ENGINEERING ANALYSIS OF CROP INVENTORY THROUGH REMOTE SENSING

FINAL REPORT

National Agricultural Statistics Service,
U.S. Department of Agriculture
Cooperative Agreement No. 58-319T-3-0208X
with
Cornell University

Warren R. Philipson
principal investigator

Willam D. Philpot
co-investigator

CLEARS
Cornell University
Hollister Hall
Ithaca, NY 14853
tel. 607-255-4330

August 1988

EXECUTIVE SUMMARY

A multifaceted investigation has addressed whether the cost, efficiency or accuracy of crop surveys in environmentally complex regions such as New York State can be improved through incorporation of information derived from satellite data, specifically, Landsat thematic mapper (TM) data. The work was conducted by Cornell University researchers under a cooperative agreement with the U.S. Department of Agriculture, National Agricultural Statistics Service. USDA support for this five-year investigation totaled $174,900 plus computer-compatible tapes for several satellite scenes.

Principal Findings:

- The capacity to identify specialty crops with TM data varies with the crop.
- Statewide inventory of field crops with TM data may require different stratification schemes for different crops.
- Until the spatial component (texture) of satellite image data can be derived and used more effectively, visual image analysis will generally provide more accurate crop identifications than digital classifications.

Recommendations:

- SPOT satellite data should be evaluated for crop inventory, recognizing the information gains (spatial) and losses (spectral) relative to TM.
- Research in image processing for crop identification with TM and, especially, SPOT must place greater emphasis on spatial features (image texture and segmentation, contextual information, and post-classification smoothing).
- Research in multispectral measurements for crop identification should place greater emphasis on understanding the role of middle and thermal infrared bands.
- Research on the effects of regional variation in New York should examine mid-season, late-season and multidate classification.
- USDA/NASS should not overlook the immediate value of visual analysis of TM image data (and potentially SPOT) for crop inventory.

Specific Findings:

- TM data are capable of providing reliable identifications of major muckland and upland vegetable crops; visual classifications are more accurate, though not as rapid as digital classifications.
- Although different types of fruit tree orchards cannot be distinguished with TM data, orchards as a class can be isolated from other vegetative cover types and used to estimate total fruit tree acreage.

- The thermal and infrared TM bands appear useful for improving the separation of orchards from woodlands; visible bands have value only if exposed soil is present.
- Spatially unique clusters or larger blocks of vineyards can be identified visually with TM, however, vineyards cannot be identified reliably through spectral classification of early or late-season TM data; mid-season and multidate TM data should be tested and supplemented with contextual information and post classification smoothing.
- Different field crops require different models to relate their early season separability to environmental factors; no single relationship could be found to characterize general crop separability.
- Regional variation is too large to be ignored in an early season TM-based inventory of New York (or of similarly complex areas); however, stratification based on readily obtainable environmental data is of only moderate value in describing the variation in field crops.
- Non-white reflectance standards are valuable for field spectroradiometric measurements of certain natural targets, especially low reflectance targets such as organic soils.

Added Benefits:

The cooperative agreement...

- supported research which produced four M.S. graduate theses, six papers at national or international symposia (and appearing in their proceedings), and four papers published or accepted for publication in refereed technical journals. (Two additional papers were recently submitted to technical journals, and two more are currently planned.)
- provided financial assistance to five graduate students, allowing them to complete their M.S. degree programs.
- provided financial assistance to two undergraduate students.

INTRODUCTION

This report summarizes a multifacted investigation of satellite data for crop inventory. The goal was to determine whether the cost, efficiency or accuracy of crop surveys in environments typified by New York State could be improved through incorporation of satellite-derived information. Toward this end, the work addressed two questions: (1) can specific 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 thoughout the state. Speciality crops (fruits and vegetables) were chosen as the initial focus for crop identification, given both their importance to New York and the lack of attention they have received elsewhere; the effect of regional variation on crop classification was chosen as the initial parameter to be assessed for statewide inventory. Based on the findings of earlier studies and because New York is variable in topography, soils, climate, field shapes and sizes, and cropping diversities, emphasis was placed on Landsat thematic mapper (TM) data, the highest resolution satellite data available at the outset of the investigation.

