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LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

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EVALUATION OF MULTITEMPORAL DATA ENHANCEMENTS FOR THE IDENTIFICATION OF WINTER WHEAT FIELDS

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LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

EVALUATION OF MULTITEMPORAL DATA ENHANCEMENTS FOR THE IDENTIFICATION OF WINTER WHEAT FIELDS

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PREPARED BY

Gary L. Kraus
G. L. Kraus

C. M. Chesnutwood
C. M. Chesnutwood

APPROVED BY

Andrew E. Potter
Andrew E. Potter, Chief
Research, Test, and Evaluation Branch

Science and Applications Directorate
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
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1. INTRODUCTION

An extensive investigation is being conducted to determine the feasibility of using multispectral scanner (MSS) data from the first Land Satellite (Landsat-1) for the inventory of wheat fields on a global basis. As a portion of these studies, image enhancement techniques are being investigated to determine the optimum methods of generating Landsat-1 MSS images so analyst interpreter's (AI's) can select, as accurately as possible, training fields of winter wheat for use in automatic data processing routines. This report summarizes the studies that have been conducted to date on one of these techniques – the combining of two and three Landsat-1 data passes over a site into a single enhanced image. This type of enhancement, which is termed multitemporal, relies upon unique seasonal changes that occur between crop types rather than solely upon spectral reflectance differences between crops on a single date.

2. DATA ANALYSIS METHOD

All of the multitemporal renditions that were investigated were produced using computer-compatible tape (CCT) data on the Aerojet Data Analysis Station (DAS). One channel of data was placed on each of the three color guns (red, green, and blue) of the DAS television monitor and combined to give a color display for visual analysis. Almost all of the image evaluations were made using the television display since the DAS filming mode now in use proved to be prohibitively time consuming. Ground truth maps were prepared in advance for use at the DAS so that the various crops could be located on the displayed images. Evaluation of each multitemporal combination was made by visually comparing the color contrast between wheat and other crops. Each rendition was rated as either poor, fair, or good relative to a simulated color infrared (CIR) image. Those that were rated as good were evaluated in greater detail using additional test fields and test sites. The final step was to generate color imagery of the best data combinations with the production film converter (PFC). A brief analysis of the PFC imagery was made to determine that the filmed images were equivalent in quality to the displayed imagery. It is emphasized here that the visual evaluations were made subjectively by only one or two investigators. The primary guideline was to arrive at a rendition that was not only useful but also not too "foreign" to the type of imagery generally utilized by the AI's. This meant that the final selections should preferably show wheat as some shade of red or orange and everything else as a good contrasting color; i.e., similar to the CIR images.

3. DATA

For any selected site, Landsat-1 makes a data-collecting pass each 18 days. During the spring and early summer growing season for winter wheat, this allows about four data sets to be obtained. If additional passes are included for the planting-emergence and the postharvest periods, the potential number of data sets available increases to at least six. In reality, this number is usually reduced to four or five because of cloud cover restrictions. The stability of the Landsat-1 orbit and scanner system is such that data from these widespread dates may be overlaid or registered with a high degree of accuracy. For these analyses, registered CCT's were prepared utilizing as many data passes as were available for each site.

The primary intensive test site (ITS) for this study is located in Finney County, Kansas (ITS 1960). The site is not entirely typical of most winter-wheat-producing areas since many of the fields are irrigated. However, the Landsat-1 data for this area were of high quality, and numerous data passes were available.

Many other potential sites were discarded because of poor wheat crops resulting from drought, floods, hail, insects, etc

Ground truth information for Finney County was gathered during the period of June 12 through July 17, 1974. The data were considered sufficient for identification of winter wheat but were too limited to permit an evaluation to be made of anomalies seen in some fields. For example, at least eight fields of wheat were consistently difficult to identify on all renditions, including the CIR. An examination of the ground truth information shows that four of the fields were fertilized and irrigated while the other four were not. Planting date information, the only other data available, revealed that the fields were planted on dates up to 3 weeks apart. No patterns in these data were evident which could account for difficulty with these fields only. A number of other wheat fields were plowed under in the spring and replanted to some other crop because of their poor stand of wheat. Winterkill and drought accounted for these losses. Drought was responsible for the losses only on non-irrigated fields, while winterkill appeared to hit primarily those fields which were irrigated. The Finney County crops did, however, follow the crop calendar fairly closely, whereas most other test sites that were examined appeared to deviate significantly from their crop calendars.

The growth cycle for winter wheat has been divided into four biological growth stages or biostages which are defined by specific events which occur irrespective of site location. Definitions of the biostages as used in this report are given in table 1. A CIR image is also given for each biostage in the figures indicated. An overlay showing all of the larger wheat fields, as determined from ground truth information, has been placed on all figures to aid in the identification of wheat fields. In general, all of

TABLE 1.– DEFINITIONS OF BIOSTAGES FOR WHEAT*

[Note: A phase is said to begin when 50% of each crop and 50% of the wheat in that area have reached the described development]

Biological window (biostage)	Phase	Other common phase name	Definition of beginning of phase
	Plowing	Seedbed preparation	Field is being plowed.
1. Crop establishment (see fig. 1)	Sowing	Planting	Seed is in ground.
	Emergence	Sprouting	The first leaf has formed above the soil surface.
	Tillering	Stooling	Additional shoots or leaves (two to six tillers) have emerged above ground.
	Dormancy	Vegetation stops	The plant stops developing and may die back.
			Winter wheat only
	Spring growth	Spring renew	When the average daily maximum temperature reaches about 42° F, the plant beings to grow again.
2. Greening-up (see fig. 2)	Jointing	Stem elongation	The stalks start elongating between joints. Joints can easily be seen. Ground cover is about 20% to 25%.
	Booting	Ear formation	The head within the leaf sheath below the top foliage leaf begins to swell. Ground cover is at its maximum.
3. Heading (see fig. 3)	Heading	Heads emerging	The head has emerged from the leaf sheath.
4. Yellow (see fig. 4)	Soft dough	Waxy ripe or intermediate maturity	Kernels in the head squeeze easily, feel plastic or pliable, and may exude some milky fluid.
	Hard dough	Mealy ripe	Kernels are firm and may be dented with the fingernail, but are not easily crushed.
	Dead ripe	Ripe	Kernel is hard and breaks in fragments when crushed.
(see fig. 5)	Harvest		Grain is being combined or swathed.

*Adapted from *Cloud Cover Probability for LACIE* by R. Baskett and D. Wilcox, Lockheed Electronics Company, Inc., Technical Memorandum LEC-4770, NASA/JSC (Houston), November 1974.

