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AGRICULTURAL LAND COVER MAPPING IN THE CONTEXT OF A GEOGRAPHICALLY REFERENCED DIGITAL INFORMATION SYSTEM

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NATIONAL SPACE TECHNOLOGY LABORATORIES

AGRICULTURAL LAND COVER MAPPING IN THE CONTEXT OF A GEOGRAPHICALLY REFERENCED DIGITAL INFORMATION SYSTEM

TECHNICAL REPORT

on the

FARMERS INFORMATION AND RESOURCE SYSTEM TECHNOLOGY (FIRST)

TECHNIQUE TEST CONDUCTED WITH

MFA, INC.

MARCH 1982

by

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EARTH RESOURCES LABORATORY

NATIONAL SPACE TECHNOLOGY LABORATORIES

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INTRODUCTION AND OBJECTIVES

Agricultural cooperatives are a major supplier of materials and service to the agribusiness community of the United States. These farmers' cooperatives provide a broad range of services, including the sale of fertilizer, pesticides, seed, and supplies and the purchase and storage of grain and other commodities. By their nature, farmers' cooperative exchanges service relatively small geographic areas within a short distance of the farm operations of their patrons. These exchange or trade areas commonly comprise portions of one or several adjoining counties and cannot be defined by traditional political boundaries. In fact, a given farmers' exchange would have different trade areas for each commodity it buys or sells, depending on the types of farm operations prevalent in different land resource areas.

Effective management of a farmers' exchange requires knowledge of the amount and distribution of crop, forest, and pasture land throughout the trade area. Miscalculation of needed supplies or expected grain production could lead to expensive overstocking or lack of adequate storage resulting in business losses in day-to-day operations. Longer term management decisions regarding facilities expansion or consolidation may require cropping information over a period of several growing seasons to develop an historical profile of production potential.

Published statistics from area frame sampling-based crop reports seldom correspond to the geographic location of individual trade areas. Limited field enumeration at the lowest level, by county, is not intended to provide precise crop estimates for given counties, but rather to furnish reliable state and national estimates. Land cover types such as forest and pasture are not included in annual area frame surveys which deal only with planted and harvested crop areas. Traditional sources of statistical cropping information are therefore not available for describing the amount and distribution of crop, pasture, and forest land within agricultural cooperative trade areas in a timely manner.

Remote sensing technology as currently available with the Landsat series of satellites and computer data processing provides a means of mapping the distribution of land surface features to the extent that the detected reflectance of these features can be defined in unique statistical terms. Distinctive reflectance properties of vegetative features in the visible and near infrared portions of the spectrum to which the four wavelength bands of Landsat's multispectral scanner (MSS) are sensitive permit agricultural land cover types to be discriminated. Repeated seasonal coverage of the same land area with Landsat improves the capability to discriminate land cover types.

Landsat-derived land cover maps readily display the distribution of agricultural land cover types throughout any area of interest, such as a trade area, and the areal measurements of these cover types can be determined through computer processing of digital format data. By registering Landsat data to a common geographic map base, other forms of existing map data can be digitized and referenced to the same coordinate system. In this manner, a data base can be constructed containing information relative to transportation networks, soil characteristics, etc., thus augmenting Landsat-derived land cover information with more specific information for managers of agricultural cooperatives.

This report documents a Technique Test project conducted jointly between the Earth Resources Laboratory (ERL) of NASA's National Space Technology Laboratories (NSTL) and MFA, Inc. The overall objective of the project was to design, construct, and test a geographic information system based on Landsat digital data and capable of responding to MFA management information requirements. The tasks necessary to accomplish this objective were conducted on three study areas in northern Missouri corresponding to three MFA trade areas. Multiple dates of Landsat MSS digital data were analyzed for each area to produce cover type maps for major agricultural land cover classes. Digital data bases were then developed by adding ancillary data such as digitized soils and transportation network information to the Landsat-derived cover type maps. Finally, procedures were developed to manipulate the data base parameters to extract information applicable to MFA requirements.

STUDY AREA DESCRIPTION

Land Resource Areas

All three of the study areas are located within MFA trade areas north of the Missouri River (Figure 1). They represent a variety of land resource areas and intensities of farming operations. The Norborne study area in Carroll County is a 70,687-ha (174,671-acre) area bounded on the west and south by the Carroll County line and on the north and east by limits defined by the Universal Transverse Mercator (UTM) map coordinate system. In this rectangular metric coordinate system, the northern limit of the Norborne study area is expressed as 4,370,000 mN for the vertical coordinate (known as northing), or 4,370 km north of the equator. Likewise, the eastern boundary of the Norborne study area is expressed as 460,000 mE for the horizontal coordinate (known as easting), or 40 km west of the central meridian at 93° west longitude (given the arbitrary value of 500,000 mE). The Norborne study area includes all of the Norborne and Carrollton West 7-1/2' quadrangle maps, most of the Roads and Bogard 7-1/2' quads, and smaller portions of surrounding 7-1/2' quads.

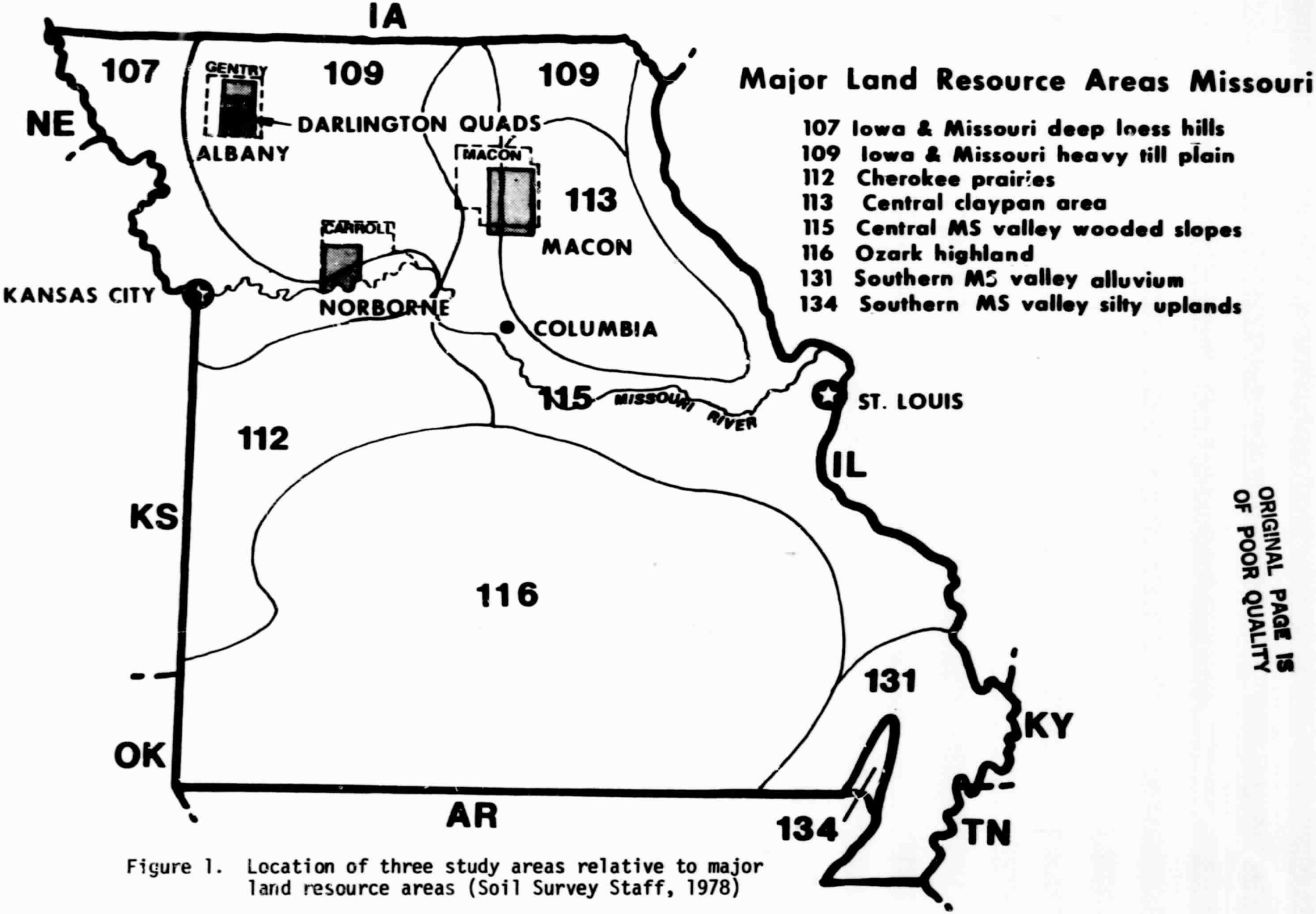

Figure 1. Location of three study areas relative to major land resource areas (Soil Survey Staff, 1978)

The Norborne study area is divided into two general land resource areas of what is known as the central feed grains and livestock region (Soil Survey Staff, 1978). A broad lowland area adjacent to the Missouri River falls in what is known as the Iowa and Missouri deep loess hills resource area. In Carroll County this area consists of an extensive level bottomland landscape of intensive row crop agriculture on soils of very high inherent fertility. This nearly level topographic region is broken by the deep loess bluffs approximately 10 km (6 mi) from the Missouri River, providing a transition to the Iowa and Missouri heavy till plain resource area. This land resource area is characterized by rolling to hilly topography in a landscape in which moderately deep loess overlies glacial till. Soils of medium to high inherent fertility are used extensively for cropland but are often left in permanent pasture on the steeper slopes. Fields in the upland positions of the heavy till plain resource area tend to be smaller and are more apt to contain grass terraces and wooded draws, factors which make these fields less uniform in appearance at the 0.5-ha (1.1 acre) resolution of Landsat than the larger fields of the level bottomland landscape.

The Macon study area contains 120,347 ha (297,385 acres) in Macon County and is bounded on the east, west, and north by UTM coordinates 530,000 mE, 560,000 mE, and 4,420,000 mN, respectively. The southern limit is the county line. The study area includes all of Bevier North, Bevier South, Axtell, and Macon 7-1/2' quads, most of Redman and Clarence 7-1/2' quads, plus smaller portions of surrounding 7-1/2' quads. This study area is also located in the central feed grains and livestock regions, and consists of two general land resource areas. The eastern half of the study area falls in the central claypan resource area, consisting of soils developed under prairie vegetation in thin loess deposits overlying glacial till. These soils have claypans, or heavy clay subsoil horizons, which form a dense, compact layer impeding the movement of water and air and the growth of plant roots. This slowly permeable claypan results in wetness problems on the nearly level topography during rainy seasons as well as drought problems during moderately dry seasons. The claypan soils are medium in fertility, with typical landscapes consisting of broad cultivated fields on nearly level uplands and some pasture and woodland on the narrow dissected topography of stream channels.

The western half of the Macon study area is comprised of the central Mississippi Valley wooded slopes resource area. In this highly dissected area, soils were formed under oak-hickory forest vegetation in thin loess on the ridgetops, in glacial till or steep side slopes, and in exposed shales below the glacial till near major streams. The natural fertility in all of these landscape positions is low and forest and pasture land predominate, with limited small grain and row crop production on the gentler slopes. Farming operations are likely to center around livestock production in this resource area, whereas the central claypan resource area is one of cash grain operations.

Also situated in the central feed grains and livestock region, the Albany study area comprises 84,279 ha (208,258 acres) in Gentry County. The study area is covered by the Grant City SW and SE quad sheets, the Darlington NW and NE 7-1/2' quad sheets in their entirety, and the Gentry County portion of the Darlington SW and SE 7-1/2' quad sheets. A smaller subset of this study area covering 49,184 ha (121,534 acres) of the four Darlington quad sheets coincided with available soil map sheets from the ongoing Gentry County soil survey and was used for more detailed analysis.

The Albany study area lies entirely within the Iowa and Missouri heavy till plain resource area. Unlike the same resource area within the Norborne study site, the Albany site contains broad level lowlands along the various channelized branches of the Grand River. Row crop cultivation is concentrated on the very highly fertile soils of these stream benches. Gently rolling upland topographic positions have soils of medium to high inherent fertility which are used extensively for cropland, but they 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.

Land Cover Types

For the purposes of this study, the major land cover types found in northern Missouri were categorized in a classification system consisting of two levels of complexity (Table 1). It should be pointed out that this classification system was developed based on MFA, Inc., agricultural information needs and does not follow the more familiar land use and land cover classification system of Anderson, et al., 1976. Whereas the Anderson system does not even attempt to separate cropland from pasture until a third level is reached, the system used here separates grain crops from pasture/hay in Level I. This is the minimum acceptable level of complexity for agricultural information needs and was the focus of effort during the early stages of this project. Once it was established that forest, water, grain crops, pasture/hay, and other land cover types could be discriminated using Landsat data, methods for mapping Level II land cover classes were developed and evaluated.

Level II land cover classes provide a breakdown of the major crops grown in this portion of the state of Missouri. Corn and soybeans predominate in all three study areas. Wheat and sorghum are important crops whose planted acreage varies significantly from year to year. Sorghum is planted

Table 1. Level I and II land cover classes for northern Missouri study areas

LEVEL I	LEVEL II
FOREST	FOREST
WATER	WATER
GRAIN CROP	CORN
	SOYBEANS
	WHEAT
	SORGHUM
PASTURE/HAY	ALFALFA
	OTHER PASTURE/HAY
OTHER	OTHER

as a cash grain crop, often as an alternative to corn in drier seasons. Wheat and soybeans are often double cropped, thus occupying the same land area in a given growing season. Alfalfa is planted as a high value hay crop, especially in the more gently rolling topography of upland portions of the three study areas. Clover is a hay crop of lesser value grown to a limited extent in all three areas. Native or established fescue pastures, which may be cut for hay or grazed, are common to the three study areas.

The land cover class referred to as "other" includes non-agricultural features which are not of particular interest in an agricultural inventory. This may comprise roads, residential and commercial sites, quarries, land fills, strip mines, and agricultural land held fallow during a given growing season. The Macon study area contains large areas of strip mines and associated reclaimed lands. The largely unchanging nature of these features lends itself to digital delineation in an agricultural data base for removal of "other" land areas from consideration when Landsat data are used to map cropland. In a similar manner, the forested land areas in the three study sites consist mainly of remnant woodlots, wooded draws, and wildlife reserves which do not change from year to year except for a limited amount of forest clearing for agriculture. As such, an adequate forest delineation from one growing season's Landsat data could serve as a base from which non-cropland vegetated features would be inferred in subsequent seasons.

