Identifying Vegetable Crops with Landsat Thematic Mapper Data

*Vicki L. Williams**, *Warren R. Philipson*, and *William D. Philpot*
Cornell Laboratory for Environmental Applications of Remote Sensing, Cornell University, Ithaca, NY 14853

ABSTRACT: Landsat thematic mapper (TM) data were evaluated for inventorying or monitoring New York State vegetables, which are grown commercially in organic (muckland) or mineral (upland) soils, in fields as small as 2 hectares. Two TM scenes of west-central New York, acquired in July and August 1984, were analyzed digitally with spectral characterizations, enhancements, and supervised classifications being referenced to field-measured reflectances and cropping records. Testing showed single-date classification accuracies of at least 90 percent for three muckland vegetables (onions, lettuce, potatoes), and over 75 percent for three of four upland vegetables (cabbage, sweet corn, potatoes, and mature, but not young, snap beans) for TM data acquired late in the growing season. In addition, visual image analysis of the digitally displayed TM data was capable of easily identifying most of the mature crops studied. Overall, either digital or visual image analysis seem capable of producing reliable classifications of vegetable crops.

INTRODUCTION

VEGETABLE CROPS are important to the economy of New York State; in 1984, vegetables occupied more than 56,000 acres and their sale exceeded $94,000,000. The census of vegetable crops by the New York Crop Reporting Service is based on field observations and survey questionnaires. This study was undertaken to determine the extent to which satellite data, specifically Landsat thematic mapper (TM) data, could be used to aid the census (Philipson *et al.*, 1985; Williams, 1986; Williams *et al.*, 1986).

Vegetables have been the focus of Landsat multispectral scanner (MSS) studies by Ryerson *et al.* (1979, 1981) and by Zhu *et al.* (1983); and several Landsat MSS investigators have included vegetables among other crops of interest (e.g., Morse and Card, 1983). Although spectral separability of the vegetables studied was generally achievable with the four MSS bands, crop inventory with MSS data would be hindered by the small, irregularly shaped fields, and the lack of continuous crop canopy.

The advantages of TM data over MSS data for crop studies have been described by several investigators. These efforts have been based on theoretical analyses or studies with simulated TM data (e.g., Markham and Townshend, 1981; Sigman and Craig, 1981; Williams *et al.*, 1984); field reflectance studies (e.g., Crist and Cicone, 1984; Daughtry *et al;*., 1984); and studies of coincident TM and MSS data (e.g., Crist, 1984). A few TM or TM-band reflectance studies have considered vegetables, but only two or three types of vegetables (Cihlar *et al.*, 1985; DeGloria, 1984; Staenz *et al.*, 1980). Moreover, vegetables were not the focus of these studies, and classification accuracies were not reported.

MATERIALS AND METHODS

In New York State, certain vegetables are grown primarily in organic soils (muckland), others are grown primarily in mineral soils (upland), and some are grown in both organic and mineral soils. Two TM scenes of west-central New York (17 July and 18 August 1984, path 16/row 30) were selected, based on locations of major vegetable-producing areas, general crop calendars, and scene dates. The TM data were obtained as computer-compatible tapes with a 1:1,000,000-scale photographic print of one band for reference.

To aid the analysis of the TM scenes, 1984 plot maps of muckland vegetable fields were obtained from the New York Crop Reporting Service (upland vegetable maps are not compiled), and regional crop calendars were prepared for both muckland and upland vegetables. In addition, panchromatic, 1:40,000-scale, 9-inch aerial photographs flown in May 1974, and low altitude 35-mm color aerial photographs flown in June 1984, were obtained from the U.S. Department of Agriculture, the latter coverage through the county office.

Field observations and reflectance measurements of vegetables were made throughout the 1984 growing season to determine best dates and bands for crop separation. Muckland onions and lettuce, upland cabbage, snap beans and sweet corn, and both muckland and upland potatoes were sampled, following the procedure described by Duggin (1980) and Philipson *et al.* (1985). Two four-band radiometers (Exotech model 100AXM-T) and a data logger (Omnidata Polycorder) were used to collect radiometric measurements for determining crop reflectances, relative to a barium sulfate standard, in the first four TM spectral bands (bands 1 through 4, respectively: 0.45 to 0.52, 0.52 to 0.60, 0.63 to 0.69, and 0.76 to 0.90 micrometres).