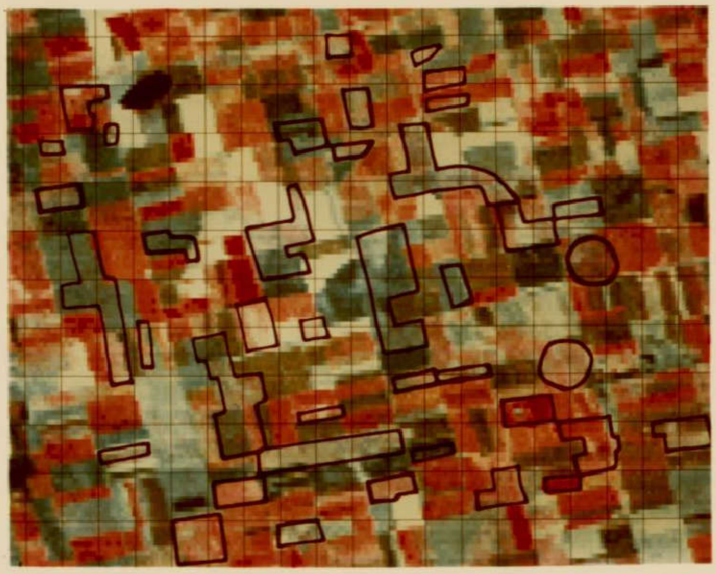

Figure 1.— CIR biostage 1 (October 23, 1973), Finney County, Kansas.

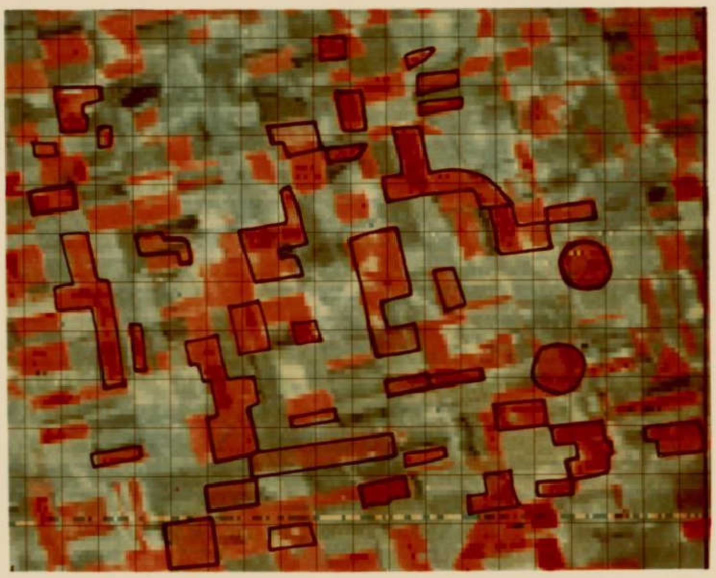

Figure 2.— CIR biostage 2 (April 20, 1974), Finney County, Kansas.

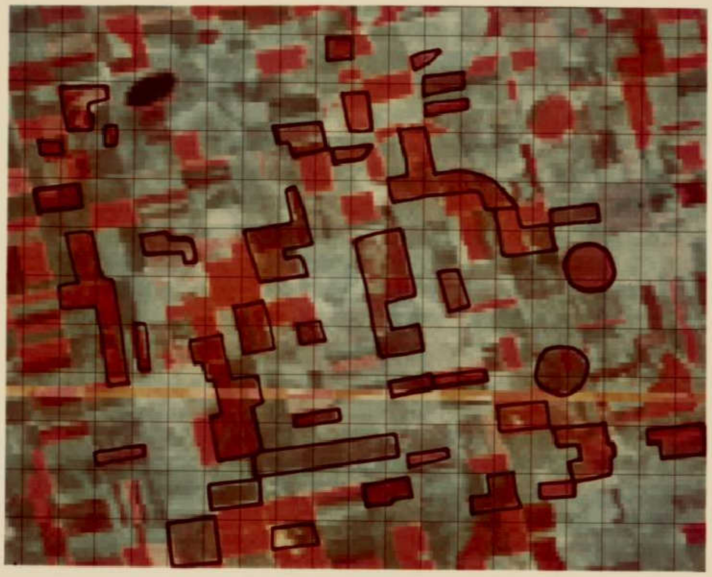

Figure 3.— CIR biostage 3 (May 26, 1974), Finney County, Kansas.

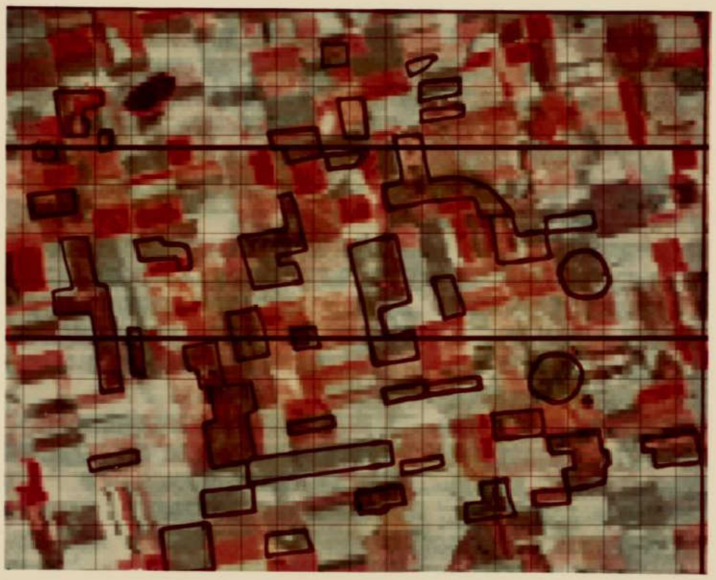

Figure 4.— CIR biostage 4 (June 14, 1974), Finney County, Kansas.

the remaining vegetated fields that are not outlined are either alfalfa or corn. More specific details for the Finney County biostage conditions are as follows:

Biostage 1 – The period between soil preparation for planting and start of dormancy. Included within this time frame are plowing, sowing, emergence, and tillering. The date of occurrence for these activities is quite irregular, however, depending upon factors such as weather and latitude. The actual condition of wheat fields in a relatively small area may range from unprepared, plowed, dry or wet soils, to the presence of young plants with several leaves (tillering). Although the Finney County test site is only 5 by 6 miles in size, the variation in field conditions was significant enough to be readily apparent on simulated CIR imagery. While biostage 1 normally extends from September 22 to November 10 in Finney County, only one data pass (October 23, 1974) in this period was available. Figure 1 is a PFC-generated CIR image of this pass.

Biostage 2 – Generally includes the earliest spring data passes available that have a minimum of cloud cover and no snow on the ground. Winter wheat is in the jointing and booting phases during this biostage while most of the other summer harvested crops are still in biostage 1. At Finney County, biostage 2 usually falls between April 2 and May 6. The April 20, 1974 data pass was used for this study. A CIR rendition of this pass is shown in figure 2.

