The analysis was accomplished using the maximum likelihood criterion, specifically, the interactive version of the LARSYS system of programs implemented on the IBM 360/75 and CDC CYBER 73 system (ERIPS).

Training field statistics (means and standard deviations) were plotted in two dimensions using various combinations of pairs of channels (see figures 1, 2 and 3). Each of these figures consists of a plot of the means and standard deviations for channels two and three of the training fields for each of three passes. Similar plots may be drawn for other pairs of channels; however, it was found that this was not necessary. The two visible channels (channels 1 and 2) are highly correlated to each other and the two infrared channels (channels 3 and 4) are similarly highly correlated. Thus, plots depicting the two visible channels or the two infrared channels convey very little information. Plots of other

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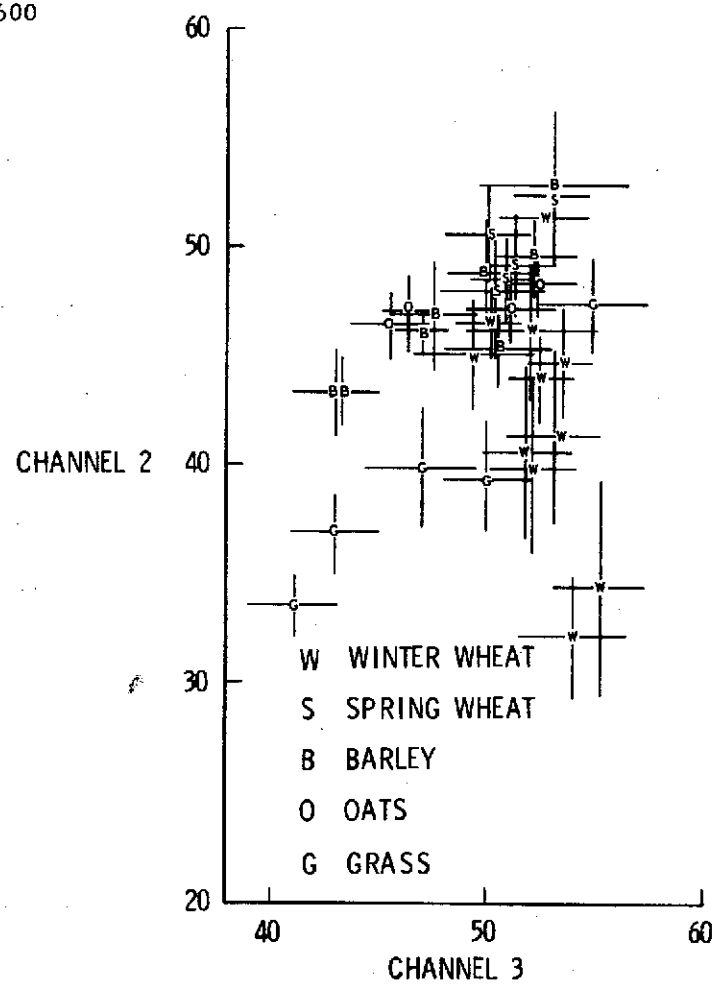


Figure 1. — Means (W, S, B, O, G) and standard deviations for training field data of the May 23 pass.

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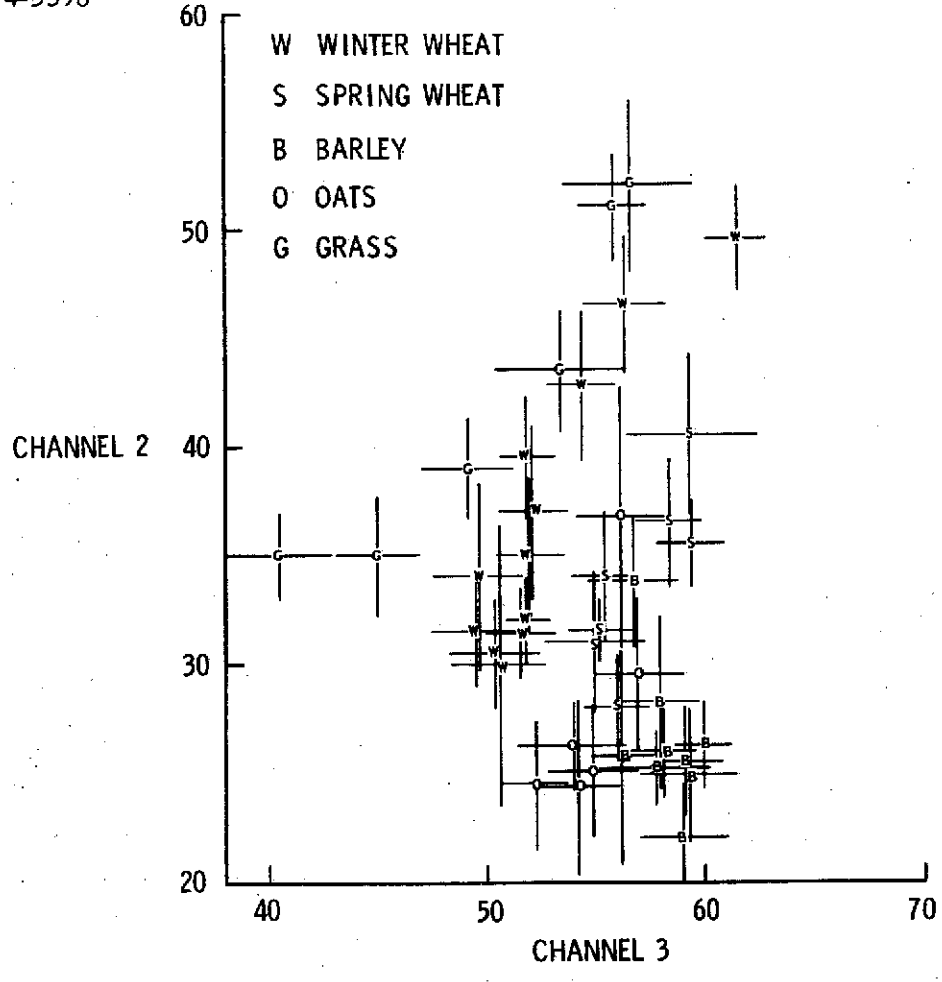


