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Manual and Automatic Crop Identification with Airborne Radar Imagery

Woods, corn, and roughland were identified most accurately (≥ 89 percent) while hay-pasture and grain fields were consistently confused (≃ 50 percent).

Abstract: *Manual and automatic crop discrimination using multidate radar imagery is presented and discussed. Woods, roughland, and corn were identified with accuracies approaching or exceeding 90 percent when using image tone and texture as the key discriminants. Hay-pasture and grain fields were consistently confused, however, leading to identification accuracies of approximately 50 percent. Although image enhancement prior to supervised classification was helpful, the lack of textural information in the digital classification led to increased class confusion due to the overlapping tonal distributions of the five classes investigated. Hay-pasture and grain fields may be more accurately identified if imagery is collected during the growing season when these two crop types are at their maximum difference in geometrical and dielectrical properties.*

Introduction

Information on the condition, acreage, and distribution of the world's major cash crops is needed on a timely basis for efficient marketing decisions. Crop Information Systems (C.I.S.) are thus being developed to provide this kind of data (King, 1979). Microwave sensors may provide valuable input to a C.I.S. because of their independence from solar illumination and weather conditions. It has been demonstrated that microwaves may be used to discriminate between crops (Schwarz and Caspall, 1968; Haralick *et al.*, 1970; Batlivala and Ulaby, 1975; Bush and Ulaby, 1978). However, the interpretation methodology and system parameters need to be more fully developed before the operational use of microwave data in C.I.S. is possible (King, 1979).

The Canadian Surveillance Satellite (SURSAT) Project was designed to determine the technical feasibility of satisfying the surveillance needs of various government departments using microwave sensors. This project included The Agricultural Working Group, which was interested in information about crops and soils that could be extracted from airborne radar imagery. The work presented in this paper resulted from an experiment the authors conducted as part of this working group (Brisco and Protz, 1979; Brisco and Protz, 1980b). Both manual and digital multi-date crop classification results using airborne synthetic aperture radar (SAR) imagery are presented and discussed.

Airborne and Ground Based Data Collection

The University of Guelph Remote Sensing Test Strip from northwest of Elora to the southeast of Hamilton, Ontario was used as the study area (Figure 1). Airborne SAR data were collected on 3 August and 28 September 1978 by the Environmental Research Institute of Michigan's (ERIM) four channel radar system. This radar system was installed in the Canada Centre for Remote Sensing (C.C.R.S.) Convair 580 aircraft and is now a com-

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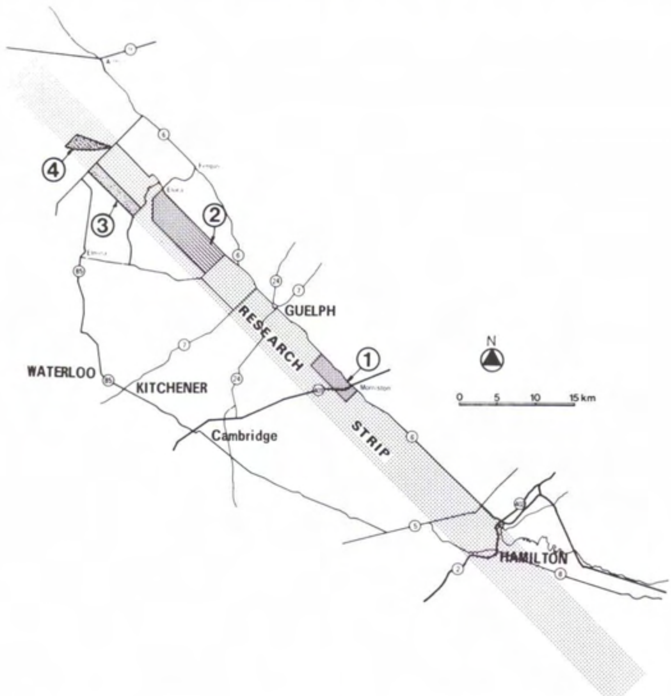


FIG. 1 Location of the University of Guelph Test Strip and the training and testing sections.

ponent of their airborne data collection program. Flight and radar system parameters pertinent to these flights are listed in Table 1. Black-and-white and color aerial photographs were taken of the same area on 30 October 1978, the first date a C.C.R.S. aircraft was available. This late photography proved useful for confirming field boundaries and cover types.