Biostage 3 – This stage is commonly termed "heading" and is the rather specific period of the growth cycle when the head emerges from the leaf sheath. At Finney County, biostage 3 usually occurs during the interval from

May 7 to June 5. Most other summer harvested crops would probably be in biostage 1 or 2 (equivalent) at this time. The May 26, 1974 data pass for Finney County was used for this stage. Figure 3 is a CIR rendition of this pass.

Biostage 4 – Inclusive for the soft dough, hard dough, dead ripe, and harvest phases. During these phases, the difference between the IR and visible reflectance is decreasing. Most other crops exhibit the reverse tendency at the time of winter wheat biostage 4. In most cases, winter wheat is harvested at least 2 weeks earlier than possible confusion crops. At Finney County, biostage 4 usually extends from June 6 to June 27. The June 14 data pass was selected as representative of this biostage. Two other data passes were also tested although they fell outside the biostage 4 window. These were for July 1, which is termed late 4, and July 19 (postharvest). Figures 4, 5, and 6 are CIR images of these data passes, respectively.

4. TWO-DATA-PASS MULTITEMPORAL ENHANCEMENTS

The initial combinations of two data passes that were investigated are as follows: biostage 1 with 2, biostage 2 with 3, and biostage 2 with 4. Toward the latter portion of the study, combinations of biostage 2 with late 4 and biostage 2 with postharvest were added. This was done because of the dramatic changes that were seen to occur in the appearance of wheat fields during this period as shown on the CIR imagery.

During the initial phases of the study, it was found that MSS 4 and 5, the visible bands, were very similar with respect to spectral information content. However, MSS 5 generally provided

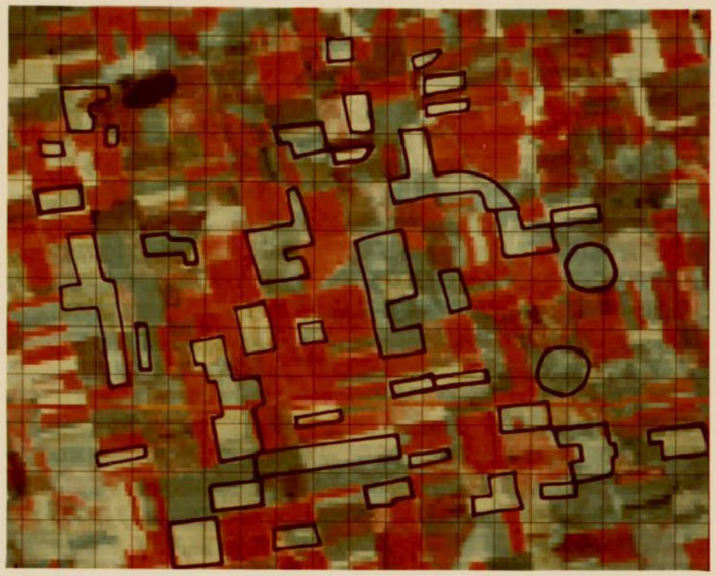

Figure 5.— CIR late biostage 4 (July 1, 1974), Finney County, Kansas.

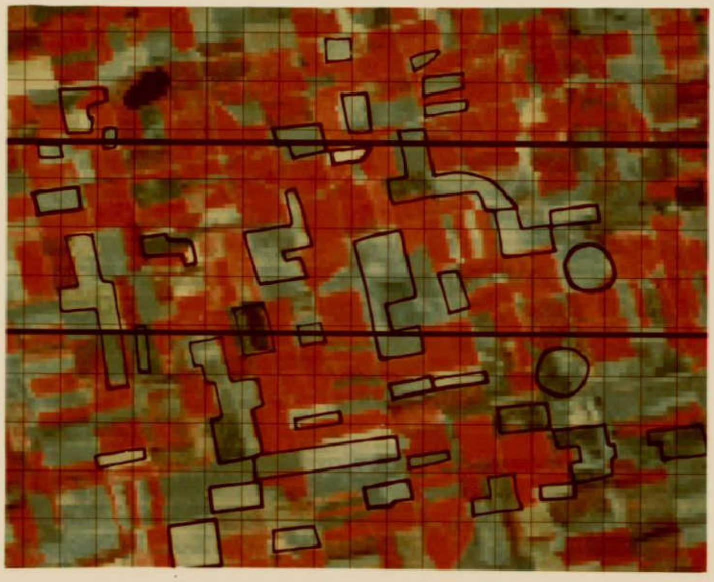

Figure 6.— CIR postharvest (July 19, 1974), Finney County, Kansas.

sharper images with better contrast and less noise. Similarly, MSS 6 and 7, the IR bands, appeared to contain much redundant information, although MSS 7 was judged to be of a more dependable high quality. In order to minimize the number of data combinations and hopefully not compromise the objectives of the study, it was decided that only MSS 5 and 7 would be used for general testing. When the best combinations of MSS 5 and 7 were selected, then MSS 4 and 6 would be substituted as a further check on their usefulness. Based on previous studies, it was also considered desirable to test each channel of data using negative as well as positive data input polarities.

Using these variables (two data passes, two MSS bands, three color guns of the DAS, and positive/negative polarities), it was possible to produce 192 different combinations for each set of two biostage data passes. Renditions which used the same channel on two color guns at the same time were not included. Each set of 192 multitemporal combinations was evaluated and the best renditions were reevaluated using equivalent data, when available, for Morton County and Ellis County, Kansas, and Hill County, Montana.

5. RESULTS – TWO-DATA-PASS COMBINATIONS

5.1 BIOSTAGE 1 WITH 2

An examination of the Finney County biostage 1 data set of October 23, 1973, was made using a simulated CIR image. Ground truth information was used to locate the fields which were winter wheat for the 1974 harvest. The wheat fields were found to range in color from dark green to white and to red in the image. These colors represent a variety of field conditions, such as plowed or wet (dark green), dry or stubble (white), and wheat or other vegetation growing (red). Even with the ground truth, the location of the wheat fields was very difficult.

Unless a more favorable data set is used, an AI would probably not be able to use biostage 1 alone for wheat identification. The most desirable set would be one in which the wheat fields were all at the same phase.

A check of the April 20 (biostage 2) CIR image revealed that almost all of the wheat was a bright pink or red in color. Unfortunately, many alfalfa fields were the same color and could not be distinguished from wheat. All other crops were planted in late spring and did not cause any confusion for this date.

Each of the 192 multitemporal combinations of biostage 1 with 2 were compared with the biostage 2 CIR image. None of the combinations proved to be superior to the CIR image as far as wheat identification was concerned. However, several were considered worthy of further evaluation using data for other ITS's. The Hill County, Montana, Ellis County, Kansas, and Morton County, Kansas, ITS's were used for additional screening in order to arrive at the best multitemporal combinations. The results are listed in table 2. It must be stressed again that none of the listed combinations were found to be superior to the biostage 2 CIR images, although several did show variations in crop conditions not otherwise apparent.

