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1986/7 Sudan Crop Estimation assisted by Remote Sensing Techniques

A PROJECT UNDER THE SUDAN EMERGENCY RECOVERY INFORMATION AND SURVEILLANCE SYSTEM FUNDED BY THE UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT IN CO-OPERATION WITH THE GOVERNMENT OF SUDAN.

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Food and Agriculture in Sudan

INTRODUCTION

In Sudan, agriculture dominates the national economy. Employment is primarily concerned with agriculture and its related activities. Public sector investment in major land irrigation schemes has been high and investment in mechanized rain-fed agriculture is large. Subsistance and traditional agriculture is practised in all the provinces of Sudan. In the majority of the provinces it defines the prevalent lifestyle of the population.

Because the arid and semi-arid climate regime means much of the country is subject to periodic drought, Sudan experiences wide fluctuations in agricultural production, especially in food crops. This means that the government agencies require timely information about food production if famine is to be averted. The project described here assisted existing government agencies to gather the required data. The data-gathering exercise was assisted by earth resources satellites and a survey strategy based on probability and statistical inference.

SATELLITE DATA

There are several systems of satellites in orbit around the earth and some of them are currently providing information about earth resources. One system, the Landsat satellites, owned and operated by the U.S.A. provides views of the earth's surface in several different regions of the electromagnetic spectrum. These data are gathered either by the multispectral scanning system (MSS) with 80 metre resolution or by the thematic mapper (TM) with 30-metre resolution. Landsat 4 and Landsat 5 are currently in operation and gathered the data used in the project reported here.

Data from the French satellite SPOT (Systeme Polyvalent pour Observation de la Terre) are also available in panchromatic form with a resolution of 10 metres and in multispectral form with a resolution of 20 metres. With resolution at these levels it is possible to view considerable detail on the ground. The picture of Khartoum on the back of this brochure shows the level of detail provided by data from the SPOT satellite. Note the definition of vegetation (shown in red), and the clarity with which this defines the irrigated agriculture north of Khartoum.

A Landsat view covers a much larger area than a single view from SPOT and shows the major types of agricultural land use in much the same way. The area studied in this project was approximately one million square kilometres and required some 50 Landsat scenes for complete coverage. The major types of agricultural land use were drawn on these scenes within the required accuracy.

Irrigated agriculture

Figure 1 shows a part of the Landsat data of the Gezira Irrigation Scheme. In this view the irrigated area is clearly defined by the pattern of fields, main and feeder canals, service roads and standard fields of 90 feddans of land. The red colour in the satellite picture indicates healthy green vegetation, and contrasts with the yellow colour of the arid desert adjacent to it. This contrast is equally marked on the ground where the prolific growth of the irrigated vegetation contrasts markedly with the stunted vegetation seen on the barren land outside the irrigation scheme. Because the irrigation schemes are carefully managed, it is relatively easy to determine the area of a given crop grown each year. This can be done by consultation with the farmers or the management of the scheme. The individual fields are of a standard size and do not change from one year to another. These areas of irrigated agriculture are differentiated from all other agriculture which is categorized as rain-fed agriculture.

Mechanized farming

This term is conventionally applied to large farms which depend upon rainfall for crop growth and are operated with agricultural machinery. There is some mechanization in the irrigated areas but the management and reporting of agriculture in irrigated areas is based on the definition given above. Mechanized farming outside the irrigated areas was initially practised only by the Mechanized Farming Corporation (MFC) which was responsible for the operation of large demarcated farms with clear boundaries and regular shape and registered with the government. Other mechanized rain-fed farming (undemarcated) has been established by commercial interests and these areas may not be demarcated nor registered with the government. In such cases it is difficult to determine the precise area under cultivation and even more difficult to determine the amount of a given crop grown each year. These areas produce a substantial quantity of the food grown in Sudan each year.

Satellite data show areas of mechanized farming clearly. Figure 2 illustrates this for an area in Blue Nile Province, east of the Blue Nile. The large field structure is visible and the uniform blocks of land (typical of mechanized farming schemes), geometrically arranged and separated by access roads, provide a clear basis for delimiting areas of mechanized farming.

Traditional agriculture

Western areas of Sudan have large numbers of farmers who till their fields by hand in the traditional manner. The fields are of varying sizes and often the fields cultivated by a single farmer may be widely scattered. In the more arid areas the fields may be interspersed with bushland or woodland and new fields may be created from bushland or old ones abandoned. In any one year a farmer may choose to cultivate only a portion of his fields making it difficult to distinguish newly abandoned fields from those not currently in use. In this situation it is difficult to determine the area planted each year. Figure 3 shows an area of traditional agriculture in North Kordofan, west of El Obeid. The small fields appear as a scatter of lighter patches across the landscape. Defining the distribution of traditional agriculture is not difficult but satellite data do not offer a viable means of determining the area or type of crops grown.

