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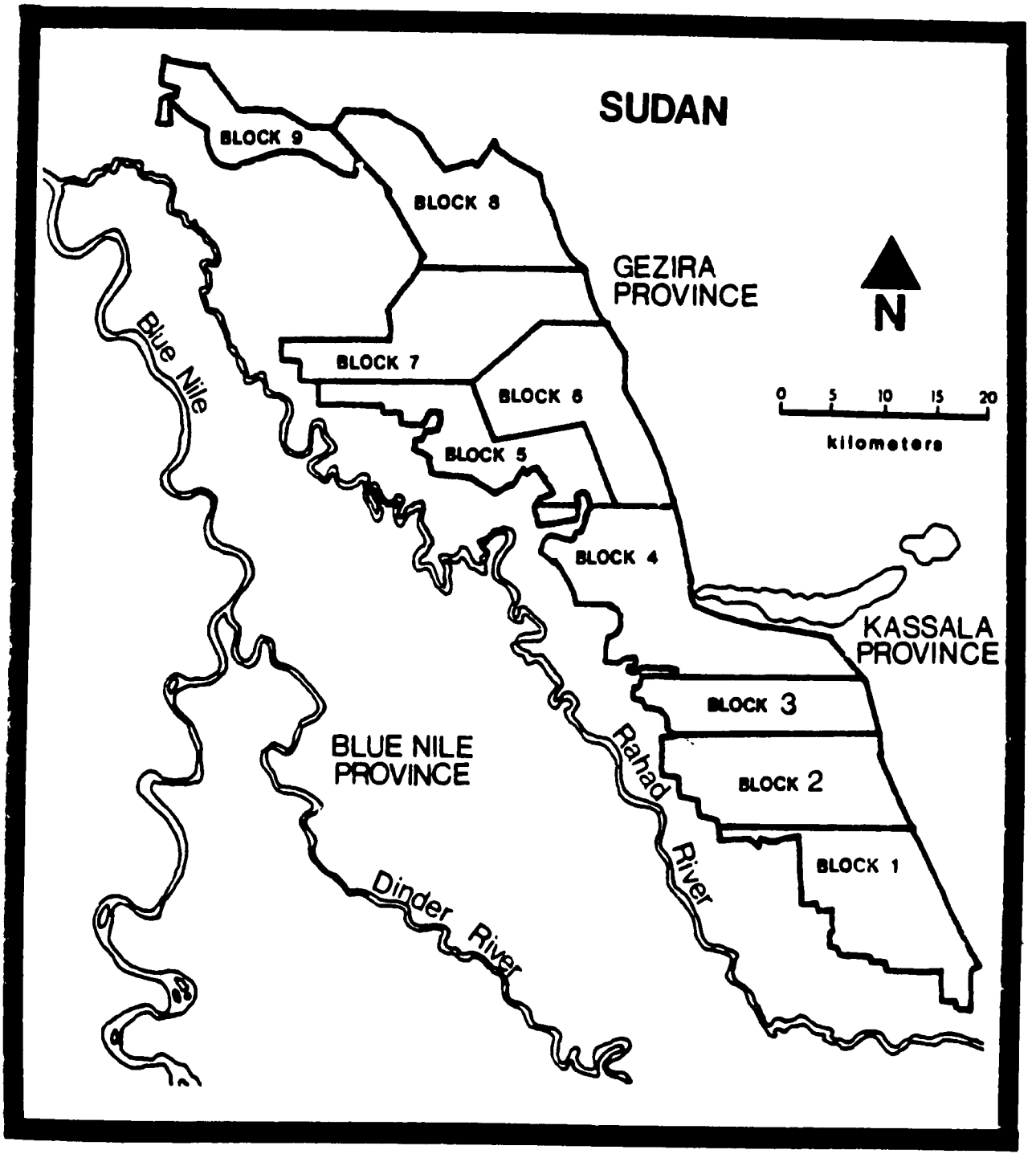
LANDSAT DATA FOR MONITORING, MANAGEMENT, AND EVALUATION OF IRRIGATION PROJECTS THE RAHAD PROJECT: SUDAN



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LANDSAT DATA FOR MONITORING, MANAGEMENT, AND EVALUATION OF IRRIGATION PROJECTS: THE RAHAD PROJECT

Final Report

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EXECUTIVE SUMMARY

LANDSAT is shown to have potential uses for monitoring, management and evaluation in the Rahad irrigation project. LANDSAT data is used to inventory crops, determine land use intensity and assess yields on the basis of plant vigor. The study found a wide diversity in the performance of separate administrative sections of the project and in the amount and direction of change between the 1979/1980 and 1981/1982 crop years.

A comparison with data from the nearby Gezira project shows the average cotton yields to be similar to Rahad, but the plant vigor in Gezira showed less variation than in Rahad.

Comparison of the plant vigor of individual cropping areas showed that they were distributed randomly throughout the project rather than being contiguous. This would indicate that the variations in yields result from the farm practices of individual farmers rather than from some underlying problem in soils or in water distribution.

A comparison of areas of high, moderate and low yields for 1979/1980 and 1981/1982 showed that three quarters of the high yielding plots in 1981/1982 were high yielding in 1979/1980. None of the plots that had low production levels in 1979/1980 were high producers in 1981/1982.

This project has demonstrated that LANDSAT analysis provides a method of analysis that is difficult to obtain on a current basis and impossible to obtain historically. Policy recommendations are:

Policy Recommendations

- LANDSAT is a low cost efficient method of irrigation analysis and should be used as a first step in the evaluation of project performance.

- Project planning for irrigation should always consider LANDSAT analysis of past and present agricultural activities in the area, if suitable data exists for such an analysis.

- Microcomputer systems capable of LANDSAT analysis and of operating a Geographic Information System should be incorporated in all large irrigation projects.

- Planning for project rehabilitation should be preceded by extensive analysis using LANDSAT where the data exists to support such an analysis.

LANDSAT DATA FOR MONITORING, MANAGEMENT AND EVALUATION OF IRRIGATION PROJECTS

INTRODUCTION

This report presents the results of an analysis of the Rahad irrigation project in the Sudan by the use of LANDSAT data. The report demonstrates the potential of LANDSAT for monitoring, management and evaluation of irrigation projects.

The Rahad Project 1/

The Rahad irrigation project is located south of Khartoum, east of the Rahad river, a branch of the Blue Nile (Figure 1). The area is flat with heavy clay soils. The Rahad river provides some seasonal flow that is supplemented by diversion from the Blue Nile. The area had been previously occupied by small villages and nomadic groups, most of whom were incorporated into the project as it was completed. Substantial areas to the southeast of the project site had been used for rainfed agriculture which has continued and expanded.

The Rahad project had been under consideration since 1961. The first crops were planted in the 1976/1977 period. Total investment is estimated at $400 million, which brought approximately 110,000 hectares into production. 140,000 persons live in 46 villages within the irrigated area and at the project headquarters located just to the east.

The project is divided into 9 administrative blocks of approximately equal area. These are further divided into a north, central and south group of 3 blocks each. Project development began with the southern blocks in 1976 (Figure 2).

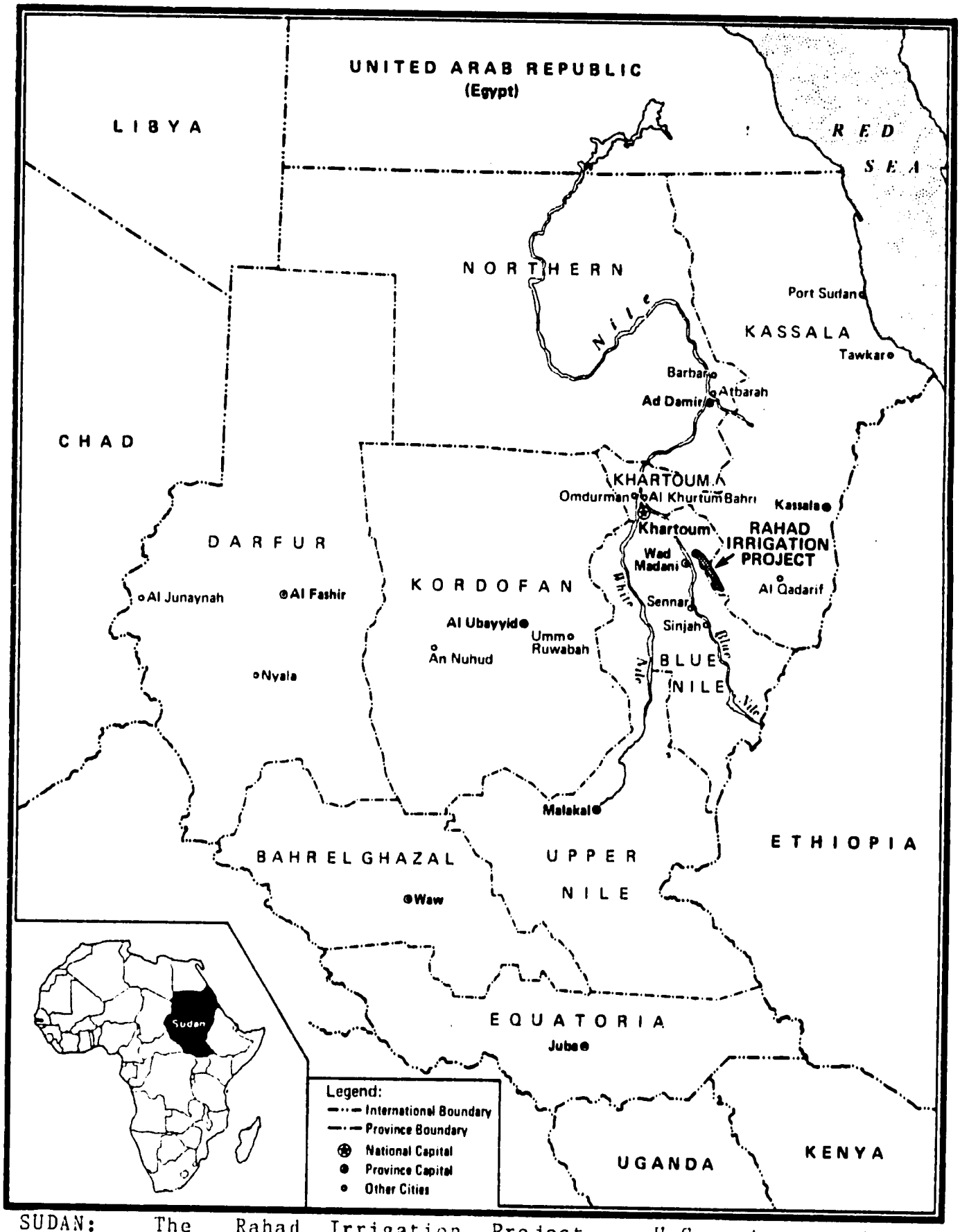
The areas and dates when production started are:

Southern Group	
Blocks 1, 2, 3	1977
Central Group	
Block 4	1977 - 1978
Blocks 5, 6	1978
Northern Group	
Blocks 7, 8, 9	1980 - 1981

1/ All the data not derived from LANDSAT is from the report: Sudan: The Rahad Project AID Impact Evaluation No. 13, Saliah, Washington, D.C., March 1983.

Figure 1

Location of Rahad Irrigation Project



SUDAN: The Rahad Irrigation Project. U.S. Agency for International Development (AID) Project Impact Evaluation Report No. 31, March 1982.

