Development of an Agricultural Land-Use GIS for Senegal Derived from Multispectral Video and Photographic Data

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ABSTRACT: Agricultural land-use patterns were mapped in a region of Senegal through the combined application of remote sensing and geographic information system (GIS) technologies. This project established that airborne multispectral video data, paired with 35-mm photography, can be used for agricultural land-use mapping. Images were manually interpreted to map a series of land-use classes characteristic of recession agricultural crop production. GIS functions were used to digitize the classes and generate a series of land-use maps. The project also demonstrated the feasibility of more automated land-use mapping techniques entailing supervised classification of multispectral video data and Landsat MSS data, and migration of these data to the GIS for map generation.

INTRODUCTION

TRADITIONALLY, RECESSION AGRICULTURE has played a major role in crop production in much of the Senegal River Valley that is shared by the West African nations of Senegal, Mauritania, and Mali. This agricultural system, in which crops are planted in floodplains after seasonal floods (October through December) have inundated an area and have receded, requires small inputs of capital and labor. Recession agriculture contributes approximately one third of the region's cereal production and has been practiced in a manner that has remained basically unchanged over the past several centuries. It is estimated that more than 375,000 people are involved in recession agriculture within a 600-km stretch of the Senegal River (Baro *et al.*, 1987).

The environmental condition of these recession zones has been affected by recent drought and desertification in the Sahel, and has thus become an area of increasing concern. Since 1984, international agencies have sought to improve their ability to forecast agricultural production and famine in sub-Saharan Africa. A large number of early warning systems have been implemented for this purpose which monitor a host of physical (e.g., rainfall) and social (e.g., market prices) variables that may indicate the likelihood of famine. Concurrently, independent research in the use of meteorological and land resource satellite data for monitoring land use, climate, and crop conditions over large areas has advanced quickly (Tucker *et al.*, 1983; 1985a; 1985b). Several famine early warning systems have been implemented by international agencies (e.g., the United Nations' Food and Agricultural Organization and the U.S. Agency for International Development) in both experimental and operational modes, which use these advances to supplement ground-based observations.

Within a broader context, the recent development of a series of dams and hydro-agriculture projects along the Senegal River could have a significant impact on long-term land-use patterns. To help define currently prevalent land-use patterns within a portion of the Senegal River Basin, a remote sensing and geographic information system (GIS) study was performed by the Arizona Remote Sensing Center (ARSC) in support of on-going agricultural development projects being conducted by the Institute of Development Anthropology (IDA) and for the U.S. Agency for International Development (U.S. AID)

The primary goals of this effort were (1) to assess the feasibility of employing low-cost airborne multispectral video data, paired with 35-mm photography, to map agricultural land use; and (2) to demonstrate the advantages of mapping this derived information utilizing a GIS. A successful demonstration of these goals could provide the impetus for future applications of these technologies for agricultural land-use mapping in the Sahel. In order to evaluate these goals, multispectral video coverage of three study sites within the Middle Valley of the Senegal River was obtained, and maps were generated of general classes of agricultural land use present at these sites. To meet these objectives, aerial two-channel, multiplexed video data and 35-mm color photography were acquired and manually interpreted. Video remote sensing systems have proven to be an effective research tool in a variety of environments (Vlcek, 1983; Nixon *et al.*, 1985; Everitt *et al.*, 1986; 1989). Our efforts were aimed at establishing some of the advantages and constraints of utilizing this type of data. The remote sensing data were first manually interpreted and then combined in a vector format GIS to generate a variety of map products. In addition, digitally classified video and Landsat MSS data were integrated into the GIS and used to produce a series of maps. The practical objective of this work was to establish a set of base-line maps that could be utilized in the future to assess changes in agricultural land use.

DESCRIPTION OF STUDY AREA

The study area is located in the Matam region of Senegal, which lies within the Middle Valley of the Senegal River, about 400 km upstream from Saint Louis, Senegal (Figure 1). Three sites within the floodplain were selected for analysis. The sites, which range in size from 20 to 65 sq km, lie within 60 km of each other. All three sites are located within the flood plain of the Senegal River. Data were acquired and land-use maps produced for all three study sites. However, discussion will be limited to the Thiemping site, which is the largest of the three and located approximately 5 km east of Matam.