CROP STATISTICS

The provision of reliable crop statistics is an important element in the management of an agricultural economy. Where there is a central marketing system for exports, the surplus crop must be known as accurately as possible. This information must also be available as soon as possible so that firm contracts for sale of the commodities can be entered into at the most advantageous prices. In the case of cash crops this is sound economic practice. In the case of food crops it is important to assess production in relation to the national need. When there is a surplus this should be exported for profit or stored, as policy determines. When there is a probable deficit timely imports of the necessary food are required to offset famine conditions.

Failure to adequately forecast a food surplus can lead to serious problems in marketing and storing food and in supporting prices paid to the farmer. Forecasting a deficit when there is surplus production also produces difficulties in the domestic market. There is a need for timely estimates which are also reliable in order to manage food supply in an agricultural economy. This is especially true in areas such as Sudan where there is wide fluctuation in rainfall and crop production from year to year and where drought and desertification are a reality.

Obtaining crop statistics

It is possible to obtain crop statistics in many ways. An agricultural census can yield general information, but it is expensive, the results may take years to tabulate and it does not provide crop-production figures during the current crop season. More frequently, a sample survey is used which can be conducted over a short period, and, if properly controlled, can yield reliable results. In the case of Sudan such a sample survey must produce two figures: the area of a given crop and the yield of that crop. Both of these figures are subject to variation within a given season and from year to year. Consequently, new surveys are required each year.

Sample surveys

A sample survey produces estimates with a certain accuracy which is a function of the size of the sample and the way that the sample is selected. These factors contribute some error in the calculation of total area or total production. This is sampling error. The conduct of the survey itself produces non-sampling errors such as incorrect recording of the data, incorrect answers to survey questions and other misinformation. Non-sampling errors can be controlled by good quality satellite data, rigorous application of interview procedures and careful editing of the data. Sampling errors can be minimized by using existing knowledge of the population being surveyed. For example sorghum (also called dura) has a yield of about 454kg/ha in irrigated areas, a yield of 256kg/ha in mechanized farm schemes (in rainfed areas) and a yield of 188kg/ha in areas of traditional agriculture.

By taking independent samples in each of the areas it is possible to produce a more accurate estimate than by proceeding on the assumption that all sorghum has the same yield. When stratified sampling is used, more accurate estimates can be obtained with less effort. If the total study area is analysed into agricultural and non-agricultural land, and the agricultural land is then categorized as irrigated, mechanized or traditional agriculture, this creates a stratification of the agriculture. By drawing a sample from each stratum it is possible to estimate the areas of given crops in each stratum. By harvesting small test areas it is also possible to estimate the yield of each crop. From these figures an estimate of crop production can be made for each crop and each stratum.

Selecting a sample

In order to select an unbiased sample, it is necessary to have every possible item available for selection with a known probability of being included in the sample. When selecting a sample for an agricultural survey, the sample can be drawn from a list of farmers or from an area of land. In Sudan, prior to 1986, the survey technique had been to select farmers from a list. However, lists were frequently incomplete and inaccurate, and contained names of people no longer farming or of several individuals who jointly own one plot of land. Cases of mistaken identity and of exaggerated claims to land also complicate the selection of an unbiased sample. In 1986 an area sampling frame was designed to overcome these difficulties.

Area sampling frame

The area sampling frame (ASF) technique is used by the National Agricultural Statistics Service of the US Department of Agriculture and is considered to be a reliable basis for selecting an unbiased sample for survey purposes. This technique requires that all land in a given stratum be available for inclusion in a sample, that the sample be drawn with a known probability of selection and that all land areas included in the sample are recorded for statistical purposes.

Stratification

To achieve this, imagery showing the entire land area was required. Landsat satellite data for the central agricultural area of Sudan formed a basis for dividing the land area into the required strata. The classification used was irrigated agriculture, mechanized farming, traditional agriculture and non-agricultural land.

Sample selection

All the land in each stratum was then divided into Primary Sampling Units (PSUs) which follow physical boundaries and are of approximately similar size. These units are numbered. The area of each PSU is measured and a random selection of the PSUs is made. Probabilities of selection are proportional to area and so every hectare of land has an equal chance of selection. Once a PSU is selected it is further sub-divided into segments. Each of these segments is defined by specific physical boundaries. For the irrigated and mechanized agriculture strata the satellite images can be enlarged to make the definition of segments clear. For traditional agriculture this is done by use of aerial photographs which give the resolution necessary to define segments by tracks, rock outcrops, vegetation boundaries, field boundaries, etc. A random selection of these segments is made and the enumerator visits the selected segments and records the crop type, area planted, area harvested and other information in a questionnaire interview.