Prior to 2 August, the two training sections (1 and 2, Figure 1) were inventoried according to crop type. Only fields easily reached from roadways bordering these areas were identified, numbered, and recorded. On both flight dates six representative fields of each crop type were visited for surface truth data collection. The inventory crop, soil, and landform observations are presented and discussed by Brisco and Protz (1979, 1980a).

MANUAL CLASSIFICATION OF RADAR IMAGERY

The August radar imagery for section 2 of the test trip is presented in Figure 2. All four channels from each flight were used for a multi-date crop classification for the five classes: woods, corn, roughland, grain, and hay-pasture.

Roughland describes fields that have been previously cleared but uncultivated for a number of years. Interpretation criteria were developed by inspection of the known fields of these cover types in the training sections (1 and 2; Figure 1). The resulting interpretation key was used to classify all fields within the testing sections (3 and 4; Figure 1) as one of the five cover types. Identification was calculated by comparing radar imagery interpretation to the color aerial photography on a field by field basis. Due to the late date of the aerial pho-

TABLE 1. FLIGHT AND RADAR SYSTEM PARAMETERS FOR THE SAR DATA COLLECTION

Radar System	— ERIM 4 channel SAR	
Wavelength	— X: 3.0 cm	L: 25.0 cm
Antennae Depression Angle	— 22°	
Polarization	— X: HH, HV	L: HH, HV
Pulse Length (μ sec)	— Aug. PRF 3373 X: +41.6 L: +43.1	Sept: PRF 3200 X: +40.5 L: +42.5
Altitude	— Aug. 19,000 ft. A.S.L.	Sept: 19,500 ft A.S.L.
Time	— Aug: 20:45-20:58	Sept: 20:15-20:26

