

**THE EFFECTS OF SOILS AND TIME ON THE ACCURACY OF
CROP IDENTIFICATION IN S.W. ONTARIO FROM 1974 SATELLITE IMAGERY**

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ABSTRACT

THE EFFECTS OF SOILS AND TIME ON THE ACCURACY OF
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ERTS-1 imagery (June 2, June 20 and July 8, 1974), supplemented with airborne photography was used to identify corn, winter wheat, soybeans, oats and fieldbeans in Southwestern Ontario.

Sample areas were selected within Chatham - Harwich Townships, Kent County, Ontario according to land use capability classes. Following the stratification, five test sites were established over eight soil types within the two Townships (Figure 2.3).

Two types of classifiers based on the maximum likelihood and minimum distance decision rules were used to analyze successfully the data derived from the imagery.

Using the maximum likelihood decision rule the highest identification accuracy for corn (100%) was achieved on June 2 over the Brookston Sandy loam. The corresponding accuracy for soybeans (100%) was achieved on June 20 and July 8 over the clyde clay/clyde loam and the Brookston silt loam; fieldbeans (100%) was achieved on June 2, June 20 and July 8 over the Beverly loam; and winter wheat (86%) was achieved on June 2, June 20 and July 8 over the Brookston silt loam.

Using the minimum distance decision rule, the highest identification accuracy for corn (82%) was achieved on July 8 over the Beverly loam. The corresponding accuracy for soybeans (80%) was achieved on June 20

and July 8 over the Brookston silt loam; fieldbeans (83%) was achieved on July 8 over the Beverly loam and the Brookston silt loam; winter wheat (100%) was achieved on June 2 and June 20 over the Beverly loam and the Brookston Sandy loam; and oats (100%) on June 2 and July 8 over the Brookston clay and the Beverly loam.

The results of classification indicated possible significant time and soil type influences on the accuracy level of crop identification achieved using ERTS-1 digital data.



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Chapter I

THE PROBLEM

1.0 INTRODUCTION

The Food and Agriculture Organization of the United Nations has stated that the production of food will have to double by 1980 and treble by the year 2000 in order to provide a decent level of nutrition for the world's peoples [4]. Today as never before, man is faced with the growing crises of inflation, bulging human populations, limited arable lands, food and water. These crises present man with the challenge of devising new and more efficient techniques for the development and management of the world's resources. Fortunately, man has at his disposal powerful remote sensing techniques which can be put to use for the development planning and management of the Earth's resources.

Because of the numerous sensors, sensor control systems and complements, as well as, the rapid rate at which techniques become obsolete, it is very difficult to give a precise definition of remote sensing or even talk about remote sensing techniques. However, for the purposes of this study remote sensing is defined as the methods for obtaining and analysing images of the Earth's resources from aircraft, spacecraft and satellites.

1.1 THE IMPORTANCE OF SPACE TECHNOLOGY IN RESOURCE MANAGEMENT

According to Colwell [4] there are several reasons why Earth resource surveys can best be made by airborne sensors. The first of

these is clearly implied in the statement that "the face of the land looks to the sky". The task of taking inventory of Earth's resources is, first of all, one of delineating boundaries between one resource characteristics and another. When confined to Earth at ground level, man often has great difficulty in recognising and delineating these boundaries. A second reason for using airborne sensors is that the broad synoptic view, so essential for a "quick and economical" delineation of Earth's resources, can only be obtained by this way. Furthermore, this is the only way vast areas can be viewed at a single point in both time and space and hence under relatively uniform lighting conditions.

The ability of aircraft or satellite to travel quickly from one camera station to another is a related advantage of great importance. For example, since the First Earth Resources Technology Satellite (ERTS-1) was launched on July 23rd 1972, several thousands of scenes of the Earth have been obtained covering all major land masses (about 75% of the world's land area [15]). By placing ERTS-1 in a sun-synchronous orbit, all areas that it covers is sensed at the same local sun-time and thus under uniform lighting conditions which in turn facilitates the photo-identification of Earth resource features.

Remote sensing from low and high altitude aircraft has been extensively used for Earth resource surveys for some time, but using satellites appear to have advantages over aircraft. The main advantages of using satellites appear to be:

- 1) the ability of satellites to provide repetitive or time-sequential photography over the same land area,
- 2) the potentialities of using satellite technology on a universal

basis (operationally and routinely). In spite of these advantages, it is not possible, at the present time, to obtain reliable measurements of crop acreages by the use of satellite data alone. Consequently, it is necessary to have at least one aircraft photograph over the area of interest to outline field boundaries (and to calculate field acreages).

It would appear that Remote Sensing is admirably suited for gathering agricultural statistics because it is objective, fast and repetitive. It would also appear to be advantageous to both the importers and exporters of agricultural commodities if the probable food supplies and exportable surpluses were estimated on world-wide basis and the information made available freely to interested nations. For an agricultural exporter like Canada, the implications are said to be obvious. According to Peet [14] even in a normal crop year, if the time-lag between the date of data collection and the dissemination of the information could be reduced by even one week, it would be possible, in some cases, for the Canadian grain exporter to beat its international competitors to the market place. A 1% increase in the accuracy of wheat production estimates, all other things being equal, could result in substantial benefits to Canada. If the new estimate indicated that wheat production would be greater than originally thought, then in a good year, an additional 5 million bushels of wheat could be available for sale which was worth more than \$20 million at 1973 prices. The benefits could be even greater if Canada could obtain crop information from the other major grain growing areas. Early knowledge of crop failure or bumper harvests in the other major grain growing areas would allow Canada to adjust its marketing policies in order to obtain maximum benefits from the sale of her grains. Even if Canada could not obtain crop

- 4 -

information from other crop growing regions, she could sell the products of her remote sensing developments to foreign governments for monitoring their own agricultural crops.

For the grain importing nations, the advantages of having information about crop conditions from the major grain growing regions of the world cannot be overemphasized. If indications are that there would be substantial grain surpluses in the international market, the knowledgeable importing nations could get excellent bargains and save millions of dollars by not rushing into contract agreements for expensive grain deliveries.

Obviously the country with the "best" information, whether a buyer or seller, is in a position to bargain for the optimal price. This concept of "better" information can take several forms: more timely data, more accurate data, more consistent data or new information. The first Earth Resources Technology Satellite (ERTS-1) may provide either the same information now being used, but at a lower cost, or better information than now being used and new kinds of information. In order to ensure a "fair" distribution of the potentially better information from space technology, as many nations as possible should be made aware of these potentials so that they can at least talk intelligently about the potential dangers posed by few nations using the ERTS-1 which is no respecter of international boundaries.

1.2 THE PROBLEM OF ESTIMATING THE PROBABLE FOOD SUPPLIES AND EXPORTABLE SURPLUSES ON WORLDWIDE BASIS

The United States, Canada and the other major food exporting countries have rather effective systems of collecting and analysing

agricultural data and making the results available to the public. However, even in these countries the time-lag between the date of data collection and the dissemination of the relevant information may be months. Statistical data on crop production for specific geographical areas or crop reporting sub-divisions are frequently required for periods of times not corresponding to data, such as census data, regularly assembled [12]. Regionally, production information obtained as early as possible may help to indicate unusual crop conditions thus assisting authorities in their decisions for modifying or establishing emergency policies. Competition in international marketing makes it necessary to have accurate data as early as possible in the growing season.

At present Statistics Canada provides statistics relevant to two basic questions in connection with the food situation in Canada:

- i) will there be enough food to feed the Canadian people; and
- ii) will there be exportable surpluses and if so, how much.

Several methods are used in an attempt to provide answers to the above questions - the post-card system whereby a sample of farmers are polled through the mails; - the direct enumeration system in which census officials go out to the field for a complete enumeration of all agricultural crops; - and the indirect system through quota books. With these methods though, it is said there is always a lag of several weeks between the time of data collection and the publication of results. It is said further than these systems do not warn of impending crop failures or impending surpluses until it is too late to do much about the situation.

If one considers the great present need for regional, national

and worldwide agricultural resource inventory and data evaluation, coupled with the capabilities of existing and proposed satellite remote sensing systems, it becomes apparent that agricultural applications are particularly promising as an area in which important benefits might be realized. Many countries presently conduct enumerative programs (however poorly) in which virtually all agricultural lands are inventoried (see Appendix A) from time to time. In addition, numerous other agencies conduct extensive crop inventories, land use surveys, and soil mapping projects of varying magnitudes. On a worldwide basis, it would appear that the principal obstacles that hinder providing enough food for the world are those of allocation and distribution. Early knowledge of how much food is being produced and how crop distributions are changing with time could provide valuable information for dealing with the world food problem.

Up to the present time agricultural inventories have required tremendous effort on the part of on-the-ground enumerations and have presented formidable data compilation problems which only few countries have managed to overcome. However, satellite sensing systems with which large areas of land can be surveyed (100 nautical miles x 100 nautical miles on one 9" x 9" frame) and which can provide relatively uniform worldwide coverage offer great promise as data collection tools for improving the world food intelligence systems. Furthermore, the dynamic nature of agricultural production requires a continuous updating of crop conditions. In fact, it has been shown that desired information about agricultural crops can often be obtained only by capitalizing on the knowledge of the patterns of changes of particular crop types. This

observation would suggest that a satellite sensing system, such as the ERTS-1, which makes possible regular (18 day interval) observations of various areas on the Earth's surface, provides a service which is totally infeasible using conventional techniques.

1.3 THE FIRST EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS-1) AND CROP IDENTIFICATION

The March 1973 Symposium at the Goddard Space Flight Centre¹ provided the first open forum where users of ERTS-1 data had the opportunity to present the significant results from their investigations. The quality of the ERTS-1 data product performance during the initial months of the system's operation was evaluated by Banchofer. The period of evaluation covered the first three to six months of the ERTS-1 operation. Data from the satellite was analyzed to determine its quality in terms of geometric accuracy, resolution and radiometric accuracy. For reference, the measured results were compared to the pre-launch estimates published in the ERTS-1 Data Users Handbook. By repetitive analysis of data taken at different times, performance indicative of sustained operation was possible and this allowed short term or start anomalies to be differentiated from normal performance or legitimate trends.

According to the investigator, the analysis lead to the general conclusion that "the quality of the system corrected products produced by the ERTS-1 system during its initial period of operation was, from a

¹ Symposium on Significant Results Obtained from the First Earth Resources Technology Satellite (ERTS-1), March 5-9, 1973, Goddard Space Flight Centre, Greenbelt, Maryland.

resolution and radiometric viewpoint, quite consistent with pre-launch estimates. In the geometric sense, the data products were somewhat better (and in a few instances considerably better) than pre-launch estimates".

The general conclusions at the Symposium were that the ability to detect and identify individual crops using ERTS-1 data was proven without question by the various users of ERTS-1 data since it was launched on July 23, 1972.

Bizzell, Wade, Prior and Spiers [3] concluded that: (i) most important, with existing technology, they were able to extract information from ERTS-1 data which satisfied certain agricultural related objectives. Specifically, they were able to detect and identify major crop species over large geographical regions and to determine the location and areal extent of the associated fields; (ii) the greater radiometric fidelity of the system corrected digital data and the subsequent flexibility available for the application of enhancement techniques to this data, to them, suggested a preference of digital data [see Appendix B] for the detection and identification process, (iii) the discrimination capability of the ERTS-1 data was found to be good and in some cases better for crop species identification activities, as compared to similar experiences they had with low altitude airborne multispectral data; (iv) their investigation revealed that significant results could be achieved with limited ground truth information or, at most, the utilization of aerial photography should be limited to merely providing the control information required for training, testing and verification purposes. In summary, the preliminary results they achieved indicated

that with proper selection of data based on crop calendars and ground truth information, and the utilization of enhancement and pattern recognition systems currently available, major crop types could be detected, identified, and their areal-extent determined from ERTS-1 multispectral scanner data.

Maurice L. Halton and Heilman [8] performed digital analysis of August 15, 1972 ERTS-1 imagery for southwestern South Dakota to determine the feasibility of conducting crop surveys from satellites. Selected areas of bands 4, 5, 6 and 7 positive transparencies were converted to digital form using Signal Analysis and Dissemination Equipment (SADE). The optical transmission values were printed out in a spatial format and visual analysis of the printouts indicated that cultivated areas were readily distinguishable from non-cultivated areas in all four bands. Bare soils were easily recognized in all four bands, corn and soybeans, the two major crops in the area, were treated as separate classes rather than a single class called row crops. Bands 6 and 7 provided good results in distinguishing between corn and soybeans. One of the greatest difficulties they encountered was in accurately locating field boundaries and in masking off appropriate area of the transparencies for digitization. Nevertheless the investigators felt that through the use of sequential ERTS-1 imagery, machine processing, and limited ground truth data, a timely and accurate picture of crop resources could be prepared.

1.4 THE OBJECTIVES OF THE STUDY

The main objective of the study was:

1) To investigate the effects of different soil types and time (growth stage) on the accuracy of crop identification in S.W. Ontario using 1974 digital Earth Resources Technology Satellite (ERTS-1) imagery supplemented by airborne data.

The working hypothesis was that there are no significant differences between crop identification accuracy results obtained for crops located on different soil types in the Chatham-Harwich Townships, S.W. Ontario.

Up to now there has not been sufficient experimental evidence to indicate how crop identification accuracy results can or should be extrapolated when using digital ERTS-1 data. The economic implications of the extrapolation question are obvious since if crop identification accuracy results cannot be extrapolated from test sites for lack of knowledge of how it can be or should be done, any acreage or yield estimates become essentially limited to the test sites in question and no legitimate claims can be made for other regions on the basis of the test site results.

Two of the important factors involved in the extrapolation question are the effects of different soil types and time on crop identification accuracy results. The important question appears to be whether different soil types give different accuracies. As our knowledge of how soils affect crop identification accuracies and how these effects change with time increases, the problem of extrapolating test site results to cover areas of interest may become easier to solve.

This study deals with soils and time effects on crop identification by analysing three time-sequential ERTS-1 imagery supplemented by

airborne photography.

The identification of agricultural crops using ERTS-1 imagery is a reality today. [1, 9, 11, 12] The results of numerous remote sensing studies using ERTS-1 data have shown that accurate crop identification is possible either manually or automatically. However, the bulk of the remote sensing literature deals with research findings obtained under fairly limited and usually carefully controlled conditions. While these studies are worthwhile and are certainly necessary first steps in ERTS-1 technology development, they do not ensure that "useful techniques" can be automatically adopted by the user for application to operational ("real-world") problems. It would appear that for the economically useful techniques to be differentiated from the merely interesting techniques, one of two things must occur: either those in applied sciences must take basic science findings and attempt to evaluate their worth in practical context, or the user of basic science findings must sufficiently develop his understanding of the technical field to be able to adequately draw inferences as to how well techniques tested in the basic science context can be applied to his very real, complex social or economic problems [2].

The potential user of remote sensing technology should ideally have at his disposal meaningful cost and capability data for the various systems at his disposal as he faces the decision of selecting a system to solve his problems. In many cases, however, such data is simply not available and hence feasibility studies must be devised. Whether the user does his own testing or relies on experimental results obtained by remote sensing specialists, the following points should be kept in mind:

- 1) the experimental design should provide for some measure of statistical reliability;
- 2) the cost and accuracy results for one task are often not at all applicable to a seemingly similar task; and
- 3) the danger of extrapolating costs and accuracy results from very limited test sites to the operational situation.

For these reasons, it is imperative for the potential user to define specifically:

- 1) the kind of environmental information needed;
- 2) the applicability of the test results to the local or regional data required;
- 3) the accuracy and timing required; and
- 4) the cost-accuracy tradeoffs, if any.

Hopefully the results of this study will make a contribution to the solution of the problem of extrapolating crop identification accuracy results from limited test sites to cover whole localities.

1.5 ORGANIZATION OF THE STUDY

It is necessary that those not very familiar with the Canada Centre for Remote Sensing (CCRS) Wheat Project Image Processing System read Appendices B and C before reading the remainder of the study which is organized as follows. Chapter II outlines the method of analysis followed in processing the digital ERTS-1 data. Chapter III discusses the classification results. The study is summarized in Chapter IV and concludes with a look at the future of Remote Sensing in world agriculture.

Chapter II

METHOD OF ANALYSIS

2.0 INTRODUCTION

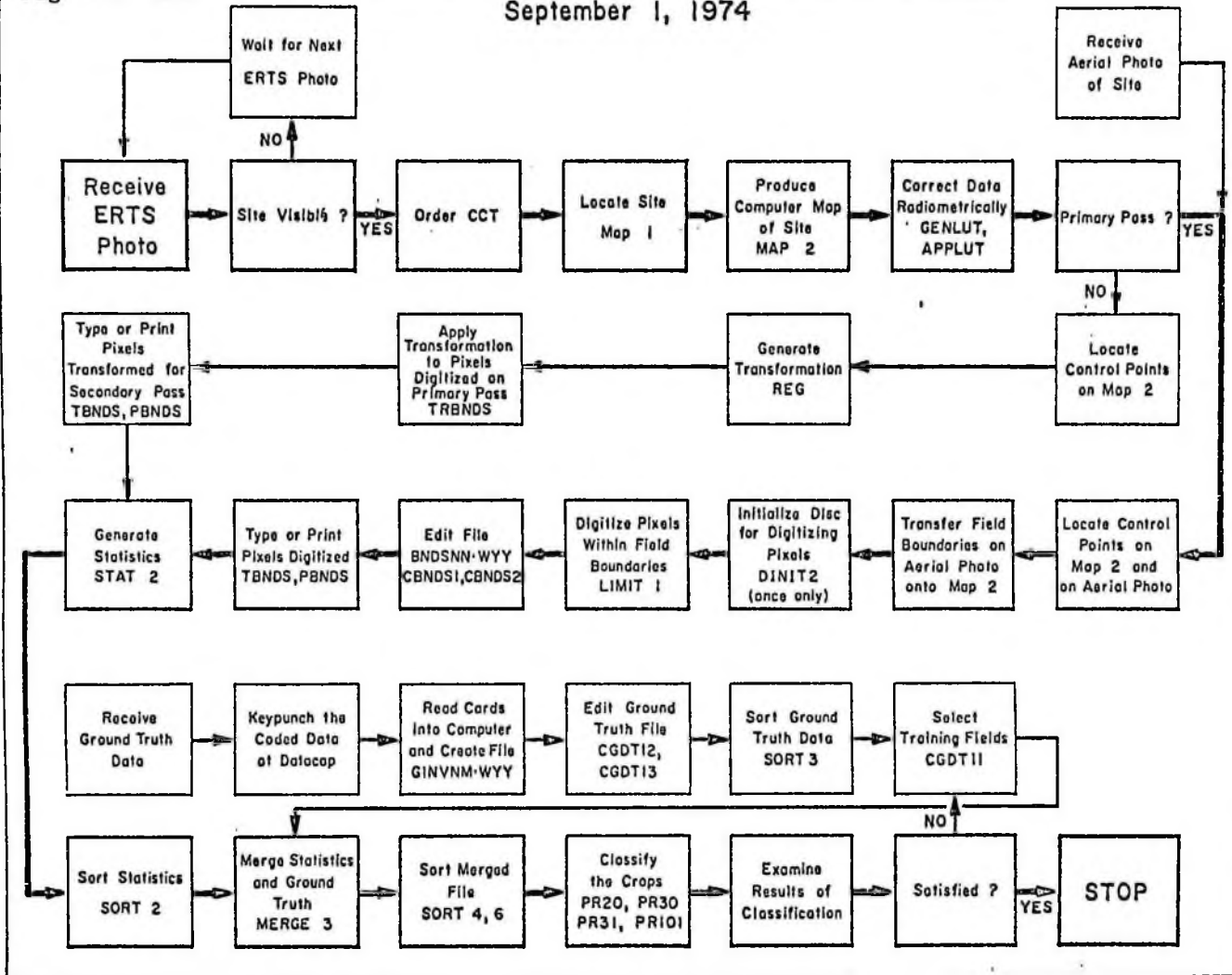
In this section an attempt is made to describe the method of analysis used in the study. There are several Satellite Image Processing Systems available at the Canadian Centre for Remote Sensing (CCRS) for processing ERTS-1 data. The method used in this study is the CCRS Wheat Project Image Processing System developed by Dr. Fred Peet. This is computer based automatic processing system used to process satellite imagery of both small and large fields with only slight modifications. There is no specific definition of small or large fields but agricultural fields of Eastern Canada are regarded as small fields while those of Western Canada are regarded as large fields. This classification has nothing to do with the value of a farm or the crops grown, the only relevance being the size of the field (farm) in terms of acres.

