THE UTILITY OF REMOTE SENSING IN AGRICULTURAL STATISTICS

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1. ABSTRACT

Remote sensing products in many forms have proven useful in agricultural statistics systems. These products range in complexity from low level, black and white aerial photography of small areas to satellite based digital scanner data of whole countries. Agricultural estimation techniques based on remote sensing usually combine remotely sensed data with current ground collected information. Both aerial photography and image products produced from LANDSAT digital data are utilized on an operational basis in the construction and stratification of area frames for statistical sampling.

Photo interpretation of remotely sensed images can sometimes be used as ground truth for agricultural statistics applications. Computer classifications of entire images, based on relationships between ground truth information and satellite scanner digital data for known areas, provide auxilliary information on the entire population from which the sample was drawn.

Keywords: Remote Sensing, agricultural statistics, area frame sampling

2. BACKGROUND

One of the most difficult papers to prepare is one which has such a broad all-encompassing title as this one. It is not possible to cover all examples of remote sensing that have been or will be a benefit to agricultural statistics and this paper is not intended as an inventory of all applications. Instead, an attempt is made to categorize the different types of utilization of remote sensing products for agricultural statistics purposes and to discuss the advantages and disadvantages of each approach. The goal is to assist the reader to plan future applications or to better understand information being created in present applications of remote sensing.

Utility is defined as usefulness or power to satisfy people's wants. That is a good definition for the proper use of remote sensing techniques. Remotely sensed products do have an ability to satisfy many agricultural information needs. However, it is important to realize that a proper mechanism for extracting information is important. Having a collection of aerial photographs or satellite images if there is no way to extract or quantify information results in what some people refer to as just "a bunch of pretty pictures". Therefore, this paper will concentrate on those applications in which remote sensing was appropriate and for which a technique was available for converting the remote sensing data into useful and reliable information.

Most examples discussed in the paper are related to crop area statistics. Estimation or forecasting of yield by remote sensing techniques is a much more difficult problem than area estimation and most breakthroughs in yield statistics will likely come from computerized yield models which may or may not involve remotely sensed data inputs. Although examples cited are mainly for crops, many of the same techniques are directly applicable to forest statistics.

Examples cited are mainly based on work in the United States. This is not to imply that there are not examples of utilizations in other countries. Through exchanges of research and operational procedures in forums such as this symposium, agriculturalists have learned from each other and similar applications can be found in many countries. Examples cited are ones most familiar to the author and included only because of that familiarity.

3. ESTIMATES DIRECTLY FROM REMOTELY SENSED DATA

Remote sensing in the form of aerial photography has long been valuable to agricultural statisticians, as well as others interested in agriculture. In some instances, aerial photography can be utilized directly to form the basis for an estimate. Fruit surveys which are based on production per tree or on estimates of the total number of bearing trees of particular crops can often utilize aerial photography to cut down the workload of identifying all orchards and particularly to monitor changes over time.

Aerial photography can be used directly in a situation in which knowledge of planted area in particular land covers is necessary and total planted area is either not known by farmers or, due to some legal requirement, the farmers must certify what acreage has been planted. The broadest application of measurement of crop acreage from photography is probably the procedures utilized by the Agricultural Stabilization and Conservation Service (ASCS) of the U.S. Department of Agriculture .ASCS has a requirement to certify the amount of acreage planted to particular crops in order for farmers to qualify for farm subsidy programs. Farmers are required to indicate fields, crops and planted acreages. Previous procedure involved a subsampling of fields for visits to determine acreage using measurement chains or other devices.

This procedure has been replaced for the most part by one in which most agricultural counties are flown with fairly low level photography using 35mm color film and the photography is developed as color slides which are utilized in the local county offices. ASCS needs very precise accuracy for the field area measurements. They have contracted with a company to adapt a digitizer to their needs. The digitizer calibrates each slide to a rectified photograph of known scale, eliminates the aircraft distortions in the current photography, and automatically calculates the total area of each field digitized. Controlling the photography at the local level with all of the measurements and work done in the local office has proved to be operationally effective for ASCS. ASCS indicates that they are able to verify the acreage on three times as many fields for the same cost as when all work was done by in-field measurements.