Figure 2. – Means (W, S, B, O, G) and standard deviations for training field data of the June 27 pass.

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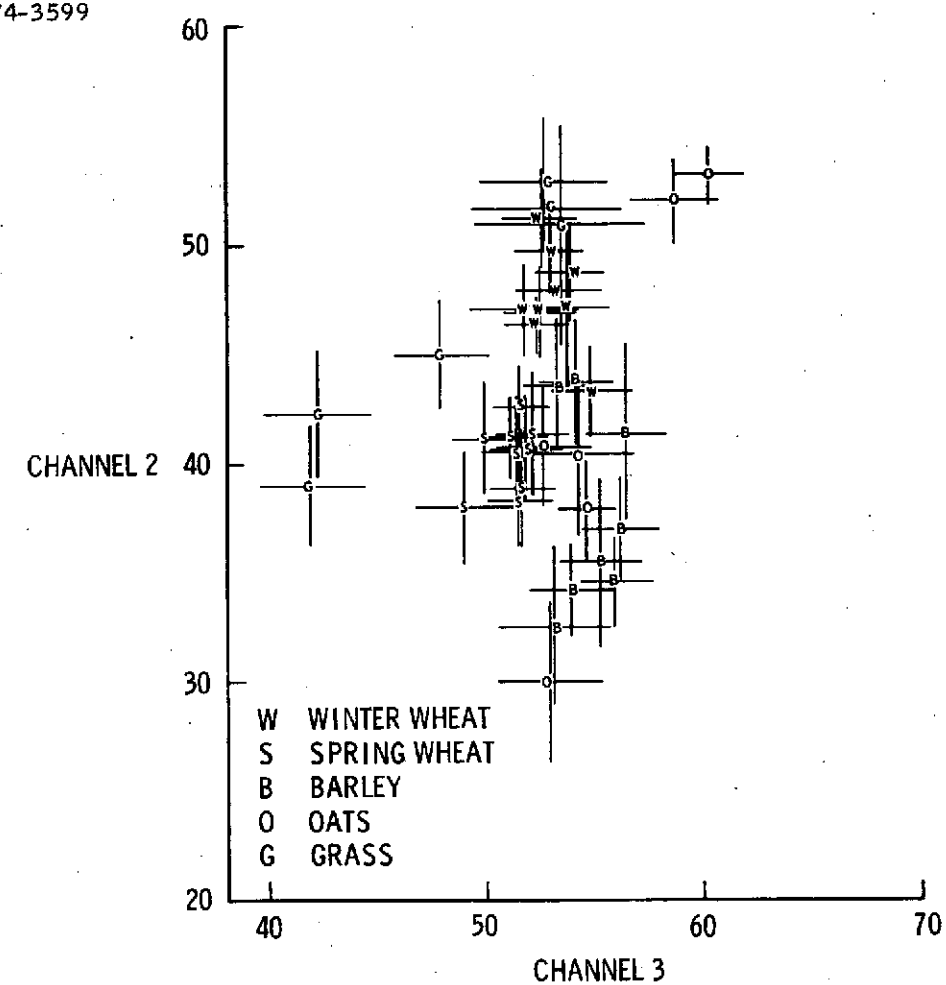




Figure 3. — Means (W, S, B, O, G) and standard deviations for training field data of the July 16 pass.

alternates of a visible channel versus an infrared channel look almost the same as the ones shown in the figures. Figures 1, 2 and 3 depict a good view of the structure of the data and aid in the selection of training fields for the various classes. In most cases they indicated the necessity of dividing some classes into subclasses. Training fields were chosen so that there would be at least one representative field for a given volume of feature space in which a particular class occurs.

All training fields in wheat, barley, and oats were selected from the southern portion of the study site, that is, the area south of Fresno reservoir, and specifically outside of the 2 × 6 mile intensive study area. Training fields for sod, crested wheat grass, summer fallow and stubble were selected from within the intensive study area because no other ground truth was available to represent these classes.

The various crops and other categories were assigned to classes and subclasses as follows: Training fields for winter wheat were divided into two subclasses. Two of these training fields were assigned part to the first and part to the second subclass on the basis that the data from these particular fields were definitely bi-modal in their distribution. Spring wheat was also divided into two subclasses. One of the training fields was assigned part to the first and part to the second subclass. Barley and oats were each divided into two subclasses. Grass (including crested wheat grass) was divided into four subclasses. Furthermore, there were several other classes to include summer fallow fields, stubble (bare soil) and water.

