Crop Monitoring in Morocco Using Remote Sensing and Geographic Information Systems: From a Management Perspective

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ABSTRACT: Since the early 1980s, a quite effective cooperative program has been established between Morocco's Ministry of Agriculture/DPAE and USDA/NASS. The main goal of the cooperative program was to create a new set of probability-based area sampling frame surveys for agricultural statistics. Maps, photographs and satellite images were used to build an area sampling frame in order to further improve the agricultural statistics system in Morocco.

Ten years later, the area sampling frame and surveys were operational and successful in all agricultural regions. The maps, photographs and satellite images were used primarily for land use stratification in a somewhat manual fashion. One management desire was to further automate the process, similar to the Computer Assisted Stratification and Sampling (CASS) system used at NASS in the 1990s. Digital satellite data, image processing systems, and geographic information systems (GIS) make the enhanced automation a reachable goal.

In 1993, a new project called Agriculture Inventories and Monitoring Assessment (AGRIMA) sponsored by the United Nations Development Program (UNDP) with participation from the Director of Programming and Economic Affairs (DPAE) and the Royal Center for Remote Sensing (CRTS) of Morocco was initiated. Over the last several years, this project has been aimed at developing the infrastructure to utilize more remotely sensed data and geographic information systems in crop monitoring and in the dissemination of agricultural statistics. In 1995, USDA/NASS and USDA/ARS also started to participate by providing some technical assistance for the AGRIMA project. The project had several major goals. The first was to use mid-resolution remotely sensed data, such as Landsat and SPOT, to update the area sampling frame for agricultural statistics. The second was to create the infrastructure for compositing coarse resolution vegetative index data for timely vegetation and crop monitoring. The third goal was to build and evaluate agrometeorological yield models. The fourth goal was to develop the database and GIS capability for the above four goals and for future dissemination of official agricultural statistics as well. This paper describes the progress made towards these goals.

1. Area Frame Sampling and Surveys

In 1983, Morocco's Ministry of Agriculture's Directorate of Programming and Economic Affairs (DPAE) entered into a long term cooperative agreement with the U.S. Department of Agriculture's National Agricultural Statistics Service (USDA/NASS) to build a fully operational area sampling frame based survey program. An area sampling frame was constructed (one agricultural province at a time) and probability based samples were drawn. Data collection was conducted and survey data edited and summarized. Survey response rates are very good in Morocco. The area frame program is fully operational and the coefficients of variation (CVs) meet management's target expectations. At the national level for small grains, CVs are in the 1 to 2 percent range. At the province level, they are in the 3 to 10 percent range.

Thus, the AGRIMA project has a fully operational area sampling frame to build on in Morocco. Some of the references on area frame sampling are Houseman [1975], Hanuschak and Morrisey [1977], Fecso, Tortora and Vogel [1986], Cotter and Nealon [1987], Bouzaffour and Merdas [1994], and FAO [1996].

2. AGRIMA Project

Having the established area sampling frame for Morocco, the AGRIMA project staff focused on the more extensive use of remotely sensed data and geographic information systems to further enhance Morocco's agricultural statistics system.

In Morocco, as all over the world, we are always looking for ways to improve geographic information, including agricultural statistics. Scientists have long been aware of the importance of overlaying more than one level of georeferenced information. A large variety of information is available such as tabular data, thematic maps, aerial photos, satellite maps, sample surveys, Censuses, etc., that can be overlaid at the same scale. For decades, the question was how to combine all these data in a homogeneous system for analysis. How can we handle and analyze different data sources to be useful for decision and policy makers? To answer these questions, information technology specialists have created several systems that can satisfy people interested in this domain. Those systems are Geographic Information Systems (GIS) and image analysis systems.

Using GIS and image analysis systems, the AGRIMA program was aimed at using more remotely sensed information and geographic information systems (GIS) technology to supplement the existing crop monitoring and official agricultural statistics systems of Morocco. The following sections of the paper discuss the progress to date of the AGRIMA project and the Morocco Census of Agriculture.

