

SATELLITE DATA ANALYSIS FOR INVENTORYING CROPS
GROWN IN A COMPLEX, SMALL-FIELD ENVIRONMENT

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ABSTRACT

A multifaceted investigation is examining whether the cost effectiveness of crop surveys in an environmentally complex state such as New York can be improved through incorporation of satellite-derived information. Emphasis has been placed on Landsat thematic mapper (TM) data for identifying specific crops (vegetables, fruit-tree orchards, vineyards) and for assessing the effect of regional variation on a statewide inventory. For crop identification, spectral information has been found crucial but not always adequate without spatial information. Even when spectral information is adequate, regional variation can alter the classification process. Results to date have been promising.

1. INTRODUCTION

The use of satellite images for identifying and inventorying cultivated crops has proven most successful in regions characterized by large fields and homogeneous cropping practices (NASA, 1979; Mergerson, 1981; AgRISTARS Program Support Staff, 1982). Recognizing that many important crops and agricultural regions in the world are not associated with large fields or low diversity (Pitts and Badhwar, 1980; Bowker, 1985), investigators have explored the problems of conducting satellite-based inventories in more complex environments (e.g., Hixson et al., 1980; Holko, 1982; Thomas et al., 1984; May et al., 1986; Badhwar et al., 1987). Results have consistently shown reduced accuracies of crop identification.

To date, most crop inventory studies have relied on Landsat multispectral scanner (MSS) data. Although numerous investigators have pointed to the comparative value of higher resolution, Landsat thematic mapper (TM) data (e.g., Badhwar et al., 1984; Crist and Cicone, 1984; Williams et al., 1984), little has been done on actual crop identification, and the work has not progressed from experiment to operational crop inventory. In most instances, moreover, TM studies have focused on large-area crops (e.g., Badhwar, 1984).

This report summarizes a multifaceted investigation of satellite data for crop inventory in New York State. In the aggregate, agriculture is New York's largest industry. While agribusiness is

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dominant, the state is also a leading producer of livestock products, specialty crops (fruits and vegetables), and several other crops (e.g., silage corn, hay). Because New York is highly variable in soils, topography, climate, field shapes and sizes, and cropping diversities, the investigation has placed primary emphasis on TM data. Begun in mid-1983, the work has been funded through a Cooperative Agreement (no. 58-319T-3-0208X) between Cornell University and the U.S Department of Agriculture, National Agricultural Statistics Service (formerly, Statistical Reporting Service).

2. RESEARCH APPROACH

The goal of the investigation is to determine whether the cost effectiveness of crop surveys in New York State could be improved through incorporation of satellite-derived information. Toward this end, the work is addressing two questions: (1) can individual crops be reliably identified with satellite data, and (2) can satellite data be used to perform a systematic inventory of all major crops as they occur throughout the state. Specialty crops (fruits and vegetables) were chosen as the initial focus for crop identification, and the effect of regional variation on crop classification was chosen as the initial parameter to be assessed for statewide inventory. Because earlier studies of specialty crops have shown the spatial resolution of Landsat MSS to be generally lacking (Morse and Carr 1983; Ryerson et al., 1979 and 1981; Zhu et al., 1983), this investigation was performed with Landsat TM data, the highest resolution satellite data available at the time the work began.

The accuracy with which TM data can be applied in identifying commercially grown specialty crops was examined initially in two studies, one on vegetables (Williams, 1986; Williams et al., 1987) and the second on fruit trees (Gordon, 1985; Gordon and Philipson, 1986; Gordon et al., 1986). A subsequent TM study was begun to assess the feasibility of identifying vineyards (L. Trolier, unpublished results), and a follow-up, TM analysis was begun to extend the original findings with fruit trees (Taberner et al., 1987). Concurrent with the latter studies, a broader scope analysis of the effect of regional factors on crop separability was begun to determine the extent to which New York's environmental complexity would affect the design of a statewide inventory with satellite data (Buechel et al., 1987).

Although work to date has emphasized Landsat TM data, preliminary crop-identification studies have been conducted with SPOT satellite data, and NOAA/AVHRR satellite data are being considered for defining New York "regions." Work with SPOT will be expanded substantially.

3. METHODS AND MATERIALS

Computer-compatible tapes of TM scenes were acquired to cover selected areas of specialty crops and to represent statewide, regional variation. Scene selection was based on crop calendars and the availability of scenes with acceptable cloud cover. Supporting the TM data were detailed field observations; crop and cropping information from growers, Cooperative Extension agents and/or the USDA Agricultural Stabilization and Conservation Service (ASCS); existing aerial photographs, including medium-scale, 35-mm color slides flown for the ASCS; and various maps and reports (geology, soils, topography and climate). Additionally, to support the vegetable and follow-up, fruit tree analyses, the New York Crop Reporting Service was able to provide plot maps of vegetables

cultivated on mucklands and the results of a statewide fruit-tree census. Two growing seasons were also spent collecting field spectroradiometric measurements of major vegetable crops. (Field reflectance data did not extend to wavelengths longer than 1.1 micrometers.)

