Agriculture Canada

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Four band airborne radar imagery for agricultural applications

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The map on the cover has dots representing Agriculture Canada research establishments.

ONE HUNDRED YEARS OF PROGRESS

The year 1986 is the centennial of the Research Branch, Agriculture Canada.

On 2 June 1886, *The Experimental Farm Station Act* received Royal Assent. The passage of this legislation marked the creation of the first five experimental farms located at Nappan, Nova Scotia; Ottawa, Ontario; Brandon, Manitoba; Indian Head, Saskatchewan (then called the North-West Territories); and Agassiz, British Columbia. From this beginning has grown the current system of over forty research establishments that stretch from St. John's West, Newfoundland, to Saanichton, British Columbia.

The original experimental farms were established to serve the farming community and assist the Canadian agricultural industry during its early development. Today, the Research Branch continues to search for new technology that will ensure the development and maintenance of a competitive agri-food industry.

Research programs focus on soil management, crop and animal productivity, protection and resource utilization, biotechnology, and food processing and quality.

Four-band airborne radar imagery for agricultural applications

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TABLE OF CONTENTS

FORWORD

This report was prepared for the Review meetings of the Surveillance Satellite Project of the Canadian Space Program. The report summarizes the airborne studies proposed by the Agriculture Sub-committee and approved by the Radarsat Review Board for the Initial Radarsat Phase of the Program. The cost of the experiments was funded under the Surveillance Satellite Project (CSP) for acquisition of the Airborne radar imagery and digital analyses and by Agriculture Canada (Crop Information Contract Research) and Canada Center for Remote Sensing for ground data acquisition and interpretation.

A.R. Mack

March 1983

ABSTRACT

This report summarizes the first comprehensive study of radar imagery to be undertaken for agricultural applications in Canada. It was carried out under the Sursat Program of the Canadian Government over areas having a wide range of crops and management practices. Imagery from two or more microwave bands was successfully provided for six of the eight test sites across Canada. Each of the test areas provided different types of data products, interpretive procedures, classification accuracies, and image acquisition problems. Collectively, the studies showed that microwave imagery has the technical capability to produce imagery which can delineate a variety of vegetative features and to discriminate amongst the major crop groups with a spatial resolution similar to the Landsat systems. Where "good" quality imagery was available in 2 or more of the 4 bands, classification methods appear to differ little in principle from those followed in analyzing Landsat or multi-band from aircraft data. Single bands of imagery for any system has limited information; whereas, each additional band provides additional factors for discriminability of features.

RÉSUMÉ

On trouvera résumée dans le présent rapport la première étude globale des applications agricoles de l'imagerie radar au Canada. Menée dans le cadre du Programme canadien de satellites de surveillance, elle a porté sur toute une gamme de cultures et de pratiques culturales. On a obtenu une imagerie à deux bandes hyperfréquences ou plus pour six des huit sites-témoins retenus. Le type de données, les méthodes d'interprétation, la fidélité des classifications et les problèmes d'imagerie ont varié d'un endroit à l'autre. Globalement, l'étude révèle que l'imagerie à hyperfréquences permet de discerner diverses cultures et caractéristiques culturales avec une résolution spatiale comparable à celle des systèmes Landsat. Lorsqu'une imagerie de bonne qualité a été obtenue dans deux ou plus des quatre bandes, la valeur des classifications a égalé à toutes fins utiles celle des systèmes multibandes actuels (satellites Landsat et photographie aérienne), et les méthodes d'analyse des données et d'interprétation des résultats ont été fort semblables. Les bandes uniques offrent peu d'information, quel que soit le système utilisé, et toute bande supplémentaire rend possible un discernement plus fin.

I. INTRODUCTION

A comprehensive study was organized under the Surveillance Satellite Program to provide preliminary information on the technical feasibility of active microwave imaging systems for acquiring information on crops and land management. The study was conducted in association with ongoing airborne and satellite remote sensing studies to facilitate an overall appraisal in relation to other data systems. Results of current remote sensing studies have indicated problems in a number of temporal, spatial and spectral areas. Acquisition of imagery which relies on a solar energy source is sensitive to interference from weather and cloud conditions. Field size and shape determine a minimum spatial resolution, and the crop types and growing conditions predicate bandwidth and spectral resolution. Thus, a self-contained system having an all-weather capability with a similar (or improved) spatial resolution and having unique specificity to crop characteristics would be a valuable adjunct to present imaging systems.

The 4-Band ERIM Synthetic Radar that was available under the Airborne part of the Sursat Program offered an excellent opportunity to obtain, study and evaluate a new date source. The system operates and evaluates imagery independent of solar and weather conditions. It has a realistic-spatial resolution similar to that from Landsat imagery from each of four spectral-polarization modes. The main objectives of the study were to indicate the technical feasibility of X and L-band radars for discrimination of major crops, to establish calibration requirements to determine requirements for image processing procedures, and to identify limitations in its useage. The study would also identify the need for ancillary data, identify areas of research and create an awareness among users of using radar in future studies.

II. SELECTION OF TEST AREAS

Proposals were accepted to provide a complementary program for assessing radar imagery under widely different imaging situation involving aircraft scheduling, navigation, digital to image processing various crops, growing conditions, crop management practices, and different photo-interpretive and automated digital classification approaches.

Data were acquired from test-site areas previously used in association with other remote sensing programs and identified with known soil-climatic regions (Figure 1 and 2). This provided a basis for extrapolations of results to other areas having similar soil-climatic and cultural features. Focus was placed on ability to discriminate:

(A) Crop growth in a mixed irrigation and dryland strip-farming management system associated with the semi-arid moisture conditions on Dark Brown Chernozemic soils (Raymond, Alta.).

(B) Low-yielding vegetation types grown under large-scale farm management systems of the sub-arid moisture conditions on Brown Chernozemic soils (Swift Current, Saskatchewan).

(C) High-yielding vegetation (cereals and oil-seed crops) grown under moderately large-scale management systems of the sub-humid moisture region on Black Chernozemic soils (Melfort, Sask.).

(D) High density types of vegetation covering a wide range of cash crops including cereals, forage, oil-seed, and horticultural crops grown under relatively small-scale management systems of the sub-humid region on humic Gleysolic soils (Simcoe, Ont.).

(E) Mixed natural and improved forage and grain crops grown on a rolling terrain in a sub-humid, humic gleysolic region (Guelph, Ont.).

(F) Mixed forage and cereal cropping system in a perhumid moisture region on humo-ferric podzol soils (Ste. Hyacinthe and Sherbrook, Quebec).

(G) Mixed crops in a dominantly large potato growing region in a rolling terrain having perhumid moisture conditions (Grand Falls, N.B.).

(H) Predetermined field and crop characteristics related to known features of leaf type, row orientation, crop density,