3. Updating the Area Sampling Frame Stratification

The first application of AGRIMA was to utilize U.S. Landsat TM and French SPOT data to update the land cover/use strata for Morocco's area sampling frame, which was established and fixed a decade earlier. Morocco's area frame has used eight land cover/use strata — non-irrigated cropland, irrigated cropland, fruit trees, forests, rangeland, small towns and large villages. Morocco has conducted area frame sample surveys for general purpose agricultural statistics for a decade now. Currently, the major input is 1:50,000 scale maps which are updated by agriculture extension personnel with field visits. The current procedures follow the strict natural boundary rules to the maximum extent feasible, similar to the U.S. area frame for general purpose agricultural statistics, and not just remote sensing applications. Figure 1 shows one map sheet of the area frame.

The AGRIMA project provides the opportunity to test more automated remotely sensed inputs for updating area frame stratification. In fact, DPAE/DSI personnel working part time at the Royal Center for Remote Sensing (CRTS) on SPARC 10 workstations are photo interpreting the eight area frame strata boundaries for several provinces using SPOT imagery. The new strata boundaries are then "overlaid" on a light table with the current area frame (1:50,000) and then the differences are identified. Then, field visits are made to verify which is correct. Corrections are made and stratum boundaries are moved to the nearest natural feature. The final product is then printed at a scale of 1:50,000. The frame for the province of Settat is shown in Figure 2.

Training in image interpretation of DPAE/DSI personnel was provided by staff from the Royal Center for Remote Sensing. In fact, training in area frame stratification procedures was provided to the staff of the Royal Center for Remote Sensing by the DPAE/DSI staff. Thus, an effective partnership was formed to design future area frame updating procedures that utilize earth resource satellite data as an input.