The Thiemping study site consists predominantly of *walo*, a local term used to characterize seasonally flooded agricultural areas. These regions of *walo* are generally found within semi-arid to arid climatic regions. Topographic relief within the Thiemping study site is minimal, with less than 10 m of vertical displacement. Soils within the site can be grouped based on geomorphic position into four classes (Tabor and Djiby, 1987). *Walo* soils occur on the floodplain, are clayey, and are the largest group of soils cultivated within the valley. *Fonde* soils are found on alluvial and aeolian levees and are generally coarser in texture than *walo* soils. *Falo* soils occur on riverbanks, flood every

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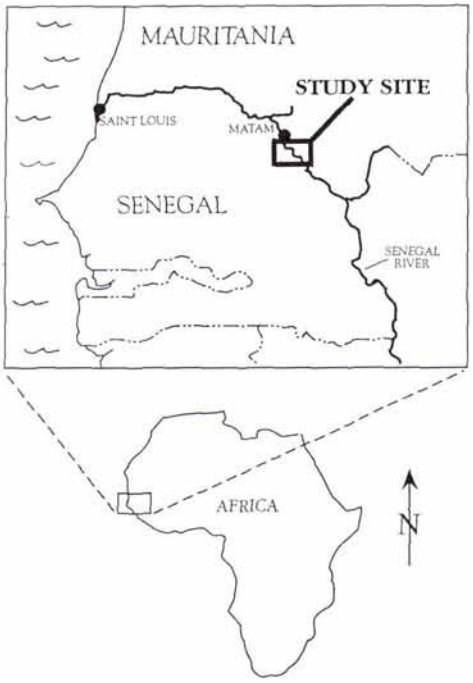

FIG. 1. Location map of the Thiemping study site within the Middle Valley of the Senegal River, Senegal.

year, and are very fertile due to the yearly deposition of sediment. *Dieri* are the coarser textured, less fertile, upland soils.

DATA ACQUISITION

AIRBORNE DATA

Data were acquired with a 35-mm camera equipped with a 28-mm wide-angle lens and a multiplex, bi-spectral video camera system equipped with 12.5-mm wide-angle lenses. There are several advantages of video data acquisition in logistically difficult environments. These include (1) the immediate availability of the data;(2) the ability to view live images during data acquisition to assess system performance and aid aircraft navigation; (3) the efficient manner in which data are recorded and stored on extremely inexpensive medium (avoiding the temperature constraints of color-infrared film); and (4) the fact that analog images can be either interpreted manually from a video monitor, or converted to digital values and enhanced using digital image processing systems (Meisner, 1986).

The video camera system employed was developed at the Arizona Remote Sensing Center and designed specifically to acquire data with which to assess vegetation signatures in rural environments (Hutchinson *et al.*, 1989). This system consists of two bore-sighted cameras fitted with red (610 to 690 nm) and near-infrared (780 to 930 nm) bandpass filters, and a multiplexing unit which can generate three processed output products in real-time. These data products are (1) a composite simulated-color-infrared output generated by mixing the red and near-infrared channels; (2) an output of alternate frames from each channel; and (3) an output of a vegetation index image derived from an analog ratio of the two channels [(NIR-RED + 0.5) / 2(NIR + RED)]. this is an electronic approximation to the classical normalized vegetation index [(NIR − RED) / NIR + RED)]. The CCD video cameras produce an image which is 780 pixels (horizontal) by 488 pixels (vertical).

The data acquisition mission was flown on 21 January 1989. These data were acquired near the peak of the sorghum growing season and approximately 1.5 to 2 months after recession of the flood waters. Detailed logistic preparation is always necessary in these environments to insure government clearance, aircraft and pilot accessibility, adequate fuel, and good weather. Coverage of the Thiemping site was acquired from nine transects flown at an altitude of approximately 1500 m above ground level. At 1500 m, the CCD camera array, equipped with 12.5-mm lenses, produced a ground pixel size of approximately three metres. In addition, one transect was also flown to acquire higher resolution data over a representative portion of the study site. For this transect, which was flown at approximately 900 m, the 35-mm camera system was equipped with a 135-mm telephoto lens. Upon return to Arizona, the analog video data were digitized using a frame-grabbing system and transferred to a conventional digital image processing system for interpretation.

SATELLITE DATA

A Landsat Multispectral Scanner (MSS) scene of the Middle Valley of the Senegal River was acquired on 27 February 1989, and was also employed in this study. This acquisition was over one month later in the sorgum growing season but was the only available scene for comparison. Though the increased spatial resolution of SPOT data (or the increased spatial and spectral resolution of Landsat Thematic Mapper data) would have aided the study, none were available. Figure 2 is an MSS band-7 print providing a regional perspective of the Thiemping study site (outlined in black). The scene was registered to a 1:50,000-scale base map utilizing ERDAS* image processing software. The area of the Thiemping study site was then extracted for study. The resultant geo-referenced scene had dimensions of 236 by 174 pixels.