Due to the limited scope of the field program, only one field was sampled for each crop, with three 1- by 1-metre sites selected to represent the variation of each field. Sampling was done on ten dates from June through September. In addition to the reflectance measurements, the sites were photographed, and descriptions of plant size, stage of development, and soil condition were recorded.

Crop reflectances were computed for each site, for each date of data collection. Although the number of sample reflectances for each crop was limited, the field measurements could be scaled to TM pixels by modeling the integrated reflectance of plant and soil within the 30-m instantaneous field-of-view of the TM sensor. The aim was to approximate the reflectance of one entire cycle of the regularly spaced crop row and soil because the 30-m pixel would image multiples of this cycle. The "cycle" reflectance was calculated from the field-measured reflectances and from the respective areas of plant and soil, determined from ground-based photographic slides (Williams, 1986; Williams *et al.*, 1986).

Cycle reflectances were plotted versus days after planting to examine crop reflectance over time, to compare reflectances of different crops, and to allow for simulations of different planting dates. In addition, an error analysis of the data collection procedure was performed to ensure that the variation of reflectances among the three sites in each field was due to field variation rather than measurement procedure.

The TM data were analyzed on an International Imaging System (IIS) model 70 digital image analysis system with a host VAX 11/750 minicomputer. The TM data were first analyzed visually with TM bands 3, 4, and 5 projected in blue, red, and green, respectively, on the IIS display. Crops were identified with the aid of field maps and aerial photographs. Means and

* Presently with SPOT Image Corporation, 1897 Preston White Drive, Reston, VA 22091.

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standard deviations of TM digital counts (0 to 255) in all seven bands were obtained for the interior pixels of the identified fields to characterize the crops and determine their separability. If the variation in digital counts between crops did not overlap (based on one standard deviation), the crops were considered separable.

The relationship between average cycle reflectance and TM measurements of the sampled fields was assessed as a separate step. The sampled fields were examined in the first four TM bands; correspondence between ground and satellite measurements was based on the means and standard deviations of the TM digital counts.

After examining the spectral properties and spectral separability of crops in single bands, classifications were done using a supervised maximum likelihood classifier. The classifications made use of different subsets of the seven TM bands as well as various band combinations, including a ratio of bands 4/3, a normalized vegetation index of (4-3)/(4+3), and [(4-3)/(4+3)]+5. To improve the classification of muckland potato and upland snap beans, different growth stages of the crops were treated as different classes.

RESULTS AND DISCUSSION

The relationship between the average field reflectances on 17 July 1984 and same-day TM measurements of the same fields was good to the extent that, when one crop was spectrally discriminable from the others in the field reflectance data, it was usually discriminable in the TM data. Although the utility of the field data was limited by having field reflectances in only four of the seven TM bands and by having only one field of each crop, they provided the basis for assessing regional crop separability.

Field reflectances plotted versus days after planting were examined (Figure 1) and analyzed together with the crop calendar. To provide some basis for relating fields of the same crop, but with different planting dates, the plots of reflectances of the sampled fields were shifted over the range in planting dates defined by the crop calendar, assuming no other changes in reflectance (Figure 2). The resulting plots showed the expected: at certain times in the growing season, field reflectances of some crops vary considerably with different planting dates, while for other crops, the variation is less pronounced (Figure 2).

These findings and the reflectance plots were directly relatable to the TM data. Comparisons of the mean TM digital counts of fields of the same crop found marked differences with the July data due to differing planting dates and the early growth stage (low percent covers) of most crops (Tables 1 and 2). For example, the average band 4 digital count of the sampled cabbage field (129, Table 1) is higher than that of other fields (96, Table 2). In August, however, the TM digital counts of the sampled fields were good predictors of the separability of fields with mature crops throughout the area, regardless of their planting dates (Table 3 and 4). (Concurrent field reflectances were not available for the August TM scene).

The results of classifying upland and muckland vegetables with bands 3, 4, 5, and 6 are reported in Tables 5 and 6. As noted in the tables, only one field was available for both training and testing of certain crops (e.g., upland potatoes).

