Fruit Tree Inventory with Landsat Thematic Mapper Data

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ABSTRACT: Landsat thematic mapper (TM) data were evaluated for inventorying New York State fruit trees. A supervised maximum likelihood classifier was used to classify single and multi-date TM scenes, with and without enhancements. The different types of fruit trees could not be reliably distinguished because of the variable contribution of ground cover or soil to orchard reflectance. As a class, however, orchards are sufficiently unique that a consistent fraction of the total orchard area could be isolated and used for estimating total acreage. Separating orchard from deciduous forest required a texture extraction procedure involving TM bands 3 and 4. Separating orchard from other vegetative cover required multi-date data—TM bands 3, 4, and 5 from two periods in the growing season, but not necessarily the same year. As a final step, a reclassification based on context was performed to increase the number of correctly classified pixels. Continuing research will assess the applicability of this functional relationship beyond the study areas, in addition to assessing whether errors of omission can be reduced without increasing errors of commission.

INTRODUCTION

NEW YORK STATE is a national leader in fruit production, ranking second in apples, third in tart cherries and grapes, fourth in pears, and sixth in sweet cherries. The estimated value of tree fruit and grapes in 1983 was $160 million. State inventories of orchards and vineyards are done through mail surveys with follow-up enumeration of growers who do not respond. Detailed inventories are conducted at approximtely five-year intervals, with less detailed surveys performed during interim years.

The objective of this study was to determine if satellite-derived data, specifically data acquired by the Landsat thematic mapper (TM), could be used to inventory or assist in the inventory of New York State fruit trees. A complete description of the study is provided by Gordon (1985).

Earlier studies involving orchards have demonstrated that Landsat multispectral scanner (MSS) data have the capacity to separate two types of citrus trees in Texas (Gausman *et al.*, 1977) and vineyards from orchards in California (Morse, 1984). These studies did not address the problems involved with identifying newly planted, immature, or abandoned orchards, or the effects of different types of orchard ground cover. More importantly, MSS studies of fruit trees from the southern and southwestern United States have limited applicability to the problem of identifying temperate zone fruit trees with TM data. The trees and cultivation practices differ (e.g., Childers, 1973), and the information content of the 4-band, 79-metre MSS data is substantially different from that of the 7-band, 30-metre TM data (e.g., Williams *et al.*, 1984).

The need for the higher resolution TM data arises from the requirement of the New York fruit tree census to inventory commercial orchards containing as few as 100 trees. Depending on tree spacing, this equates to a block of trees from 30 to 60 metres on a side. While nearly half of New York's apples are produced on farms with at least 100 acres in apple trees, the average number of acres a farm has in tart cherry, pear, peach, and sweet cherry is 15, 7, 6, and 4, respectively (New York Crop Reporting Service, 1981).

METHODS AND MATERIALS

STUDY AREA AND DATA

Orleans County, a major tree fruit producing county in western New York, was selected as the general study area because of the number of representative orchards and the availability of two TM scenes, 28 August and 13 September 1982 (path 17, row 30), and corresponding panchromatic aerial photographs (May 1982; 1:40,000 scale). A third TM scene, 22 June 1984, was also acquired when it became available.

Two areas within the county were chosen for detailed analysis. Each area, 14.7-by-14.7 km, corresponded to a subscene of 512-by-512 TM pixels, which is the display capability of the digital image processing system used in the investigation. These areas will be referred to as the western and eastern subscenes.

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Orchards used for training and testing were identified on the aerial photographs and field checked to measure or estimate orchard row spacing, tree spacing within rows, row direction, tree height, crown diameter, crown density, and the type, amount, and vigor of ground cover.

Digital Analysis

All image processing was performed on an International Imaging Systems Model 70 digital analysis system, operated with a VAX 11/750 as the host computer. The initial effort was to classify orchards by fruit tree type. Supervised classification of fruit tree types was done in the western and eastern subscenes using single dates of TM data. A maximum likelihood classifier was used, and only mature orchards were included to minimize the affects of ground cover. The results showed much confusion among different orchard types as well as with other cover types. Given the high degree of confusion when classifying single date data and the consistency of the confusion at different dates, a multi-date classification for orchard type was not attempted.

The failure to classify orchards by fruit tree type directed the effort toward isolating orchards, as a class, from other cover types. This was approached by attempting to separate orchards from two groups of confusing cover types: those phenologically different from orchards (field crops, pasture, and abandoned or idle fields) and those phenologically similar to orchards (mixed deciduous forests).