TABLE 2.– BIOSTAGE 1 WITH 2

Combination number	Band, biostage			Color of wheat
	Red	Green	Blue	
*1	MSS +5, 1	MSS +5, 2	MSS −7, 2	Red (fig. 7)
*2	−5, 1	−7, 2	+5, 2	Brown (fig. 8)
3	+5, 1	+5, 2	+7, 1	Pink
4	+5, 1	+5, 2	−7, 1	Magenta
5	+7, 1	+5, 2	−5, 1	Red-brown

*Most favorable renditions.

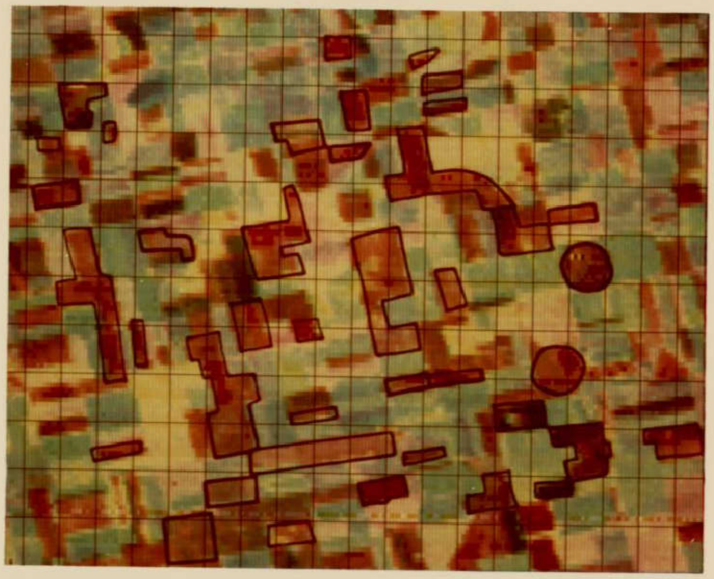

Figure 7.— Multitemporal combination 1 of biostage 1 with 2, Finney County, Kansas.

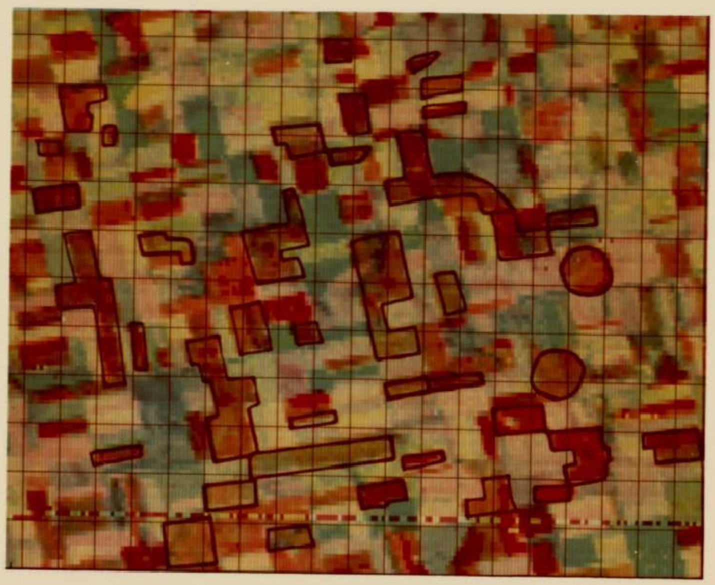

Figure 8.— Multitemporal combination 2 of biostage 1 with 2, Finney County, Kansas.

Each of the above combinations was filmed with the PFC. The imagery was evaluated, and the two most promising renditions were selected. These are indicated with asterisks in the above table and are shown in figures 7 and 8. By examining the colors of the bounded wheat fields, it is easily seen that numerous other nonwheat fields are similar. The primary confusion crop in this case is alfalfa. Alfalfa was not a significant confusion crop for the other sites that were used, and yet each site had a confusion crop of some kind; e.g., barley, grass, etc.

5.2 BIOSTAGE 2 WITH 3

Winter wheat was well into the heading phase at the time of the May 26, 1974 data pass over Finney County and should accurately represent biostage 3 conditions. An examination of the CIR image displayed on the DAS showed that wheat was distinguishable from other crops with a relatively high degree of accuracy. Wheat appeared as a red-brown color because of its reduced IR reflectance and increased visible reflectance. Most other crops were early in their growth stages and were similar to bare soil in appearance. Several fields of wheat were confused with alfalfa and were apparently late in maturing. The cutting of some alfalfa fields also occurred and produced signatures which were confused with wheat.

Each of the possible multitemporal combinations of biostage 2 with 3 was tested relative to the biostage 3 CIR display. Again, most of the renditions were found to be poor as far as wheat identification was concerned. None was clearly superior to the CIR image. It was found on many occasions that a poor rendition for one site was good at another site. This was especially true for Ellis County, where all good Finney County renditions were found to be poor and vice versa. An early season and hot, dry conditions in Ellis County probably account for some of the difficulties, but many other variables may have contributed to this. Because of limited ground truth information, no attempt was made to isolate them. Sixteen of the renditions were initially considered to be as good as the CIR image and were reevaluated using other ITS's. The ones that most often proved to be good or fair are listed in table 3.

TABLE 3.— BIOSTAGE 2 WITH 3

Combination number	Band, biostage Red	Green	Blue	Color of wheat
1	MSS +7, 3	MSS +5, 2	MSS -7, 2	Red to magenta
2	+7, 3	+5, 2	+5, 3	Red to magenta
3	+7, 2	+5, 3	+5, 2	Orange
*4	-7, 3	+5, 2	-7, 2	Reddish (fig. 9)
5	+7, 3	+5, 3	+5, 2	Green, red, or brown
*6	-5, 3	-7, 3	-7, 2	Orange (fig. 10)

*Most favorable rendition.

Imagery of each rendition was generated with the PFC, and the two best versions were selected. These are indicated with asterisks in table 3 and are shown in figures 9 and 10.

5.3 BIOSTAGE 2 WITH 4

A CIR image of the biostage 4 data pass (June 14) was displayed and evaluated against the ground truth information. Wheat fields were found to be less distinct than on earlier passes and were generally of a dark green color. Few wheat fields showed any trace of pink or red, which means that green vegetation was generally absent. The AI would probably have some difficulty delineating field boundaries and might fail to identify certain fields as wheat. This phase of biostage 4 (dead ripe) is not as useful as biostages 2 or 3 for wheat field identification.