With the July TM data, best results were obtained classifying with all TM bands, but the results were nearly as good with bands 3, 4, 5, and 6 (Table 5). (The addition of band 6 (thermal band) caused substantial improvement to the classification with bands 3, 4, and 5.) For most muckland crops, accuracies were 88 percent or greater. For several upland fields, however, accuracies were low and errors of commission were high. In general, most crops were young, percent cover was low, and the variation in growth stages (causing variability in reflectance) was especially apparent.

In mid-August, the crops were mature and more easily identified. Classifications improved using the August scene with all TM bands and, again, they were nearly as good with bands 3, 4, 5, and 6 (Table 6). 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. Only snap beans was classified poorly; training data were limited and did not represent the variation in reflectance found in most fields in the region. Dividing snap beans into young and mature classes improved the classification of the mature crop, but classification accuracies remained low with young beans.

Overall, classification of muckland vegetables was more accurate than upland vegetables. This was expected because the mucklands are characteristically flat, uniform areas, with narrow, rectangular fields in contrast to the regional variability in topography and soils found in most upland areas. Although other bands and band combinations were used for classification, the results changed little. In addition, the results of multi-date classification with the July and August scenes were poor; good training sites were not available for the same fields on both the July and August images.

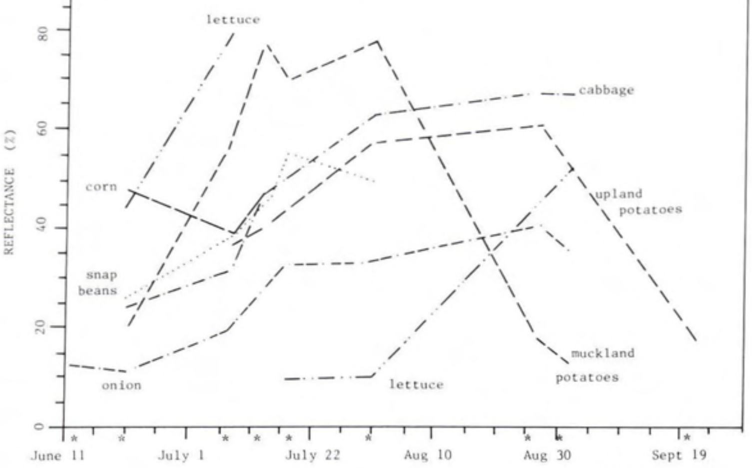

FIG. 1. Cycle reflectance in band 4 versus date for seven upland and muckland vegetables.

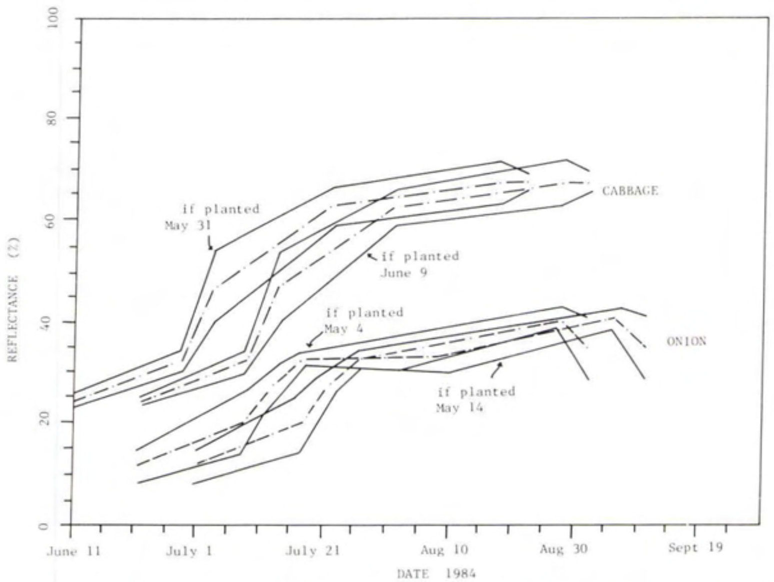

FIG. 2. Change in band 4 reflectance with shift in planting date for cabbage and onions. (Dashed lines represent average reflectance; solid lines represent field variation in reflectance based on one standard deviation of sample measurements.)