Classification runs were made for each of the single passes, all three combinations of two passes, and all three passes. Classification runs for each of the single passes were completed using all four channels. Classification runs for combinations of two passes were completed using all eight channels. Classification runs for the three-pass case were completed using all twelve channels and using the best six and the best eight channels according to the average divergence criterion. For comparison purposes, the same training and test fields were used for all runs. Acreage estimates for wheat were computed by pixel counting inside the intensive study area where all wheat fields are known.

## 3.0 RESULTS

The results of classification runs are shown in Tables 1 through 9 and summarized in graphical form in figures 4 and 5. The tables depict classification accuracy for training and test fields of wheat (winter wheat and spring wheat taken together), winter wheat and spring wheat taken taken separately, oats, barley and grass. There were eight training and six test fields for winter wheat, five training and four test fields for spring wheat, four training and two test fields for oats, six training and four test fields for barley and six training and no test fields for grass. The same fields were used for all nine runs.

Acreage measurements of the area sown to wheat are shown in Table 10. The acreage measurement was completed by outlining the boundary of the 2 × 6 mile intensive study area and computing the number of pixels per acre from the total number of pixels classified as wheat inside the outlined section. The accuracy figures are then roughly independent from the accuracy to which it is possible to outline the area.

TABLE 1.— CLASSIFICATION ACCURACIES, MAY 23 PASS - ALL FOUR CHANNELS

| | Type of Fields | Total Number of Pixels | Number of Pixels Wheat | Number of Pixels Oats | Number of Pixels Barley | Number of Pixels Grass | Percent Wheat | Percent Oats | Percent Barley | Percent Pixels Grass |
|---|---|---|---|---|---|---|---|---|---|---|
| Wheat | TRG | 1195 | 808 | 48 | 32 | 258 | 67.6 | 4.0 | 2.7 | 21.6 |
| | TST | 634 | 437 | 16 | 31 | 146 | 68.9 | 2.5 | 4.9 | 23.0 |
| Winter Wheat | TRG | 858 | 590 | 9 | 19 | 234 | 68.7 | 1.0 | 2.2 | 27.3 |
| | TST | 379 | 250 | 1 | 6 | 122 | 66.0 | .2 | 1.6 | 32.2 |
| Spring Wheat | TRG | 337 | 218 | 39 | 13 | 24 | 64.7 | 11.5 | 3.8 | 7.1 |
| | TST | 255 | 187 | 15 | 25 | 24 | 73.4 | 5.9 | 9.8 | 9.4 |
| Oats | TRG | 182 | 61 | 46 | 4 | 10 | 33.5 | 25.2 | 2.2 | 5.5 |
| | TST | 68 | 43 | 5 | 2 | 12 | 63.2 | 7.3 | 2.9 | 17.6 |
| Barley | TRG | 305 | 112 | 33 | 70 | 28 | 36.7 | 10.8 | 22.9 | 9.2 |
| | TST | 186 | 52 | 31 | 11 | 12 | 28.0 | 16.6 | 5.9 | 6.4 |
| Grass | TRG | 439 | 40 | 7 | 16 | 273 | 9.1 | 1.6 | 3.6 | 62.2 |

TABLE 2.- CLASSIFICATION ACCURACIES, JUNE 27 PASS - ALL FOUR CHANNELS

| | Type of Fields | Total Number of Pixels | Number of Pixels Wheat | Number of Pixels Oats | Number of Pixels Barley | Number of Pixels Grass | Percent Wheat | Percent Oats | Percent Barley | Percent Pixels Grass |
|---|---|---|---|---|---|---|---|---|---|---|
| Wheat | TRG | 1195 | 1032 | 79 | 30 | 30 | 86.4 | 6.6 | 2.5 | 2.5 |
| | TST | 634 | 558 | 32 | 16 | 23 | 88.0 | 5.1 | 2.5 | 3.6 |
| Winter Wheat | TRG | 858 | 774 | 32 | 0 | 29 | 90.2 | 3.7 | 0 | 3.4 |
| | TST | 379 | 344 | 12 | 0 | 23 | 90.7 | 3.1 | 0 | 6.1 |
| Spring Wheat | TRG | 337 | 258 | 47 | 30 | 1 | 76.6 | 13.9 | 8.9 | .3 |
| | TST | 255 | 214 | 20 | 16 | 0 | 83.9 | 7.8 | 6.3 | 0 |
| Oats | TRG | 182 | 54 | 94 | 34 | 0 | 29.6 | 51.7 | 18.7 | 0 |
| | TST | 68 | 20 | 43 | 5 | 0 | 29.4 | 63.2 | 7.3 | 0 |
| Barley | TRG | 305 | 52 | 50 | 199 | 0 | 17.0 | 16.4 | 65.3 | 0 |
| | TST | 186 | 32 | 32 | 122 | 0 | 17.2 | 17.2 | 65.6 | 0 |
| Grass | TRG | 439 | 39 | 1 | 0 | 387 | 8.9 | .2 | 0 | 88.3 |