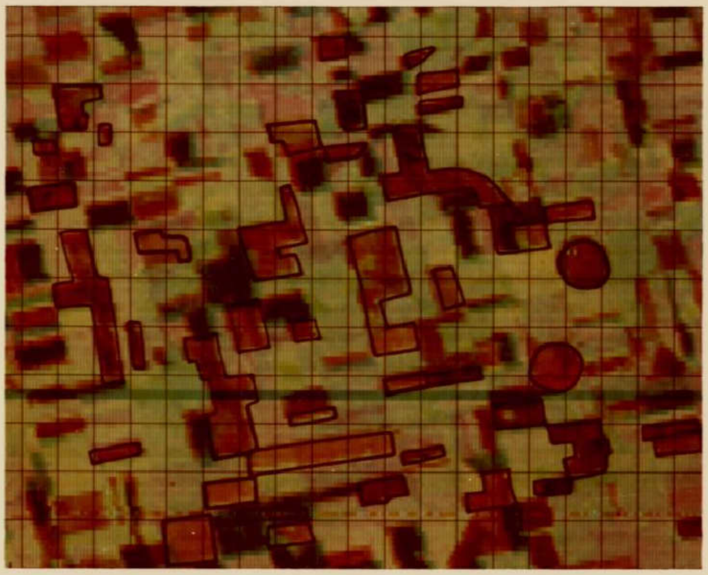

Figure 9.— Multitemporal combination 4 of biostage 2 with 3, Finney County, Kansas.

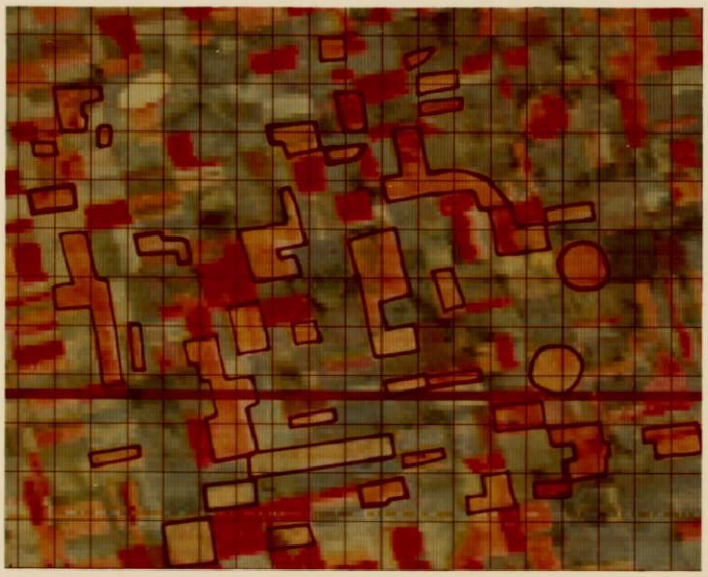

Figure 10.— Multitemporal combination 6 of biostage 2 with 3, Finney County, Kansas.

Each of the multitemporal combinations of biostage 2 with 4 was tested relative to the biostage 2 CIR display. A total of 15 renditions proved to be fair or good. A more critical evaluation reduced the number to five, and these were then tested with Ellis County data. The two best combinations are shown in figures 11 and 12 and are indicated with asterisks in table 4.

TABLE 4.— BIOSTAGE 2 WITH 4

Combination number	Band, biostage			Color of wheat
	Red	Green	Blue	
*1	MSS +7, 4	-MSS -7, 2	-MSS -5, 4	Pink (fig. 11)
*2	-7, 4	+5, 2	+5, 4	Red, magenta (fig. 12)
3	-7, 4	-7, 2	+5, 2	Red, orange
4	-7, 4	+5, 2	-7, 2	Red, pink
5	-5, 4	+7, 4	+5, 2	Red, brown

*Most favorable renditions.

By comparing the bounded wheat fields with the remaining fields, it can be seen that wheat is shown as distinct from all else, even from alfalfa, in almost all cases. The indistinctness of some field borders is perhaps the greatest difficulty with these renditions.

5.4 BIOSTAGE 2 WITH LATE 4

A CIR image for the July 1, 1974 data pass over Finney County was displayed for comparison with the ground truth information. Most wheat fields were found to be recently harvested. A number of alfalfa fields had also been cut, and others were in various stages of regrowth. In some fields, the wheat stubble appeared about equally reflective in each band and showed as a white

Figure 11.— Multitemporal combination 1 of biostage 2 with 4, Finney County, Kansas.

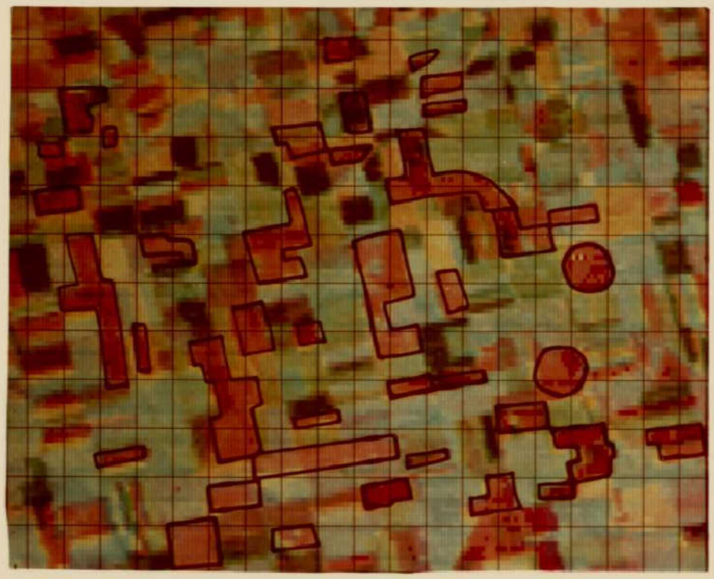

Figure 12.— Multitemporal combination 2 of biostage 2 with 4, Finney County, Kansas.

color on the CIR. Other wheat fields were of a greenish cast, which implies that they were plowed under after harvest. Several fallow fields were also light colored or greenish and could be confused with harvested wheat. Refer to figure 5 for the CIR image.

Each of the combinations of biostage 2 with late 4 was evaluated relative to the biostage 2 CIR image. About 15 renditions were rated as good as, or better than, the CIR image. These combinations were in turn reevaluated using Morton County, Ellis County, and Hill County. The combinations that most often were found to be good are listed in the following table.

TABLE 5.— BIOSTAGE 2 WITH LATE 4

Combination number	Band, biostage			Color of wheat
	Red	Green	Blue	
*1	MSS +5, 4	MSS +5, 2	MSS -7, 4	Red (fig. 13)
2	+5, 4	+5, 2	+7, 4	Pink
3	+7, 2	+5, 2	-5, 4	Red
4	+7, 4	+5, 2	-5, 4	Red-brown
5	-5, 2	-7, 2	-5, 4	Red, orange
6	+5, 4	+5, 2	+7, 2	Pink
*7	+5, 4	+5, 2	-7, 2	Red, pink (fig. 14)

*Most favorable renditions.