TABLE 1. TM DIGITAL COUNTS OF FIELDS WHERE REFLECTANCES WERE COLLECTED 17 JULY 1984 (MEAN VALUE FOR INTERIOR PIXELS OF FIELDS WITH STANDARD DEVIATION IN PARENTHESES)

Crop	band 1	band 2	band 3	band 4	band 5	band 6	band 7	pixels
up corn	92 (2)	37 (1)	33 (1)	140 (4)	85 (3)	139 (1)	25 (2)	34
up cabb	124 (4)	54 (3)	64 (5)	129 (5)	101 (8)	143 (3)	48 (6)	32
up bean	106 (5)	45 (4)	50 (6)	113 (11)	104 (8)	152 (2)	44 (6)	122
up potato	111 (5)	49 (3)	61 (6)	118 (4)	126 (4)	160 (3)	62 (5)	25
m potato	93 (6)	40 (3)	36 (5)	191 (14)	102 (4)	140 (4)	28 (2)	27
m lettuce	88 (2)	29 (1)	35 (2)	45 (5)	96 (3)	149 (3)	56 (3)	33
m onion	89 (2)	33 (1)	32 (1)	101 (8)	55 (5)	152 (2)	23 (4)	70

TABLE 2. TM DIGITAL COUNTS OF FIELDS THROUGHOUT THE REGION 17 JULY 1984 (MEAN VALUE FOR INTERIOR PIXELS OF FIELDS WITH STANDARD DEVIATION IN PARENTHESES)

Crop	band 1	band 2	band 3	band 4	band 5	band 6	band 7	pixels
up corn	107 (15)	47 (11)	56 (20)	109 (13)	119 (30)	152 (6)	58 (27)	208
up cabb	125 (4)	58 (3)	78 (6)	96 (16)	139 (15)	159 (4)	83 (14)	91
up beans	128 (10)	62 (7)	86 (13)	95 (6)	155 (16)	160 (5)	95 (12)	67
m potato*	98 (6)	42 (2)	39 (5)	116 (33)	105 (4)	144 (6)	32 (5)	67
m lettuce	98 (3)	47 (3)	40 (3)	179 (10)	86 (4)	150 (4)	26 (3)	73
m onions	91 (3)	33 (2)	35 (3)	68 (11)	85 (6)	171 (4)	44 (5)	421

*only one field of upland potatoes was grown in the region

TABLE 3. TM DIGITAL COUNTS OF FIELDS WHERE REFLECTANCES WERE COLLECTED 18 AUGUST 1984 (MEAN VALUE FOR INTERIOR PIXELS OF FIELDS WITH STANDARD DEVIATION IN PARENTHESES)

Crop	band 1	band 2	band 3	band 4	band 5	band 6	band 7	pixels
up corn	80 (1)	32 (1)	30 (1)	114 (2)	72 (1)	129 (1)	21 (1)	35
up cabb	92 (2)	37 (1)	34 (2)	137 (4)	49 (2)	131 (1)	15 (2)	55
up bean				(crop was harvested)				
up potato	78 (1)	32 (1)	26 (1)	152 (10)	88 (2)	131 (1)	24 (1)	37
m potato	79 (3)	32 (2)	31 (3)	79 (22)	70 (5)	138 (1)	27 (4)	55
m lettuce	81 (2)	33 (1)	31 (2)	72 (13)	63 (6)	140 (2)	23 (2)	31
m onion	83 (5)	36 (5)	32 (5)	119 (13)	45 (8)	136 (2)	14 (3)	96

Visual identification of vegetables in the digitally displayed TM data was even more successful than the digital classifications. Nearly all fields of known crops could be identified. Where the variation in maturity of a single crop reduced digital classification accuracies of fields or parts of fields, those fields with the same crop could be visually identified by a characteristic color or pattern. Similarly, visual interpretation would be more accurate than digital classification where some narrow fields were covered by only one or two pixels, neither of which was pure, or by boundary pixels, imaging two or more adjacent

TABLE 4. TM DIGITAL COUNTS OF FIELDS THROUGHOUT THE REGION 18 AUGUST 1984 (MEAN VALUE FOR INTERIOR PIXELS OF FIELDS WITH STANDARD DEVIATION IN PARENTHESES)