TABLE 3.– CLASSIFICATION ACCURACIES, JUNE 16 PASS - ALL 4 CHANNELS

| | Type of Fields | Total Number of Pixels | Number of Pixels Wheat | Number of Pixels Oats | Number of Pixels Barley | Number of Pixels Grass | Percent Wheat | Percent Oats | Percent Barley | Percent Pixels Grass |
|---|---|---|---|---|---|---|---|---|---|---|
| Wheat | TRG | 1195 | 993 | 60 | 77 | 59 | 83.4 | 5.0 | 6.4 | 4.9 |
| | TST | 634 | 511 | 31 | 13 | 67 | 80.6 | 4.9 | 2.1 | 10.6 |
| Winter Wheat | TRG | 858 | 710 | 34 | 55 | 56 | 82.8 | 4.0 | 6.4 | 6.4 |
| | TST | 379 | 302 | 5 | 3 | 58 | 79.7 | 1.3 | 0.8 | 15.3 |
| Spring Wheat | TRG | 337 | 283 | 26 | 20 | 3 | 84.0 | 7.7 | 5.9 | 0.9 |
| | TST | 255 | 209 | 26 | 10 | 9 | 81.9 | 1.0 | 3.0 | 3.0 |
| Oats | TRG | 182 | 22 | 101 | 68 | 9 | 12.1 | 55.5 | 37.4 | 4.9 |
| | TST | 68 | 1 | 34 | 21 | 5 | 1.5 | 50.0 | 30.9 | 7.4 |
| Barley | TRG | 305 | 68 | 34 | 133 | 3 | 22.3 | 11.1 | 43.6 | 1.0 |
| | TST | 186 | 32 | 33 | 117 | 20 | 17.2 | 17.7 | 62.9 | 10.8 |
| Grass | TRG | 439 | 9 | 3 | 1 | 385 | 2.1 | 0.7 | 0.2 | 87.7 |

TABLE 4.– CLASSIFICATION ACCURACIES, MAY 23 AND JUNE 27 PASSES - ALL 8 CHANNELS

| | Type of Fields | Total Number of Pixels | Number of Pixels Wheat | Number of Pixels Oats | Number of Pixels Barley | Number of Pixels Grass | Percent Wheat | Percent Oats | Percent Barley | Percent Pixels Grass |
|---|---|---|---|---|---|---|---|---|---|---|
| Wheat | TRG | 1195 | 1125 | 31 | 29 | 10 | 94.2 | 2.6 | 2.4 | .8 |
| | TST | 634 | 539 | 17 | 46 | 21 | 85.1 | 2.7 | 7.3 | 3.3 |
| Winter Wheat | TRG | 858 | 841 | 5 | 3 | 9 | 98.0 | .6 | .3 | 1.1 |
| | TST | 379 | 350 | 0 | 2 | 18 | 92.4 | 0 | .5 | 4.7 |
| Spring Wheat | TRG | 337 | 284 | 26 | 26 | 1 | 84.3 | 7.7 | 7.7 | .3 |
| | TST | 255 | 189 | 17 | 44 | 3 | 74.2 | 6.7 | 17.3 | 1.1 |
| Oats | TRG | 182 | 18 | 153 | 11 | 0 | 10.0 | 84.0 | 6.0 | 0 |
| | TST | 68 | 12 | 47 | 9 | 0 | 17.7 | 69.1 | 13.2 | 0 |
| Barley | TRG | 305 | 46 | 30 | 229 | 0 | 15.1 | 9.8 | 75.1 | 0 |
| | TST | 186 | 9 | 81 | 96 | 0 | 4.8 | 43.6 | 51.6 | 0 |
| Grass | TRG | 439 | 6 | 0 | 0 | 429 | 1.3 | 0 | 0 | 97.8 |

TABLE 5.— CLASSIFICATION ACCURACIES, MAY 23 AND JULY 16 PASSES - ALL 8 CHANNELS

| | Type of Fields | Total Number of Pixels | Number of Pixels Wheat | Number of Pixels Oats | Number of Pixels Barley | Number of Pixels Grass | Percent Wheat | Percent Oats | Percent Barley | Percent Pixels Grass |
|---|---|---|---|---|---|---|---|---|---|---|
| Wheat | TRG | 1195 | 1087 | 34 | 37 | 33 | 91.2 | 2.8 | 3.1 | 2.7 |
| | TST | 634 | 558 | 3 | 20 | 51 | 88.1 | .5 | 3.1 | 8.1 |
| Winter Wheat | TRG | 858 | 796 | 5 | 22 | 33 | 92.8 | .6 | 2.5 | 3.8 |
| | TST | 379 | 327 | 2 | 2 | 48 | 86.3 | .5 | .5 | 12.6 |
| Spring Wheat | TRG | 337 | 291 | 29 | 15 | 0 | 86.3 | 8.6 | 4.4 | 0 |
| | TST | 255 | 231 | 1 | 18 | 3 | 90.6 | .4 | 7.1 | 1.2 |
| Oats | TRG | 182 | 5 | 152 | 21 | 2 | 2.7 | 83.5 | 11.5 | 1.1 |
| | TST | 68 | 6 | 34 | 26 | 2 | 8.8 | 50.0 | 38.2 | 2.9 |
| Barley | TRG | 305 | 49 | 33 | 222 | 0 | 16.1 | 10.8 | 72.8 | 0 |
| | TST | 186 | 24 | 79 | 78 | 5 | 12.9 | 42.5 | 41.9 | 2.7 |
| Grass | TRG | 439 | 2 | 1 | 0 | 426 | .4 | .2 | 0 | 97.0 |