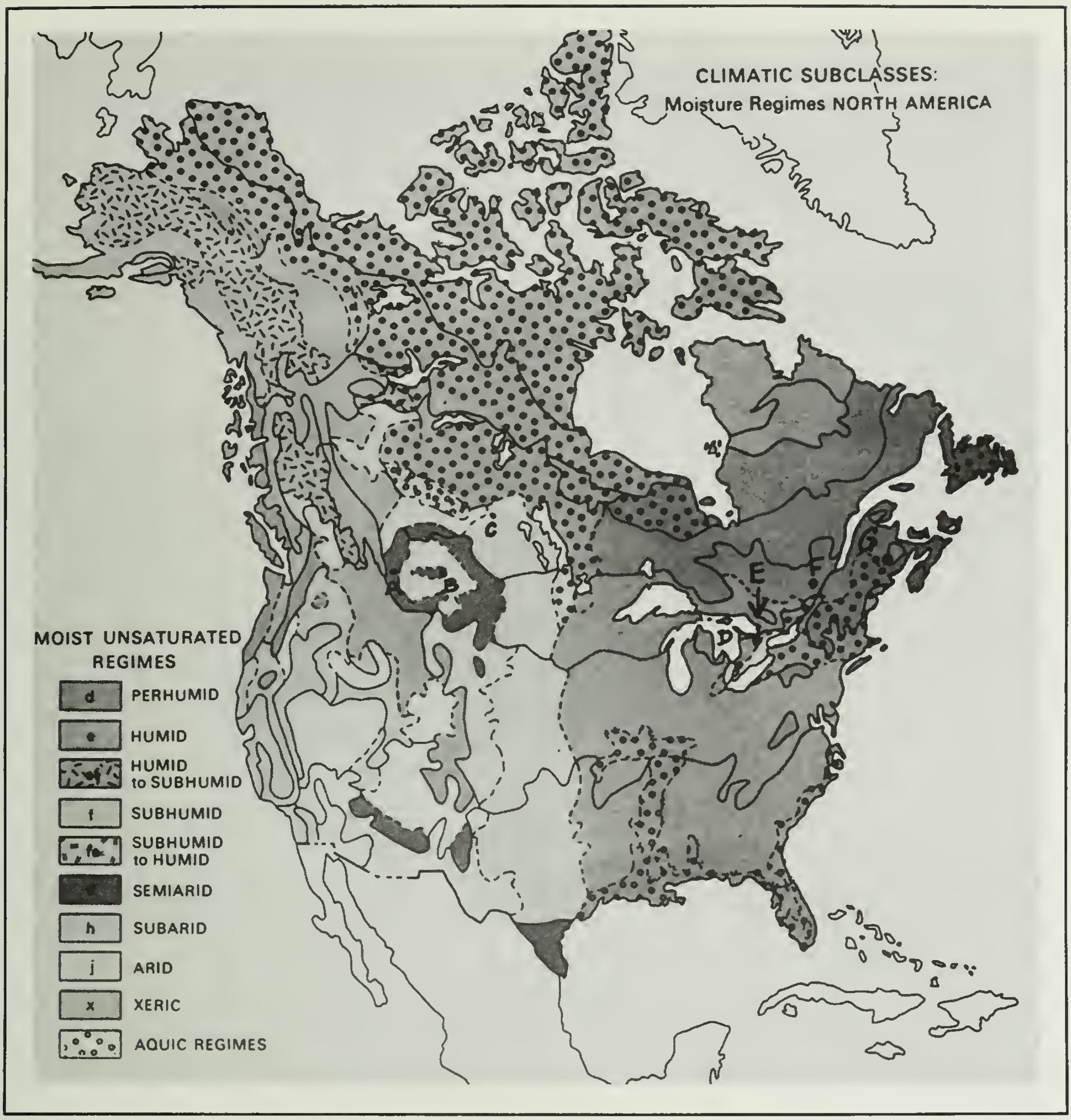

Fig. 1. Location of the seven test sites in Canada with respect to the main climatic soil moisture regimes of North America.

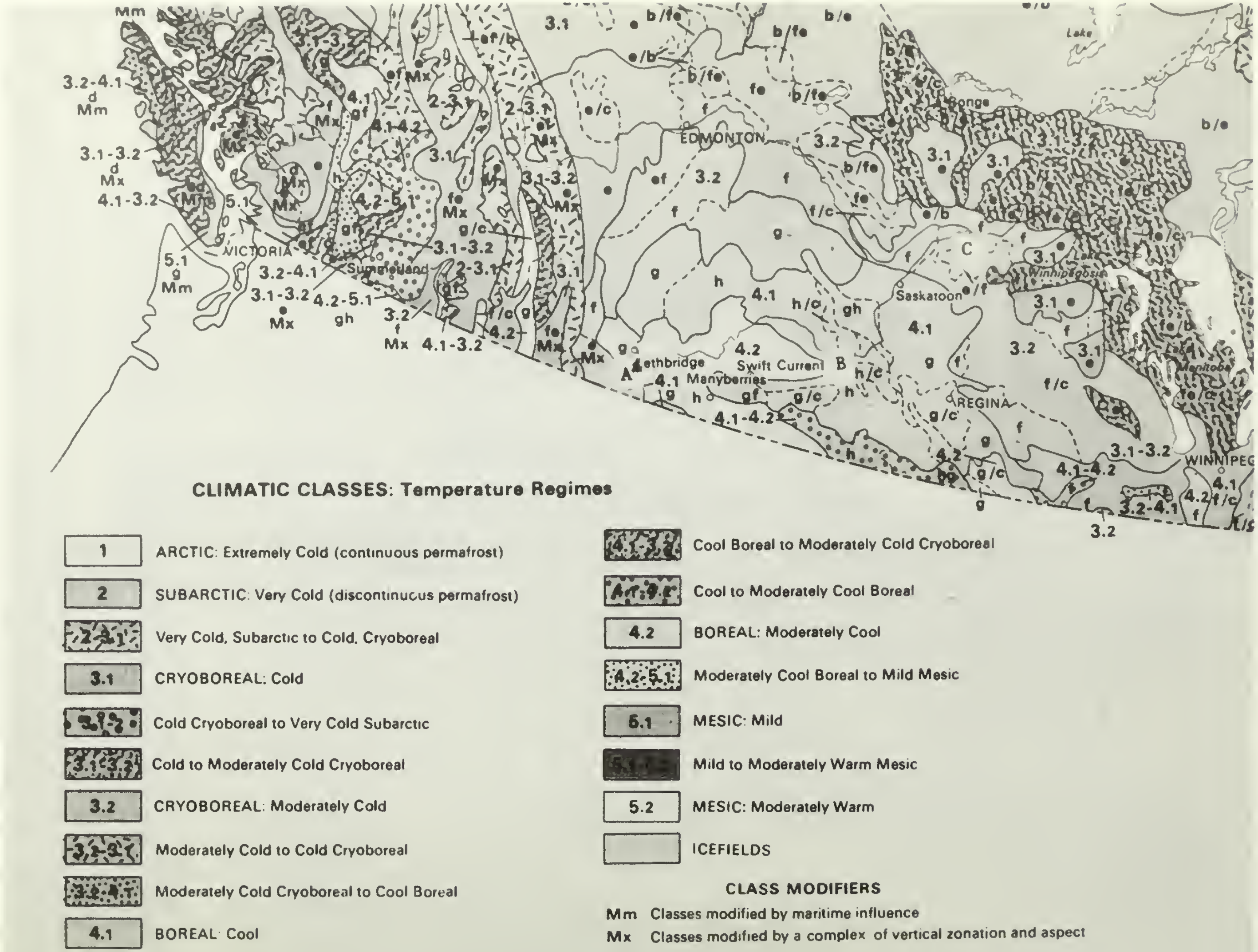

Fig. 2. Location of the three sites in the prairie region with respect to the climatic soil temperature regimes of North America.

maturity and tillage operations at a test site having specifically designed tillage and crop patterns.

The projects included analytical procedures for data processing and interpretation by: (1) manual photometry, simple digital discrimination; and (2) automated computerization using the "original digital" data source produced on magnetic tape.

Most of the analysis associated with the ERIM 4-band system were to be complemented later with Seasat data for selected sites (Raymond, Swift Current and Grand Falls) through arrangements with data acquisition facilities of JPL (Goldstone) and CCRS at Shoe Cove.

III. MIXED IRRIGATION AND DRYLAND FARMING SYSTEMS OF WESTERN CANADA (Sites A, B, C)

A program of acquiring field data for remote sensing studies had been carried out at sixteen sites since 1973 under the Canadian-U.S. Spring Wheat Project (Peet, Mack, Crosson, 1974). Data were collected on crop type, acreages, percentage of crop cover, growth stages of the crops, and soil moisture conditions.

Three of these sites were chosen in Western Canada to represent major typical areas having diverse conditions for growing spring wheat and oilseeds in different cropping rotations and management practices. The approximate geographical locations of the three sites are shown in Figures 1 and 2: A - Raymond, Alberta; B - Swift Current, Saskatchewan; and C - Melfort, Saskatchewan. These sites represent much of Canada's western agricultural land and provide a good representation of the soil and climate affecting types of crops grown with spring wheat in the Prairie Provinces. The analysis of the data were carried out by L. Garron and J. Schubert of The Sibbald Group, Calgary, Alberta.

Site Descriptions

The sites were similar in size: ten miles long and two miles wide. The main crops, field size, growth stage, and the type of useable imagery are shown for each of the three sites (Table 1).

Data

The radar imagery was acquired on July 31, 1978 for the three sites by Environmental Consultants Ltd. using the Environmental Research Institute of Michigan (ERIM) 4-channel X-L radar system. The antenna was set in the shallow angle mode with the incidence angles ranging from 59.5° to 68.5° within the imaged area (i.e. the centre depression angle from horizontal is 24°).

TABLE 1. Summary of crops and imagery available for analysis at each site

Site	Crops	Field Size		Growth Stage for Cereals	Ground Cover	Useable Imagery Available
		Modal	Average			
		acres			%	Bands/Polarization
A Raymond	Spring Wheat, Winter Wheat Oats, Barley Sugar Beets Fallowland, Pasture, grasses	60	73	Heading to Flowering	80-100	Transparencies: X_{HH} X_{HV} L_{HH}
B Swift Current	Spring Wheat, Fallow, Pasture, grasses	160	92	Heading to Flowering	40-60	Prints: X_{HH} X_{HV}
C Melfort	Spring Wheat, Oats, Barley, Rapeseed, Peas, fallow	80	95	Heading to Flowering	80-100	Transparencies: X_{HH} L_{HH} Prints: X_{HV}

Analytical Method

A manual two-step supervised classification procedure was used in the evaluation of the radar imagery for crop identification. A step-wedge with twelve levels of gray densities ranging from 0.09 to 1.92 was used in providing numerical values to the grey levels in both steps.