For the initial studies, image analyses were conducted on a minicomputer-based system (International Imaging Systems model 70, with a host VAX 11/750). For reasons of economy, however, later efforts shifted to microcomputer-based systems (an ERDAS System, with a host IBM PC/AT, and an IBM PC/AT with specially written image processing software).

For visual and digital classification of vegetables and vineyards, the analysts have relied on the spectral properties of crops; but for classification of fruit trees, greater weight has been placed on spatial properties. Regional variation within and among cropping areas has been examined through statistical comparisons of crop spectral data from sample locations, across the state.

4. RESULTS AND DISCUSSION

4.1. VEGETABLES

TM data appear capable of providing reliable identifications of major vegetable crops, except in the smallest fields (those with one dimension smaller than approximately one TM pixel). The results of classifying upland and muckland vegetables, using a supervised, maximum likelihood classification of four bands of a *single* August TM scene, are reported in Table 1.

Table 1. Confusion matrix from classifying vegetables with bands 3 through 6 of an August TM scene (Williams et al., 1987).

	PERCENT OF CLASSIFIED PIXELS ¹								UNCL	NUMBER PIXELS
	CORN	CABB	BNY	BNM	UPOT	MPOT	LET	ONI		
UP CORN	87	1	0	0	0	0	0	0	12	194
UP CABBAGE	1	75	0	0	0	0	0	1	23	507
UP BEAN,young ²	0	0	9	10	0	0	0	0	86	106
UP BEAN,mature	0	0	0	96	0	0	0	0	4	71
UP POTATO ²	0	0	0	4	96	0	0	0	0	41
MUCK POTATO ^{2,3}	0	0	0	7	0	90	0	0	3	29
MUCK LETTUCE ²	0	0	4	0	0	0	96	0	0	31
MUCK ONION	0	0	0	0	0	0	0	96	0	389

1 Three standard deviations are used for classification.

2 Training and testing done on the same field.

3 Class divided into mature and senesced.

Testing found accuracies of at least 90 percent for three vegetables grown in mucklands, and at least 75 percent for three of four vegetables grown in uplands. Although highest accuracies with single-date classification were obtained late in the season, when the crops were mature, a second, earlier scene may be needed for some crops.

Of possibly greater significance for crop inventory is that visual identification of vegetables (performed from the digital display) was even more successful than the digital classification. Nearly all fields of known crops could be identified (particularly, with the band-color assignments of bands 3, 4 and 5 projected in blue, red and green, respectively). Whereas planting date variability led to confusion in the digital classification, the resultant spectral differences could be accommodated in the visual classification. Overall, digital analysis might provide a more rapid classification, but visual analysis should provide higher accuracies. The higher accuracies with visual identifications suggest that digital classifications can be improved.

Future efforts will expand the sampling base for vegetables and begin to address yield relationships. SPOT data will be examined to determine whether the increased spatial resolution can substitute for TM band 5, a spectral band which is important for vegetable identification but absent from SPOT.

4.2. FRUIT TREES

Orchards used for training and testing were identified on aerial photographs and characterized fully on the ground. Nevertheless, initial attempts to classify different types of fruit-tree orchards showed much confusion among the orchards as well as between orchards and other cover types. This is mostly attributed to the large contribution of background to the reflectance of young and mature orchards. As a consequence, the effort was redirected toward isolating orchards, as a class, from other cover types. The approach was to distinguish orchards from two groups of confusing, vegetative cover types: those phenologically different from orchards (field crops, pasture, and abandoned or idle fields) and those phenologically similar to orchards (mixed deciduous forests).

Separating orchard from non-forest vegetation was accomplished best through multi-date classification, using bands 3,4 and 5 of TM scenes acquired on two dates in the growing season, June and August (need not be same year). Testing found fewer than 8 percent of the non-forest vegetation pixels misclassified as orchards.

Because of the spectral overlap between orchard and mixed deciduous forest, the separation of orchards from forest had to rely on image texture. A filter was applied to enhance the texture of bands 4 and 3 prior to ratioing, smoothing, and level-slicing to a binary image on the basis of supervised training. Including the binary image in supervised classification of single date imagery reduced misclassifications of forest as orchard from 75 percent of the forest pixels to fewer than 7 percent.

As a final step in isolating orchards from all other vegetative cover, the binary image was included with the other multi-date TM bands in supervised classification. Misclassification of forest

pixels was reduced to fewer than 2 percent of the pixels, and misclassification of non-forest vegetation pixels was reduced to 4 percent or fewer. Although orchards could be successfully isolated, a relatively high percentage of orchard pixels were not classified as orchards. Results to date have shown this error of omission to be quite uniform. If this is found to be the norm, TM data could be used to isolate a relatively constant fraction of the total orchard acreage, which could then be used as a base for estimating total acreage.