It is important to point out that ASCS office personnel are not trained photo interpreters as such. The farmer has already indicated which crop is planted. If the appearance on the photograph does not match up with other fields of the same crop the person making the measurements can spot that discrepancy and have the crop verified but they are not attempting to do all of their identification of crops from the photography as such.

The examples above related to location of fields or orchards and determination of total area or total tree numbers from a remotely sensed product. Below are some examples of using remotely sensed interpretations for crop identification and statistical expansion. Both types of direct use have the same advantages and disadvantages.

Using aerial photography as a direct survey tool allows coverage of a broader area than would be possible with ground based crews only. This can result either in coverage of a wider area with the same number of people and the same time frame or in accomplishing a particular operation in a shorter time frame. Statistical sampling designs can be developed with aerial photography collected and interpreted for only a sample of the total area but results expanded to area totals. Aerial photography based interpretations provide hardcopy products for later quality control and editing investigations and for observing changes in repetative surveys. (If aerial observation is used instead of aerial photography the documentation feature is lost but the other advantages above still accrue.) Where aerial based interpretations are feasible, there is a great advantage from reducing the burden on respondents and avoiding problems of respondent reluctance to participate in a survey.

One of the most obvious disadvantages of aerial based interpretation surveys is cost. Planes, pilots, equipment and supplies are needed for the data acquisition as well as a facility for timely processing of the imagery. Trained interpreters are needed for most such applications. If a quick turn around is desired for a survey the schedule can be affected by weather problems. Even in good weather there may be interpretation problems due to of differences in photography at various times of day or processing variations. Another important disadvantage is the problem of adequately covering or sampling a very large area with an aerial based approach. Considerable care is needed in selection of a proper design, verification that data collected were for the correct sample, and that expansion of data has been done properly. The design must provide for proper measurement of photo interpretation errors and interpreter variations.

There are examples in which aerial photography or aerial interpretation have been utilized directly to form an estimate. One very effective procedure was developed in the grape growing area of California, USA.(Ref. 1) A large portion of the grape production in this area is of a multi-purpose grape which can be dried for raisins or be harvested for fresh or wine usages. The industry was interested in very timely estimates of the quality of grapes which had been harvested for raisins. When grapes are harvested for raisins they are placed on large trays and set out to dry. A sampling plan was established in which flight lines were established statistically across the producing area. These flight lines could be flown and photographed during one day's time. The photography was developed immediately and that evening interpreters observed the photography and identified the crop and condition at each designated sampling point. If the crop was grapes an interpretation was made as whether trays of grapes were present or not and the total number of trays. These data were summarized and an estimate of the total amount of grapes harvested for raisins up to that date was available within 24 hours.

Similarily, current photography, or for the most part, interpretation from small aircraft or helicopters has been utilized to fly sample points in order to formulate an estimate of potato acreage. Again this approach again was satisfactory and was used when there was no other statistically valid survey information present. However, this approach has been replaced by an area sampling approach in which farmers are interviewed within designated areas of land and potato fields identified from that process.

4. USE OF REMOTE SENSING FOR AREA FRAME CONSTRUCTION

One approach which may be overlooked in terms of utility for agricultural statistics is the utilization of image products in the development of sampling frames. Since it is rarely possible to conduct a complete census of any agricultural commodity in a timely fashion, proper sampling is the key to good agricultural statistics. Sampling of area frame units is often a preferrable approach to some type of list sampling.

The advantages of area frame sampling are that all units can be identified, true probability samples can be selected, and frame units do not move or leave the total population. Associated advantages are that, if good boundaries are utilized for sampling units, interviewers can relate data to each unit very accurately and it is often possible to overcome problems of a non-literate population or situations in which farmers do not know the total area planted. The disadvantages of area frame surveys are the cost associated with visiting sampling units and the cost of constructing the sampling frame.