In the first step, critical gray-level values were established for each test site. Gray levels for each band/polarization combination were obtained for all the fields in each site. Next, using ground records, the fields were grouped according to crop type. The groupings were examined to determine whether specific gray levels were unique to a particular crop type. Cut-off values were then established for each class. These critical values were incorporated into decisin flow schemes (Figs. 3, 4, 5). This training procedure was performed on each of the three test sites separately.

In the second step, the schemes established in the training step were used in the interpretation of the test sites. Two types of decision flow shemes were tested in this study. The first scheme used the critical values independently for each single band of imagery and is referred as "single-band interpretation". The second type of decision-flow utilized the information from all bands of data for one site and is referred to as "multi-band interpretation". Depending on the test area and the data available, the schemes of classification established varied. In some sites data were used for the classification of very broad groupings of crops, whereas in others, data were used for the classification of particular crops. The use of these procedures are restricted to comparing features within a set of imagery which has been produced simultaneously under similar processing conditions.

Single-Band Classification

The separation of "fallow" and "crop" fields was achieved with X_{HH} prints for Swift Current. Omitted field errors did not surpass 6.8% and committed field errors were never over 7.7%. In

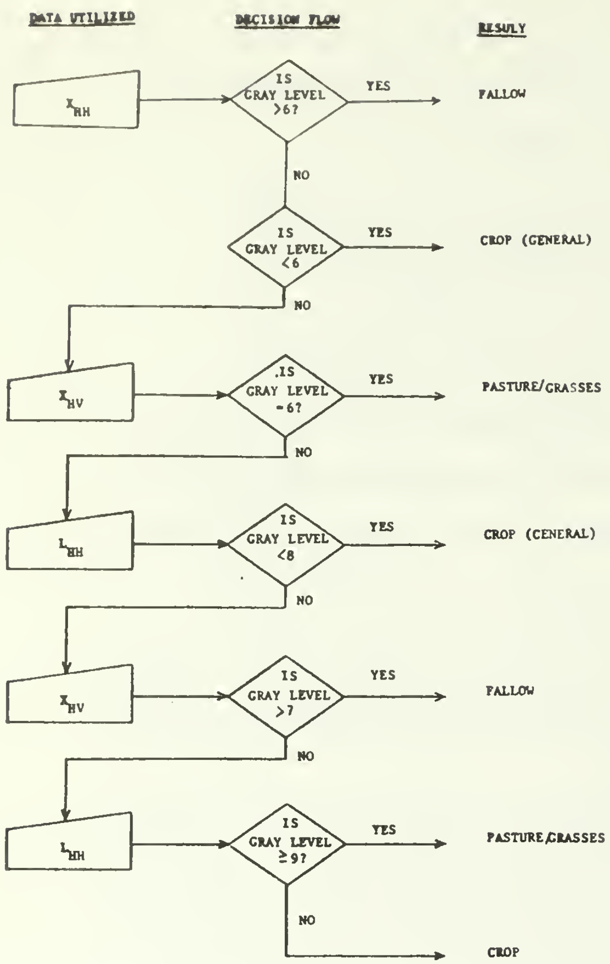

Fig. 3 - Decision Flow Scheme used in the Multi-Band Interpretation of Cropland in Raymond, Alberta

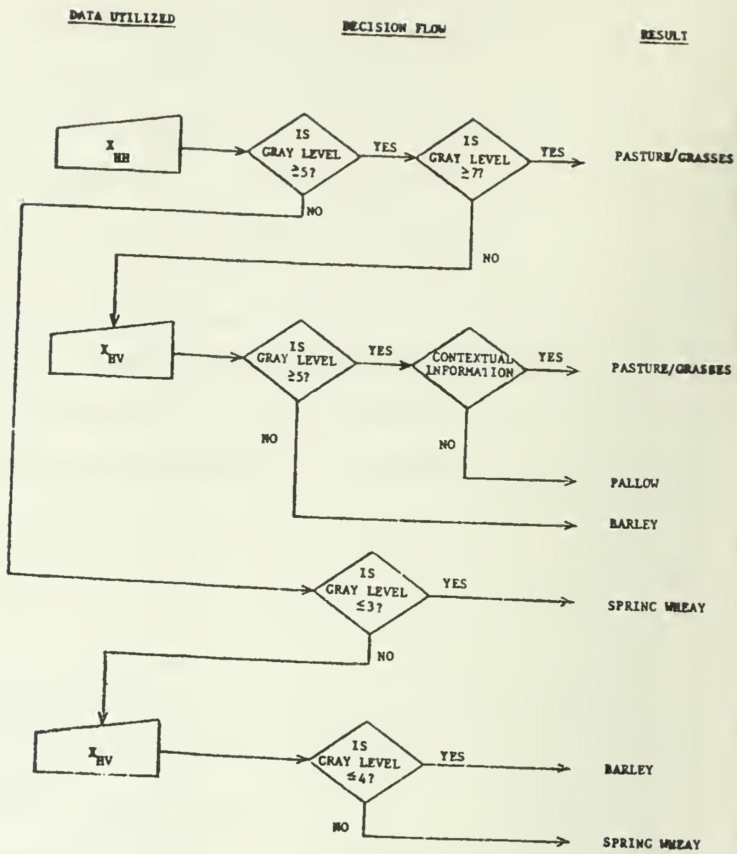

Fig. 4 - Decision Flow used in the Multi-Band Interpretation of Swift Current

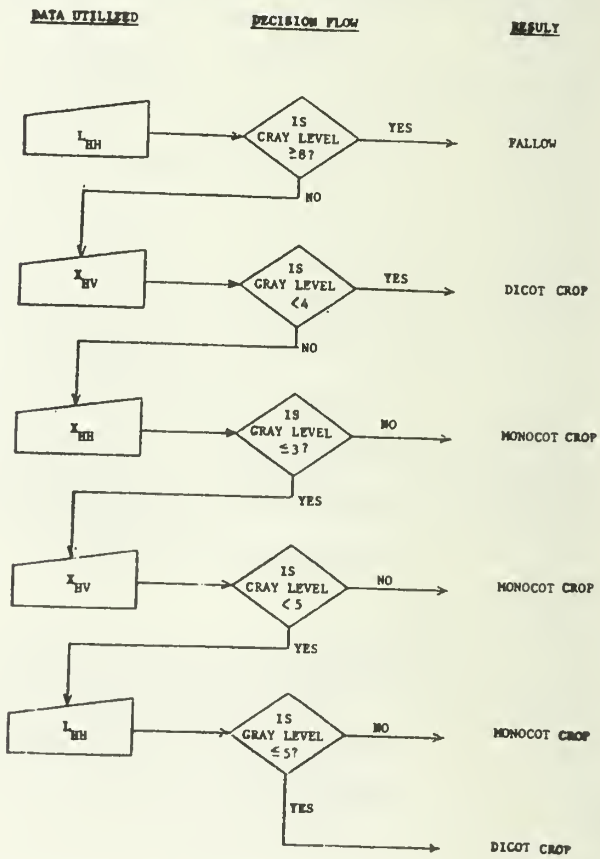

Fig. 5 - Decision Flow used in the Multi-Band Interpretation of Melfort

contrast, using transparencies of the longer wavelength of L_{HH} bands proved to be of no value for single band interpretation as shown by the analyses of L_{HH} imagery available for the Raymond site.

Multi-Band Classification Results

The multi-band classification results were obtained using all available imagery respectively for each test site. The schemes developed for this purpose were designed to give the best interpretation within that site, thus they differ from site-to-site. The schemes were developed, as discussed in Methods, from the gray level values determined for each field and reported in the previous section.

The classification was performed by comparison of the values for each field in each band with values in the flow-charts shown in Figs. 3, 4 and 5 and assigned to a single class. The assigned class for each field was compared with the class reported in the field data. The results of these comparisons were then summarized as the number of fields or as the acres in the fields as reported in the field data. The percentages of each class correctly identified or omitted, and the percentage of other classes incorrectly assigned to that class (committeed error) were calculated for each site.