The investigation was supported by the U.S. Department of Agriculture, National Agricultural Statistics Service (formerly Statistical Reporting Service), through Cooperative Agreement No. 58-319T-3-0208X with Cornell University. Begun during the summer of 1983, this agreement was terminated in March 1988, after having awarded Cornell a total of $174,900 plus computer-compatible tapes for several satellite images. (A new cooperative agreement will focus on higher resolution, SPOT satellite data.)

RESEARCH APPROACH

The accuracy with which TM data can be applied in identifying comercially 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 (Trolier and Philipson, 1988), and a follow-up, TM analysis extended the original findings on fruit trees (Taberner et al., 1987; Taberner, 1988). Concurrent with the latter studies, a broader scope analysis of the effect of regional factors on crop separability was conducted 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; Buechel, 1988). This latter analysis focused on the early season separability of field crops.

METHODS AND MATERIALS

The methods and materials employed for the different studies are reported in detail in the cited papers and theses. In brief, 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 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 ASCS compliance programs; and various maps and reports (geology, soils, topography, climate). Additionally, to support the vegetable and follow-up fruit tree analyses, the New York Agricultural Statistics Service (formerly, NY Crop Reporting Service) was able to provide plot maps of vegetables cultivated on mucklands and the results of a statewide fruit-tree census. (Notably, part of the area frame for this census was based on interpretations of the ASCS 35-mm slides by Cornell staff--work performed under the agreement.) For the vegetable analyses, two growing seasons were spent collecting field spectroradiometric measurements. (Field reflectance data did not extend to wavelengths longer than 1.1 micrometers.)

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

For crop identification, equal emphasis was placed on visual and digital methods of image analysis. Digital classification of vegetables and vineyards relied on the spectral properties of crops; while digital classsification of fruit trees placed equal weight on spatial properties. Regional variation within and among cropping areas was examined through statistical comparisons of crop spectral data from sample locations across the state.

SUMMARY OF FINDINGS

General

The findings to date have been described in four M.S. graduate theses (Gordon, 1985; Williams, 1986; Buechel, 1988; Taberner, 1988), six papers presented at national and international symposia and included in their proceedings (Buechel et al., 1987; Philipson et al., 1985a; Philipson et al. 1985b; Philipson et al., 1987; Taberner et al., 1987; Williams et al., 1986), and four papers published or accepted for publication in refereed technical journals (Gordon and Philipson, 1985; Gordon et al. 1986; Philipson et al., 1988; Willliams et al. 1987). Two additional papers were recently submitted to technical journals (Buechel et al., 1988; Trolier and Philipson, 1988), and two more are currently planned.

Vegetables

TM data are capable of providing reliable identifications of major vegetable crops, except in the smallest fields (i.e., those with dimensions smaller than or approaching a single TM pixel). Classifications of vegetables using a supervised, maximum likelihood classifier and TM bands 3 through 6 of a single, August scene produced accuracies of at least 90 percent for three muckland vegetables and at least 75 percent for three of four upland vegetables. (Although the value of the thermal band was clearly established, its precise contribution was not.) Highest accuracies of single-date classification were obtained late in the season, when the crops were mature, yet a second, earlier scene may be needed for double-cropped or early harvested vegetables.

Of possibly greater significance for crop inventory is that visual identification of vegetables (performed from the digital display) was even more successful than digital classification. Nearly all fields of known crops could be identified (particularly, with the band-color assignments of 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 identification also suggest that digital methods can be improved.

Future efforts should expand the sampling base for vegetables and address yield relationships. SPOT data should also be examined to determine whether the increased spatial resolution can offset the absence of TM band 5, a mid-infrared band which is important for vegetable identification but absent from SPOT. Given the success in visual-crop identification, a development/extension program should be considered for transferring the visual image analysis techniques to the New York Agricultural Statistics Service as well as to others.

Fruit Tree Orchards

In the initial study, orchards were first identified on aerial photographs and characterized fully on the ground. Attempts to classify different types of orchards with TM data were unsuccessful, principally because of the large contribution of the background to orchard reflectance. The effort was then redirected toward isolating orchards, as a class, from other cover types. This involved separating 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 (mixed deciduous forests).