Figure 1. An Area Frame Strata Map, Morocco

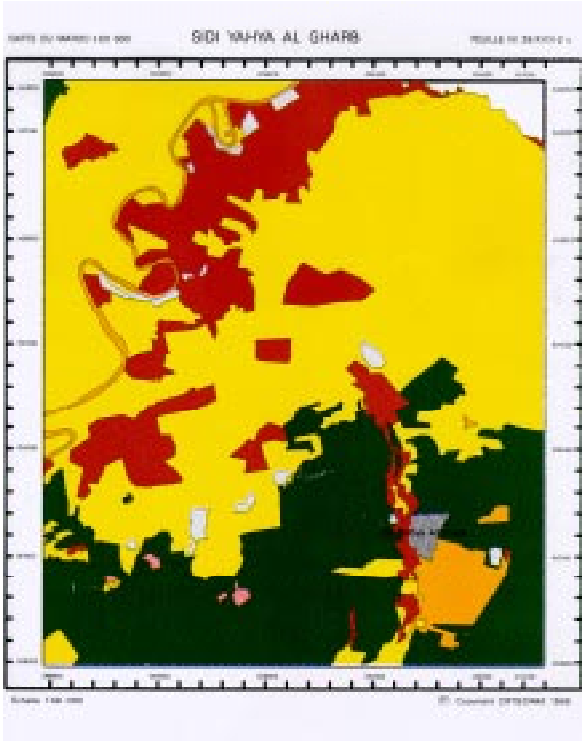


Figure 2. Area Frame for Settat Province, Morocco

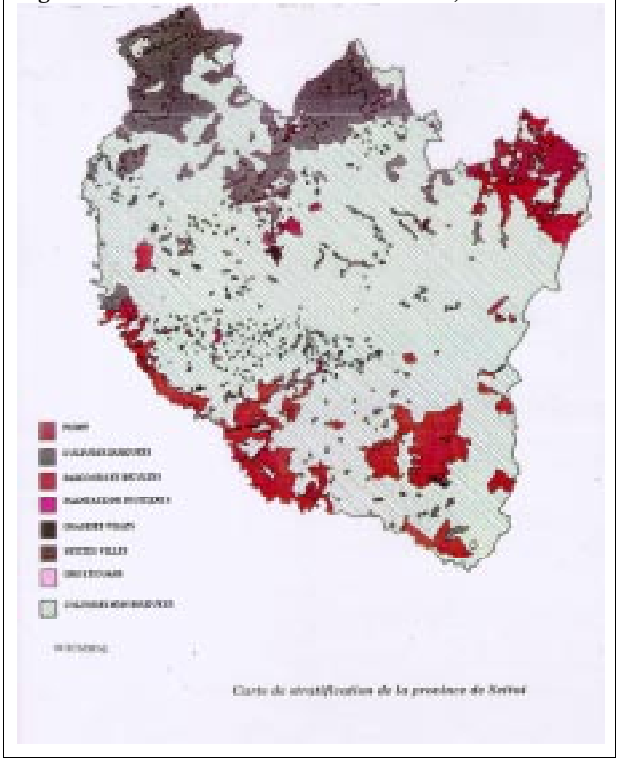
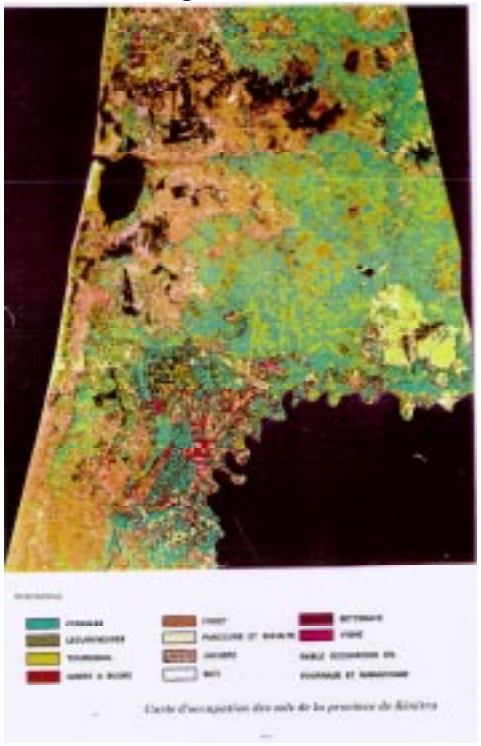


Figure 3. SPOT Image of Kenitra Province, Morocco



This procedure has worked well for Kenitra, a major agricultural province in Morocco, and other provinces are underway. A categorized SPOT image of Kenitra is shown in Figure 3.

The future plan is to overlay the digitized vector version of the original frame with the satellite imagery using GIS and remote sensing image analysis software. One ingredient missing for Morocco is the lack of digital versions of topographic maps, such as the digital line graph (DLG) data for the U.S.. The plan is to overlay the old frame strata and primary sampling unit (PSU) boundaries onto the satellite imagery in a GIS and only update the changes necessary in the strata and PSU boundaries, as well as any new political or map boundaries. Field work can still be used to verify changes that are not certain. However, the manual step of matching and transferring two versions of the frame to one paper map can be eliminated and will thus save labor.

The area frame objective following the AGRIMA project is to prove the process and develop the methodology and technology transfer for digital area frame construction in Morocco. Areas with different topographical features and agricultural practices will be chosen to test the process.

Some other general issues associated with Morocco's area frame are: 1) when has the frame changed enough to warrant redoing the frame and sampling for a province, 2) changing political boundaries, 3) formation of a speciality strata for vegetables, 4) examining point sampling as an option in provinces with non intensive cultivation, and 5) the use of an area frame sample to measure the Agriculture Census coverage.

As regards what criteria to use to decide if a province is due for an updated area frame, there are several. Examining the Landsat TM or SPOT for major land use changes is certainly one method. Another method is to examine the current area frame sample data to see if the sample segments still meet the original strata definition. Also, if the total number of tracts increase measurably, this could be an indicator of urban growth into agricultural areas. Since stratification often provides a rather flat optimum survey, the change in land cover/use should be quite substantial before the financial investment in updating the area frame becomes feasible.

Morocco's original area sampling frame did not have a rotation scheme. It is now desirable to have a rotation scheme. Respondent burden relief and an ability to respond to special survey needs with additional replications are now both desired. A rotation scheme similar to the one used by USDA/NASS will be used in the future.

In recent years, the need for vegetable statistics has increased. In the future, a vegetable stratum will be built into new frames for major vegetable producing provinces. Until then, however, a post-stratification of the area frame sample is recommended. The SPOT data have been useful in identifying major vegetable producing areas. The irrigated and rectangular field patterns aid in locating these areas. In addition, field observers have been locating vegetable producing areas on their maps. This is especially necessary for the smaller, irregularly shaped fields. Thus, post-stratum boundaries can be created for a vegetable domain estimator in the meantime. There is an additional data collection challenge in that some of the fields are used to produce several seasonal vegetable crops during a calendar year.