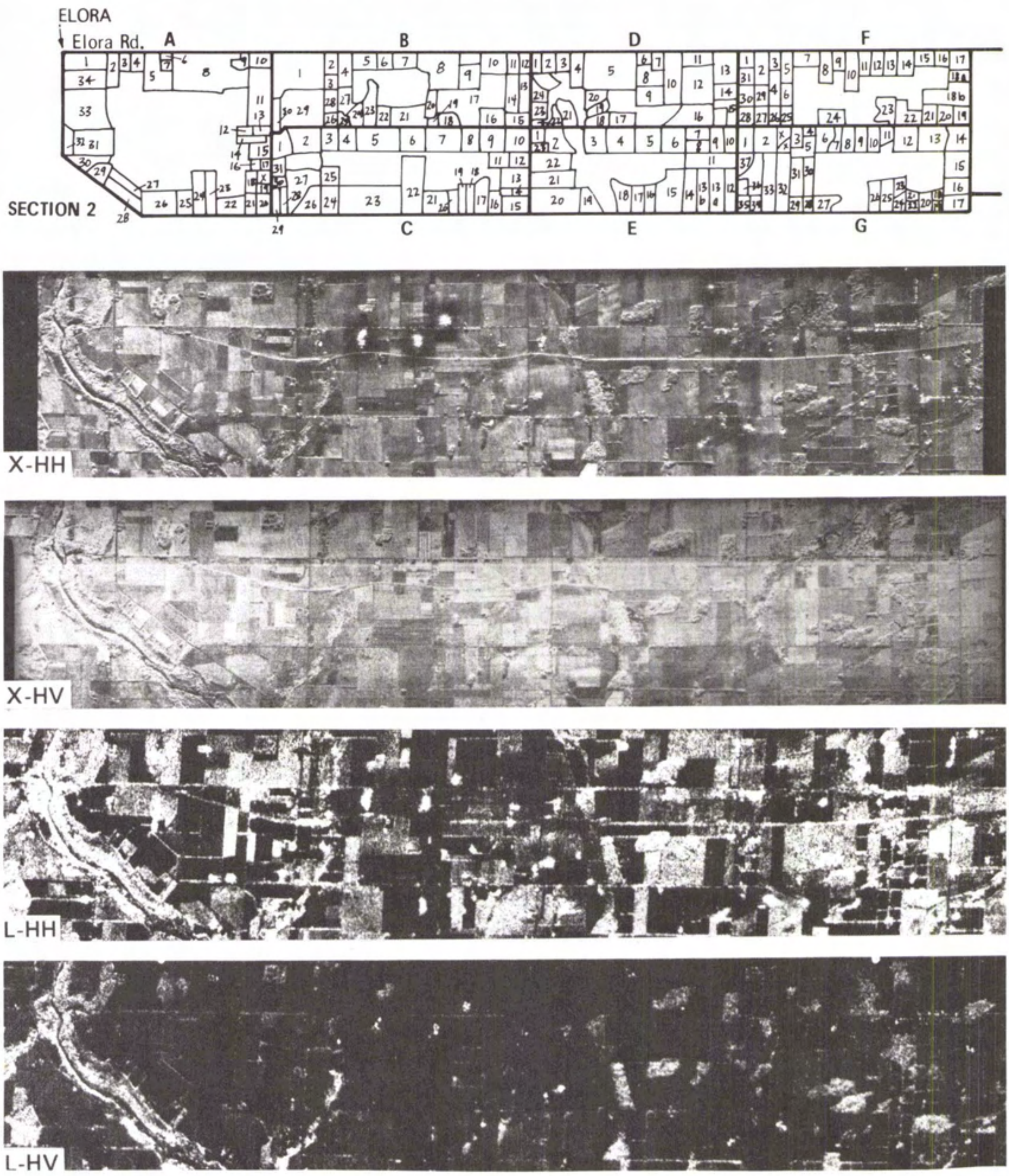


FIG. 2. Inventory field locations and radar imagery for section 2. August.

tography acquisition (30 October), many fields had their surface cover altered by harvesting and tillage operations. Thus, it was assumed that if a field were classified as either corn or grain it was correctly identified if it appeared as a bare surface on the photography. Hay-pasture and roughland fields were assumed to be unaltered; thus, if they were bare on the photography, they were considered incorrectly identified fields.

Digital Classification of Radar Imagery

Inspection of Figure 2 reveals some problems with the radar imagery. The L-HV channel exhibits vertical banding and a low signal-to-noise ratio, limiting the use of these data in an automatic classification. The August X-HV and September L-HV channels were also of limited use due to these problems. As a result, the digital analysis was concentrated on the use of the like-polarized channels. The optically processed image films for both dates were digitized at C.C.R.S. using the PDS microdensitometer. The resulting disk files were read on to magnetic tapes for subsequent digital analyses on the Applied Resource Image Exploitation System (ARIES). Due to the limited system time available, only section 2, which has a more uniform topography and more intensive agricultural use, was utilized.

The four-channel data set was registered using manually selected ground control points with the L-band channel registered to the X-band channel. After the two channels for each flight data were registered, these two data sets were registered to create the multi-date image set. This was subsequently median filtered using a 3 by 3 box car filter to reduce the coherent speckle associated with SAR data (Lowry *et al.*, 1978). The multi-date image was then enhanced using the Karhumen-Loeve (K-L) principal component transform (Kourtz and Scott, 1978) prior to supervised and unsupervised classification. Corn field identification accuracy for section 2 was calculated in a manner similar to the manual classification.

Results and Discussion

The manual interpretation key developed from known fields in the training sections is presented in Table 2. An overall identification accuracy of 72.6 percent was obtained with corn, woods, and roughland being the least confused classes (Table 3). Hay-pasture and grain fields were consistently confused with each other, leading to identification accuracies of approximately 50 percent. Some of the identification errors can be attributed to the date of the color aerial photography acquisition and the assumptions made for hay-pasture and grain field identification. For example, some hay or pasture fields may be tilled, in preparation for a new crop, and thus be interpreted incorrectly as a grain field. Less frequently, a roughland or fallow field may be brought back into crop production, leading to an interpretation error. This illustrates the necessity of having the aerial photography collection timed synchronously with the radar flights, if the photographs are to be used for checking the interpretation accuracy. Although this would be a small source of error, it is avoidable.