The CCRS Wheat Project Image Processing System used in this study is presented in Fig. 2.1. This system is used to separate various agricultural crops from each other in a given agricultural area called test sites.

The inputs for crop identification based on the CCRS Wheat Project Image Processing System are:

- 1) Earth Resources Technology Satellite digital data (see Appendix B). The digital data contains information about the intensity of radiation received by the Satellite for each of the four ERTS-1 sensing bands. It is the intensity values (reflectance values),

Fig. 2.1 CCRS WHEAT PROJECT FLOW CHART FOR SMALL FIELDS
September 1, 1974



determined for each field, that form the basis for classification.

2) Aerial photograph of the study area - it is not possible, with the present state of technology, to obtain reliable measurement of crop acreages by the use of satellite data alone. Consequently, it is necessary to have at least one aircraft photograph over the test sites to outline field boundaries and to calculate field acreages. It is the geometry of the aerial photograph that is transformed onto the computer map (by a computer map is meant the computer printout obtained when one assigns symbols to the pixel values and prints these symbols) (see Fig. 2.2) in order to locate field boundaries on the computer map.

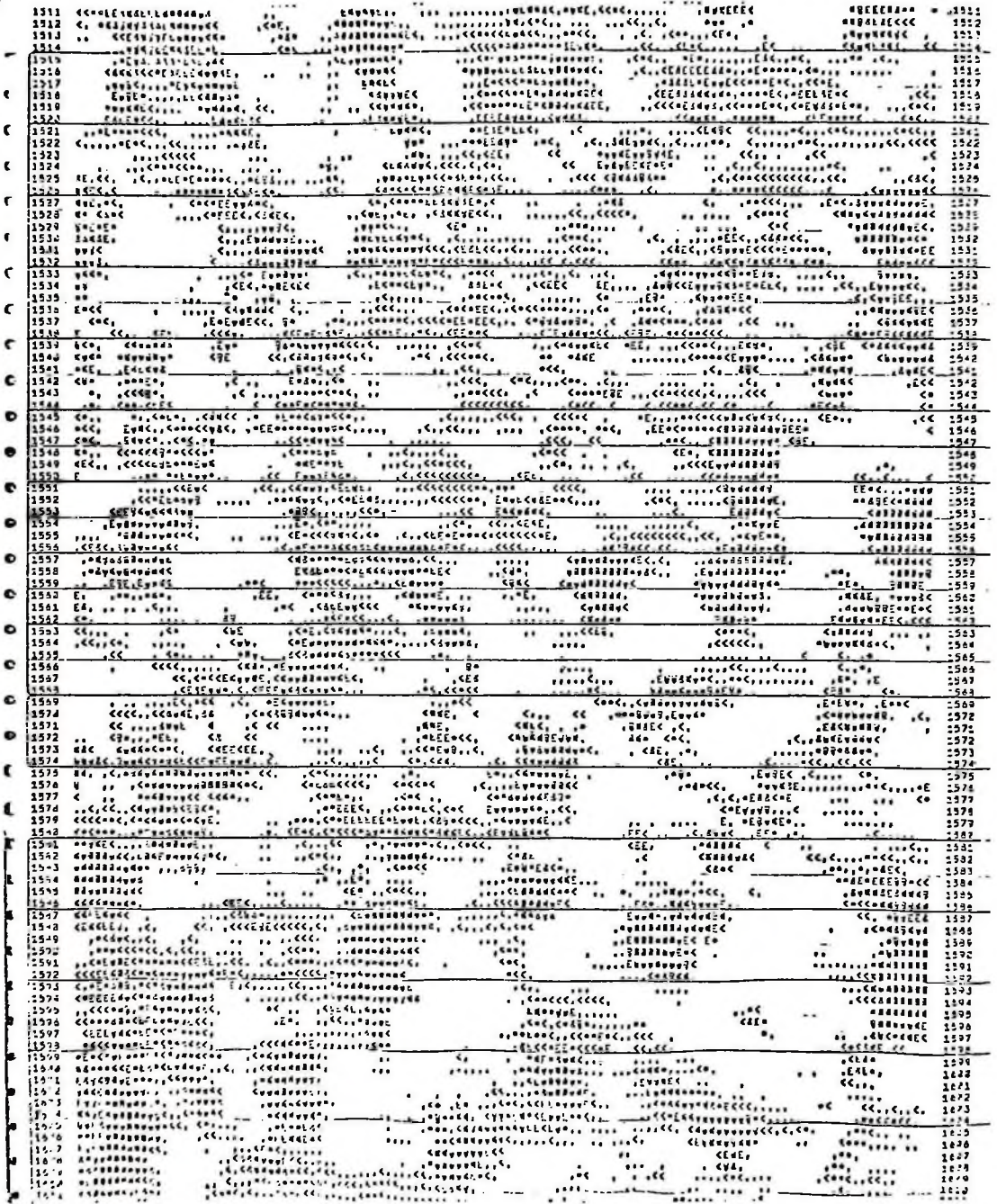
3) Ground truth data - in order to evaluate how successfully the computer has been trained to recognise different crop types, it is necessary to have before hand a complete inventory of all the crops growing in the test site. Such a complete inventory of crops growing in a test site is known as ground truth data.

4) Classifiers - these are computer programs designed to identify various crops based on the ground truth and satellite data.

Section 2.1 describes the study area, Section 2.2 discusses the climate of the study area, section 2.3 takes a look at the soils within the study area, section 2.4 describes the acquisition of the ground truth data, section 2.5 describes the airborne data used in the analysis while section 2.6, which is divided into two sections, discusses the satellite data used in the study.

Fig. 2.2

COMPUTER PRINTOUT MAP



2.1 STUDY AREA

The area of study consists of the Townships of Chatham and Harwich in Kent County, South Western Ontario. The two townships are representative of the County as to the percentage area in each land capability class [Table 2.1] and the distribution of crops [Table 2.2]. The percentage of Winter Wheat in Kent County is comparatively small [9.28%] in comparison to that of corn [53.95%]; Soybeans [24.67%] and other crops [12.10%]. This relative distribution of crops in the County should be taken as a guide only since the crop acreages vary from year to year depending on the relative prices of the crops.

The study area covers approximately 28 miles by 10 miles and it is defined by the following co-ordinates:

<u>Latitude</u>	<u>Longitude</u>
42° 40'	82° 30'
42° 40'	82° 10'
42° 20'	81° 40'
42° 15'	82° 05'

2.2 CLIMATE OF THE STUDY AREA

The climate is much the same over the whole County [6]. Temperatures are modified by Lakes Erie, Huron and Ontario and the mean annual temperature is 7.8°C (46°F). Spring temperatures are about 6.1°C (43°F) and summer temperatures average about 18.9°C (66°F). The frost-free period varies from 145 days to 160 days depending on the distance from the lakes but the length of the growing season is a uniform 200 days.

Table 2.1 PERCENTAGE AREA IN EACH LAND CAPABILITY CLASS FOR
THE SITES IN COMPARISON TO HARWICH AND CHATHAM
TOWNSHIPS, AND KENT COUNTY, ONTARIO

Agriculture Land Capability Class	Kent County	Chatham and Harwich Townships Sites
	percent	
1	9.6	13.4
2	75.7	69.5
3	11.5	14.3
4	0.4	0
5	1.0	0
Organic	1.8	2.8
Total	100.0	100.0

Table 2.2 PERCENTAGE DISTRIBUTION OF CROPS IN HARWICH AND CHATHAM TOWNSHIPS AND KENT COUNTY, SOUTHWESTERN ONTARIO, 1971

Crop	Kent County	Chatham-Harwich
	percent	
Winter Wheat	9.28	8.10
Corn	53.95	59.05
Soybeans	24.67	17.22
Field Beans	2.51	4.70
Oats	4.01	4.30
Alfalfa	1.58	2.00
Barley	1.06	1.00
19 others ^a	2.94	3.63
Total	100.00	100.00

^a Mixed grains, rye, peas, tame hay, other fodder, potatoes, tobacco, other field crops, tree fruits, grapes, strawberries, sunflowers, buckwheat, mushrooms, cutflowers, raspberries, greenhouses (100' x 100').

Source: 1971 Agricultural Census.

The average precipitation is 86.4 cm (34 inches) over all the region except the Western part, which has about 81.3 cm. (32 inches) during the year. Warm temperatures and early season permit growing a variety of crops but rainfall must be supplemented by irrigation on certain crops grown on sandy soils.

2.3 SOIL DATA

The study area was stratified according to land use capability classes [see Appendix E]. Five test sites were established over three land use capability classes containing EIGHT SOIL TYPES [Table 2.3] [Fig. 2.3].

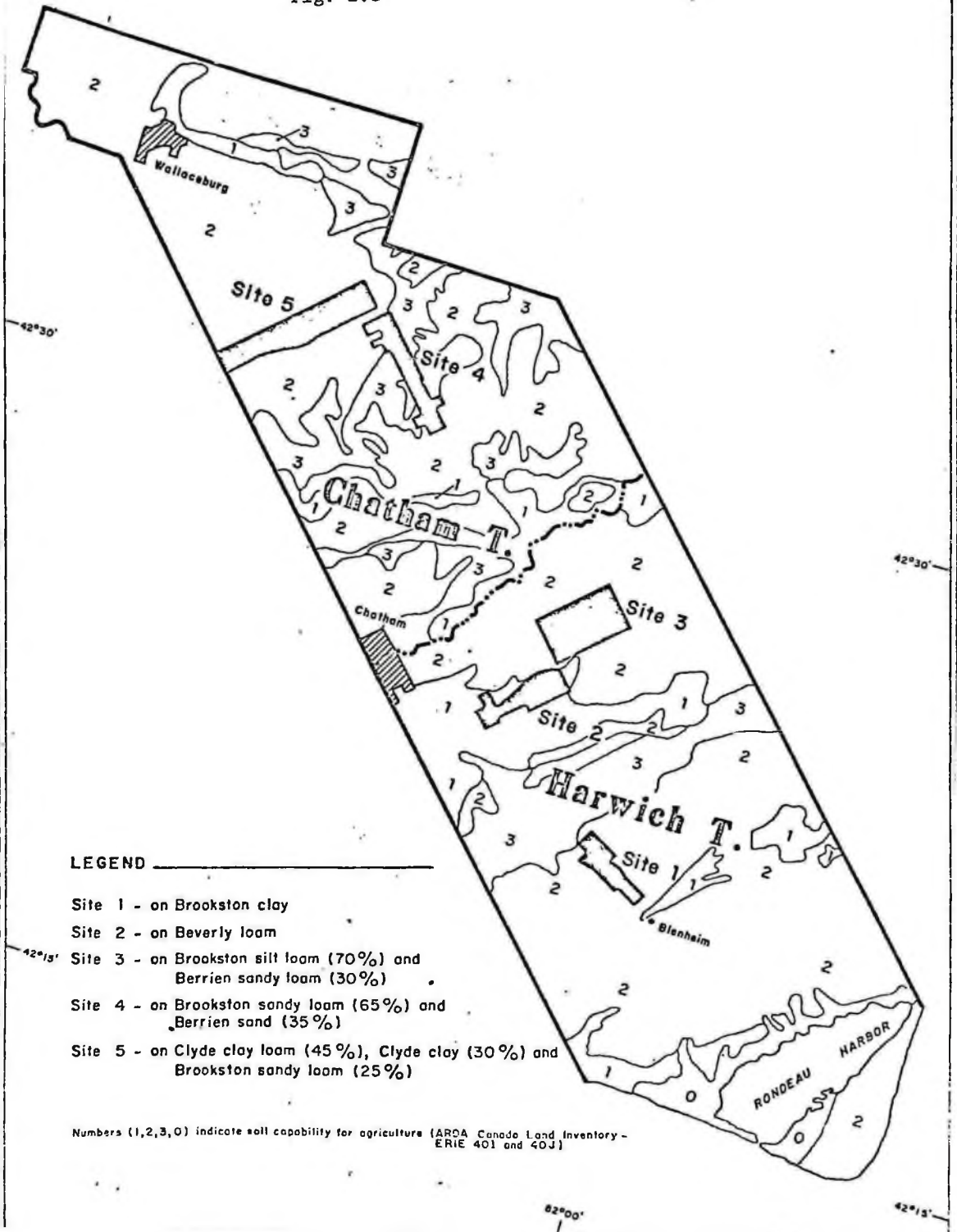
Table 2.3 DISTRIBUTION OF SOIL TYPES AND LAND USE CAPABILITY CLASSES AT THE FIVE TEST SITES WITHIN CHATHAM - HARWICH TOWNSHIPS, SOUTHWESTERN ONTARIO, JUNE 1974

Site	Soil Type	Land Capability Class ¹
1	Brookston clay	2w
2	Beverly loam	1
3	Brookston silt loam	2w
	Berrein Sandy loam	2f
4	Brookston Sandy loam	3 ^w _s
	Berrein sand	2f
5	Clyde clay	2w
	Clyde loam	2w

¹ See Appendix E.

GEOGRAPHIC LOCATIONS OF SITES IN HARWICH AND CHATHAM TOWNSHIPS, KENT COUNTY, ONTARIO, 1974

Fig. 2.3



LEGEND

- Site 1 - on Brookston clay
- Site 2 - on Beverly loam
- Site 3 - on Brookston silt loam (70%) and Berrien sandy loam (30%)
- Site 4 - on Brookston sandy loam (65%) and Berrien sand (35%)
- Site 5 - on Clyde clay loam (45%), Clyde clay (30%) and Brookston sandy loam (25%)

Numbers (1,2,3,0) indicate soil capability for agriculture (ARCA Canada Land Inventory - ERIE 401 and 40J)

The Brookston clay soils are poorly drained, high in organic matter, and slightly acid to alkaline. They cover about 177,000 acres in Kent County.

The Beverly loams are imperfectly drained, friable and underlain by stratified sand, silt and clay. They are neutral to slightly alkaline and they cover about 10,000 acres in Kent county.

The Brookston silt loams are poorly drained, high in organic matter, and slightly acid to alkaline. They cover about 37,000 acres in Kent county.

The Berrein Sandy loams are imperfectly drained, low in organic matter, and acidic. They cover about 46,000 acres in Kent county.

The Brookston sandy loams are poorly drained, high in organic matter, and slightly acid to alkaline. They cover about 51,000 acres in Kent county.

The Berrein Sands are imperfectly drained, low in organic matter, and acidic. They cover 53,000 acres in Kent county.

The clyde clays are poorly drained, deep black soils, high in organic matter, and usually neutral to alkaline. They cover about 35,000 acres and they usually require artificial drainage.

The clyde loams are poorly drained black soils, very high in organic matter, and usually neutral to alkaline. They cover about 17,000 acres in Kent county.

The chief elements in the land use capability classes are the soils and their characteristics. While land use capability classes 1, 2 and 3 are suitable for sustained production of common field crops, their actual productivity depends on the soil characteristics and the

kinds of limitations they have. As has been pointed out previously the study area was relatively small (28 miles x 10 miles) with uniform climatic conditions. For this reason all factors other than the soils and time were assumed to be exogenous in this investigation.

The composition and characteristics of soils are important economically to the farmer in two ways:

1) they determine the amount and quality of nutrients available to his crops and hence the amount of fertilizers required to supplement production; and

2) they determine the management and conservation practices the farmer adopts and how effectively these practices are carried out. Differences in soil moisture holding capacity, porosity, drainage and susceptibility to erosion determine, to a large extent how well the land is managed. Thus by stratifying the study area according to land use capability classes, we may, in effect, be separating the well managed farms from the poorly managed ones.

2.4 GROUND TRUTH DATA

Three field observations were made at the five test sites on June 20, July 13 and August 13, 1974. The June 20 field observation coincided with the June 20 ERTS-1 coverage of the test sites. The July 13 field observation was made five days after the July 8 ERTS-1 coverage of the test sites while the August 13 field observation was made on the same date as the August 13 ERTS-1 coverage of the test sites. At each of the five test sites, a complete inventory of all the fields lying on either side of the major road running through the site was taken using

the CCRS Wheat Project Ground Truth Periodic Observation Forms (Table 2.4). All fields lying to the North or East of the roads were assigned odd numbers while those lying to the South or West were assigned even numbers (Fig. 2.4). This system of numbering the fields was adopted for convenience only and had nothing to do with method of analysis. In order to associate each field with the crop growing in it, it was necessary to determine the field boundaries and also identify the crops growing in each field. Field boundaries were initially identified at the test sites using 1973 colour infrared aerial photographs of the test sites during the June 20 and July 8 field observations. The field boundaries were subsequently updated during the August 13 field observation by 1974 colour infrared photographs of the test sites taken on July 6, 1974. The crops growing in the fields were identified by carefully studying the characteristics of the crops as seen in the field. For each field, the crop type, plant height, plant growth stage, percentage ground cover, soil surface moisture and the standing quality of the crops were recorded.