Crops were grouped together differently in each site; in some cases there was more than one grouping of crops within a site. These groupings were done hierarchically, i.e. general crops (including pasture crops) vs. fallow; crops vs. pasture/grasses vs. fallow; a breakdown of "crops" into small grains (monocot) crops vs. broad-leaf (dicot) crops; and, finally, a breakdown of grain crops into spring wheat, barley, etc. In some cases, there were fields which did not fall into designated categories; these were designated as "other" in the tabulations of results. However, no "other" class was included in the classification schemes, so no fields could be interpreted as "other".

Raymond Test Site

The decision flow scheme for Raymond utilized three bands of imagery, X_{HH}, X_{HV}, and L_{HH}. A field was classified as "fallow" if the gray level was greater than 6 on X_{HH}, as "crop" if less than 5. Next, fields with gray levels of 6 on X_{HH} were examined on X_{HV} imagery. If the gray levels on band X_{HV} were equal to 6, the fields were classified as pasture/grasses. Fields not yet assigned were then examined on L_{HH}. Those with gray levels less than 8 were classified as "crop" fields while the rest were re-examined on X_{HV}. Unclassified fields with gray levels of greater than 7 on X_{HV} were classified as "fallow". Finally, the remaining unclassified fields were examined again on L_{HH} imagery. Fields with levels greater than or equal to 9 were classified as pasture/grasses and all others still unclassified were assigned to crop. The flow scheme for Raymond is shown in Figure 3.

Swift Current

The multi-band interpretation results for the Swift Current test site are shown in Table 2. In general, the crops were easy to separate. Identification of spring wheat in particular was very accurate. All spring wheat fields were correctly identified with only a 4.0% committed error. In the identification of pasture/grasses there was a 0.0% committed error, with a correct acreage identification of 93.2%. As before, the basis for such good results in the identification of pasture/grasses is the association of pasture/grasses to breaks in the uniform topography, defined as contextual information in the classification scheme. Results obtained from the identification of summer fallow were also accurate with a correct acreage identification of 97.2% and a committed error of only 6.2%.

The results obtained when the grains i.e. monocotyledons were subdivided were not nearly as accurate - only 32.6% correct barley identification with, however, an extremely low committed error of only 0.3%. The only confusion was spring wheat which was classified as barley. Much of this error may be accounted

Table 2. Multi-band identification results for Swift Current

Crop	True Acreage	Acreage Identified as Crop	Correct Acreage Identified	Omitted Error(%)	Committed Error(%)
	Results Based on Acreage Identification				
Spring Wheat	2435	2760	2435	0.0	4.0
Fallow	2830	3230	2750	2.8	6.2
Pasture/Grasses	4680	4360	4360	6.8	0.0
Barley	475	185	155	67.4	0.3
Other	115	0	0	100.0	0.0
Totals	10535	-	9700	7.9	2.0

Crop	True No. of Fields	No. of Fields Identified as Crop	Correct No. of Fields Identified	Omitted Error(%)	Committed Error(%)
	Results Based on Field Identification				
Spring Wheat	27	32	27	0.0	7.4
Fallow	32	35	31	3.1	6.3
Pasture/Grasses	30	25	25	16.7	0.0
Barley	4	3	2	50.0	1.1
Other	2	0	0	100.0	0.0
Totals	95	-	85	10.5	2.6

Table 3a. Multi-band interpretation results for the Melfort test area

Crop	True Acreage	Acreage Identified as Crop	Correct Acreage Identified	Omitted Error(%)	Committed Error(%)
	Results Based on Acreage Identification				
Fallow	1402	1402	1402	0.0	0.0
Dicots	2202	2237	2002	9.1	5.1
Monocots	3172	3207	2937	7.4	7.3
Other	70	0	0	100.0	0.0
Totals	6846	-	6341	7.4	2.5

Crop	True No. of Fields	No. of Fields Identified as Crop	Correct No. of Fields Identified	Omitted Error(%)	Committed Error(%)
	Results Based on Field Identification				
Fallow	13	13	13	0.0	0.0
Dicots	24	24	21	12.5	6.1
Monocots	35	36	32	8.6	10.5
Other	1	0	0	100.0	0.0
Totals	73	-	66	9.6	3.2

for by the small sample size of only 4 fields (475 acres) for training the barley class.

The combined results obtained for the Swift Current test site showed excellent separation for the cereal group: 92.1% of all acreage was correctly identified with a committed error of only 2.0%.

Melfort, Saskatchewan

Identification results from the Melfort test site were recorded in two ways using two separate tables (Tables 3a and 3b). In Table 3a the results were recorded for three specified classes including summer fallow, dicotyledenous crops and monocotyledenous crops. Table 3b was set up in a similar fashion except monocotyledonous crops were further subdivided into spring wheat and barley.

The results obtained from the identification of summer fallow were excellent - 100% correct identification with a 0.0% committed error. In the identification of dicotyledenous crops accuracies were obtained of 90.9% of the acreage correctly identified and a 5.1% committed error. In the identification of monocotyledonous crops the correct acreage identification was 92.6%, coupled with a committed error of 7.3% (Table 3a). After subdividing the monocotyledon cereals class into spring wheat and barley, individual crop identification results were obtained (table 3a). The correct acreage identification was 62.6% for spring wheat, with a committed error of 10.5%. A committed error of 5.5% resulted from the identification of 20% of the barley acreage as wheat. Barley was correct in 80% of the area, and there was no committed error.

In the identification of only three classes (Table 3b) in the Melfort test site, the total combined results were very good. -- 92.6% of the total acreage was correctly identified with only a 2.5% committed error. In further subdividing the monocotyledonous crop classification (not shown) the total combined results were subtantially lower -- 83.7% of the total acreage was correctly identified with a 4.1% committed error. This decrease was due to confusion of wheat and barley.

Table 3b. Multi-band interpretation results for the Melfort test area

Results Based on Acreage Identification

Crop	True Acreage	Acreage Identified as Crop	Correct Acreage Identified	Omitted Error(%)	Committed Error(%)
Fallow	1402	1402	1402	0.0	0.0
Dicot Crop	2202	2237	2002	9.1	5.1
Spring Wheat	847	1160	530	37.4	10.5
Barley	2245	2047	1795	20.0	5.5
Other	150	0	0	100.0	0.0
Totals	6846	-	5729	16.3	4.1

Results Based on Field Identification

Crop	True No. of Fields	No. of Fields Identified as Crop	Correct No. of Fields Identified	Omitted Error(%)	Committed Error(%)
Fallow	13	13	13	0.0	0.0
Dicot Crop	24	24	21	12.5	6.1
Spring Wheat	9	13	5	44.4	12.5
Barley	25	23	19	24.0	8.3
Other	2	0	0	100.0	0.0
Totals	73	-	58	20.5	5.1

Table 4. Summary of interpretation errors for single band vs multi-band classification

	BEST SINGLE BAND			MULTI-BAND	
	Band	Omitted (%)	Committed (%)	Omitted (%)	Committed (%)
A. FALLOW					
Swift Current	X_{HH}	28.3	4.6	2.8	6.2
Melfort	L_{HH}	0.0	0.0	0.0	0.0
Raymond (Total site)	X_{HH}	22.7	0.9	10.4	10.5
(East only)	X_{HH}	10.5	0.0	7.4	0.0
B. SMALL GRAINS					
Swift Current	X_{HH}	10.9	20.7	0.0	4.0
Melfort	L_{HH}	25.2	13.5	7.4	7.3
Raymond (Total)	X_{HH}	17.9	22.2	16.7	22.1
(East only)	X_{HH}	6.3	8.5	0.0	3.8

Discussion and Conclusions (Sites A, B, C)

Two criteria of accuracy were defined for this study, one for separating fallow from crops, the second for identifying grain fields in the presence of crops.

Acceptable accuracy for the first criterion (i.e. separating fallow fields from all other crop fields) was established at 80 percent or better correct identification of fallow and other fields in all three sites on at least one band or combination of bands of data. For the second criterion (i.e. grain vs. all other crop, fallow and pasture fields), 65 percent correct identification of fields was considered minimal. In both tests of accuracy, identification of fields of other crops as the criterion class (committed error) or failure to recognize the criterion class were considered errors; however, confusion among non-criterion crops was not considered an error.