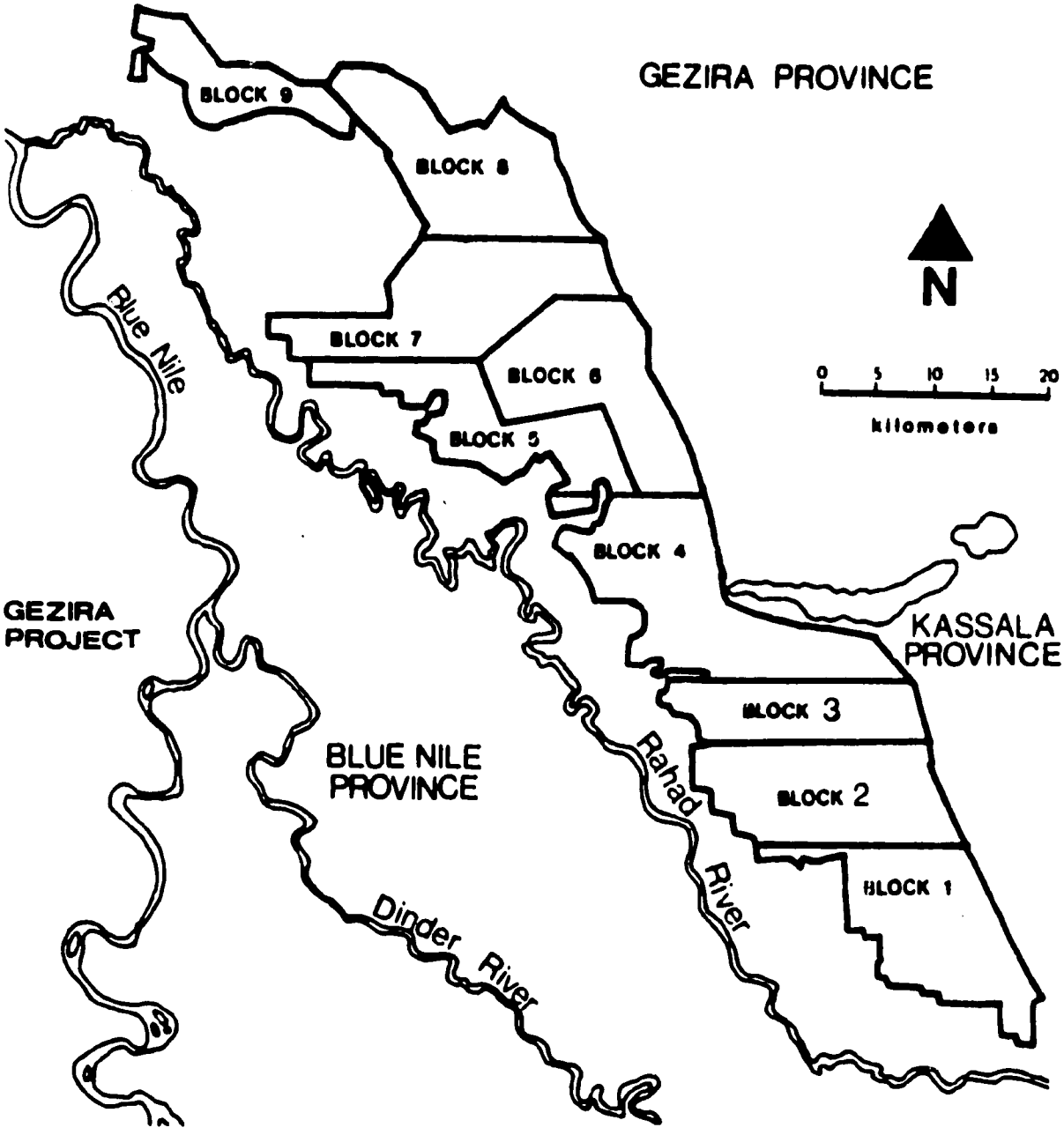

GEZIRA PROVINCE
BLOCK 9
BLOCK 8
BLOCK 7
BLOCK 6
BLOCK 5
BLOCK 4
BLOCK 3
BLOCK 2
BLOCK 1
N
0 5 10 15 20
kilometers
Blue Nile
GEZIRA PROJECT
BLUE NILE PROVINCE
Dinder River
Rahad River
KASSALA PROVINCE

Figure 2

Project land holdings.--There are three types of land holdings in the project. The basic tenancy accounting for 97 percent of the irrigation area, is a nontransferable 9.25 hectare unit devoted to raising cotton and groundnuts. 2/ Other tenancies are a 2 hectare fruit and vegetable unit and a 5 hectare animal unit.

Study Definition

This study is an evaluation of the Rahad project, but equally important is designed to demonstrate the value of LANDSAT data for monitoring and assessment of irrigation projects. In this study LANDSAT data is used to do crop inventories, assess yields and monitor performance.

Technology

To understand how LANDSAT data was used to prepare this report, a short background is required for those not familiar with the technology.

The United States has launched four LANDSAT satellites. The first three covered every area of the earth every 18 days. 3/ Data from LANDSAT is archived and thus a historical record of landcover dating back to 1972 currently exists for most of the world. The record theoretically has a data entry every 18 days for all land areas and coastal waters of the earth. 4/ Actually, cloud cover and problems with the satellite sensors restrict the amount and quality of data that is available. The data that does exist is controlled to assure concurrence between successive sets of data for a specific site. LANDSAT data is available from a number of sources. The United States collects data worldwide and other countries collect and archive data of regional interest.

Each satellite carries two systems for gathering data: the return beam vidicom (RBV) and the multispectral scanner (MSS). Both systems sense and record the reflected value of the sun from an area of the earths surface. The unit of area for data collection by either system is designated as a picture element or pixel. The size of the pixel determines the resolution of the data gathering system. Pixels are aggregated into LANDSAT scenes measuring 185 kilometers square.

The RBV collects 3 channels of data in the visible spectrum. The pixel size is 30 meters square. The MSS collects four bands of data in the green, red, near infrared and infrared spectral

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2/ Farmers are now allowed to plant dura, a staple of the local diet.

3/ Data unless specified relates to LANDSAT 1, 2, and 3. LANDSAT 4 has a repetition rate of 16 days.

4/ During one period LANDSAT 2 and 3 were both operational and provided data every 9 days.

bands. The pixel size of MSS data is 79 meters square. The data consists of a number in each of the four bands or channels with a value of between zero and 127 that is the measure of reflectivity of the energy of the sun from each 79 meter square portion of the earth.

The four data values represent the value of the specific ground cover for the pixel and is designated a signature. Since like pixels have the same or approximately the same signatures, they can be clustered by computer into groups. The process is known as classification. 5/ Water, rocks, bare soil and vegetation all have distinctively different signatures and can be classified readily into separate clusters. Vegetation can be further subdivided primarily on the value of the reflectance in the green and infrared band. Most vegetation has a high reflective value in these bands, with the most healthy plants having the higher values. Crops with a full canopy of leaves will have a much higher value than those with small leaf area and more exposed soil.

The system used to analyze data for this report was a microcomputer system with a color monitor to display the results, a printer to provide mapped output and a keyboard and digitizing tablet to enter data from sources other than LANDSAT. The software includes two basic systems, one for LANDSAT analysis and the other for spatial data storage and analysis commonly designated as a Geographic Information System.

Once the LANDSAT data is classified it becomes a landcover file and is stored in the computer along with other data relating to the project. Socio-economic data, land ownership, family operations, actual yields, and any other data relating to specific land areas can be entered, stored and used for project management. The data can be printed as a map or displayed on a monitor either as separate files or in combination with any of the other data.

The LANDSAT digital data used in this study were from October 1, 1979 and October 10, 1981. In addition, a false color photographic reproduction of the MSS data from November 1, 1972 was used to provide a reference for the area prior to the study. An RBV photograph from December 1979 was also used to confirm some surface features such as roads and canals.

FINDINGS

The analysis focused on the land area under irrigation in the Rahad project and a comparison of Rahad and the Gezira project located to the west. Data for Rahad was divided into areas corresponding to the administrative designations of project. Blocks one through six were each analyzed separately for both the 1979/1980 and the 1981/1982 growing seasons. The northern tier,

5/ For a discussion of classification see Appendix D.

blocks seven, eight and nine were not in cultivation in 1979/1980 and since there were no early data for comparison, they were analyzed as a single group for the 1981/1982 period.

Due to the scope of this study, it was impossible to test the accuracy of the findings. However, for the cotton crop the findings would appear to be over 90 percent correct based on the distribution of the infrared reflectance, the spatial patterns of the data and the distinct differences between cotton and the other vegetation. Groundnut accuracy would be somewhat less since they were past their peak growing season, close to the term of harvest. The level of accuracy could be improved in a number of ways; multiple scenes for the same planting period would allow more careful discrimination between groundnuts and cotton, a site visit would resolve some questionable classifications or additional careful manipulation of the results beyond the scope of this project would result in some marginal improvement. 6/ This latter method is discussed in some detail in Appendix A.

Intensity of Land Use

For this analysis, intensity is defined as the percentage of the available cotton/groundnut area that was under cultivation for the 1979/1980 and the 1981/1982 growing seasons. Since cotton and groundnut tenancies make up over 97 percent of the irrigated area, the results are generally valid for the entire project.

Intensity is an important economic measure. The capital cost of bringing one hectare under irrigation is nearly $4,000. Land that is idle is an expensive unused asset. 7/ Intensity of land use which was generally low in 1979/1980 had improved by the 1981/1982 season. The overall improvement masks some significant differences between groups and individual blocks.

Overall, the project shows a low, but increasing level of land use. Less than seventy percent of the land in the southern and central groups was in cultivation in the 1979/1980 period. By 1981/1982 these areas were 87 percent productive. The improvement means that resources with a value of over $500 million that were previously idle were productive in the 1981/1982 crop period.

The southern and central groups were both equal at nearly seventy percent of land in production in 1979/1980. (The northern group was not under cultivation during the first period of analysis.) Both groups increased the level of intensity and by the 1981/1982 season the southern group had reached an average

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6/ This project was funded at less than $10,000, which included a demonstration of the findings, equipment and techniques at the AID Irrigation Conference May 83. The level of funding precluded additional extensive analysis.

7/ Based on a project cost of $4 million and a total irrigated area of 110,000 hectares.

of nearly eighty percent of the irrigated land actually under cultivation compared with nearly one hundred percent for the central group.

Individual blocks show great discrepancies in the intensity of land under cultivation and in the amount and direction of change between the 1979 period, the least intense were blocks three and five, both had less than half the land cultivated. By 1981/1982 these blocks had reached 95 percent and 94 percent of full use respectively. All blocks with the exception of block one increased in intensity of cultivation between 1979/1980 and 1980/1981. Block one decreased during the period from 90 percent of use to 66 percent of use, the least intense rate of cultivation of all blocks in the southern and central groups (Table 1).

Cotton Groundnut Rotation

The management plan is for full use of the land with half in groundnuts and the other half in cotton. The analysis shows a shift from cotton to groundnuts. For 1979/1980, two thirds of the land was in use and over half was in cotton. Between 1979/1980 and 1981/1982, the trend ws to plant more crops with the predominant increase devoted to groundnuts. As noted previously, intensity increased significantly between 1979/1980 and 1981/1982 with a net gain of over 15,000 hectares, two thirds of which was accounted for by increases in groundnuts. (Table 2)

Cotton Yields

Yield per unit of land under cultivation is a critical measure of economic performance. LANDSAT data cannot be used for a direct measure of yields but does provide a good surrogate, the reflectance value of the infrared band. Studies have shown that there is a high correlation between plant vigor and infrared reflectance although the relationship varies with crop and stage of growth cycle. Plant vigor is in turn highly correlated with yield. 8/ To carry the analysis further would require historical data on actual yields. This could then be correlated with the LANDSAT data bands to derive a predictive statistic.

Cotton rather than groundnuts was selected to assess yield because it was in a vigorous period of growth and at this period would have a full leaf canopy covering the soil and thus provides a more sensitive measurement. Groundnuts on the other hand were fully mature and approaching harvest. At this stage of the crop cycle plant vigor would be low.

The reflectance value and therefore the presumed yields varied substantially in both the 1979/1980 and the 1981/1982 periods. Because of the significance of the variation between blocks, a

8/ See Appendix C.

Table 1.--Land Use Intensity by Block 1979/1980 and 1981/1982 (Hectares) Cotton and Groundnut Tenancies a/

Group	Blocks	Total area	Area under cultivation 1979/1980	Area under cultivation 1981/1982	Percent under cultivation 1979/1980	Percent under cultivation 1981/1982
Southern	1	12732	11450	8455	90	66
	2	12741	8389	8965	66	70
	3	11291	5272	10746	47	95
Total Southern Group		36764	25111	28166	68	77
Central	4	14211	12987	14788	91	100
	5	12046	5761	12391	48	100
	6	12353	7592	10380	61	84
Total Central Group		38640	26340	37559	68	97
Northern	7,8,9	32312	---	17307	--	54
Total Northern Group		32312	---	17307	--	54
Total Project		107716	51451	83032	68	81

a/ Almost all of the area is used for growth of cotton or groundnuts. There are two other types of tenancies, one for animals and one for mixed market gardening. Combined, these account for 2.25 percent of the irrigated area.

Table 2.--Cotton and Groundnut Plantings by Block (Hectares)

Inventory of Cotton and Groundnut Planting by Block
1979/1980 and 1981/1982

		1979/1980 (Hectares)		1981/1982 (Hectares)	
Group	Block	Cotton	Groundnuts	Cotton	Groundnuts
Southern	1	4564	6886	4500	3955
	2	4801	3587	3991	5327
	3	2798	2474	5879	4866
Total Southern		12163	12947	14370	14148
Central	4	7570	5417	7133	7655
	5	2782	2979	5907	6484
	6	4787	2805	4426	5952
Total Central		25239	11201	17466	20091
Northern	7,8,9	---		8128	
Total Project		27302		39964	

detailed analysis was prepared showing the distribution of infrared reflectance value by block for both years. The detailed tabular data and graphs in Appendix B show the difference between cotton in all of the blocks.

The 1979/1980 results show block six had substantially higher reflectance levels than the balance of the project. The mean

reflectance level of block six was over 20 percent higher than the lowest block and ten percent higher than the average. Other blocks varied from a medium value of 50 to 58.

By the 1981/1982 season, the results were more uniform. Of the southern and central groups every block with the exception of block six had a median value of 60 or 61 on a scale of 0 to 127. Block six again was higher than any of the others, but the difference had decreased. Block six had a weighted average reflectance value ten percent higher than the other blocks (Table 3).

Two conclusions can be drawn from the data. The first is that cotton yields for block six are far better than any other block. The second is that the extreme variability in yields shown in 1979/1980 has been reduced in 1981/1982.

Comparison with Gezira.--Portions of the Gezira project were included in the data for 1979/1980. Gezira predates the Rahad project and also is used to raise irrigated cotton. A measure of the reflectance value in the infrared band show that it was, on the average, similar to the yield in Rahad. There was not, however, the wide range in reflectance shown in Rahad in 1979/1980.