Forty-three fields were selected on the Brookston clay soil; thirty-one on the Beverly loam; sixty on the Brookston silt, thirty-two on the Brookston sandy loam/Berrein sand; and forty-seven on the Clyde clay/clyde loam soils. There were a total of 213 fields covering 4,936 acres.¹ The major crops included corn, soybeans, winter wheat oats and field beans [Tables 2.5, 2.6]. Details of the growth stage,

¹ The acreages were calculated from the July 6, 1974 colour infrared aerial photographs of the test sites.

Table 2.4

CCRS WHEAT PROJECT GROUND TRUTH PERIODIC OBSERVATION FORM

TEST SITE OBSERVATION #5		MONTH DAY	
PHOTO		ERTS PASS DATE	-- / -- /74
Y- YES,	01- NOT PLANTED	OBSERVATION DATE	-- / -- /74
N- NO	02- PLANTED, NO EMERGENCE	STAND QUALITY RATING AS COMPARED TO OTHER FIELDS OF THE SAME CROP IN THE TEST SITE	
PHOTOGRAPH	03- 1, 2, OR 3 LEAVES SHOWING	1- POUR	4- ABOVE AVERAGE
STARRED FIELDS	04- 4 OR MORE LEAVES AND BOOT	2- BELOW AVERAGE	5- EXCELLENT
	05- HEADING IN PROGRESS	3- AVERAGE	6- DOES NOT APPLY
	06- FULLY HEADED		
		07- TURNING COLOR	
		08- RIPE	1- DRY
		09- SWATHED	2- DAMP
		10- HARVESTED	3- WET
		11- DOES NOT APPLY	4- STANDING WATER

MAP REFERENCE # OF FIELD	ACREAGE	PHOTO	GROWTH STAGE (CIRCLE ONE)	GROUND COVER (IN %)	PLANT HEIGHT (INCHES)	SURFACE MOISTURE (CIRCLE ONE)	SUBJECTIVE EVALUATION OF STAND QUALITY	STAND QUALITY RATING (CIRCLE ONE)
---	---	Y N	01 02 03 04 05 06 07 08 09 10 11	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> %	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> IN.	1 2 3 4		1 2 3 4 5 6
---	---	Y N	01 02 03 04 05 06 07 08 09 10 11	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> %	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> IN.	1 2 3 4		1 2 3 4 5 6
---	---	Y N	01 02 03 04 05 06 07 08 09 10 11	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> %	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> IN.	1 2 3 4		1 2 3 4 5 6
---	---	Y N	01 02 03 04 05 06 07 08 09 10 11	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> %	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> IN.	1 2 3 4		1 2 3 4 5 6
---	---	Y N	01 02 03 04 05 06 07 08 09 10 11	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> %	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> IN.	1 2 3 4		1 2 3 4 5 6
---	---	Y N	01 02 03 04 05 06 07 08 09 10 11	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> %	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> IN.	1 2 3 4		1 2 3 4 5 6
---	---	Y N	01 02 03 04 05 06 07 08 09 10 11	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> %	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> IN.	1 2 3 4		1 2 3 4 5 6
---	---	Y N	01 02 03 04 05 06 07 08 09 10 11	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> %	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> IN.	1 2 3 4		1 2 3 4 5 6
---	---	Y N	01 02 03 04 05 06 07 08 09 10 11	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> %	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> IN.	1 2 3 4		1 2 3 4 5 6
---	---	Y N	01 02 03 04 05 06 07 08 09 10 11	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> %	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> IN.	1 2 3 4		1 2 3 4 5 6
---	---	Y N	01 02 03 04 05 06 07 08 09 10 11	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> %	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> IN.	1 2 3 4		1 2 3 4 5 6
---	---	Y N	01 02 03 04 05 06 07 08 09 10 11	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> %	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> IN.	1 2 3 4		1 2 3 4 5 6
---	---	Y N	01 02 03 04 05 06 07 08 09 10 11	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> %	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> IN.	1 2 3 4		1 2 3 4 5 6

SITE 3, Photograph 2

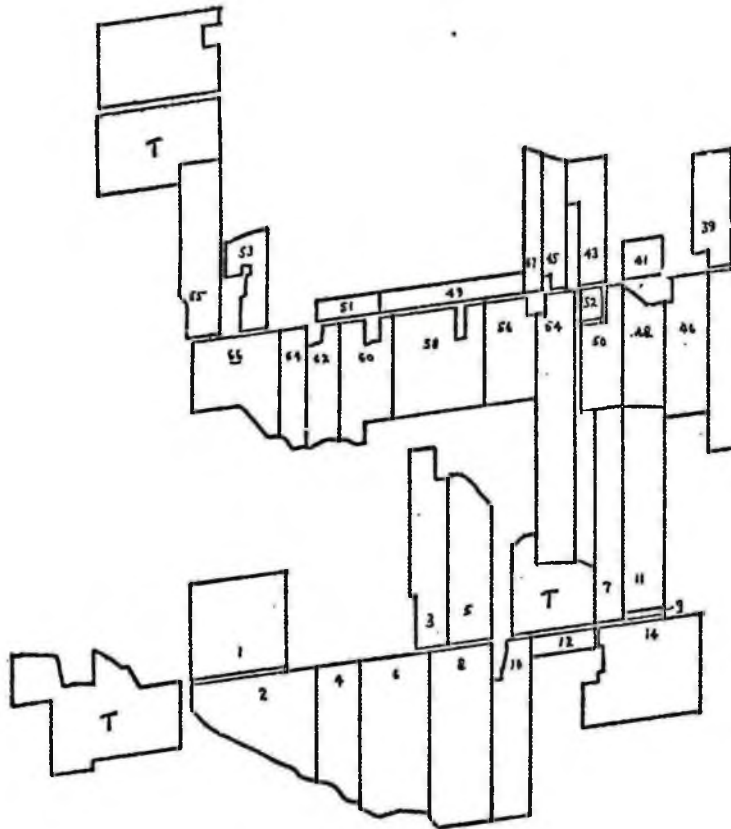


Fig. 2.4 Field Layout for Site 3

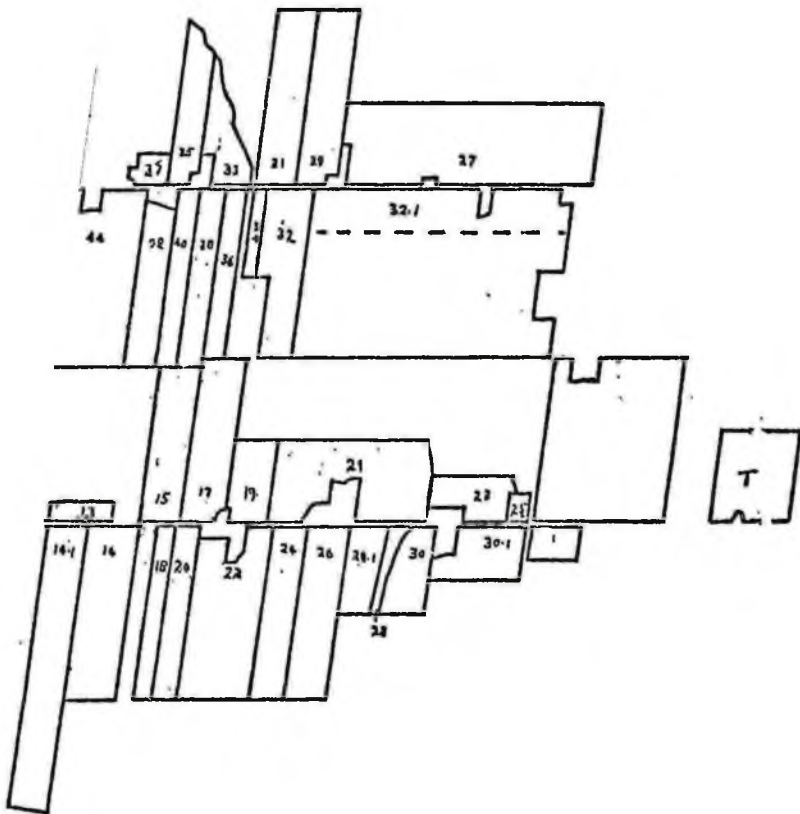


Table 2.5 THE DISTRIBUTION OF CROPS AT THE FIVE TEST SITES IN CHATHAM - HARWICH TOWNSHIPS, SOUTHWESTERN ONTARIO, JUNE, 1974

CROP	Site 1	Site 2	Site 3	Site 4	Site 5	Total
Winter Wheat	2	3	14	4	1	24
Corn	10	11	17	16	29	83
Soybeans	19	-	5	7	8	39
Oats	4	3	2	1	1	11
Fieldbeans	-	6	12	1	-	19
Others ^a	8	8	10	3	8	37
TOTAL	43	31	60	32	47	213

Table 2.6 THE DISTRIBUTION OF CROP ACREAGES AT THE FIVE TEST SITES IN CHATHAM - HARWICH TOWNSHIPS, SOUTHWESTERN ONTARIO, JUNE, 1974

CROP	Site 1	Site 2	Site 3	Site 4	Site 5	Total
Winter Wheat	34.3	51.8	203.9	64.1	46.8	400.9
Corn	154.3	158.6	453.2	445.3	1407.3	2618.9
Soybeans	358.5	-	93.2	196.6	228.6	876.9
Oats	66.7	68.6	14.1	7.0	14.3	170.7
Fieldbeans	-	128.2	303.4	35.8	-	467.4
Others ^a	45.6	91.2	78.7	19.1	166.5	401.1
TOTAL	659.4	498.4	1146.5	767.9	1863.5	4935.7

^a Others: These include green peppers, barley, hay, pasture, tomatoes, cabbage and grass.

plant height and the percentage ground cover for the crops are presented in Table 2.7. These conditions are not listed for August 13 because the computer compatible tape for the August 13 orbital pass was cloud covered and was not used in the study. The information from the June 20 field observation was key punched and the cards read into a computer to create 5 ground inventory files (GINV01.W74, GINV02.W74, GINV03.W74, GINV04.W74 and GINV05.W74). The figure 01 in the file GINV01.W74 identifies the file as belonging to site 1, the 02 in GINV02.W74 identifies the file as belonging to site 2, etc. The ground truth files were sorted by field ID (SORT 3), in ascending order.

Three to five training fields (see Section 3.1) were selected at random for each of the crops from each of the ground inventory files using the program CGDT11. There are several points to note at this point. Only one set of ground inventory files was created and that was from June 20 field observation. The other field observations were not used in the study because the only information required from the ground inventory files for the classification process are the field IDs and the crops associated with the field IDs. This information is adequately provided by one ground observation. The other parameters such as plant growth stage, plant height, percentage ground cover, surface moisture and standing quality of the crops do not form part of the information required for the classification process when using the maximum likelihood and the minimum distance classifiers. The basis for classification using the above classifiers is the average signal levels for the four ERTS-1 sensing bands; nevertheless the plant growth stage, plant height, percentage ground cover, etc. are recorded during the field observation

(CHATHAM - HARWICH TOWNSHIPS)

	SITE 1			SITE 2			SITE 3			SITE 4			SITE 5		
	G.S. ¹	P.H. ²	G.C. ³	G.S.	P.H.	G.C.	G.S.	P.H.	G.C.	G.S.	P.H.	G.C.	G.S.	P.H.	G.C.
<u>JUNE 20</u>															
Corn	03	3-12"	1-20%	03	6-14"	5-25%	03	4-14"	5-30%	03	5-14"	3-40%	03	6-14"	3-30%
W. Wheat	05	36"	100%	05	32-36"	100%	05	30-36"	100%	05	36-40"	100%	05	36"	100%
Soybeans	03	1-6"	1-10%				03	3-6"	5-10%	03	3-6"	5-30%	03	4-8"	3-15%
Fieldbeans				02-03	1-4"	0-1%	03	3-5"	5-8%	03	4"	6%			
Oats	04	18-20"	100%	04	18-24"	100%	04	14"	100%	04	16"	100%	04	18"	100%
<u>JULY 13</u>															
Corn	03-04	14-32"	12-80%	03-04	18-45"	30-95%	03-04	20-50"	50-95%	03	32-55"	50-85%	03-04	30-40"	40-90%
W. Wheat	06	36-40"	100%	07	36-40"	100%	07	36-40"	100%	07	36-40"	100%	07	36"	100%
Soybeans	03	10-14"	5-35%				03	10-12"	40-60%	03	8-18"	25-75%	03	10-14"	30-60%
Fieldbeans				03	8-18"	10-40%	03	4-12"	15-70%	03	10"	25%			
Oats	05	30-32"	100%	05	30-32"	100%	05	32"	100%	05	30"	100%	06	36"	100%

¹G.S.: Growth Stage
²P.H.: Plant Height
³G.C.: Ground Cover

CODE GROWTH STAGE
02 Planted, No Emergence
03 1,2, or 3 Leaves Showing
04 4 or More Leaves and Boot
05 Heading in Progress
06 Fully Headed
07 Turning Colour

so as to obtain accurate description of the state of the crops during the study period. It may well be that the best identification results for agricultural crops are obtained during the maturing phases of the crops' cycles. Secondly, it is important to note that training fields are not selected in the field but are selected from the ground truth files usually after studying the distribution of the signal levels for the pixels digitized within each field, the more normally distributed the signal levels, are within a field, the more likely that field is chosen as a training field. Once the training fields for the various crops have been chosen for each site, the ground file is ready to be merged with the statistics file.

2.5 AIRBORNE DATA

A two-camera pack was flown on July 6, 1974 over the Chatham-Harwich area with 250 mm Infrared RC.10 cameras [Table 2.8].

Field boundaries were identified on the ground using 250 mm infrared prints enlarged to provide a scale of 1:3000. Field acreages were calculated from the aerial photograph¹ using a Hewlett-Packard 9864A digitizer in combination with a mini-computer and XY Plotter using an acreage calculating subroutine developed at CDA, Economics Branch, Ottawa. The geometry of the aerial photograph was transformed onto the computer printout map in order to locate the field boundaries on the computer map using the mathematical transformation known as Affine Transformation (see Appendix B).

¹ Uncorrected

Table 2.8

AIRBORNE HARDWARE (JULY 6, 1974) FLOWN OVER CHATHAM -
HARWICH TOWNSHIPS IN KENT COUNTY, S.W. ONTARIO

Camera Type and No.	Calibrated F.L.	Film Type	Emulsion No.	Filter Type and No.
Wild RC.10	153.29 mm	Aerochrome Infrared	2443-202-3	NAV2 .2X + Wr.12
Wild RC.10	153.12 mm	Aerochrome Infrared	2443-101-2	Pan 525 AV2X#4360

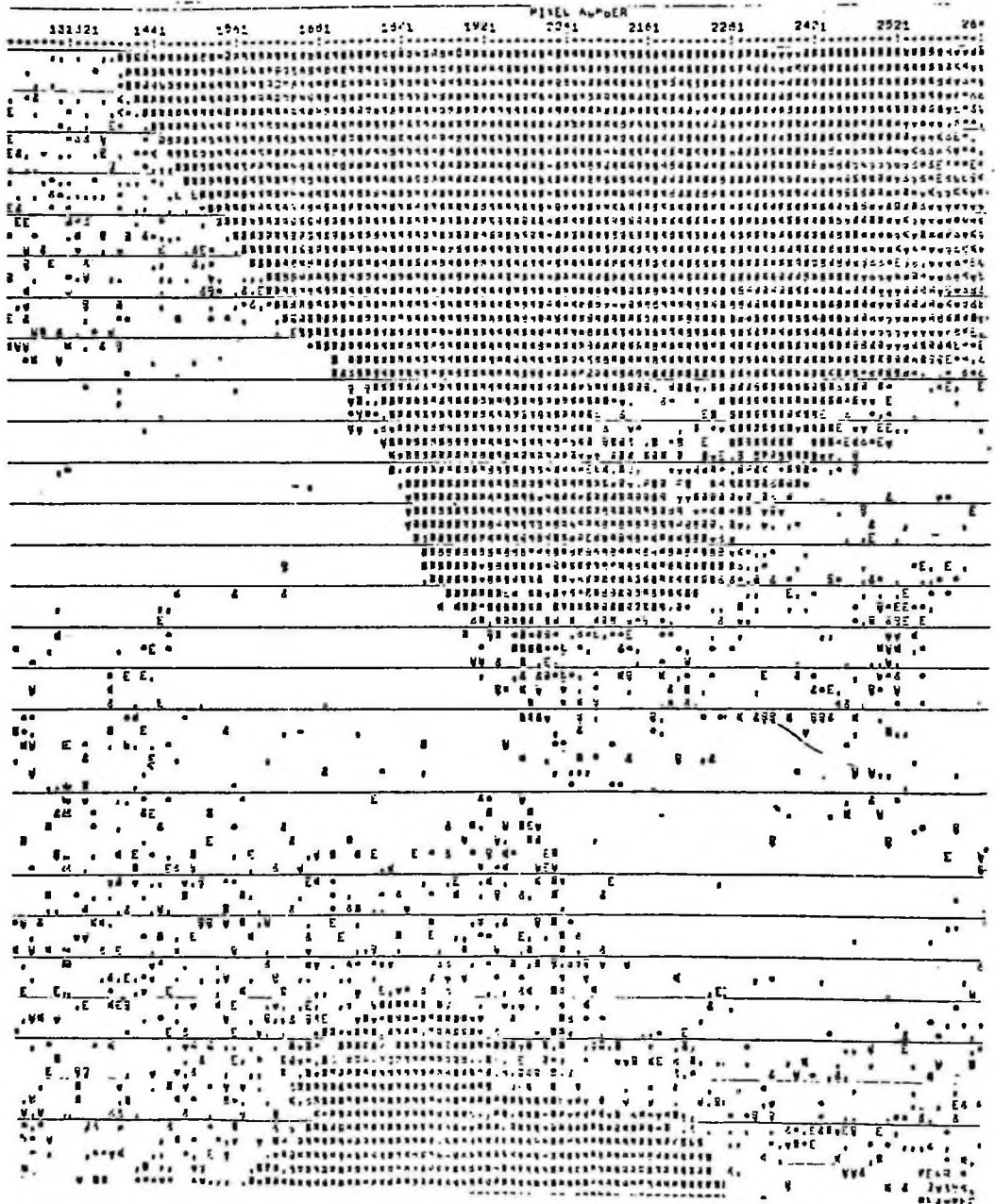
2.6 SATELLITE DATA

This section is divided into two parts. Part 1 describes the Canadian Centre for Remote Sensing (CCRS) Wheat Project Image Processing System for small fields used in the analysis of digital ERTS-1 data. Part 2 presents the details of the analysis of the three computer tapes used in this study.