4. Census of Agriculture

Morocco has recently conducted an agricultural census for the first time in more than 20 years. The Census will supply a nearly complete list of farm operators in Morocco. The list can then be used for

list-only surveys, if desired, but certainly for multiple frame surveys. For multiple frame surveys, a list sampling frame can be developed from the agricultural census. As part of the process, we retain as much information as possible about each operation. This should include information on the size of the operation, the number and type of livestock, and the farmer identification number. All of this information will be useful for list-only or multiple frame surveys. In either case, stratification of the list is highly desirable to reduce variance for the items of interest.

A second part of the agricultural census is to check for any undercoverage. In any census of this size, some farmers will be missed. A good way to independently check the census is by conducting an area survey to detect missed operations. An area survey was conducted to check for Census undercoverage. The traditional area segment design was used for the survey and both the central office staff and the enumerators were familiar with the concepts. The area frame sample was designed for national coverage measures. The agricultural census would probably require more enumerators than were currently on staff. A careful coordination effort was needed to not let an enumerator work both the census and an undercoverage segment in the same area. The independence of the two activities is important.

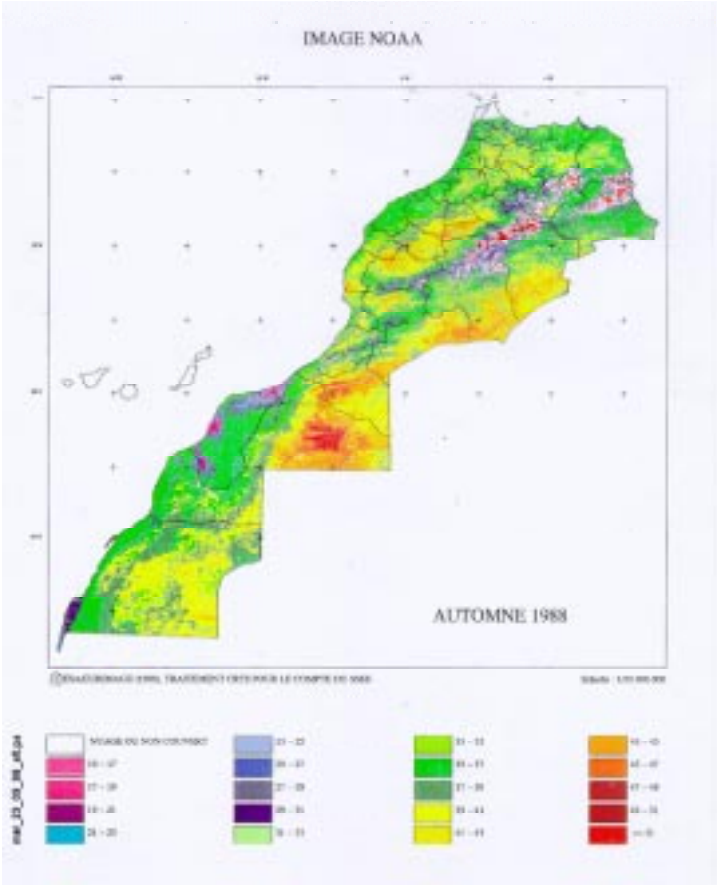
The important volume of data to be derived from the Agricultural Census needs a powerful system to help manage it. The Agricultural Information System (AIS) to be developed will satisfy these needs. Integrating this large amount of information in a cartographic system needs the use of new technologies of information management. This is of a great help to draw samples at any moment and analyze them in an easy and interactive way by statistics or cartographic software.

5. Vegetation Condition Monitoring

One of the goals of AGRIMA was to develop the infrastructure necessary to monitor vegetative condition across large areas using polar orbiting weather satellite data, such as from NOAA's AVHRR sensor. Morocco initially had difficulty in obtaining AVHRR data in a timely fashion from third party providers. The Royal Center for Remote Sensing made the decision to build a receiving station for NOAA AVHRR data, and similar future sensors. They have invested the funds and staff to build a receiving station and data processing facility for Morocco. This staff and facility will enable Morocco to assemble timely composites (7 days, 10 days, 14 days, etc.) of a Normalized Difference Vegetative Index (NDVI) for the AVHRR data. One nice feature for Morocco is that one AVHRR scene covers the country, thus eliminating the need for mosaicing. Since a major concern in Morocco is early detection of drought conditions for rainfed small grains, vegetative index monitoring will be a useful addition. Initially, the vegetative index maps will be used for qualitative viewing of crop areas during the season, such as those currently displayed on USDA/NASS's Internet Web Page, *www.usda.gov/nass*, using the Statistical Research icon [Allen et al. 1994].

