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AGRICULTURAL LAND COVER MAPPING WITH THE AID OF DIGITAL SOIL SURVEY DATA

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I. ABSTRACT

Analysis of multitemporally registered Landsat MSS data has proven beneficial over single date analysis by the ability to characterize the spectral profiles of what to the observer are often obvious seasonal differences in crop, forest, and range land phenology. The subtle spectral differences among cultivated land cover types which follow similar crop development cycles present a more difficult task in land cover mapping with remotely sensed data.

The capability to register remotely sensed data with ancillary data sources by means of georeference information systems has enchanced the applicability of sensor-derived land information. This study assessed the application of digital soil survey data to the classification process to stratify land areas into homogeneous soil landscape units, minimizing the effects of factors which are extraneous to the discrimination of characteristic spectral differences among agricultural land cover types. Large scale soil maps published as part of the National Cooperative Soil Survey possess the level of cartographic and categoric detail suitable for stratification of Landsat MSS data.

Landsat MSS data from three 1980 growing season acquisitions and digitized county soil map data were registered to a common coordinate system for a 50,000 ha study area in northwestern Missouri. Stratification of the Landsat multidate data set into areas of analogous soil characteristics and cropping intensity was accomplished by aggregating soil mapping units into three distinctive soil physiographic strata. In this manner an unsupervised classification procedure could be directed to each individual stratum, with the result that land cover classification accuracies improved over a conventional unsupervised approach.

II. INTRODUCTION

Accurate land cover maps showing the location of crop, forest, and pasture land provide useful resource management information that may be found lacking in the limited sample data from area frame type surveys. Agricultural cooperatives have expressed the need to know the amount and distribution of crops within relatively small sub-county trade areas serviced by farmer exchanges. Cropping information from several growing seasons is often needed to develop an historical profile of production potential to support decisions regarding facilities expansion or consolidation. Land cover maps derived from Landsat MSS data readily characterize the spatial distribution of agricultural land cover types throughout trade areas. When these maps are combined with ancillary data through a geographic information system, areal measurements and production estimates can be made.

Multidate Landsat MSS data selected from among crucial dates in the growing season, when submitted to machine processing by various statistical pattern recognition algorithms, can be used to discriminate agricultural cover types growing in resolvable land parcels to the extent that spectral overlap among different crops can be avoided. It has been well established, for example, that May and August Landsat acquisitions facilitate discrimination between woods and corn based on the distinct spectral differences between leafed-out trees and the exposed soil predominant in emerging Midwest cornfields in May.[4,10] Separation of corn and soybean fields is typically more difficult because of similarities in their crop calendars. Closer examination of corn and soybean cropping practices reveals, however, that the subtle spectral differences between corn and soybean fields may be confounded by differing crop management practices and exposed background soil. Fortunately, many of these apparently confounding effects are not random in nature, but follow recognized mapped differences in soil characteristics.

Soils contrasting in drainage, moisture holding capacity, inherent fertility, topography, and surface reflectance affect crop spectra in different manners. As an indirect morphological and phenological effect, soils have been observed to influence crop development.[12] Well drained upland soils may be planted to crops earlier in the spring than poorly drained bottomland soils. Crops grown on soils high in moisture holding capacity and inherent fertility may attain complete ground cover earlier in the season than on droughty infertile soils. Fields on level sites tend to be larger and more uniform in reflectance than fields on rolling terrain where conservation practices such as strip cropping, grass terraces, and irregular field shape lead to highly variable reflectance given the 0.5 ha resolution of Landsat MSS.

As a direct effect, soil background reflectance has been found to dominate canopy reflectance to the extent that corn does not become spectrally apparent until 20 to 25 percent ground cover is achieved, while soybeans must reach 30 to 35 percent ground cover before they become readily distinguishable from the soil on which they are grown.[11] Soil patterns have been observed in aircraft MSS imagery in spite of dense corn canopy cover at the tasseling stage.[6] Crops grown on droughty upland soils may never achieve total ground cover, in which case the contribution of background soil reflectance predominates over vegetative response well into the growing season. In canopies with less than total ground cover, even field to field soil moisture differences can be expected to affect canopy reflectance on the same soil (Figure 1). These soil-induced spectral variations are of the same magnitude as the inherent spectral differences between corn and soybean canopies.