Crop	band 1	band 2	band 3	band 4	band 5	band 6	band 7	pixels
up corn	80 (2)	32 (2)	29 (2)	109 (7)	73 (3)	129 (1)	21 (2)	277
up cabb	94 (3)	40 (2)	39 (3)	128 (15)	64 (6)	132 (2)	22 (3)	247
up beans	81 (3)	37 (3)	32 (5)	135 (22)	100 (7)	131 (1)	33 (5)	151
m potato*	78 (2)	31 (3)	31 (2)	68 (25)	67 (5)	138 (3)	28 (5)	175
m lettuce	95 (2)	50 (2)	42 (2)	163 (8)	78 (2)	135 (1)	23 (1)	31
m onions	76 (2)	29 (2)	26 (2)	82 (11)	39 (5)	134 (2)	13 (2)	445

*only one field of upland potatoes was grown in the region

TABLE 5. CONFUSION MATRIX FOR JULY SCENE, BANDS 3 THROUGH 6

	Percent of classified pixels[1]									
	corn	cabb	bean	upot	mpm	mpy	lett	on	uncl	number pixels
up corn[2]	3	2	9	2	0	13	0	22	50	208
up cabb	0	28	1	0	0	0	0	0	71	222
up bean	0	5	2	0	0	0	0	0	93	118
up potato[3]	0	0	0	87	0	0	0	0	13	31
m pot mat[2,4]	0	0	0	0	97	0	0	0	3	31
m pot yng[4]	0	0	0	0	0	51	0	49	0	55
m lettuce[3]	0	0	0	0	0	0	88	0	12	65
m onions[2]	0	0	0	0	0	0	0	100	0	266

(see Table 6 for footnotes)

TABLE 6. CONFUSION MATRIX FOR AUGUST SCENE, BANDS 3 THROUGH 6

	Percent of classified pixels[1]									
	corn	cabb	bean	mpot	mpv	mpm	lett	on	uncl	number pixels
up corn	87	1	0	0	0	0	0	0	12	194
up cabb	1	75	0	0	0	0	0	1	23	507
up bn yng[3,5]	0	0	9	10	0	0	0	0	86	106
up bn mat[5]	0	0	0	96	0	0	0	0	4	71
up potato[3]	0	0	0	4	96	0	0	0	0	41
m pot mat[3,4]	0	0	0	7	0	90	0	0	3	29
m lettuce[3]	0	0	4	0	0	0	96	0	0	31
m onions	0	0	0	0	0	0	0	96	0	389

[1]three standard deviations are used for classification
[2]high errors of commission outside test fields
[3]training and testing done on the same field
[4]muckland potato class was divided into young and mature in July, and mature and senesced in August
[5]snap beans were divided into young and mature in August

fields. Visual identifications were especially accurate on the muckland, where vegetables are normally the only cultivated crop and where the types of vegetables grown are limited.

From the field reflectances, crop calendar, and TM data, it is evident that the best single date for identifying vegetables is late in the season, when most crops are mature. For some crops, however, an additional scene, acquired midway through the growing season, may also be needed: crops with a wide range in planting dates (e.g., snap beans), crops which are double-cropped and/or harvested early (e.g., lettuce), or crops which have a pronounced senescence (e.g., potatoes).

CONCLUSION

Based on analysis of one season's data on seven muckland and upland vegetables grown in one part of central New York, TM data appear capable of providing reliable identification of vegetable crops. Testing of a single-date, supervised maximum likelihood classification showed accuracies of at least 90 percent for muckland vegetables and over 75 percent for most upland vegetables, with low errors of commission. Similarly, subjective testing found that visual image analysis of the digitally displayed image could easily identify most of the crops studied (as well as other vegetables and field crops).

Overall, digital analysis should provide a more rapid approach, and visual analysis should provide higher accuracies. Where digital classifications were limited by varying growth stages and narrow fields, these fields could be recognized through visual interpretation. For single-date analysis, highest accuracies were obtained late in the season, when the crops were mature; however, for some crops, an additional scene, acquired midway through the growing season, may also be needed.

Key to success in identifying vegetable crops are regional crop calendars, the availability of TM data on the best dates for crop identification, and data on representative fields for training and testing. Crop reflectance measurements in representative fields provide an important aid in analyzing the TM data, even when there is considerable variation in planting date for the crops. When used together with a crop calendar, the field data can be used to determine the best dates for crop identification and to assess the regional crop separability with TM data. Judging from the results of the TM image analysis, however, efforts should be made to extend these measurements to TM bands 5 or 7.

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