Data processing

The questionnaires completed in the field are returned to Khartoum where the Ministry of Agriculture staff in the statistics department edit the forms and code the data before they are entered into computers. After data are entered and edited, the data collected are summarized and estimates are made of total area planted, area harvested and total production.

THE 1986/7 CROP SEASON

In order to provide timely estimates of food-crop production for the 1986/7 growing season the Government of Sudan concluded an agreement for the United States Agency for International Development to provide technical assistance and support for this activity. The Nairobi-based Regional Centre for Services in Surveying, Mapping and Remote Sensing (RCSSMRS) was selected as the contractor for this

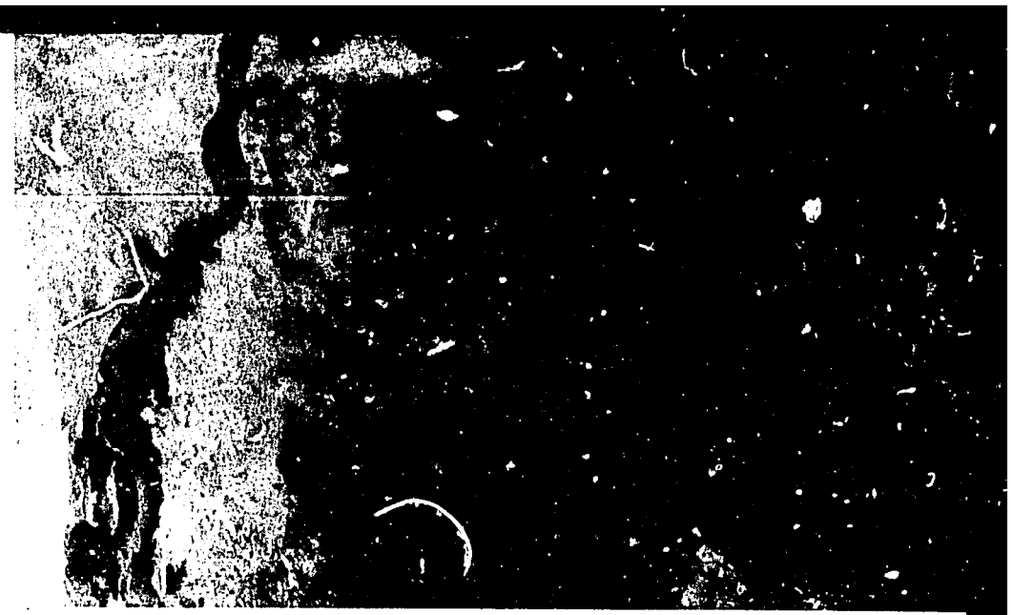


Figure 1
Irrigated Agriculture seen in the Gezira scheme between the Blue Nile (right) and White Nile (left) south of Khartoum. Note the regular field patterns and the strong red colour which identifies the irrigated crops on this portion of scene number Y5059807383X0 gathered by Landsat-5 on 20 October 1985 reproduced by permission of EOSAT.

Figure 2
Mechanized Agriculture in eastern Sudan as seen from Landsat 5 on 7 November 1985. Crops depend on local rainfall and are grown in large fields to facilitate mechanized farming. In this image red colours show vegetation and the cultivated fields in which no crop has germinated appear in blue and green colours, the patterns of large fields are clearly visible in the portion of scene number Y5061607262X0, reproduced by permission of EOSAT.