2.6.1 CCRS Wheat Project Image Processing System

The CCRS Wheat Project flow chart for small fields was presented in Fig. 2.1. The procedure involves ordering ERTS-1 photographs of the test sites from the National Air Photo Library (NAPL), Ottawa. If the test sites are clear (not cloud covered) on the ERTS-1 photograph, a computer compatible tape (CCT) (see Appendix B) of the test sites is ordered from the CCRS using the frame number of the appropriate ERTS-1 photograph. If the test sites are not clear on the ERTS-1 photograph, one waits for the next ERTS-1 photograph on which the sites are clear. Once the CCT is delivered, the next step is to determine the geographic correspondence between the CCT and the ERTS-1 photograph - because even though the CCT is ordered using the frame number of the ERTS-1 photograph, it is only in rare cases that the first line on the ERTS-1 photograph corresponds to the first line on the CCT. As one recalls from Appendix B, a CCT contains 2400 lines and over 3200 pixels. Since it is very expensive, in terms of computer time, to print every pixel in every line from a CCT, a computer printout map in which every 12th pixel of every 20th line is produced using the program Map 1. A portion of such a computer map is presented in Fig. 2.5. The position of the test sites relative

Fig. 2.5 A map from a portion of frame 175115374 to determine the geographic correspondence between tapes and ERTS photos 1 line in every 20 has been printed and within a line 1 pixel in every 12 has been printed.



to some easily recognisable features such as large bodies of water is established so that a more detailed map of the test sites can be produced for further analysis. It is very important that the position of the test site is first established on the computer map from the program Map 1 because a computer compatible tape contains information for 10,000 square nautical miles while a study area(test site) usually covers anything from 20 square miles to a few hundred square miles at the most. It is a complete waste of time and money to print a computer map covering 10,000 square nautical miles when only a few square miles is needed. Once the approximate location of the test sites has been established on the computer map from the program map 1, a more detailed computer map of the test site area in which every pixel in every line is printed is produced using the program map 2. A portion of such a computer map is presented in Fig. 2.2. It contains 100 lines x 120 pixels. It is obvious that if the test site covers about 400 lines and 1200 pixels, several such computer maps must be produced because the CCRS Wheat Project Image Processing System can print only 120 pixels at a time on one computer map. After the required number of computer maps have been printed, they are carefully joined together to form one huge computer map in which all the agricultural fields in the study area are included. The next step is to precisely define the field boundaries on the computer map so that the characteristics of the pixels within each field can be studied to determine which crops the fields belong. To outline the field boundaries on the computer map, the satellite data is corrected radiometrically using the programs Genlut and Applut and if the computer map for the corrected satellite data is being used as a primary pass (the

computer map used to register subsequent computer maps of the same test sites), about 8 control points are located on both the computer map and the aerial photographs of the test site(s). (By a control point is meant an easily recognizable point on both the computer map and the aerial photograph). Field boundaries from the aerial photographs are transformed onto the computer map (at the scale of the computer map) using a mathematical transformation known as Affine Transformation (see Appendix C). The product of such a transformation is given in Fig. 2.6. The next step is to digitize the pixels within each field outlined on the computer map. By digitization is meant the automatic recording of the coordinates (line and pixel numbers) of a point. The output from the digitization is used to create a file (BNDSNN.WYY) which in turn serves as the input for another file known as a Statistics file (STANNM.WYY). The output from the statistics file known as the statistics (the distribution, according to signal levels of the digitized pixels within a field) is generated using the program STAT2. The statistics for selected fields from site 1, July 8, 1974 are presented in Table 2.9. In column 1 are the crops whose statistics are being described. Typically, the statistics include field IDs instead of crops but since each field number is associated with a particular crop, the identities of the crops can be obtained. The next four columns give the average signal levels for each of the 4 ERTS-1 Sensing bands. The basis for classification using the minimum distance and the maximum likelihood decision rules (see Section 3.1) is the average signal levels of the 4 ERTS-1 Sensing bands.

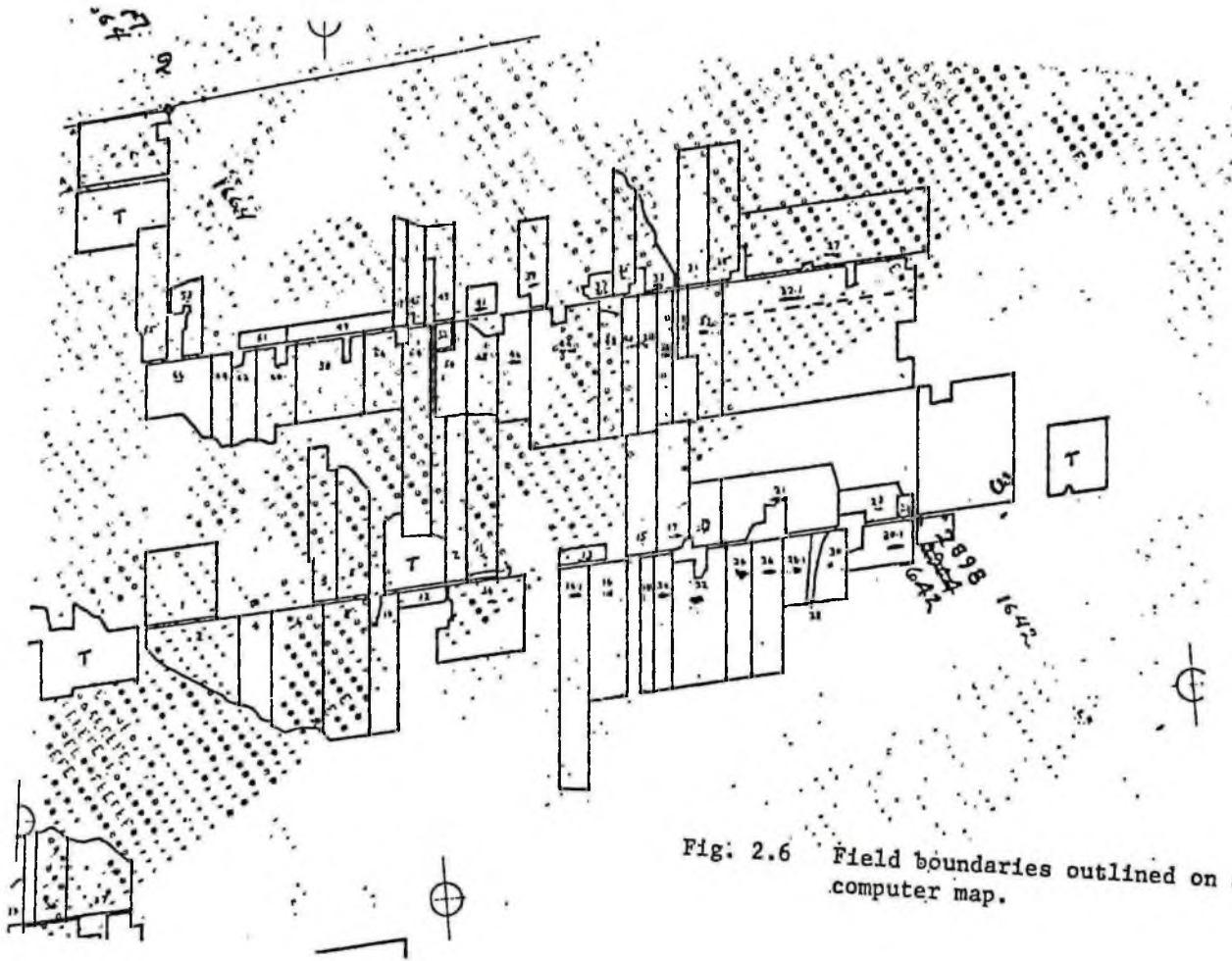


Fig: 2.6 Field boundaries outlined on a computer map.

Table 2.9

STATISTICS FOR SELECTED FIELDS FROM SITE 1, JULY 8, 1974

CROP	Band Averages				Band Variances				Band Correlations						No. of pixels
	4	5	6	7	4	5	6	7	4-5	4-6	4-7	5-6	5-7	6-7	
Corn	15.00	14.67	27.00	20.00	0.00	0.00	0.00	0.00	0.22	0.33	0.00	0.67	0.00	0.00	3
	13.50	11.13	21.88	20.75	0.25	0.06	-0.06	0.00	0.36	-0.48	-0.97	4.61	5.72	8.19	8
	15.29	15.43	24.43	21.71	0.78	0.73	0.45	-0.06	17.39	-0.33	-0.31	0.82	0.84	1.92	7
	15.09	16.09	23.36	21.27	0.26	-0.01	0.24	0.34	13.54	0.24	-1.30	1.14	0.99	1.29	11
Soybeans	15.14	13.71	23.00	20.71	0.12	0.04	0.29	0.18	0.49	0.29	-0.08	1.43	1.00	1.06	7
	14.75	13.25	20.75	18.25	0.19	0.06	0.19	-0.19	-0.19	-0.06	-0.31	0.19	-0.19	0.69	4
	15.30	17.80	21.20	18.00	0.21	-0.74	0.14	0.10	24.76	0.44	0.00	0.56	0.10	0.20	10
Winter Wheat	16.67	18.50	26.50	24.17	1.56	-0.83	0.50	0.72	10.58	1.42	2.42	0.92	1.08	1.47	6
	12.88	9.87	22.63	22.87	0.36	-0.14	0.83	0.61	2.86	-2.42	-3.27	4.98	5.58	6.86	8
Oats	12.50	9.83	25.00	26.33	0.25	0.25	-0.67	-0.50	0.47	-0.67	-0.44	2.00	1.67	1.56	6
	13.43	10.71	23.37	22.86	0.24	0.41	-0.67	-0.65	1.35	-1.41	-1.61	2.53	2.22	2.41	7
	13.00	12.00	22.00	20.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	2

The next four columns give the band variance while the next six columns represent the band correlations. The number of pixels digitized within each field are presented in the last column. The output from the statistics file is sorted by field ID in ascending order using the program Sort 2. At this point, the sorted statistics data is merged with the ground truth data containing the training fields, using the program Merge 3, to create a new file called Merge. The output from the file Merge for site 3 (July 8 orbital pass) is presented in Table 2.10. Column 1 gives the field IDs for site 3, the first digit (3) in column 1 of the merge file is consistent and it identifies the data in the merge file as belonging to site 3, the next two digits in column 1 represent the field numbers at the site. According to this system, the field ID 301 refers to the first field of site 3 (Fig. 2.3). The next four columns are the average signal levels for the pixels digitized as sensed by the 4 ERTS-1 bands. For example the figure 14.61 in column 1 of field 301 represents the average signal level (see Appendix B) of the pixels digitized in field 301 as sensed by the green ERTS-1 band (4). Similarly, the figures 13.00, 24.89 and 23.94 of field 301 are the average signal levels for the red, and the two infrared ERTS-1 bands (bands 5, 6 and 7) respectively.

The last column identifies the crop associated with each field by the code name of the crop. For example, the code 601 represents corn, 602 is soybean and 603 is fieldbean. The letter T preceding the code number of the crop indicates to the computer that the characteristics of that field are to be considered as part of the training set for that crop. The letter U indicates that the characteristics of that

Table 2.10 OUTPUT FROM MERGE FILE FOR SITE 3,
 July 8, 1974

<u>FIELDID</u>	<u>Band 4</u>	<u>Band 5</u>	<u>Band 6</u>	<u>Band 7</u>	<u>Crop ID</u>
301	14.61	13.00	24.89	23.94	T 601
302	14.19	12.00	26.00	25.31	T 601
303	17.40	17.70	29.30	26.50	T 603
304	13.25	10.87	20.88	21.00	T 400
305	14.29	12.10	26.10	25.86	U 601
306	14.42	11.75	26.50	26.58	T 601
307	14.87	14.00	25.38	23.75	U 603
308	14.87	13.52	24.57	22.43	T 601
.
.
.
.
.
356	17.39	17.72	25.83	22.39	U 603
358	14.89	13.78	23.89	22.00	U 601
360	15.50	14.80	26.60	25.00	T 603
362	14.75	12.25	25.75	25.25	U 400
364	14.67	12.67	26.00	25.67	U 601

field do not form part of the training set for that crop.

The output from the file Merge is sorted by T (training) and U (unknown) fields, by field ID in ascending order (Sort 4). The file may be sorted further by increasing field ID, increasing signal level in band 6 and then by increasing signal level in band 7 (Sort 6). At this stage, the satellite and ground truth data in the merge files are ready for classification using the maximum likelihood and the minimum distance classifiers.

2.6.2 Analysis of the Three Computer Compatible Tapes used in the Study

Six time sequential computer compatible tapes were obtained from the May 14, June 2, June 20, July 8, July 26 and August 13 (Frame Nos. 1660-15350, 1679-15401, 1697-15394, 1715-15390, 1733-15382 and 1751-15374 respectively) ERTS-1 orbital passes over the test sites in the Chatham - Harwich Townships, S.W. Ontario. Only the June 2, June 20 and July 8 computer compatible tapes were used in the study because several errors were detected on the May 14 and July 26 tapes while the August 13 tape was cloud covered. The June 20 computer compatible tape (CCT) was used as the primary pass. The program map 1 was used to determine the geographic correspondence between the ERTS-1 photographs and the computer compatible tapes (CCTS). After locating the approximate positions of the test sites on the computer map 2, more detailed maps of the test site areas were produced using the program map 2 by printing every pixel in every line for lines between 1000 and 1900 and pixels between 2320 and 3520. Ten computer maps each measuring 900 lines by 120 pixels were carefully joined together to produce a giant computer map measuring 900 lines by 1200 pixels, the largest

computer map ever produced in Canada at that time. Using such readily identifiable features as water bodies, rivers, woodlots, railways, roads, coastal features and sometimes individual pixels as well as the aerial photographs of the test sites, the precise coordinates of the five test sites were determined. The five test sites were combined into three sites in order to obtain a good spread of control points for registering the secondary computer maps (see Appendix B). At each of the three combined test sites, eight control points were located on both the aerial photographs and the computer map and the coordinates of the control points on the computer map recorded. A mathematical transformation called affine transformation was used to transform the field boundaries on the aerial photographs of the test sites onto plotting paper using a Hewlett-Packard 9864A digitizer in combination with a mini-computer and XY plotter. The fields boundaries were carefully transferred onto acetate paper and then placed on the computer map thus outlining the field boundaries on the computer map (see Fig. 2.6). The pixels within each field at the five test sites were digitized (automatic measuring and recording of the coordinates of a point) and the output put into five files (each presenting one test site) (BNDSNN.WYY). The coordinates of the pixels digitized were printed out, using the program (PBND5), and checked to make sure that only pixels lying within field boundaries were digitized.

The output from the digitizing was used as input for the program STAT2 to generate the statistics for the digitized pixels. The output from the STAT2 program was put into five new files (STATNNM.WYY) called statistics files, each file representing the statistics for one of the

five test sites. The statistics files were sorted in ascending field ID (Sort 2). As noted earlier, the statistics files contain the average signal levels for the 4 ERTS-1 bands for each field. It should also be noted that it is the average signal levels contained in the statistics files that form the basis for classification by the maximum likelihood and the minimum distance classifiers (see Section 3.1). The sorted statistics files were then merged with the sorted ground truth files containing the training fields to create five new files called merge file, using the program Merge 3. At this stage all the data needed for the classification of the fields have been assembled but before the actual classification is discussed, the procedure used in analysing the June 2 and July 8 CCTs is discussed.

The computer printout maps of the infrared band (.9 - 1.1 μ) were produced from the June 2 and July 8 CCTs. After the satellite data for the June 2 and July 8 CCTs were corrected radiometrically, control points corresponding to those located on the June 20 computer map were located on the June 2 and July 8 computer maps. Using the mathematical program called affine transformation, the June 2 and July 8 computer maps were registered (see Appendix C) with the June 20 computer map. The purpose of the registration was to identify pixels on the June 2 and July 8 computer maps that corresponded with the pixels digitized on the June 20 computer map. In this way, one is sure that only the same fields and pixels are studied on the June 2, June 20 and July 8 CCTs. After the registration of the June 2 and July 8 CCTs with the June 20 CCT, the statistics for the June 2 and July 8 data were generated, sorted and merged with the sorted ground truth data as in the case of

the June 20 data. It should be noted that statistics file for site 1 can only be merged with the ground truth data for site 1, because the merge program must have corresponding field IDs from the statistics and the ground truth files. At this point, every thing was ready for applying the maximum likelihood and the minimum distance decision rules on the assembled data.

Chapter III

CLASSIFICATION RESULTS

3.0 INTRODUCTION

At this stage five merge files, each containing the following:

- 1) field IDs for the crops at each site;
- 2) the average signal levels for each of the 4 ERTS-1 sensing bands (green, red and the two near infrared bands); and
- 3) the code numbers for the various crops identified as either T (training) or U (unknown) fields, have been created from each of the three computer compatible tapes. Each file represents a test site.

The purpose of the classification exercise is to ask the computer to separate the fields into groups belonging to the various crops on the basis of the average signal levels computed for the fields [see Table 2.9]. In this study, 3-8 training fields were selected at random for each crop. The only parameters from the ground truth data files that appeared in the merge files are the field IDs and the code numbers of the crops because at the time of the study, none of the other parameters such as the plant growth stage, plant height, percentage ground cover, and soil surface moisture formed part of the classification. The maximum likelihood and the minimum distance classifiers are described in Section 3.1. Sections 3.2 and 3.3 present the classification accuracy results obtained using the two classifiers. Sections 3.4 and 3.5 relate the variations in the identification accuracies achieved by the two classifiers to the different soil types. The term

soil effects of crop identification is introduced in Section 3.4. Sections 3.6 and 3.7 relate the variations in the crop identification accuracies achieved by the two classifiers to time of identification. The term time effects of crop identification is introduced in Section 3.6. Implicit in the term time effects are the growth stages and percentage ground coverage of the crops since each of the three dates (June 2, June 20 and July 8) were associated with different growth stages of the crops. Section 3.8 takes a look at the combined soil and time effects of crop identification when using the two classifiers. For each classifier, this section identifies the highest accuracy achieved, when it was achieved and over what soil type.

3.1 CLASSIFIERS¹

Once the location of the site and its fields on the computer map has been determined, the next problem is to determine what each of the fields is.

Let the set of 4 numbers for each pixel in the site be called a feature vector x . One can average all the feature vectors over a given field and come up with an average feature vector for that field.