Separating orchards 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 eight percent of the non-forest vegetation pixels misclassified as orchard. Separating orchards from forest, had to rely on image texture, given the high degree of spectral overlap between these cover types. A filter was applied to enhance the texture of bands 4 and 3 prior to ratioing (4/3), smoothing, and level-slicing to a binary image on the basis of supervised training. Including the binary image in supervised classification of a single date image reduced misclassifications of forest as orchard from 75 percent of the forest pixels to fewer than seven percent. As a final step in isolating orchards from forest and non-forest vegetation, the binary image was included with the other multi-date TM bands in a supervised classification. Misclassification of forest pixels was reduced to fewer than two percent of the pixels, and misclassifications of non-forest vegetation pixels was reduced to four percent or fewer.

Although orchards could be successfully isolated, a relatively high percentage of orchard pixels were not classified as orchards. Limited testing has shown this error of omission to be quite uniform, however, suggesting that 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.

In a follow-up effort, more complete training data were obtained and used to determine (1) the limits of orchard spectral characterizations, (2) the main factors affecting orchard spectral distributions, and (3) the spectral effects of fall phenology. Some 120 orchards and orchard-woodland groups were examined through principal components (PC) analysis of an August and a September TM scene. Although it was still impossible to distinguish reliably among orchards of different fruit types, orchards and woodland were observed to have a somewhat different spectral structure, most obviously, in the thermal band (band 6). Certain infrared band combinations also enhanced differentiation. As before, the background--particularly the amount of exposed soil--was found to be the main source of spectral variation. Visible bands were found to be important only when there is a contribution from the soil. If there is little or no exposed soil, orchard variation is dominated by tree to vegetation understory contrasts, and the data structure is defined by combinations of infrared bands. Variation in woodland sites is also defined primarily in the infrared bands. It is interesting to note that, although fall phenological differences were not observed among the different types of fruit trees, they were observed between orchards and woodland.

Future efforts could further test the uniformity of TM classifications for obtaining orchard area estimates or expand the initial use of spatial information. The latter would seem to offer great promise given the availability of SPOT data. Of particular interest would be the texture of individual orchards and the relationship of texture with orchard spectral response and physical characteristics. Image processing techniques to accommodate the increase spatial resolution should benefit from pre-classification image segmentation.

Vineyards

Vineyards in the two principal grape areas of New York were analyzed with either early-season (June) or late-season (August) TM coverage. 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. In the late-season coverage, much confusion occurred between vineyards and brush or some field crops. The late-season 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). Digital classifications at either date could produce relatively high accuracies (over 70 percent), but errors of commission were always high.

Future work should examine mid-season TM data, alone and in a multi-date scenario. In mid-July, vines are at full vegetative development, weeds within vineyards are still being controlled, and there exists the greatest possibility for spectral separations. Unfortunately, at the time of this study, cloud-free July data were not available. Recognizing that spectral classifiers were not effective primarily because of the high error of commission, the introduction of contextual information (e.g., distance from lake) and post-classification smoothing are also recommended. Finally, SPOT data should also be examined, especially since the spatial uniformity of vineyards might be significant in separating vineyards from brush. It is conceivable that the absence of a middle-infrared band with SPOT can be offset by the higher spatial resolution.

Regional Variation

Past study of several crops in the midwestern U.S. found that variation in crop spectral radiance associated with regionally varying environmental factors can be important to crop inventory design using Landsat multispectral scanner data. To assess the combined effects of a more complex environment and a higher resolution sensor on regionally definable parameters, a study of variation in crop separability in New York was conducted with TM data.

Three measures of crop variability were determined from early season (June) TM scenes for 31 sites across the state: unsupervised classification accuracy, divergence of crop spectra, and vegetation indices. The principal crops analyzed were winter wheat, pasture, hay, oats and corn. The three measures of separability were related statistically to 12 environmental variables: topography, frost-free season length, growing degree days base-40 and base-50, soil drainage and yield characteristics, crop diversity, field size, the proportion of crop at the site, seasonal rainfall, and recent precipitation. Simple correlations and multiple linear regressions were considered.

Although statistically significant models were found for individual crops, no significant relationship was found to characterize general crop separability. Regional variation is too large to be ignored in an early season TM-based inventory of New York (or of similarly complex areas); yet, stratification based on readily obtainable environmental data is of only moderate value in describing the variation.

Future work should consider the effect of mid-season, late-season and multi-date classification, reduced spectral dimensions, and more detailed ground data.

CONCLUSIONS

As described, the success in applying satellite data for crop identification in environments as complex as that of New York has varied with the particular crop. Spectral information and knowledge of the crop calendar have been found to be crucial for identifying specialty crops (especially vegetables); however, these are not always sufficient without spatial information (orchards and possibly vineyards). Moreover, even when crops can be identified reliably at one location, regional variation can greatly influence the classification results at other locations, as shown with field crops. This is especially significant if multi-crop inventories are to be performed.