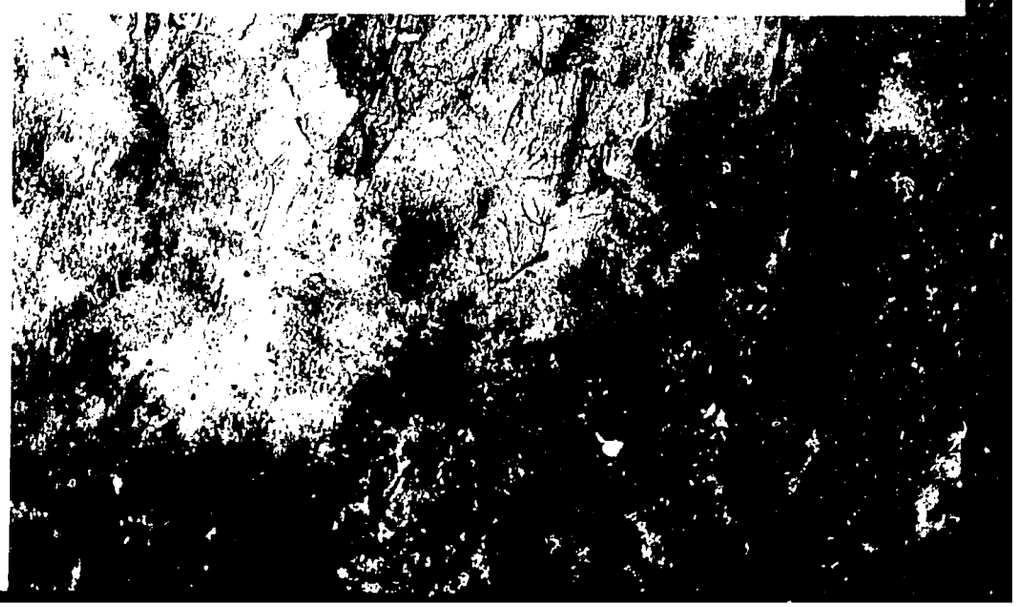


Figure 3
Traditional Agriculture in North Kordofan where the scattered small fields are visible as white dots. Dry vegetation shows in blue green colours and green vegetation as red colours. The crops are hand cultivated, fed by local rainfall and the fields are scattered. Not all fields are necessarily planted each year and not all crops planted are harvested. This portion of scene number Y5093907485X0 gathered by Landsat 5 on 26 September 1986 is reproduced by permission of EOSAT.