Water bodies are relatively easy to discriminate with Landsat data providing they are not smaller than the minimum resolution of the MSS system (1.1 acre). The Norborne study area's southern boundary is the Missouri River, which is wide enough to map with Landsat. Macon contains the large Thomas Hill and Macon Reservoirs which are obvious features in Landsat data, while the Albany site has no water bodies larger than farm ponds which are smaller than Landsat resolution. Although small rivers and streams may not be detectable as water bodies, the drainage networks they form are still apparent with Landsat data.

Crop Calendars

Crucial to the selection of optimum dates of Landsat coverage for agricultural land cover mapping is an understanding of the phenology of vegetative features in a study area. For most purposes, the phenology of vegetative cover types does not differ to any significant extent over the three study areas in northern Missouri. Spring leaf-out of hardwood forests normally would begin in April and be complete by late May. Fall senescence would occur from late September to late October for these same woodland areas.

Phenology of agricultural crops can be expressed by means of each crop's calendar of development through the growing season. On such a calendar, the significant events and growth stages in the development of a crop can be expressed, as shown in Figure 2. The time periods for ground preparation, planting, possible cultivation and weed control, harvest, and post-harvest ground preparation are shown in a cumulative scale of completion of effort for any single event. Also, the relative crop height is expressed in an ascending and descending curve which relates very closely with the development of green vegetative cover to the point of maximum expected vegetative growth through subsequent leaf senescence and maturity. Although there are many ways to describe crop development by field measurable parameters such as leaf area index, percent ground cover, above ground biomass, etc., these curves of relative crop height convey the important stages in crop development in relation to increasing and decreasing vegetative cover.

Remote sensing techniques for discrimination of crop types are more likely to succeed when sensor acquisition dates coincide with maximum periods

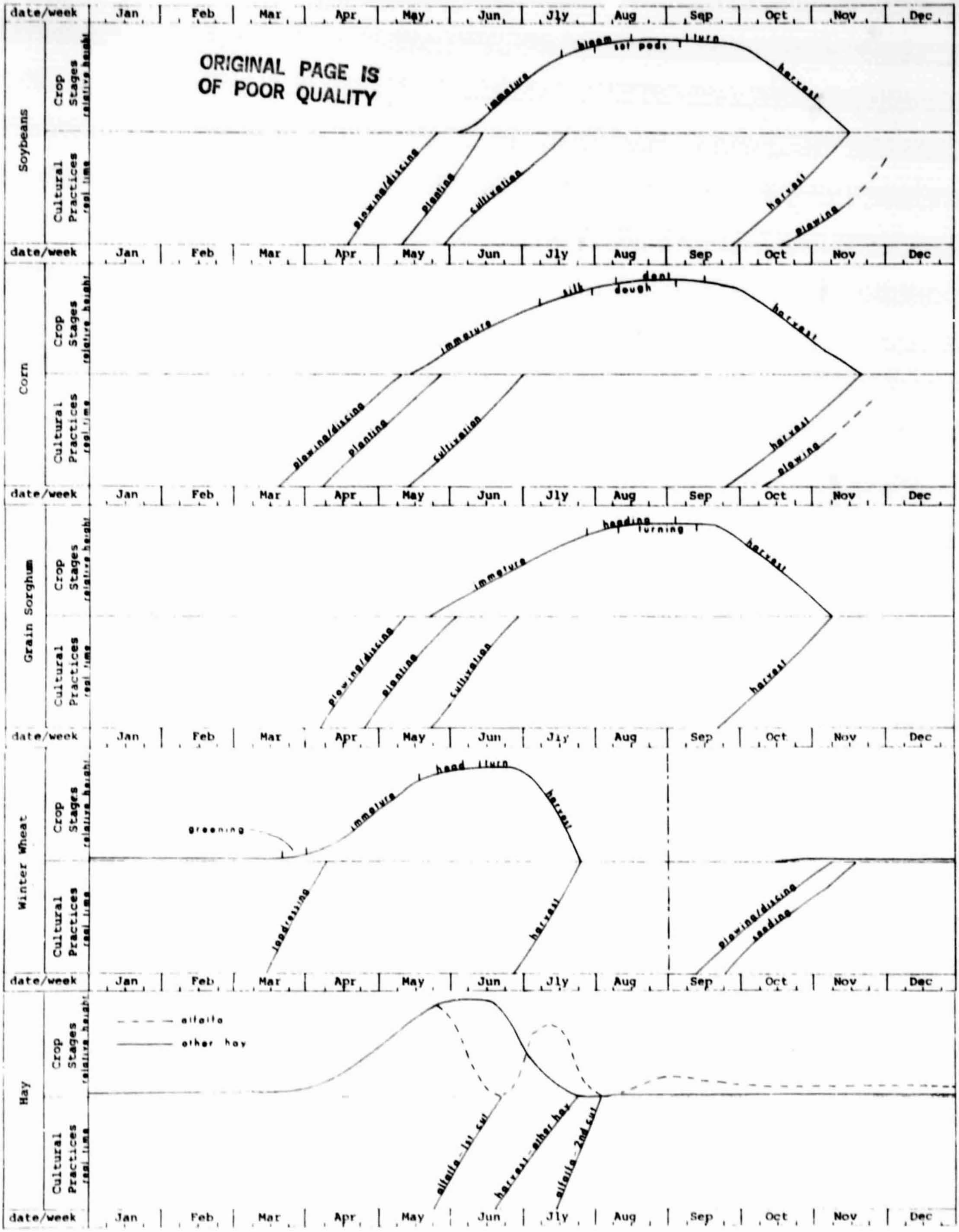

Figure 2. Crop calendars for major land cover types

of vegetative ground cover. Whereas early season detection of crop types may be desirable for certain applications, it has been found 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 (Tucker, et al., 1979). Landsat acquisition dates from the tasseling period in corn and the heading period of wheat have been found best for crop type discrimination in the midwest United States (Hixson, et al., 1980). Inclusion of a spring Landsat data set after tree leaf-out has been found to increase the accuracy of Landsat-derived cover type mapping by providing a strong contrast between vegetated woodland and fields of exposed soil in preparation for planting (Stoner, et al., 1981).

Examination of the crop calendars for major northern Missouri crops (Figure 2) reveals 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. By adding a Landsat data set from mid-May to mid-June to the previous Landsat data, wheat can be discriminated at its peak of vegetative cover. 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. An example of the reflectance characteristics of major cover types measured by Landsat on various dates is given in Figure 3 for a 1978 growing season data set for the Norborne study area. The unique contribution of each date to the agricultural scene can be noted.

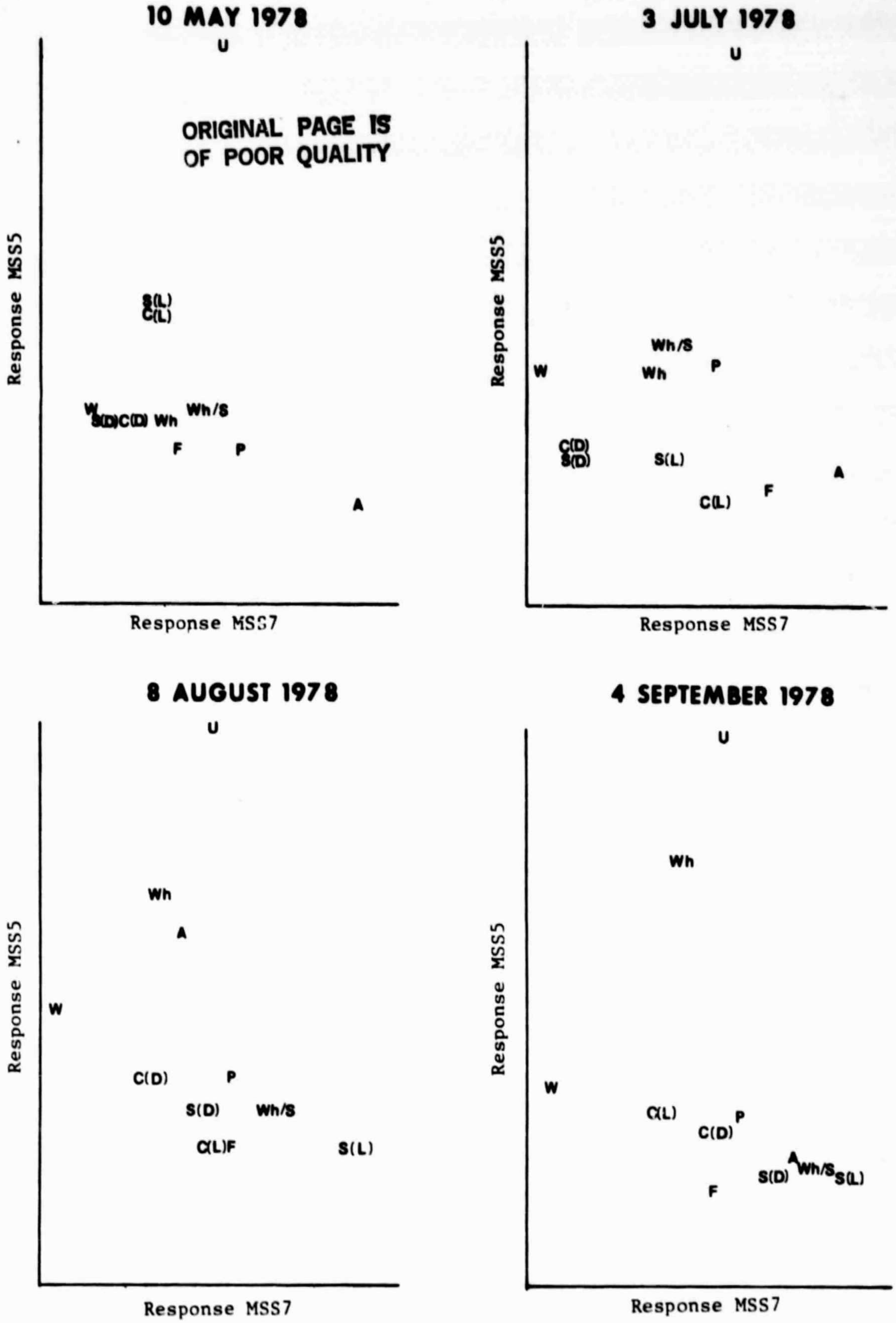

Figure 3. Representative reflectance of major land cover types for four dates. F = forest, W = water, U = Urban area of unchanging reflectance, P = pasture, S(L) = soybeans on light soil, S(D) = soybeans on dark soil, C(L) = corn on light soil, C(D) = corn on dark soil, Wh = wheat, Wh/S = double cropped wheat and soybeans, A = alfalfa.

Spectral Overlap Considerations

Discrimination among vegetative land cover types with Landsat MSS data is possible to the extent that the land areas resolved by the Landsat sensors (1.1 acre minimum size) represent "pure" units of a single cover type and with the requirement that different cover types not be spectrally similar. Spectral overlap occurs when two different cover types produce the same spectral response as measured by the Landsat sensors. This situation has been observed in regard to the reflectance of tasseled corn canopies and deciduous forest vegetation, which are difficult to differentiate based solely on reflective spectral characteristics on a single date in late summer. As an obvious solution to this specific spectral overlap problem, as mentioned earlier, addition of a spring Landsat scene registered to the summer scene reveals a distinct spectral contrast between the leafed-out forest land and emerging corn fields with little vegetative cover.

As another example of a solution to a spectral overlap problem, headed wheat canopies and lush green pasture and hay which may appear spectrally similar in late May are readily distinguishable in early July at the time of wheat maturity and harvest. Permanent pasture and alfalfa hay, which may both be at peak vegetative growth in late May, would appear quite different shortly after the alfalfa is harvested for hay, an event whose frequency is unique to the crop calendar of alfalfa.

Other spectral overlap problems are more difficult to solve because of the lack of distinct differences in crop development calendars for such crops as corn, soybeans, and sorghum. Although the spectral differences among corn, soybean, and sorghum canopies may permit their discrimination in the case of large, uniform, weed-free, fully developed fields, these spectral differences are often subtle ones which may be confounded by differing crop management practices and exposed background soil. These problems cannot be resolved by the inclusion of additional dates of Landsat data into the analysis. Fortunately, however, many of these apparently confounding effects are not random occurrences, but tend to follow recognized mapped differences in soil characteristics.

Soils contrasting in drainage, moisture holding capacity, inherent fertility, topography, and surface reflectance affect crop spectra differently. Some of these soil differences result in slight deviations from the "typical" crop calendar for a given crop, either accelerating or delaying crop development on certain fields. On certain droughty infertile soils, crop canopies may never reach the point of complete ground cover that would be expected on soils high in moisture-holding capacity and inherent fertility. 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, contour planting, and grass waterways on small irregular fields lead to highly variable reflectance at the 1.1-acre resolution of Landsat.

To avoid possible confusion among crop types because of differences in spectral reflectance that are related more to edaphic properties than to species characteristics, an analysis approach was developed to isolate and analyze Landsat data corresponding to certain homogeneous soil areas as defined by digital soil survey data. In this manner, for example, the broad fertile bottomland soils can be isolated and the Landsat data for this land area processed to produce a land cover map in which the risk of confusing a certain crop type grown on bottomland soils with another crop type grown on an upland site would be eliminated. Given the availability of cartographically and categorically detailed soil map data such as those contained in a modern soil survey, it is then up to the analyst to decide on the best way to group the basic soil mapping units into landscape strata of similar crop management practices and land use-related soil characteristics.

DIGITAL DATA SOURCES

Landsat MSS Data

Computer-compatible tapes (CCT's) of individual Landsat scenes were obtained for the three study areas. The preliminary study of the Norborne and Macon study areas utilized Landsat MSS data from the 1978 growing season in what is known as X-format CCT's in which individual picture elements, or pixels, represented a 56m x 79m (1.1 acre) area. These X-format data were also geographically skewed and distorted because of Landsat operating characteristics. Results of the analysis of 1978 Landsat data will not be reported here, but serve as the basis for many of the procedures that were developed to work with 1980 Landsat data.