Plot Yields

One of the basic issues in the management of large irrigation projects is to maintain and increase yields. Yields can be increased by interventions affecting the entire project or by selective changes such as improvement in water management for areas with low productivity or by improvement of cultural practices of individual farmers. The key to selecting the most effective management option is first to identify the areas of high and low productivity.

The spatial patterns of yields would show whether the cause of low yields was related to the efforts of the individual or were the result of some common condition. If, for example, all the low yields were grouped in a single area, the presumption would be that soil conditions might be poor or that these areas might not have received the same level of some common input such as water or fertilizers. On the other hand, areas of high yields or low yields that were randomly distributed would indicate that success or failure were products of individual efforts.

Table 3.--Weighted Average of Infrared Reflectance 1979/1980 and 1981/1982 a/

Group	Block	1979/1980 Average infrared value	1981/1982 Average infrared value
Southern	1	58	62
	2	55	63
	3	56	63
Central	4	52	62
	5	60	64
	6	63	70
Northern	7,8,9		60

a/ Infrared reflectivity is a reliable indication of yields for a specific scene. The data is not directly transferable from scenes of the same area from different time periods because of changes in atmospheric conditions. While the data values of 1981/1982 are higher than for 1979/1980, the yields may not in fact be higher.

When the LANDSAT data was classified and cotton yields were displayed or mapped, the result was a random pattern. No clear spatial pattern emerged. The highest and lowest levels of plant vigor were distributed throughout the blocks. See Appendix F.

The assumptions therefore, must be that individual practices such as cultivation or weeding determines the level of productivity. The results for both the 1979/1980 and the 1981/1982 period showed the same random patterns of productivity. If, as the analysis shows, it is the individual tenant that makes the difference, good tenants in 1981/1982 should have also been good tenants in 1979/1980. To test this hypothesis, comparison was made of cotton production in 1979/1980 and 1981/1982 for those plots where cotton was planted in both years. Block six which had the highest levels of production in both years was used for the analysis.

Since there is a pattern of crop rotation, the first step was to isolate for comparison those plots that were planted to cotton in both 1979/1980 and 1981/1982. The results show that half the area in cotton in 1979/1980 was also in cotton in the 1981/1982 season. This substantial overlap provided a good sample size, approximately 2400 hectares to compare the yield for the two production periods in block six.

The reflective values were grouped into: high, medium and low. On this nominal scale, the 1979/1980 data showed that over half of the values (56 percent) were high, 30 percent were moderate and fourteen percent had low values. The high, medium and low values were not evenly distributed, but tended to clump into small groups of like values, consistent with patterns of individual holdings.

If the assumption that productivity was based on individual efforts was correct then the level of productivity should be consistent, that is, plots with high productivity levels in 1979/1980 would tend to be high in 1981/1982. The results show that this is what had happened. Three quarters of the high production plots in 1981/1982 had been high productive plots in 1979/1980. The other 25 percent of the high productive plots in 1981/1982 had been moderately productive in 1979/1980. None of the plots that were low producers in 1979/1980 were high producers in 1981/1982 (Table 4).

The implications are that project results could be improved by the identification and training of people responsible for the lowest production tenancies. Continued monitoring of the training and the results could be used to evaluate the effectiveness of the interventions designed to increase productivity.

Table 4.--Production Levels by Plots 1979/1980 Compared with Production Levels in the Same Plots in 1981/1982

Production levels 1979/1980	Percent of total in 1979/1980	Percent of Production levels 1981/1982	
Low	14	Low	< 1
		Moderate	13
		High	< 1
Medium	30	Low	0
		Moderate	28
		High	2
High	56	Low	< 1
		Moderate	50
		High	6

Pre-Planning

For the analysis of Rahad there is a prior question; was the investment in Rahad warranted? This question has been raised retrospectively by the Government of Sudan in reviewing alternatives such as rainfed agriculture and livestock production.

Nothing in the analysis can be used to defend or attack the rationale for Rahad. However, the 1972 LANDSAT data does show extensive rainfed agriculture to the east of the present site. LANDSAT data for successive years could be used to determine the extent of the area cultivated and to get an indication of the years in which there was sufficient rainfall for it to be successful.

IMPLICATIONS FOR IRRIGATION

This project has demonstrated that LANDSAT analysis can be used for monitoring, evaluation and management of irrigation projects.

LANDSAT provided a method of gathering data that would be difficult to obtain on a current basis and impossible to obtain historically. It also permitted an examination and comparison with Gezira and could have been extended through adjoining scenes north and south of the Rahad project. This is an important conclusion in providing project oversight and in pinpointing the reasons for the economic achievement of the project.

LANDSAT provided answers on the key economic and management questions; intensity of use, yields, crop inventories and crop rotation.

One of the most important issues addressed was the variation on yields. Spatial patterns of yields were the key to a diagnosis of whether project yields were being affected by the individual cultural practices of the tenants on the farm, or by some underlying condition affecting a larger area of the project. Random yield patterns indicate individual variations in farming practices such as cultivation and weeding while large, contiguous patterns may indicate an underlying condition.

Low yield areas adjacent to distribution or collection canals or at the tail end of the water distribution system would suggest the start of salinization. If a project has soil conditions that are not uniform, data on yields by soil type might suggest alternative cultural practices or different crop selection.

While LANDSAT data has been used almost exclusively as a source of data for the analysis, the value of LANDSAT data is enhanced when it is part of a functioning Geographic Information System. Such a system would compile LANDSAT data for current information with actual data from project operations. Both would be stored

in a Geographic Information System that matched specific land area to the farmer cultivating the area. Actual yields of previous years, the mechanical farm services provided, the extension visits and other physical, social or economic data considered relevant, could be part of a computer based Geographic Information System data base.

Such a data base would allow not only the identification of the least productive (or most productive) tenancies, but could be used to evaluate the effectiveness of interventions designed to increase productivity.

APPENDIX A

ANALYSIS PROCEDURE

Equipment and Techniques

The equipment used for the preparation of this report is a microcomputer with associated input and output devices. Input devices are a tape drive and floppy disk drives and a table digitizer. Output devices are a color monitor and a printer. The cost of the specific system used for this analysis is $65,000. The price of other appropriate systems range from $50,000 to $150,000.

The data used in this study was LANDSAT digital data and photographic images and a map of the administrative divisions of the project from the AID impact evaluation report. In this section the process of data selection and analyses are discussed in some detail to provide a how-to-do background for those with an interest in the technical details.

The entire process required these sequential steps:

1. Data selection
   A. Scene identification
   B. Scene selection
2. Data subset and transfer from tape to disk
3. Data classification
4. Class aggregation
5. Testing the classifications
   A. Examples of distributions
6. Inventories of crop by block
7. Determining cotton vigor by pixel for 1979/1980 and 1981/1982.
8. Determining cotton vigor by pixel for sample area of Gezira.
9. Determining relationship between vigor in 1979/1980 and 1981/1982.
10. Assessment of changes in rainfed agriculture outside irrigated perimeter.

Data Selection

LANDSAT data for the world are indexed to the Worldwide Reference System. This single worldwide geographic referencing system identifies approximate centroids of 185 kilometers square LANDSAT scenes by a specific numbered path and row. Since the orbital paths and data formats are the same for the first three LANDSAT satellites, the reference system is common for all. LANDSAT 4 has a different orbital path and repetition rate and as a result has different path and row numbers although the same scene coverage has been maintained.

Data selection is a three step process: the location of the path and row of the area, selecting the appropriate year and season and locating high quality images that are most appropriate for the particular application. The Worldwide Reference System is divided into 10 regions of which region three, Europe and North Africa, includes Sudan. Reference to the map of the area shows that path 185, row 50 includes the area of Rahad (Figure A-1).

Since the study sought to determine the changes in the area as a result of Rahad and to look at the success of the project itself, three scenes were needed; one prior to the project, one while the project was in the early year of operation and a final scene with current data. The data should be collected at a time when the crops are growing rapidly and had time to develop a full set of leaves of canopy. The cycle of crop production limited the period of ideal conditions to a period from mid September to early October. By mid September, cotton would have been planted for at least one month. By mid October, groundnuts harvest would begin.

The final consideration was to get images that were of suitable quality. LANDSAT image quality is affected by cloud cover, haze, and other atmospheric conditions and the status of the MSS sensors, which periodically require recalibration.

Some forty scenes with minimal cloud cover and suitable sensor quality dating from 1972 were available. The following dates were selected:

9/13/72 - as a full color MSS photographic image
10/1/79 - MSS digital tape
10/9/81 - MSS digital tape
10/13/80 - RBV photographic image

Data Suitability

The analysis of a large project such as Rahad is possible either by the analysis of the entire 185 kilometers square scene or by selecting out portions of the area. For this project where the divisions into administrative blocks were so well defined, the decision was made to subset the LANDSAT data for each block on a separate floppy disk. The one exception was the three northern blocks which were only in production for the last year of analysis. These were subset as one unit. Subsetting the data before classification allowed an analysis of the differences between blocks in the classification of crops.

The primary task of classification is to develop significant landcover classes from LANDSAT data and to determine amount and type of agriculture and other land uses. The concept of classification relies on the structure of LANDSAT data. The LANDSAT satellites are equippped with a multiple spectral scanner (MSS). The instrument is designed to collect data from the

Figure A-1

frequency bands representing red, green, near infrared and infrared frequencies. The data is actually a record of the amount of energy reflected from these four segments or channels of the electromagnetic spectrum.

LANDSAT's level of spatial detection is approximately .6 hectares per unit. These units are designated pixels (picture elements) and for a 2.5 hectare tenancy there are 15 LANDSAT pixels, each with four pieces of information; a value for the relative reflectance in each of the four channels.

The overall response range of the LANDSAT MSS electromagnetic spectrum is between .5 and 1.1 micrometers.

	Frequency (Micrometers)	
Channel 1	.5 - .6	Green
Channel 2	.6 - .7	Red
Channel 3	.7 - .8	Near infrared
Channel 4	.8 - .11	Infrared

The data from the multispectral scanner can be used to discriminate between specific landcover types by use of a single specific band. Using only the single band analysis can usually identify agriculture and forest. The ability to discriminate increases when the four present channels are used and will be further improved with the seven bands available in LANDSAT 4.

The classifications of groups of pixels into specific landcover types is complicated by the natural variabilty of the landcover. The reflectance of LANDSAT will vary with color, texture, orientation and any of the attributes that allow for the infinite variability within any landcover type. Agricultural crop reflectance will vary with vigor, spacing, stage of growth, and variety.

A further complication is introduced because the range of values do not stay absolute. Reflectance values are different because of atmospheric and temporal conditions. For example, reflectance values of a field just after a rain storm might be different than the reflectance value from the same field after a long, dry period. Also, seasonal and year changes, clouds, fog, and haze cause enough variation in the scene that the analyst must analyze each scene individually, rather than rely on standard values.

The grouping of pixels or classification involves some methods of encompassing the variabilty of like classes into groups, i.e. cotton plants that range from excellent to very poor in a single class. There are two basic methods: supervised and unsupervised.

The supervised classification assumes that the analyst knows an area or areas that represent a specific crop or other landcover class. These are identified and used as a sample or standard by

which the computer can use the reflectance values of the four bands associated with the known pixels to select out other areas with the same reflectance values. In supervised classifications, the analyst only selects out as many classes as there are known landcover sample areas. All other areas are grouped into a class of "other" landcover.

Unsupervised classification used in this analysis is a statistical method of clustering data into groups with similar reflectance values in each of the four channels of data. The analyst sets the parameters; how many groups, how much variability is allowed within a group and the type of grouping algorithm that will be used.

After experimental runs, data was grouped into 27 clusters or classes. The clusters each represent pixels, which are relatively homogeneous. Cotton for example might be represented by six or more clusters depending on the relative vigor and thus the reflectance value of the particularly cotton pixel.

The 27 groupings are aggregated into single classes, i.e., cotton, groundnuts, other crops, mixed vegetation and bare soil. The groups are aggregated again on the basis of reflectance values.