Corn and woods are readily discriminated from all other classes when using a two-channel combination of X- and L-Band data. Corn and woods are the only vegetative targets exhibiting high returns on the L-Band channels, while the smooth textural appearance of corn on X-Band channels allows it to be separated from woods (Brisco and Protz, 1980b). Batlivala and Ulaby (1975) found that corn and woods were confused on the ERIM L-Band like-polarized channel, with the use of the cross-polarized channel increasing separability. They reported accuracies of only 65 percent and 74 percent, illustrating the improvements possible when X-Band data are included in the analysis. Similar results were reported by Ulaby *et al.* (1980), again using only L-Band data, with these authors indicating that shorter wavelengths (< 3.75 cm) are preferred for crop discrimination.

Roughlands generally have a large variability of vegetative cover type and distribution and thus exhibit a rough image texture. This enables accurate discrimination from the other cover types. The hay-pasture and grain fields, however, have overlapping tonal and textural appearances, resulting in identification accuracies of 50 percent or less. Although some of the error may be attributed to the color aerial photograph interpretations, as previously mentioned, the hay-pasture and grain fields remain the most confused classes.

Image texture was used extensively in the interpretation procedure, and a more quantitative approach may improve classification accuracy sig-

Table 2. Image Interpretation Key for Manual Classification of Corn, Woods, Hay-Pasture, Grain and Roughlands

1.0	Medium to High Return on X-Band -- 2.0
1.1	Low to Medium Return on X-Band -- 7.0
2.0	High Return on L-Band -- 3.0
2.1	Low to Medium Return on L-Band -- 4.0
3.0	Rough Texture on X-Band ------ *WOODS*
3.1	Smooth Texture on X-Band ------ *CORN*
4.0	Medium Return on L-Band -- 5.0
4.1	Low Return on L-Band -- 6.0
5.0	Rough Texture on X-Band -- *ROUGHLAND*
5.1	Smooth Texture on X-Band -- *GRAIN*
6.0	Rough Texture: Lower Return on X-Band ------ *HAY-PASTURE*
6.1	Smooth Texture: Higher Return on X-Band ------ *GRAIN*
7.0	Low Return on X-Band ------ *HAY-PASTURE*
7.1	Medium Return on X-Band ------ 8.0
8.0	Rough Texture on X-Band ------ *HAY-PASTURE*
8.1	Smooth Texture on X-Band ------ *GRAIN*

TABLE 3. MANUAL CROP CLASSIFICATION ACCURACY ACHIEVED WITH MULTI-DATE RADAR IMAGERY

Crop Type	Fields Correctly Identified		Fields Incorrectly Identified		Fields not Identified		Total # of Fields
	Number	Accuracy %	Number	Inclusion Error %	Number	Omission Error %	
			Section 3				
Woods	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
			Section 4				
Woods	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 Fields		179
					Overall Accuracy		72.6

nificantly. The information content of texture on radar images is considerable and should be included in image analyses (Lowry *et al.*, 1978). Morain (1976) emphasizes the importance of texture in radar image interpretation for vegetation and suggests that micro-texture may be the most useful. Texture has been used for crop discrimination before (Kedar and Hsu, 1972), and the methodology should be developed to incorporate this information into crop identifications with SAR data. Enlargement of the imagery may also improve the identification accuracy by making the location of field boundaries more visible. Several very small fields in close association with large fields of a similar cover type were not separated from the larger field. This source of error may be greatly reduced when working with enlarged imagery, a technique which is currently being investigated.

Registration accuracy of one line and one pixel was achieved, which was considered adequate for the subsequent digital analysis. The multi-date enhanced image (of a portion of section 2) is presented in Plate 1. Although Lowry *et al.* (1978) reported that principal component enhancements worked poorly on their SAR data, the K-L transform applied here proved helpful. Corn and forested areas are enhanced and still separable because image texture has not been lost. Some hay-pasture (purplish) and grain fields (orangish) appear as relatively uniform fields, but there is still considerable overlap between these two classes. The enhanced image was used for training site selection, prior to supervised classification, because the interpreter could select "purer" areas of each class from the enhancement for generating the class's statistics.