Another use of the AVHRR NDVI data is to show broad land cover/use theme maps at the national and regional level similar to the USGS's [Loveland et al. 1991]. Of course, the number of categories and the accuracy is limited by the 1.1 kilometer resolution. However, for relatively quick "annual" looks at Morocco's broad land cover, it is quite feasible. National AVHRR coverage for the "surface temperature is shown in Figure 4.

Figure 4. Surface Temperature, Morocco

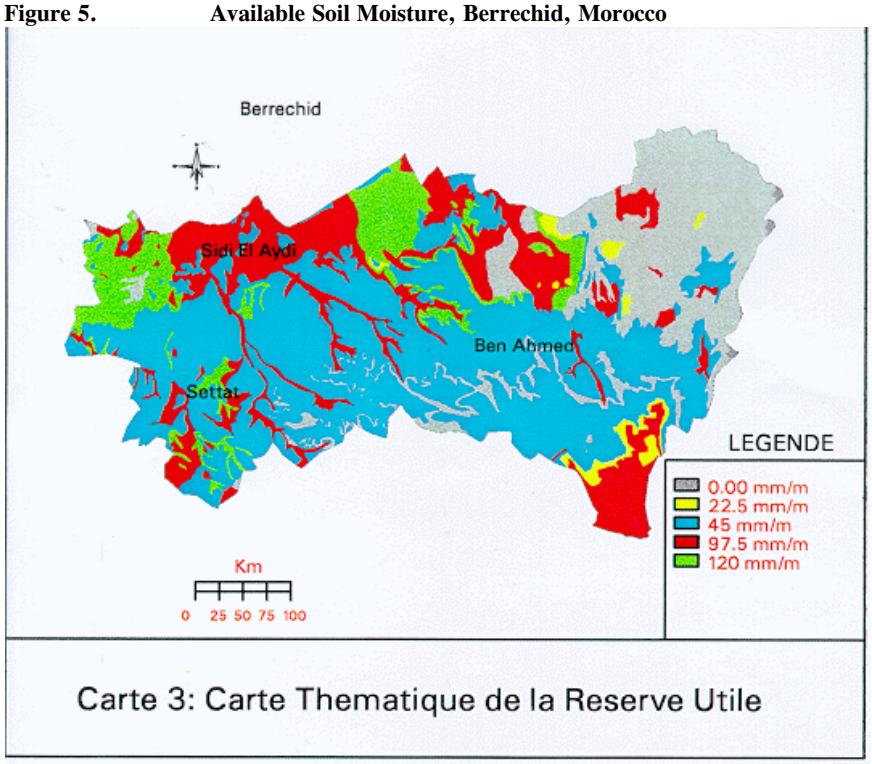


6. Crop Yield Forecasting

Early season crop yield forecasts remain a serious challenge around the world. The major reason is that in some crop seasons there is substantial variation in yield potential between the early forecast period and the final yield at harvest, due to weather, insects, diseases, etc. However, building the data base of related factors, such as conventional agricultural statistics forecasts, data from extension agents and farmers, weather station data, and related models such as plant water stress and NOAA NDVI data, various model outputs can be calculated and compared to the final crop cutting data and official estimates from DPAE/DSI. The long term goal is to increase the accuracy of the early season forecasts. Measurable improvements in the early season forecasts would be quite beneficial to the economy and import/export decisions and plans of Morocco.

The Agricultural Institute in Rabat, the Royal Center for Remote Sensing and USDA's Agricultural Research Service are involved in defining and testing agrometeorological crop yield models at the province level. The models are similar to those from the U.S. LACIE and AgRISTARS programs, follow-on work [Tayaa et al. 1996] which describes the Morocco situation and modeling approach, and the use of NDVI in spring wheat yield modeling in the U.S. [Doraiswamy and Cook 1995]. One of the calculated model inputs, available soil moisture, is shown in Figure 5.