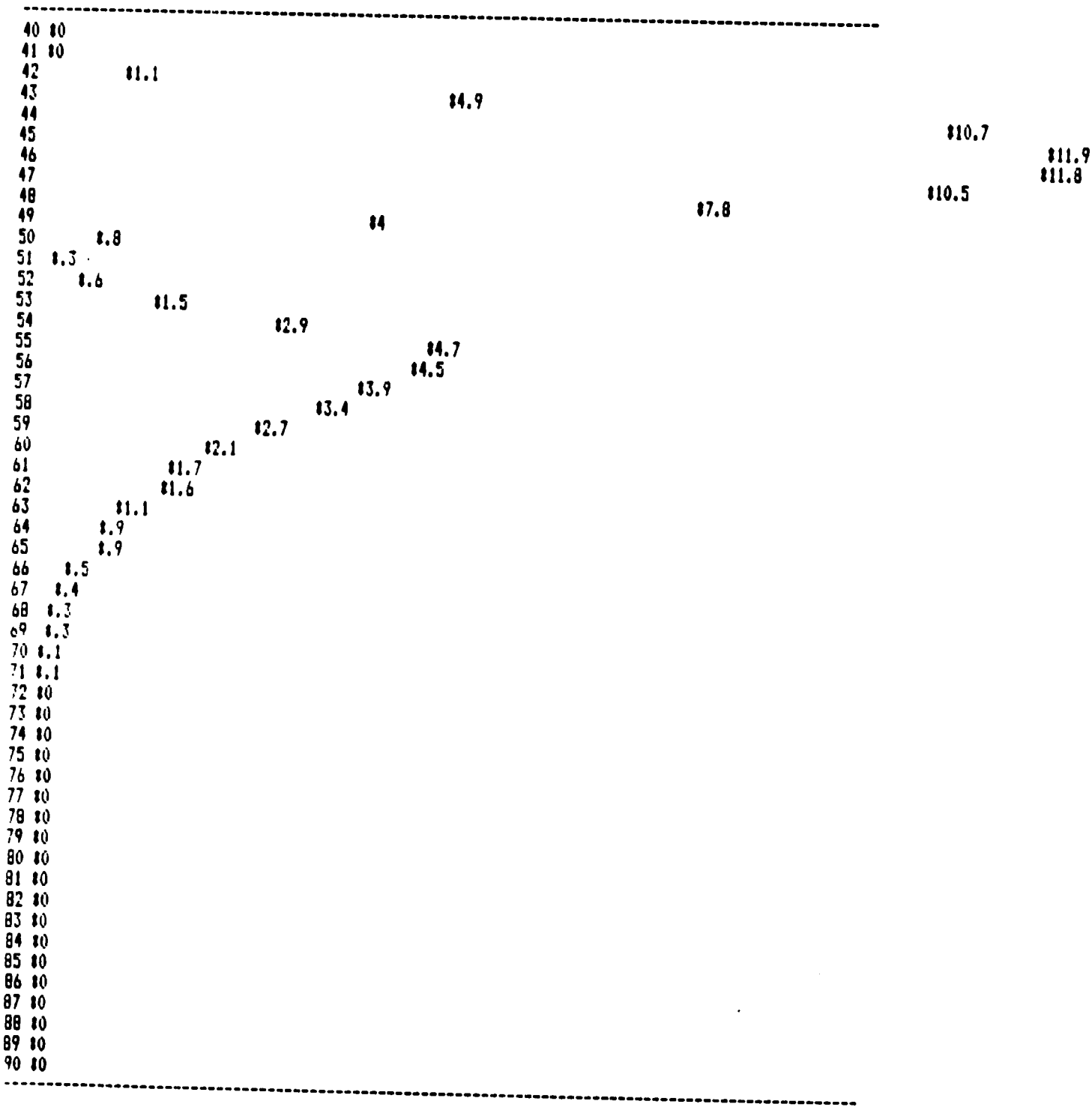
Testing the Results

The entire classification process results in a limited number of classes of concern for the specific analyses. In the case of Rahad, six classes were used: cotton, groundnuts, other crops, mixed vegetation, bare soil, and wet areas. The results are tested in two ways. Each class is displayed over the LANDSAT data to determine if the spatial distribution conforms to known or assumed patterns. One would expect, for example, that cotton pixels would tend to be in adjacent areas rather than being uniformly distributed among pixels of groundnuts.

Classifications are also tested statistically. The number of pixels of cotton are plotted against the reflectance value of channel four. The results of such a plot should be a normal distribution. Distribution varying from normal usually indicates some confusion in the grouping of clusters. A bi-modal distribution shows that more than one crop type is contained in a single class (Figure A-2).

The plots of the reflectance value of cotton in channel four (Appendix B) all show a distribution in which the lower values are skewed indicating some of the less vigorous cotton plantings have been eliminated from the cotton class. The result is an error which effectively understates the quantity of cotton under cultivation. The error could be reduced by selecting out individual clusters from the unsupervised clustering routines, most like those representing the lower classes of cotton and selectively adding these to the cotton class until the

Figure A-2



Note that the distribution is bimodal with one mode at a band 4 value of 45 and another at 56. The lower peak is a groundnut class that was included with cotton. The final data for Block 1, 1979 are depicted in Appendix B.

distribution was more nearly normal. This was not done since the results are well within the 10 percent level of error anticipated. Further manipulation would serve little useful purpose.

APPENDIX B

CLASSIFICATION PLOTS

The tables and graphs in this section are the results of selecting out the cotton from the other classes. The separate cotton class is then matched with the reflectance value of the infrared band. The plots are reflectance values plotted against the number of pixels. In addition to plotting the data, the results were displayed on the computer monitor to see if high or low productivity areas were random or had some spatial organization that would indicate underlying problems that might be caused by soil conditions or water distribution. No such patterns were found.

The plots serve as a check on the classifications of cotton. The output of the unsupervised classifications were a group of 27 like clusters. Cotton was represented by five different clusters which were grouped into a single cotton class. If the grouping is correct, the graph should approach a normal distribution. A bi-modal distribution as illustrated in figure A-2 indicates more than one type of vegetation was included in the cotton class.

YEAR : 1975
BLOCK :
TOTAL POINTS: 5130

VALUE	POINTS	PERCENT	CUM. PERCENT
43	1	.02	.02
44	1	.02	.04
45	2	.04	.08
46	6	.12	.2
47	14	.27	.47
48	10	.19	.66
49	25	.49	1.15
50	23	.45	1.6
51	38	.74	2.34
52	95	1.85	4.19
53	217	4.23	8.42
54	418	8.15	16.57
55	662	12.9	29.47
56	645	12.57	42.04
57	554	10.8	52.84
58	482	9.4	62.24
59	387	7.54	69.78
60	298	5.81	75.59
61	247	4.81	80.4
62	226	4.41	84.81
63	162	3.16	87.97
64	132	2.57	90.54
65	129	2.51	93.05
66	81	1.58	94.63
67	59	1.15	95.78
68	53	1.03	96.81
69	48	.94	97.75
70	27	.53	98.28
71	25	.49	98.77
72	13	.25	99.02
73	10	.19	99.21
74	13	.25	99.46
75	10	.19	99.65
76	6	.12	99.77
77	3	.06	99.83
78	4	.08	99.91
79	3	.06	99.97
80	1	.02	99.99

YEAR 1979
BLOCK 1

40	0%
41	0%
42	0%
43	0%
44	0%
45	0%
46	0.1%
47	0.2%
48	0.1%
49	0.4%
50	0.4%
51	0.7%
52	1.9%
53	4.2%
54	8.1%
55	
56	12.5%
57	10.8%
58	9.4%
59	7.5%
60	5.9%
61	4.8%
62	4.4%
63	3.1%
64	2.5%
65	2.5%
66	1.5%
67	1.1%
68	1%
69	0.9%
70	0.5%
71	0.4%
72	0.2%
73	0.1%
74	0.2%
75	0.1%
76	0.1%
77	0%
78	0%
79	0%
80	0%
81	0%
82	0%
83	0%
84	0%
85	0%
86	0%
87	0%
88	0%
89	0%
90	0%

YEAR : 1975
BOOK : 2
TOTAL POINTS: 14777

VALUE	POINTS	PERCENT	CUM. PERCENT
45	10	.07	.07
46	120	.81	.88
47	431	2.92	3.8
48	965	6.53	10.33
49	1202	8.13	18.46
50	1282	8.68	27.14
51	1158	7.84	34.98
52	1096	7.42	42.4
53	1038	7.02	49.42
54	917	6.21	55.63
55	877	5.93	61.56
56	740	5.01	66.57
57	654	4.43	71
58	551	3.73	74.73
59	537	3.63	78.36
60	491	3.32	81.68
61	410	2.77	84.45
62	370	2.5	86.95
63	322	2.18	89.13
64	299	2.02	91.15
65	232	1.57	92.72
66	218	1.48	94.2
67	169	1.14	95.34
68	129	.87	96.21
69	101	.68	96.89
70	81	.55	97.44
71	72	.49	97.93
72	55	.37	98.3
73	55	.37	98.67
74	37	.25	98.92
75	31	.21	99.13
76	25	.17	99.3
77	23	.16	99.46
78	20	.14	99.6
79	21	.14	99.74
80	8	.05	99.79
81	5	.03	99.82
82	8	.05	99.87
83	6	.04	99.91
84	4	.03	99.94
85	1	.01	99.95
86	3	.02	99.97
87	2	.01	99.98
88	1	.01	99.99

YEAR 11 1973
BLOCK 2

40	$0
41	$0
42	$0
43	$0
44	$0
45	$0
46	$.8
47	$2.9
48	$6.5
49	$8.1
50	$8.6
51	$7.8
52	$7.4
53	$7
54	$6.2
55	$5.9
56	$5
57	$4.4
58	$3.7
59	$3.6
60	$3.3
61	$2.7
62	$2.5
63	$2.1
64	$2
65	$1.5
66	$1.4
67	$1.1
68	$.8
69	$.6
70	$.5
71	$.4
72	$.3
73	$.3
74	$.2
75	$.2
76	$.1
77	$.1
78	$.1
79	$.1
80	$0
81	$0
82	$0
83	$0
84	$0
85	$0
86	$0
87	$0
88	$0
89	$0
90	$0

YEAR = 1979
BLOCK = 3
TOTAL POINTS = 8812

VALUE	POINTS	PERCENT	CUM. PERCENT
47	3	.03	.03
48	64	.74	.77
49	304	3.53	4.3
50	639	7.42	11.72
51	901	10.46	22.18
52	834	9.68	31.86
53	771	8.95	40.81
54	703	8.16	48.97
55	623	7.23	56.2
56	551	6.4	62.6
57	517	6	68.6
58	385	4.47	73.07
59	378	4.39	77.46
60	355	4.12	81.58
61	264	3.07	84.65
62	238	2.76	87.41
63	198	2.3	89.71
64	193	2.24	91.95
65	126	1.46	93.41
66	124	1.44	94.85
67	82	.95	95.8
68	77	.89	96.69
69	64	.74	97.43
70	44	.51	97.94
71	45	.52	98.46
72	26	.3	98.76
73	27	.31	99.07
74	19	.22	99.29
75	17	.2	99.49
76	9	.1	99.59
77	7	.08	99.67
78	12	.14	99.81
79	1	.01	99.82
80	5	.06	99.88
81	5	.06	99.94
82	1	.01	99.95

YEAR 1979
BLOCK 3

40	0
41	0
42	0
43	0
44	0
45	0
46	0
47	0
48	.7
49	3.5
50	
51	7.4
52	10.4
53	9.6
54	8.9
55	8.1
56	7.2
57	6.4
58	6
59	4.4
60	4.3
61	4.1
62	3
63	2.7
64	2.3
65	2.2
66	1.4
67	1.4
68	.9
69	.8
70	.7
71	.5
72	.5
73	.3
74	.3
75	.2
76	.2
77	.1
78	0
79	.1
80	0
81	0
82	0
83	0
84	0
85	0
86	0
87	0
88	0
89	0
90	0

YEAR :: 1979
BLOCK 1
TOTAL POINTS: 33800

VALUE	POINTS	PERCENT	CUM.PERCENT
41	8	.03	.03
42	118	.51	.54
43	544	2.33	2.87
44	1163	4.99	7.86
45	1514	6.5	14.36
46	1654	7.1	21.46
47	1541	6.61	28.07
48	1465	6.29	34.36
49	1456	6.25	40.61
50	1322	5.67	46.28
51	1345	5.77	52.05
52	1148	4.93	56.98
53	1125	4.83	61.81
54	1048	4.5	66.31
55	1011	4.34	70.65
56	927	3.98	74.63
57	775	3.33	77.96
58	659	2.83	80.79
59	643	2.76	83.55
60	534	2.29	85.84
61	468	2.01	87.85
62	410	1.76	89.61
63	383	1.64	91.25
64	334	1.43	92.68
65	275	1.18	93.86
66	267	1.15	95.01
67	212	.91	95.92
68	172	.74	96.66
69	150	.64	97.3
70	117	.5	97.8
71	116	.5	98.3
72	80	.34	98.64
73	67	.29	98.93
74	43	.18	99.11
75	29	.12	99.23
76	31	.13	99.36
77	37	.16	99.52
78	19	.08	99.6
79	24	.1	99.7
80	16	.07	99.77
81	17	.07	99.84
82	15	.06	99.9
83	2	.01	99.91
84	6	.03	99.94
85	3	.01	99.95
86	3	.01	99.96
87	3	.01	99.97
88	1	0	99.97

YEAR 11 1979
BOOK 1

40	$0
41	$0
42	$.5
43	$2.3
44	$4.9
45	$6.5
46	$7.1
47	$6.6
48	$6.2
49	$6.2
50	$5.6
51	$5.7
52	$4.9
53	$4.8
54	$4.5
55	$4.3
56	$3.9
57	$3.3
58	$2.8
59	$2.7
60	$2.2
61	$2
62	$1.7
63	$1.6
64	$1.4
65	$1.1
66	$1.1
67	$.9
68	$.7
69	$.6
70	$.5
71	$.5
72	$.3
73	$.2
74	$.1
75	$.1
76	$.1
77	$.1
78	$0
79	$.1
80	$0
81	$0
82	$0
83	$0
84	$0
85	$0
86	$0
87	$0
88	$0
89	$0
90	$0