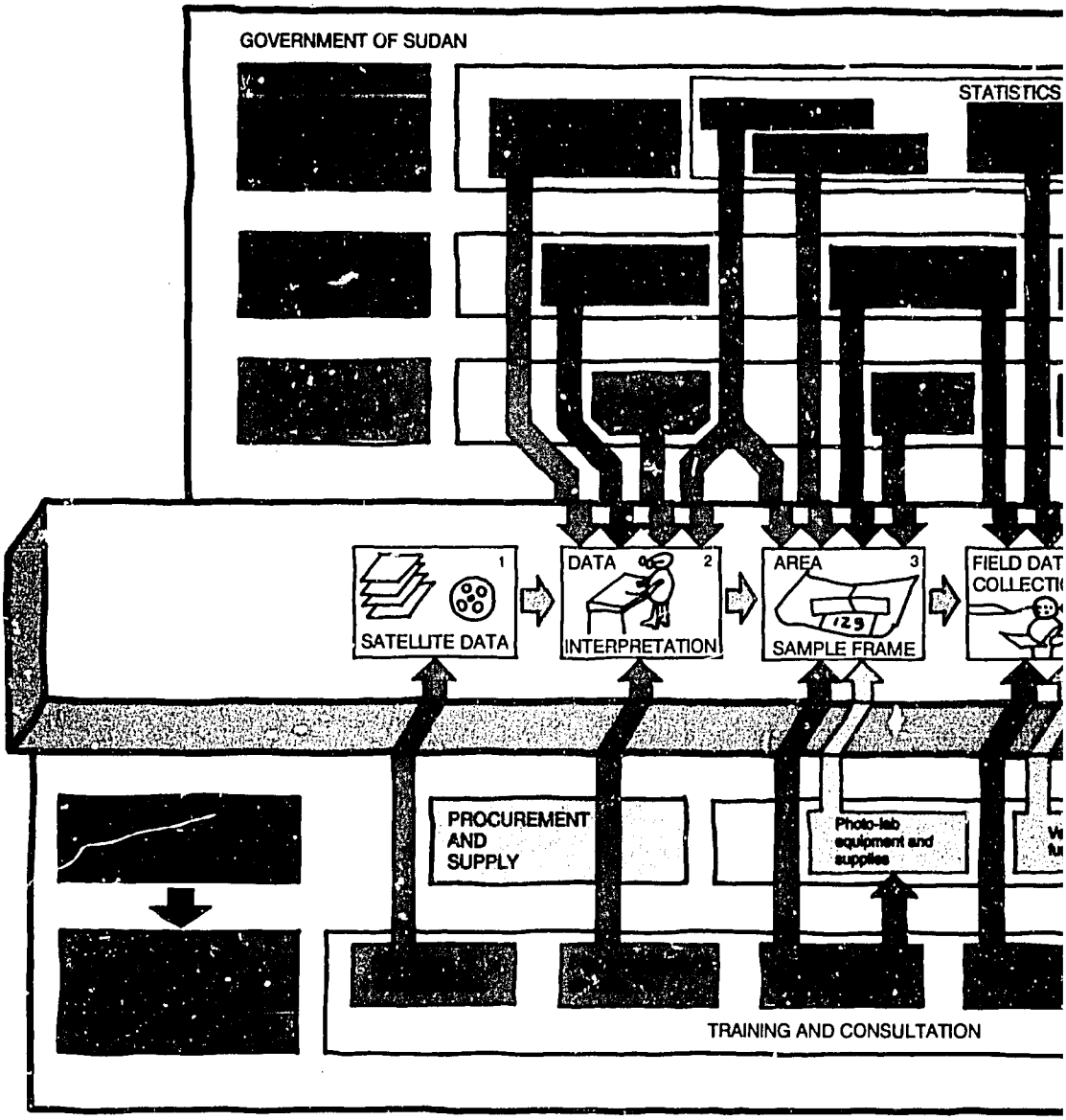


Diagram showing the inputs to the food crop estimation project fr

activity and provided training and consultancy services in remote sensing applications. Data from Landsat 5 were used to create the initial stratification of the agricultural areas.

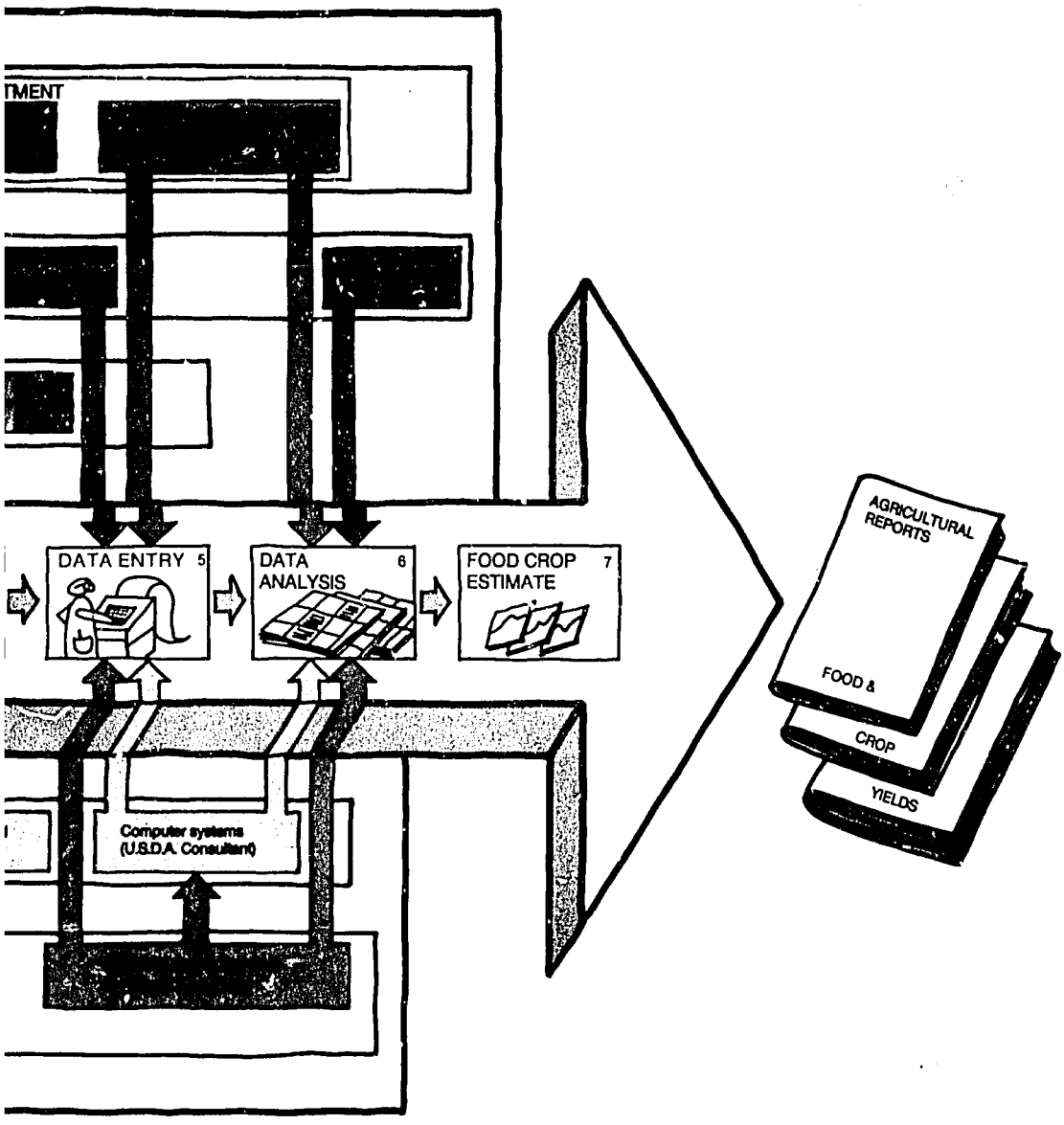
This was done by Government of Sudan personnel from the National Remote Sensing Centre (National Council for Research), from the Statistics Department of the Ministry of Agriculture (MOA) and from the Sudan Soil Survey. This stratification was completed in a remarkably short time and the strata were divided into PSUs. Satellite data were enlarged to scales of 1:100,000 and 1:50,000 for the delineation of PSUs, sampling units and segments in the areas of irrigated and mechanized agriculture.