No single rendition proved to be the most favorable for all test sites, although the two versions that are marked with asterisks in table 5 were found to be good most often. These are shown in figures 13 and 14. Overall, this group of multitemporal combinations was considered to have a greater potential than any other group, especially if the late biostage 4 data pass

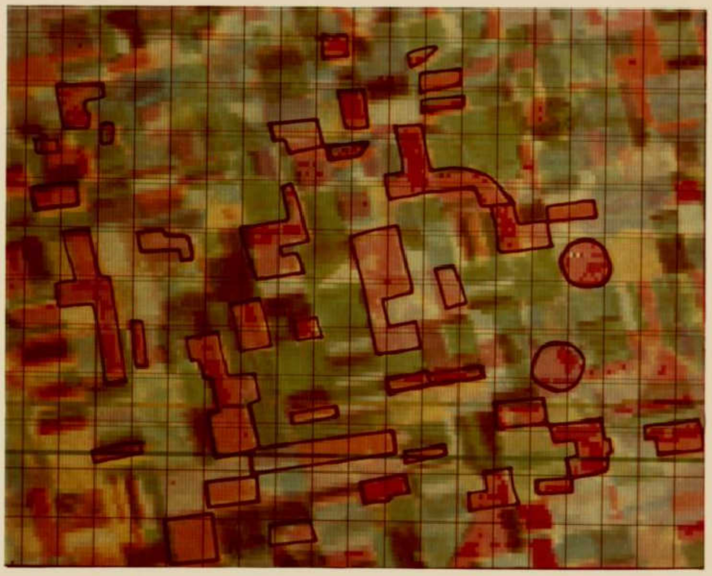

Figure 13.– Multitemporal combination 1 of biostage 2 with late 4, Finney County, Kansas.

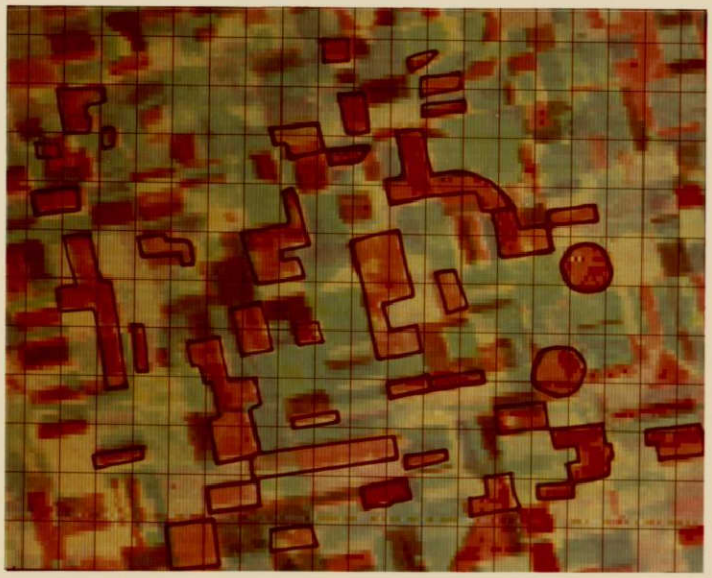

Figure 14.– Multitemporal combination 7 of biostage 2 with late 4, Finney County, Kansas.

coincides closely with end of harvest. The margin for error is perhaps 1 week either way.

5.5 BIOSTAGE 2 WITH POSTHARVEST

A postharvest data pass was tested multitemporally in order to determine if the renditions classed as good using biostage 4 or late 4 would also prove useful when substituted with postharvest data. An examination of the CIR image for the July 19, 1974 data pass over Finney County revealed that significant changes had occurred in several wheat fields. Refer to figure 6. Apparently, some of the harvested wheat fields were plowed while others remained as stubble. Several alfalfa fields which had been cut at about the time of the previous data pass showed a regrowth while corn fields were reaching a maximum in vigor. Fields of bare soil were similar to many of the wheat fields, making the identification of wheat difficult when using the CIR image only.

Each of the possible multitemporal combinations of biostage 2 with postharvest were evaluated. The most favorable renditions are given in the following table, and the two best versions are shown in figures 15 and 16.

TABLE 6.- BIOSTAGE 2 WITH POSTHARVEST

Combination number	Band, biostage (ph = postharvest) Red	Green	Blue	Color of wheat
*1	MSS -7, ph	MSS -7, 2	MSS -5, ph	Red, brown (fig. 15)
2	-7, ph	-7, 2	+5, 2	Red, brown
*3	+5, ph	+5, 2	+7, ph	Red, pink (fig. 16)
4	+5, ph	+5, 2	-7, 2	Red
5	+5, ph	-7, 2	+5, 2	Red, orange

*Most favorable renditions.

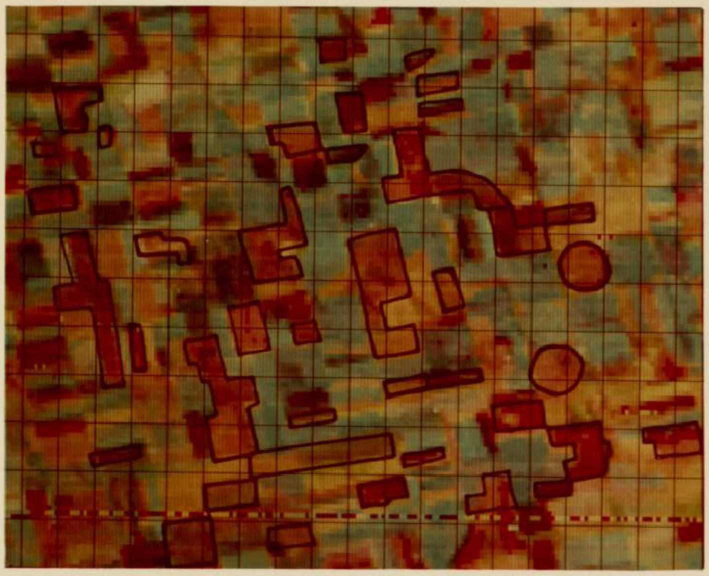

Figure 15.— Multitemporal combination 1 of biostage 2 with postharvest, Finney County, Kansas.

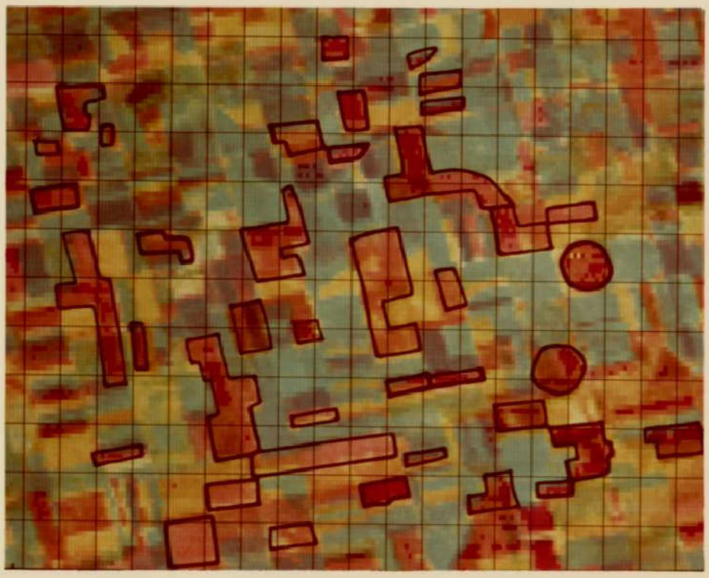

Figure 16.— Multitemporal combination 3 of biostage 2 with postharvest, Finney County, Kansas.