Preliminary results involving a stratification of Landsat MSS data along parent material boundaries defined by soil association maps indicated an improvement in corn classification accuracy.[1] Stratification of Landsat data based on uniform soil productivity areas delineated on enhanced Landsat imagery served for selection of training data and correlation with spring wheat yields.[7] Neither of these studies utilized detailed soil survey data in digital form.

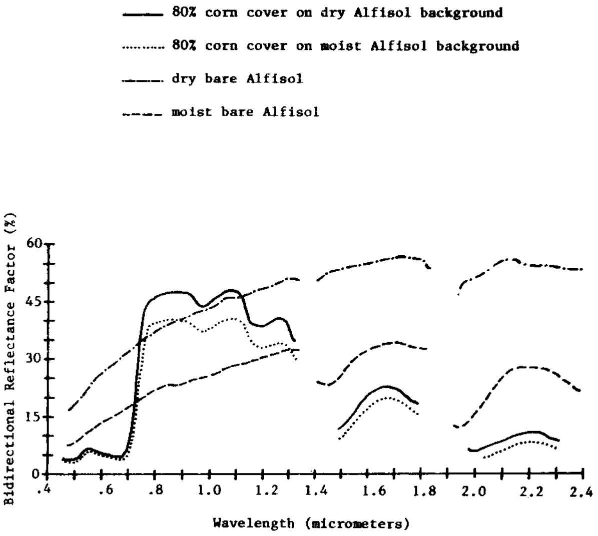

Figure 1. Field measured spectroradiometric characteristics of a pretasseling corn canopy and the soil on which it is grown.

III. OBJECTIVES

The overall objective of this study was to assess the effect of stratifying multidate Landsat MSS on land cover classification accuracy. Uniform soil landscapes defined in terms of homogeneous soil characteristics as derived from detailed 1:24,000 soil survey maps converted to digital form served as the basis for the stratification. Resulting land cover maps were compared for a maximum likelihood classification of the entire study area as contrasted with three separate maximum likelihood classifications directed one at a time to individual soil strata and later merged to produce a land cover map.

IV. STUDY AREA DESCRIPTION AND DATA SOURCES

A. LAND RESOURCE AREA

A study area in Gentry County in northwestern Missouri was chosen for analysis. The 49,184 ha (121,534 acre) area is covered by the Darlington NW and NE 7-1/2' quadrangle sheets in their entirety, and the Gentry County portion of the Darlington SW and SE 7-1/2' quadrangle sheets. This area coincided with available soil map sheets from the ongoing Gentry County soil survey at the time the study began.

This study area lies entirely within what is known as the Iowa and Missouri heavy till plain resource area of the central feed grains and livestock region.[9] It is characterized by broad level lowlands along the various channelized branches of the Grand River with gently rolling to very steep uplands of glacial till or shale residuum origin. Row crop cultivation is concentrated on the very highly fertile soils of the stream benches. Gently rolling upland topographic positions have soils of medium to high inherent fertility which are used extensively for cropland, but are frequently left in permanent pasture to control erosion on steeper slopes. Certain very steep upland soils are not suitable for cultivation and remain in woodland and permanent pasture. Farming operations are mostly mixed cash grain and livestock enterprises.

B. LAND COVER TYPES

Corn and soybeans predominate in the study area. Wheat and sorghum are important crops whose planted acreage varies significantly from year to year. Sorghum is planted as a cash grain crop, often double cropped, thus occupying the same land area in a given growing season. Alfalfa and clover are planted as hay crops, especially in the more gently rolling topography of upland sites. Native or established fescue pastures, which may be cut for hay or grazed, are common on upland soils.

Forested land areas consist mainly of remnant woodlots and wooded draws. Land areas which are not agricultural in nature have been referred to as "other". This comprises roads, residential and commercial areas, quarries, land fills, and agricultural land held fallow during a given growing season. Water bodies are restricted mainly to farm ponds which in this case were smaller than the Landsat MSS resolution.