TABLE 6.— CLASSIFICATION ACCURACIES, JUNE 27 AND JULY 16 passes - ALL 8 CHANNELS

| | Type of Fields | Total Number of Pixels | Number of Pixels Wheat | Number of Pixels Oats | Number of Pixels Barley | Number of Pixels Grass | Percent Wheat | Percent Oats | Percent Barley | Percent Pixels Grass |
|---|---|---|---|---|---|---|---|---|---|---|
| Wheat | TRG | 1195 | 1119 | 35 | 22 | 19 | 93.7 | 2.9 | 1.8 | 1.6 |
| | TST | 634 | 566 | 29 | 14 | 21 | 89.3 | 4.5 | 2.2 | 3.3 |
| Winter Wheat | TRG | 858 | 819 | 14 | 7 | 18 | 95.4 | 1.6 | .8 | 2.1 |
| | TST | 379 | 350 | 1 | 9 | 19 | 92.3 | .2 | 2.4 | 5.0 |
| Spring Wheat | TRG | 337 | 300 | 21 | 15 | 1 | 89.1 | 6.2 | 4.4 | .3 |
| | TST | 255 | 216 | 28 | 5 | 2 | 84.7 | 11.0 | 1.9 | 8.0 |
| Oats | TRG | 182 | 14 | 138 | 28 | 0 | 7.7 | 75.8 | 15.4 | 0 |
| | TST | 68 | 3 | 52 | 13 | 0 | 4.4 | 76.5 | 19.1 | 0 |
| Barley | TRG | 305 | 30 | 29 | 246 | 0 | 9.8 | 9.5 | 80.6 | 0 |
| | TST | 186 | 16 | 46 | 124 | 0 | 8.6 | 24.7 | 66.6 | 0 |
| Grass | TRG | 439 | 1 | 3 | 0 | 429 | .2 | .7 | 0 | 98.0 |

TABLE 7.– CLASSIFICATION ACCURACIES, JUNE 27 AND JULY 16 PASSES - BEST 6 CHANNELS OUT OF 12

| | Type of Fields | Total Number of Pixels | Number of Pixels Wheat | Number of Pixels Oats | Number of Pixels Barley | Number of Pixels Grass | Percent Wheat | Percent Oats | Percent Barley | Percent Pixels Grass |
|---|---|---|---|---|---|---|---|---|---|---|
| Wheat | TRG | 1195 | 1120 | 20 | 12 | 33 | 93.8 | 1.7 | 1.0 | 2.8 |
| | TST | 634 | 588 | 6 | 7 | 30 | 92.8 | .9 | 1.1 | 4.8 |
| Winter Wheat | TRG | 858 | 816 | 6 | 5 | 31 | 95.2 | .7 | .5 | 3.6 |
| | TST | 379 | 354 | 0 | 0 | 25 | 93.4 | 0 | 0 | 6.6 |
| Spring Wheat | TRG | 337 | 304 | 14 | 17 | 2 | 90.2 | 4.1 | 5.0 | .6 |
| | TST | 255 | 234 | 6 | 7 | 5 | 91.8 | 2.3 | 2.7 | 2.0 |
| Oats | TRG | 182 | 3 | 164 | 15 | 0 | 1.6 | 90.2 | 8.2 | 0 |
| | TST | 68 | 1 | 57 | 10 | 0 | 1.5 | 83.8 | 14.7 | 0 |
| Barley | TRG | 305 | 17 | 34 | 254 | 0 | 5.6 | 11.1 | 83.3 | 0 |
| | TST | 186 | 17 | 68 | 101 | 0 | 9.1 | 36.5 | 54.3 | 0 |
| Grass | TRG | 439 | 10 | 0 | 0 | 424 | 2.3 | 0 | 0 | 96.6 |

TABLE 8.– CLASSIFICATION ACCURACIES, MAY 23, JUNE 27 and JULY 16 - BEST 8 CHANNELS OUT OF 12

| | Type of Fields | Total Number of Pixels | Number of Pixels Wheat | Number of Pixels Oats | Number of Pixels Barley | Number of Pixels Grass | Percent Wheat | Percent Oats | Percent Barley | Percent Pixels Grass |
|---|---|---|---|---|---|---|---|---|---|---|
| Wheat | TRG | 1195 | 1149 | 13 | 19 | 7 | 96.1 | 1.1 | 1.6 | .6 |
| | TST | 634 | 580 | 4 | 18 | 31 | 91.5 | .6 | 2.3 | 4.9 |
| Winter Wheat | TRG | 858 | 842 | 0 | 4 | 7 | 98.2 | 0 | 0.5 | .8 |
| | TST | 379 | 352 | 0 | 0 | 27 | 92.9 | 0 | 0 | 7.1 |
| Spring Wheat | TRG | 337 | 307 | 13 | 15 | 0 | 91.2 | 3.9 | 4.4 | 0 |
| | TST | 255 | 228 | 4 | 18 | 4 | 89.5 | 1.5 | 7.1 | 1.5 |
| Oats | TRG | 182 | 3 | 168 | 6 | 0 | 1.6 | 92.4 | 3.3 | 0 |
| | TST | 68 | 1 | 53 | 14 | 0 | 1.5 | 72.9 | 20.6 | 0 |
| Barley | TRG | 305 | 11 | 31 | 263 | 0 | 3.6 | 9.8 | 86.3 | 0 |
| | TST | 186 | 7 | 60 | 119 | 0 | 2.6 | 31.0 | 64.0 | 0 |
| Grass | TRG | 439 | 3 | 0 | 0 | 433 | .6 | 0 | 0 | 98.7 |