To distinguish orchards from field crops, pasture and other non-forest vegetation, a multi-date classification was performed. Bands 3, 4, and 5 from both the August 1982 and the June 1984 TM data were included in a supervised classification. These bands were chosen on the basis of correlation matrices derived from the TM statistics for each orchard type, as well as on the basis of previous research (Staenz *et al.*, 1980; Chavez *et al.*, 1984).

To distinguish orchards from forest, the approach changed from relying on overall spectral differences, where there were few, to relying on image texture, where differences were apparent, particularly in TM band 4. The texture-extraction procedure has been described by Gordon and Philipson (1986). In brief, the texture of TM bands 3 and 4 was enhanced by passing a 3-by-3 pixel filter over the images, replacing the center pixel in the filter with the sum of the absolute differences between the center pixel and each of the eight surrounding pixels. This procedure brightened areas with high variance (coarse texture) and darkened regions with low variance (smooth texture). Boundaries between dissimilar targets (field edges, roads, etc.) were also brightened; however, most edges were brightened in both bands. Dividing (ratioing) the texture-enhanced band 4 image by the texture-enhanced band 3 image reduced the brightness of the boundary pixels while increasing the more subtle band-to-band texture differences in the orchard areas. Within-class variation in the ratioed image was reduced by twice applying a 3-by-3 pixel smoothing filter, which replaced the center pixel with the averge of the nine pixels; and, lastly, a binary image was produced depicting non-orchard (forest) pixels as white and pixels of orchards plus confused non-forest vegetation as black. The binary image was produced by level-slicing the smoothed image based on a threshold selected through training with representative orchards, as would be done in supervised classification. The threshold was set at a level (digital count) below which 95 percent of the training orchards were represented.

For the final discrimination of orchards from all non-orchard vegetation, the methods used for separating orchards from forest and for separating orchards from non-forest vegetation were combined. That is, supervised classification with a maximum likelihood classifier was applied to seven images: the band 3, 4, and 5 images from the August 1982 and June 1984 subscenes and the single binary image produced by texture analysis of bands 3 and 4 of the June 1984 subscene.

To improve the classification, pixels were reclassified on the basis of context. A 3-by-3 pixel window was passed over the classified subscenes, reclassifying the center pixel to the classification of the majority of surrounding pixels if at least six of the eight surrounding pixels had the same classification ("mode filter"). The presumption is that a pixel is likely to be orchard if most of the surrounding pixels are orchards.

Reclassification was necessary due to the large number of pixels near roadways which were classified as orchards because of their orchard-like composition of tree, shade, and grass. Also, many pixels on the orchards/non-orchard boundary of the binary texture image were mis-classified as orchard. These pixels were located on the edge of a forest, but they were identified as orchard due to their proximity to a change in cover type. This problem was more prevalent in the eastern subscene where the smaller, more numerous forested areas caused a higher proportion of edges in the binary image.

RESULTS AND DISCUSSION

As described, unenhanced single date TM data could not be used to discriminate different types of mature orchards. The level of spectral overlap is typified by the training statistics for the August 1982 sub-scenes, reported in Table 1. In essence, the appearance of orchards on TM images is more dependent on tree size and ground cover than on the type of fruit tree. Because orchard type could not be determined, the study focused on isolating orchards, as a class, from all other vegetative cover types.

Distinguishing orchards from non-forest vegetation was accomplished best through multi-date classification with bands 3, 4, and 5 of the August 1982

Table 1. Training class means and standard deviations from the August thematic mapper subscenes.

WEST CLASS	BAND 1* mean**	1* s.d.	2 mean	2 s.d.	3 mean	3 s.d.	4 mean	4 s.d.	5 mean	5 s.d.	7 mean	7 s.d.
Apple	63.0	2.2	25.2	1.4	20.5	2.0	93.8	6.0	66.5	6.4	22.1	3.7
Cherry												
Tart	63.0	2.5	24.7	1.5	21.1	2.1	87.2	3.3	61.5	5.6	21.2	3.5
Sweet	61.7	1.8	25.4	1.1	21.2	1.3	85.2	3.0	59.2	2.0	14.0	2.3
Pear	63.4	2.0	25.4	1.4	21.6	2.0	77.0	3.6	67.7	7.9	24.8	3.9
Peach	61.6	1.8	23.0	1.3	18.9	1.2	101.8	2.2	63.3	4.6	19.8	2.1
EAST CLASS	BAND 1 mean	1 s.d.	2 mean	2 s.d.	3 mean	3 s.d.	4 mean	4 s.d.	5 mean	5 s.d.	7 mean	7 s.d.
Apple	63.1	1.6	26.6	1.1	21.6	1.3	98.8	5.8	72.6	5.2	24.0	2.5
Cherry												
Tart	69.3	2.4	30.7	1.8	30.7	2.6	81.4	3.2	87.4	3.1	37.6	3.5
Sweet	65.0	1.6	27.3	1.3	25.8	1.8	81.6	2.4	71.9	2.7	29.8	2.2
Pear	63.2	1.6	26.2	0.8	21.9	0.9	82.2	3.9	73.0	2.7	27.2	2.1
Peach	63.9	2.4	26.5	1.5	23.6	2.3	93.3	4.6	71.7	6.3	26.3	4.2