Using the above criteria, the radar bands and polarization available for this study when interpreted in combination with each other (i.e. multiband interpretation) gave acceptable accurate results (Table 4). However, acceptable accuracies were not possible with single band imagery. In Raymond, no single band of imagery gave acceptable results for the whole site by either criterion; in Melfort, fallow could be separated acceptably, but grain crop separation was not satisfactory. It should also be noted that the best separation and identification of crops occurred on different bands of imagery in different sites (Table 4). Fields in both the Swift Current and Raymond sites in the Brown and Dark Brown soil zones were separated the best with X_{HH} band imagery, while fields in the Melfort site in the Chernozemic zone were separated the best with L_{HH} band imagery. The crop which caused the difference in Melfort was barley, which was not separable on X_{HH} imagery from fallow (Table 3); however, in the other sites, barley and fallow also occurred and were separable. There are differences in soils, weather patterns, climate and, thus, phenology, among the sites. It was not possible to determine which of these factors was responsible for the similarity of soil and barley response on X_{HH} imagery of

Melfort since the field observation data on growth stage, soil moisture, etc. did not coincide with the radar data acquisition. Future studies are needed to clarify this situation. Furthermore, requested L_{HV} data were not received for any of the 3 sites.

The two-band imagery combination with the greatest information content appears to be the X and L bands both horizontally polarized. This combination was required to separate fallow from grain crops with acceptable accuracy in Melfort (Figure 5).

X_{HV} imagery, used in conjunction with the other available bands, contributed significant information for interpretation of crops. This is especially emphasized in Swift Current where no L band data were available. Here the error for fallow classification decreased from 28% omitted on X_{HH} or X_{HV} alone to less than 3% omitted on X_{HH} and X_{HV} combined (Table 4).

There was little loss of accuracy in either fallow-crop separation or crop identification due to small field size in this study. Accuracies were as great on both X_{HH} alone or on X_{HH}, X_{HV} combinations in the strip farming areas (alternate grain-fallow fields) of Swift Current or East Raymond (one-fourth mile vs. one-tenth mile wide strips).

The relative growth stage of a crop was not a significant factor in the one site where growth stage differences were noted in the field data. In Raymond, where spring wheat and barley were mainly in the heading to beginning to ripen stage, winter wheat was ripe to mature. However, there were no consistent differences in appearance between fields of the three grains on any band or polarization.

In Melfort, barley was separable on X_{HH} imagery from spring wheat (but not from fallow). Although, it is suspected that difference in growth stage may have been a factor, there is no supporting evidence in the field data to confirm this.

Wheat fields occurred in the three sites in growth stages varying from seeding to fully ripe or mature. There was no evident difference in the accuracy of separating fields of these different stages from non-grain fields, or especially, from fallow. Thus it is probable that a "window" of at least three to four weeks is possible for useful radar observation of grain crops.

In conclusion, it appears that multi-band radar data with different polarizations are potentially very useful for separation and identification of grain crops in the Prairie Provinces of Canada. Any single band imagery with only parallel or cross polarization is much less useful for either crop identification or for separating fallow from cropland.

IV. SUPPLEMENTARY STUDY OF THE RAYMOND TEST SITE

On July 31, 1978 additional ground data to that regularly recorded on phenological features were taken on the Raymond Test Site to study later anomalous features in the radar imagery in relation to specific crop feature at time of imaging. The analysis of the data was carried out by Dr. P. Crown, University of Alberta, Edmonton. The quality of the data has to date not justified further analysis; the lack of a densiometric range to which the L-band was processed eliminated perception of grey lands and the uncertainty of the data associated with characteristics of densiometric curve under which the X-bands were produced has restricted studies. Reprocessing of the imagery has not eliminated these problems.

Prior to the overflight a map of general land use had been prepared for the site as part of the crop information system program. During the time of the overflight additional ground data were collected including the following:

(a) for fields containing crops - crop height; growth stage; row direction; row spacing; direction of lean for stems and heads; blow-down due to wind; and other changes in stand geometry.

(b) for fields of bare soil (fallow) - direction of cultivation; height and width of surface irregularities due to cultivation; estimates of % trash cover; and soil moisture samples from selected fields.

Some tonal differences could be observed for fallow fields that could be attributed to the amount of trash cover or residue from the previous year's crop. These differences are observed on the X_{HH} band imagery but not on the X_{HV} band imagery where all fallow fields have a similar dark tone.

Most spring grains have somewhat similar tones on both X bands of imagery when seeding dates and growth stage are the same. Winter wheat appears similar in tone to spring grains on the X_{HH} band but with lighter tones on the X_{HV} band. Sugar beet fields have lighter tones than grain fields (on both X bands).

Row direction and row spacing for grain fields does not provide significant tonal variation based on a visual assessment of the imagery. However, a change in stand geometry caused by lodging or wind damage provides a change in tonal pattern that, after a preliminary investigation, appears to be unique for this condition.

Future Requirements

1. Information on the relationship between image gray scale and relative signal strength.
2. Processing of the L bands to produce useful imagery.
3. Digital data for all bands from the original signals obtained on the aircraft.

V. ANALYSIS OF SAR DATA OF CROPS NEAR SIMCOE, ONTARIO (Site D)

Abstract

During August 1978, 4-channel Synthetic Aperture Radar (SAR) data of agricultural fields near Simcoe, Ontario were obtained by Agriculture Canada under the Surveillance Satellite (SURSAT) Program. Simultaneous imagery for X-band (HH and HV polarizations) and L-band (HH and HV) were obtained for various crops such as barley, corn, oats, rye, soybeans, wheat, cauliflower, cucumber, potato, strawberry, tobacco, and tomato.

Results obtained from both manual and digital analysis are presented. The manual interpretation indicates that major separation occurs between two classes; grains (wheat, barley,

oats, rye, hay) and non-grains (corn, soybean, tobacco, potato, cucumber, cabbage, cauliflower, strawberries). The harvested winter fields can be delineated from non-harvested fields and also bushland from farmland. The digital data of about 50 fields indicates that best separation among crops occur with X-HV and L-HH channel combination. Corn, wheat, tobacco and cucumber can be discriminated using scattergrams.

Introduction

On August 2, 1978 approximately 40 square miles (10 x 4 miles) area near Simcoe, Ontario were imaged using a 4-channel Synthetic Aperature Radar (SAR) belonging to the Environmental Research Institute of Michigan (ERIM). This SAR imagery of about 2,000 fields, characterized by small irregular acreages and the juxtaposition of a large variety of crops, was obtained by Agriculture Canada under the Surveillance Satellite (SURSAT) Project (Inkster and Kirby, 1977). The analysis was carried out by the Principal Investigator, Mr. G. King, Agriculture Canada, Ottawa, and by the Technical Investigator, Remotec Applications, Inc., St. John's, Newfoundland.

The simultaneously obtained imagery at X-band (3.2 cm) and L-band (25 cm) wavelengths with both HH (Horizontal transmit - Horizontal receive) and HV (Horizontal transmit - Vertical receive) polarizations presented here corresponds to antenna depression angle of 22° from an altitude of 6,500 m. The near edge of the imagery corresponds to a depression angle of 29° and the far edge to 14°. This imagery presented in the slant range mode has a swath-width of about 5200 m and a spatial resolution of 3 m x 3 m and 6 m x 6 m for the X-band and L-band data, respectively. The characteristics of the ERIM SAR system are given by Rawson et al., 1975.

The ground verification data was obtained by visiting the site in June 1980 to coincide with the aerial photographic mission and in July coinciding with the radar pass. A land use inventory was taken on most fields and detailed ground verification data (growth stage, plant height, ground cover, row direction, row spacing plant density, soil and plant moisture) were obtained for about 70 fields. Two types of soil were generally present in the imaged area, the right half contained clay and the left half sandy-loam. Ground photos of representative fields were taken.

The year 1978 was not a representative crop year in the test area due to a late spring and extended drought. Crops were generally two weeks behind "normal" and extremely uneven within a field. The late seeded crops (cabbage, cauliflower, cucumber, pepper, tobacco, tomato) were stunted and grains did not fill properly. As a result, uniformity between and within the field was poor and yields were below average. At the time of the radar flight about 60 percent of the winter wheat fields had been harvested. Similarly, other small grains such as barley and rye were in their later growth stage; ripe to past maturity. Tobacco was beginning to ripen and corn was fully headed at this time. The strawberry fields had been mowed. Some irrigation pattern could only be noticed in the tobacco fields.

Methodology

Radar imagery was available in the form of positive transparencies. From these, positive prints of about two and a half times enlargement were made. To provide a quick-look system beween aerial photos, radar imagery, and base map each zone and crop type was marked on the base map. Using the radar imagery prints and transparencies, tone and texture classes were assigned to all fields in the test area. The four tonal classes assigned varied from very dark (1, no return) to very bright (4, strong return). The three textural classes consisted of smooth (A), rough (B), and very rough (C) texture.

A table of tonal and textural classification of crops within each zone was initially prepared for each radar channel to avoid making comparisons between fields in the near and far range. Similarly, crop to crop discriminating ability was noted in a matrix form for each channel and zone by using a code ND for not distinguishable, D for distinguishable, and SD for sometime distinguishable. This classification procedure is similar to the one used by Shuchman et al. (1975).

