REMOTE SENSING FOR CROP INVENTORY OF EGYPT'S OLD AGRICULTURAL LANDS

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ABSTRACT:

Mapping and monitoring the intricate cropping pattern of Egypt's 'old agricultural lands' constitutes an enormous challenge for government ministries tasked with their annual inventory. Having a year-round favorable climate with several cropping seasons, fertile alluvial soils, and a dependable high-quality water supply for irrigation, Egypt has some of the richest agricultural resources in the world. Millions of acres of the Nile Delta and Valley have been under continuous cultivation for several millennia. Land division over time has resulted in seventy percent of farms being one acre or less in size. The cropping pattern is dynamic due to the small size of individual fields and the intensive, year-round crop rotation. The acquisition of accurateand timely crop data is essential for efficient management of Egypt's complex agricultural production system and vast irrigation and drainage networks . This paper will present an overview of how the Government of Egypt has conducted agricultural inventories in the past and at present. Recent applications of photographic and non-photographic remote sensing technologies for crop survey in Egypt will be described. Capabilities and limitations of satellite image classification and aerial photo interpretation will be compared and contrasted for practical use in monitoring change in Egypt's old agricultural lands.

KEY WORDS: Egypt, Remote Sensing, Crop Inventory, Color Infrared Aerial Photography, Satellite Image Processing, Resolution.

INTRODUCTION

A prolonged drought in the mid 1970s to 1980s in East Central Africa resulted in alarmingly low water levels in Egypt's High Aswan Dam. This alerted the Government of Egypt of the necessity to conserve and more efficiently manage its limited water resources. At the same time, Egypt's rapidly increasing population — which more than doubled between 1960 and 1990 — is placing increased demands on the country's limited supply of agricultural land which is being lost to expansion of urban areas. At the same time new agricultural lands are increasingly being reclaimed from deserts and wetlands.

Accurate water requirement data for agricultural lands is a key element needed for efficient management of irrigation and drainage systems. Water needs, irrigation scheduling and drainage requirements are highly dependent on cropping throughout an irrigation system.

Remote sensing can provide agricultural inventory data required by irrigation system managers to more efficiently manage the finite water resources of Egypt. The focus of this paper is practical — what has actually been accomplished by interpretation/classification of remote sensing data — versus theoretical — what might be accomplished by interpretation/classification of data from a particular sensor.

AGRICULTURAL LANDS IN EGYPT

Over the past several decades there has been increased discussion in Egypt over the size of the total area of land under cultivation and the area occupied by the main crop varieties. Agricultural data is generated by different government ministries— at times with conflicting results. Table 1 summarizes area estimates of cultivated land in Egypt over the past ninety years. Of particular interest is a large unexplained apparent increase in total area under cultivation by approximately 500,000 feddans between 1981 and 1982. All of the cultivated land data listed in Table 1 was collected by direct field observation and annotation of large scale cadastral maps or aerial photographs except for the 1976 data which was obtained from classification of satellite imagery. Field annotation of large scale maps is the predominant method of crop data collection by the Ministry of Agriculture and the Egyptian Survey Authority. The Ministry of Agriculture collects data on up to 22 crop types on an annual basis. The Egyptian Survey Authority collects data on wheat, rice and cotton annually. Field observations are made at the village level and data are condensed to the agricultural district and larger administrative levels. The accuracy and consistency of data collected in this manner is frequently questioned. This is why remote sensing solutions for annual crop inventory are currently being explored.

Year	Cultivated Area *Millions of feddans**
1898	5.35[a]
1929	5.67[b]
1937	5.26[c]
1947	5.74[c]
1960	5.83[c]
1961	5.97[b]
1966	5.95[c]
1972	5.88[d]
1976	5.84[c]
1977	5.86[d]
1979	5.84[c]
1981	5.92[d]
1982	6.63[d]
1989	7.49[b]
1990	7.55[b]

*1 feddan = 1.04 acres

Data source:
a Willcocks et al., 1917
b ESA, 1991
c Hady et al., 1983
d ARS, 1986

Table 1 -- Cultivated Lands in Egypt.