TABLE 9.— CLASSIFICATION ACCURACIES, MAY 23, JUNE 27 AND JULY 16 - ALL 12 CHANNELS

| | Type of Fields | Total Number of Pixels | Number of Pixels Wheat | Number of Pixels Oats | Number of Pixels Barley | Number of Pixels Grass | Percent Wheat | Percent Oats | Percent Barley | Percent Pixels Grass |
|---|---|---|---|---|---|---|---|---|---|---|
| Wheat | TRG | 1195 | 1166 | 12 | 12 | 3 | 97.6 | 1.0 | 1.0 | .3 |
| | TST | 634 | 590 | 8 | 0 | 17 | 93.1 | 1.2 | 0 | 2.7 |
| Winter Wheat | TRG | 858 | 847 | 4 | 4 | 3 | 98.7 | .4 | .4 | .3 |
| | TST | 379 | 363 | 2 | 0 | 14 | 95.7 | .5 | 0 | 3.7 |
| Spring Wheat | TRG | 337 | 319 | 8 | 8 | 0 | 94.7 | 2.4 | 2.4 | 0 |
| | TST | 255 | 227 | 6 | 17 | 3 | 89.0 | 2.3 | 6.7 | 1.2 |
| Oats | TRG | 182 | 2 | 167 | 13 | 0 | 1.1 | 91.7 | 7.1 | 0 |
| | TST | 68 | 4 | 52 | 12 | 0 | 5.9 | 76.5 | 17.6 | 0 |
| Barley | TRG | 305 | 9 | 24 | 272 | 0 | 2.9 | 7.8 | 89.1 | 0 |
| | TST | 186 | 9 | 66 | 111 | 0 | 4.8 | 35.4 | 59.7 | 0 |
| Grass | TRG | 439 | 2 | 0 | 0 | 435 | .4 | 0 | 0 | 99.2 |

TABLE 10.— ACREAGE ESTIMATE FOR THE HILL COUNTY NORTH 2 × 6 MILE INTENSIVE STUDY AREA

| | PIXEL COUNT | | | ACREAGE | | | PERCENT ACCURACY | | |
|---|---|---|---|---|---|---|---|---|---|
| | Spring Wheat | Winter Wheat | Wheat | Spring Wheat | Winter Wheat | Wheat | Spring Wheat | Winter Wheat | Wheat |
| Actual Acreage | n.a. | n.a. | n.a. | 516 | 1806 | 2322 | n.a. | n.a. | n.a. |
| May 23 Pass | 531 | 760 | 1291 | 600 | 859 | 1459 | 84 | 48 | 62 |
| June 27 Pass | 502 | 1808 | 2310 | 567 | 2042 | 2609 | 90 | 87 | 88 |
| July 16 Pass | 322 | 1345 | 1667 | 363 | 1520 | 1883 | 70 | 84 | 81 |
| May 23 and June 27 | 442 | 1485 | 1927 | 499 | 1679 | 2178 | 97 | 93 | 93 |
| May 23 and July 16 | 345 | 1194 | 1539 | 390 | 1350 | 1740 | 76 | 75 | 75 |
| June 27 and July 16 | 339 | 1466 | 1805 | 383 | 1657 | 2040 | 74 | 92 | 87 |
| May 23, June 27 and July 16 (best 6 channels out of 12) | 395 | 14 | 1805 | 446 | 1681 | 2127 | 86 | 93 | 91 |
| May 23, June 27 and July 16 (best 8 channels out of 12) | 395 | 1466 | 1861 | 446 | 1658 | 2104 | 86 | 92 | 90 |
| May 23, June 27 and July 16 (all channels) | 402 | 1561 | 1963 | 454 | 1764 | 2218 | 88 | 98 | 95 |