Landsat MSS data obtained for the 1980 growing season are in what is known as P-format, fully corrected, high density tapes (Geological Survey Staff, 1979). The P-format data are deskewed and resampled with the aid of ground control points to provide Landsat data in a geographically referenced format. Pixel size for the P-format CCT's is 57m x 57m. Although the P-format data are more geographically correct than the X-format data, studies have shown that the registration accuracies are inconsistent and do not substitute for more rigorously controlled scene-to-map registration procedures (Graham and Luebbe, 1981). As a result, P-format data must be geographically referenced based on the hand-selected location of numerous control points on a map base and in the Landsat scene.

Landsat scenes were selected based on key dates as indicated by the crop calendars and also according to the availability of high quality, cloud-free scenes. The Macon and Albany study areas each had three good Landsat scenes available from the desired time frame. The Norborne site, however, did not have a good quality cloud-free scene from late summer 1980. Scenes chosen (with identification number) were as follows:

Albany: 5 June 1980 (21961-16195)
28 July 1980 (22014-16152) - base scene
3 September 1980 (22051-16213)

Macon: 25 May 1980 (30812-16033)
21 June 1980 (21977-16085)
23 August 1980 (30902-15595) - base scene

Norborne: 20 April 1980 (30777-16102)
28 July 1980 (22014-16155) - base scene

Individual Landsat scenes indicated as the base scene were the point of reference for a partly manual, partly automated procedure to register Landsat data from one date to another. The various computer software programs that accomplish this and other digital imagery processing tasks comprise the comprehensive operating subsystem known as the Earth Resources Laboratory Applications Software (ELAS--Whitley, et al., 1981). ELAS consists of pattern recognition and data base program modules which constitute a geographic information system. Data processing with ELAS was performed on a Perkin-Elmer 3242 system with four megabytes of memory. This system supports interactive data processing and image analysis using a color digital display device to perform such activities as manual seed point selection for the scene-to-scene registration algorithms. Details of program function for the ELAS software modules used will not be dealt with in this report, but can be reviewed in the ELAS Manual (Junkin, et al., 1981).

Base scenes selected for scene-to-scene and scene-to-map overlay were from mid to late summer. The principal reason for this choice was the very sharp contrast between vegetated fields and the intersecting road network evident in late summer Landsat imagery, which makes the selection of ground control points considerably easier than is possible with spring imagery. Whereas the scene-to-scene overlay procedure requires the selection of only 6-12 seed points for the otherwise automated algorithms, scene-to-map registration requires the selection of many control points, depending upon the size of the area being registered. Typically both scene-to-scene and scene-to-map registration can be achieved within one Landsat pixel (57m) of the correct location.

Pattern recognition algorithms which are a part of ELAS cannot handle more than eight channels of sensor data at one time; therefore, it was decided not to retain all four Landsat MSS bands for each date. Instead, Landsat bands 5 and 7, corresponding respectively to the wavelength regions of chlorophyll absorption and the near infrared reflectance peak of green vegetation, were the ones chosen for analysis. In this manner, six-channel multidate Landsat data sets were produced for the Macon and Albany study areas while a four-channel multidate Landsat data set was produced for the Norborne study area, with each data set consisting of Landsat MSS bands 5 and 7 for each date.

At this point, the base scene from each multidate Landsat data set was used to select ground control points for referencing the Landsat data to a map. The Universal Transverse Mercator coordinate system was used as a map base. This scene-to-map registration procedure involves locating the same ground reference points (often road intersections or stream confluences) in the base scene and on a 7-1/2' USGS quadrangle map. The line and element (row and column) coordinates for the Landsat scene are recorded along with the northing and easting (North-South and East-West) metric coordinates for the same points on the map. At the same time the Landsat data are being registered to match the correct UTM coordinate positions, the mapping algorithms can resample the data to a different pixel or cell size. In this case, the Landsat data were resampled and registered using a nearest neighbor algorithm to fit into a 50m cell size. This procedure completes the establishment of geographically referenced multidate Landsat data sets to permit a cell-by-cell comparison of remotely sensed data with mapped soil characteristics.

Soil Survey Data

Soil survey maps are not commonly available in digital form suitable for machine processing. For those areas where soil maps have been digitized, however, the many uses of digital format surveys have become apparent, especially for the ease with which interpretive soil maps can be produced to illustrate specific uses of the basic soil map data. Awareness among users of soil surveys of the versatility of digital soil map data has led to increased soil map digitization activity at the state and national level.

Modern county-level soil surveys were not available for the Norborne and Macon study areas. The Albany study area in Gentry County was being actively mapped by a field survey party of the Soil Conservation Service during the time of this project. Advance map sheets from this modern survey were made available to NSTL/ERL in early 1981 for a portion of the county. Soil map unit boundaries were drawn on 7-1/2' orthophoto quads at 1:24,000 for an approximately 50,000-ha (120,000-acre) area comprising the Darlington NW, NE, SW, and SE quads less unmapped sections 15 and 22 in Township 62N, Range 30W. The soil maps that were available for the Norborne and Macon study areas consisted of 1:62,500 soil association maps adapted from generalized surveys conducted in Carrol County (1912) and Macon County (1913) before the current soil classification system came into use.

The level of detail in modern soil surveys is well suited to adaptation with remotely sensed data in the context of a geographic information system. Not only are these surveys the most cartographically detailed because of extensive field verification of map boundaries, but they 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. These county level surveys are the best widely available source for soil management information on a field-by-field basis. 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 (Soil Survey Staff, 1975).

Digitization of soil association map boundaries was accomplished by line segment digitization on an X-Y tablet digitizer. The Darlington SW and SE 7-1/2' quad sheet soil maps were likewise digitized on an X-Y tablet digitizer. The degree of complexity of a modern soil survey map makes line segment digitization with a manual cursor extremely tedious. The numerous irregular line segments comprising soil map unit polygons must be digitized one at a time and later reconstructed in a digitally coded representation of the original map. The ELAS program PUDR was used to reconstruct the digitized soil map data in ELAS data file format by converting floating point coordinates of digitized vertices to line and element coordinates of the 50m UTM data base. A completed digital soil map consists of a contiguous imagery-type file in which every 50m x 50m cell has a number code corresponding to a particular soil mapping unit.

An alternative method to manual digitization, conducted at the Geographic Resources Center of the University of Missouri/Columbia, was used for the remaining two 7-1/2' quad sheets of the Darlington NW and NE soil maps. Soil map boundaries were copied onto a mylar base in such a way that the only lines present were ones defining soil units. A raster scanner digitization procedure using a vidicon camera system was followed, with the camera being brought close to the map to avoid edge distortion. Each 7-1/2' quad sheet was digitized in 12 overlapping segments. An intermediate step to digital map reconstruction regrouped the 12 individually scanned segments and "thinned" the detected lines forming the map unit boundaries. Interactive processing with a digital display device and polygon forming software was used to assign number codes to each soil map unit after placing a cursor within each polygon. Adaptation to ELAS data file format was done by reading in the automatically digitized data and creating a disk file with program AUD . The resampling program RECE was then used to resample and convert the data from a 28.6m cell size to the 50m cell size of the data base.

Digitized sections of the four Darlington quad sheets were copied into an ELAS data file and were in effect pieced together by their common reference to the UTM coordinate system. A certain amount of manual editing was necessary to ensure the continuity of map data at sheet junctions. The completed digital soil map file can be represented pictorially by assigning colors to each soil mapping unit (Figure 4). Soil series and phase names with corresponding area totals for each numbered soil mapping unit are presented in Table 2.

[redacted]

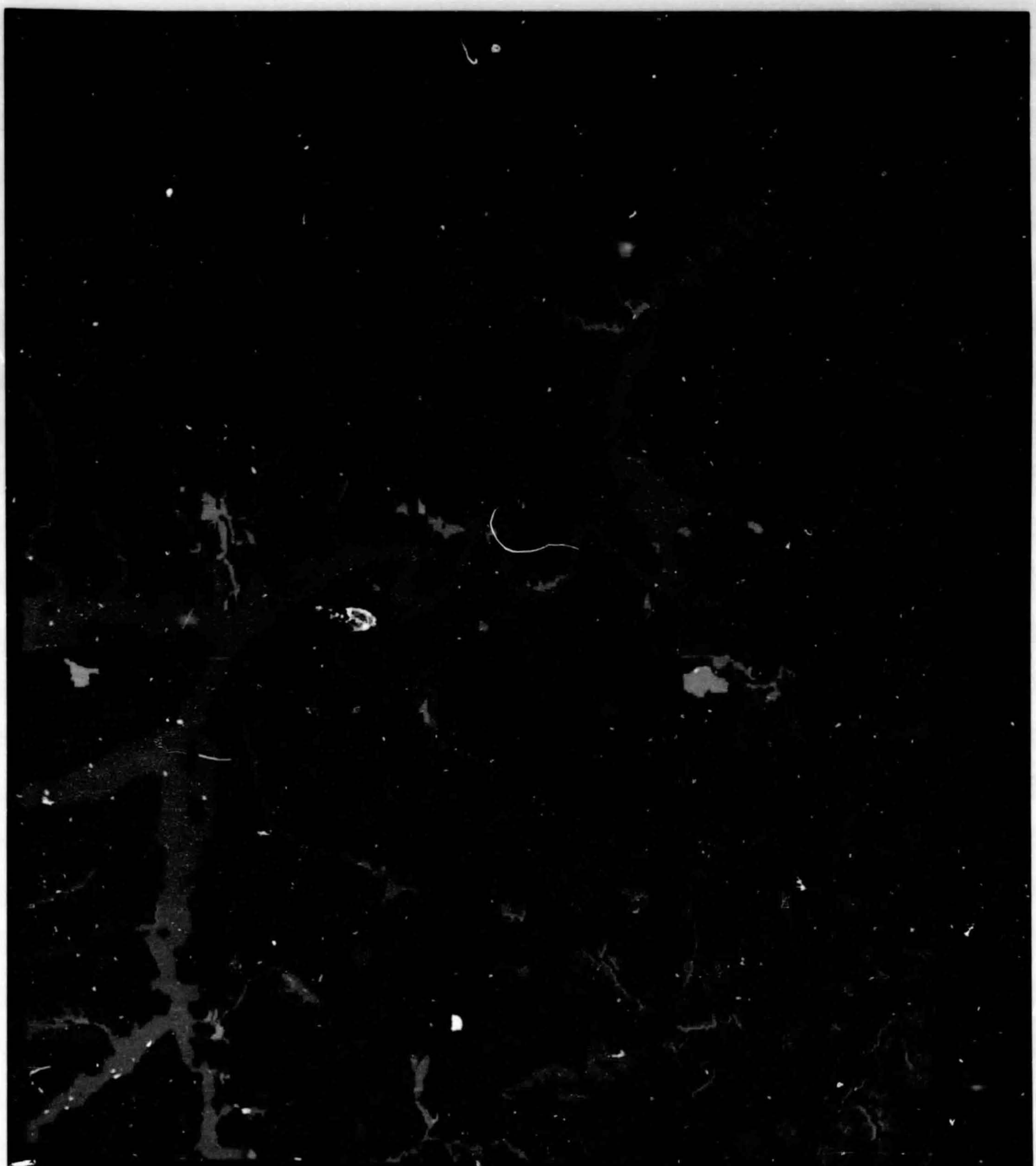

Figure 4. Soil mapping units for the Darlington quads portion of the Albany study area

Table 2. Gentry County soil mapping units and corresponding areas for the Darlington quads portion

MAPPING UNIT	AREA	MAPPING UNIT	AREA
1. SHARPSBURG SICL, 2-5%	45 ha (112 acres)	19. GARA CL, 14-20%, E	297 ha (734 acres)
2. LAGONDA SICL, 5-9%, E	529 ha (1307 acres)	20. ARMSTRONG L, 5-9%	298 ha (738 acres)
3. GRUNDY SIL, 2-5%	4512 ha (11150 acres)	21. ARMSTRONG CL, 5-9%, E	1389 ha (3433 acres)
4. GRUNDY SIL, 5-9%	613 ha (1515 acres)	22. PERSHING SIL, 2-5%	615 ha (1520 acres)
5. GRUNDY SICL, 2-5%, E	736 ha (1819 acres)	23. PERSHING SICL, 5-9%, E	312 ha (771 acres)
6. GRUNDY SICL, 5-9%, E	906 ha (2238 acres)	24. VANMETER SICL, 14-40%	1545 ha (3817 acres)
7. CLARINDA SICL, 5-9%, E	125 ha (309 acres)	25. BREMER SICL	353 ha (872 acres)
8. LAMONI L, 5-9%	2564 ha (6337 acres)	26. HUMESTON SIL	168 ha (414 acres)
9. LAMONI CL, 5-9%, E	13295 ha (32852 acres)	27. ARBELA SIL	93 ha (229 acres)
10. SHELBY L, 9-14%	1271 ha (3140 acres)	28. KENNEBEC SIL	256 ha (633 acres)
11. SHELBY L, 14-20%	238 ha (587 acres)	29. OLMITZ L, 2-5%	284 ha (702 acres)
12. SHELBY CL, 5-9%, E	6878 ha (16997 acres)	30. ZOOK SICL	1212 ha (2994 acres)
13. SHELBY CL, 9-14%, E	791 ha (1955 acres)	31. COLO SICL, 0-2%	949 ha (2344 acres)
14. LADOGA SIL, 5-9%	376 ha (930 acres)	32. COLO SICL, 2-5%	1495 ha (3694 acres)
15. LADOGA SICL, 5-9%, E	34 ha (83 acres)	33. NEVIN SIL	847 ha (2093 acres)
16. GARA L, 9-14%	252 ha (623 acres)	34. WABASH SIC	310 ha (767 acres)
17. GARA L, 14-20%	436 ha (1077 acres)	35. NODAWAY SIL	4403 ha (10380 acres)
18. GARA CL, 9-14%, E	567 ha (1400 acres)	36. QUARRIES	109 ha (269 acres)
		37. WATER	80 ha (196 acres)
		TOTAL	49,184 ha (121,534 acres)

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Once the digital soil map file is completed, the individual soil mapping units can be regrouped or aggregated in any desired manner to illustrate specific interpretations of the basic soil properties characteristic of each soil mapping unit. For example, a map of soil capability classes can be produced by aggregating all soil mapping units into one of nine classes representing increasing limitations to cultivation according to the severity of erosion hazard or wetness (Figure 5). With this map it is much easier to understand the suitability of soils for different kinds of farming than would be possible by referring back and forth between the basic soil map (Figure 4) and tables of soil properties. Any soil attribute or combination of attributes can be selected as a basis for soil mapping unit aggregation to produce the required interpretive map. These attributes are contained in most published soil survey reports and soil survey investigation reports as well as the established series description sheet and soil interpretations record (Soil Form 5) for each soil series in the United States (Soil Survey Staff, 1975).