AGRICULTURAL REMOTE SENSING

Agricultural scientists in Egypt need to develop a sustainable, efficient and cost effective method of meeting the annual agricultural data needs for the country. Some form of remote sensing will likely be part of the strategy. The essence of agricultural remote sensing is the collection and measurement of electromagnetic radiation reflected by vegetation, soil, water and other features of the earth's surface. A knowledge of actual ground conditions makes it possible to interpret remote sensing data which encompasses both photographic and non photographic sensors. All remote sensing data types have their limitations, however. What needs to be done is to match the data needs of the user with the appropriate technology that has demonstrated that it can meet those needs given the constraints presented by the intricate cropping environment of the old agricultural lands of Egypt.

Satellite Sensors

Satellite images are composed of discrete picture elements, or pixels. Pixel sizes vary for different satellite sensors. Early (1972) Landsat 1-5 Multi Spectral Scanner (MSS) images have a pixel size of 57m by 79m. Later (1982) Landsat multi spectral Thematic Mapper (TM) images have a smaller pixel size of 30m by 30m. The French Satellite Probatoire d'Observation de la Terre (SPOT), in operation since 1986, has the smallest currently available spatial resolution in both the multi-spectral (20m) and panchromatic modes (10m). SPOT sensors were designed primarily for mapping applications and include a stereoscopic coverage capability.

Image resolution is an important factor in feature identification, analysis and classification accuracy (Markham, et al., 1981). Table 2 summarizes pixel size and approximate resolution of multi-spectral satellite data currently available in Egypt.

Sensor	Pixel Size *meters*	Pixels *per feddan*
Landsat MSS	57 x 79	0.6
Landsat TM	30 x 30	4.7
SPOT1	20 x 20	10.5

Table 2 -- Satellite Multi-spectral Scanner Pixel Sizes.

Resolution

Throughout remote sensing literature, diversity exists in discussion of image processing and classification as related to sensor measurement resolution. It is generally accepted, however, that resolution strongly influences the accuracy of interpretations that may be obtained (Lintz and Simonett, 1976).

Four types of resolution are generally recognized; spatial, spectral, radiometric and temporal (American Society of Photogrammetry, 1983). The two types most important in remote sensing agricultural inventories (spatial and spectral) are discussed in the following sections.

Spatial Resolution

Spatial resolution refers to the fineness of detail depicted in an image. It describes the minimum size of objects on the ground that can be separately distinguished or measured. In satellite scanner systems this is expressed as the instantaneous field of view (IFOV) which is an angular measure expressed in radians. In photographic systems spatial resolution is expressed as line pairs per millimeter that can be resolved on the film. Spatial resolution combined with complexity of the landscape place practical limits on interpretation capability and classification accuracy.

Previous researchers conducting agricultural inventories using non photographic sensors have developed guidelines relating spatial resolution as expressed by the ground-projected instantaneous-field-of-view (IFOV) of satellite sensors to an ability to discriminate crop types. In North America and the USSR, field sizes are such that Landsat MSS data, with a ground-projected IFOV of about 80m x 80m, has been shown to be marginally adequate in crop discrimination studies (American Society of Photogrammetry, 1983). Other research (Harmage and Landgrebe, 1975) has shown that identification and analysis become acceptable when fields are greater than 64 pixels in size (Slater, 1980). When applied to TM and SPOT imagery this relationship gives approximate minimum field sizes needed for identification and analysis to be 13.7 feddans for TM and 5.7 feddans for SPOT. In the old agricultural lands of Egypt approximately seventy percent of all farms are one feddan or smaller in size. It is clear that the spatial resolution of current satellite sensors presents a severe limitation in the effective use of these sensors for agricultural inventories.

Spectral Resolution

Spectral resolution refers to the width of the regions in the electromagnetic spectrum that are sensed and the number of channels used (Lintz and Simonett, 1976). The number and widths of spectral bands available for processing are an important factor in image classification potential. The Landsat Thematic Mapper sensor operates in seven wavebands in the visible, near infrared, middle infrared and thermal infrared regions of the spectrum (Table 3).

Band	Wavelength (μm)
1	0.45-0.52
2	0.52-0.60
3	0.63-0.69
4	0.76-0.90
5	1.55-1.75
6	10.4-11.7
7	2.08-2.35

Table 3 -- Landsat TM Spectral Bands.