YEAR : 1979
BODY : 5
TOTAL POINTS: 8581

VALUE	POINTS	PERCENT	CUM.PERCENT
50	19	.22	.22
51	115	1.34	1.56
52	312	3.64	5.2
53	452	5.28	10.48
54	535	6.25	16.73
55	538	6.28	23.01
56	634	7.41	30.42
57	614	7.17	37.59
58	656	7.66	45.25
59	645	7.53	52.78
60	584	6.82	59.6
61	492	5.75	65.35
62	454	5.3	70.65
63	371	4.33	74.98
64	318	3.71	78.69
65	275	3.21	81.90
66	235	2.74	84.64
67	191	2.23	86.87
68	173	2.02	88.89
69	152	1.78	90.67
70	135	1.58	92.25
71	99	1.16	93.41
72	83	.97	94.38
73	90	1.05	95.43
74	67	.78	96.21
75	66	.77	96.98
76	42	.49	97.47
77	44	.51	97.98
78	37	.43	98.41
79	37	.43	98.84
80	22	.26	99.10
81	17	.2	99.30
82	23	.27	99.57
83	14	.16	99.73
84	13	.15	99.88
85	2	.02	99.90
86	5	.06	99.96

YEAR 11 1973
BLOCK 5

40	$0
41	$0
42	$0
43	$0
44	$0
45	$0
46	$0
47	$0
48	$0
49	$0
50	$.2
51	$1.3
52	$3.6
53	$5.2
54	$6.2
55	$6.2
56	$7.4
57	$7.1
58	$7.6
59	$7.5
60	$6.8
61	$5.7
62	$5.3
63	$4.3
64	$3.7
65	$3.2
66	$2.7
67	$2.2
68	$2
69	$1.7
70	$1.5
71	$1.1
72	$.9
73	$1
74	$.7
75	$.7
76	$.4
77	$.5
78	$.4
79	$.4
80	$.2
81	$.2
82	$.2
83	$.1
84	$.1
85	$0
86	$0
87	$0
88	$0
89	$0
90	$0

YEAR : 1978
BLOCK : 8
TOTAL POINTS: 14787

VALUE	POINTS	PERCENT	CUM.PERCENT
48	2	.01	.01
49	3	.02	.03
50	37	.25	.28
51	149	1.01	1.29
52	343	2.33	3.62
53	560	3.8	7.42
54	751	5.1	12.52
55	790	5.36	17.88
56	850	5.77	23.65
57	799	5.42	29.07
58	807	5.48	34.55
59	839	5.69	40.24
60	733	4.97	45.21
61	792	5.37	50.58
62	702	4.76	55.34
63	660	4.48	59.82
64	602	4.08	63.9
65	609	4.13	68.03
66	549	3.73	71.76
67	493	3.35	75.11
68	440	2.99	78.1
69	451	3.06	81.16
70	412	2.8	83.96
71	387	2.63	86.59
72	340	2.31	88.9
73	261	1.77	90.67
74	253	1.72	92.39
75	188	1.28	93.67
76	155	1.05	94.72
77	136	.92	95.64
78	122	.83	96.47
79	113	.77	97.24
80	94	.64	97.88
81	84	.57	98.45
82	61	.41	98.86
83	49	.33	99.19
84	39	.26	99.45
85	24	.16	99.61
86	20	.14	99.75
87	14	.09	99.84
88	11	.07	99.91
89	6	.04	99.95
90	1	.01	99.96
91	4	.03	99.99
92	1	.01	100
93	1	.01	100.01

YEAR : 1979
BLOCK 6

40	0
41	0
42	0
43	0
44	0
45	0
46	0
47	0
48	0
49	0
50	.2
51	1
52	2.3
53	3.8
54	5.1
55	5.3
56	5.7
57	5.4
58	5.4
59	5.6
60	4.9
61	5.3
62	4.7
63	4.4
64	4
65	4.1
66	3.7
67	3.3
68	2.9
69	3
70	2.8
71	2.6
72	2.3
73	1.7
74	1.7
75	1.2
76	1
77	.9
78	.8
79	.7
80	.6
81	.5
82	.4
83	.3
84	.2
85	.1
86	.1
87	0
88	0
89	0
90	0

YEAR: 1981
BLOCK: 1
TOTAL POINTS: 13848

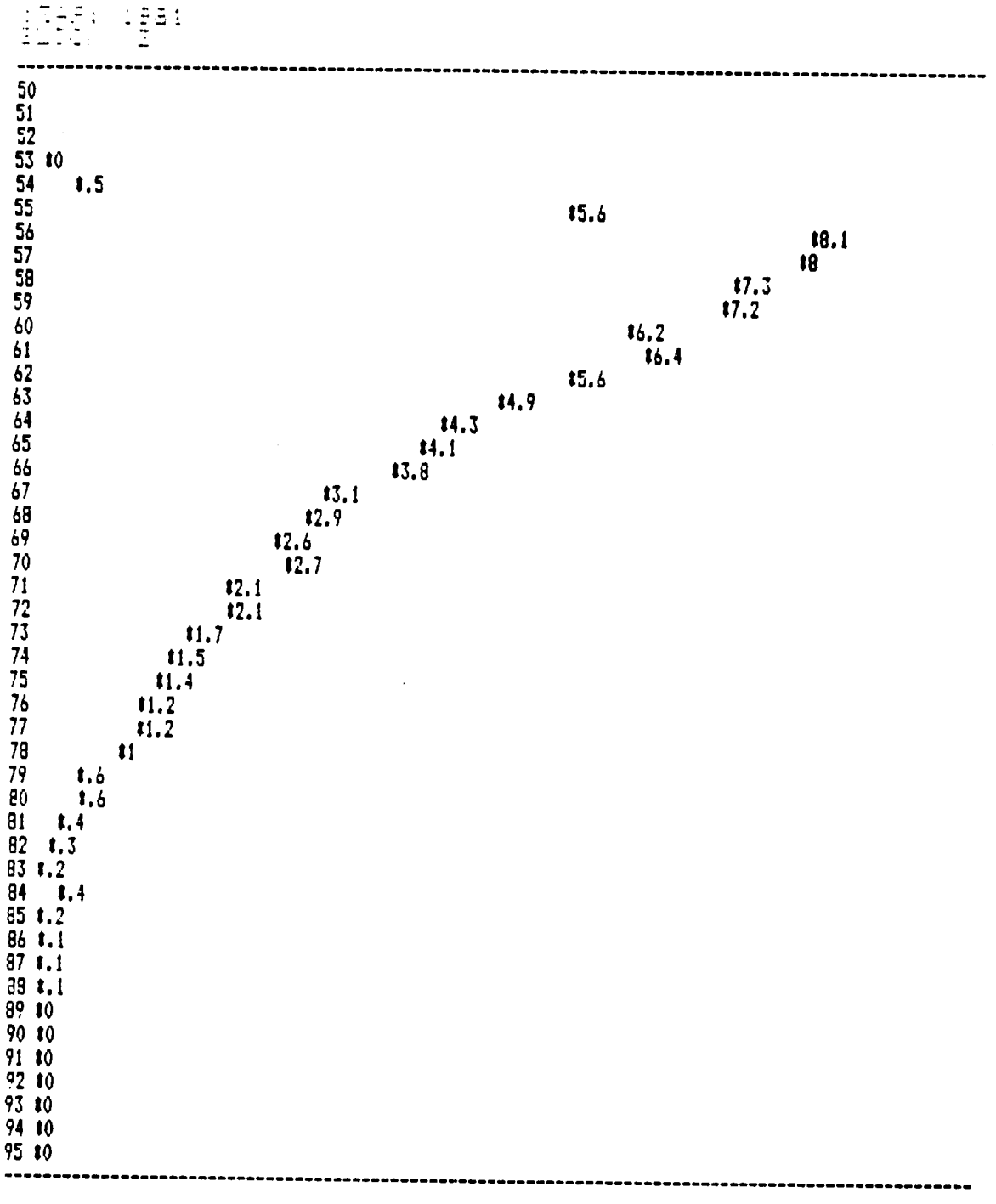
VALUE	POINTS	PERCENT	CUM.PERCENT
52	8	.06	.06
53	90	.65	.71
54	400	2.89	3.6
55	818	5.91	9.51
56	1196	8.64	18.15
57	1274	9.2	27.35
58	1196	8.64	35.99
59	1170	8.45	44.44
60	1007	7.27	51.71
61	929	6.71	58.42
62	778	5.62	64.04
63	699	5.05	69.09
64	622	4.49	73.58
65	537	3.88	77.46
66	458	3.31	80.77
67	426	3.08	83.85
68	391	2.82	86.67
69	299	2.16	88.83
70	308	2.22	91.05
71	238	1.72	92.77
72	189	1.36	94.13
73	153	1.1	95.23
74	155	1.12	96.35
75	88	.64	96.99
76	88	.64	97.63
77	78	.56	98.19
78	66	.48	98.67
79	50	.36	99.03
80	33	.24	99.27
81	19	.14	99.41
82	20	.14	99.55
83	24	.17	99.72
84	7	.05	99.77
85	7	.05	99.82
86	7	.05	99.87
87	6	.04	99.91
88	2	.01	99.92
89	4	.03	99.95
90	3	.02	99.97
91	1	.01	99.98
92	1	.01	99.99
93	3	.02	100.01

YEAR: 1981
SEX: 1

50	$.4
51	$.7
52	$0
53	$.6
54	$2.8
55	$5.9
56	
57	$8.6
58	$9.2
59	$8.6
60	$8.4
61	$7.2
62	$6.7
63	$5.6
64	$5
65	$4.4
66	$3.8
67	$3.3
68	$3
69	$2.8
70	$2.1
71	$2.2
72	$1.7
73	$1.3
74	$1.1
75	$1.1
76	$.6
77	$.6
78	$.5
79	$.4
80	$.3
81	$.2
82	$.1
83	$.1
84	$.1
85	$0
86	$0
87	$0
88	$0
89	$0
90	$0
91	$0
92	$0
93	$0
94	$0
95	$0

YEAR: 1981
BOOK: 1
TOTAL POINTS: 11827

VALUE	POINTS	PERCENT	CUM.PERCENT
53	1	.01	.01
54	69	.58	.59
55	667	5.64	6.23
56	966	8.17	14.4
57	952	8.05	22.45
58	867	7.33	29.78
59	860	7.27	37.05
60	736	6.22	43.27
61	758	6.41	49.68
62	665	5.62	55.3
63	579	4.9	60.2
64	516	4.36	64.56
65	492	4.16	68.72
66	449	3.8	72.52
67	374	3.16	75.68
68	351	2.97	78.65
69	314	2.65	81.3
70	325	2.75	84.05
71	255	2.16	86.21
72	250	2.11	88.32
73	201	1.7	90.02
74	177	1.5	91.52
75	176	1.49	93.01
76	151	1.28	94.29
77	146	1.23	95.52
78	119	1.01	96.53
79	74	.63	97.16
80	79	.67	97.83
81	55	.46	98.29
82	45	.38	98.67
83	30	.25	98.92
84	47	.4	99.32
85	24	.2	99.52
86	14	.12	99.64
87	14	.12	99.76
88	13	.11	99.87
89	1	.01	99.88
90	2	.02	99.9
91	5	.04	99.94
92	3	.03	99.97
93	2	.02	99.99
94	2	.02	100.01
95	1	.01	100.02


50
51
52
53 %0
54 %.5
55 %5.6
56 %8.1
57 %8
58 %7.3
59 %7.2
60 %6.2
61 %6.4
62 %5.6
63 %4.9
64 %4.3
65 %4.1
66 %3.8
67 %3.1
68 %2.9
69 %2.6
70 %2.7
71 %2.1
72 %2.1
73 %1.7
74 %1.5
75 %1.4
76 %1.2
77 %1.2
78 %1
79 %.6
80 %.6
81 %.4
82 %.3
83 %.2
84 %.4
85 %.2
86 %.1
87 %.1
88 %.1
89 %0
90 %0
91 %0
92 %0
93 %0
94 %0
95 %0

YEAR: 1981
BLOCK: 3
TOTAL POINTS: 18085

VALUE	POINTS	PERCENT	CUM.PERCENT
50	2	.01	.01
51	9	.05	.06
52	76	.42	.48
53	221	1.22	1.7
54	556	3.07	4.77
55	813	4.49	9.26
56	1094	6.05	15.31
57	1250	6.91	22.22
58	1194	6.6	28.82
59	1221	6.75	35.57
60	1062	5.87	41.44
61	1022	5.65	47.09
62	994	5.49	52.58
63	934	5.16	57.74
64	825	4.56	62.3
65	802	4.43	66.73
66	706	3.9	70.63
67	651	3.6	74.23
68	599	3.31	77.54
69	540	2.98	80.52
70	526	2.91	83.43
71	447	2.47	85.9
72	454	2.51	88.41
73	357	1.97	90.38
74	348	1.92	92.3
75	242	1.34	93.64
76	242	1.34	94.98
77	215	1.19	96.17
78	168	.93	97.1
79	132	.73	97.83
80	99	.55	98.38
81	95	.52	98.9
82	53	.29	99.19
83	40	.22	99.41
84	29	.16	99.57
85	23	.13	99.7
86	16	.09	99.79
87	10	.06	99.85
88	12	.07	99.92
89	7	.04	99.96
90	4	.02	99.98
91	3	.02	100
92	2	.01	100.01