Radar imagery of each channel was color coded through a VP-8 Image Analyzer system. The relative density values of representative fields (point measurement) were obtained to produce scattergrams and compute dynamic range and statistical parameters of radar return for channel comparison.

Results

A comparison indicates that bushland areas appearing bright with rough texture can be delineated or all the channels with X-HH providing the best and L-HH the worst discrimination. The harvested winter wheat fields along with some bare fields give darkest tone on all the channels. The fields containing tomato, tobacco, and corn appear brightest on all the channels in general (Fig. 6). The distinction between corn and bushland cannot normally be made on the L-HH but the two can be distinguished on the L-HV imagery. In general, the relative tonal distribution among crops appear to be similar from channel to channel. Most of the crops exhibit middle range of tonal values for X-band and extreme values for L-band. The harvested and non-harvested winter wheat fields can be delineated with X-HH providing the best discrimination between the two.

The number of corn fields out of the total 15 which can be distinguished from winter wheat are 12 on X-HH, 13 on X-HV, and 14 on L-HH and L-HV imagery. But the number of winter wheat fields out of the total 14 which can be distinguished from corn are 11 on X-HH, 11 on X-HV, 13 on L-HH, and 12 on L-HV. Corn is only sometimes distinguishable from barley on X-HH but all the 15 corn fields can be distinguished from barley fields on the L-band channel. This matrix indicates that major separation occurs between two classes; grains and non-grains. The number of fields considered for some crops is too small to draw any meaningful conclusion. The separation within grains (wheat, barley, oats, rye and hay) is difficult as is the separation within non-grain

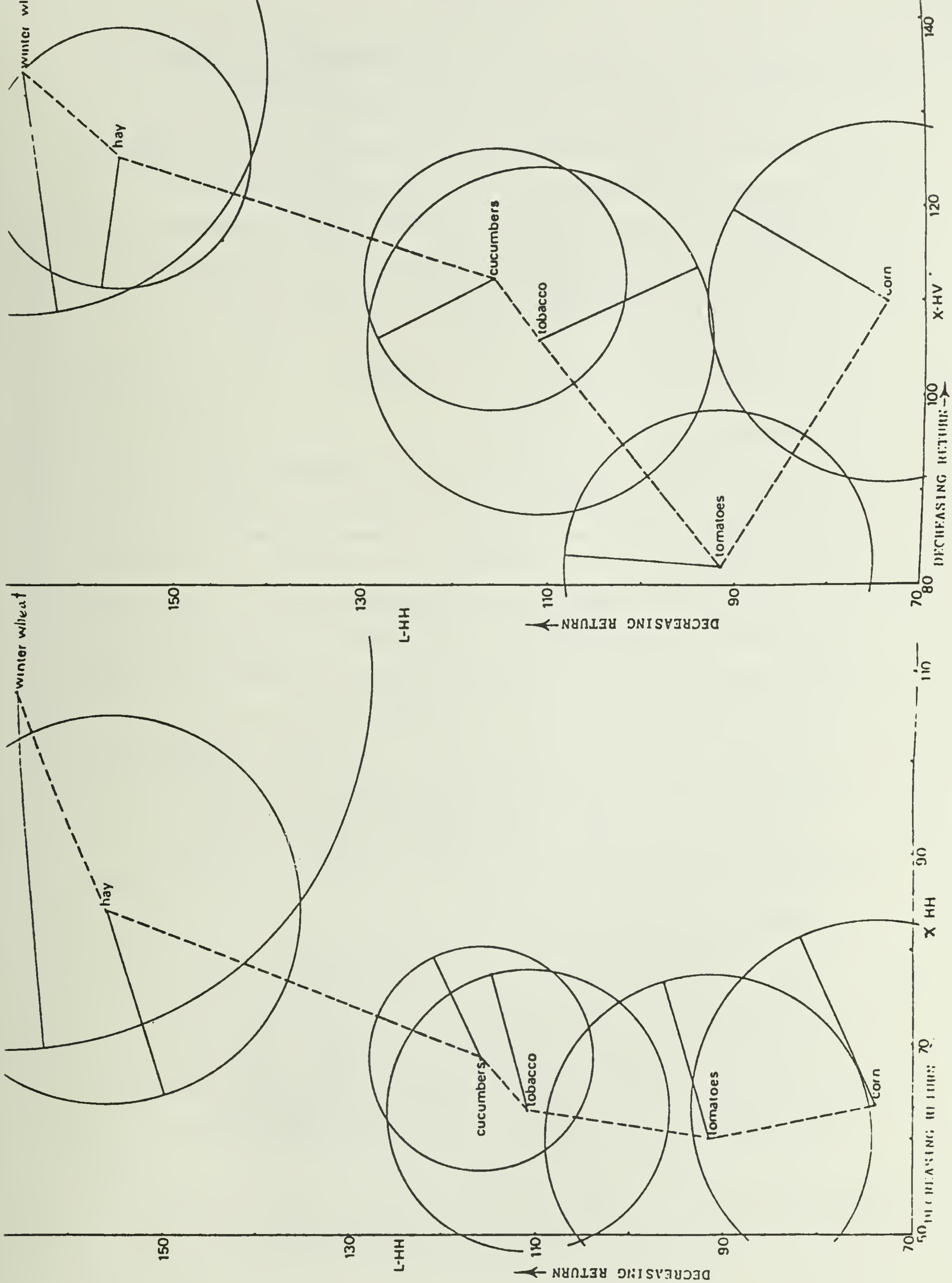

Fig. 6   Discriminability of crops with two bands, L_{HH} and H_{HV}

classes (corn, soybean, tobacco, potato, cucumber, cabbage, cauliflower, strawberries).

The preliminary results of the effect of row direction on the radar return have indicated that some fields having row direction oriented parallel to the sensor look direction (North-South) exhibit a brighter return than the orthogonal orientation (East-West) in accordance with past measurements. The effect of row direction, however, is more noticeable on the X-HH imagery than on other channels possibly because of the quality of other imagery.

Discussion

Although some of the crop and soil parameters which influence radar return are known from the past studies, it is unclear as to how these interact to produce changes in observed tone and texture on a radar image. Even though it was difficult to separate some crops, nevertheless three groups of crops may be separated as shown in Table 5. The number of crops which were in the imaged area (about 18) were too many to separate individually and the number of fields for some crops were too small to establish effective criteria following the manual interpretation. As there are only four tonal classes considered, realistically only four crop classes can be identified on each channel. Although texture does provide added information, but the variations within each crop makes it difficult to assign a mean texture to each crop.

The dynamic range of the exhibited signals is less than 10db. That means each tonal class corresponds to about 2.5db. The changes that can be expected due to variations in crop parameters are smaller than this. As a result, the subtle variations in radar return and multiple bands make it difficult to identify on the basis of manual interpretation alone.

Table 5. Crop Separatability

Relative Intensity of Return	Classification Level I	II	III
Low	Grassland	Hay Pasture Harvested - Cereals - Horticultural	Not Used
Medium	Cropland	Cereals Potatoes Tomatoes Soybean Tobacco	
High	Bushland	Deciduous Coniferous	

Summary of Results

(1) Bushland (deciduous, hardwood trees) areas can be best distinguished from farmland on X-HH.

(2) Corn, tomato, and tobacco can be discriminated from other crops on the basis of high return on L-HH.

(3) Harvested winter wheat fields can be distinguished from non-harvested winter wheat fields, especially on X-HH.

(4) Major separation seems to occur between two classes: grains (wheat, barley, oats, rye and hay) and non-grains (corn, soybean, tobacco, potato, cucumber, cabbage, cauliflower, and strawberry). The separation within grain and non-grain classes is difficult. The number of fields for certain crops is too small to generalize the results.

(5) The manual analysis of radar imagery of agriculture targets can only provide limited information due to:

a) small number of tonal and textural classes that could be effectively classified on the imagery which was available.

b) unsystematic variability in crop and field conditions from field to field.

c) subtle variations in tone and texture due to variations in crop and field parameters.

(6) Multi-channel radar imagery provides more information than an individual channel.

(7) X-HV: L-HH channels appears best in discriminating crops.

(8) The pixel-to-pixel classification and use of the spatial method of classification does not appear to be suitable to the digital analysis of the SAR date of agriculture targets due to speckle and variability among fields belonging to the same crop.