Thematic Mapper data have been widely used for geologic, forestry, hydrologic and agricultural mapping. SPOT's multi-spectral sensor operates in the three bandwidths listed in Table 4.

Band	Wavelength (μm)
1	0.50-0.59
2	0.61-0.68
3	0.79-0.89

Table 4 -- SPOT Multi-Spectral Bands.

For agricultural mapping applications Landsat Thematic Mapper data has better spectral resolution available for processing and classification. SPOT data, however, have greater spatial resolution. Actual results of agricultural classifications in Egypt with each of these sensors follow.

Satellite Image Classification

In a conventional spectral classification of an image each pixel is assigned to a certain class, e.g. crop, urban, natural vegetation, desert. Every pixel in an image contains spectral information averaged over the area covered by the picture element. Because a pixel grid is arbitrarily overlain on a landscape, not every pixel belongs to one distinct class. If a pixel comprises more than one class, e.g. rice, cotton and fallow, the spectral information from these classes is recorded as an mixture of all three. Such a pixel is called a boundary or mixed pixel. The number of boundary pixels in any given image is dependent on resolution of the sensor and the complexity of the landscape. In the case of agricultural inventories, average field size, variability of the crop planting calender and image acquisition date influence the level of detail and accuracy possible. Small fields and a dynamic crop calender combine to increase the number of boundary pixels in an image. A high percentage of boundary pixels in an image restricts both the number of discrete land-use classes that can be identified and the overall accuracy of the classification. Factors affecting classification accuracy for crop inventory in Egypt's old agricultural lands are detailed below.

- § Complexity of the landscape
  - Number of crops planted
  - Average field or plot size
  - Variability of crop planting dates
  - Stressed crop conditions
  - Degree of intercropping
  - Uniformity of soil conditions
- § Number of classes to be distinguished
- § Date of image acquisition
- § Image multi-spectral pixel size
- § Sensor bandwidths available for processing

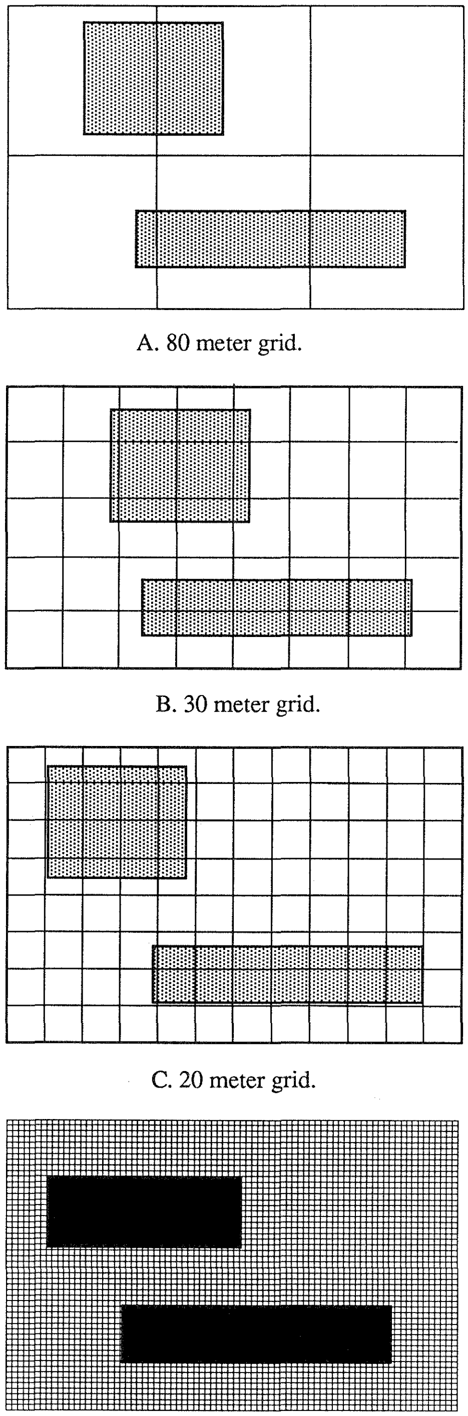
Figure 1 illustrates how pixel grids when overlaid on small fields can result in many pixels having mixed spectral signatures (boundary pixels). In this figure pixel grids representative of Landsat MSS, Landsat TM, SPOT multi spectral and CIR aerial photography (1:20,000 scale) are compared.