YEAR: 1981
BLOCK: 3

50	$0
51	$0
52	$.4
53	$1.2
54	$3
55	$4.4
56	$6
57	$6.9
58	$6.6
59	$6.7
60	$5.8
61	$5.6
62	$5.4
63	$5.1
64	$4.5
65	$4.4
66	$3.9
67	$3.6
68	$3.3
69	$2.9
70	$2.9
71	$2.4
72	$2.5
73	$1.9
74	$1.9
75	$1.3
76	$1.3
77	$1.1
78	$.9
79	$.7
80	$.5
81	$.5
82	$.2
83	$.2
84	$.1
85	$.1
86	$0
87	$0
88	$0
89	$0
90	$0
91	$0
92	$0
93	$0
94	$0
95	$0

YEAR: 1981
GROUP: 1
TOTAL POINTS: 31554

VALUE	POINTS	PERCENT	CUM.PERCENT
50	2	.01	.01
51	47	.21	.22
52	285	1.3	1.52
53	860	3.92	5.44
54	1373	6.25	11.69
55	1458	6.64	18.33
56	1514	6.9	25.23
57	1519	6.92	32.15
58	1433	6.53	38.68
59	1363	6.21	44.89
60	1204	5.48	50.37
61	1135	5.17	55.54
62	1055	4.81	60.35
63	942	4.29	64.64
64	851	3.88	68.52
65	799	3.64	72.16
66	695	3.17	75.33
67	664	3.02	78.35
68	659	3	81.35
69	528	2.4	83.75
70	541	2.46	86.21
71	412	1.88	88.09
72	418	1.9	89.99
73	373	1.7	91.69
74	298	1.36	93.05
75	235	1.07	94.12
76	228	1.04	95.16
77	185	.84	96
78	156	.71	96.71
79	139	.63	97.34
80	118	.54	97.88
81	113	.51	98.39
82	90	.41	98.8
83	65	.3	99.1
84	70	.32	99.42
85	38	.17	99.59
86	28	.13	99.72
87	19	.09	99.81
88	18	.08	99.89
89	8	.04	99.93
90	3	.01	99.94
91	6	.03	99.97
92	3	.01	99.98
93	2	.01	99.99
94	1	0	99.99
95	1	0	99.99

JEEP 1981
BLOCK 4

50	$0
51	$.2
52	$1.3
53	$3.9
54	$6.2
55	$6.6
56	$6.9
57	$6.9
58	$6.5
59	$6.2
60	$5.4
61	$5.1
62	$4.8
63	$4.2
64	$3.8
65	$3.6
66	$3.1
67	$3
68	$3
69	$2.4
70	$2.4
71	$1.8
72	$1.9
73	$1.7
74	$1.3
75	$1
76	$1
77	$.9
78	$.7
79	$.6
80	$.5
81	$.5
82	$.4
83	$.3
84	$.3
85	$.1
86	$.1
87	$0
88	$0
89	$0
90	$0
91	$0
92	$0
93	$0
94	$0
95	$0

YEAR: 1981
BLOCK 9
TOTAL POINTS: 18175

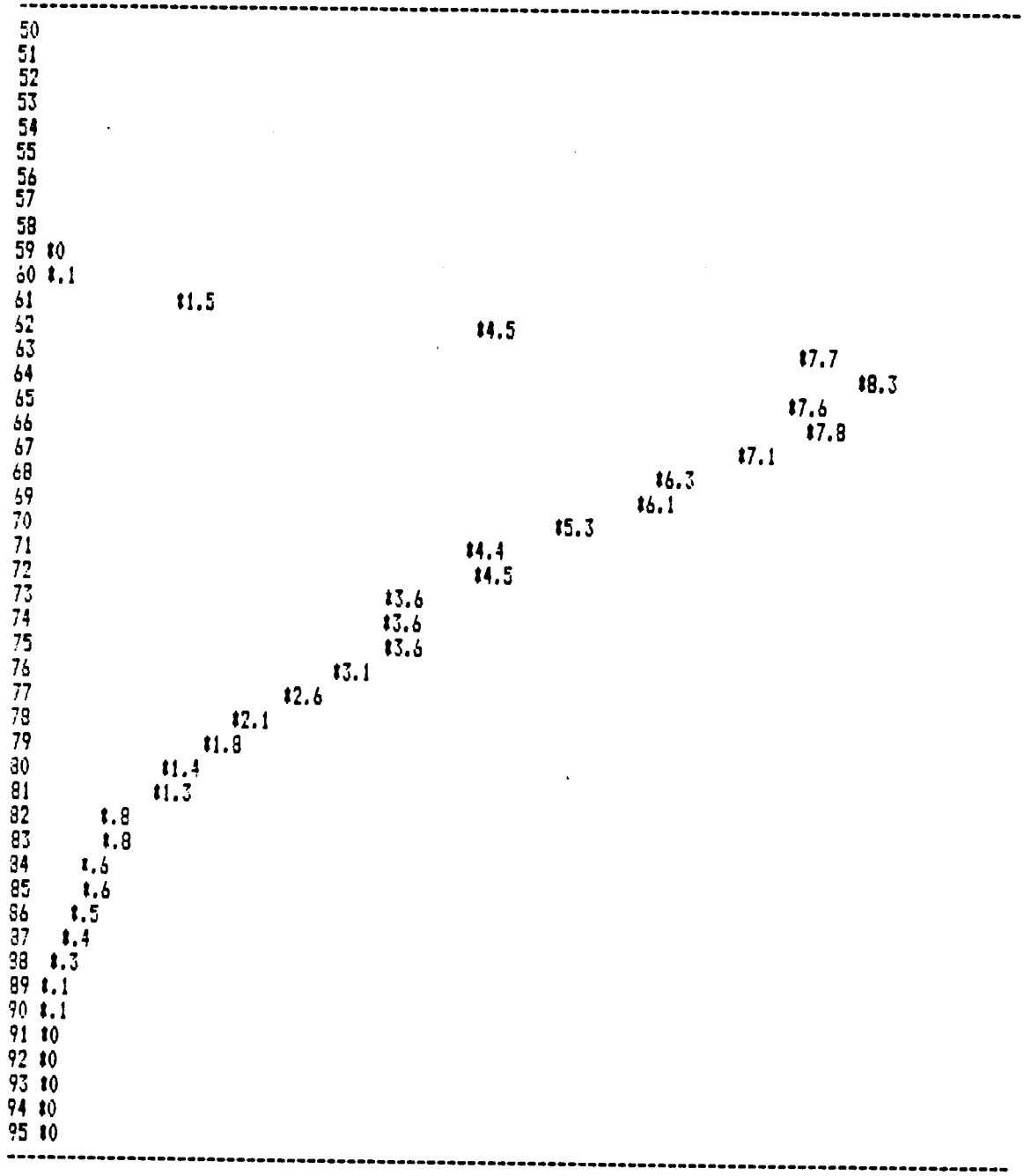
VALUE	POINTS	PERCENT	CUM.PERCENT
52	10	.05	.05
53	305	1.68	1.73
54	666	3.66	5.39
55	807	4.44	9.83
56	953	5.24	15.07
57	1018	5.6	20.67
58	1091	6	26.67
59	1159	6.38	33.05
60	1135	6.24	39.29
61	1115	6.13	45.42
62	1060	5.83	51.25
63	1028	5.65	56.9
64	941	5.18	62.08
65	851	4.68	66.76
66	747	4.11	70.87
67	694	3.82	74.69
68	633	3.48	78.17
69	530	2.92	81.09
70	490	2.7	83.79
71	459	2.52	86.31
72	424	2.33	88.64
73	318	1.75	90.39
74	287	1.58	91.97
75	256	1.41	93.38
76	222	1.22	94.6
77	175	.96	95.56
78	149	.82	96.38
79	139	.76	97.14
80	135	.74	97.88
81	84	.46	98.34
82	73	.4	98.74
83	46	.25	98.99
84	50	.27	99.26
85	30	.16	99.42
86	26	.14	99.56
87	21	.12	99.68
88	14	.08	99.76
89	17	.09	99.85
90	7	.04	99.89
91	4	.02	99.91
92	6	.03	99.94
93	1	.01	99.95
94	3	.02	99.97

YEAR 1981
BLOCK 5

50	$.2
51	$1.3
52	$0
53	$1.6
54	$3.6
55	$4.4
56	$5.2
57	$5.6
58	$6
59	$6.3
60	$6.2
61	$6.1
62	$5.8
63	$5.6
64	$5.1
65	$4.6
66	$4.1
67	$3.8
68	$3.4
69	$2.9
70	$2.7
71	$2.5
72	$2.3
73	$1.7
74	$1.5
75	$1.4
76	$1.2
77	$.9
78	$.8
79	$.7
80	$.7
81	$.4
82	$.4
83	$.2
84	$.2
85	$.1
86	$.1
87	$.1
88	$0
89	$0
90	$0
91	$0
92	$0
93	$0
94	$0
95	$0

YEAR: 1981
BLOCK 8
TOTAL POINTS: 13824

VALUE	POINTS	PERCENT	CUM.PERCENT
59	2	.01	.01
60	24	.18	.19
61	210	1.54	1.73
62	615	4.51	6.24
63	1049	7.7	13.94
64	1135	8.33	22.27
65	1045	7.67	29.94
66	1066	7.82	37.76
67	972	7.13	44.89
68	871	6.39	51.28
69	838	6.15	57.43
70	725	5.32	62.75
71	609	4.47	67.22
72	622	4.57	71.79
73	499	3.66	75.45
74	490	3.6	79.05
75	490	3.6	82.65
76	433	3.18	85.83
77	367	2.69	88.52
78	294	2.16	90.68
79	249	1.83	92.51
80	198	1.45	93.96
81	185	1.36	95.32
82	110	.81	96.13
83	121	.89	97.02
84	87	.64	97.66
85	86	.63	98.29
86	70	.51	98.8
87	55	.4	99.2
88	41	.3	99.5
89	24	.18	99.68
90	14	.1	99.78
91	12	.09	99.87
92	8	.06	99.93
93	2	.01	99.94
94	3	.02	99.96
95	3	.02	99.98


50
51
52
53
54
55
56
57
58
59 %0
60 %.1
61 %1.5
62 %4.5
63 %7.7
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65 %7.6
66 %7.8
67 %7.1
68 %6.3
69 %6.1
70 %5.3
71 %4.4
72 %4.5
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75 %3.6
76 %3.1
77 %2.6
78 %2.1
79 %1.8
80 %1.4
81 %1.3
82 %.8
83 %.8
84 %.6
85 %.6
86 %.5
87 %.4
88 %.3
89 %.1
90 %.1
91 %0
92 %0
93 %0
94 %0
95 %0

[illegible]

VALUE	POINTS	PERCENT	CUM.PERCENT
44	1	0	0
45	5	.02	.02
46	29	.12	.14
47	123	.49	.63
48	355	1.42	2.05
49	564	2.25	4.3
50	743	2.97	7.27
51	1059	4.23	11.5
52	1347	5.38	16.88
53	1665	6.66	23.54
54	1776	7.1	30.64
55	1662	6.64	37.28
56	1466	5.86	43.14
57	1357	5.42	48.56
58	1227	4.9	53.46
59	1153	4.61	58.07
60	1053	4.21	62.28
61	1002	4.01	66.29
62	913	3.65	69.94
63	808	3.23	73.17
64	763	3.05	76.22
65	671	2.68	78.90
66	567	2.27	81.17
67	542	2.17	83.34
68	473	1.89	85.23
69	437	1.75	86.98
70	359	1.43	88.41
71	348	1.39	89.8
72	320	1.28	91.08
73	298	1.19	92.27
74	266	1.06	93.33
75	244	.98	94.31
76	227	.91	95.22
77	185	.74	95.96
78	165	.66	96.62
79	144	.58	97.2
80	133	.53	97.73
81	92	.37	98.1
82	80	.32	98.42
83	69	.28	98.7
84	62	.25	98.95
85	63	.25	99.2
86	31	.12	99.32
87	38	.15	99.47
88	26	.1	99.57
89	31	.12	99.69
90	25	.1	99.79
91	15	.06	99.85
92	13	.05	99.9
93	5	.02	99.92
94	8	.03	99.95
95	1	0	99.95
96	3	.01	99.96
97	2	.01	99.97
98	2	.01	99.98

YEAR 1981
BLOCK [illegible] 9

50	$2.9
51	$4.2
52	$5.3
53	$6.6
54	$7.1
55	$6.6
56	$5.8
57	$5.4
58	$4.9
59	$4.6
60	$4.2
61	$4
62	$3.6
63	$3.2
64	$3
65	$2.6
66	$2.2
67	$2.1
68	$1.8
69	$1.7
70	$1.4
71	$1.3
72	$1.2
73	$1.1
74	$1
75	$.9
76	$.9
77	$.7
78	$.6
79	$.5
80	$.5
81	$.3
82	$.3
83	$.2
84	$.2
85	$.2
86	$.1
87	$.1
88	$.1
89	$.1
90	$.1
91	$0
92	$0
93	$0
94	$0
95	$0

APPENDIX C

RELATIONSHIP OF REFLECTANCE VALUES TO PLANT VIGOR AND YIELDS 1/

There is both a theoretical and pragmatic relationship between the amount of infrared reflectivity as a measure of plant vigor and the achieved yields from a crop. The following six graphs show how the radiation of winter wheat has varied over the growing season from late March (Julian date 80) to early July (Julian date 180) and how well the reflective measurement on May 19 could predict yield.