C. CROP CALENDAR CONSIDERATIONS FOR LANDSAT DATA SELECTION

Examination of crop calendars for periods of maximum vegetative ground cover revealed that the best single date for corn and soybean discrimination would be from mid-August, at which time most corn fields are tasseled out, to mid-September, prior to the onset of senescence. A Landsat MSS scene from 3 September 1980 (ID 22051-16213) fit these criteria. By adding a Landsat data set from mid-May to mid-June to the previous Landsat data, confusion between foliated woodland and emergent row crops was avoided, while catching wheat at its peak of vegetative cover. The Landsat MSS scene from 5 June 1980 (ID 21961-16195) served these purposes. A third Landsat data set from early to mid-July would be capable of distinguishing alfalfa hay and pasture at a stage in their development when they are at optimum vegetative growth while wheat is senesced or harvested and row crops are still in stages of partial ground cover. Although a scene from this limited time period was not available, a Landsat MSS scene from 28 July 1980 (ID 22014-16152) provided most of the desired information.

Landsat MSS data were obtained as P-format computer compatible tapes. Although the P-format CCT's had geometric corrections applied, the registration accuracies have been found to be inconsistent.[3] Consequently, the Landsat MSS data had to be geographically referenced through a procedure involving the location of surface features that are suitable as control points, and can be visually located in the Landsat MSS data and on a map with Universal Transverse Mercator (UTM) coordinates.[2]

A six channel multidate Landsat MSS data set was formed by registering MSS bands 5 and 7 of each Landsat scene to the 28 July base scene. The partly manual, partly automated scene-to-scene registration procedure is part of the comprehensive operating subsystem known as the Earth Resources Laboratory Applications Software (ELAS).[13] ELAS consists of pattern recognition and data base program modules which constitute a geographic information system. The scene-to-scene registration and scene-to-map registration were achieved to within one Landsat pixel of the correct location. For ease of comparison with digital soil map data, the multidate Landsat MSS data set was resampled and registered using a nearest neighbor algorithm to fit into a 50m cell size in the UTM coordinate system.

D. SOIL SURVEY DATA

Advance map sheets from the Gentry County soil survey were obtained for the study area with soil map unit boundaries drawn on the four 7-1/2' orthophoto quads at 1:24,000. The level of detail in such a modern county level soil survey is well suited to integration with remotely sensed data in the context of a geographic information system. This type of soil survey is the most cartographically detailed form widely available through the National Cooperative Soil Survey because of extensive field verification of map boundaries. These surveys are also the most categorically detailed in their delineation of soil mapping units at the lowest category in soil taxonomy, that of phases of soil series.[8] They represent the best source for soil management information on a field-by-field basis, and are thus appropriate as an aid for field-by-field land cover inventory. Conversely, soil association maps do not possess the intensity of field verification nor do the associations of series used as mapping units necessarily represent uniformity of soil properties to the extent that the name implies.

Digitization of soil map boundaries was accomplished partly by line segment digitization on an X-Y tablet digitizer, and partly by raster scanner digitization with a vidicon camera. Both forms of digitized polygon data were adaptable to formation of a 50m UTM coded soil map data file, corresponding to the geographic coordinates of the multidate Landsat MSS data set.

E. FIELD SAMPLED LAND COVER DATA

The field sampling scheme involved a total enumeration of land cover types along a certain road route throughout the study area. Field locations were digitized with an X-Y digitizer and brought into the 50m UTM data file coded by land cover type. Pixels forming the boundaries of sampled fields were delineated and were removed from the file of field verified land cover data. Accuracy assessment was based on the remaining field interior pixels.

V. LAND COVER MAPPING

A. CONVENTIONAL MULTIDATE APPROACH

Spectral class development with the conventional multidate approach utilized an algorithm known as SRCH, which collects training statistics from the multichannel data set by passing a 3 by 3-pixel window through the data.[5] Typically, less than 10% of the total pixels in a data set are selected by this algorithm because heterogeneous areas typical of small fields are discarded. For the six channel multidate Landsat MSS data set, 44 spectral classes were defined by the SRCH algorithm in terms of means and covariance matrices.

Assignment of each Landsat pixel to one of the SRCH-derived spectral classes was accomplished by means of a maximum likelihood ratio algorithm, MAXL. Using a threshold value of 99.9%, a total of 20% of the pixels were not assigned to any of the 44 classes. This difficulty was resolved in part by applying a contextual information classifier, CICL, as a post-classification refinement technique to reassign the unclassified pixels based partially on their spatial proximity to mapped pixels. The spectral classes derived using this technique may not have adequately represented the total spectral variability in the data set.

Spectral class labeling was done with the aid of plots of relative reflectance in Landsat MSS band 5 vs. band 7 for each date. A pixel-by-pixel comparison of the classified data with the field verified data confirmed tentative class labels while the distribution of mapped spectral classes in relation to other spectral classes and recognizable map features was established on a digital display device.