The resulting supervised classifications, for the same portion of Section 2, is presented in Plate 2. Clustering the final product (no area of three or less pixels is independently classified) resulted in fields being identified more uniformly as one cover type. Image texture is lost in the spectral classification such that woods are either red (corn) or yellow (signal saturation). Thus, corn fields, red for standing corn an mauve for cut corn, are identified with 75.7 percent accuracy when woods are included as a confusion class. However, forests are easy to identify on the raw image (Brisco and Protz, 1980b) or on the enhancement and can be separated from the corn fields. When this is done corn field classification accuracy increases to 95.5 percent. Class impurity, represented by more than one color in one field, is present in the corn fields and is common in all other classes. The presence of an area of poor crop growth, due to the dry conditions of the 1978 growing season, usually accounts for the impurity in the corn fields (see Plates 1 and 2). Identification accuracy was not calculated for the other cover types because the class confusion is so great that it would be difficult to classify a field as one cover type or another.

As with the manual classification, the greatest confusion exists between the grain fields and the hay-pasture fields due to the overlapping tonal values. The problems of spectral overlap between the classes are illustrated in Figure 3 by the histograms generated on the C.C.R.S. Image 100. Note the bimodal distribution in the August L-HH data for grain fields. As described earlier for corn fields, the 1978 growing season was quite dry, resulting in areas of poor crop growth within some fields. The secondary peak in the grain's histogram could represent slight depressions in the

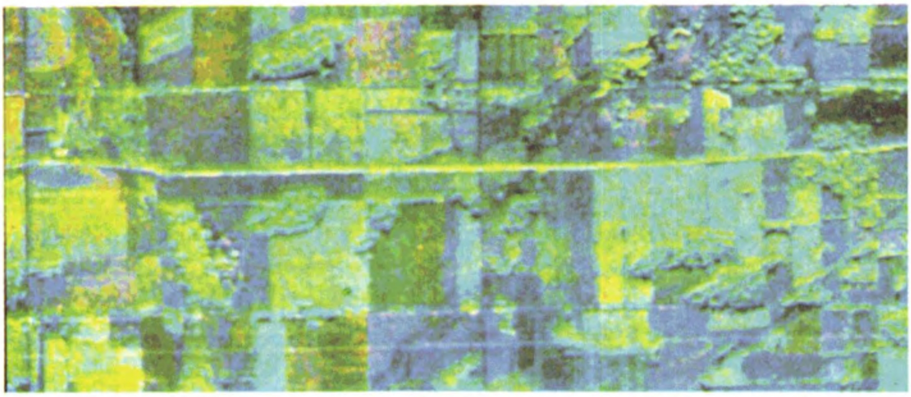
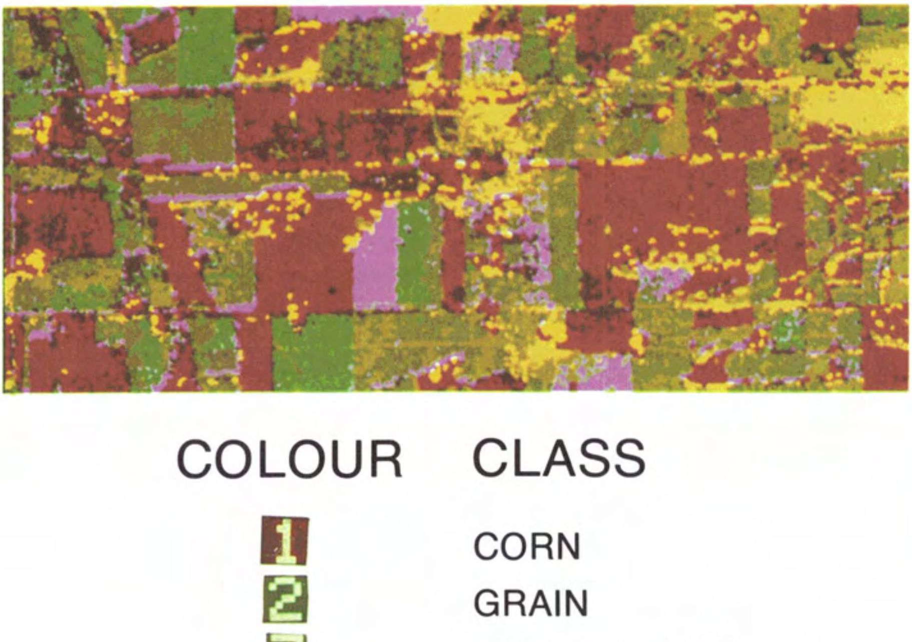


PLATE 1. Multi-date image enhancement from ARIES.