AGRICULTURAL LAND-USE MAPPING

PROCEDURES

The initial evaluation of the data relied on classical photo-interpretation techniques to establish land-use classes within the study sites. The procedures entailed (1) initial establishment of land-use classes through on-site discussions with field analysts and analysis of the high-resolution sample video transect at a scale of 1:7,200; (2) interpretation of cultivated fields from the digital video images; (3) mapping of the extent of land-use classes through interpretation of the lower resolution (1:12,900) color photographs; (4) transfer of map data to a 1:20,000-scale base map; and (5) digitizing and insertion of the data into the ARC/INFO geographic information system for map generation and analysis. Subsequent field verification by IDA personnel in Senegal further refined the map products. Effort was then devoted to development of more automated mapping techniques utilizing combined image processing and GIS technologies. Supervised classifications and level-sliced vegetation index images from the Landsat MSS and digital video data were created. These image products were than entered in the ARC/INFO GIS and used to generate maps that could be quantitatively compared with our photo-interpreted land-use map.

MAPPING OF THE THIEMPING STUDY SITE

Land-use classes defined for the Thiemping site fall into two main geographic catergories — *walo* and upland. *Walo* is the area inundated during flooding and the site of recessional agriculture. Upland is the area that does not experience flooding. Three classes were established within the *walo*: (1) cultivated *walo* (2) uncultivated *walo* and (3) water. Five classes were established

*Trade names are included for the benefit of the reader and do not imply an endorsement to the product by the University of Arizona.

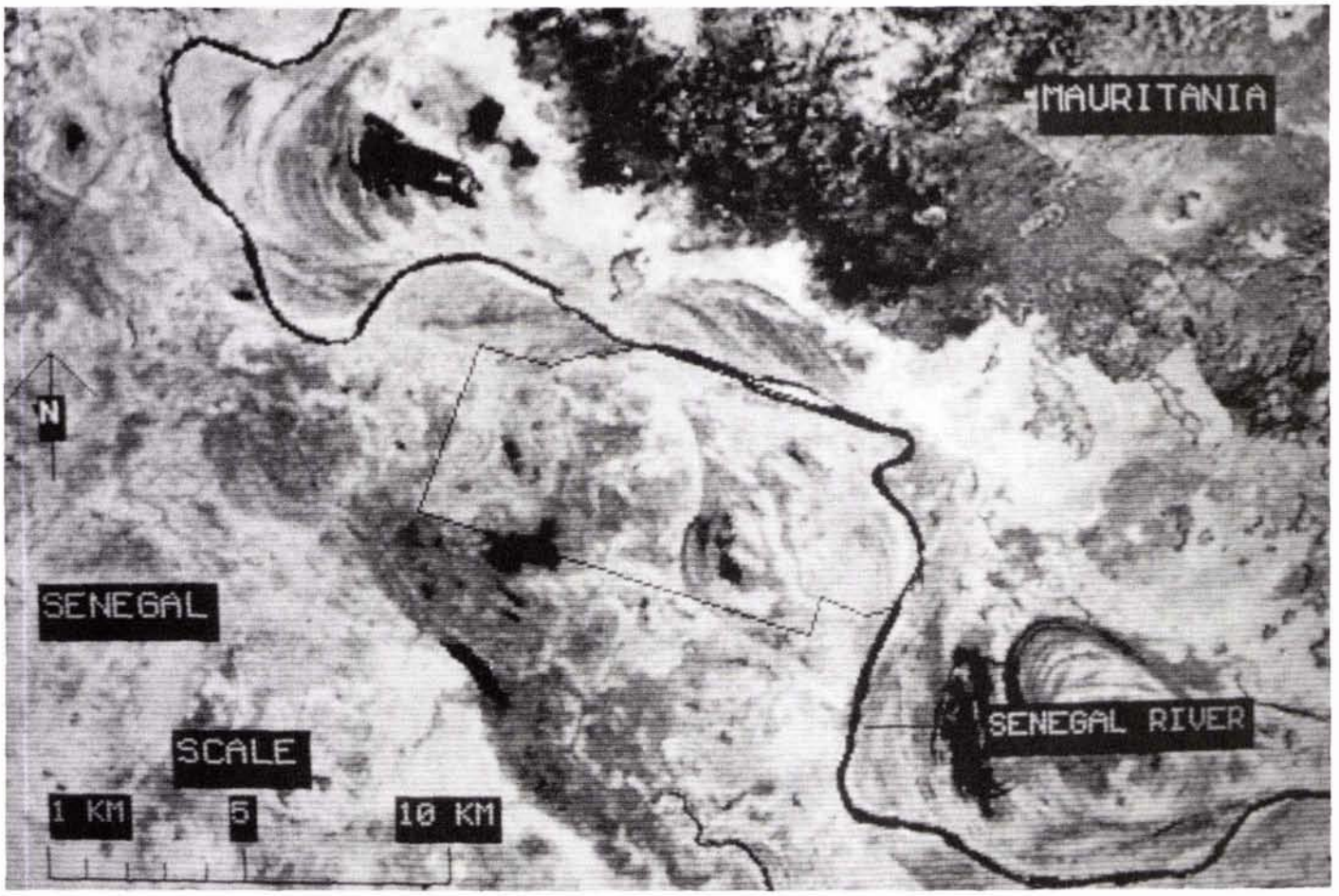

FIG. 2. Landsat MSS band 7 inage of the study site. Approximate scale of image is 1:180,000.

within the upland: (1) *dieri* (dryland farming) plots, (2) garden, (3) forest, (4) village, and (5) grassland.