Field Sampled Land Cover Data

Sampled land areas of known cover type are necessary in the analysis of remotely sensed data for spectral class labeling and verification of map accuracy. Spectral class labeling consists of identifying the probable land cover type represented by each set of statistical means and standard deviations developed by unsupervised pattern recognition processes that "cluster" homogeneous reflectance values of the multichannel Landsat data set. Comparison of a Landsat-derived spectral classification with field verified land cover information allows the spectral classes to be labeled in cases where a clear majority of classified pixels occur on land areas identified as belonging to specific cover type.

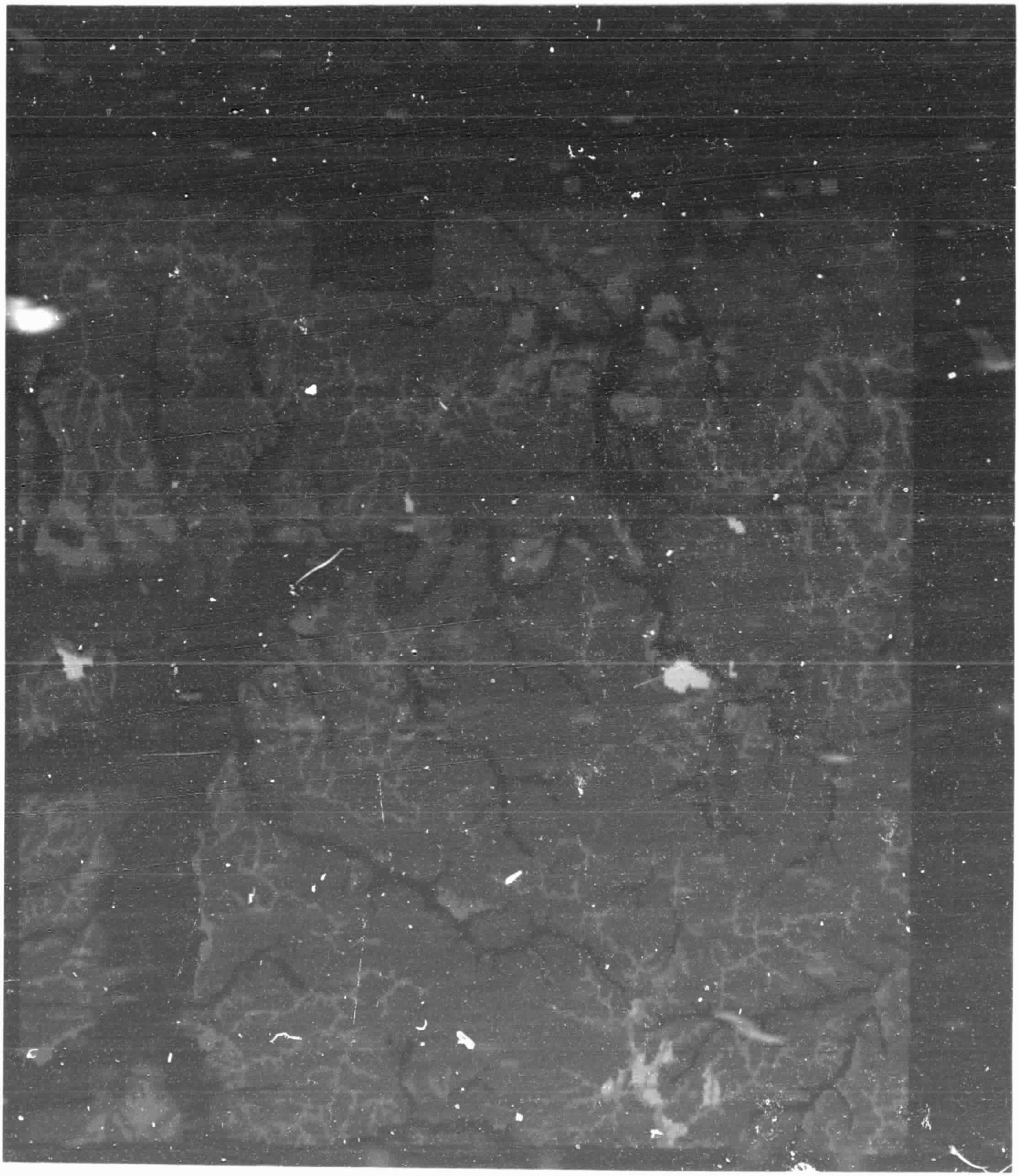

Figure 5. Soil capability classes for the Darlington quads portion of the Albany study area

Ideally, a stratified random sampling scheme should be established to collect land cover information from uniformly-sized sampling units. Field sampling during the 1981 growing season was carried out on randomly selected quarter sections of land falling along an established road route throughout each study area. Field boundaries and cover types were noted on 7-1/2' topographic quads or orthophoto quads for all of the 45-50 65-ha (160-acre) segments within each study area. This sampling scheme is not biased toward any particular land cover type and has the advantage of allowing the same land areas to be revisited year after year with only a minimum amount of redigitization necessary as field boundaries change.

The field sampling scheme used during the 1980 growing season involved a total enumeration of land cover types along a certain road route throughout the study areas. This resulted in collection of a large quantity of land cover information which was useful in the development of land cover mapping techniques, but would not be advisable from an operational standpoint. Digitization of field boundaries with an X-Y tablet digitizer was very time consuming (which strongly supports the more limited standard sampling scheme outlined above). As was done with line segments digitized from soil maps, the line segments defining field polygons were brought back together with the PUDR program to produce an ELAS data file of coded land cover types for sampled fields, also referenced to the same 50m UTM coordinate system. An additional capability of PUDR was utilized to delineate those pixels which formed the boundaries of sampled fields. These field boundaries could then be eliminated from the field verified land cover data files to avoid erroneous conclusions drawn from Landsat pixel areas which were not "pure," but represented a mixture of land cover types. A representation of the field verified land cover classes minus field boundaries is shown in Figure 6

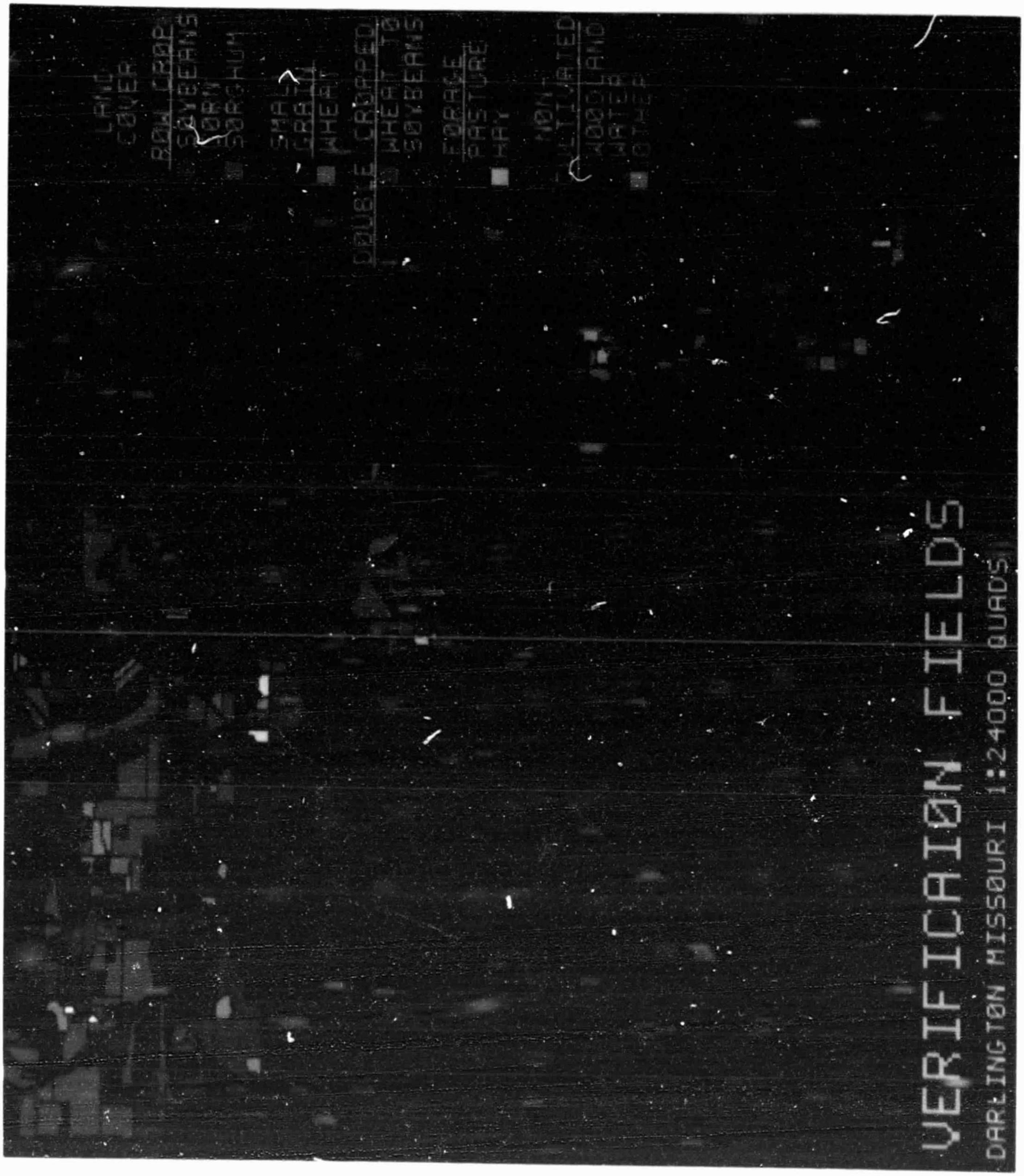

Figure 6. Field verified land cover types for the Darlington quads portion of the Albany study area

for the same land area covered by the four Darlington quad sheets. These are the fields which were compared pixel by pixel with eventual Landsat-derived land cover maps to assess the accuracy of classification procedures.

LAND COVER MAPPING

Conventional Multidate Approach

Pattern recognition algorithms used to produce land cover maps from multidate Landsat data are all part of the ELAS software package. Both approaches used to map land cover started with what is known as an unsupervised training procedure for aggregating similar data elements, in this case count values representing spectral responses in different Landsat MSS bands. Statistics are estimated for each aggregate or cluster in such a manner that each cluster defines a population. The two approaches differ largely in the way spectral class "cluster" statistics are developed, on the one hand collecting statistics from contiguous homogeneous blocks throughout the data set while on the other hand collecting statistics on a pixel-by-pixel basis within previously defined land areas (according to soil map data).

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 (Joyce, et al., 1980). 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. Output is in the form of means and covariance matrices for each spectral class and does not include a cluster map of those pixels selected as being representative of each spectral class. SRCH parameters were modified for use with the highly variable multidate data sets. With six-channel data sets, an upper bound standard deviation of 1.4, a coefficient of variation of 7%, and a maximum bin size of 90 were selected. With four-channel (two-date) data sets, a standard deviation of 1.2, a coefficient of variation of 6%, and a maximum bin size of 90 were selected. From 40 to 60 spectral classes were commonly defined by the SRCH algorithm for each study area.

Assignment of each Landsat pixel to one of the SRCH-derived spectral classes was accomplished by means of a maximum likelihood ratio algorithm, MAXL (or the version programmed for running on the array processor, MXAP). A threshold value of 99.9% was used to avoid assigning pixels to spectral classes of only faint similarity. This resulted in 5% to 20% of the pixels in each study area being assigned to no spectral class, indicating that the SRCH-derived spectral classes may not have adequately represented the total spectral variability in a data set. 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.

Spectral class labeling was done with the aid of plots of relative reflectance in Landsat MSS band 5 vs. band 7 for each date, similar to the example in Figure 3. Certain inferences can be made at this point to make tentative identification of classes based on characteristic reflectance sequences of different land cover types. Also, a pixel-by-pixel comparison of the classified data with the field verified data using program ACTB revealed the frequency of occurrence of known land cover pixels for each spectral class. When a plurality of pixels of a given spectral class fell in a certain land cover type, the class was given the label of that cover type. Confirmation of class labels was completed by viewing the distribution of mapped spectral classes on a digital display device in relation to other spectral classes and recognizable map features.

Layered Soil Strata Approach

The same multidate Landsat data sets were used in this approach, differing initially in the manner in which spectral class statistics were collected. Rather than applying a spectral class development algorithm to the entire study area, the layered soil strata approach directed spectral class development to only those pixels which the analyst had determined (with the aid of digital soil map data) to belong to homogeneous soil landscape groupings. The algorithm WCCL, or within-class cluster, collected training statistics on a pixel-by-pixel basis within previously defined classes (in this case, individual soil strata). A companion program, WMAX, assigned each pixel within the indicated 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." Since as many as three soil strata were analyzed per study area, with 40-60 spectral classes per stratum, the risk of under-representation of scene spectral variability was diminished. Unique spectral classes of small areal features were also more likely to be distinguished by WCCL than by SRCH.

Labeling of spectral classes was done in the same manner previously described, with the exception that the labeling exercise was repeated as many times as there were soil strata. 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.

Definition of homogeneous soil strata varied among the three sites, depending on the level of detail of the available soil data. For the Macon site, three soil strata were defined corresponding exactly to the three soil associations mapped there. The Putnam-Mexico soils were on level upland sites with intensive row crop farming. The Weller-Leonard-Armstrong-Keswick-Lindley soils were on rolling terrain with a greater amount of pasture and woodland than row crops. The narrow, level floodplains where the Mandeville-Blackoar-Arbela-Piopolis soils were found consisted mostly of pasture and native forest with limited crop production. The eight mapped soil associations of the Norborne ,ite were simplified into two general soil strata representing level, intensively farmed floodplain soils and rolling upland soils with more pastureland than cropland.