Let us assume that an average feature vector (herein referred to simply as a feature vector) could represent one of n possible items or classes. In this study for example, a given feature vector could represent Winter Wheat, Soybeans, Fieldbeans, Oats, Barley, Corn or pasture. The classification problem is to decide into which class a

¹ Source: F. Peet, "Procedures Manual for the Wheat Project".
CCRS Technical Note 73-22.

given feature vector falls.

Let $g_i(X)$, $i=1, \dots, n$, be a real-valued function of the feature vector X . That is for each class there is a function g_i which when evaluated at a feature vector X , gives a real number. The g_i are chosen such that if the feature vector belongs to the class k , $g_k(X) > g_i(X)$, $i=1, \dots, n$, $i \neq k$. This then is the basis of classification. Given an X , the functions $g_i(X)$, $i=1, \dots, n$, are evaluated, the largest is chosen, and this gives the class to which the feature vector X is assumed to belong.

The g_i are called discriminant functions. They contain a certain number of parameters which can be estimated from feature vectors whose class is known from the ground-truth data. The set of feature vectors whose class is known is called the training set.

1. Minimum Distant Classifier (PR30)

Let $A_1 \dots A_n$ represent the average feature vector in each class obtained by averaging over the feature vectors belonging to the training set for each class.

Let $D_n^2 = (X - A_n)^2 = X^2 - 2X \cdot A_n + A_n^2$ be the square distance from the X unknown vector to the known vector A_n . We assume that X belongs to the known vector A_k if $D_k < D_n$ for all $n \neq k$.

When D_k is a minimum, $-2X \cdot A_k + A_k^2$ is a minimum and therefore $2X \cdot A_n - A_n^2$ is a maximum. Hence we choose $g_i(x) = 2X \cdot A_n - A_n^2 \dots$ (3).

Thus given an unknown vector X , we evaluate $g_i(X)$, $i=1, \dots, n$ and pick the largest which immediately gives the class into which X has fallen.

2. Maximum Likelihood Classifier

This is the method of classification used in the LARS system.

Let $p(X|i)$ be the probability of occurrence of the feature vector X given that it belongs to the class i . We assume that this can be given by the multivariate normal distribution:

$$p(X|i) = 1/((2\pi)^2 |\Sigma_i|^{1/2}) e^{-(1/2)(X - A_i)^T \Sigma_i^{-1} (X - A_i)} \dots (4)$$

where

$$(\Sigma_i)_{kl} = E (x_k - (a_i)_k) (x_l - (a_i)_l) \dots (5)$$

is the covariance matrix of the i^{th} class, A_i is the average feature vector for the i^{th} class as determined from the training set, Σ is the determinant of Σ , and Σ^{-1} is the inverse of Σ .

Let $p(j|X)$ be the probability that the feature vector X falls in the j^{th} class, and let $p(X)$ be the probability of occurrence of X , regardless of class.

Let $\omega(i|j)$ be the loss incurred when the classifier puts a feature vector belonging to class j into class i . The average loss incurred would be

$$L_X(i) = \sum_j \omega(i|j) p(j|X) \dots (6)$$

From Bayes' Law, one has

$$p(j|X) = p(X|j) p(j)/p(X) \dots (7)$$

Let us choose for the loss function

$$\omega(i|j) = c(1 - \delta_{ij}) \dots (8)$$

which gives a loss of c units when X is misclassified and a loss of 0 when X is correctly classified.

Upon substitution of (7) and (8) into (6), one obtains

$$L_X(i) = c(p(X) - p(X|i) p(i))/p(X) \quad \dots (9)$$

We want to minimize the loss so to do this we maximize $-L_X(i)$.

Therefore, we choose for the discriminant functions

$$g'_i(X) = (p(X|i)p(i) - p(X))/p(X) \quad \dots (10)$$

$p(X)$ is the same number for each g'_i so it can be dropped. The log function is a monotonic increasing function and therefore one can choose $\log(g'_i)$ for the discriminant functions. The result is

$$g_i(X) = \log(g'_i) = \log(p(i)) + \log(p(X|i)) \quad \dots (11)$$

($p(i)$ is the probability of occurrence of the class i).

Upon substitution of (4) into (11), one obtains

$$g_i(X) = \log(p(i)) - (1/2)\log(|\Sigma_i|) - (1/2) (X - A_i)^T \Sigma_i^{-1} (X - A_i) \dots (12)$$

To determine the class to which an unknown vector X is most likely to belong, one evaluates the functions (12) above and chooses the largest which immediately gives the class.

3.2 CLASSIFICATION RESULTS (MAXIMUM LIKELIHOOD CLASSIFIER (PR20))

The percentages of fields correctly identified using the maximum likelihood classifier (PR20) are presented in Table 3.1. According to Table 3.1, 80% of the corn fields on the Brookston clay soil was correctly identified on June 2, 70% on June 20 and 60% on July 8. Details of how these percentages were arrived at are presented in Appendix D. For example, referring to Appendix D, there were 10 corn fields and 19 soybean fields on the Brookston clay soil. On June 2, 8 of the 10 corn fields were correctly identified by the maximum likelihood classifier thus giving 80% identification accuracy. The 2 remaining corn fields were committed to the soybean fields while 4 soybean fields

Table 3.1

PERCENTAGE OF FIELDS AND ACREAGES IDENTIFIED
OVER DIFFERENT SOIL TYPES

Classifier: Maximum Likelihood (PR20)

	JUNE 2					JUNE 20					JULY 8				
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 1	Site 2	Site 3	Site 4	Site 5	Site 1	Site 2	Site 3	Site 4	Site 5
	Brookston Clay	Beverly Loam	Brookston Silt Loam	Brookston Sandy Loam	Clyde Clay Clyde Loam	Brookston Clay	Beverly Loam	Brookston Silt Loam	Brookston Sandy Loam	Clyde Clay Clyde Loam	Brookston Clay	Beverly Loam	Brookston Silt Loam	Brookston Sandy Loam	Clyde Clay Clyde Loam
% Winter Wheat			86 (88)					86 (88)					86 (88)		
% Corn	80 (76)	91 (97)	35 (30)	100 (100)	62 (70)	70 (73)	55 (54)	59 (51)	25 (15)	52 (64)	60 (73)	73 (76)	76 (74)		66 (72)
% Soybeans	79 (83)		60 (61)	14 (13)	75 (90)	79 (73)		80 (62)	14 (26)	100 (100)	74 (76)		100 (100)		66 (72)
% Field beans		100 (100)	58 (66)				100 (100)	75 (79)				100 (100)	92 (95)		

were committed to the corn fields. On June 20, 7 of the 10 corn fields were correctly identified thus giving 70% identification accuracy. On July 8, only 6 of the 10 corn fields were correctly identified for a 60% identification accuracy. The corresponding acreages correctly identified are indicated in brackets. The acreages were calculated from enlarged colour aerial photographs (1:3000) of the test sites using a Hewlett-Packard 9864A digitizer in combination with a mini-computer, and XY plotter and an acreage calculating sub-routine developed at the Economics Branch of Canada Department of Agriculture, Ottawa.

The percentage of Winter Wheat fields correctly classified for the June 2 data was 86% (88%) over the Brookston Silt Loam. The percentage of corn fields correctly classified over the five test sites for the June 2 data ranges from 35% (30%) on the Brookston Silt Loam to 100% (100%) on the Brookston Sandy Loam. The corresponding figures for the soybean fields ranged from 14% (13%) on the Brookston Sandy Loam to 79% on the Brookston clay (90% on the clyde clay/clyde loam). The corresponding figures for the fieldbean fields ranged from 58% (66%) on the Brookston Silt Loam to 100% (100%) on the Beverly Loam.

The percentage of corn fields correctly classified over the five test sites for the June 20 data ranged from 25% (15%) on the Brookston Sandy Loam to 70% (73%) on the Brookston clay. The corresponding figures for the Soybean fields ranged from 14% (26%) on the Brookston Sandy Loam to 100% (100%) on the clyde clay/clyde loam. The fieldbeans results ranged from 75% (79%) on the Brookston Silt Loam to 100% (100%) on the Beverly Loam. The result for the Winter wheat fields was 86% (88%) on the Brookston Silt Loam.

The percentage of corn fields correctly classified over the three test sites for the July 8 data ranged from 60% on the Brookston clay (72% on the clyde clay/clyde loam) to 76% on the Brookston silt loam (76% on the Beverly loam).

The corresponding figures for the Soybean fields ranged from 66% (72%) on the clyde clay/clyde loam to 100% (100%) on the Brookston Silt Loam.

The corresponding figures for the fieldbean fields ranged from 92% (95%) on the Brookston Silt Loam to 100% (100%) on the Beverly Loam. The result for the Winter Wheat fields was 86% (88%) on the Brookston Silt Loam.

3.3 CLASSIFICATION RESULTS (MINIMUM DISTANCE CLASSIFIER (PR30))

The classification results obtained using the minimum distance classifier are presented in Table 3.2. The percentage of Winter Wheat fields correctly classified over the five test sites for the June 2 data ranged from 64% (69%)¹ on the Brookston Silt Loam to 100% (100%) on the Beverly Loam and the Brookston Sandy Loam.

The corresponding figures for the corn fields ranged from 18% (11%) on the Brookston Silt Loam to 56% on the Brookston Sandy Loam (70% on the Brookston clay).

The corresponding figures for the Soybean fields ranged from 0% (0%) on the Brookston Silt Loam to 71% (77%) on the Brookston Sandy Loam. The corresponding figures for the fieldbeans ranged from 33%

¹ The figures in brackets show the corresponding percentages of acreages correctly classified.

Table 3.2

PERCENTAGE OF FIELDS AND ACREAGES IDENTIFIED OVER
DIFFERENT SOIL TYPES

Classifier: Minimum Distance (PR30)

	JUNE 2					JUNE 20					JULY 8				
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 1	Site 2	Site 3	Site 4	Site 5	Site 1	Site 2	Site 3	Site 4	Site 5
	Brookston Clay	Beverly Loam	Brookston Silt Loam	Brookston Sandy Loam	Clyde Clay Clyde Loam	Brookston Clay	Beverly Loam	Brookston Silt Loam	Brookston Sandy Loam	Clyde Clay Clyde Loam	Brookston Clay	Beverly Loam	Brookston Silt Loam	Brookston Sandy Loam	Clyde Clay Clyde Loam
% Winter Wheat		100 (100)	64 (69)	100 (100)			67 (64)	86 (88)	100 (100)			67 (73)	86 (88)	50 (48)	
% Corn	50 (70)	55 (47)	18 (11)	56 (49)	34 (30)	60 (61)	64 (68)	29 (27)	56 (49)	41 (35)	70 (60)	82 (91)	35 (34)	38 (34)	55 (61)
% Soybeans	63 (60)		0 (0)	71 (77)	38 (36)	58 (60)		80 (64)	71 (77)	50 (66)	63 (62)		83 (87)	71 (62)	63 (62)
% Field beans		33 (47)	57 (67)				0 (0)	67 (54)				83 (89)	83 (87)		
% Oats	100 (100)	100 (100)				75 (80)	67 (73)				75 (76)	100 (100)			

THE FIGURES IN BRACKETS ARE ACREAGES.

(47%) on the Beverly loam to 56% (67%) on the Brookston Silt Loam. Only one site had enough oat fields for the classification to be made and the result showed 100% (100%) identification on the Beverly Loam.

The percentage of Winter wheat fields correctly classified over the five test sites for the June 20 data ranged from 67% (64%) on the Beverly Loam to 100% (100%) on the Brookston Sandy Loam. The corresponding figures for the corn fields ranged from 29% (27%) on the Brookston Silt Loam to 64% (68%) on the Beverly Loam.

The corresponding figures for the Soybean fields ranged from 50% (36%) on the clyde clay/clyde loam (60% on the Brookston clay) to 80% on the Brookston Silt Loam (77% on the Brookston Sandy Loam). The corresponding figures for the fieldbeans 0% (0%) on the Beverly Loam to 67% (54%) on the Brookston Silt Loam. The result for the oat fields showed 67% (73%) on the Beverly Loam.

The percentage of Winter Wheat fields correctly classified over the five test sites for the July 8 data ranged from 50% (48%) on the Brookston Sandy Loam to 86% (88%) on the Brookston Silt Loam.

The corresponding figures for the corn fields ranged from 35% (34%) on the Brookston Silt Loam to 82% (91%) on the Beverly Loam.

The corresponding figures for the Soybeans ranged from 63% (62%) on the Brookston clay and clyde clay/clyde loam to 83% (87%) on the Brookston Silt Loam.

The corresponding figures for the fieldbeans ranged from 83% (87%) on the Brookston Silt Loam to 83% (87%) on the Brookston Silt Loam.

The corresponding figures for the fieldbeans ranged from 83%

(87%) on the Brookston Silt Loam to 83% (89%) on the Beverly Loam.

The result for the oat fields showed 100% (100%) on the Beverly Loam.

3.4 SOIL EFFECTS OF CROP IDENTIFICATION

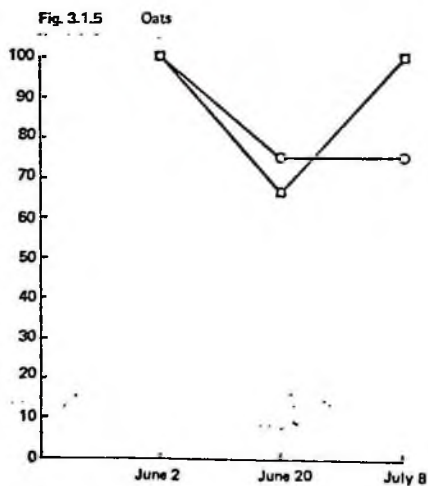
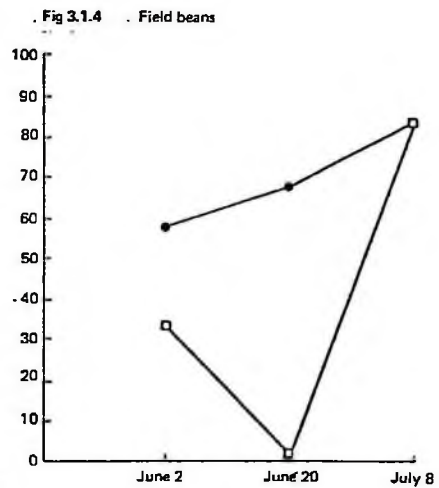
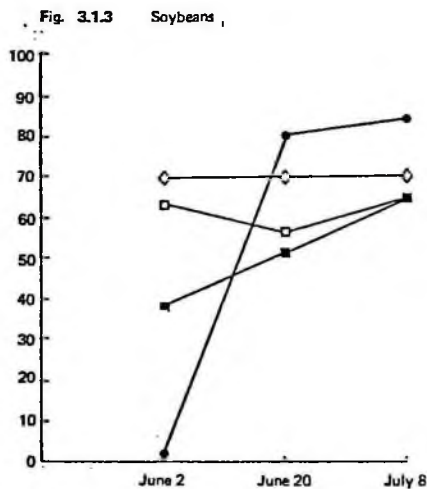
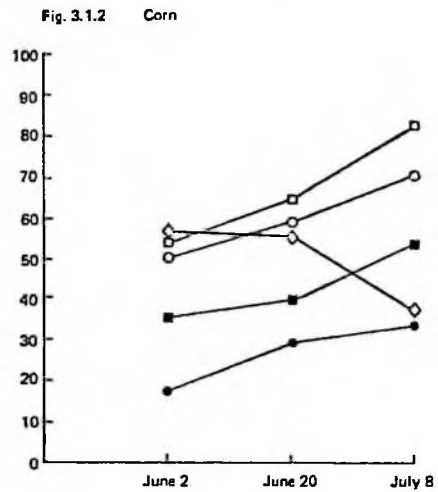
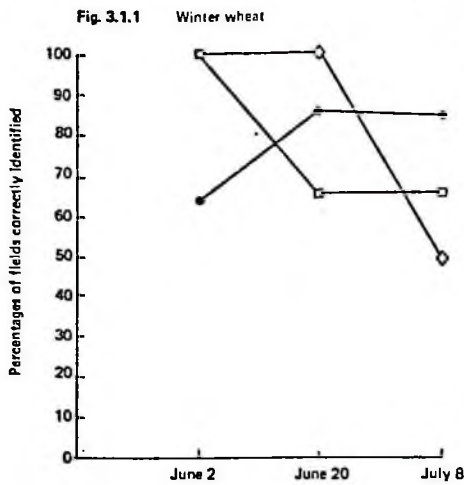
Minimum distance classifier (PR30)

The term soil effect - for the purposes of this study - is defined as the variation of crop identification accuracy for a given crop over different soil types. The variation is defined for a given date (say June 2, June 20 or July 8 ERTS-1 flyover dates) (see Table 3.2).

The soil effects of the Winter Wheat fields are presented in Figure 3.1.1. The results showed that there were no differences between the crop identification accuracy results obtained for the winter wheat fields over the Brookston Sandy Loam and the Beverly Loam soils for the June 2 date. There were significant differences between the results obtained over the Brookston silt loam, the Beverly loam and the Brookston sandy loam soils for the June 20 and July 8 dates. The highest identification result (100%) was achieved over the Beverly loam and the Brookston Sandy loam on June 2 and again on June 20 over the Brookston sandy loam.

The soil effects of the corn fields are given in Figure 3.1.2. The results showed that the crop identification accuracies for the corn fields were dissimilar over the Beverly loam, Brookston sandy loam and the Brookston clay soils for the June 2 and June 20 dates. Only the results over the Brookston sandy loam and the Brookston silt loam soils were similar. The best identification result (82%) was achieved over the

Fig. 3.1 Soil effects of crop identification (minimum distance classifier (PR 30))



- Beverly loam
- Brookston clay
- Brookston silt loam
- ◇— Brookston sandy loam
- Clyde clay/clyde loam

Beverly loam on July 8.

The soil effects of the soil soybean fields are given in Figure 3.1.3. The identification accuracy results were similar over the clyde clay/clyde loam and the Brookston clay soils for the June 20 date.

The soil effects of the fieldbean fields are given in Figure 3.1.4. The results were similar over the Beverly loam and the Brookston silt loam soils on July 8. The highest accuracy (80%) was achieved on July 8 over the Beverly loam and the Brookston silt loam.

The results of the oat fields are presented in Figure 3.1.5. The results were the same (100%) over the Beverly loam and the Brookston clay soils for the June 2 date. The highest accuracy (100%) was achieved on July 8 over the Beverly loam.