In the areas of traditional agriculture the field size is too small to be reliably detected by the sensors on the satellite. For these areas the satellite data were used to define the PSUs. The selected PSUs were then photographed from the air by the Sudan Survey Department's aircraft. The aerial photographs were then used to define the sampling units and segments within the PSUs in the area of traditional agriculture.

After the selection of the sample, enumerators were despatched to the sample areas to conduct the survey. Costs of vehicles and operational expenses were met from project funds and Sudan Government funds. The questionnaire used in the survey was designed by the Statistics Department and is reviewed annually. A consultant supplied through RCSSMRS was closely involved with the area frame construction and worked with the Statistics Department in the stratification of the area and the selection of the sample.

When the questionnaires were returned from the field, computer summarization began. In the early part of the season the results gave areas of each crop planted. Initial projections of food production were made on the assumption that the areas would give some expected yield. At the end of the season enumerators determined the area actually harvested. MOA statistics division also conducted crop cutting surveys in important areas to provide yield estimates at harvest.

Crop production estimates issued by the Agricultural Statistics Division of the MOA were based on these figures. Area frame sampling using remote sensing data provides an objective assessment of crop status. In the initial survey of



ncies of the Government of Sudan, the donor and the contractor.

planted area the figures generated by the area sampling frame were compared to available data for verification. In the irrigated areas where detailed management figures are kept, the comparison showed excellent agreement between the sample estimates and the figures provided by the management (see Table 1).

Table 1. Estimates of area under irrigated agriculture ('000 feddans)

Crop type		Area planted (management)	ASF estimate	C.V. of estimate	Sample size
Sorghum (dura)	1	708	704	6%	81
Cotton	2	753	748	5%	76
Groundnuts	3	232	228	10%	55

1. Based on preliminary figures from a sample drawn from the Blue Nile, Gezira, Rahad, White Nile, Gash, Suki and New Halfa schemes.
2. Based on preliminary figures from Blue Nile, Gezira, Rahad, White Nile, Suki and New Halfa schemes.
3. Based on preliminary figures from Gezira, Rahad, Suki and New Halfa schemes.

In areas of mechanized agriculture, comparison of totals showed less agreement. The comparison of the Mechanized Farm Corporation (MFC) figures and the sample survey estimates for the demarcated lands in Kassala and Blue Nile provinces is shown in Table 2.

Table 2. Estimates of area under mechanized demarcated agriculture in Kassala and Blue Nile Provinces ('000 feddans)

Crop Type	Area planted (MFC)	ASF estimate
Sorghum (dura)	2,791	2,236
Sesame	142	197

Figure 4
Preparation of the area sampling frame. A scientist from the Ministry of Agriculture is interpreting a satellite image and defining areas of irrigated, mechanized and traditional agriculture. Each area is divided into sample units.

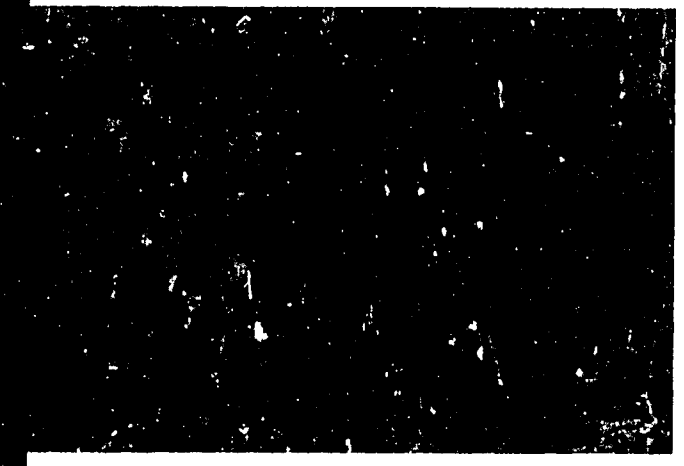


Figure 5
In this illustration a satellite image has been divided into sample units. The sample units in the mechanized agriculture area are numbered in red and sample units in the traditional agriculture area are numbered in black.