Figure 5. Available Soil Moisture, Berrechid, Morocco



The models use meteorological inputs from ground stations and some from meteorological satellites, soil types and texture, plant growth processes and measurements, and remotely sensed vegetative index data. Results so far indicate some promise for early season yield forecasting. However, DPAE/DSI is not an operational user for such models. DPAE/DSI relies on farmer reported yields and objective yield data as inputs to their official yield statistics.

7. Crop Acreage Estimation

Morocco currently conducts an annual area frame based sample survey, which is the primary input to official statistics on major crop acreage. This method is quite satisfactory for major crops.

However, the AGRIMA project wanted to examine mid-resolution remotely sensed data as a supplement to the area frame ground data sample approach. USDA/NASS has used a regression estimator approach for such purposes on a limited basis in a number of States, since 1978 [Allen and Hanuschak 1988, Craig 1993]. Even in the U.S., the cost/benefit analysis results of this approach, at the state level, has been debatable at times. However, the wall-to-wall categorization of Landsat TM data also enables the calculation of county level estimates of crop acreage with measurable statistical precision, as well as for new areas of interest such as watersheds and river basins. In addition, spatial maps of those areas, showing where the crops of interest are as well as the total acreage, are provided to a variety of interested data users. These features enhance the cost effectiveness of processing the satellite data for agricultural data users.

In the U.S., the operational general purpose (number of farms, size and type of farms, livestock inventories, crop acreage, census coverage statistics, etc.) area frame sample has been in place for

several decades. Thus, the regression estimator was built on top of the existing investment in a general purpose area frame sample. In general, if a country does not already have a mature area sampling survey program for general purpose agricultural statistics, then the regression estimator would likely be cost prohibitive.

In Morocco, plans are to test a double sampling approach because of cost concerns. A sample of SPOT scenes and the area frame sample ground data can be used to calculate a double sampling estimator for a test in a major crop producing province. While the double sampling estimator will cost less, the wall-to-wall benefits are also lost. It will be interesting to see if Morocco can afford either type of estimator on an operational basis. If satellite data (categorized) can be shared among several user agencies, then the cost per agency becomes more feasible for operational implementation.

8. Database and Geographic Information System

The Royal Center for Remote Sensing is building the GIS and remote sensing analysis infrastructure necessary for DPAE/DSI to expand its use of these technologies. Plans were developed and are now being implemented for a GIS and remote sensing analysis system for Morocco to support agricultural statistics and crop monitoring activities. The staff of the Royal Center for Remote Sensing is building an "enterprise GIS" for DPAE/DSI. An "enterprise GIS" is an application(s)-specific GIS that is easier and more user friendly to operate. It is being designed and built to service end users (primarily agricultural statisticians and economists and area frame personnel) at DPAE/DSI. An "enterprise GIS" increases the chances for a successful GIS implementation in an organization (other than cartographic institutions), as compared to a general GIS software distribution to end users. End users will often not be adequately trained to create specific GIS applications from a complex general purpose GIS, but are highly qualified to run GIS applications designed to meet their needs and in a considerable more user-friendly fashion. Inputs to Morocco's "enterprise GIS" for agricultural statistics and crop monitoring are: soils data, meteorological data (ground and/or satellite based), remotely sensed data such as SPOT or Landsat TM, area sampling frame strata and PSU boundaries, and conventional official agricultural statistics at different geographic levels. DPAE also plans to use GIS for dissemination of agricultural statistics [Hanuschak, Wade and Craig 1997].

9. Conclusions and Summary

The AGRIMA project has increased the capability of utilizing more remotely sensed data and GIS products to supplement the existing agricultural statistics system in Morocco. An effective four way partnership was developed with United Nations Development Program (UNDP), Morocco's Royal Center for Remote Sensing and Department of Agriculture and Environment, and the USDA participating in the AGRIMA project. Each party provided unique resources to the AGRIMA project. However, the critical two way partnership between the Royal Center for Remote Sensing and DPAE/DSI was the most essential for continued progress in Morocco.

An effective partnership was developed between these two well-matched organizations in Morocco. The DPAE/DSI has a mission to provide timely, accurate and official agricultural statistics for Morocco and the Royal Center for Remote Sensing has extensive staff expertise and appropriate equipment for remote sensing and GIS projects. The partnership enables a strong joint effort to utilize more remotely sensed data and GIS applications as a future supplement to the agricultural statistics system of Morocco. UNDP provided the needed funding and USDA provided some part-time consulting on remote sensing and GIS.

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