Of continuing interest is the higher success attained in identifying crops through visual rather than digital image analysis. Overall, this poses a challenge to those seeking to take advantage of the potential efficiency of digital image processing for inventorying and analyzing crops over large areas. Clearly, the means for deriving and incorporating spatial information from the satellite images must be improved.

ACKNOWLEDGMENTS

Over the past five years, these studies have benefitted immeasurably from the advice and assistance of numerous individuals, ranging from students to farmers to cooperative extension agents to state and federal agency representatives to colleagues at other institutions and instrument manufacturers. The reader is referred to the various papers and theses for proper acknowledgments. For this summary report, the authors are grateful for the review and comments of Malcolm Taberner, graduate research assistant, under the subject grant.

REFERENCES CITED

Buechel, S. 1988. Early season, thematic mapper-based crop separability as influenced by regional variation in New York State. Unpub. M.S. thesis, Cornell Univ., Ithaca, N.Y. 169p.

Buechel, S., W. Philipson and W. Philpot. 1987. Regional variation and crop separability in a thematic mapper-based crop inventory of New York State. Proc. 21st Intl. Symp. Remote Sensing of Environment. ERIM, Ann Arbor, Mich. (in press).

Buechel, S., W. Philipson and W. Philpot. 1988. The effects of a complex environment on crop separability with Landsat TM. (submitted for publication)

Gordon, D. 1985. An investigation of thematic mapper satellite imagery for inventorying fruit trees in New York. Unpub. M.S. thesis, Cornell Univ., Ithaca, N.Y. 128 p.

Gordon, D. and W. Philipson. 1986. A texture-enhancement procedure for separating orchard from forest in thematic mapper data. Intl. Jour. Remote Sensing 7:301-304.

Gordon, D., W. Philipson and W. Philpot. 1986. Fruit tree inventory with Landsat thematic mapper data. Photogrammetric Engineering & Remote Sensing 52:12:1871-1876.

Philipson, W., D. Gordon, W. Philpot and M. Duggin. 1988. Field reflectance calibration with grey standard reflectors. Intl. Jour. Remote Sensing (in press).

Philipson, W., D. Gordon, W. Philpot and V. Williams. 1985a. Calibration for radiometirc measurements with non-white reflectance standards. Proc. 51st Annual Mtg. Amer. Soc. Photogrammetry. ASP, Falls Church, Va. p.47-54.

Philipson, W., W. Philpot, S. Buechel and M. Taberner. 1987. Satellite data analysis for inventorying crops grown in a small-field environment. Proc. 21st Intl. Symp. Remote Sensing of Environment. ERIM, Ann Arbor, Mich. (in press).

Philipson, W., V. Williams, D. Gordon and W. Philpot. 1985b. Vegetable and fruit tree inventory with Landsat TM data: Preliminary results. Proc. 51st. Annual Mtg. Amer. Soc. Photogrammetry. ASP, Falls Church, Va. p.39-46.

Taberner, M. 1988. Spectral characterisation of orchards with Landsat TM data. Unpub. M.S. thesis, Cornell Univ., Ithaca, N.Y. 250 p.

Taberner, M., W. Philpot and W. Philipson. 1987. Spatial and spectral characterization of orchards in New York State using thematic mapper imagery. Proc. 21st Intl. Symp. Remote Sensing of Environment. ERIM, Ann Arbor, Mich. (in press).

Trolier, L. and W. Philipson. 1988. Landsat TM analysis of vineyards in New York. (submitted for publication)

Williams, V. 1986. Analysis of thematic mapper satellite data for inventorying commercial vegetable crops in New York. Unpub. M.S. thesis, Cornell Univ., Ithaca, N.Y. 133 p.

Williams, V., W. Philipson and W. Philpot. 1986. Vegetable crop inventory with Landsat TM data. Proc. 52nd. Annual Mtg. Amer. Soc. Photogrammetry & Remote Sensing. ASPRS, Falls Church, Va. p.290-296.

Williams, V., W. Philipson and W. Philpot. 1987. Identifying vegetable crops with Landsat thematic mapper data. Photogrammetric Engineering & Remote Sensing 53:187-191.