*Bands, in micrometres, are: 1, 0.45–.52; 2, 0.52–.60; 3, 0.63–.69; 4, 0.76–.90; 5, 1.55–17.5; 6, 10.4–12.5; and 7, 2.08–2.35.
**Mean and standard deviations are calculated from TM digital counts which range from 0 to 255.

and June 1984 subscenes. Fewer than 8 percent of the non-forest vegetation pixels from the Western and eastern subscenes were misclassified as orchards (4.3 percent and 7.4 percent, Table 2). In contrast, because orchards and forests are phenologically similar, multi-date analysis did not aid in their separation. Over 25 percent of the forest pixels (26.3 percent and 27.2 percent, Table 2) were misclassified as orchards.

The separation of orchards from forest required a texture-extraction procedure. As outlined, the first step in the procedure was to enhance the texture of each TM band. Sample class statistics for the enhanced bands 3 and 4 of the June subscenes are reported in Table 3. Notably, the local variation in gray value of forest pixels is generally higher than that of orchard pixels in band 4 (infrared, 0.76 to 0.90 μm) and lower in band 3 (red, 0.63 to 0.69 μm). The comparatively high variation of forest pixels in band 4 (digital counts of 56.2 and 52.4) is attributed to the mixture of tree species common to deciduous forests and to their high infrared reflectance (Gordon and Philipson, 1986). In contrast, given the orchard row spacing (7 to 13 metres) and the pixel size (30 metres), each orchard pixel contains a comparable amount of tree canopy and background and is thus similar to adjacent orchard pixels. That forests exhibit less variation than orchards in band 3 is attributed to the overall low reflectance of vegetation in band 3 and to the more uniform absorption of light by a closed canopy of different forest tree species than by the orchard trees and background.

TABLE 2. CONFUSION MATRIX FROM CLASSIFYING TM BANDS 3, 4, AND 5 FROM AUGUST 1982 AND JUNE 1984.

	Western Subscene (% test pixels)		Eastern Subscene (% test pixels)	
	Orchard	Unclass.	Orchard	Unclass.
Orchards				
Medium crown	72.7	27.3	57.1	42.9
Large crown	73.8	26.2	64.5	35.5
Forest	26.3	73.7	27.2	72.8
Other vegetative cover	4.3	95.7	7.4	92.6

The statistics for peach in Table 3 are somewhat anomalous because of the small number of pixels, which include a larger proportion of edge pixels.

To reduce the edge effect and complete the texture-extraction procedure, the texture-enhanced bands 3 and 4 were ratioed (4/3), twice smoothed, and level-sliced to a binary image which separated forest from orchard. The effectiveness of the binary image is evidenced by the confusion matrix in Table 4; no more than 5 percent of the forest pixels were misclassified as orchard (1.5 percent and 4.6 percent).

Isolation of orchards from other vegetative cover types was accomplished by combining the six bands of multi-date images (to "remove" non-forest vegetation) and the binary texture image (to "remove" forest) in a single supervised classification. This combination reduced misclassification of non-orchard cover types to 4 percent or less (Table 5).

The lower classification accuracy of orchards in the eastern subscene is due in part to the training statistics being derived in the western subscene. The limited number of orchards in the eastern subscene forced the use of some younger orchards during testing. These younger orchards may not have been well represented in the western subscene training areas, causing the lower rate of classification.

As described, the classification was improved by twice passing a 3-by-3 pixel mode filter over the classified subscenes, reclassifying based on context. After reclassification, fewer than 2 percent of the non-orchard pixels were misclassified as orchard (Table 6).

The results in Table 6 also indicate that, while orchards were isolated effectively from non-orchards, a relatively high percentage of orchard pixels were not classified as orchards 27 to 28 percent in western subscene, 43 to 47 percent in eastern subscene). It is important to point out that the overall error of omission is consistent in the two subscenes and not a result of the inclusion of the binary image or reclassification. Although the consistency is not seen in the classifications of test pixels (Table 6), it is seen in a comparison of the TM classifications with airphoto-derived orchard acreages for the entire subscenes (Table 7). Orchard acreages estimated by the original classification of multi-date and bi-

TABLE 3. CLASS MEANS AND STANDARD DEVIATIONS OF TM BANDS 3 AND 4 OF THE JUNE SUBSCENE AFTER TEXTURE ENHANCEMENT.