3.5 SOIL EFFECTS OF CROP IDENTIFICATION

Maximum likelihood classifier (PR20)

The soil effects for corn using the maximum likelihood classifier are presented in Figure 3.2.1. The results for the June 2 date were widely scattered (35% on the Brookston silt loam, 100% on the Brookston sandy loam). However, the results for the June 20 date were quite similar over the Brookston silt loam (58%), the Beverly loam (55%), and the clyde clay/clyde loam (53%). The highest accuracy result (100%) was achieved over the Brookston Sandy loam on June 2 (see Table 3.1).

The soil effects of the soybean fields are presented in Figure 3.2.2. The June 2 results were similar over the Brookston clay (79%) and over the clyde clay/clyde loam (75%) on June 2. On June 20, the results were similar over the Brookston silt loam (81%) and over the Brookston clay (79%). The results for the July 8 were quite scattered

Fig. 3.2 Soil effects of crop identification (maximum likelihood classifier (PR 20))

Fig. 3.2.1 Corn

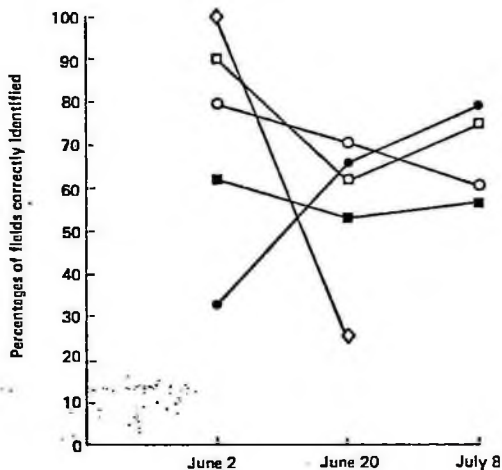


Fig. 3.2.3 Field beans

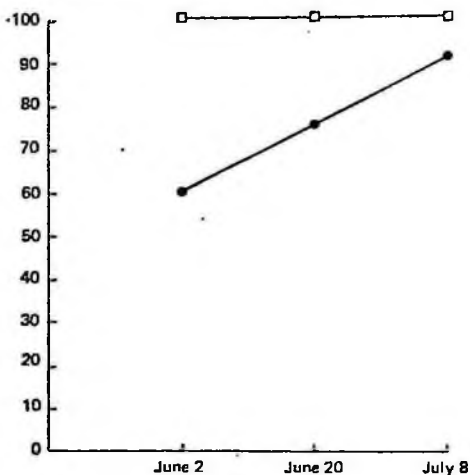
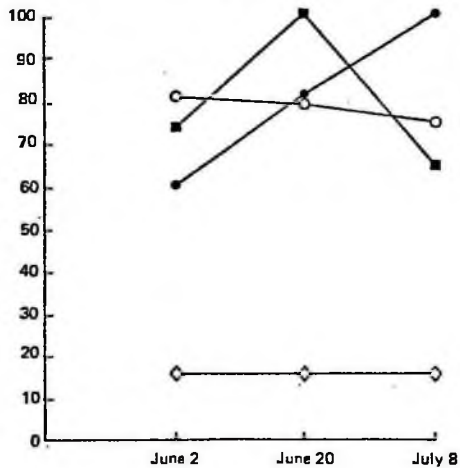


Fig. 3.2.2 Soybeans



- Brookston clay
- Beverly loam
- △— Brookston silt loam
- ◇— Brookston sandy loam
- Clyde clay/Clyde loam

over the Brookston silt loam (100%), the Brookston clay (77%), and clyde clay/clyde loam (63%). The highest accuracy (100%) was achieved over the clyde clay/clyde loam on June 20.

The soil effects of the field bean fields are given in Figure 3.2.3. The identification results were similar over the Beverly loam (100%) and the Brookston silt loam (92%) on July 8. The highest accuracy (100%) was achieved over the Beverly loam soil for the June 2, June 20 and the July 8 dates.

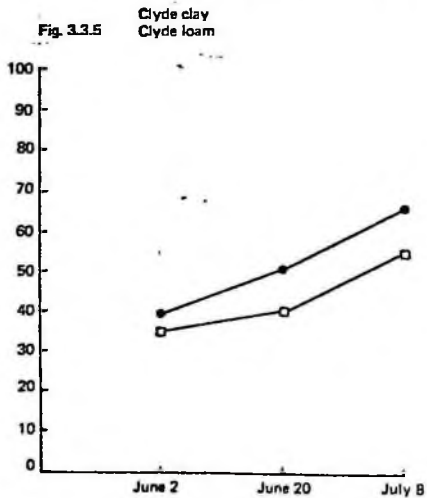
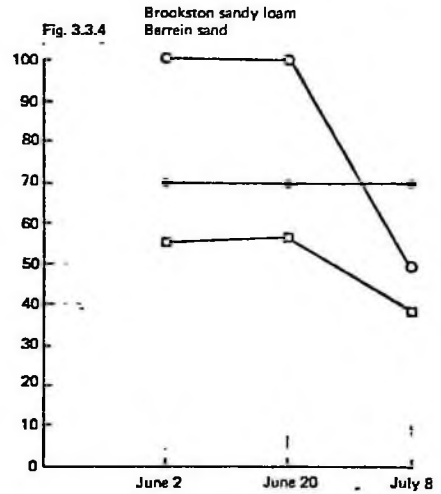
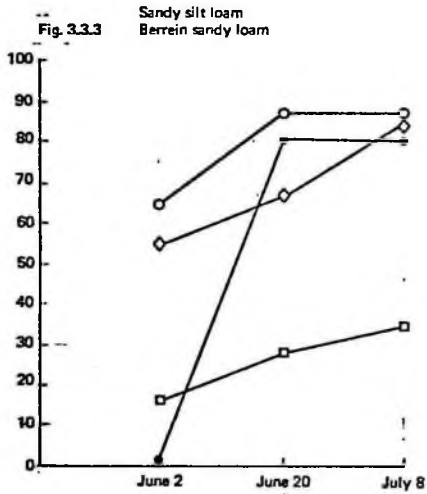
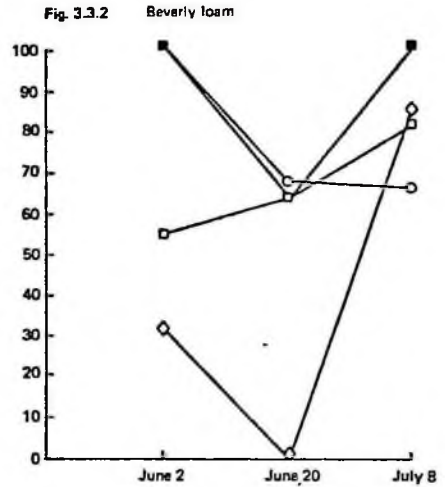
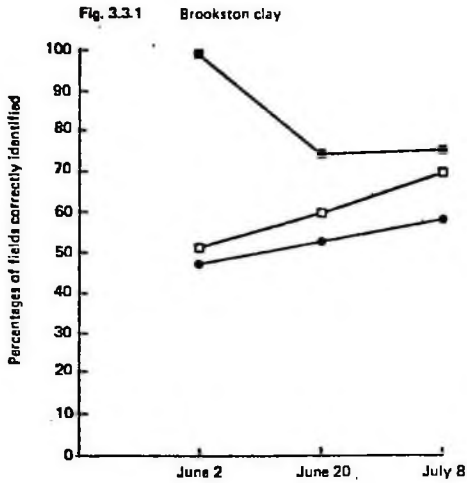
3.6 TIME EFFECTS OF CROP IDENTIFICATION

Minimum distance classifier (PR30)

The term time effect of crop identification - for the purposes of this study - is defined as the variation of crop identification accuracies, over a given soil type, with respect to time [see Table 3.3].

The results of the time effects of crop identification over the Brookston clay soil are presented in Figure 3.3.1. The results indicated that the time effects were similar for the corn and soybean fields (50% and 47% respectively) but significantly different for the oat fields (100%) on June 2. The highest identification accuracies for the corn and soybean fields (67% and 58% respectively) were obtained on July 8 while the highest accuracy for the oat fields (100%) was achieved on June 2.

The time effects of the oats, corn, winter wheat and the field bean fields are presented in Figure 3.3.2. The results were the same for the oats and winter wheat fields (100%) on June 2. The results for the oats, corn and winter wheat fields for the June 20 dates were very



- Winter wheat
- Corn
- Soybeans
- ◇ Field beans
- Oats

similar (67%, 64% and 64% respectively) for the June 20 date while the results for the corn and fieldbean fields were the same (85%) for the July 8 date. The other results were substantially different from each other. The highest identification accuracy result (100%) for the oat fields occurred on June 2 and July 8. Those of corn (85%) and field beans (83%) occurred on July 8 while that of winter wheat (100%) occurred on June 2.

The time effects of the winter wheat, fieldbean, soybean, and corn fields over the Brookston silt loam are presented in Figure 3.3.3. The results of the winter wheat, fieldbean and soybean fields were similar for the July 8 date (86%, 83% and 80% respectively). These results were also the highest identification achieved for the three crops. The highest accuracy for corn (35%) occurred on July 8.

The time effects of the winter wheat, soybean and corn fields over the Brookston sandy loam are presented in Figure 3.3.4. The results for the soybean, winter wheat and corn were substantially different for all the three dates. The highest identification accuracy result for the winter wheat fields (100%) occurred on June 2 and June 20 while that of the soybean fields (75%) occurred on all the three dates. The highest accuracy for the corn fields (56%) occurred on June 2 and June 20.

The time effects of the corn and soybean fields over the clyde clay/clyde loam are presented in Figure 3.3.5. The highest identification accuracy results for the soybean and corn fields occurred on July 8 (63% and 58% respectively).

3.7 TIME EFFECTS OF CROP IDENTIFICATION

Maximum likelihood classifier (PR20)

The time effects of crop identification, using the maximum likelihood classifier, for the corn and soybean fields over the Brookston clay soil are presented in Figure 3.4.1. The accuracy results for the June 2 date were very similar for the corn and soybean fields (80% and 79% respectively). The June 2 results were the highest accuracies achieved for the corn and soybean fields. The difference between the two results became progressively larger with time. (see Table 3.4)

The time effects of the corn and fieldbean fields over the Beverly loam are presented in Figure 3.4.2. The results were most similar for the June 2 date (92% and 100% respectively) and most dissimilar for the June 20 date (55% and 100% respectively). The highest accuracy result for the corn fields was achieved on June 2 (92%) while that of the fieldbean fields (100%) was achieved on all the three dates (June 2, June 20 and July 8).

The time effects of the soybean, fieldbean, winter wheat and corn fields over the Brookston silt loam are presented in Figure 3.4.3. The results for the June 2 date were similar for the corn and soybean fields (58% and 60% respectively) with the differences increasing with time. The highest accuracy results for all the crops were achieved on July 8 except the winter wheat fields which had similar results for the other two dates (June 2 and June 20).

The time effects of the corn and soybean fields over the Brookston Sandy loam soil are presented in Figure 3.4.4. The highest accuracy result for the corn fields (100%) was achieved on June 2. The time effects of the corn and soybean fields over the clyde clay/ clyde loam are presented in Fig. 3.4.5. The highest accuracy for the

Fig. 3.4.1 Brookston clay

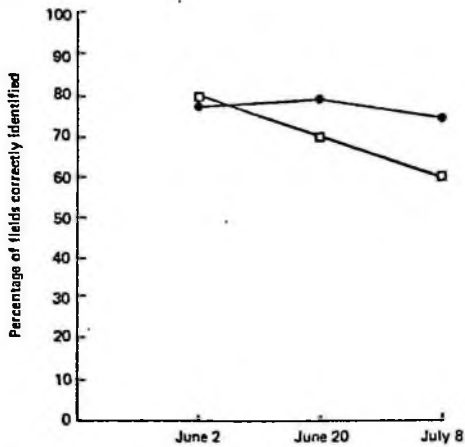


Fig. 3.4.2 Beverly loam

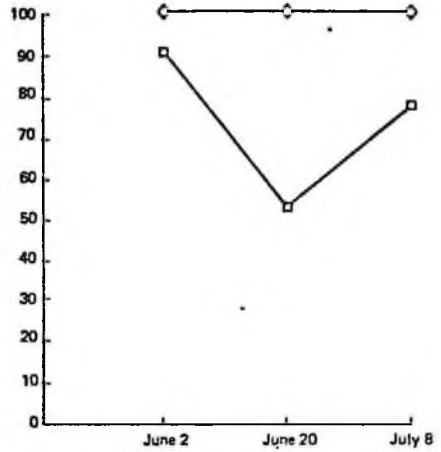


Fig. 3.4.3 Brookston silt loam
Berrein sandy loam

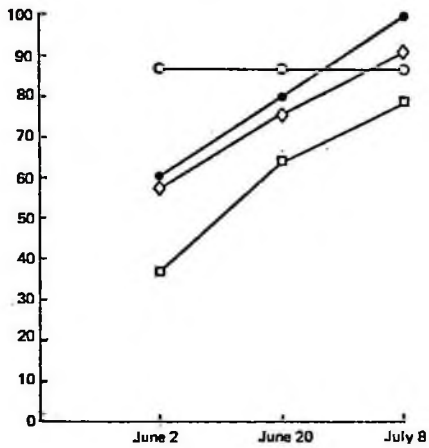


Fig. 3.4.4 Brookston sandy loam
Berrein sand

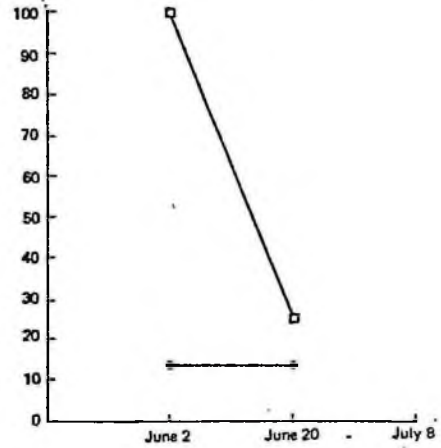


Fig. 3.4.5 Clyde clay
Clyde loam

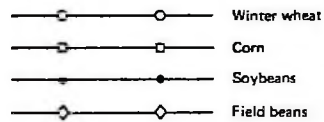
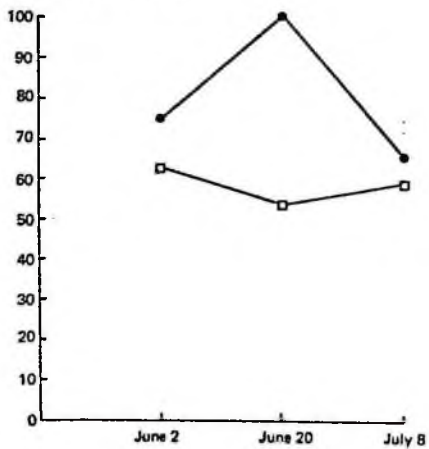


Table 3.4 PERCENTAGE OF CROPS IDENTIFIED OVER DIFFERENT SOIL TYPES AT DIFFERENT TIMES
USING THE MAXIMUM LIKELIHOOD CLASSIFIER (PR20)

	SOIL TYPE														
	Brookston Clay			Beverly Loam			Brookston Silt Loam, Berrein Sandy Loam			Brookston Sandy Loam Berrein Sand			Clyde Clay Clyde Loam		
	SITE 1			SITE 2			SITE 3			SITE 4			SITE 5		
	ERTS - 1			ERTS - 1			ERTS - 1			ERTS - 1			ERTS - 1		
	June 2	June 20	July 8	June 2	June 20	July 8	June 2	June 20	July 8	June 2	June 20	July 8	June 2	June 20	July 8
% Winter Wheat	-	-	-	-	-	-	86	86	86	-	-	-	-	-	-
% Corn	80	70	60	91	55	73	35	59	76	100	25	-	62	52	55
% Soybeans	79	79	74	-	-	-	60	80	100	14	14	-	75	100	63
% Fieldbeans	-	-	-	100	100	100	58	75	92	-	-	-	-	-	-
% Oats	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

corn fields (63%) was achieved on June 2 while the highest accuracy for the soybean fields (100%) was achieved on June 20.

3.8 COMBINED SOIL AND TIME EFFECTS

A summary of the combined effects of soils and time on the accuracy of crop identification in Southwestern Ontario using the Canadian Centre for Remote Sensing (CCRS) Wheat Project Image Processing System (WPIPS) are presented in Table 3.5.

The highest identification accuracy for the corn fields (100%), using the maximum likelihood classifier (PR20), was achieved on June 2 date on the Brookston Sandy loam.

The corresponding accuracy for the soybean fields (100%) was achieved on June 20 and July 8 on the clyde clay/clyde loam and the Brookston silt loam respectively.

The corresponding accuracy for the fieldbean fields (100%) was achieved on June 2, June 20 and July 8 over the Beverly loam.

The corresponding accuracy for the winter wheat fields (86%) was achieved on June 2, June 20 and July 8 on the Brookston silt loam.

None of the highest identification accuracy results for the corn, soybean, fieldbean and winter wheat fields occurred on the Brookston clay soil, one occurred on the Beverly loam, one on the Brookston sandy loam, one on the clyde clay/clyde loam and two on the Brookston silt loam.

The highest identification accuracy for the corn fields (82%) using the minimum distance classifier (PR30) was achieved on the Beverly loam soil on July 8.

Table 3.5 SUMMARY OF THE EFFECTS OF SOILS AND TIME ON THE ACCURACY OF CROP IDENTIFICATION
IN SOUTHWESTERN ONTARIO USING THE WHEAT PROJECT IMAGE PROCESSING SYSTEM, CCRS, OTTAWA

Classifier	Maximum Likelihood (PR20)			Minimum Distance (PR30)		
	Highest Accuracy Achieved	Time of Achievement	Soil Type	Highest Accuracy Achieved	Time of Achievement	Soil Type
Corn	100%	June 2	Brookston Sandy loam	82%	July 8	Beverly loam
Soybeans	100%	June 20 July 8	Clyde clay/ Clyde loam Brookston Silt loam	80%	June 20 July 8	Brookston Silt loam
Fieldbeans	100%	June 2 June 20 July 8	Beverly loam	83%	July 8	Beverly loam Brookston Silt loam
Winter wheat	86%	June 2 June 20 July 8	Brookston Silt loam	100%	June 2 June 20	Beverly loam Brookston Sandy loam
Oats				100%	June 2	Brookston clay Beverly loam

The corresponding accuracy for the soybean fields (80%) occurred on the Brookston silt loam on June 20 and July 8.

The corresponding accuracy for the winter wheat fields (100%) was achieved on the Beverly loam and the Brookston sandy loam soils on June 2 and June 20.

The corresponding accuracy for the oat fields (100%) was achieved on the Brookston clay and the Beverly loam on June 2 and July 8.