Color and topographic position were the two most important interpretation criteria utilized to distinguish *walo* and the areas outside of the floodplain. The *walo* soils are discernably darker than the sandier upland soils. Delineation of the classes was based on the following interpretation keys:

Cultivated Walo - The dense and darker clay-rich soils of the *walo* retain sufficient soil moisture to permit cultivation throughout the growing season. The primary crop cultivated in this part of the valley is sorghum. The cultivated *walo* with actively growing crops was identified on the basis of a strong near-infrared response on the digital video data and the presence of man-made patterns, such as straight field borders.

Uncultivated Walo - *Walo* without active cultivation or vegetation was identified on the basis of a weak near-infrared response and the lack of obvious man-made features. Those areas that displayed a stronger near-infrared response but were geographically associated with stream beds or had no artificial boundaries were interpreted as areas of riparian vegetation (weeds and rushes) and were placed in this class.

Water - This class was recognized in the topographically lowest areas of the *walo*. Features within this class represent both perennial ponds and areas of seasonal ponding of flood water.

Five classes were identified in the upland areas:

Dieri Plots - These dryland farming plots are depressions outside of the floodplain which catch rainfall during the rainy season (June through September). They are associated with topographic lows and are generally fenced by linear stacks of brush. Sorghum and corn are the predominate crops grown in these areas.

Gardens - Interpreted on the color photography on the basis of their size, pattern, and proximity to villages.

Forest - Recognized as shrubs and trees on both the photography and video data.

Village - Easily identifiable on both the photography and video images on the basis of geometric patterns and presence of structures.

Grassland - Identification of grasslands was based on field observation; due to the lack of distinctive spectral signatures, it served as the mapping category for all other unidentified land-use patterns.

Two additional classes, *active* and *inactive irrigated perimeters*, were identified both within the *walo* and the upland areas. These classes were mapped using pattern recognition techniques. The perimeters are enclosed by substantial earthen berms.

The final agricultural land-use classification map was created by digitizing the boundaries of the various classes in the ARC/INFO GIS. This enabled the creation of a series of maps based upon particular geographical and analytical requirements. In addition, field analysts have been compiling a wide range of ground data, including precipitation, depth to vadose zone, and social variables. The capabilities of the GIS will permit the digital integration of the land-use classification database with the on-site parameters being collected.

Figure 3 is a GIS-generated, 1:20,000-scale map of the entire Thiemping study site with *walo*, cultivated *walo*, and a grouping

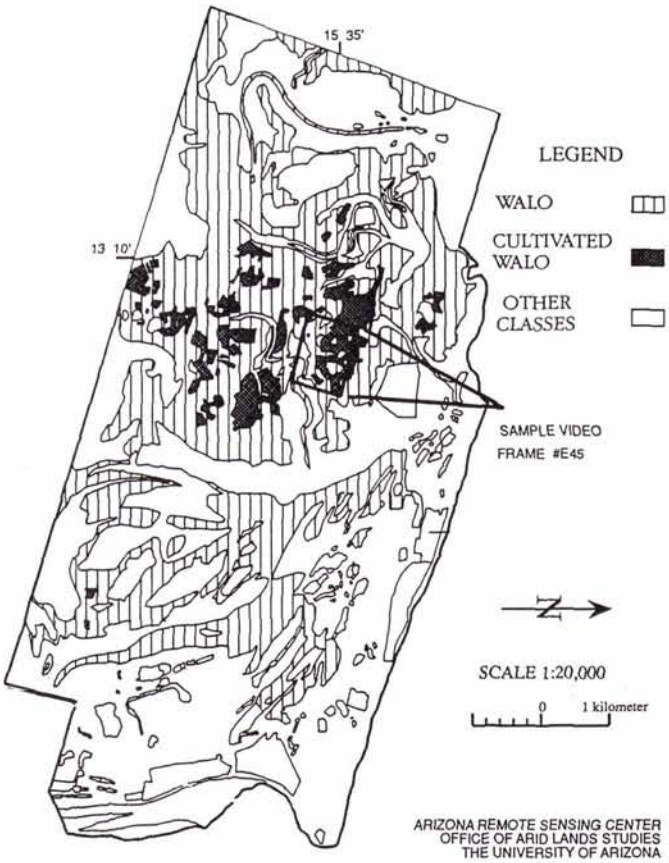

FIG. 3. Agricultural land-use map of the Thiemping study site, created by manual interpretation of digital video and photographic data.

of all other classes delineated. This was accomplished by assigning appropriate class numbers in a look-up table. The complete agricultural land-use map for the Thiemping site was field-checked during May and June of 1989 by IDA personnel in Senegal. This field work indicated that our mapping successfully delineated the areal extent of the land use classes. The most significant discrepancies were in the distinction between cultivated and uncultivated *walo*. These errors generally involved areas mistakenly mapped as uncultivated *walo* that were either at a very early growth stage or devastated by locust. Final map products were then revised based upon the input from field personnel.