Figure 6
An interview team gathering information about crop type, condition and area from the owner of the fields selected from the area frame. The completed questionnaire will be returned to Khartoum and the information entered into the Ministry of Agriculture computer.

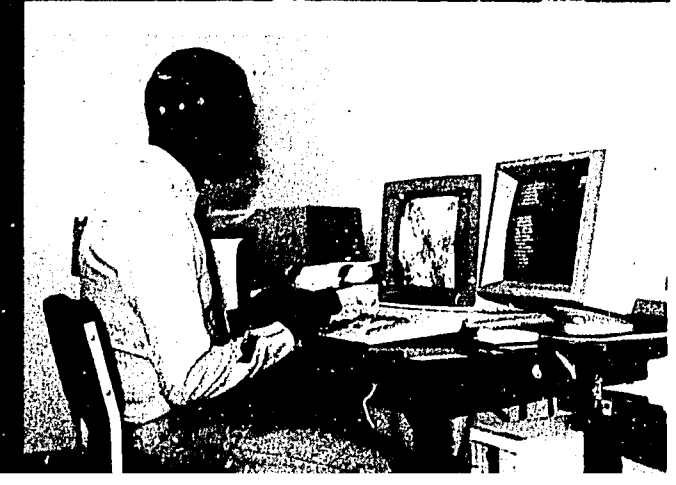


Figure 7
The computers tabulate and analyse the data providing the required statistics for food crop estimation. Computers located in the National Remote Sensing Centre and the Ministry of Agriculture are capable of producing maps of the data and of analyzing satellite images in picture form as shown in the adjacent photograph.

There is a discrepancy between the two estimates obtained from MFC and the ASF. The MFC estimates are not as accurate as estimates for irrigation schemes. For this reason, comparisons must be done with caution. One of the problems is the difficulty of differentiation between mechanized demarcated and undemarcated agriculture on the images. MFC estimates of demarcated agriculture are usually accurate while estimates of undemarcated land are less accurate.

For areas of traditional agriculture there are no accurate data for comparison as the Government figures are generated from visual estimates or sample surveys. Determining planted area is made more difficult by the light sandy soils found in the west of the country. These soils, often with a sparse cover of bush, are common in areas of traditional agriculture. In cases where the land is cleared for farming and the field subsequently abandoned or left fallow, it is difficult to determine if the result is agricultural land or former agricultural land.

Such fields may be remote from settlements and providing an accurate classification of them is extremely difficult. Satellite data do not resolve the problem. The fields are small, and the high levels of reflectance from the light sandy soil give a bright appearance to the whole area making it difficult or impossible to interpret detail with accuracy. This problem is overcome by the use of aerial surveys which give the resolution and the detail needed for the definition of PSUs and sample segments.

In areas of irrigated and mechanized agriculture the soils are darker, humus and moisture levels are higher and vegetation is denser, thus giving overall lower levels of reflectance and greater contrast between vegetation, soils and semi-arid bushland. The field size is much larger than in areas of traditional agriculture and the patterns of the fields, plus the contrasts between cultivated crop and adjacent natural vegetation, are distinctive. Consequently the satellite data of these areas are invaluable for guiding crop assessment work.

CROP FORECASTS

Government crop-production estimates were originally based on inputs from administrative centres and interviews with experienced farmers, heads of villages and local agriculturalists. Statistics Department personnel, with the help of local staff, tour the main agricultural areas to supplement or improve existing information. In 1986/7 the results of the area sampling frame survey were also used. Because of the small size of the sample in the traditional sector, and the large coefficients of variation, it is apparent that the area frame survey in these areas must be strengthened. In particular, the aerial survey of sampling units must be increased so that a more detailed definition of sampling units and segments can be achieved. Aerial photography of a much larger number of PSUs is also required.

The methods of crop survey benefit greatly from the objectivity of the area sampling frame. Once the area frame is in place, and the sample size adjusted to give the desired coefficient of variation, the system should work extremely well.During the 1986/7 crop season the area frame was constructed and used with positive results in the irrigated and mechanized sectors.