B. SOIL STRATIFICATION APPROACH

The 37 soil mapping units of the Gentry County soil survey were aggregated into three soil physiographic strata plus one non-agricultural stratum, which was eliminated from the Landsat analysis (Figure 2, Table 1). Aggregation of the soil mapping units into three strata simplified the analysis, while maintaining uniform soil landscape units with common soil characteristics and similar land use. At the same time, the precision of soil strata boundary location was retained in accordance with the cartographic detail of the original soil map.

Table 1. Characteristics of Gentry County, Missouri soil strata derived from modern soil survey data.

Physiographic Stratum (Percent of Study Area)	Map Units*	Soil Suborders	Major Soil Characteristics	Predominant Cover Types
Level stream benches 10,984 ha (22.3%)	12	Aquolls, Albolls, Aqualfs, Fluvents	slopes less than 5%, somewhat poorly to very poorly drained, high organic matter contents, formed in fine-textured alluvium	mostly cropped to corn and soybeans with some wheat and sorghum
Rolling uplands 35,734 ha (72.6%)	20	Udolls, Udalfs	slopes from 5 to 14%, moderately well to somewhat poorly drained, low organic matter contents, formed in loess over glacial till	mostly pastureland with cultivated hay, corn, soybeans, and wheat
Steep uplands 2,278 ha (4.6%)	3	Ochrepts, Udalfs	slopes greater than 20%, moderately well drained, low organic matter content, formed in calcareous clay shale residuum	mostly pastureland and woodland
Non-agricultural 188 ha (0.4%)	2	-	-	quarries, landfills, and water bodies
49,184 ha (121,534 acres) Total	37 Total			

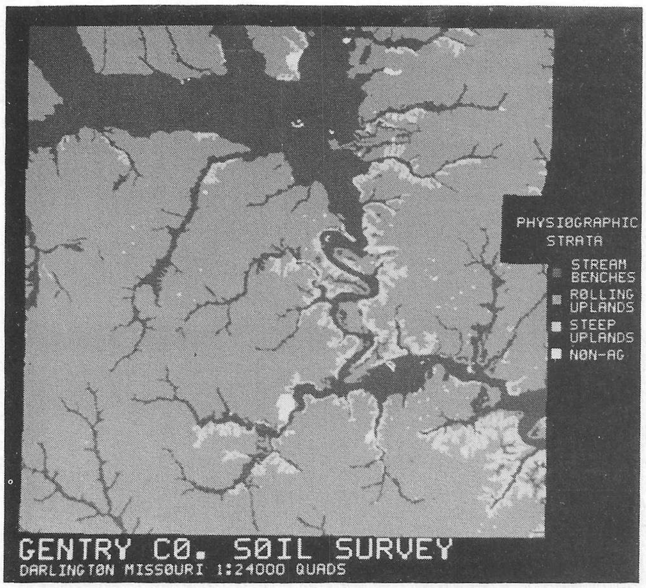

Figure 2. Soil strata map. Aggregation based on the 37 soil mapping units of a 50,000 ha portion of the Gentry County, Missouri soil survey (see Table 1).

This approach utilized the same six channel multidate Landsat MSS data set mentioned earlier, but made use of a spectral class development algorithm which derived spectral class statistics only from those pixels identified as belonging to a certain soil stratum. The program WCCL, or within-class cluster, collected training statistics on a pixel-by-pixel basis within individual soil strata. A companion program, WMAX, assigned each pixel within the selected soil stratum to one of the point cluster derived statistics using a maximum likelihood ratio algorithm. When a threshold value of 99.9% was used, typically less than 5% of the pixels were not assigned to spectral classes. These unclassified pixels tended to follow roads and field boundaries and were therefore not of sufficient concern to warrant any post-classification "cleanup". There were 61 spectral classes in the level stream bench stratum, 50 in the rolling upland stratum, and 17 in the steep upland stratum.

Labeling of spectral classes was done in the same manner previously described, with the exception that the labeling exercise was repeated three times. Upon completion of class labeling, the individually classified land areas defined by soil strata were merged back together to produce a wall-to-wall land cover map.