ENHANCED MAPPING TECHNIQUES UTILIZING IMAGE PROCESSING AND GIS

LANDSAT ANALYSIS

Our initial developmental work on more automated mapping involved an evaluation of the utility of Lansat MSS data for agricultural land-use mapping at the Thiemping study site. Our primary question concerned the potential of the MSS data to distinguish *walo* using automated mapping techniques. The MSS data were geographically registered to an existing 1:50,000-scale base map, and a subset (236 by 174 pixels) of the scene covering the study site was extracted. A supervised maximum-likelihood classification was then run on the subset scene using the ERDAS software. A total of five training fields were selected to define the *walo*, upland, and water classes. The training fields selected were proportional in area to the extent of each cover type in the sub-scene and designed to represent the variability of spectral signatures associated with these cover types. MSS bands 4, 5, and 7, along with a Normalized Difference Vegetation Index (NDVI) band [(MSS7 − MSS5) / (MSS7 + MSS5)]., were input to the classification. The resulting classification image was smoothed in ERDAS with a 3 by 3 majority filter and exported to the ARC/INFO GIS. This yielded a map with 936 polygons, over 50 percent of which represented areas of less than four square pixels in size. To facillitate processing and plotting, these areas were flagged and removed from the coverage through use of the INFO database "eliminate" algorithm. Figure 4 is the resulting GIS map showing just the distribution of *walo*.

The Landsat MSS classification accuracy was assessed on the basis of total area coverage utilizing the database management capabilities of the GIS (Table 1). Because of the limited spatial resolution (80 metres) of the MSS data, the cultivated and uncultivated *walo* were grouped into a single class and the five upland classes were grouped into a single class on the land-use map. The Landsat classification produced an area estimate for

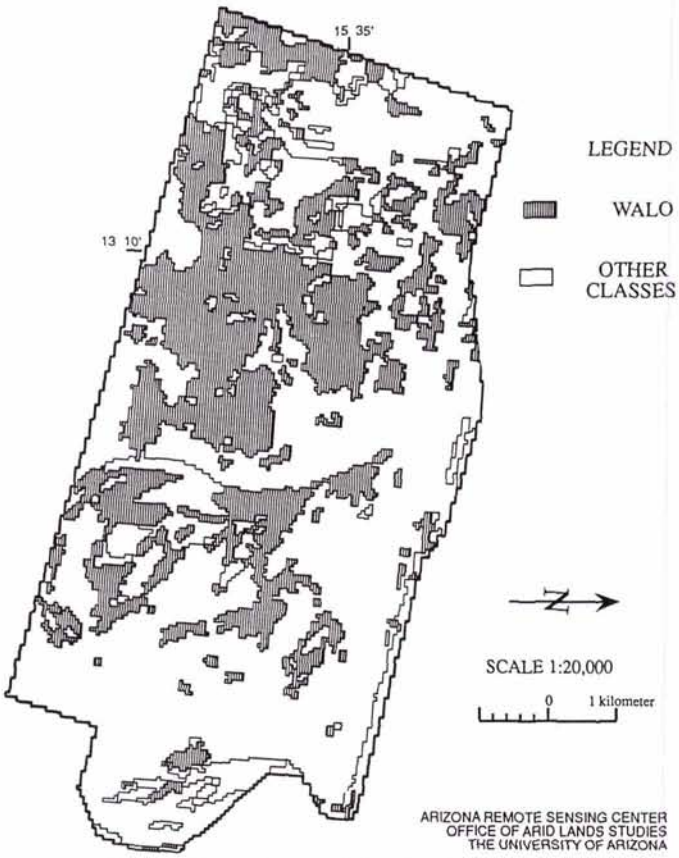

FIG. 4. GIS (vector format) map of the Landsat supervisedclassification of the Thiemping study site, Senegal.