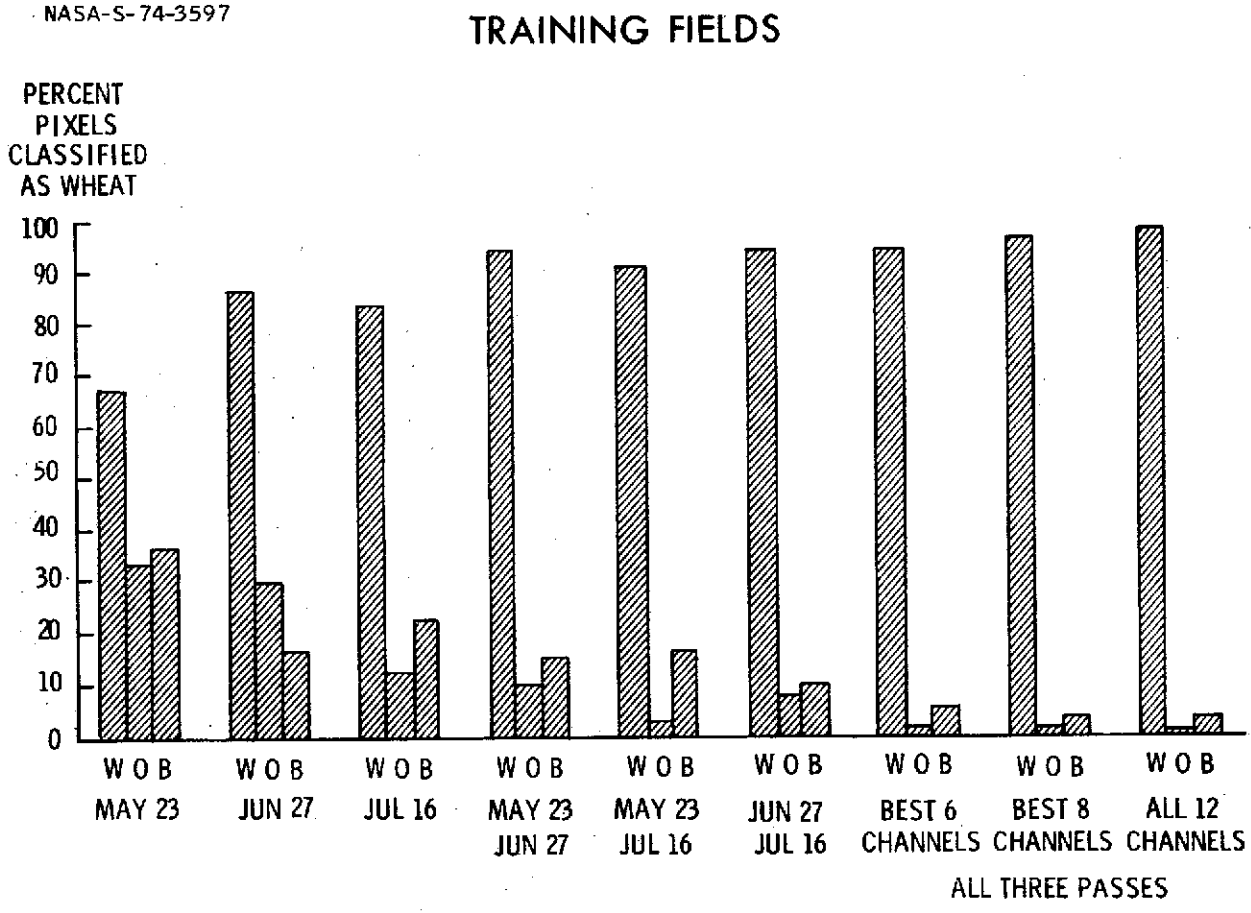


Figure 4. – Percent classification accuracy for wheat (W) training fields. Percent pixels of oats (O) and barley (B) training fields misclassified as wheat.

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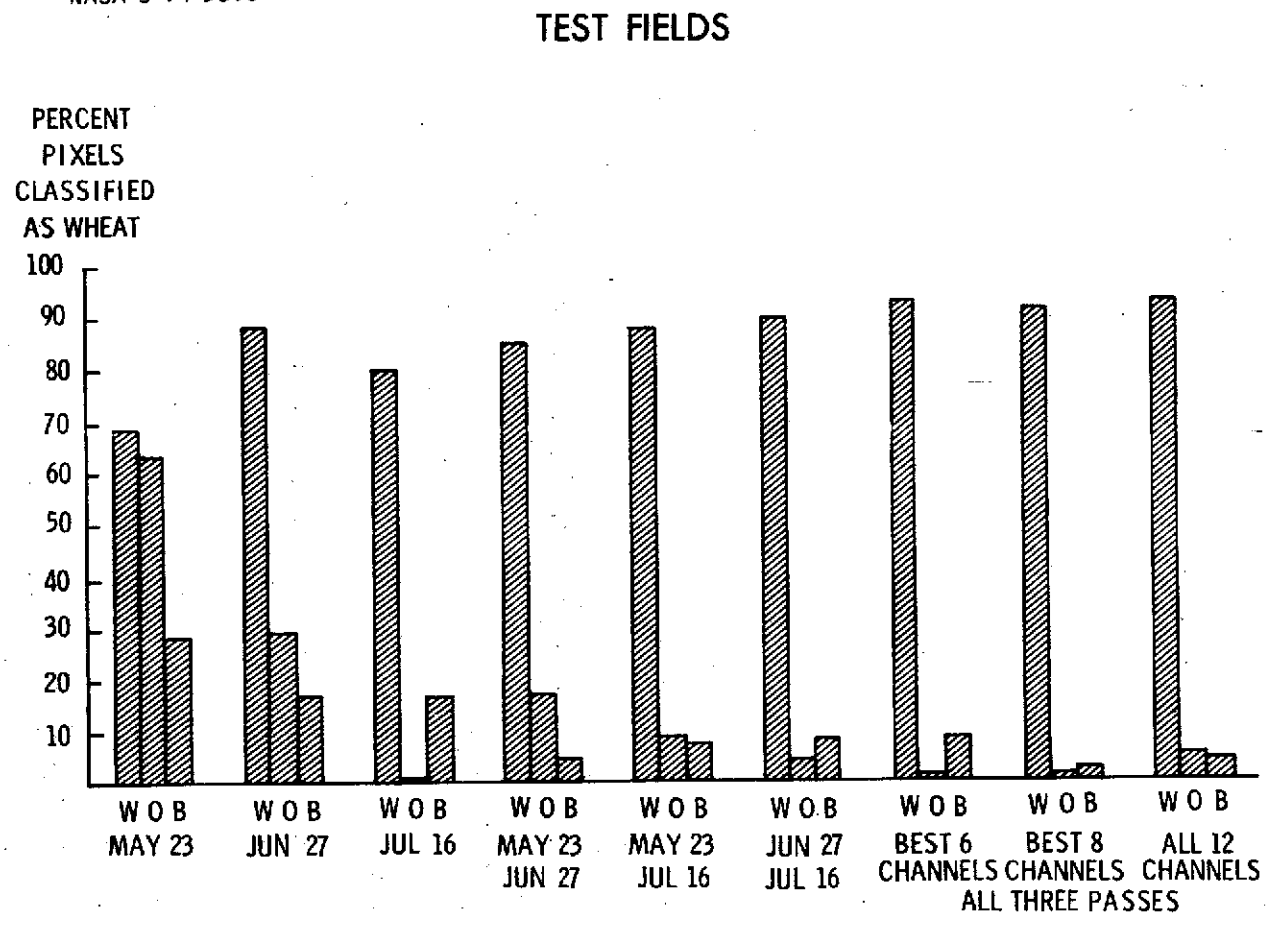


Figure 5. – Percent classification accuracy for wheat (W) test fields. Percent pixels of oats (O) and barley (B) test fields misclassified as wheat.