VI. RESULTS AND DISCUSSION

A pixel-by-pixel comparison of the two land cover classifications with field verified land cover indicated improvements in identification of all cover types when land areas were stratified by soils (Table 2). The accuracy of corn identification improved by 5%, while identification of soybeans improved by a smaller amount. Confusion of wheat with pastureland was reduced, although wheat was still identified correctly only 47% of the time, probably because of confusion between the appearance of harvested wheat and unusually dry pastures in the summer of 1980. Overall correct classification improved slightly more than 3% for over 15,000 field verified pixels. On a visual basis, field definition was seen to be much more distinct in the soil-stratified land cover map, with less evidence of pixels of one cover type scattered throughout the interior of fields of another cover type, as was common in the conventional classification.

Classification accuracies varied considerably among the three individual soil strata (Table 3). Classification results for corn and soybeans were highest for the level stream bench stratum where crop production was concentrated. Correct identification of pastureland was highest on the rolling and steep upland sites where it predominates. Poorer performance for corn and soybeans on the rolling upland sites followed the reduction in field size and decrease in field uniformity going from the stream bench to the upland sites. Corn fields on these droughty upland soils did not attain as complete a canopy cover as did soybean fields under the below normal rainfall conditions of 1980. The highly reflective background soil in the sparse upland corn fields could be expected to contribute to confusion with other crop types. Interestingly, ground data confirmed the presence of 30 pixels of soybeans in steep upland sites which would not normally be cultivated, but probably represent corners of less steeply sloping fields.

An additional outcome of using a point cluster procedure with soil stratification for land cover classification was the ability to identify spectral classes representing sorghum, hay, and double cropped wheat and soybeans. Although field verified data were scarce for these cover types, it was possible to positively identify them as distinct classes. Sorghum pixels were consistently confused with soybeans while hay was inseparable from pasture with the conventional classification. With the very small field size of the few double cropped fields in the study area it is likely that the SRCH algorithm did not pick up this unique spectral class. These results are attributable to basic differences in the way the two different spectral class development algorithms operate.

VII. SUMMARY AND CONCLUSIONS

Large scale soil maps published as county soil surveys in the United States contain the level of cartographic and categoric detail which is appropriate for stratification of land areas into homogeneous units as an aid to classifying Landsat MSS data. The ability to digitize this soil map information and reference it to remotely sensed data by means of a geographic information system enhances the capability to produce accurate maps of agricultural land cover. The introduction of soil map information to the land cover mapping process can improve discrimination of land cover types and

Table 2. Percent correct identification of field verified pixels for major cover types for two data processing approaches using a June/July/Sept. Landsat data set.

Cover Type	Conventional Approach	Soil Stratification Approach
Soybeans	$\frac{6300}{7042}$ = 89.5%	$\frac{6347}{6963}$ = 90.8%
Corn	$\frac{3012}{4390}$ = 68.6	$\frac{3213}{4364}$ = 73.6
Wheat	$\frac{268}{888}$ = 30.2	$\frac{417}{888}$ = 47.0
Pasture	$\frac{2603}{3063}$ = 85.0	$\frac{2675}{3061}$ = 87.4
Woods	$\frac{351}{355}$ = 98.9	$\frac{352}{354}$ = 99.4
Weighted Average	$\frac{12534}{15738}$ = 79.6	$\frac{13004}{15660}$ = 83.0

Table 3. Percent correct identification of field verified pixels for major cover types within three soil physiographic regions.

Cover Type	Level Stream Benches	Rolling Uplands	Steep Uplands
Soybeans	$\frac{4304}{4610}$ = 93.4%	$\frac{2018}{2353}$ = 85.8%	$\frac{25}{30}$ = 83.3%
Corn	$\frac{2727}{3507}$ = 77.8	$\frac{486}{857}$ = 56.7	None Present
Wheat	$\frac{70}{153}$ = 45.8	$\frac{347}{735}$ = 47.2	None Present
Pasture	$\frac{128}{177}$ = 72.3	$\frac{2514}{2845}$ = 88.4	$\frac{33}{39}$ = 84.6
Woods	$\frac{1}{1}$ = 100.0	$\frac{55}{56}$ = 98.2	$\frac{296}{297}$ = 99.7
Weighted Average	$\frac{7230}{8448}$ = 85.6	$\frac{5420}{6846}$ = 79.2	$\frac{354}{366}$ = 96.7

reduce confusion among crop types that may be caused by soil-specific management practices, soil-induced crop development differences, and background reflectance characteristics.

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