These combinations were compared with those of biostages 4 and late 4. Figures 11 and 15 and figures 14 and 16 use the same arrangement of bands, color guns, and polarities. This indicates that these two renditions are perhaps the most useful for multitemporal composites when using biostage 4 or later with biostage 2.

6. THREE-DATA-PASS MULTITEMPORAL ENHANCEMENTS

Combinations of three data passes were investigated in much the same manner as the two-data-pass enhancements. Due to the large number of possible combinations that were available, it was necessary to select only a representative sample for study. The following list gives the combinations that were evaluated.

MSS band, biostage			MSS band, biostage		
7, 1	7, 2	7, 3	5, 2	5, 3	5, 4
7, 1	7, 2	7, 4	7, 2	7, 3	5, 4
7, 1	7, 3	7, 4	5, 2	7, 3	5, 4
5, 1	5, 2	5, 3	5, 2	5, 3	7, late 4
5, 1	5, 2	5, 4	5, 2	7, 3	5, late 4
5, 1	5, 3	5, 4	7, 2	7, 3	5, late 4
7, 2	7, 3	7, 4	5, 3	5, late 4	7, ph

Each of the above groups was evaluated using all combinations of the three data passes, positive and negative input polarities, and 3-color guns of the DAS for a total of 672 multitemporal renditions. Those that were rated as good are listed in table 7. It may be noted that none of the combinations using biostage 1 or 4 were considered as good as, or better than, a CIR rendition. This is only an indication of a trend, however, since it was extremely difficult to correlate biostages with data passes for ITS's other than Finney. This problem was encountered during the entire study and was due primarily to a lack of reliable ground truth information.

TABLE 7.— MOST FAVORABLE THREE-DATA-PASS MULTITEMPORAL ENHANCEMENTS

Combination number	MSS band, biostage Red	Green	Blue	Color of wheat
1	5, late 4	5, 2	7, 3	Red, red-pink (fig. 17)
2	5, late 4	-7, 2	7, 3	Red, orange (fig. 18)
3	-7, 3	5, 2	-5, late 4	Red-brown, black
4	-7, 3	-7, 2	-5, late 4	Red-brown, black
5	7, 2	7, 3	-5, late 4	Red-orange
6	5, late 4	5, 3	7, ph	Orange (fig. 19)
7	5, late 4	5, 2	7, ph	Red-orange (fig. 20)

The renditions which were the most favorable for Finney County are shown in figures 17 through 20. Tests with Ellis, Morton, and Hill Counties did not necessarily confirm the value of these combinations since generally they were found to be of only fair quality. Because of the extensive screening that would be required, it was not considered feasible to evaluate all 672 combinations on these counties. The general impression was, however, that three-data-pass multitemporal renditions are potentially of more value than those of two data passes.

7. MISCELLANEOUS RESULTS

A number of findings made during this study were concerned with wheat field identification; however, these were not appropriate for inclusion in the preceding sections. The findings were made while evaluating data tapes, selecting test sites, and experimenting with computer programs being developed for the DAS. These "miscellaneous" results are as follows:

1. Winter wheat was easiest to separate from confusion crops at most ITS's when using a CIR rendition of early biostage 2.

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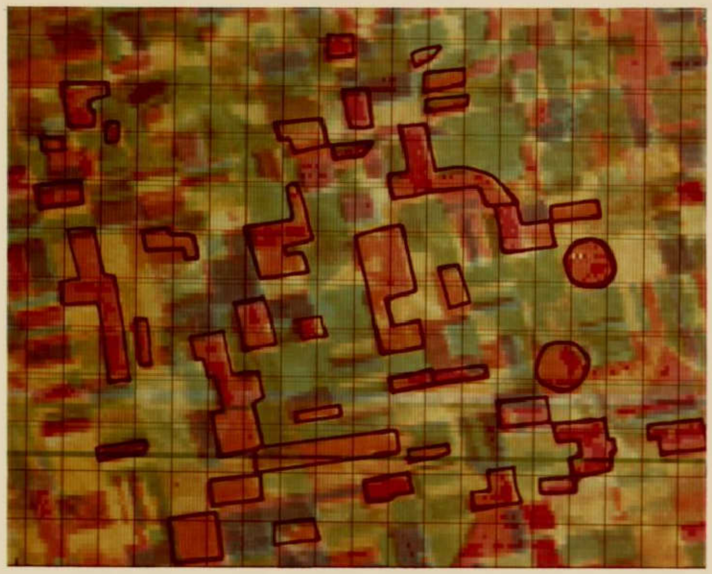

Figure 17.— Three-data-pass combination 1 of biostages 2, 3, and late 4, Finney County, Kansas.

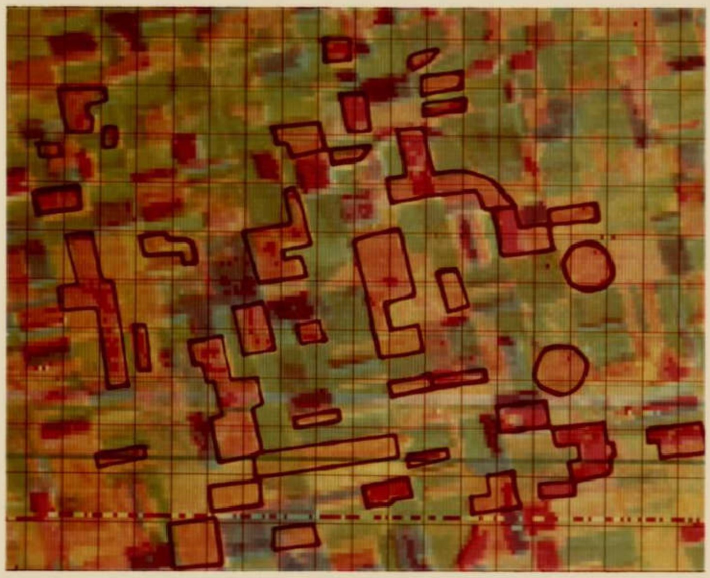

Figure 18.— Three-data-pass combination 2 of biostages 2, 3, and late 4, Finney County, Kansas.