COLOUR	CLASS
1	CORN
2	GRAIN
3	HAY-PASTURE
4	CUT CORN
5	SIGNAL DEPRESSION
6	SIGNAL SATURATION
7	UNKNOWN
8	UNKNOWN

PLATE 2. Supervised classification of multi-date SAR imagery from ARIES.

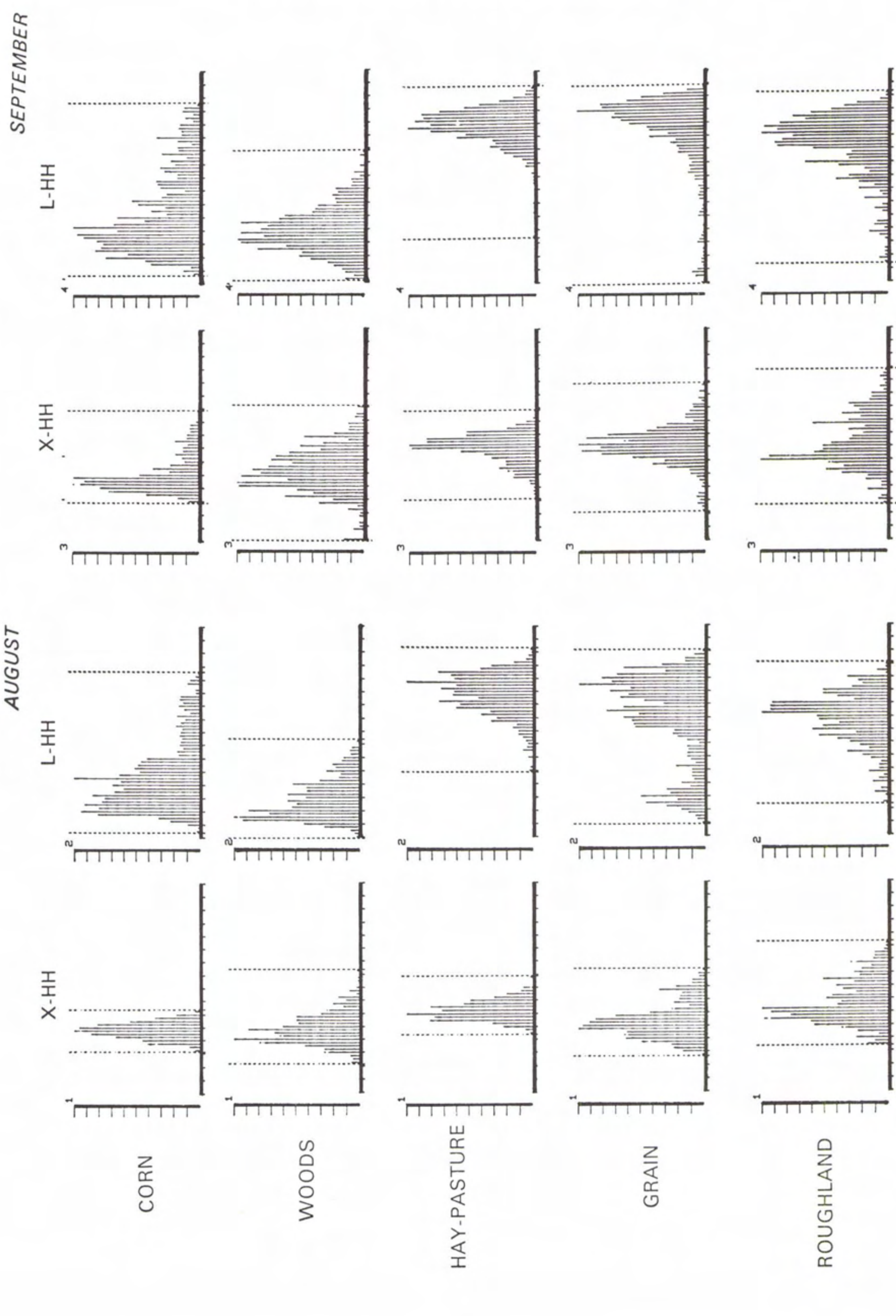


FIG. 3. Histogram displays for corn, woods, hay-pasture, grain, and roughland cover types for two dates, 3 August and 28 September 1978.

TABLE 4. ESTIMATED CROP HEIGHTS FOR NORMAL PLANTING IN THE GUELPH AREA. HEIGHTS IN CM—RANGES INDICATED ARE ESTIMATES OF 10-90: PROBABILITY RANGE. SUPPLIED BY DR. T. B. DAYNARD, CROP SCIENCE, UNIVERSITY OF GUELPH

	June		July		August		September	
	1	15	1	15	1	15	1	15
Corn	0-20	10-40	20-60	60-120	120-220	180-230	same	-------->
Spring grains	5-15	20-50	40-90	60-90	same	0-90	0-90	0
Winter grains	20-50	50-100	70-100	70-100	0-100	0	0	0
Alfalfa grass	40-90	10-100	same-------------------	-------------------	-------------------	------------------->	20-100	same

fields, which would result in more moisture availability and thus more vigorous crop growth. This large within-class tonal variability in SAR data makes unsupervised classifications difficult due to the large number of machine generated classes that result. Unsupervised classification on the ARIES system did not produce as good a final product as the supervised classification and thus the results are not presented. This class confusion would be reduced if the time periods for SAR data collection would correspond to times that maximum difference in dielectrical and geometrical properties exit in the various cover types. The observation that plant moisture contents vary at crop maturity (Ulaby and Bush, 1975; Ulaby and Bush, 1976) and the data presented in Table 4 may be used to select these time periods. For example, SAR data collected around middle June, after the first cut of hay, and again in late August, after the grains have been harvested, may allow for the maximum separability of these two cover types.