None of the highest identification accuracy results for the corn, soybean, fieldbean, winter wheat and the oat fields occurred on the clyde clay/clyde loam soils, one occurred on the Brookston clay and the Brookston sandy loam soils, two on the Brookston silt loam and four on the Beverly loam.

Chapter IV

SUMMARY

4.0 SUMMARY AND CONCLUSIONS

Many people concerned with the world's food supply situation think that there is an urgent need, especially in the developing countries, to improve the world's food intelligence systems. On a worldwide basis, it would appear that the principal obstacles that hinder providing enough food for the world are those of allocation and distribution. Early knowledge of how much food is being produced and how crop distributions are changing with time could provide valuable information for dealing with the world's food problem. One of the many promising techniques that can be put to use to provide such information is remote sensing from satellites.

If one considers the great present need for regional, national and worldwide agricultural resource inventory, and data evaluation, coupled with the capabilities of existing and proposed satellite remote sensing systems, it becomes apparent that agricultural applications are particularly promising as areas in which important benefits might be realised by both exporters and importers of agricultural products. In spite of potential benefits such as more timely data, more accurate data, more consistent data, new information, or even the provision of the same agricultural information being used now but at a lower cost, there are several problems to be solved before remote sensing from satellite can be applied routinely and universally.

One of the problems to be solved is that of extrapolating experimental results to cover whole localities when using digital ERTS-1 data. The economic implications of the extrapolation question are obvious since if crop identification accuracy results cannot be extrapolated from test sites for lack of knowledge of how it can or should be done, any acreage or yield estimates become essentially limited to the test sites in question, a situation which is not ideal to agricultural application.

Two of the important factors involved in the extrapolation question are the effects different soil types and time have on the accuracy of crop identification when using digital ERTS-1 data. This study dealt with these effects by analysing three ERTS-1 imagery over Chatham-Harwich Townships, S.W. Ontario. The main objective of the study was:

- To investigate the effects of different soil types and time on the accuracy of crop identification in S.W. Ontario by analysing 1974 digital ERTS-1 data supplemented by airborne data.

Starting with a tentative hypothesis that there are no significant differences between crop identification accuracy results obtained for crop located on different soil types, five test sites, containing eight different soil types, were established in the Chatham-Harwich Townships, Kent County, S.W. Ontario. The area of study was approximately 28 miles by 10 miles with uniform climatic conditions. Because of the uniformity of the climatic conditions over the study area, only the different soil types and time were taken as endogenous variables in the analysis. ERTS-1 imagery for three dates, June 2, June 20

and July 8, 1974 were analysed using the Canadian Centre for Remote Sensing (CCRS) Wheat Project Image Processing System. The results of the analysis indicated that different soil types significantly affect the crop identification accuracy results obtained for different crops thus contradicting the tentative hypothesis that there are no significant differences between crop identification results obtained for crops located on different soil types.

The key word *significant* was not rigorously defined in the study because of the many factors that appear to influence identification accuracies. For the word significant to be rigorously defined, there should be, among other things, the same types of crops growing at each site so that the identification will involve the separation of the same types of crops on each of the soils. Since this was not the case in the study (see Table 2.5) differences in identification accuracy results could have been partly owing to identifications involving different crops. For example, identification at site 1 involved the separation of corn from soybeans, at site 2 the separation involved corn and fieldbeans, at site 3, the separation was between winter wheat, corn, soybeans and fieldbeans and at sites 4 and 5, the separation was between corn and soybeans (see Table 3.1). Nevertheless, it was felt that a variation of 10% or more in the identification accuracies achieved for a particular crop over the five test site was significant.

By this criterion, the 100% identification accuracy achieved for corn over the Brookston Sandy loam on June 2 (see Table 3.1) was judged to be significantly different from the 80% obtained over the Brookston clay, 35% over the Brookston silt loam and the 62% over the

clayde clay/clayde loam but not significantly different from the 91% obtained over the Beverly loam.

It has been suggested that perhaps the important factors that determine variations in crop identification accuracies are the growth stage of the crop rather than soil types. A look at Tables 2.7 and 3.1 indicates that this may not be so. For example, the 70% accuracy achieved for corn on June 20 over the Brookston clay soil occurred when the growth stage over the Brookston clay was 1, 2, or 3 leaves showing (03), the plant height varied between 3" to 12", and the percentage ground cover varied between 1% to 20%. The corresponding figures over the Beverly loam were 1, 2 or 3 leaves showing (03), 6" to 14" and 5% to 25% yet the classification accuracy was only 55%; 1, 2, or 3 leaves showing (03), 4" to 14" and 5% to 30% over the Brookston silt loam (59%); 1, 2, or 3 leaves showing (03); 5" to 14" and 3% to 40% over the Brookston sandy loam (25%); and 1, 2, or 3 leaves showing (03), 6" to 14" and 3% to 30% (52%). Again the 14% to 100% identification accuracy results obtained for the soybean fields on June 20 occurred when the growth stages, plant heights and the percentage ground coverage were very similar (see Table 2.7).

The evidence from this study tends to support the idea that different soil types affect the classification accuracy results differently when using ERTS-1 digital data even though no generalization can be made from this study.

4.1 THE NEED FOR FURTHER STUDIES

It would be fair to assume that one of the aims of those who

advocate the use of satellite remote sensing in agriculture is to increase the accuracy and reduce the time element in the estimation of crop yields and to thereby reduce costs more than is now possible using conventional data gathering and analysis methods. To fulfill this aim, several goals, such as: -

1) increasing the accuracy of crop acreage measurement through remote sensing;

2) decreasing the time required to estimate crop acreages through remote sensing;

3) comparing the costs of estimating crop acreages/yields using remote sensing with costs using conventional methods; and

4) ascertaining how crop acreage/yield estimates obtained using remote sensing should be used to provide statistical sample and data required by agriculture, should be achieved.

The objective of the study was designed to contribute towards the achievement of the fourth goal by increasing the present knowledge of how soils and time affect crop identification accuracies obtained when using digital ERTS-1 imagery. Further studies are necessary to develop crop identification calendar for S.W. Ontario and other parts of the country and to develop other classifiers to improve the present crop identification accuracies obtained. The classifiers used by the CCRS Wheat Project Image Processing System are the Minimum Distance Classifier (PR30) and the Maximum Likelihood Classifier (PR20) (see Section 3.1). The basis of crop identification used by these two classifiers is the average feature vector X . The average feature vector

X is the average of the set of four numbers representing the intensities of radiation received from each pixel - by the satellite for each of the 4 ERTS-1 radiation bands. Even though the present classifiers appear to give high accuracies, it may be necessary to incorporate additional parameters, such as, soil types, plant height, plant growth stage, and percentage foliage cover, etc. to improve the present classification accuracies achieved. In order to investigate the possibility of incorporating some of the above parameters in future classifiers, a regression of the average feature vector X, for the 213 fields studied, on soil type, soil class, plant height, plant growth stage, intensity of the sun's radiation and percentage foliage cover was constructed using SPSS regression model.

The results of the regression are presented in Appendix F. While the overall regression results are disappointing (see Appendix F, Table A) the results nevertheless point out some interesting things. In the first place, the highest R^2 obtained was 0.69 which means that at best only about 70% of the variations in the average signal levels can be explained by crop type, percentage ground cover, plant height, sun radiation, soil type, soil class, and plant growth stage. Of these parameters, the most important explanatory variables as determined by their F values were sun radiation, (386.70), soil type (27.87) and ground cover (26.82). Plant growth stage, plant height, and crop types were not significant explanatory variables of the variations in the average signal levels. A second regression involving the average signal levels and sun radiation, crop type and soil type was run after eliminating the unimportant parameters from the first regression. The

results of the second regression are presented in Appendix F, Table B.

Again the highest R^2 obtained was 0.656, the most important explanatory variable for the variations in the average signal levels were sun radiation (637.68), followed by soil type (105.06) followed by crop type (31.55). The results tend to indicate that average signal levels may not be the most important parameters for separating crop types because crop types have little effects on the variations in the average signal levels.

Soil type was consistently significant (as determined by the F values) for all the results obtained thus supporting the hypothesis that soil types significantly affect the crop identification accuracy results obtained when using the maximum likelihood and the minimum distance classifier whose basis of classification are the average signal levels. The strong influence of soil types is not surprising since even though the reflectance of a plant canopy is similar to that of a leaf, it is modified by the non-uniformity of incident solar radiation, plant structures, leaf areas, shadows and background reflectivities (coming mainly from soils). The radiation received by airborne and space sensors are the integrated view of all these effects and not just the radiation from the plant canopy. This underlies the need for other classifiers based either on the individual infrared bands (6 and 7) or their ratios and summations.

4.2 THE FUTURE OF SATELLITE REMOTE SENSING IN WORLD AGRICULTURE

It would normally appear wrong to discuss the future of satellite remote sensing in world agriculture as a result of such a limited

study because such a discussion will not be based on all the available information. In the first place, the method of analysis used in this study is only one of several methods currently available and therefore the results do not necessarily represent the overall capabilities of the system. However, in this particular instance, some sort of speculative views are called for because of the urgency of the world food situation.

I do not believe that remote sensing from space platforms should be considered as a substitute for on-the-ground and airborne resource surveys. On the contrary, I see remote sensing from space platforms as being complementary to the conventional methods of resource surveys. I can foresee, in the near future, the setting up of an international body responsible for providing synoptic views of all agricultural lands throughout the world and advising the nations concerned where to concentrate their efforts. I think it would be tragic if each nation decides to do it alone not because it can't be done but because of the economic wastes that will ensue. As to the usefulness of remote sensing from space platforms to agriculture I think two and a half years of using such a complex system are too short to make any critical assessment. Only time will tell.

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APPENDIX A

Country and Responsible Agency	Type of Statistics	Information Collected	Methodology	Frequency
<u>EGYPT, A.R.</u>				
Ministry of Agriculture	Yield statistics	Yield of all crops	Estimates by the agricultural staff by means of enquiry to the farmers and by eye estimate	Annual
		Yield of 8 principal crops incl. paddy, wheat, maize, potatoes.	Crop cutting sample surveys.	Annual
	Livestock numbers	Livestock numbers by sex + age.	Complete enumeration census.	every 2 years
<u>IRAQ</u>				
Central Statistical Organization, Ministry of Planning	Statistics of area and yield	Area and yield of wheat, barley paddy and cotton, sesame.	Sample survey - crop cutting experiment to estimate average yield. Production was obtained by multiplying yield by harvested area.	Annual
	Livestock Survey	Numbers of different kinds of livestock.	Sample survey of livestock holdings and numbers of livestock in cities and towns obtained by enquiry.	1971
<u>KUWAIT</u>				
Central Office of Statistics		A programme of current agricultural statistics is proposed.		
<u>LYBIA</u>				
Agricultural Statistics and Marketing Division, Dept. of Planning and Agric. Economics, Min. of Agric. and Agrarian Reform	Area, production and livestock numbers	Area harvested, production and yield of wheat, barley, maize. Production of potatoes, dry onions, groundnuts and tomatoes. Number of fruit trees; number of sheep, goats, cattle, camels, horses, mules, donkeys, poultry.	Estimates based on: data obtained from an enquiry conducted in 1964/65, information supplied annually by local authorities and farmers.	Annual

GHANA

Division of Economics and Marketing,
Ministry of Agric.

Current agric. statistics

Holding characteristics, machinery, fertilizer use, land production, livestock numbers, farm population.

Livestock

Livestock number by species, sex, age.

GUINEA

Agric. Statistics Section, Ministry of Planning, Statistical Dept.

Census of Agriculture

Usual programme incl. crop production and livestock number.

KENYA

Ministry of Economic Planning and Statistics Division

Production statistics

Production sold.

Production for home consumption.

Livestock

Livestock numbers.

LESOTHO

Bureau of Statistics

Area and production statistics

Land use and crop yields.

Livestock

Livestock number.

Sample surveys of small scale holdings and complete enumeration of large and specialized holdings. Interview and objective measurement.	Annual
Census	Annual
Sample census of agriculture,	1970
Data on production are supplied by various marketing boards and in some cases estimates made mostly on results of the farm sample census or from other sources.	Annual
Estimates of crop production for home consumption were made on the basis of a sample survey in 1957 and are brought up-to-date every year.	Annual
Data collected during the annual census of agriculture.	Annual
Eye estimates made by the staff of the Agriculture Department.	Annual
Estimates made by the staff of the Agriculture Department.	Annual

Country and Responsible Agency	Type of Statistics	Information Collected
<u>LIBERIA</u>		
Bureau of Statistics Dept. of Planning and Economic Affairs	Agricultural survey	Population, agricultural workers, land utilization, crop area, livestock and poultry numbers.
<u>AUSTRIA</u>		
Austrian Central Statistical Office	Crop yields	Yield of winter wheat
	Livestock numbers	Number of horses, cattle, pigs, sheep, poultry, geese, ducks
	Livestock numbers	Pig numbers and slaughterings.
<u>BELGIUM</u>		
National Institute of Statistics	Livestock	Livestock numbers and other agricultural information. Pig numbers.
	Production	Cereal yield and production.

Methodology	Frequency
Survey on sample basis carried out in different regions during the years. Objective methods.	1967/68/ 69
Random sample surveys covering about 300 farms. Objective method.	Annual
Livestock census on complete enumeration basis. Interview method. Every 5 years particular information on livestock and livestock owners is collected with the General Livestock Census.	Annual (3 Dec.)
Sample survey.	Quarterly (3 Dec. 29 March 3 June 3 Sept.)
Census by interview.	Biannual (May-Dec.)
Sample survey by interview. Sample covering all holders in 10% of communes.	Biannual (April-August)
Estimates of yield by the Agricultural Correspondents of the NIS. Production is obtained by multiplying area by yield.	Annual

<u>Country and Responsible Agency</u>	<u>Type of Statistics</u>	<u>Information Collected</u>
<u>BULGARIA</u>		
National Statistical Office	Production statistics	Average yields of wheat.
	Livestock	Livestock by kind, age, and sex.

Source: Unknown

Methodology**Frequency**

Estimates for 25 crops are made by communal council. Production is estimated by multiplying yield by area.

Sept. Dec.
April of
following
year.

Census of livestock.

Annual
1 Jan.

APPENDIX B

A: DIGITAL ERTS-1 DATA¹

As the ERTS-1 satellite moves overhead electromagnetic energy from the surface of the earth is reflected by an oscillating mirror on the satellite into a set of 24 sensors. These sensors form an array which may be pictured schematically as a set of 4 columns, of 6 sensors each, with 1 column for each ERTS-1 band (see below).

		Sensors for					
		Band 4	Band 5	Band 6	Band 7		
		0	0	0	0	Line 1	
		0	0	0	0	Line 2	
WEST		0	0	0	0	Line 3	EAST
		0	0	0	0	Line 4	
		0	0	0	0	Line 5	
		0	0	0	0	Line 6	

Direction of Satellite motion

The instantaneous view which each sensor has of the ground is a square of approximately 255 feet by 255 feet in area.

The 6 sensors in a given band view collinear and contiguous resolution elements. Thus the set of 6 sensors in a given column views instantaneously a strip approximately 1530 feet by 255 feet.

The region on the ground viewed by the sensors in a given band in one sweep of mirror from West to East is called a swath. It is about 1500 feet (6 times 255) wide and 114 miles long. That region within a swath which is viewed by a single sensor is called a line.

¹ Source: Peet, F.G., "A Guide to the Use of Digital ERTS-1 Data", March 1, 1974, CCRS, Ottawa, Canada.

The swaths do not lie perpendicular to the ground-track of the satellite because while the mirror is scanning the satellite is moving and the earth is rotating. The velocity of the satellite is such that when the mirror has returned to its starting point and is ready to begin the next sweep, there is no gap and no overlap between swaths. On an ERTS-1 photo there are on average 381 swaths or 2286 lines or 125 lines/cm on a $9\frac{1}{2}$ " x $9\frac{1}{2}$ " image.

Each of the sensors is said to measure the intensity of the energy it receives from the earth and produces an output signal. This signal is sampled on average 3206 times in one line by the satellite electronics. The region on the ground for which the intensity is measured and recorded is called a pixel, which is an acronym for picture element. Because 3206 times 255 feet is greater than 114 miles the pixels overlap. All 3206 pixels though are represented on an ERTS-1 photo which results in approximately 174 pixels/cm on a $9\frac{1}{2}$ inch format image.

The numbers obtained as a result of the sampling procedure are referred to as pixel values. These values range between 0 and 63: 0 meaning that little energy has been received from the earth.

Because of the geometry of the situation, sensors in two different bands do not view the same region on the ground simultaneously. In fact, in a given line, pixel 7 of band 7 correspond to pixel 5 of band 6, to pixel 3 of band 5, and pixel 1 of band 4. However, it is easy to bring these sensors into correspondence (radiometric correction) so that it is usually assumed that the sensors for each band view the same region of the earth. Thus for each pixel there is a set of 4 numbers representing

the intensities of each of the 4 bands. These numbers for areas under Canadian jurisdiction are transmitted by the satellite to the receiving station at Prince Albert and recorded on magnetic tape. This tape is shipped to Ottawa and from it, 2 products are made:

- 1) ERTS-1 photos
- 2) Magnetic tapes called 'computer compatible tapes' or CCTS which contain the pixel values for 400 swaths or 2400 lines (compared with 2286 lines on ERTS-1 photos).

The tapes are ordered by ERTS-1 frame numbers on ERTS-1 order forms, and the data obtained corresponds to that represented by the specified ERTS-1 frame.

It is product 2) which is called digital ERTS-1 data.

The digital ERTS-1 data is of use because:

- 1) it contains more information than is contained in the ERTS-1 photos since information is lost in the photographic process;
- 2) it lends itself to automatic methods of interpretation.

B: LOCATING SUB-REGIONS WITHIN A SITE ON A CCT¹

In most instances one is interested in sub-regions (fields) within a site. Since it is seldom possible to discern the boundaries of the fields on the computer map itself some other technique is required. If one has an aerial photograph of the site on which the field boundaries are well defined the following method can be used to accurately locate the fields on the computer map or CCT.

1) Check to see if parallel lines on the aerial photo are parallel on the computer map. If lines parallel on one are parallel on the other (necessary and sufficient conditions), the following mathematical transformation, called an Affine Transformation, may be used to transform the geometry of the aerial photo into the geometry of the computer map or into the geometry of the CCT. The transformation works this way:

$$\begin{aligned}\text{Let } X &= a_1U + b_1V + C_1 \\ Y &= a_2U + b_2V + C_2 \quad \dots \quad (1)\end{aligned}$$

where X and Y are the coordinates of the computer map or the CCT and U and V are the coordinates of the aerial photo.