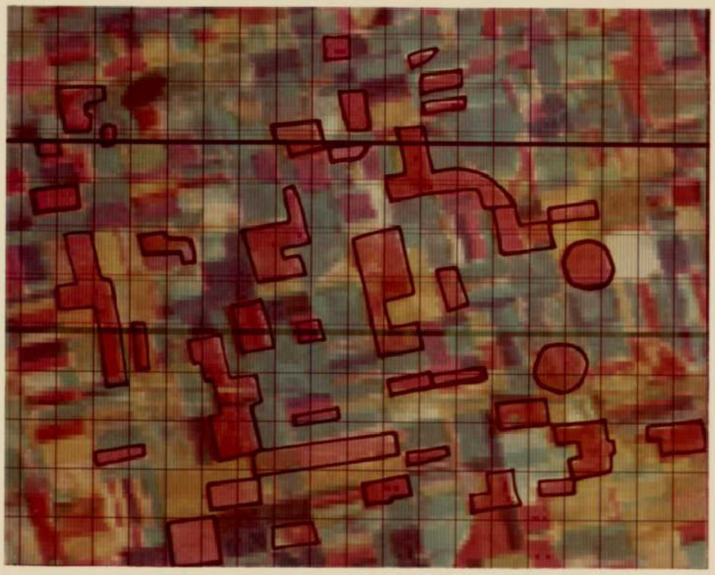

Figure 19.— Three-data-pass combination 6 of biostages 3, late 4, and postharvest, Finney County, Kansas.

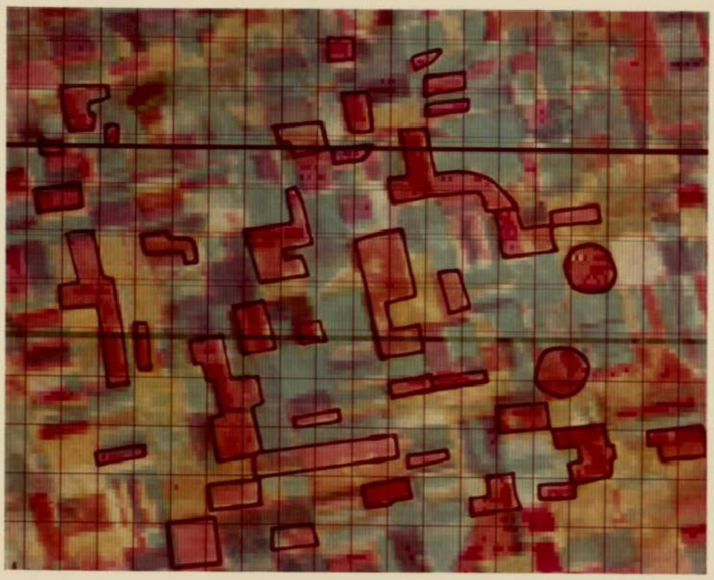

Figure 20.— Three-data-pass combination 7 of biostages 2, late 4, and postharvest, Finney County, Kansas.

Since the actual onset of biostage 2 varies according to seasonal conditions, it is necessary to examine each available data pass near the predicted start of biostage 2. Winter wheat appears to show signs of "greening up" earlier than most other vegetation. Alfalfa and crops such as winter barley may cause some difficulty, but with experience the interpreter should be able to minimize these errors.

2. A mid-December data pass for Morton County, Kansas, was examined, and winter wheat was found to be easier to identify than on any of the available data passes within biostage 1 (September 22 to November 10). Apparently, because of warmer than average temperatures, the start of dormancy occurred later than predicted and provided the wheat extra growing time. An extension of the biostage 1 time frame by perhaps 1 month or more would handle the eventuality of a late onset of dormancy and provide the AI with a higher quality image than may otherwise be obtained.

3. Registered CCT's of up to 28 channels of Landsat-1 data were prepared for use in this study. The data was placed in chronological order on the registered tapes; but no attempt was made to key the channel number to a particular biostage. When switching from one ITS to another, it was often necessary to change channel numbers in order to maintain biostage combinations. This proved to be confusing and led to erroneous entries on occasion. It is suggested that biostage and channel number be keyed together in order to simplify the use of multitemporal data by the AI and for automatic data processing techniques. Channels 1 through 4 would be assigned to biostage 1, channels 5 through 8 would be assigned to biostage 2, and so on. It would, of course, be necessary to determine accurately the predominant wheat biostage in the scene for this to work properly.

4. One of the most recent DAS programs to be developed provides the capability of subtracting two channels of data per color gun and combining the differences as a color display. Both single-date and multitemporal data may be used. The effort to date has not provided any significant improvements to the single-date imagery, but multitemporal subtraction does appear to be promising. Additional testing of this and other programs is needed in order to assess their value.

8. CONCLUSIONS

The major conclusions drawn from this study are as follows:

1. Biostage 1 data passes for wheat do not appear to show promise for "before the season" identification of wheat fields.
2. Biostage 1 with 2 multitemporal combinations were not found to be superior to a CIR rendition of biostage 2.
3. Alfalfa is a significant confusion crop when identifying wheat in some areas. This includes all stages of wheat.
4. Biostage 2 with 3 renditions proved to be only marginal in providing additional information for wheat identification.
5. Biostage 2 with 4 combinations were found to be useful and were as good as any single-date CIR imagery.
6. Biostage 2 with late 4 renditions provided some of the best enhancements that were tested. The data pass for late biostage 4 should coincide closely with the end of wheat harvest.
7. Biostage 2 with postharvest provided several good combinations similar to biostages 4 and late 4. Postharvest should be within one data pass of harvest, however.

8. MSS 4 and 6 were found to be of poorer quality than MSS 5 and 7 and did not contain enough additional information to warrant their use as components in multitemporal combinations.

9. In order to obtain reliable results from enhancements using multitemporal data, it is essential that the true biostage for wheat be identified for the data passes being utilized. Crop calendars are not always accurate.

10. No single multitemporal combination was found to be useful for all biostages. Little or no correlation between the most favorable combinations for the various biostages was found.

11. Three-data-pass renditions are potentially as good as, or better than, those of two data passes.

9. RECOMMENDATIONS

The following recommendations are made based upon this study:

1. Two- and three-data-pass renditions using biostages 2 and 4, late 4, or postharvest should receive final testing with data for other ITS's and the best combinations provided to the AI's as a part of their data package used in winter wheat identification tasks.

2. Biostage 1, as currently defined, is not recommended for use in the identification of winter wheat.

3. The CIR imagery should continue to be the primary type of image data used by the AI. Because of its less predictable nature, multitemporal imagery should be used only as a supplement.

4. In order to simplify the requirements for production processing, Landsat-1 data should be assigned channel numbers according to the dominant wheat biostage in the scene. For example, biostage 1 would occupy channels 1 through 4,

biostage 2 would occupy channels 5 through 8, and so on. Multitemporal renditions would then be composed of fixed channel numbers and could be optimized to fit the available data passes using prearranged tables of combinations.