The 37 soil mapping units of the detailed Gentry County soil survey were grouped into three general soil physiographic strata plus one stratum consisting of pits, quarries, and water bodies, which was eliminated from the Landsat analysis (Figure 7). The level stream bench stratum consisted of alluvial soils with generally less than 5% slope. Row crop production was concentrated in this stratum, as the Landsat-derived land cover map for this area will attest (Figure 8). The rolling uplands stratum consisted of gently to moderately sloping soils ranging in slope from 5-14%. Pastureland predominated on this stratum with row crops and wheat occurring to a lesser extent (Figure 9). The steeply sloping uplands stratum consisted of land generally considered unsuitable for cropland because of slopes in excess of 20%. The small amount of cropland occurring on these soils was likely to consist of field corners in the otherwise forested and grass covered landscape (Figure 10).

Macon Map Assessment

Evaluation of the effect of different data processing approaches on land cover mapping was done using the accuracy tabulation program, ACTB. Percent

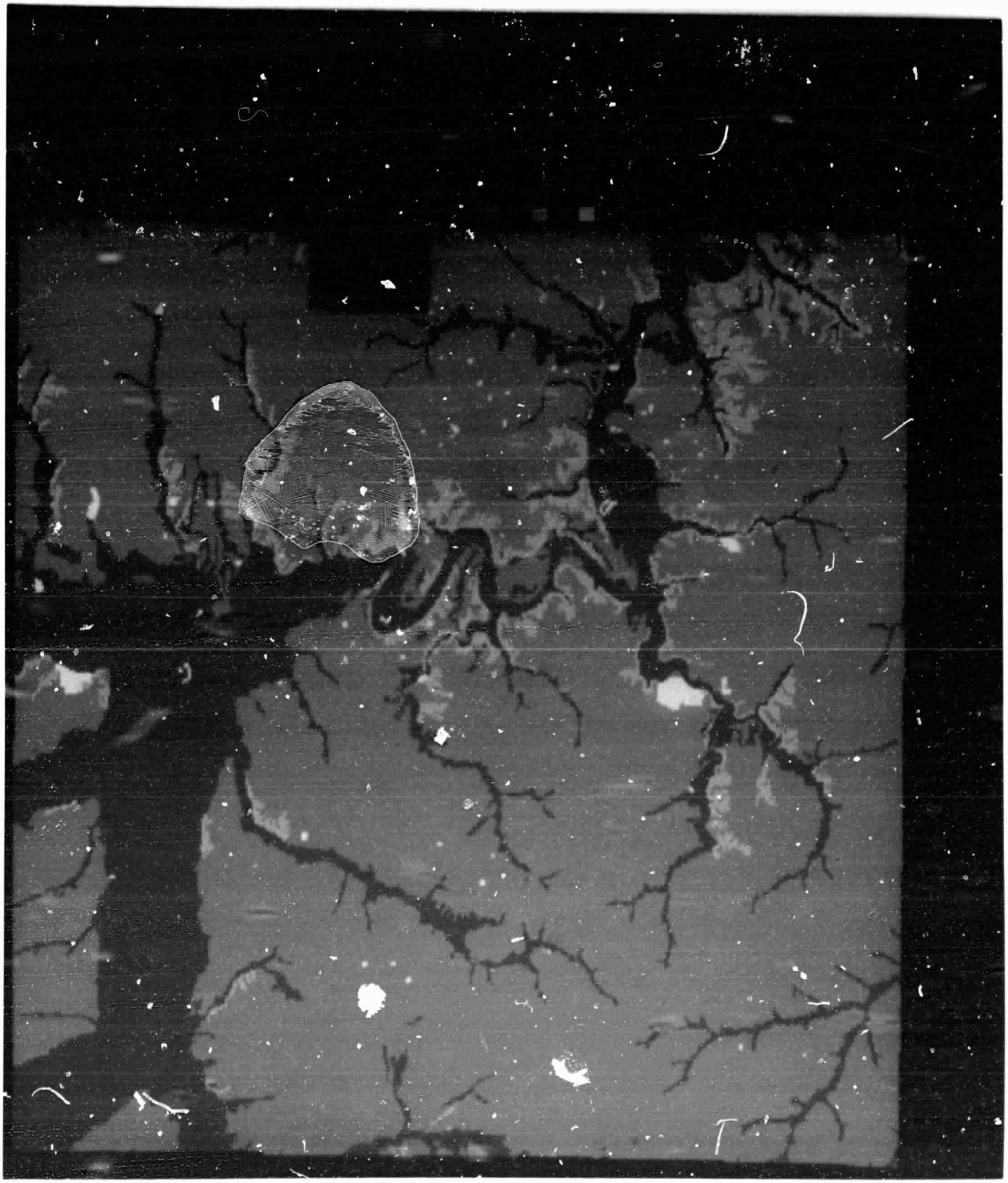

Figure 7. Soil physiographic strata for the Darlington quads portion of the Albany study area

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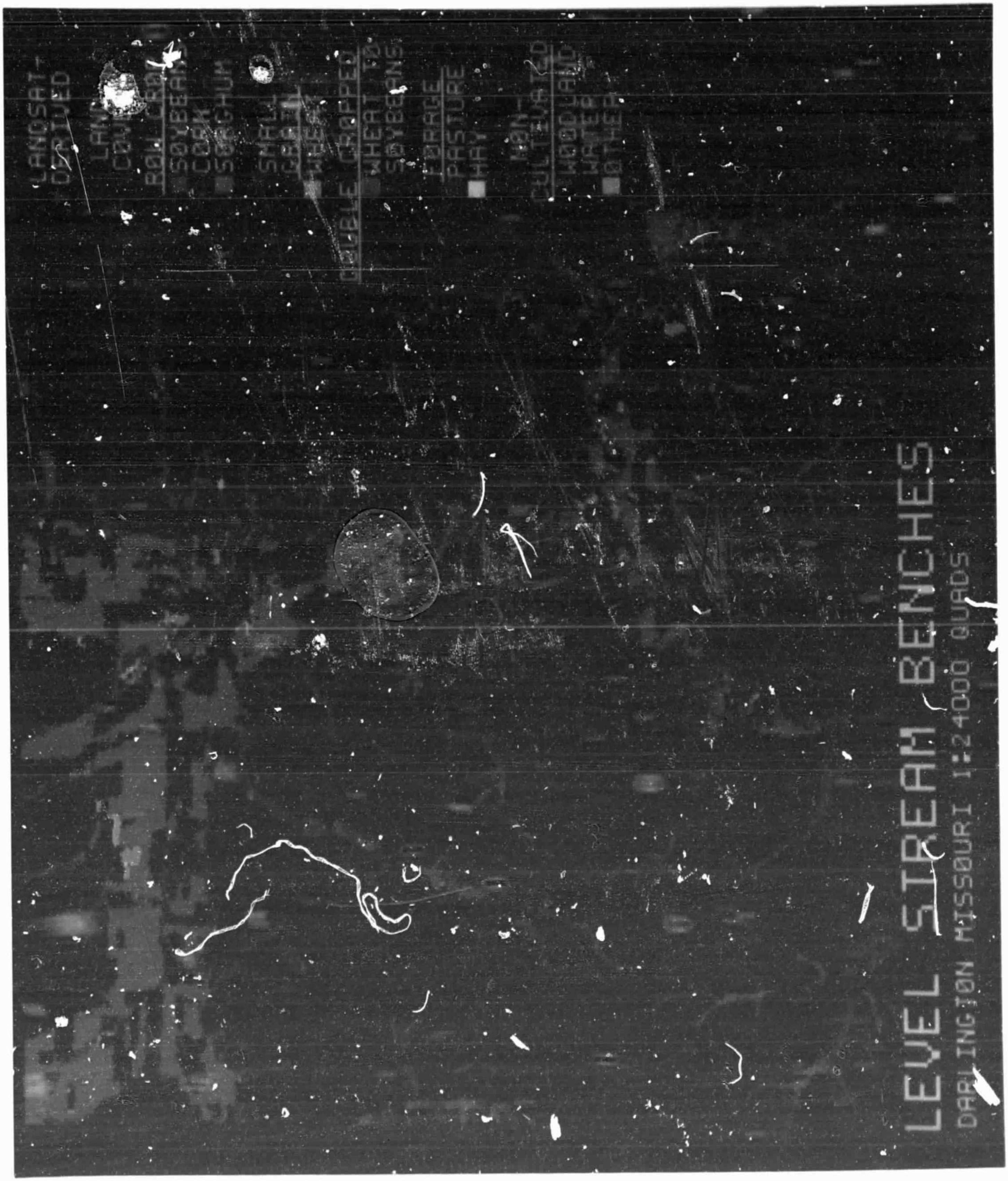

Figure 8. Landsat-derived land cover map of the level stream bench physiographic stratum

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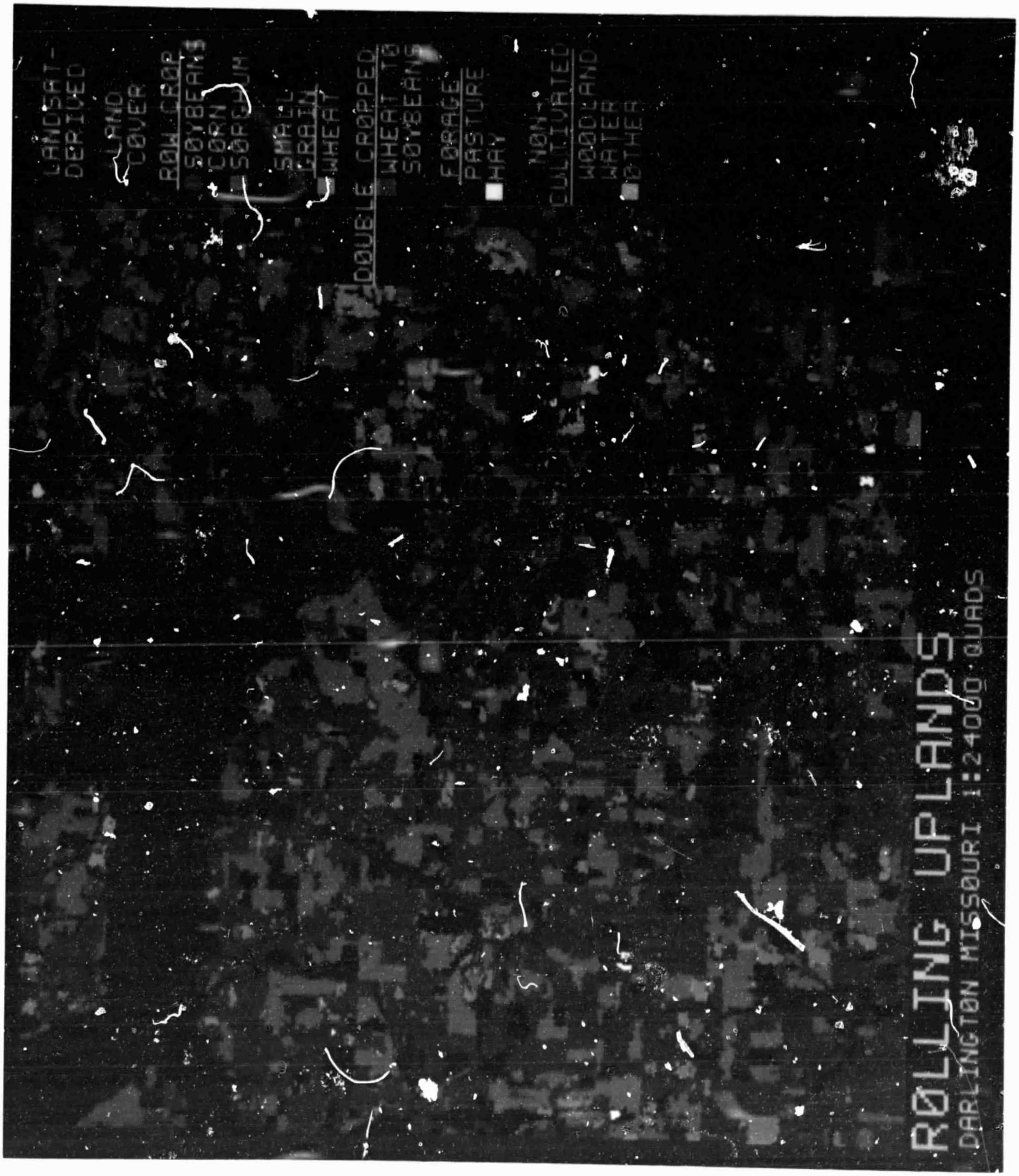

Figure 9. Landsat-derived land cover map of the rolling uplands physiographic stratum

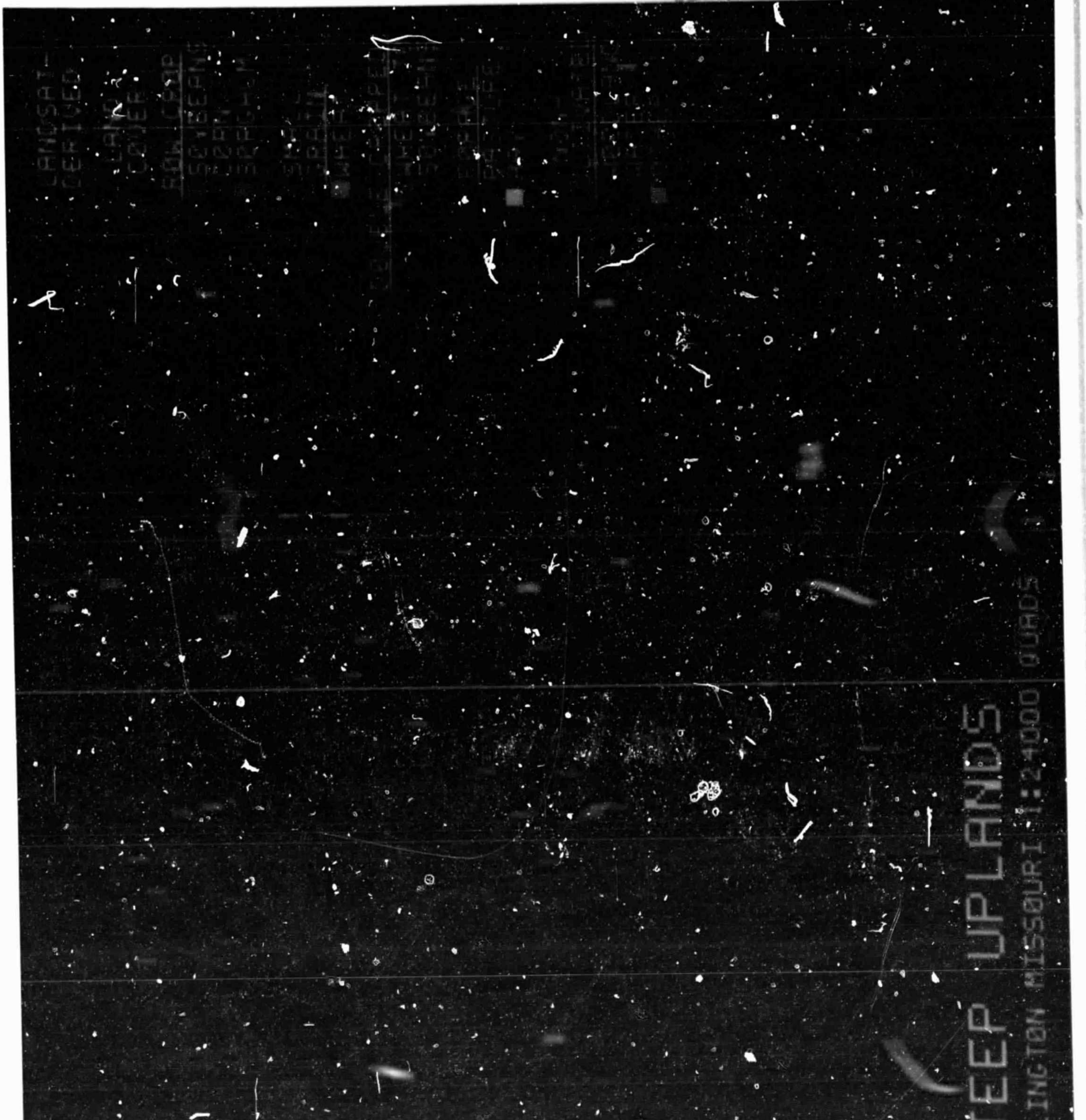

Figure 10. Landsat-derived land cover map of the steep uplands physiographic stratum

correct identification of field verified land cover is presented along with pixel totals. Although land cover types of lesser extent may have been mapped by certain Landsat classification procedures, only those results for the major land cover types of soybeans, corn, wheat, pasture, and woodland are given.