At least 3 points, called control points, are located on both the aerial photograph and the computer map. The more such points one locates, the better, though 8 such points have been found to be adequate. In the wheat project at CCRS, for example, road intersections are often used as control points.

¹ Source: Peet, F.G., "A Guide to the Use of Digital ERTS-1 Data," March 1, 1974, CCRS, Ottawa, Canada.

3) The coordinates of the control points (they are just the line and pixel numbers) are located on the computer map.

The U and V coordinates of the control points on the aerial photograph are determined with respect to some convenient coordinate system such as the number of inches from the left edge of the photo and the number of inches from the bottom of the photo.

4) The method of least square is then used to estimate the parameters a_1 , b_1 , c_1 , a_2 , b_2 , c_2 in equation (1). One then has the following system of equations to solve to obtain a_1 , b_1 and c_1 :

$$\begin{aligned}\sum X_i U_i &= a_1 \sum U_i U_i + b_1 \sum V_i U_i + c_1 \sum U_i \\ \sum X_i V_i &= a_1 \sum U_i V_i + b_1 \sum V_i V_i + c_1 \sum V_i \quad \dots \quad (2) \\ \sum X_i &= a_1 \sum U_i + b_1 \sum V_i + n c_1\end{aligned}$$

The subscript i denotes the i th control point, and n is the number of control points. The set of equations for a_2 , b_2 and c_2 is obtained by replacing X_i by y_i in equation (2).

5) The location of the fields on the computer map is determined by finding the coordinates U, and V on the aerial photo (with respect to the same coordinate system used in 3) for the control points) and applying the transformation (1) to these coordinates. In the wheat project at CCRS, the transformation is applied to the coordinates of the field vertices on the aerial photo to determine the vertex coordinates on the computer map.

APPENDIX C

REGISTRATION OF TWO COMPUTER MAPS OR CCTs¹

Often one wants to monitor a given region on the surface of the earth using sequential ERTS-1 imagery. This is simplified if one has a method of registering two or more CCTs or computer maps. This can be done using a mathematical transformation called affine transformation (see Appendix B).

The method of least squares is used to estimate the parameters of the transformation (1).

Then to locate any feature on the second computer map or CCT, when the location of the feature on the first map or CCT is known, just apply the transformation to the known coordinates. In the wheat project, for example, the known coordinates are the field vertices. To locate these vertices on any other computer map (secondary passes) the appropriate transformation is applied. It should be noted that this results in a considerable saving of storage pass. For instead of saving 2000 odd field vertices for each pass, one just has to store the vertices for one pass and the 6 transformation parameters ($a_1, b_1, c_1, a_2, b_2, c_2$) for other passes.

¹ Source: Peet, F.G., "A Guide to the Use of Digital ERTS-1 Data", March 1, 1974, CCRS, Ottawa, Canada.

THE TIME INVOLVED IN ACQUIRING
GROUND CALIBRATION DATA

<u>ITEM</u>	<u>TIME</u>
3 trips from Ottawa to Kent county, Southwestern Ontario for Ground truthing and Observation (June 21, July 13, August 13).	12 days
Preparation of the June 21 Ground Truth and Observation data for keypunching (213 fields)	6 hours
Keypunching the June 21 Ground data at DATACAP, Ottawa	1 week

THE COMPUTER TIME REQUIRED TO PROCESS ERTS-1 DIGITAL DATA AT CCRS
(SEPT. 1974) USING THE WHEAT PROJECT IMAGE PROCESSING SYSTEM

PROGRAM ¹	ELAPSED TIME	CPU
MAP1 (One ERTS-1 Frame)	20 min. 4.50 sec.	1 min. 49.6 sec.
MAP2 (900 lines x 1320 pixels)	2 hrs. 43 mins. 3.74 sec.	46 min. 52.96 sec.
GENLUT (One ERTS-1 Frame)	10 mins. 48.13 sec.	4 min. 49.14 sec.
APPLUT (360 lines)	19 mins. 1.42 sec.	36.87 sec.
LIMIT1 (Digitizing 213 fields, June 20 pass)	4 hrs. 37 mins. 20 sec.	1 min. 14.88 sec.
TBND5 (5 sites, 213 fields)	10 mins. 40.7 sec.	14.9 sec.
STAT2 (5 sites, 213 fields, June 20 pass)	10 mins. 56.5 sec.	34.04 sec.
SORT2 (5 sites, 213 fields, June 20 pass)	5.0 sec.	0 sec.
MERGE3 (5 sites, 213 fields, June 20 pass)	7 mins. 58.92 sec.	10.57 sec.
SORT3 (5 sites, 213 fields, June 20 pass)	5.0 sec.	0 sec.
SORT4 (5 sites, 213 fields, June 20 pass)	1.0 sec.	0 sec.
SORT6 (5 sites, 213 fields, June 20 pass)	5.0 sec.	0 sec.
CGDT11 (5 sites, 213 fields, June 20 pass)	2 mins. 27.52 sec.	1.59 sec.
PR20 (5 sites, 213 fields, June 20 pass)	5 mins. 35.36 sec.	54.6 sec.
PR30 (5 sites, 213 fields, June 20 pass)	6 mins. 52.36 sec.	56.0 sec.

¹ See next page.

PROGRAMS USED¹ IN THE ANALYSIS

<u>MAP1</u>	This program is used to determine the geographic correspondence between ERTS-1 photo and the corresponding computer compatible tape (CCT).
<u>MAP2</u>	This program produces a computer map of a test site.
<u>GENLUT,</u> <u>APPLUT</u>	These programs allow one to radiometrically correct the satellite data using the method of M. Strom and S. Vishnubhatla.
<u>LIMIT1</u>	This program allows one to digitize pixel positions from a computer map.
<u>TBNDS</u>	This program types the coordinates of the pixels digitized during the running of the program LIMIT1.
<u>STAT2</u>	This program generates statistics from the corrected Satellite data.
<u>SORT2</u>	This program sorts the statistics generated by STAT2, by field ID, in ascending order.
<u>MERGE3</u>	This program merges the ground truth data and the statistics data.
<u>SORT3</u>	This program sorts the ground truth data by field ID, in ascending order.
<u>SORT4</u>	This program sorts the output from MERGE by T (Training) and U (unknown) fields, by crop ID and then by field ID in ascending order.
<u>SORT6</u>	This program sorts the merged file, by increasing crop ID, increasing signal level in band 6, and then by increasing signal level in band 7.
<u>CGDT11</u>	This program allows one to select training fields in the ground truth data.
<u>PR20</u>	This program classifies fields by using the maximum likelihood rule.
<u>PR30</u>	This program classifies fields by using the minimum distance rule.

¹ Source: F. Peet, Procedures Manual for the Wheat Project, CCRS Technical Note 73-22.

APPENDIX D

DATE	JUNE 2					JUNE 20					JULY 8				
	No. of Fields	No. of Fields Correctly Identified	Percentage Identified	No. of fields committed to other crops	No. of other fields committed to	No. of Fields	No. of Fields Correctly Identified	Percentage Identified	No. of fields committed to other crops	No. of other Fields committed to	No. of Fields	No. of fields Correctly Identified	Percentage Identified	No. of fields Committed to Other Crops	No. of other Crops committed to
Corn	10	8	80%	2	4	10	7	70%	3	4	10	6	60%	4	5
	(154)	(117)	(76%)	(37)	(60)	(154)	(113)	(73%)	(40)	(82)	(154)	(113)	(73%)	(41)	(86)
	19	15	79%	4	2	19	15	79%	4	3	19	14	74%	5	4
Soybeans	(356)	(295)	(83%)	(60)	(37)	(356)	(274)	(77%)	(82)	(40)	(356)	(269)	(76%)	(86)	(41)
SITE 2 Soil Type: Heverly loam Soil Class: 1															
Corn	11	10	91%	1	0	11	6	55%	5	0	11	8	73%	3	0
	(159)	(153)	(97%)	(6)	(0)	(159)	(85)	(54%)	(74)	(0)	(159)	(120)	(76%)	(38)	(0)
	6	6	100%	0	1	6	6	100%	0	5	6	6	100%	0	3
Fields	(128)	(128)	(100%)	(0)	(6)	(128)	(128)	(100%)	(0)	(74)	(128)	(128)	(100%)	(0)	(38)
SITE 3 Soil Type: Brookston Silty loam Soil Class: 2W															
Corn	17	6	35%	11	1	17	10	59%	7	4	17	13	76%	4	2
	(453)	(134)	(30%)	(319)	(18)	(453)	(330)	(73%)	(223)	(24)	(453)	(336)	(74%)	(117)	(16)
	5	3	60%	2	5	5	4	80%	1	5	5	5	100%	0	1
Soybeans	(93)	(54)	(61%)	(39)	(127)	(58)	(58)	(62%)	(35)	(132)	(93)	(93)	(100%)	(0)	(15)
Fields	(303)	(189)	(62%)	(5)	(254)	(238)	(79%)	(65)	(123)	(303)	(288)	(95%)	(15)	(4)	
Winter Wheat	14	12	86%	2	5	14	12	86%	2	0	14	12	86%	2	0
(204)	(176)	(87%)	(28)	(103)	(204)	(180)	(88%)	(24)	(0)	(204)	(180)	(88%)	(24)	(0)	
SITE 4 Soil Type: Brookston Sandy loam Soil Class: 3W															
Corn	16	16	100%	0	0	16	4	25%	12	6	16	19	66%	10	0
	(445)	(445)	(100%)	(0)	(172)	(69)	(152)	(378)	6	12	(445)	(722)	(72%)	(394)	(0)
	7	1	14%	6	0	7	1	14%	6	12	7	100%	0	10	
Soybeans	(197)	(25)	(13%)	(172)	(0)	(197)	(51)	(26%)	(138)	(378)					
SITE 5 Soil Type: Clyde clay Soil Class: 2W															
Corn	29	18	62%	11	2	29	15	52%	14	0	29	19	66%	10	0
	(1407)	(983)	(70%)	(424)	(24)	(1407)	(642)	(45%)	(513)	(0)	(1407)	(1013)	(72%)	(394)	(0)
	8	6	75%	2	11	8	8	100%	0	14	8	8	100%	0	10
Soybeans	(229)	(205)	(90%)	(24)	(424)	(229)	100%	(0)	(513)	(229)	(229)	100%	(0)	(394)	

Acreages are indicated in brackets.

APPENDIX E

LAND USE CAPABILITY CLASSIFICATION¹

There are several hundred soil types in Ontario each one of which is different from all others in one or more observable feature. Classification of soil into types is important in itself because it helps one to remember the soil characteristics. The next important step, however, is the interpretation of the soil characteristics in terms of agronomic use, i.e. land use capability.

In order to reduce the number of classes of soil and to assist in land use planning, soil types are grouped into land use capability classes. The capability classification is an interpretive grouping that shows, in a general way, what the capabilities of the soils are for crop production. There are seven soil capability classes. Soils are placed in one of these classes on the basis of profile features, degree of slope, risk of erosion, etc. Soils in Class 1 are the soils that have few limitations, the widest range of use and the least risk of damage when they are used for intensive agriculture. The soils in the other classes have progressively greater natural limitations.

Soils in Classes 1, 2 and 3 are suitable for sustained production of common field crops, soils in Class 4 are marginal for arable agriculture, soils in Classes 5 and 6 are capable of use for permanent pasture, while soils in Class 7 are unsuitable for arable agriculture or permanent pasture.

Major kinds of limitations within classes are indicated by

¹ Source - Department of Land Resources, University of Guelph, Guelph, Ontario.

subclasses. Five different subclasses are commonly recognized and are shown by adding a letter e, p, s, t, or w to the class numeral, for example 2e. The letter e indicates that the main limitation is risk of erosion; p indicates that stones are sufficiently numerous to significantly increase the difficulty of tillage, planting and harvesting; s indicates soils having limitations of low fertility difficult to correct, low water-holding capacity, or poor structure; t indicates soils in which topography is a limitation to agricultural use; and w indicates that excess water in the soil will interfere with plant growth, cultivation, or harvesting.

In Class 1 there are no subclasses because the soils of this class have few or no limitations. Within most of the other classes there can be up to five subclasses.

The classes are described briefly below.

SOIL CAPABILITY CLASSIFICATION FOR AGRICULTURE

In land capability classification, areas of soil are classified by use limitations into seven capability classes. Such a classification indicates to a farmer the major limitations in the use of his land. Farming practices may be adopted that permit the use of the land while maintaining a high level of productivity.

Class 1

Soils in this class have no significant limitations that restrict their use for crops.

Class 1 soils have level or gently sloping topography. They are deep, well to moderately drained, and have good water-holding

capacities. These soils are naturally well supplied with plant nutrients. They are easily maintained in good tilth and fertility. The erosion hazard (wind and water) is low.

Class 2

Soils in this class have moderate limitations that reduce the choice of crops or require moderate conservation practices.

Class 2 soils require careful soil management, including conservation practices to prevent soil deterioration or to improve air and water relations. Moderate limitations singly, or in combination, may result from: (1) topography, (2) slight to moderate damage from erosion, (3) somewhat less than ideal soil depth, (4) some difficulty in tillage owing to soil structure or stoniness, (5) wetness requiring drainage but existing permanently as a moderate limitation, (6) occasional hazard from flooding, (7) slow permeability of the subsoil, (8) moderate climatic limitations on soil management and use.

Soils in this class have good water-holding capacities and are either well supplied with plant nutrients or highly responsive to inputs of fertilizer.

Class 3

Soils in this class have severe limitations that reduce the choice of crops or require special conservation practices.

Class 3 soils have moderately more severe restrictions than those in Class 2 and conservation practices are usually more difficult to apply and maintain. Limitations adversely affect the timing and ease of tillage, planting, harvesting; the choice of crops, the

application of conservation practices; or some combination of these limitations. The limitations may result from: (1) moderately rough topography, (2) moderate damage from erosion, (3) less than ideal soil depth, (4) difficulty in tillage owing to soil structure or stoniness, (5) wetness or continued water logging after drainage, (6) frequent overflow accompanied by crop damage, (7) moderately low water-holding capacity, (8) very slow permeability of the subsoil, (9) moderate fertility status and not highly responsive to inputs of fertilizer, (10) moderately severe climatic limitations on soil management and use.

Class 4

Soils in this class have severe limitations that restrict the choice of crops; require special conservation practices and very careful management.

Class 4 soils have such limitations that they are only suited for a few crops. The yield for a range of crops may be low or the risk of crop failure high. Limitations may result from (1) rough topography or steep slopes, (2) severe damage from erosion, (3) shallow soils, (4) serious difficulty in tillage owing to soil structure or stoniness, (5) excessive wetness with continued hazard of water logging after drainage, (6) frequent overflows, accompanied by severe crop damage, (7) low water-holding capacity, (8) low fertility not easily corrected, (9) severe climatic limitations on soil management and use.

Class 5

Soils in this class are unsuited for cultivated field crops, except perennial forage crops, and are responsive to improvement

practices.

Class 5 soils have such serious soil, climatic, or other limitations as to make them unsuited for the production of field crops. However, they are suited to the production of adapted grasses and legumes. Improvement practices may include cultivation, seeding, liming, fertilizing, and water control.

Class 6

Soils in this class are unsuited to cultivation but are capable of use for unimproved permanent pasture.

Class 6 soils have a natural grazing capacity for farm animals but have such serious soil, climatic, or other limitations as to make impractical the application of improvement practices which can be carried out on Class 5 soils. Soils are placed in this class because their physical nature prevents the use of farm machinery to improve them, or because the soils are not responsive to improvement practices, or because of a short grazing season, or because stock watering facilities are inadequate.

Class 7

Lands unsuited for agriculture.

The soil areas in this class have very serious climatic or soil limitations that prevent their use for cultivated crops or improved permanent pasture. All land areas not included in Classes 1 to 6 are placed in this class. Hence this class includes productive forest land, waste land, bodies of water too small to delineate on maps, townsites, parks, airports, railroads, and roads.

APPENDIX F

Table A. SIMPLE CORRELATION MATRIX FOR THE
REMOTE SENSING REGRESSION

VARIABLE	AVERAGE SIGNAL LEVEL				
	DATE				
	June 2	June 20	July 8	June 20 + July 8	June 2, 20 + July 8
Field ID	-0.46	-0.40	-0.49	-0.29	-0.31
Crop	-0.22	-0.53	0.06	-0.19	-0.18
Date				0.73	-0.02
Ground Cover		0.67	-0.21	0.49	0.12
Plant Height		0.47	-0.10	0.45	-0.08
Sun Radiation				0.73	-0.21
Soil Type	-0.51	-0.44	-0.53	-0.32	-0.34
Land Capability Class	-0.07	-0.13	-0.00095	-0.05	-0.05
Growth Stage		0.58	0.02	0.35	-0.15

THE REGRESSION EQUATIONS

June 2 Signal Level = 91.22 + 0.10 FieldID - 0.02 Crop - 11.33 Soil
 $R^2 = .32587$ F values = (11.3) (7.0) (24.0)
 - 0.14 Land Class
 (0.008).

June 20 Signal Level = 50.27 + 0.06 FieldID - 0.00063 Crop + 0.18
 $R^2 = .58835$ (9.07) (0.003)

Table A. (continued)

		Ground Cover - 0.11	Plant Height - 6.69	
		(17.84)	(1.43)	
		Soil Type - 1.78	Land Class + 1.22	Growth Stage
		(20.08)	(2.47)	(2.23)
July 8	Signal Level =	77.22 + 0.05 FieldID + 0.00064 Crop		
	R ² = 0.38532	(7.98)	(0.008)	
	- 0.064 Ground Cover + 0.052 Plant Height - 6.63 Soil Type			
	(7.23)	(1.53)	(21.92)	
	+ 1.77 Land Class - 0.016 Growth Stage			
	(3.52)	(0.001)		
June 20 + July 8	Signal Level =	-932.61 + 0.046 FieldID + 0.002 Crop		
	R ² = 0.69468	F value = (9.44)	(0.87)	
	+ 0.115 Ground Cover - 0.062 Plant Height + 1.48 Sun Radiation			
	(26.82)	(1.74)	(386.70)	
	- 6.30 Soil Type - 0.015 Land Class - 0.13 Growth Stage			
	(27.87)	(0.000)	(0.090)	
June 2,20 July 8	Signal Level =	178.27 + 0.060 FieldID - 0.022 Crop		
	R ² = 0.19965	(8.59)	(15.03)	
	- 0.143 Sun Radiation - 7.69 Soil Type + 0.13 Land Class			
	(36.90)	(22.14)	(0.013)	