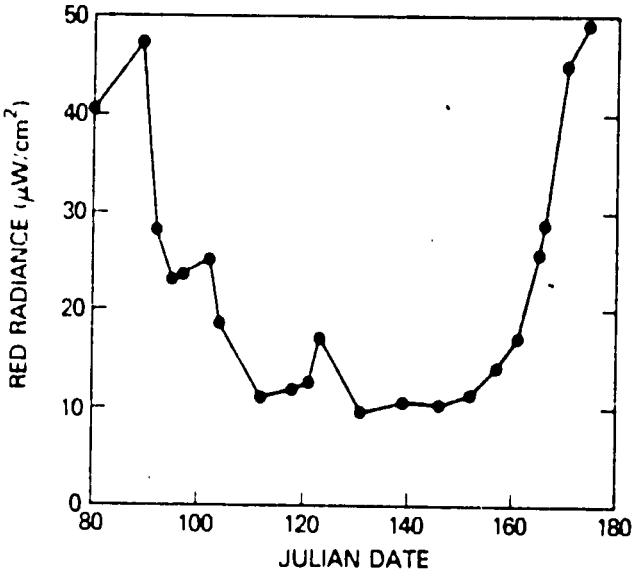
Figure A is the reflection of energy in the red band, This is inversely related to the infrared reflection (figure B). The ratio of the infrared/red is shown in figure C. Figure D is the normalized difference of the infrared and red reflectance calculated as (infra red - red)/(infrared + red).

Figure E is the normalized difference calculated to obtain figure D and plotted against the crop calendar, growing degree days. Finally, figure F illustrates the results of a regression of the normalized value of the ratio of infrared/red as measured on month after planting and crop yields. The normalized difference predicted yields accurately 65 percent of the time (r2 = .65). Although crop types vary in the usefulness of reflectance as predictor of yields, it is in general a useful and robust measure. Note in figure E that data readings taken over a period of a month would not have changed the conclusions on yields significantly.

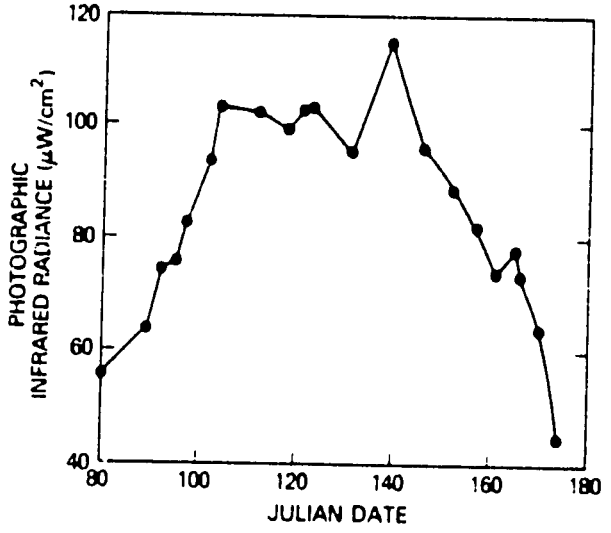
The data also shows the potential of assessing the effect of stress on reflectance values. There was a period of drought from approximately April 10 to May 15 that caused a sharp dip in infrared values.

1/ Bands are not exactly comparable to present LANDSAT data, but are illustrative of TM data from LANDSAT 4. General conclusions, however, still hold. This discussion and diagrams are from Nicholas Short, The LANDSAT Tutorial Workbook: Basics of Remote Sensing, NASA, Washington, D.C. 1982, pp. 173-175.

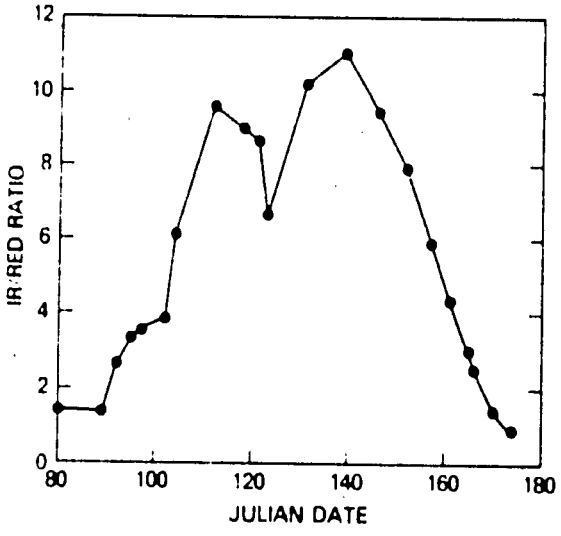
Variations in red and IR band radiances as a function of temporal growth history (crop calendar).



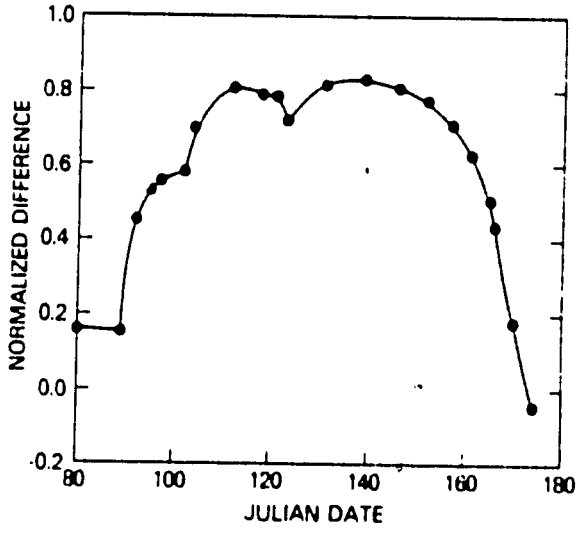
A



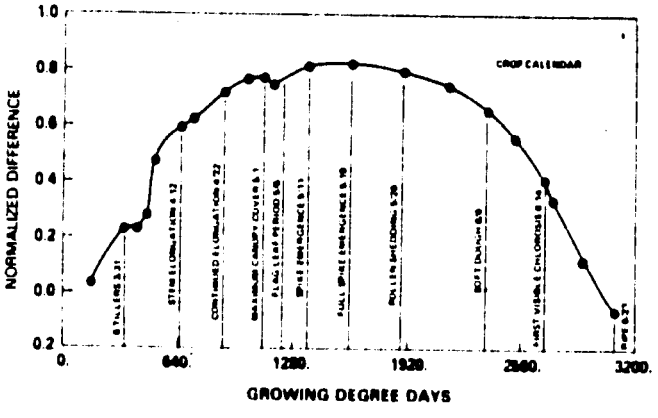
B



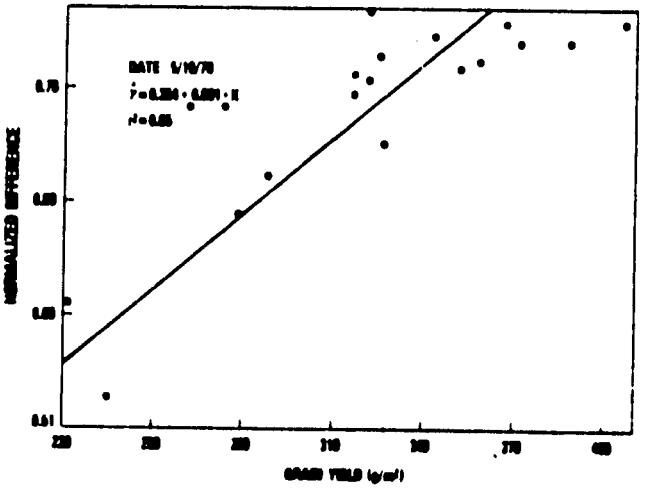
C



D



E



F

APPENDIX D

APPLICATION OF SATELLITE DATA TO DEVELOPMENT

Introduction

Development project planners are frequently hampered by data on land use that is outdated, unreliable or in some instances data is completely lacking. Those responsible for monitoring change in land use that accompanies project implementation have traditionally relied on site visits and area surveys to determine the changes resulting from development projects. In both project planning and monitoring of projects the costs of collecting the data can be high and the results are valid only for the period of the site visit. A knowledge of project induced changes such as cropping patterns throughout the year may require periodic visits and even then, the results may be ambiguous if the area of interest is large and access difficult. This report is a brief review of the potential use of LANDSAT data as a supplement to project planning and monitoring.

A historical record of landcover dating back to 1972, currently exists for most of the world. The record theoretically provides data every 18 days for all land areas and coastal waters over the surface of the earth. 1/ Actually cloud cover and problems with the satellite sensors restrict the amount and quality of data that is available. The data that does exist is carefully controlled to assure registration so that for a specific site there is concurrence between successive sets of data.

There has been very little use made of the available LANDSAT data projects in developing countries. Even the existence of such a record is often not known by those involved in planning and monitoring development projects. To date, major users in developing countries have been large engineering firms, resource companies exploring for energy resources, minerals and subsurface water sources; universities, government agencies, and those engaged in large scale mapping projects. The World Bank for example has funded mapping projects using LANDSAT data in a number of countries. In Bangladesh for example, a series of maps have been published that depict land cover, land use, and a number of separate thematic maps.

Description of Technology

The United States has launched four LANDSAT satellites. The first 3 satellites measure the intensity of the suns energy reflected from the earth in four frequencies or bands. These bands correspond to the red and green bands in and near the

1/ Data unless specified relates to LANDSAT 1, 2, and 3. LANDSAT 4 has a repetition rate of 16 days.

infrared spectrum. The measurements are translated to numbers that reflect the intensity of the radiation. Reflective measurements have a range of zero to 127. The latest satellite LANDSAT 4 records reflected sun intensity in seven frequency bands. In addition, data range has been doubled and is now from zero to 256.

LANDSAT 1, 2, and 3 collect and record data from land areas (pixels) of 79 meters by 79 meters, approximately 1 acre. For LANDSAT 4, the pixel size is 30 meters by 30 meters or approximately .2 acres. Within that land area, the reflectivity is a composite of the landcover of that area. The reflective index of the combined bands is designated a signature. The signature is specific for landcover categories and can be used to distinguish not only agricultural and other uses, but to distinguish species and estimate vigor of vegetative cover.

The following section outlines four examples of how the LANDSAT data can be used either alone or as part of a geographic information system (GIS). These examples are: to inventory area landcover; to detect change; to select project sites and finally as an aid to resource identification.

Applications

The following four applications are illustrative of the potential of using LANDSAT data for development planning and monitoring. In the first three, landcover inventory, detection of change, and site selection studies the LANDSAT data with its multispectral data is used to produce a landcover map.

The process of converting the multispectral LANDSAT data with 4 or 7 numbers ranging from zero to 127 for each pixel to a single type of landcover is called classification. Classification can be either supervised or unsupervised. Both methods are based on the recognition of the signature or pattern of reflectively in the data bands associated with each pixel.

A supervised classification requires the analyst to define portions of the image that are known classes. This is done by drawing boundaries around sample areas of each of the desired classes. The computer will then analyze the data associated with each pixel and determine if it is like one of the selected classes or not. If the pixel is, it is assigned the class number associated with the sample. If it is different from any of the selected classes, it is assigned a number associated with all classes that are different.

The unsupervised classification is a clustering routine in which the computer sets up a number of classes and assigns each pixel to one of the classes. This method will almost always produce too many classes to be useful so the computer operator combines clusters that may be slightly different spectrally, but in practice may only represent crops where the cultural practices are slightly different.

The output of both of the classification routines is a data set in which every pixel is assigned a single number ranging from zero to as many classes as have been defined in the supervised classification or as have resulted from the unsupervised clustering. This data can then be displayed as a gray scale image. The analyst then assigns appropriate colors to each of the classes. In most cases, this step will indicate where two or more classes defined as different by the unsupervised classification routine should be combined into a single class. Such a distinction would be made in unsupervised classification where part of a field is in direct sun and part in shadow.

Landcover Inventories

Inventories are calculated directly from the classified image. With little or no specific knowledge, LANDSAT data can provide general landcover categories and provide area counts by class. These general categories include agriculture by major types, bare soil, rock, forest by major types, water, wet areas, and general urban features.

The categories can be refined if the analyst has or can get knowledge of the specific area known as ground truth or if multiple images are available that would reflect changes related to seasonal change. With either or both ground truth and multiple images, the classes can be refined to include categories such as specific crop type, urban density, commercial or industrial development, deciduous or coniferous forest, irrigated and non-irrigated agriculture, water logged or salinized land and cropping patterns and practices.

Change Detection

One of the most valuable applications of the technology is in detecting changes in landcover. This technique involves the use of two images of the same area but for different time periods.

The images can represent different seasons or different years but the same area. The comparison of images from different periods can be used to detect changes in landcover. These changes can be important in both project planning, project monitoring or project evaluations.

For example, changes in forest cover, agricultural land use, or urbanization can be used to monitor or plan projects in irrigation, road construction or reforestations. Desertification or salinization of soils can be detected and may indicate the need for new projects or modification of existing ones.

Siting Decisions

Project siting decisions are ideally based on many factors, only some of which can be obtained from LANDSAT. To integrate what data is available from satellite with other physical data and

political, social and economic data a set of computer based data files are required. These files all relating to a specific land area that is under consideration as a project site are designated a geographic information system.

A decision model based on all the relevant parameters for which data exists could then be formulated. A model could be a combination of weighted factors and yes or no factors. For example in setting up a model for determining the suitability of an area for irrigation, sufficient natural rainfall or land with excessive slope would be excluded from consideration even if all other factors were favorable.