VI. TERRAIN AND VEGETATIVE FACTORS INFLUENCING RADAR IMAGERY OF SOUTHERN ONTARIO (GUELPH)

In February 14, 1977 pre-Sursat imagery was acquired with the ERIM 4-band System on a trial flight over the Guelph test at a time when the ground was covered by ≤ 2 feet of snow (Briscoe and Protz, 1978). The analyses, related to studying topographical soil, geological features, was carried out by R. Briscoe, University of Guelph. The incident radar beam for all channels except X-Band$_{HH}$ penetrated the snow pack which had been subjected to frequent thawing and freezing. Major landscape features and land-use patterns were readily identified. This was followed by a more detailed summer acquisition under the Sursat program in July 1978:

1. To determine if agricultural cover types in the University of Guelph Test strip can be accurately classified using tonal and textural information from 4-channel SAR imagery. Both manual and automatic (digital) classification techniques will be investigated.

2. To determine which of the measured target parameters have a significant effect on the tonal signatures of the crops investigated.
3. To summarize the ground based data, radar imagery and interpretation techniques required to obtain the best classification accuracies for the crop types in the test strip.

Data

Over 300 fields were identified and detailed features were recorded on 48 fields on two dates (August 3 and September 31) on the Guelph test site (crop type, plant height, percent ground cover and slope). Imagery from the airborne, ERIM 4-channel SAR was acquired on August 3 and September 28, 1978. Airborne color IR and Black and White photographs were taken on November 30, 1978.

Analytical Methods

Multiple regression analysis were performed on the data using X-HH and L-HH backscatter values (1-256) as dependent variables and plant height, % cover, % plant moisture, % soil moisture, slope and aspect as independent variables. This was done repetitively until all independent variables had a significant relationship (90% significance level) with the dependent variable (X-HH or L-HH).

Manual discrimination of corn fields was carried out by subdividing the strip into six sections using criteria developed from corn fields in the training sections. Single channel, multi-channel and multi-date imagery were classified and compared. An independent group of several soil surveyors, lacking radar imagery interpretation expertise, were given the discrimination criteria which they then applied to 1 of the testing sections. The results were compared to those who had previous radar experience to compare accuracy of classifications.

A manual discrimination of woods, roughland, hay-pasture, corn and grain fields was carried out in two sub-sections of the test strip using criteria developed from inspection of the training sections. Multi-date - multi-channel radar imagery were used for this analysis.

Digital analysis on the C.I.A.S. from Canada Center for Remote Sensing was done using registered image data sets that had been median filtered to reduce the coherent speckle. The X-HH and L-HH channels, for August and September dates, were used in single-date and multi-date analyses. Both supervised and unsupervised classification techniques were investigated. A second digital analysis of the same registered and median filtered image data sets was performed on the ARIES image analysis system (DIPIX). Image enhancement (using the Karhumen - Loeve principle component transformations) was performed on the image data sets prior to supervised and unsupervised classification.

Results

1. No significant relationship was found between the L-HH channels and any of the measured target parameters. This is probably due to the transparent nature of many of the targets to L-band radar.
2. A significant relationship (Table 6) was found between the X-HH channels and slope, plant height and % cover. The negative relationship between slope and X-HH backscatter values was due to the absence of corn and grain crops (which have the highest return) on fields without flat topography. The positive relationship between plant height and radar backscatter is as expected due to the increase of plant biomass to intercept and return the radar signal. The negative relationship between % cover and radar backscatter was due to the complete canopy (100% cover) of hay and roughland fields which exhibit lower tones on the imagery. The R^2 value was equal to 55.8 with an F-value of 11.49 which is significant at the 99% significance level.

Table 6. Results of regression analysis for X-HH channel

Var.	Coeff.	St. Error	T-Value	Variation
Plant Height	0.16951	0.054410	3.12**	29.59
% Cover	-0.31464	0.151190	-2.08*	6.56
Slope	-4.04530	1.173270	-3.45**	19.03
S.E. of Estimate		18.20316		
F-Value		11.49**		
Multiple R-Square		55.18		

Significance Level *95%
**99%

3. Using single-channel imagery corn field identification accuracies ranged from 58-100%. The use of multi-channel - or multi-date imagery increased accuracies to over 90% in every case. Only 1 X-band and 1 L-band channel are needed as corn can be discriminated from woods on X-band imagery due to textural difference while corn and woods can be separated from all other cover types of L-band imagery due to tonal differences. It was found that no expertise in radar imagery interpretation was needed to achieve these accuracies.
4. For the manual interpretation and multi-date (Table 7), multi-channel imagery corn, roughland and woods were discriminated comparatively easy with accuracies approaching or exceeding 90%. Corn and woods have similar light tonal appearances while roughland exhibited a wide range of tonal values. The use of texture enabled the discrimination of these cover types. Hay pasture and grain crops were consistently confused with each other however, leading to discrimination accuracies of approximately 50%. The overall accuracy of classification was 72.6% for a total of 179 cases.

Table 7. Manual crop classification accuracy achieved with multidate SAR imagery (Aug. 3, Sept. 28).

Crop Type	Fields Correctly Identified		Fields Incorrectly Identified		Fields Not Identified		Total # of Fields
	Number	Accuracy %	Number	Inclusion Error %	Number	Omission Error %	
Site 1							
Forest	8	89	1	11	0	0	9
Roughland	5	83	1	17	0	0	6
Corn	20	91	0	0	2	9	22
Grain	16	50	4	13	12	37	32
Hay-Pasture	10	39	12	46	4	15	26
Site 2							
Forest	12	100	0	0	0	0	12
Roughland	5	72	1	14	1	14	7
Corn	20	100	0	0	0	0	20
Grain	12	52	6	26	5	22	23
Hay-Pasture	11	50	5	23	6	27	22

TOTAL # OF FILES 179

OVERALL ACCURACY 72.6

5. There were considerable problems encountered with digital analysis of the radar imagery on the Image 100. Single-date and multi-date supervised classifications both lead to the same problems. The tonal signatures of woods, corn, roughland, grain and hay-pasture exhibited considerable overlap leading to separability problems for these classes. In general grain and hay-pasture were consistently confused as were woods and corn. Roughlands had the widest tonal distribution and were confused with corn, hay-pasture and grain. These results could be improved by using such approaches as histogram modification to improve class separability. Woods and corn will always be confused using tonal signatures alone but are readily separable using textural information after the classification is completed (by referring to the original imagery). Unsupervised classification was unsuccessful.
6. The use of enhanced imagery on the ARIES system alleviated some of the problems of classification. Both single-date and multi-date enhancements yielded similar results except that cut corn was separable as another class using multi-date imagery. The advantage of using enhanced imagery is that areas of purer tonal representations of the class of interest could be identified and used as training areas to generate each class' statistics. This information is then used in the supervised classification. There was improved separability of hay-pasture and grain using this technique but considerable confusion still existed. Corn and woods were still confused but as before a simple textural analysis on either the enhanced or original imagery would separate woods from corn, especially on X-band channels. The final results of the classification are custered such that no areas of fewer than 3 pixels are classified. As with the image 100 analysis unsupervised classification produced poor results.

Conclusions

1. A more extensive and comprehensive surface truth program is needed to evaluate the relationships between radar backscatter and plant-soil variables for these radar wavelengths.
2. Repetitive radar coverage is needed during the earlier part of the growing season to determine if a time period exists when the cover types investigated in this experiment are more separable on SAR imagery.
3. The use of a median filter (3x3) greatly reduces the coherent speckle in the radar imagery making digital classifications more attractive and useful.
4. Image enhancement appears to be a valuable preprocessing technique for radar imagery analysis.
5. Most agricultural targets appear rather transparent to L-band radar wavelengths suggesting radar bands closer to X-band frequencies may contain more information for agricultural discriminations.

VII. CROP CLASSIFICATION STUDY USING SAR (Site F)

The principle objectives of the study were to identify and then compare crop classification accuracies obtained by radar data to that identified by False-color Infra-red Photography, thermal, and the ground truthed information. The analysis was carried out by R. Paquin and Bonn, Research Station, Agriculture Canada, St. Foye and University of Sherbrooke.

The SAR flight passes for this experiment were conducted on August 19, 1978. Preceeding the passes ground data were collected from 880 fields within the study area. Twenty varieties of crops dominantly arranged in rang system agricultural plots, as well as four soil types, were identified. Coincident meteorological information describing air temperature, humidity, and soil moisture was collected the day before the flight passes. Rain showers on the day of the flights, however, would modify these statistics.