TABLE 1. MANUAL INTERPRETATION AND DIGITAL LANDSAT CLASSIFICATION COMPARISON

	Manual Interpretation	Digital Classification
walo	40 %	31 %
upland	52 %	56 %
water	6 %	11 %
other	2 %	2 %

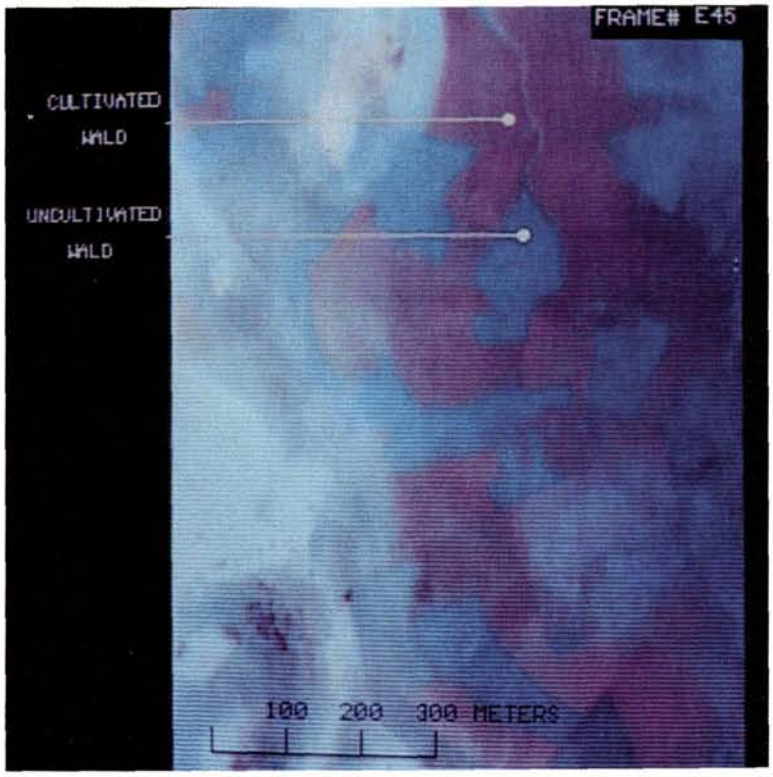

PLATE 1. Simulated false color composite of video frame E-45. Approximate scale of Image is 1:10,000.

walo of 31 percent compared to 40 percent on the land-use map produced from interpretation of the video and 35-mm photography. An evaluation of this discrepancy revealed that a significant number of the *walo* fields, both cultivated and uncultivated, were misclassified as water. This was probably due to the fact that many of the small ponds were overgrown with vegetation, producing a strong near-infrared response. These vegetated ponds were included as training fields in the MSS water class in hopes of more accurately representing standing water in the area. It follows that the inaccuracy of the Landsat water classification was also the result of the complicated spectral character of these water bodies and the spatial resolution of the data.

This comparison suggests that the Landsat MSS data can be used to delineate the extent of the floodplain. Though this data set, with its 80-meter resolution, provided inferior spatial resolution compared to the airborne video and 35-mm photography, it did provide complete areal coverage that could be used to achieve a regional perspective to the mapping of the floodplain. In addition, far more automated procedures were utilized in the Landsat MSS analysis. The supervised classification and GIS map generation procedures consumed significantly less time and manpower than the manual interpretation of the airborne data. Given adequate a *priori* knowledge to establish the location of floodplain training classes, more accurate supervised classifications might be achieved utilizing satellite data with higher spatial resolution (e.g., Landsat TM or SPOT). In addition, a more accurate classification might be achieved utilizing a scene acquired much earlier in the growing season (December). In December, contrast is high between the recently inundated *walo* soils and the soils of the upland, and vegetation within the *walo* (both natural and agricultural) is not yet well developed. Obviously, multitemporal data acquired at optimum times in the growing season would provide the ideal data set.

MULTISPECTRAL VIDEO ANALYSIS

To assess the potential of a more automated analysis of the multispectral video data, an individual frame of the video coverage was analyzed. The video frame (#E45; see Figure 3 for location) primarily covers cultivated and uncultivated *walo*. Plate 1 is a contrast-stretched, simulated false-color composite of the video frame produced by assigning the NIR band (780 to 930 nm) to red and the red band (610 to 690 nm) to both blue and green on the image display.

An NDVI image was generated to assess, on a digital basis, the ability to discriminate the agricultural vegetation within the video frame. The image was level-sliced using three, eight, and sixteen levels. The eight level-slice had the closest correspondence to the interpreted land-use map. The level-sliced image was then smoothed, using a 3 by 3 majority filter, and exported to ARC/INFO. Figure 5 is the level-sliced NDVI video image for the study frame. Results showed a very good comparison between the manually interpreted class of cultivated *walo* and the highest NDVI values.