Other variables could be weighted either positively or negatively. A weighted index of existing conditions could be readily prepared that would provide a value for each land area that ranged from highly suitable to highly unsuitable.

The index could assign highest scores to land which meets the physical, social and economic criteria for irrigation. Lower scores would be assigned to areas that required roads, land leveling or other resource commitments. The scores could be based on sophisticated models in which land modification or infrastructure development could be assigned to land areas on the basis of costs. For example, road construction costs could be assessed to each area on the basis of distance from existing roads and slope of the land.

Resource Identification

Resource identification is one of the most widely used applications. Energy and mineral companies routinely use the LANDSAT data to direct exploration. In identification of resources, the analysis is of the unclassified LANDSAT data. The object is to manipulate the data display and thereby enhance features that are not obvious before the data is manipulated. Since surface features, such as faults or rock types are an indication of subsurface conditions, the enhancement is a guide to direct subsurface exploration. One useful application in addition to energy and mineral exploration is to assist in the location of ground water.

A Role for AID

Satellite data can be used by both AID and the host countries. For AID satellite data can assist in project planning and supplement the existing, monitoring and evaluation activities. As the Agency strives for cost effectiveness, the use of LANDSAT data as a substitute for some site visits will become more important.

While LANDSAT data can never replace present monitoring, it can provide information not available from site visits. Where projects have as a purpose or goal activities that will change land use, the satellite data will document what and how much has changed. Penetration roads or irrigation projects are obvious candidates for satellite monitoring.

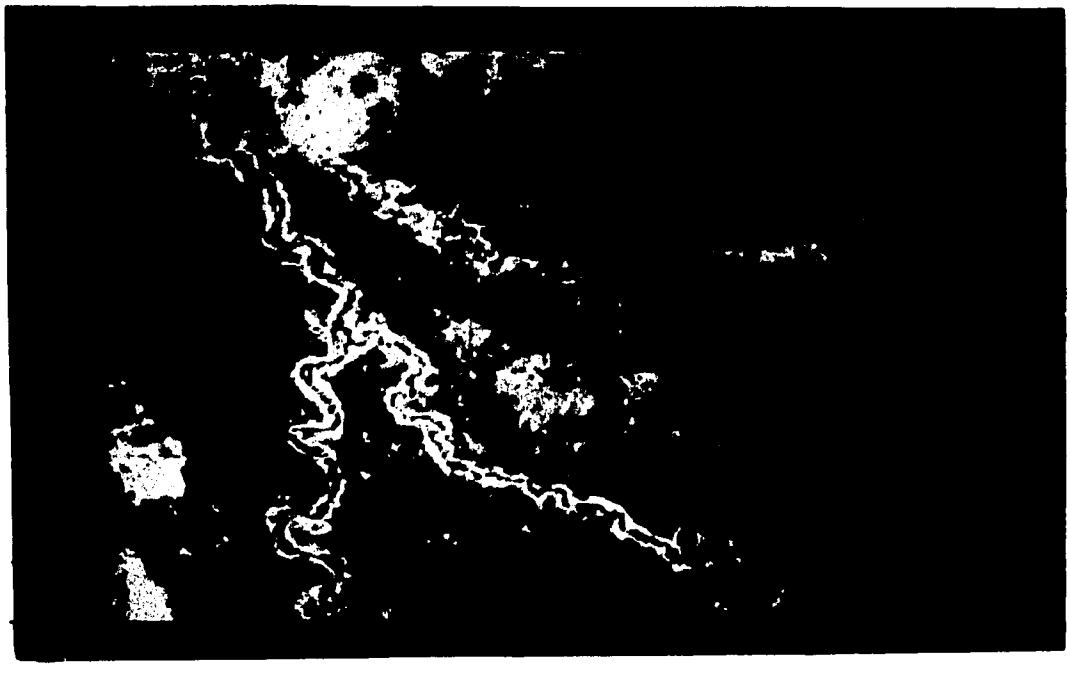
APPENDIX E

ILLUSTRATIONS OF ANALYSIS

The following illustrations show some of the stages in the analysis of the Rahad project. Illustrations E-1 is a Geographic Information System file of the administrative districts. This is the basis for subsetting the LANDSAT data for further analysis. Block 4 used in the following illustrations is labeled.

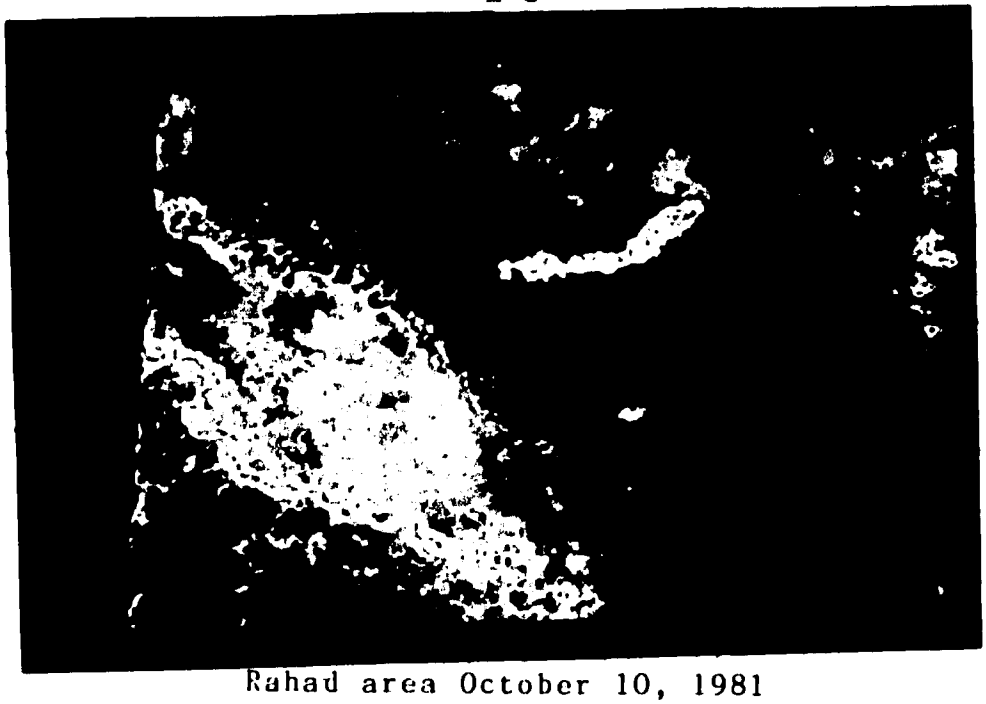
E-1

E-2



Rahad area October 1, 1979

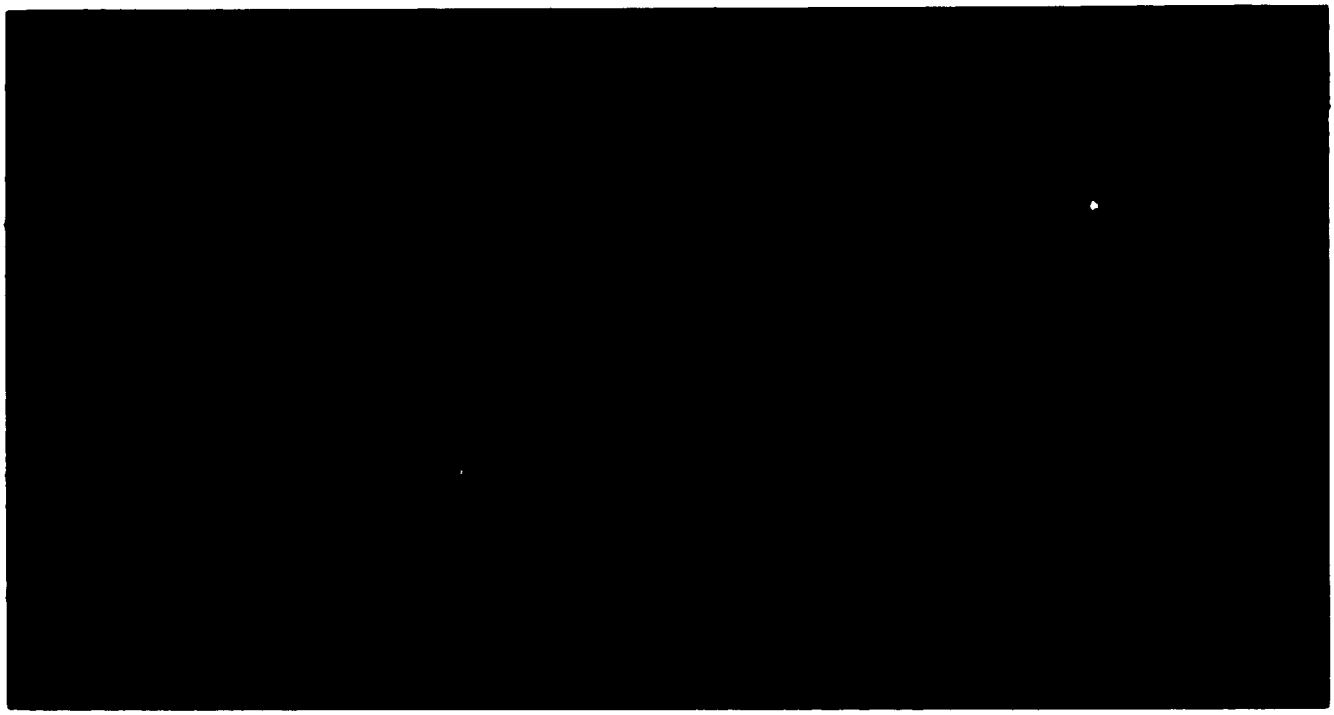
E-3



Rahad area October 10, 1981

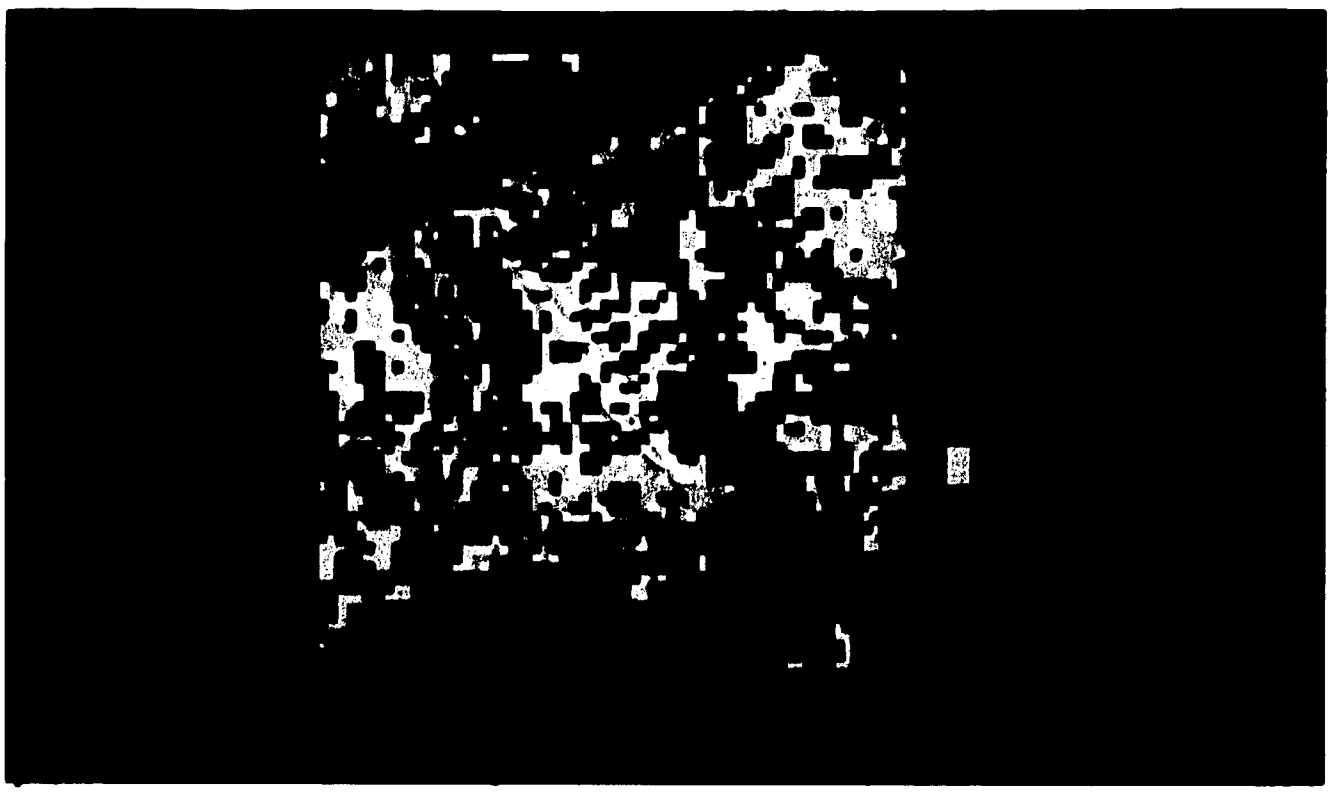
Block 4 1979/1980 growing season. Area approximately 15 miles east-west.

E-5



Area in cotton. Pixel size 57 meters. Approximately 2 miles east-west.

E-6



Reflective values of cotton.