The conventional multidate approach and the layered soil strata approach are compared for the Macon study area in Table 3. The largest improvements with the layered soil strata approach were for corn and pasture. On an overall basis, the layered soil strata approach was slightly better than the conventional classification. However, when results are examined for land cover mapping within individual soil strata, the influence of such factors as field size, uniformity, and absence of interfering background reflectance can be seen for level, intensively cultivated areas such as the Putnam-Mexico soils (Table 4). Soybeans and corn can be distinguished with a much higher accuracy on these soils than on any other soil stratum. In addition, the bulk of the corn and soybeans in the entire study area are grown on these soils, as the field verified pixel totals suggest. Consistently poor identification of wheat is probably related to small field size and unusually dry conditions in 1980 that prevented mature wheat from being discriminated from stressed pastures. Accuracy of corn identification was likewise influenced by the dry growing season, causing confusion with other cover types such as soybeans and pasture.

Norborne Map Assessment

Identification of land cover types from maps produced using the two data processing approaches did not differ to any significant extent for the Norborne study area (Table 5). Overall accuracy was low for both procedures. Several reasons can be cited for this poor classification performance. The April 20, 1980 Landsat scene was probably too early in the growing season to catch trees

Table 3. Percent correct identification of field verified pixels for major cover types in the Macon study area for two data processing approaches using a May/June/August Landsat data set

COVER TYPE	CONVENTIONAL	LAYERED BY SOIL STRATA
SOYBEANS	$\frac{5673}{6824} = 83.1$	$\frac{5803}{6824} = 85.0$
CORN	$\frac{1607}{2482} = 64.7$	$\frac{1747}{2482} = 70.4$
WHEAT	$\frac{1249}{2040} = 61.2$	$\frac{1262}{2040} = 61.9$
PASTURE	$\frac{6030}{7526} = 80.1$	$\frac{6404}{7526} = 85.1$
WOODS	$\frac{641}{696} = 92.1$	$\frac{644}{696} = 92.5$
WEIGHTED AVERAGE	$\frac{15200}{19568} = 77.7$	$\frac{15860}{19568} = 81.0$

Table 4. Percent correct identification of field verified pixels for major cover types within individual soil association units of the Macon study area

COVER TYPE	PUTNAM-MEXICO SOILS	WELLER-LEONARD-ARMSTRONG-KESWICK-LINDLEY SOILS	MANDEVILLE-BLACKOAR-ARBELA-PIOPOLIS SOILS
SOYBEANS	$\frac{5041}{5714}$ = 88.2%	$\frac{567}{802}$ = 70.7%	$\frac{195}{308}$ = 63.3%
CORN	$\frac{1499}{2002}$ = 74.9	$\frac{96}{258}$ = 37.2	$\frac{152}{222}$ = 68.5
WHEAT	$\frac{1048}{1550}$ = 67.6	$\frac{194}{444}$ = 43.7	$\frac{20}{46}$ = 43.5
PASTURE	$\frac{2291}{2756}$ = 83.1	$\frac{3669}{4284}$ = 85.6	$\frac{444}{486}$ = 91.4
WOODS	$\frac{236}{242}$ = 97.5	$\frac{391}{433}$ = 90.3	$\frac{17}{21}$ = 81.0
WEIGHTED AVERAGE	$\frac{10115}{12264}$ = 82.5	$\frac{4917}{6221}$ = 79.0	$\frac{828}{1083}$ = 76.5

Table 5. Percent correct identification of field verified pixels for major cover types of the Norborne study area using an April/July Landsat data set with two data processing approaches

COVER TYPE	CONVENTIONAL	LAYERED BY SOIL STRATA
SOYBEANS	$\frac{11149}{16893}$ = 66.0	$\frac{11042}{16893}$ = 65.4
CORN	$\frac{3553}{5567}$ = 63.8	$\frac{3512}{5567}$ = 63.1
WHEAT	$\frac{2057}{3235}$ = 63.6	$\frac{2223}{3235}$ = 68.7
PASTURE	$\frac{1045}{1668}$ = 62.6	$\frac{1138}{1668}$ = 68.2
WOODS	$\frac{40}{75}$ = 53.3	$\frac{18}{75}$ = 24.0
WEIGHTED AVERAGE	$\frac{17844}{27438}$ = 65.0	$\frac{17937}{27438}$ = 65.4

in a leafed out state, while the July 28, 1980, scene was too early to catch corn and soybeans at their maximum vegetative development. It is clear that an inadequate selection of Landsat dates makes it difficult to produce an accurate land cover map no matter what processing procedures might be used. In the case of the Norborne study area, cloud cover and technical problems with the two Landsat satellites operating at that time precluded the acquisition of optimum dates of coverage.

Albany Map Assessment

Because of the poor mapping performance in the Norborne study area with only two Landsat dates, a comparison was made for the Albany study area between the use of two Landsat dates and three Landsat dates, including a scene from early September. Overall classification accuracy improved greatly with the addition of the third Landsat date (Table 6). Soybeans and corn had not attained maximum vegetative growth by July 28 and could not be adequately discriminated without Landsat data from later in the growing season. The decrease in accuracy for wheat is related to confusion between wheat and dry pastures and should not occur under normal conditions.

An analysis of results for the Darlington quads portion of the Albany study area can be made both visually and with pixel tallies. The merged classifications of the individual soil strata produced the land cover map shown in Figure 11. This can be compared to the classification produced by the conventional multidate approach (Figure 12). Field definition is seen to be much more distinct in the layered classification, with less evidence of pixels of one cover type scattered throughout the interior of fields of another cover type, as is common in the conventional classification.

Table 6. Percent correct identification of field verified pixels for major cover types in the Albany study area for two multidate Landsat data sets

COVER TYPE	JUNE/JULY DATA SET	JUNE/JULY/SEPT. DATA SET
SOYBEANS	$\frac{6748}{10611} = 63.6$	$\frac{9454}{10611} = 89.1$
CORN	$\frac{4843}{7810} = 62.0$	$\frac{5563}{7810} = 71.2$
WHEAT	$\frac{795}{1394} = 57.0$	$\frac{452}{1394} = 32.4$
PASTURE	$\frac{4073}{4953} = 82.2$	$\frac{4341}{4953} = 87.6$
WOODS	$\frac{874}{926} = 94.4$	$\frac{898}{926} = 97.0$
WEIGHTED AVERAGE	$\frac{17333}{25694} = 67.4$	$\frac{20708}{25694} = 80.6$

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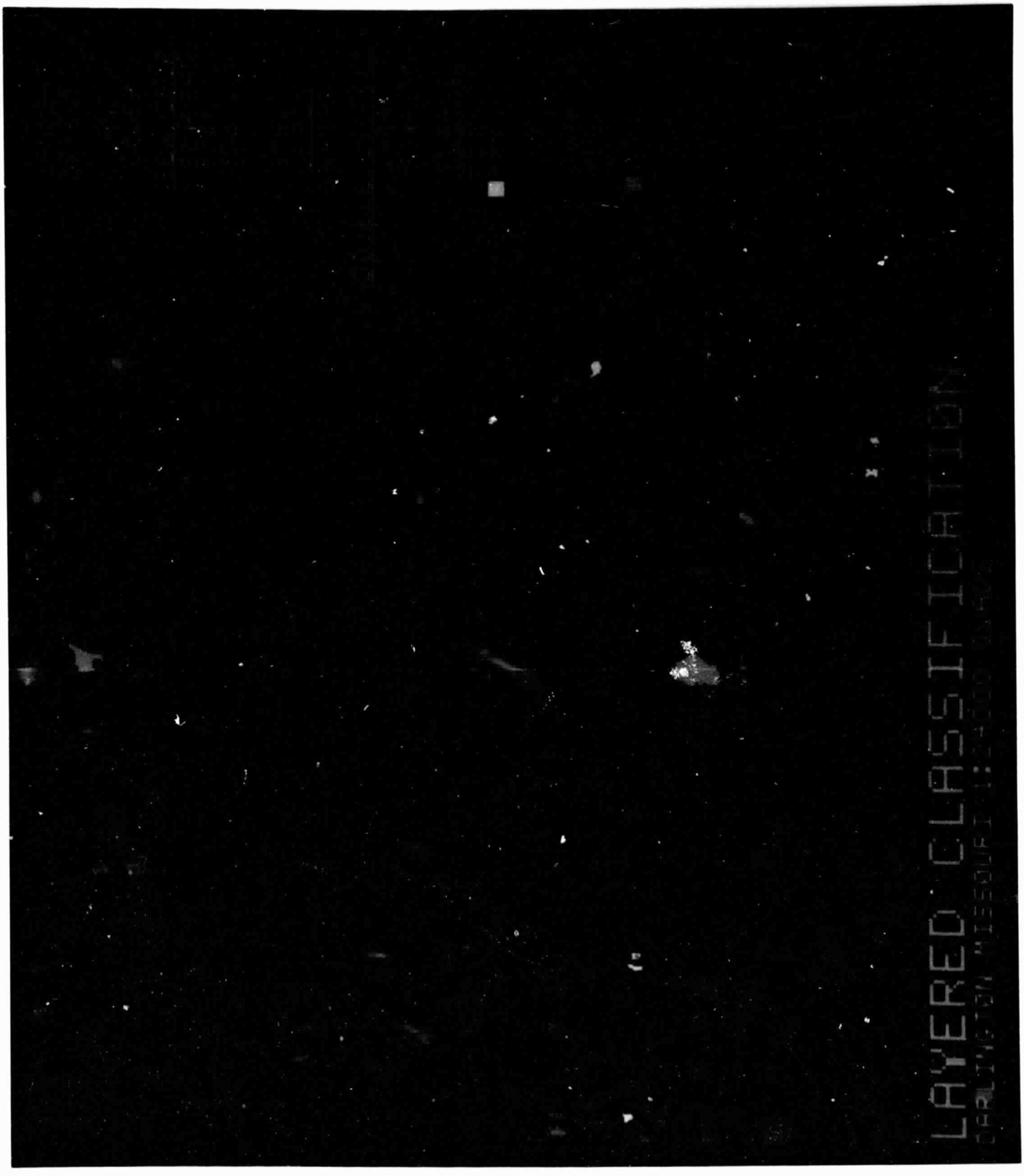

Figure 11. Landsat-derived land cover map developed by the layered soil strata approach

capable of meeting these needs is more than a data bank for the collection and storage of data, but also involves the analysis and interpretation of these data for resolution of agricultural production and distribution problems.

The application of a geographic information system containing Landsat-derived land cover data as well as soil survey data to certain specific agricultural production and distribution problems has been demonstrated for the 50,000-ha (120,000-acre) study area in the vicinity of Darlington, Missouri. Five agricultural management information requirements and the data base components that contribute to their estimation are outlined in Table 10. Data base manipulation for the creation of mapped products illustrating the areal distribution and rank of crop/soil interactions was accomplished with the program DBAS. Attributes of soil mapping units were obtained from soil interpretations records and Soil Form 5's and were entered into the data file by modification of coded soil classes with the table editor program, TBED.

Modern soil surveys contain information relating to the productive capacity of each soil mapping unit for growing specific crops. This information comes from field trials as well as inferences from soils with similar properties. An example of how this information can be used to demonstrate soybean yield potential on Landsat-identified soybean fields is shown in Figure 13. In this case, the basic soil mapping units, representing soil phases, were evaluated to possess 21 levels of yield potential at high management levels. The Landsat-derived land cover map was used to extract only those land areas representing location of soybean fields in 1980. Field patterns are obvious, as is the concentration of high yielding soybean fields in the level stream bench area contrasted with the lower yielding soils on the upland sites. It should be stressed that this data base application does not involve yield modeling, but rather attempts to rank the soils on which soybeans were grown during the 1980 growing season in

Tabular results indicate improvements in identification of all cover types with the layered soil strata approach (Table 7). Again, classification results for corn and soybeans were highest for the level stream bench sites where crop production was concentrated (Table 8). Identification of pastureland was highest on the upland sites where it predominates. An indication of the difficulty in discriminating among crop types on the rolling upland site can be seen in Table 9. This pixel identification matrix illustrates those cover types which are confused with the one being mapped. For example, 48.8% of the pixels which were in fact wheat were called pasture, largely because of confusion between the appearance of harvested wheat and unusually dry pastures. Corn was misidentified 36.3% of the time as soybeans. Again, corn fields on the upland sites tended to be smaller and less uniform than those on stream benches. The presence of grass waterways and other conservation practices could be expected to result in highly variable reflectance at the 1.1-acre resolution of Landsat. Also, corn fields on these droughty upland soils were likely not to have achieved total ground cover, in which case the contribution of the background soil reflectance could be expected to cause further confusion with other cover types.