Previous Satellite Agricultural Remote Sensing Studies in Egypt

Processing of satellite imagery for use in agricultural inventories has been attempted in Egypt since 1983 when the Remote Sensing Center of the Academy of Scientific Research conducted the first estimation of irrigated agricultural areas in Egypt using digital processing of Landsat multi-spectral scanner data. This study determined that the total area of irrigated agricultural land in Egypt during the 1976 winter season was 5.84 million feddans. Researchers concluded that Landsat MSS image resolution was not satisfactory for crop differentiation in Egypt because of the small field sizes involved (Hady et al, 1983).

In 1986, IWACO, Consultants of Water and Environment, Rotterdam, The Netherlands in cooperation with the Egyptian Survey Authority used Landsat TM images (February and July, 1985) of the Fayoum, Egypt to determine the total area of cultivated land, waterlogged and saline areas and to document the growth of urban areas (Wolters et al., 1989). The authors concluded that "in the Fayoum, satellite remote sensing probably cannot help in making a detailed crop map because of the small field size and fragmented land use." The authors observed that in irrigated areas of the world with small average field sizes classification of any accuracy is impossible if the land use is complex, with many different crops in different stages of growth next to each other (Wolters et al., 1989).

In 1988, the Institute Geographique National (IGN), Paris, France and the Egyptian Survey Authority, produced a 1:100,000 scale thematic map of the Fayoum, Egypt using SPOT imagery (Bakir et al., 1989). The goal of this study was to obtain an accurate assessment of the cultivated area of the Fayoum. The researchers used a supervised classi-



A. 80 meter grid.

B. 30 meter grid.

C. 20 meter grid.

D. 3 meter grid. *Note: Display capabilities preclude illustration of a one meter grid.*

Figure 1 -- Remote Sensing Pixel Grids Superimposed on 1 Feddan Fields.

fication of a March 1987 SPOT image. Classes differentiated by this study are listed in Table 5.

Bakir et al., stratified the study area into four classes to assist in the differentiation of: natural vegetation and tree crops; uncultivated bare ground and fallow fields. The

1	Crops
2	Tree Crops
3	Fallow Land
4	Flooded Land
5	Natural Vegetation
6	Bare Ground Uncultivated
7	Housing
8	Open Water

Table 5 -- Winter Season Classification Legend, SPOT, Fayoum (IGN, 1987).

differentiation of these four classes were found to be problematical. IGN and Bakir concluded that classification of the SPOT image yielded data on arable land area which correlated closely with data obtained by photo interpretation.

In 1989, the International Institute for Land Reclamation and Improvement (IWACO), Rotterdam, The Netherlands, classified Landsat Thematic Mapper images of the Nile delta and Nile Valley for the Ministry of Public Works and Water Resources (MPWWR). A supervised maximum likelihood classification (bands 2, 3, 4 and 7) of a July, 1987 Landsat Thematic Mapper scene of the Nile Valley between Beni Suef and El Minya yielded the following classification;

1	Crop 1
2	Crop 2
3	Crop 3 early
4	Crop 3 late
5	Crop 4 early
6	Crop 4 late
7	Brush
8	Reed
9	Urban
10	Sabkha*
11	Desert 1
12	Desert 2
13	Desert 3
14	Desert 4
15	Desert 5
16	Open Water

* Sabkha - playa or salt flat

Table 6 -- Summer Season Classification Legend TM, Nile Valley, (IWACO, 1989).

IWACO was able to classify a greater number of crop classes using a maximum likelihood classification (bands 2, 3, 4, 5 and 7) of a July 1987 Landsat 5 Thematic Mapper scene of the Eastern Nile Delta. They were able to map the twelve classes listed in Table 7.