Five somewhat arbitrarily selected tone categories were established for photographically enlarged X-band data. Each field was identified, the tone noted and compared to the actual crop growing in the area. The accuracy of crop identification using the radar data was subsequently compared to the results derived from an analysis of FCIR and thermal information. Gradations in tone on the radar imagery, however, complicated the analysis. Unfortunately only the X-band information was analyzed because the L-band imagery was too dark to be utilized, and reprocessing did not improve it. The results were discouraging. Significant correlations between the tone displayed on the image and specific crop types were nonexistant. Although pasture lands, bare soil, corn, and sugar beets were frequently delineated the accuracy was not as consistent to that which was derived from the thermal or FCIR information.

VIII. IMAGE ANALYSIS OF MIXED CROPS IN A DOMINANTLY LARGE POTATO GROWING AREA (GRAND FALLS, N.B. (Site G)

The objective of the study of the test site in New Brunswick was to investigate classification accuracies using an integrated combination of airborne multi-scanner data (11 channels), synthetic aperture radar data (4 bands), Seasat data and Landsat data (4-bands) with ground control data of crops and crop condition and high resolution field spectra. A test site area (8 km x 8 km) in the main potato growing area of New Brunswick was selected in a cooperative study with various sections of CCRS and New Brunswick Dept. of Agriculture. However, Seasat orbital testing was not completed in time for acquiring data and cloud conditions prevented acquiring the 11-channel airborne data. Thus, the 4-Band airborne data set (minus L_{HH}) was the only data acquired for analysis. The analysis was carried out by D. Goodenough and Staff, Canada Center for Remote Sensing, Ottawa.

A number of signal processing analysis were carried out as part of a pre-classification study for quantitative evaluation:

(1) The output on digital tape from the optical correlation at ERIM.

(2) The digital data from the PDS microdensitometer measurements of film produced by the precision optical processor.

The data were further analyzed by comparing various transformations of the data: square root, linear, and wide band width (Optimize mode). Analyzing various combinations of data is still being carried in various rather complicated procedures: aircraft multispectral scanner, Landsat multispectral scanner data, Seasat SAR SAR 580. The plan is to produce disk files of radiometric correction and geometric correction, utilize a digital terrain model for radiometric correction as well as geometric correction, and integrate the data sets. Having integrated the data sets, and sampled the various resolutions, digital classification procedures for combining aerial photographic data and ground data are being made to conduct spectral comparisons and evaluate channels. We look at the 3 meter by 3 meter spatial features to see whether the spatial information content in the SAR data is substantially greater than the speckle information content.

Studies in using the digital elevation models are required. One of the things that we've done is to develop segmentation techniques. Aerial photographs are taken and select linear boundaries, a transparency of the boundaries are scanned, segmented and labeled. It now becomes a way of producing "ground truth" and this way we can classify segment by segment to produce the classification estimates. Conclusions for the agricultural part of this experiment are if we combined SAR and Landsat data we can recognize potatoes fields from anywhere from 87 to 94% accuracy at a 50 meter by 50 meter pixel size. The average classification accuracy for the seven classes that was tested was 88%. Landsat data alone had the average classification accuracy of 64%. For SAR data the average classification accuracy was 52%. Thus a combination is superior to anyone alone. With the hybrid digital processor at ERIM, the square root mode with the wide band width was found superior. Medium filtering was absolutely to remove the speckle and improve the data for quantitative analysis. Also the digital elevation model was found to be important if SAR data are to be used in any kind of terrain that has significant changes in topography. Even in Grand Falls the data were improved using the DTM future integration of SAR and MSS data. There are significant distortions that are going to demand a use of elevation models when integrating SAR and MSS data: the production of these models is very difficult and there are very few around. The geometric correction of the aircraft SAR data is easier than the airborne spectral scanner data.

IX. ANALYSES OF PROGRAM FOR AGRICULTURAL APPLICATIONS

(a) Technical Feasibility for Crop Discrimination

The first comprehensive study of radar imagery to be undertaken for agricultural applications in Canada was carried out under the Sursat Program over areas having a wide range of crops and management practices before the end of the 1978 growing season. Imagery for two or more bands was successfully provided for six of the eight test sites across Canada as compared to the first ERTS project when imagery for less than 50% coverage was provided (August 1972). Each of the test areas provided different types of data products, interpretive procedures, classification accuracies, and image acquisition problems. Collectively, the studies showed that microwave imagery has the technical capability to produce imagery which can delineate a variety of vegetative features across Canada and to discriminate among most of the major crop groups grown with a practical spatial resolution similar to Landsat systems. Where "good" quality imagery was available in 2 or more of the 4 bands, classification levels approached those of current multi-band satellite (Landsat) systems (eg. Prairie region 10% error) when interpreted manually; thus, providing support for future development of digital analytical system where details of crop effects on backscatter attenuation becomes better understood.

The "self-contained" radiation system provided imagery under a range of adverse weather and nightime conditions so long as stability of the aircraft was not affected. The importance of precision Inertial Navigation System was clearly identified. Of course flight lines resulted in the cancellation of one test site and only partial coverage of several other sites. Quality of the data was highly variable and a critical evaluation of relative advantages among the bands was impossible without calibrated reference or processing controls included in the system. Thus, no definite conclusion could be made on the relative importance of all four bands as good quality imagery of the four bands were not available at any location for direct comparisons.

(b) Analytical Procedures

The approaches to analyzing the data and interpreting the results appear to differ little in principle from those followed in analyzing Landsat or multi-band from aircraft data. Single bands of imagery for any system has limited information; whereas, each additional band provides additional factors for discriminability of features. Crop separability was limited to the few crops grown in regions of low yielding vegetation in sub-arid moisture conditions on Brown Chernozemic soils (Swift Current). Successful identification was possible in the high yielding vegetation regions of sub-humid Black Chernozemic soils (Melfort) and in sub-humid regions in humic gleysolic soils where a wide range of cash crops were grown (Simcoe, Ontario).

The manual photometric procedures used to analyze the imagery for the three Prairie sites (Raymond Swift Current and Melfort) showed that simple layered procedures can provide high levels of accuracy and that expensive equipment is not required if good quality imagery is provided to the interpreter. The manual procedures are similar to those used in the first few years of the Landsat program in quantifying and extracting the information from the imagery and are still used to evaluate data for automated image analyses systems. Even with uncalibrated data processed with no referencing, identifying the major crop groups was achieved for cereals, large seeded crops (docololedenous, grassland, etc. in the mixed cropped areas of the Chernozemic region (Melfort 90%).

The detailed studies conducted on the data from Grand Falls, N.B. illustrate the important need for Terrain Corrections (Slope). Studies conducted at Laval University will contribute significantly to correcting imagery for terrain features. Recent advances being made in TD methods at University of Guelph and elsewhere may assist in these areas. The use of special enhancement analyses used by the Guelph group were of particular interest in increasing accuracy of analyses even when only 2 of the 4 bands were of acceptable quality.

(c) Unique Aspects of Radar

It was unfortunate that no imagery was acquired for the test area containing variations in specific crop and tillage conditions known to influence backscatter. Detailed studies are required to better elucidate many of angular, moisture and crop variables to which microwave energy is more sensitive than the visible energy range is sensitive, eg. Raymond imagery.

Conclusions

1. Synthetic aperture radar offers excellent possibilities for complementing present remote sensing systems which use solar energy sources. Single band radar imagery was only of value in the soil-climatic regions having only a few crops to classify. Multi-band imagery was required for high classification accuracies in areas where a number of crops are grown.
2. Current analytical techniques, developed for analyzing multi-band Landsat data, were shown to offer suitable methodology for analyses of Radar image, eg. Manual Layered Classifiers, Digital Image Analyzers (ARIES). Ground control

data, however, are required to train and verify results in a sampling concept.

3. When used in association with traditional photographic imagery, survey maps, and thematic land-resource maps, the non-cartographic aspects are not a serious limitation to provide information on crops and major land-use feature during unfavorable weather conditions. However, as multi-band imagery is needed, it is essential that correlation among bands be done in the pre-analyses processing phase image development.
4. The program identified many areas for improving reliability, quality, processing, navigational aspects related to availability of image data to the image analyst and interpreter. The program conducted at the several major regions in Canada showed that a number of anonymous image features occurred which requires specific studies for modelling angular density maturity, plant structural interaction effects on each of the wavelengths and polarities.
5. The 1978 program clearly showed that microwave spectroscopy of vegetation can be used to discriminate a number of main crop groups. Therefore, research studies are justified at selected areas for conducting specialized studies to determine fundamental relationships of various crop features and their effect on the backscatter of pulsed radar signals. Initial studies should be established to characterize essential attribution to establish controls and calibration procedures at all stages of acquisition and processing. Afterward, careful studies are needed to clarify relative information on each band in relation to measured crop and soil parameters.

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