INFORMATION SYSTEM APPLICATIONS

The demand for agricultural management information is generated by the need of users such as commercial farm producers, local suppliers of goods and services, and international grain traders to make decisions. The nature of the key decisions that must be made in each sector of the agribusiness community have been studied, and requirements pertaining to crop area estimation and soil specific land management practices repeatedly appear in accounts of information needed to make these decisions (Baumgardner et al., 1977). An information system

Table 7. Percent correct identification of field verified pixels for major cover types in the Darlington quads portion of the Albany study area for two data processing approaches using a June/July/Sept. Landsat data set

COVER TYPE	CONVENTIONAL	LAYERED BY SOIL STRATA
SOYBEANS	$\frac{6300}{7042} = 89.5$	$\frac{6347}{6993} = 90.8$
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 8. Percent correct identification of field verified pixels for major cover types within three soil physiographic regions of the Darlington quads portion of the Albany study area

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

Table 9. Pixel identification matrix for the rolling upland physiographic region o. the Darlington quads portion of the Albany study area

FIELD VERIFIED CLASSES	MAPPED CLASSES					
	SOYBEANS	CORN	WHEAT	PASTURE	WOODS	TOTAL
SOYBEANS	2018 (85.8)*	178 (7.6)	19 (0.1)	132 (5.6)	6 (<0.1)	2353
CORN	311 (36.3)	486 (56.7)	14 (0.2	44 (5.1)	2 (<0.1)	857
WHEAT	24 (3.3)	5 (0.1)	347 (47.2)	359 (48.8)	0	735
PASTURE	151 (5.3)	85 (3.0)	66 (2.3)	2514 (88.4)	28 (0.1)	2845
WOODS	1 (1.8)	0	0	0	55 (98.2)	56
TOTAL	2505	755	446	3048	91	6846

*Pixel count and percentage of row totals

Table 10. Contribution of data base components to agricultural management information requirements

REQUIREMENT	LAND COVER LOCATION LANDSAT-DERIVED	SOIL MAPPING UNIT LOCATION AND ATTRIBUTES						
		ORGANIC MATTER CONTENT	SURFACE TEXTURE	SLOPE	AVAILABLE WATER CAPACTIY	INTERNAL DRAINAGE	PERMEABILITY	EXPECTED YIELDS AT HIGH LEVELS OF MANAGEMENT
1. Productive Capacity								
Soybeans	Soybean Field Location							Unique for each Soil Phase
Corn	Corn Field Location							Unique for each Soil Phase
2. N,P,K Fertilizer Potential	Average Usage by Crop from Sales Records							
3. Herbicide Potential								
Atrazine	Corn Field Location	<5%-low rate >5%-high rate	Coarse-low rate Medium-high rate					
Trifluralin (Treflan)	Soybean Field Location	<5%-low rate >5%-high rate	Medium-low rate Heavy-high rate					
4. Irrigation Suitability	Location of Cultivated Fields			0-5% Suitable 5-9% Restricted >9% Unsuitable	<4" H_2O /36" Depth Unsuitable	Poor Drainage Unsuitable		
5. Trafficability for Spring Planting	Row Crop Location		Swelling Clays Restricted				Very Slow-Restricted Moderate-Unrestricted	

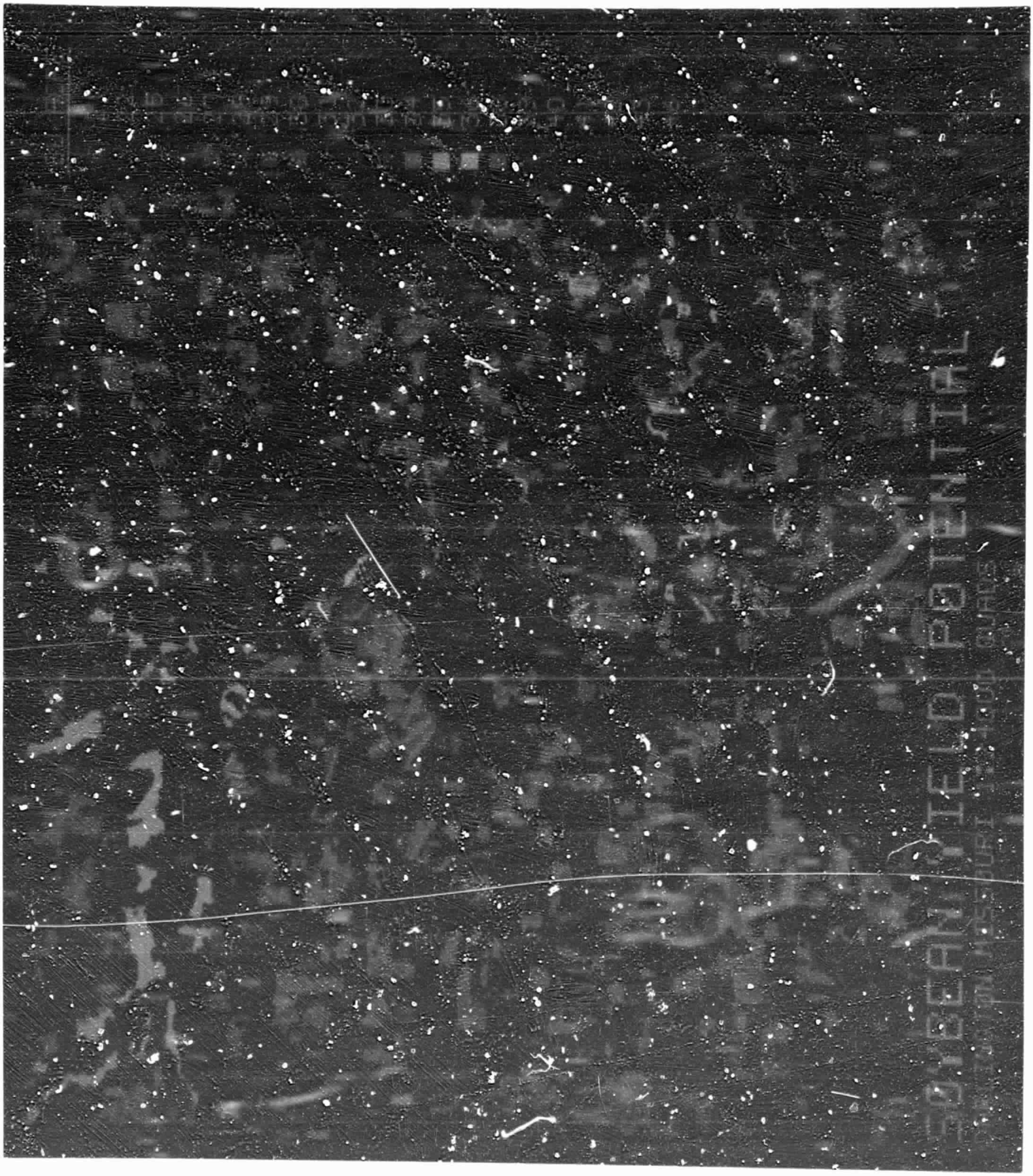

Figure 13. Soybean productive capacity for the Darlington quads portion of the Albany study area

the order of their inherent productive capacity. For a "normal" growing season these yield levels would be expected. Total estimated soybean production for the area can be tallied by multiplying yield levels by area totals to arrive at production figures (Table 11).

The market capacity for fertilizer sales in a given area can be estimated by taking average fertilizer application rates by crop (according to MFA, Inc., sales records) and specifying these rates for each Landsat-identified crop type. An example for the case of nitrogen fertilizer rates ranks individual crop types from low to high applied nitrogen needs (Figure 14). Soybeans, which are capable of meeting their nitrogen needs by association with nitrogen-fixing rhizobia bacteria, do not require application of nitrogen fertilizer. However, inoculant containing effective rhizobia strains may be added to the soybean seeds at planting time and would be of interest to farmer cooperatives that sell the inoculant packets. According to the area tally, 13,228 ha (32,686 acres) of land would have had sales potential for soybean inoculant in this area in 1980. Likewise, total nitrogen fertilizer potential by crop would have been as follows: wheat, 118 metric tons (130 tons); sorghum, 10 metric tons (11 tons); corn, 1,044 metric tons (1,150 tons). Phosphorus and potassium fertilizer potential could be estimated in the same manner by extracting crop location with Landsat data. Actual fertilizer recommendations by field according to soil map unit characteristics were not made, but will be possible when state-wide soil test results are recorded and compiled by soil series name.

A major input in modern cash grain farming is the vast array of selective herbicides for controlling specific weed types in specific crops. In a recent year, 99% of the corn grown in Missouri had chemical weed control, while 96% of the soybeans had applications of herbicides. Effective weed control requires

Table 11. Soybean productive capacity assessment for the Darlington quads portion of the Albany study area

YIELD POTENTIAL CLASS (BU/ACRE)	AREA (ACRES)	PRODUCTION (BU)	YIELD POTENTIAL CLASS (BU/ACRE)	AREA (ACRES)	PRODUCTION (BU)
21	32	672	34	4250	144,500
22	742	16,324	35	986	34,510
25	50	1,250	36	1785	64,260
26	50	1,300	38	4360	165,680
27	8301	224,127	39	842	32,838
28	830	23,240	40	1718	68,720
29	930	26,970	41	201	8,241
30	760	22,800	42	4065	170,730
31	406	12,586	43	1449	62,307
32	300	9,600	46	177	8,142
33	348	11,484	TOTAL	32,582 acres (13,185 ha)	1,110,281 bu (28,202 metric tons)

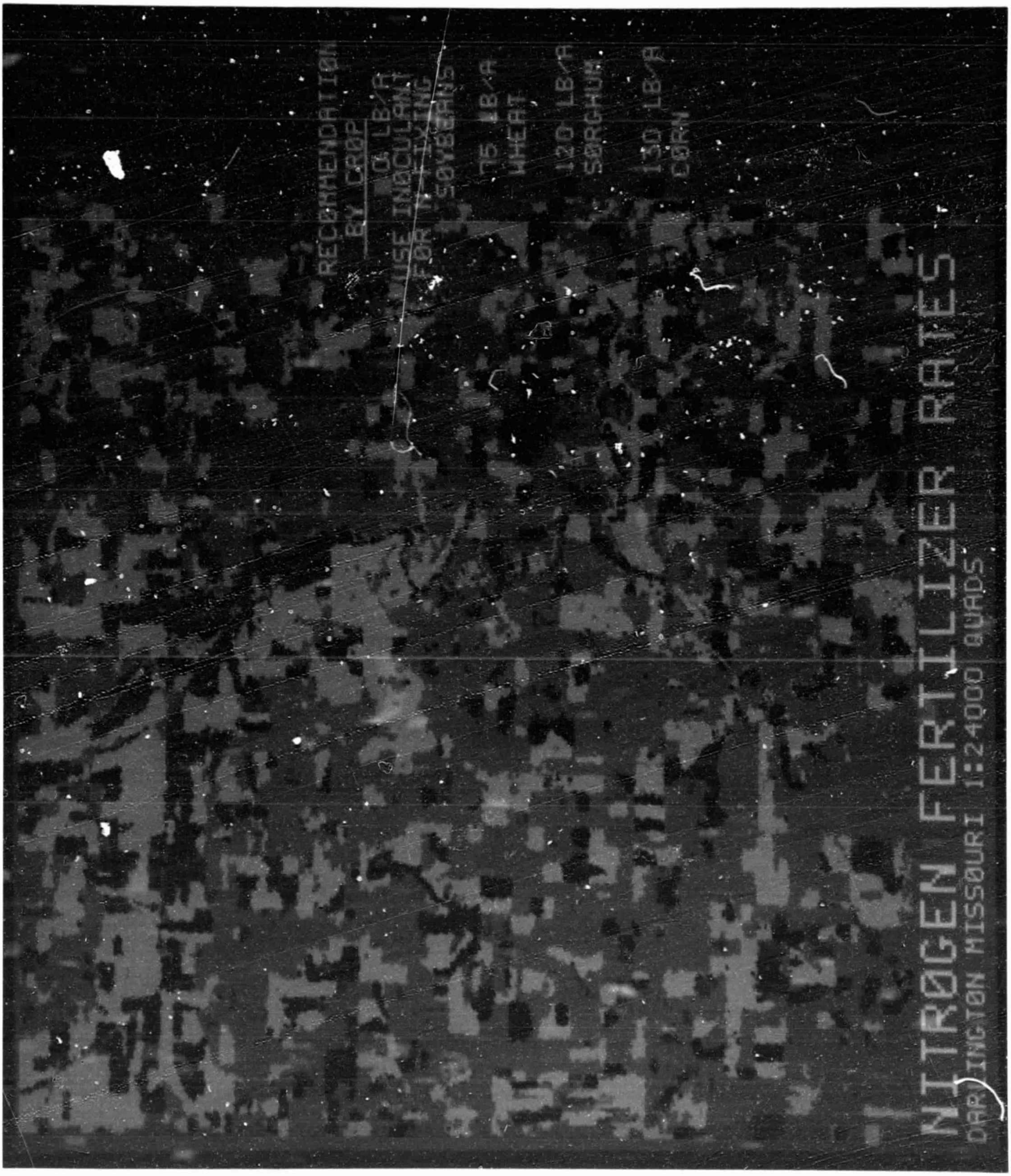

Figure 14. Nitrogen fertilizer application rates for major crops in the Darlington quads portion of the Albany study area

adjustment of herbicide application rates according to differences in soil organic matter and clay content from field to field. Soils with high organic matter content have high cation exchange capacities and physical adsorptive characteristics. There is also a similar relationship with clay content of soils; the high clay content soils require higher application rates for optimum herbicide performance. With the information contained in a modern soil survey, specific organic matter levels and texture of surface soils can be determined.

As much as 85% of the land planted to corn in Missouri uses some form of atrazine herbicide alone or in combination with other herbicides. A widely used herbicide in soybeans is trifluralin (Treflan). Both of these herbicides have higher label rates when used on soils with greater than 5% organic matter content (Fletchall, et al., 1981). The land areas which would require these higher application rates can be shown using the information contained in the data base (Figure 15). In this illustration, only those Landsat-derived land areas planted to row crops are shown, while the soils with high adsorptive capacity for atrazine and trifluralin are shown in the darker color. A total of 16,825 ha (41,575 acres) could use the lower application rates, while 3,660 ha (9,045 acres) would require the higher application rates for effective weed control. This translates to a market potential for 27,070 kg (59,665 lb) of atrazine or 19,277 kg (42,487 lb) of trifluralin if either herbicide is used exclusively on its adapted crop. If this simplified example were not the case over a typical trade area, actual proportions of the many herbicides sold could be factored in to provide more realistic market potential figures.