During 1989 and 1990 the Soil and Water Research Institute of the Ministry of Agriculture Remote Sensing Unit, Agricultural Research Center, Cairo estimated cultivated areas in Lower and Upper Egypt using a supervised classification of May 1990 Landsat TM data (Hamdi and Fawzy, 1991). Data on cultivated lands from this study compared favorably with data from the Agricultural Authority using

1	Cotton
2	Rice/Marsh
3	Maize
4	Urban
5	Bare
6	Sabkha 1
7	Sabkha 2
8	Sabkha 3
9	Desert 1
10	Desert 2
11	Desert 3
12	Open Water

Table 7 -- Summer Season Classification Legend TM, Eastern Nile Delta, (IWACO, 1989).

manual techniques.

The Remote Sensing Unit also estimated wheat, rice and cotton in 1989 and 1990 using supervised classifications of TM images and field spectroscopy (Hamdi et al, 1991). Remotely sensed area data on rice and cotton per governorate compared favorably with Agricultural Authority figures (see Tables 8 and 9).

Governorate	R.S.	Ag. Auth.
Kafr El Sheikh	238,000	224,000
Damietta	63,000	61,000
Gharbiya	91,000	89,000
Fayoum	14,000	13,000
Dakahliya	310,000	305,000
Sharquiya	153,000	149,000

Table 8 -- Official and Remotely Sensed Areas of Rice in feddans (adapted from Hamdi et al., (1991).

Governorate	R.S.	Ag. Auth.
Kafr El Sheikh	114,000	115,000
Damietta	63,000	61,000
Gharbiya	104,00	104,000
Fayoum	14,000	13,000
Dakahliya	159,000	159,000
Sharquiya	124,000	124,000

Table 9 -- Official and Remotely Sensed Areas of Cotton in feddans (adapted from Hamdi et al., 1991).

Aerial Photographic Interpretation

Aerial photography has been widely used in the United States since the 1930s for crop inventories. Determining the amount of land planted to specific crops has historically been an important activity of the U.S. Department of Agriculture, and aerial photography has long provided that agency with a cost-effective and timely means of obtaining such data (Rundquist et al., 1988). Traditionally, black-and-white (or "panchromatic") aerial photography has been the most common information source. With this type of film, the various colors and patterns of the land surface are depicted as a series of gray tones ranging from white to black. Panchromatic film is still widely used for many agricultural applications despite the fact that, in some cases, it is difficult to distinguish between different types of crops.

Color infrared (CIR) film is a relatively recent development and is widely used in the United States for crop inventory and analysis. CIR film has the advantage that it is sensitive to near infrared radiation which is part of the light spectrum just beyond the sensitivity of the human eye. Vegetation exhibits a much higher sensitivity in the near-infrared wavelengths than in the visible wavelengths. Near infrared sensitive films record an entire range of tone gradations in vegetation which cannot be recorded with standard color and panchromatic films. Crop types are delineated by classical photo interpretation techniques involving human interpretation of photo tone and color, texture, size, shape, pattern and site association. CIR film offers the greatest reliability for single-date crop discrimination (Avery, 1985). Where interpretation is based solely on panchromatic photography, crop identification is extremely difficult unless multi-date photography is available. As with spaceborne sensor data, the date of photo acquisition in relationship to the crop calender is a critical factor for classification accuracy.

Photographic Agricultural Inventories in Egypt

Currently the USAID funded Survey and Mapping (S&M) Project is conducting a crop and soil mapping program interpreting 1:20,000 CIR film transparencies of the Nile Delta to produce digital crop and soil overlays for the Winter 90-91 and Summer 91 crop seasons. This is the first time that CIR film has been used for crop classification in Egypt. Detailed crop inventory is possible with 1:20,000 scale CIR film transparencies because of their high spatial resolution (greater than one meter) and unique spectral properties. The minimum mapping unit size of the current project is 0.6 feddans. Photo polygons will be transferred to 1:10,000 orthophoto base maps. Resultant crop overlays will be scan digitized into a geographic information system. The crop and soil classification legend for the Winter 90-91 season is listed in Table 10.