A supervised maximum-likelihood classification was also run on this video scene. Eight training fields were selected to define three classes: *walo*, cultivated *walo*, and upland (area outside of flood extent). The NIR and red video bands, along with an NDVI band generated from the individual video bands, were input to the classification. The resulting classification image was smoothed, again using a 3 by 3 majority filter, in the image processing system and exported to the ARC/INFO GIS. Figure 6 is the resulting map of *walo*, cultivated *walo*, and upland. It closely resembles the initial interpretation derived from the

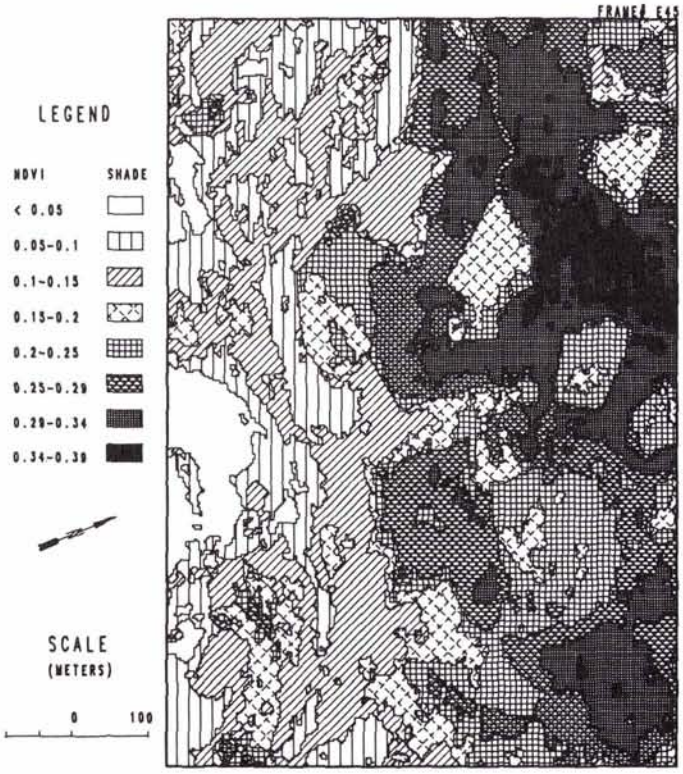

FIG. 5. GIS (vector format) map of the level-sliced NDVI image of video frame E-45.

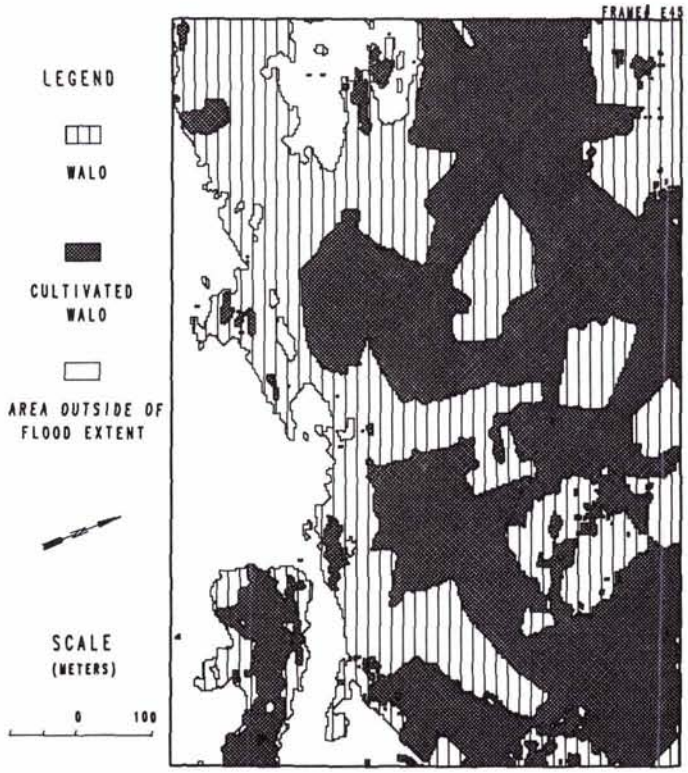

FIG. 6. GIS (vector format) map of the supervised classification of video frame E-45.

manual interpretation of the video false-color composite and 35-mm color photography that was used to produce the agricultural land-use map. Table 2 provides the numerical comparison between the manual and digital classifications based on video frame E-45. In this example, the digital classification yields close agreement for the cultivated *walo* areas; however, it tends to overestimate the percentage of upland at the expense of *walo*.

The favorable comparison between the photo-interpreted and supervised classification maps encourages a more comprehensive approach using a complete video data-set, supervised classification techniques, and entry of the resulting classified image into the GIS. However, to accomplish this for the entire video data set would require the creation of a mosaic of video frames.

An initial effort was made to create a mosaic of video frames for the smallest of the three study sites, in which 30 video frames were mosaicked. No individual video frame contained more than one or two ground control points that were identifiable on both the frame and on the available 1:50,000-scale base maps. Therefore, the rectification procedure involved (1) evaluation of the site to determine the number of frames needed to cover the area; (2) creation of an "image box" large enough to accommodate the 30 video frames; (3) insertion of the initial frame in the lower-right corner of the box; (4) registration of successive frames utilizing control points found in areas of frame overlap; and (5) rectification of the resulting mosaic to the 1:50,000-scale map.