Another application of the data base would be to show those land areas which, because of their soil characteristics, are suitable for installation of center pivot or traveling gun irrigation systems. Water source was not considered a

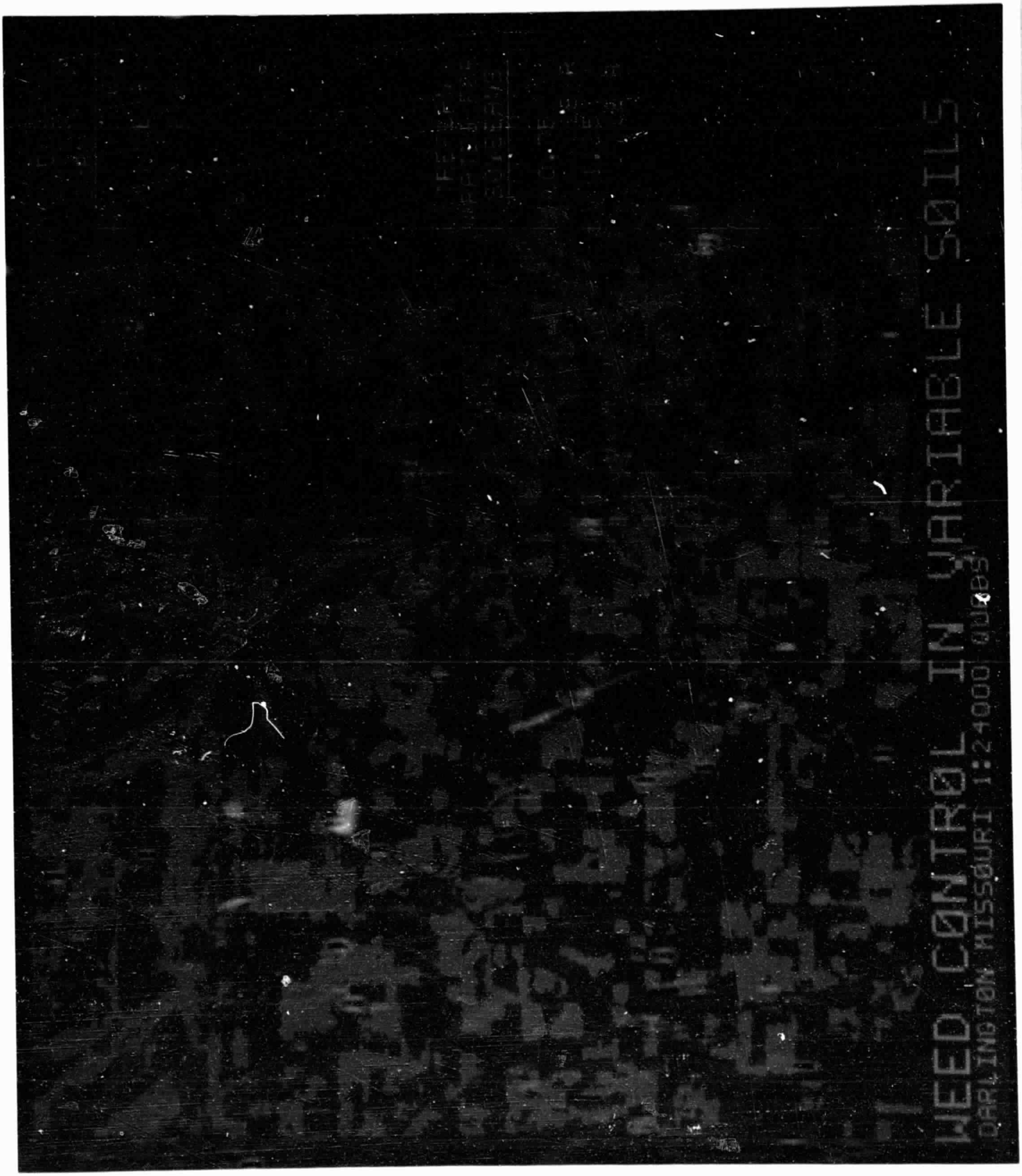

Figure 15. Herbicide application rates for weed control in soils of the Darlington quads portion of the Albany study area

limiting factor here. Soil characteristics which are considered limiting are outlined in Table 10. Soils well suited are generally those on level slopes with adequate available water capacity and good drainage. In this example the Landsat-derived land cover data are used to illustrate only the cultivated fields (Figure 16). Of this total land area of 21,888 ha (54,084 acres), 3,896 ha (9,628 acres) are well suited for irrigation, 7,984 ha (19,729 acres) are restricted because of slope and aeration limitations, 6,452 ha (15,944 acres) are restricted because of steep slopes, 242 ha (599 acres) are restricted because of low available water content and aeration problems, and 715 ha (1,767 acres) are unsuitable because of a combination of all these limiting factors, principally steep slope.

Generally, highest yields are obtained in corn in this part of the Midwest if corn is planted before May 15. As a general rule, if corn is not planted by this date a farmer will switch to planting soybeans or sorghum. The principal reason this might occur is the inability to move planting equipment into a slow drying field during a wet spring. The soil map provides information on the trafficability of different soils for the kind of heavy equipment used to plant row crops. In this example, the Landsat-derived land cover map is again used to delineate row crop areas, and the digital soil map separates these areas into four rates of soil dry-down (Figure 17). Soils with swelling clays which are very slowly permeable have very slow dry-down rates, indicated in red. These 290 ha (718 acres) would be difficult to plant to corn during a wet spring. Under very wet conditions, 11,403 ha (28,178 acres) which are slow to dry down may not be capable of being planted to corn tnat season. With knowledge of local weather conditions, an exchange manager would be able to assess planting delays and arrange for appropriate seed and products as planting intentions are forced to change.

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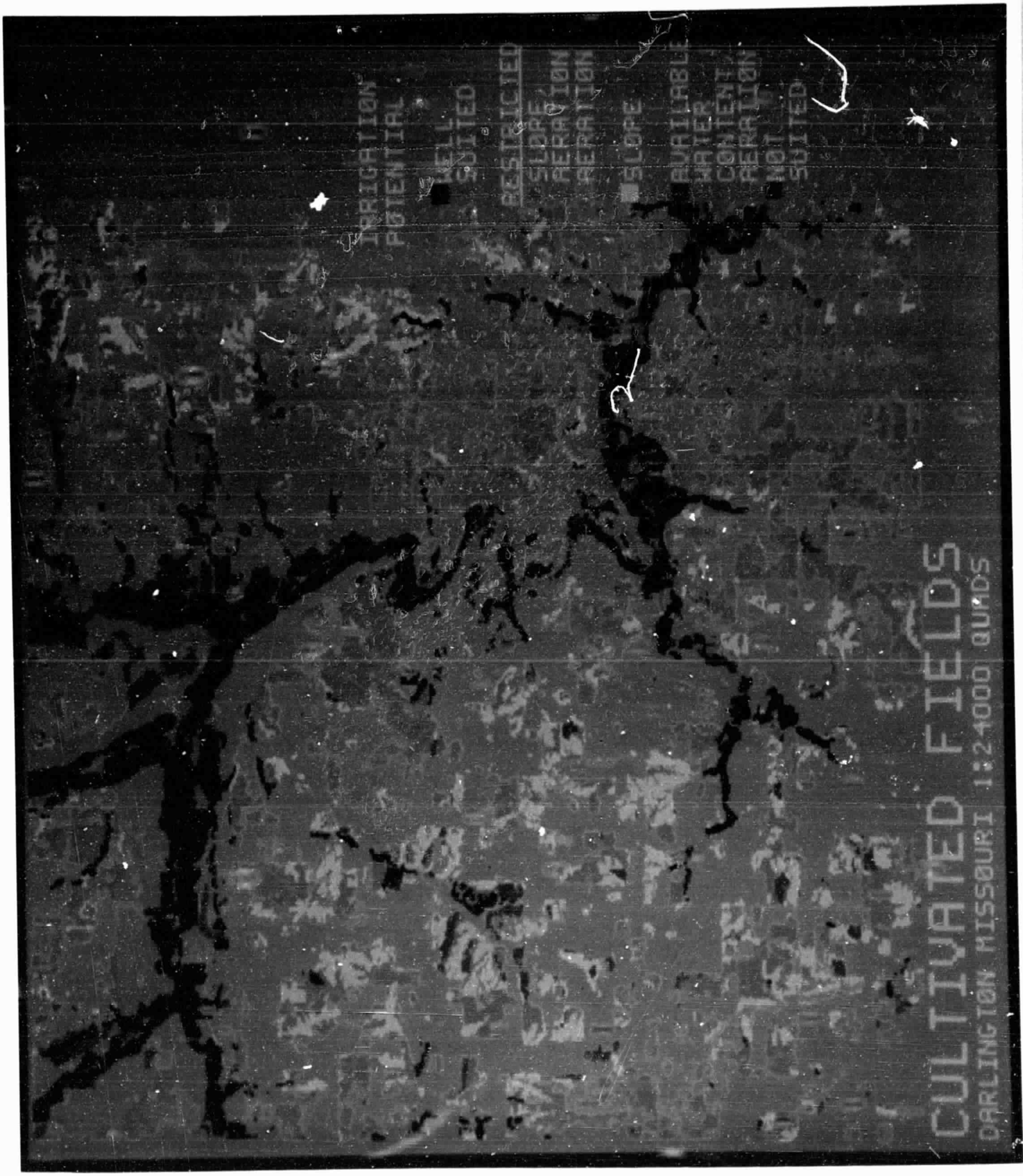

Figure 16. Irrigation potential on cultivated fields of the Darlington quads portion of the Albany study area

SUMMARY AND CONCLUSIONS

Landsat-derived land cover information provides one component of an agriculturally oriented digital information system. Multidate Landsat MSS data in digital format from key dates in the crop calendars of the principal crops can be submitted to machine processing to produce land cover maps which are referenced to a convenient, familiar map base. The introduction of soil map information to the land cover mapping process can improve discrimination of land cover types and reduce confusion among crop types that may be caused by soil-specific management practices and background reflectance characteristics.

Land cover map data illustrate the distribution and areal extent of cover types across an area of interest. Agricultural management information requirements can benefit from the addition of interpretive soil information to the land cover map. The amount of information contained in the cartographically and categorically detailed soils data of a modern soil survey is especially well suited to inclusion in a digital data base for computer analysis. In this manner, land areas represented by the Landsat pixel size (1.1 acre) can be matched with the soil attributes characteristic of that same area of land.

An agricultural information system combining Landsat-derived land cover data with digital soils data can be applied to the information needs of agricultural cooperatives. Productive capacity of land to grow crops, fertilizer needs, chemical weed control rates, irrigation suitability, and trafficability of soil for planting are information requirements which have been assessed with the aid of soils data as well as with Landsat-derived land cover maps. Other applications can be demonstrated by applying additional soil interpretive map information to yearly land cover map information extracted from remotely sensed data. An historical record of cropping patterns can be built up in this manner to aid in the preparation of feasibility studies of trade area market potential.

REFERENCES

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. U.S. Geol. Surv. Prof. Paper. 964. 28 p.

Baumgardner, M.F., M.E. Bauer, M.A. Martin, and R.M. Peart. 1977. Requirements of a global information system for corn production and distribution. Laboratory for Applications of Remote Sensing Contract Report 112977. Final Report of NASA Contract No. NAS9-14970, Task 2.3. 116p.

Fletchall, O.H., H.D. Kerr, J.H. Scott, W.J. Murphy, R.J. Aldrich, and L.E. Anderson. 1981. 1981 recommendations for chemical weed control. Missouri Ruralist. Cooperative Extension Service, Columbia, MO. 16p.

Geological Survey Staff. 1979. Landsat data users handbook, revised edition. U.S. Dept. of Interior. U.S. Geological Survey, Arlington, VA.

Graham, M.H. and R. Luebbe. 1981. An evaluation of MSS P-format data registration. AgRISTARS report no. DC-Y1-04069. National Technical Information Service, Springfield, VA. 57p.

Hixson, M.M., M.E. Bauer, and D.K. Scholz. 1980. An assessment of Landsat data acquisition history on identification and area estimation of corn and soybeans. Proceedings of the 6th International Symposium on Machine Processing of Remotely Sensed Data. Purdue University, West Lafayette, IN. pp. 72-77.

Joyce, A.T., J.H. Ivey, and G.S. Burns. 1980. The use of Landsat MSS data for detecting land use changes in forestland. Proc. 14th Int. Symp. on Remote Sensing of Environ. II: 979-987.

Junkin, B.G., R.W. Pearson, B.R. Seyfarth, M.T. Kalcic, and M.H. Graham. 1981. ELAS, Earth Resources Laboratory Applications Software. Report no. 183. Revised Edition. National Aeronautics and Space Administration. National Space Technology Laboratories. Earth Resources Laboratory. NSTL Station, MS.

Soil Survey Staff. 1975. Soil taxonomy - a basic system of soil classification for making and interpreting soil survey. Soil Conservation Service. U.S. Dept. of Agric. Agriculture Handbook No. 436. Washington, DC.

Soil Survey Staff. 1978. Land resource regions and major land resource areas of the United States. U.S. Dept. of Agric. Agriculture Handbook No. 296. Washington, DC.

Stoner, E.R., G.A. May, and M.T. Kalcic. 1981. Evaluation of multiband, multitemporal, and transformed Landsat MSS data for land cover area estimation. AgRISTARS report no. DC-Y1-04089. National Technical Information Service, Springfield, VA. 24p.

Tucker, C.J., J.H. Elgin, Jr., and J.E. McMurtrey, III. 1979. Temporal spectral measurements of corn and soybean crops. Photogram. Eng. and Remote Sensing. 45: 643-653.

Whitley, S.L., R.W. Pearson, B.R. Seyfarth, and M.H. Graham. 1981. ELAS: a geobased information system that is transferable to several computers. Proc. of the 15th Inter. Symp. on Remote Sensing of Environment, Ann Arbor, MI.