CIR aerial photography has an added advantage for crop studies in Egypt that it can be used to interpret and map stressed crop areas. In Egypt, stressed crops are commonly associated with soil salinity and water-logging caused by over irrigation and/or inadequate drainage. A secondary goal of the CIR mapping program of the S&M Project is to delineate areas where crop growth is being adversely

1	Wheat
2	Clover
3	Fool Bean
4	Orchards
5	Potatoes
6	Sugar Cane
7	Mixed Row Crops
8	Other crops
9	Fallow Field
10	Lands under Reclamation
11	Stressed Crops*
12	Non Productive Land**

* Areas of atypical photo signatures consisting of unidentifiable crops under stress due to soil salinity, waterlogging or other reasons. This class can also be used as a modifier of crop classes to yield up to seven additional classes (e.g. stressed wheat, stressed clover, etc.)

** Absence or non growth of crops in predominantly arable area due to soil salinity, waterlogging or other reasons.

Table 10 -- Winter Season Photo Interpretation Legend.

affected by salinity and waterlogging. CIR photography is an excellent remote sensing medium for this kind of an inventory.

One major disadvantage of aerial photography is its high cost per unit area. Table 11 lists a cost comparison of different remote sensing coverages available in Egypt. Table 12 lists advantages and disadvantages of photographic and non photographic remote sensing data for agricultural inventory in Egypt.

Sensor	Landsat TM	SPOT1 XS	CIR Aerial Photography
Cost/image Sq. KM*	4,500	2,150	48
Image area Sq. KM	34,225	3,600	8
Coverage cost Sq. KM	0.14	0.60	3.3

* Full scene -6250 BPI format, $US, no pre-processing

Table 11 -- Cost Comparison of Remote Sensing Data Sources - Egypt.

SUMMARY

Accurate measurements of Egypt's agricultural areas is needed for development, calibration and maintenance of complex water allocation, irrigation and agro-economic models used by ministries of the Government of Egypt. The selection of an appropriate remote sensing technology for agricultural inventory should be based on what will most efficiently and cost effectively meet the users agricultural data requirements.

As can be seen by the project summaries outlined in previous sections, satellite remote sensing has proven to be able to provide accurate data on total area of cultivated land in Egypt and areas of two crops in the summer season (rice and cotton) and one crop in the winter season (wheat). The current problem with satellite image classification is the complex nature of the landscape of Egypt's old agricultural lands with small field sizes and non uniform planting dates. These conditions have resulted in image classifications which, to date, have demonstrated only limited capability for obtainment of detailed crop information.

If five or more crop classes are required by the user and crop areas need to be spatially located the only proven techniques to accomplish this level of classification detail are;

1. Photo interpretation of color infrared aerial photography (census approach);
2. Refinement and automation of the current field map annotation approach.

If a non-spatial estimate of crop areas is adequate a stratified statistical sampling (area sampling frame) approach may be a solution (Hassan and Wigton, 1990; Spiers, 1977). This technique uses multiple layers of remote sensing data at different scales to yield crop area estimates with only one to two per cent of the survey area requiring aerial photography (Wigton, 1977).

Ultimately, the end data user must determine the level of detail required for the agricultural data needed. Appropriate remote sensing technology can then be applied—either photographic or non-photographic—to satisfy the data needs of the user.

Agricultural Remote Sensing in the Future

Remote sensing is a dynamic technology. Future advances in satellite scanners and image processing software requires continued research in classification capabilities of satellite remote sensing data. At some point in the future, detailed crop inventories using satellite data may be possible, even with the complex cropping pattern dynamics present in Egypt's old agricultural lands.

Data Source	Advantages	Disadvantages
Aerial Photography	High resolution Well established technique Simplicity of processing Small details visible Detailed crop inventory possible	Small area covered by each frame High cost per unit area Heavy logistics Possible delay and confiscation of imagery by Military Security Low automation possibilities Data must be transferred to map base for spacial accuracy Increased potential accuracy with greater number of classes interpreted (less heterogeneity) Large staff required for large areal surveys
Satellite Scanner	Up to seven multi-spectral bandwidths available for processing Low logistics High automation capability Limited potential difficulties with military security Low cost per area Fast interpretation Small staff required for large areal surveys	Low multi-spectral resolution High percentage of boundary pixels in areas of high landscape intensity Detailed crop inventory capability not yet demonstrated for old agricultural lands of Egypt Reduced accuracy with increased number of classes mapped

Table 12 -- Sources of Remote Sensing Data Available for Agricultural Inventory in Egypt (after Rochon, 1990).

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