## 4.0 DISCUSSION OF RESULTS

In general, the results indicate that the data contains the necessary information to separate wheat from barley, oats and the different types of grasses. Classificaton accuracies for wheat test fields ranged from 88 percent for the best single pass data set to 93 percent for the best three-pass data set. On the other hand, misclassification of barley and oats into wheat range from 20 percent to 30 percent for the best single pass data set, 10 percent to 20 percent for the two-pass set to less than 10 percent for the three-pass data set.

It should be pointed out that these classification accuracies are for those fields for which ground truth is available. There is no intent to claim that these figures represent the accuracy to which it is possible to identify wheat. In the present study, the sample of fields is too small (twelve for winter wheat, less for other classes) to compute statistically reliable accuracy figures. The reason for this is that the variation of spectral signatures for the different fields of each class is to large to be represented by such a small sample. Specifically, the scatter in feature space of data from different fields of any one crop is three to ten times greater than typical variances of data from single fields (see figures 1, 2 and 3).

The problem is further compounded by the fact that the distribution of the data in feature space is not known. Specifically, it is not normal and in some instances it is very complex in configuration. Furthermore, data from the various confusion crops (i.e. the small grains) lie

typically very close to one another in feature space and in some cases they are heavily overlapped. Therefore, a random selection of training fields from among the few available would not have yielded statistically significant results. Fields were in fact randomly selected in the initial stages of the analysis. Typical classification accuracies ranged between 60 percent to 90 percent but were not self consistent when changing training data around. A significant improvement was obtained when an effort was made to have at least one training field per variety in feature space of each class. This was done by observation of the two dimensional plots such as the ones shown in figure 1, 2 and 3.

Further improvement in classification accuracy was obtained by dividing some of the classes into subclasses, each of which was represented by a single multivariate normal function. It should be noted that typically only two to five fields were used to determine the parameters of each of the normals that represent each subclass. A total of between four to eight fields were used to determine what amounts to an unknown data distribution function for each of the classes (i.e. crops).

Test fields were chosen from the remaining fields as well as from those that were considered to be too small for training purposes. This procedure does bias the test field classification accuracy figures since some of the test fields were certainly not randomly selected. Probably, the best interpretation for the accuracy figures given here is as an upper limit to the accuracy to which it is possible to separate wheat from other crops, but only for those fields for which ground truth was available.

A limited signature extension experiment was performed by taking training data from the southern portion of the study site whenever possible. Specifically, training data of wheat, barley and oats were selected from south of Fresno reservoir. The success of the experiment was judged by analyzing the results of classification on the 2 × 6 mile intensive study area which lies north of the reservoir. This makes all training fields in these four classes between 6 to 14 miles away from the intensive study site. The result of this effort is inconclusive although there are indications that the problem of signature extension should be the subject of further and more intensive study. Some fields in the intensive study area were classified correctly to a high accuracy. On the other hand, there were at least three winter wheat fields in the northern area that were partially misclassified as oats or barley or classified, perhaps by chance, as spring wheat. The spectral response of these fields is definitely different from that of the twelve fields south of the reservoir (see winter wheat field on the upper right hand corner of figure 2). It is difficult at this point to assess the severity of this problem other than to point out that it occurred for three distinct fields out of a total of some twenty known winter wheat fields north of the reservoir. It cannot be concluded at this time whether the difference in spectral response is statistical in nature or a result of different conditions that occur only north of the reservoir, or for that matter, in any other area ten to fifteen miles away from the training data.

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

This investigation attempted to determine the feasibility for wheat identification in a section of Hill County, Montana using ERTS data. In doing this, it evaluated the utility of presently available systems and methods. The following summarizes the extent to which this objective was achieved:

- It was found that wheat can be separated from other crops with a classification accuracy of roughly 90 percent or better and with a maximum misclassification error of other crops into wheat of 10 percent using two or three registered data sets.
- The best single data set occurs after wheat is fully headed and before it turns yellow. Classification accuracy for test fields in this case was 88 percent and misclassification of other crops into wheat was 30 percent for oats and 20 percent for barley.
- The best overall performance was obtained using the three-pass data set using the best 8 and all 12 channels. Classification accuracy for test fields in these runs is about 93 percent and misclassification of other crops into wheat is about 2 percent to 6 percent for oats and 4 percent for barley.
- For any one crop, the configuration of the distribution of the data in feature space is highly complex, definitely non-normal and otherwise not predictable at the present time. The scatter of the data is always greater between different fields of the same crop than within individual fields. Therefore, the practice of using two to five fields (i.e., samples) per crop to train the classifier

is at best questionable. This is particularly true if the same set of fields are to be used to classify a large area. Further research into the minimum sample to represent the distribution of the data of any one crop is necessary.

- The question of signature extension has not been answered. More research has to be done in this area to find how far it is possible to use a set of training data or, otherwise find relevant corrections that may be applied to the data in order to be able to do so. In fact, there should be an answer to this problem before a decision is made regarding the miminum sample size (ground truth) necessary to classify large areas.