The traditional sector proved difficult because the aerial surveys were incomplete. The size of the sample was reduced because the air photos were not available for selection of the sampling units and segments in several areas. As a result, the sample obtained was too small, as shown by the large coefficient of variation. The survey results also indicated that the boundaries of the traditional agriculture stratum required adjustment to allow for fields not in use for crop production in a given year.

Crop estimates 1986/7

Overall the results of the survey were amalgamated with the other information available to give the final crop-production estimates. The total food-crop estimates from the February report of the Statistics Department are shown in Table 3.

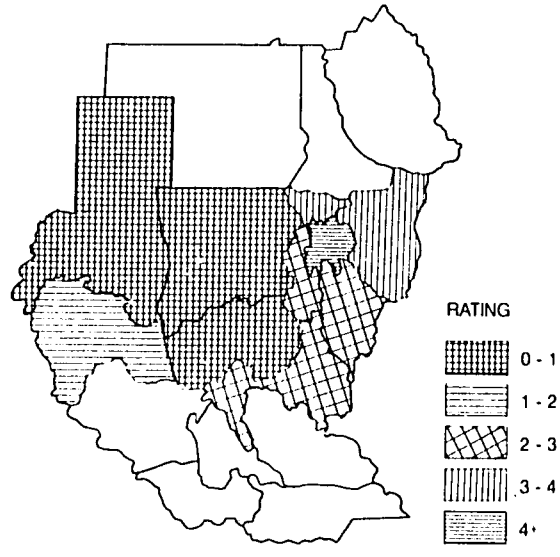
Table 3. Crop-production estimates, 1987/7 ('000 metric tonnes)

	Farming type			
Crop type	Irrigated	Mechanized	Traditional	Total
Sorghum (dura)	459	2,395	428	3,282
Sesame	-	165	99	264
Wheat	147	-	-	147
Millet	5	11	269	285
Groundnuts	186	-	213	399
Total	797	2,571	1,009	4,377

The figures resulting from the survey were matched against food needs and showed an adequate supply of food grains for the year. Because the questionnaire responses are entered into a computer system which has a mapping capability it is possible to present results in map form, which is particularly useful to administrators. For example Maps 1 and 2 indicate the interaction of pest infestation and crop condition. Note the areas in which pest infestation is high and crop condition poor.

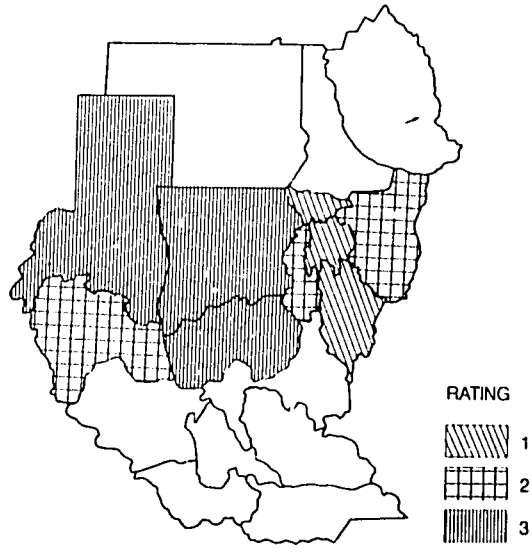
Crop Condition Rating Sorghum 1986/87 season

1 = POOR, 2 = FAIR, 3 = GOOD, 4 = VERY GOOD, 4+ = EXCELLENT



Pest Infestation

1 = BELOW NORMAL, 2 = NORMAL, 3 = ABOVE NORMAL



This view of Khartoum was created by R. Anderson, Photoscientist at RCSSMRS by combining 10m and 20m resolution data from the SPOT satellite, Scene 122-319 22 October and 17 November 1986. Copyright CNES 1987 DISTRIBUTION. SPOT IMAGE

These maps assist the definition of cause and effect relationships. For any and all of these areas satellite data can be perused and crop estimates studied to understand the interaction of terrain type, agricultural practices and crop production. These interactions, and many others, will become more apparent as data accumulate over time. These data from the area sampling frame and the satellite and aircraft remote sensing systems should be entered into the computerized geographic information systems (GISs) in the Statistics Department and the National Remote Sensing Centre. The systems should then produce a whole range of maps comparing information from different years and sources to guide decision taking in such matters as food security and crop protection.

Sudan now has a system for objective estimation of the annual food crop firmly in place. The equipment and staff are available to operate the system which is capable of meeting many information requirements. As the system is used, sample size and sample selection details should be refined in the light of experience. Stratification of the agricultural area may need further elaboration and data gathering and summary should be improved as the system matures. The project has provided a sound basis for this growth.