Image texture was used extensively in the manual interpretation but was not included in the digital classification. This element of image interpretation is important in automatic classification of radar data and should be available for future analyses (Lowry *et al.*, 1978). Alternate filtering and enhancement methods should be employed and evaluated, as well as the use of boundary algorithms and thresholding procedures, for digital analyses of SAR data. Although the state-of-the-art is not adequately developed for the operational use of SAR data in a C.I.S. as yet, future research may make this type of remotely sensed data an integral part of such an information system.

CONCLUSIONS

- An overall accuracy of 72.6 percent was achieved for the discrimination of woods, corn, roughland, hay-pasture, and grain fields on multi-date SAR imagery using manual interpretation methods. Woods, corn, and roughland were identified most accurately (≥ 89 percent) while hay-pasture and grain fields were consistently confused (≃ 50 percent).
- Image enhancement using the K-L transform improved the image appearance for digital classification procedures. Supervised classification yielded the best results although the lack of textural measure resulted in increased class confusion compared to the manual interpretation.
- Hay-pasture and grain fields may be more accurately identified if the SAR imagery collection was timed with the crop calendar. The time period should be chosen to maximize the difference in the crops geometrical and dielectrical properties.

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Commission III: Mathematical Analysis of Data
Working Group III-4

The co-chairman of Commission III, WGIII-4 on "Mathematical Aspects of Image Registration, Rectification, and Enhancement" would like to remind participants and potential participants that there will be an Inter-Congress Symposium of Commission III at

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The co-chairmen are also tentatively considering holding a Working Group meeting in Denver during the 1982 ACSM-ASP Convention (14-20 March 1982). By that time, it is hoped that the WG Symposium Session(s) will be fairly well stabilized.

If you plan to present a paper related to the WGIII-4 area at the symposium, please send the abstract *as soon as possible* (deadline for abstracts in Helsinki is 31 January 1982) to

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