Class	West Pixels	Band 3 Mean	Band 3 S.D.	Band 4 Mean	Band 4 S.D.	East Pixels	Band 3 Mean	Band 3 S.D.	Band 4 Mean	Band 4 S.D.
Apple	459	18.0	9.6	27.6	12.8	162	16.4	10.1	37.0	20.0
Cherry										
Tart	31	25.0	8.9	38.6	27.9	93	19.8	9.6	15.8	8.1
Sweet	69	13.7	5.5	29.9	17.5	13	37.0	7.4	52.4	31.1
Pear	53	26.1	12.3	17.5	8.4	55	14.1	6.5	33.6	13.0
Peach	10	49.3	36.5	25.6	7.2	44	27.8	9.9	29.8	16.4
Forest	2194	9.9	7.9	56.2	30.3	1482	9.8	6.9	52.4	24.6

TABLE 4. CONFUSION MATRIX FROM CLASSIFYING THE JUNE SUBSCENES WITH A TEXTURE-BASED BINARY IMAGE.

	Western Subscene (% test pixels)		Eastern Subscene (% test pixels)	
	Orchard	Unclass.	Orchard	Unclass.
Orchards				
Medium crown	92.1	7.9	78.5	21.5
Large crown	88.2	11.8	80.1	19.9
Forest	1.5	98.5	4.6	95.4
Other vegetative cover	41.9	58.1	42.5	57.5

TABLE 5. CONFUSION MATRIX FROM CLASSIFYING BANDS 3, 4, AND 5 FROM AUGUST AND JUNE SUBSCENES, WITH A TEXTURE-BASED BINARY IMAGE FROM THE JUNE SUBSCENE.

	Western Subscene (% test pixels)		Eastern Subscene (% test pixels)	
	Orchard	Unclass.	Orchard	Unclass.
Orchards				
Medium crown	72.7	27.3	52.9	47.1
Large crown	72.3	27.7	56.7	43.3
Forest	1.5	98.5	2.5	97.5
Other vegetative cover	4.0	96.0	2.1	97.9

TABLE 6. CONFUSION MATRIX FROM RECLASSIFYING THE CLASSIFIED MULTI-DATE IMAGES WITH THE TEXTURE-BASED BINARY IMAGE.

	Western Subscene (% test pixels)		Eastern Subscene (% test pixels)	
	Orchard	Unclass.	Orchard	Unclass.
Orchards				
Medium crown	72.7	27.3	52.5	47.5
Large crown	72.3	27.7	58.0	42.0
Forest	0.4	99.6	1.2	98.8
Other vegetative cover	1.5	98.5	0.5	99.4

TABLE 7. COMPARISON OF AIRPHOTO AND TM-DERIVED ORCHARD ACREAGE.

		TM Estimates as % of Airphoto Estimates			
	Airphoto orchard	original	reclassified subscenes**		
Subscene	acreage	classification*	1 pass	2 passes	3 passes
Western	3,652	96	61	56	54
Eastern	2,369	133	71	60	58

*classification with multi-date and binary texture image (Table 5)

**reclassification with 3-by-3 mode filter

nary images were 96 percent and 133 percent, respectively, of the airphoto-derived values. The difference between these estimates for the two subscenes was reduced to 4 percent with two passes of the mode filter (i.e., 56 percent versus 60 percent).

Efforts are being made to reduce the error of omission through better training during the classification procedure. Most importantly, however, the low error of commission indicates that the classified orchard pixels represent a defined fraction of the total number of pixels that should be classified as orchard. The estimate of orchard acreage is, therefore, predominantly dependent on the amount of orchards and not on some unknown cover type. The texture-extraction procedure and multi-date classification can thus provide a base value for estimating total orchard acreage.

CONCLUSIONS

This study found that, due to the large contribution of background to the reflectance of young as well as mature orchards, the different types of fruit trees in New York State could not be reliably separated using Landsat TM data. Small changes in the composition or condition of the ground cover (usually grass) or bare soil cause significant changes in orchard reflectance. Although the results are not reported here, preliminary analysis suggests that a vegetative index (band 4 − band 3)/(band 4 + band 3) is directly related to crown size and might, therefore, be used for classifying orchards by age if not by types (Gordon, 1985).

Despite the negative findings regarding the separability of fruit tree types, this study also found that, as a class, orchards are sufficiently unique that a fraction of the total orchard acreage could be isolated and thereby used as a base for estimating total acreage. Continuing research will assess the applicability of this functional relationship beyond the study areas, in addition to assessing whether errors of omission can be reduced without increasing errors of commission.

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