Ultimately, the method proved to be unsuccessful. Rectification errors generated during the procedure were propagated and compounded as one frame was registered to the next. In addition, the time required to co-register 30 video frames proved to be impractical.

CONCLUSIONS

This project was designed to establish the feasibility of mapping current agricultural land-uses patterns through the combined application of airborne video and satellite remote sensing with geographic information system technologies. The logistical advantages of utilizing a multispectral video system, coupled with the map generation capabilities of the GIS, proved to be a successful method of mapping *walo* within the Senegal study site. Landsat MSS data were used to delineate the extent of the general land-use classes. Our assessment of the capabilities of these data for land-use mapping was based upon both classical photointerpretation of the video image data and an evaluation of more automated mapping techniques involving supervised classification of the airborne and satellite data. The feasibility of both approaches was demonstrated. However, to successfully apply automated mapping techniques utilizing the video data, additional applications research must be devoted to establishing a fast and accurate means of combining multiple video scenes into a single, geographically registered image. One method currently being investigated by ARSC is the use of global positioning system (GPS) technology.

TABLE 2. MANUAL INTERPRETATION AND DIGITAL VIDEO CLASSIFICATION COMPARISON OF FRAME #E45

	Manual Interpretation	Digital Classification
walo	46 %	36 %
cultivated walo	42 %	44 %
upland	12 %	20 %

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In Memoriam

Georg Strasser

Dr. Georg Strasser died on the 15th of September 1989. For several years he had fought a severe illness successfully, a fact known only to a few.

Even for his friends and colleagues it is almost impossible to describe fully his outstanding personality and his eventful life.

Georg was born on the 8th of March, 1910, in Munich, where he also went to school. When he was sixteen, both his parents died, a tragic event which undoubtedly influenced his future life. A scholarship granted by the City of Munich enabled Georg to begin his studies at the local Technical University. He selected Surveying/Geodesy and related fields, such as Cartography and Photogrammetry, and passed the final examinations very successfully in the shortest possible time in 1934.

Originally, Georg wanted to begin a career in the civil services of the Bavarian state. Nevertheless, the call-up for military service in an artillery survey unit changed his ideas and he served then for three years as a junior surveyor in military surveying, before passing the so-called second "State Examination" with the marks "very good" in 1938.

In World War II Georg Strasser took part as an officer in his special field of military survey in nearly all the theatres of war in Europe and achieved the rank of Major.

During the early post-war years, Georg was employed at the renowned "Institut fur Erdmessung" in Bamberg and thereafter he worked as curator and lecturer at the Geodetic Institute of the Munich Technical University. The first of nearly forty scientific publications dates back to this time. His papers dealt not only with geodetic and cartographic problems, but also with aspects of metrology in general as well as with instrumental design and procedures. Some of his very carefully researched articles on certain historical events will serve as references for a long time.

One year before being awarded his doctor's degree (1950), Georg married and the Strasser family went in 1951 to Cooma, N.S.W., Australia, where he had accepted a leading position on a three-year contract with the Snowy Mountains Hydro-Electric Authority. Among other achievements during this time, he introduced terrestrial photogrammetry for engineering works. In 1954, the Strassers returned to Munich and Georg became director of Department I of the German Geodetic Research Institute.

In 1962, Edwin Berchtold, head of the Geodesy Department of Wild Heerbrugg, reached retirement age and Dr. Georg Strasser, then already well known in Switzerland, was elected as successor from January, 1963.

The enormous progress in the fields of electronics and computing techniques forced instrument manufacturers to develop new equipment and methods. Electronic and infra-red distance measuring instruments, as well as gyro-supported instruments and development planning at that time. Georg was always thinking ahead. He was not only extremely well qualified technically, but also a very gifted manager who knew the importance of quality control and the proper introduction of new products on the market. He made many trips to nearly all continents where he attended congresses and symposia and presented numerous papers and made many friends. Above all, Georg wanted to collect opinions and suggestions from users of survey instruments in order to improve existing equipment and gather ideas for new instruments.

Under Georg Strasser's leadership, not only did new instruments come on the market, but the whole range of Wild surveying equipment was modernised and partly redeveloped. Despite the heavy workload, Georg found time to publish articles of current importance. Even after retirement at the end of 1977, he was editor of the company's news bulletin "Wild Reporter" until 1988.

Contact with Dr. Strasser could be quite difficult for those who did not know him well. The ice had to be broken first. But behind his Bavarian temper there hid the very human Georg, sociable, cheerful, always helpful and interested in a variety of fields beyond profession and business.

Georg Strasser is survived by his wife Hiltrud in Rebstein, Switzerland, and his son Georg and daughter Sabine. All relatives, friends and colleagues all over the world will remember his remarkable personality with affection.

—Gert E. Bormann