Ongoing work with TM data on orchards is using more complete training data to re-evaluate the spectral separability of specific types or sizes of fruit trees through an in-depth assessment of pixel-value distributions in color space. As an extension of the texture-enhancement procedure, emphasis is being placed on Fourier transforms to better characterize orchard spatial properties. Ideally, the spectral and spatial analyses should lead to reduced errors of omission, with no increase in errors of commission, and to the capacity to extract orchard-specific information. The results with TM notwithstanding, follow-up efforts will focus on SPOT data, particularly, on their increased spatial information.

4.3. VINEYARDS

Vineyards in two locations of New York were analyzed with either early-season (June) or late-season (August) TM coverage. No mid-season, cloud-free coverage of vineyards was available. In general, spatially unique clusters or larger blocks of vineyards were usually separable visually, at either date. In the early-season coverage, vineyards exhibiting characteristics of "average" management could be distinguished reasonably well; however, poorly managed (weedy or unpruned) and abandoned vineyards were often confused with brushland, and very well-managed vineyards were often confused with exposed soil (Table 2).

In the late-season coverage, much confusion occurred between vineyards and brush or some field crops. The late-season spectral overlap is at least partly attributed to the practice of allowing weeds to grow after the vines mature (reduces soil loss and damage caused by harvester; also, competition causes more vine energy to be used to ripen grapes rather than develop foliage).

Follow-up analyses are planned with mid-season TM coverage. Mid-season images should capture vineyards at full vegetative development, while weeds are still being controlled. Contextual information may also be incorporated since vineyards in New York are normally associated with lake or other physical features. Lastly, SPOT data will be examined. The increased resolution should aid significantly in vineyard identification.

4.4. REGIONAL VARIATION

In assessing the effects of regional variation on crop separability, the immediate objectives are to determine the impact of particular environmental factors on *early season* crop variability, and to assess that information in terms of the need for, and type of inventory approach which might be required in New York State. To answer these questions, crop (corn, hay, cut-hay, wheat, oats, and

Table 2. TM mean (and standard deviation) digital counts for vineyards and other cover types in western and central New York .

COVER TYPE	THEMATIC MAPPER BANDS							NUMBER PIXELS
	1	2	3	4	5	6	7	
<i>JUNE DATA -- WESTERN NEW YORK</i>								
<i>vineyard</i>								
well-managed	96(3)	42(2)	50(3)	100(7)	132(5)	140(3)	58(4)	173
average	92(3)	40(2)	42(2)	116(6)	117(4)	135(2)	48(4)	210
weedy	90(2)	38(2)	37(2)	130(6)	113(4)	135(2)	40(2)	179
abandoned	83(2)	36(2)	30(2)	135(10)	90(4)	130(2)	27(2)	225
<i>grass</i>								
	92(2)	40(2)	39(3)	137(6)	129(4)	146(3)	42(2)	120
<i>brushland</i>								
	86(2)	39(1)	34(2)	133(6)	95(4)	132(2)	28(2)	238
<i>forest</i>								
	77(1)	30(1)	24(1)	51(7)	85(5)	122(1)	22(2)	852
<i>AUGUST DATA --CENTRAL NEW YORK</i>								
<i>vineyards</i>								
	79(3)	33(3)	31(4)	99(9)	86(11)	131(2)	30(5)	854
<i>brush</i>								
	78(2)	34(2)	34(3)	92(10)	96(6)	132(2)	32(3)	661
<i>forest</i>								
	91(14)	37(12)	36(9)	119(15)	85(11)	119(4)	28(6)	1600

pasture) and other supporting data were collected for 30 sites across the state. (The size of each site is defined by a 512-by-512 TM-pixel window.) Ongoing analyses and site comparisons are examining statistical relationships between regional parameters (e.g., soil drainage, topography and growing degree days) and crop spectral characteristics measured as (1) normalized vegetation index, (2) divergence of the crop spectral distributions at each site, and (3) unsupervised classification accuracies at each site. Preliminary results indicate that the regional characteristics of greatest importance in explaining the crop variability measures are strongly dependent on crop type and the particular separability measure examined. As planned, follow-up efforts will examine differences between the effects of regional variation on early versus late-season crop classification, and on TM versus SPOT classification. Lastly, it is of interest to determine whether NOAA/AVHRR data can assist in defining the parameters of regional variation.

5. CONCLUSION

As described, the specific approaches to applying satellite data for crop identification in the complex environment of New York State have varied with the particular crop. Spectral information and knowledge of the crop calendar have been found crucial for identifying vegetables, orchards, and vineyards; however, these are not always sufficient without spatial information. Moreover, even when crops can be reliably identified at one location, regional variation can greatly influence the

classification results, as shown with field crops. This is especially significant if multi-crop inventories are to be performed.

Investigations at Cornell University are continuing to address these topics. Where efforts to date have emphasized Landsat TM data, work with NOAA/AVHRR and, especially, SPOT will be expanded.

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