An area frame can be constructed from a variety of map or photography products depending upon what materials are available. However, LANDSAT data images have proven to be particularly valuable for the preliminary area frame construction steps. (Ref.2) LANDSAT images provide broad area coverage in one product. They provide much more detail than do most maps. LANDSAT images are preferred over aerial photography mosaics because photography quality variations and confusions added in the mosaicing process are avoided. LANDSAT products are usually very timely while map or photography coverage of an area may be quite outdated and fail to include information on recent land use changes. It is also possible to compare LANDSAT images for multiple dates if needed to best determine land uses.

estimate. One very effective procedure was developed

The disadvantage of LANDSAT imagery for area frame construction is that only major land uses can be broken out and precise boundaries can not be identified on the images. However, combining LANDSAT images with other, higher resolution products can overcome the boundary definition problems.

e basic concept of area frame sample is to divide the total universe (total area) into sampling units and then select a sample from this complete collection. However, the approach is simplified and the workload of constructing a frame greatly reduced by performing the delineations sequentially and avoiding the need to draw boundaries for each and every sample unit. Sampling is commonly a three step process. The first step in achieving statistical efficiency is to divide the land area into strata or homogeneous land uses. That is, the area is divided into general categories based on percent of cultivation or type of agriculture. The total area is divided, including those areas which have little or no agriculture, since it is important to develop a complete frame. Within each strata a two step approach is utilized in which the first delineation is drawing the boundaries of clusters of sampling units.

A typical cluster might be of sufficient size to contain an average of 5 or 10 actual sampling units depending upon the overall sampling rate which is expected. Once all of these clusters have been defined the total number of sampling units can be calculated. A sample is then drawn which identifies those clusters in which sampling units will be selected. For each selected cluster all sampling units in that cluster need to be delineated and one sampling unit randomly selected. Properly done, this two step process within strata can easily eliminate 75% or more of the precision work needed in developing an area frame.

Area frame survey procedures do not necessarily utilize ' remote sensing techniques after construction. The roach of using LANDSAT images in the first stage of area frame construction has been used in the past few years to develop area sampling frames in Morocco, the Philippines, Thailand, the Sudan, Jamaica, Costa Rica, Zaire, and several other countries. In most of these countries no consistent programs for current agriculture statistics existed and the area frame approach was important in developing an agricultural information system for the country.

LANDSAT data has been utilized in the United States for the updating of area frame samples for a number of states in the last 5 years. A recent application of use of LANDSAT data was the examination of several dates of imagery along with other information such as soils data to construct a very finely stratified frame for improving estimates of planted area of one particular crop (dry edible beans).

One other area frame use of remotely sensed data is as a data collection and recording tool. In the United States field interviewers utilize large scale rectified aerial photographs (a scale of approximately 1:8000) for recording sampling unit and field boundaries. This photography, available from another Agency, insures a high measure of quality control in the survey.

5. EXPANSION OF GROUND TRUTH THROUGH REMOTE SENSING

The Statistical Reporting Service (SRS) of the U.S. Department of Agriculture has developed techniques and is evaluating procedures for improving the precision of major crop area estimates by utilizing LANDSAT multispectral scanner data. (Ref. 3) Ground truth from the randomly selected area frame is used for training and again for the crop estimation formula. Requirements for the SRS approach are that fairly large fields (10 hectares or larger) must be available for training, the crop to be estimated must be present in most sampling units within a LANDSAT scene, and imagery must be available during peak growing season stages in order to properly discriminate between crops. There also must be an ability to obtain accurate ground to satellite data registration (target accuracy is plus or minus 1/2 data pixel). This accuracy of registration is needed in order to obtain a pure training set for correlating satellite data with ground data.

The advantages of LANDSAT data for this purpose is that each scene provides coverage of a wide geographic area, multiple bands of data are available for each pixel, data are available in a digital format for data processing, and image products allow evaluation of digital data before processing. Because of the area frame survey approach just described, processing of the LANDSAT data results in statistical estimates with calculatable precision.

The SRS approach is one of selecting a sample of known ground data fields for training at random from all sampling units available in the scene. Multivariate techniques are used to define clusters of data present for each known crop or land cover of interest. Once the clustering is finished all pixels are classified. Classification of all pixels in the sampling units in the scene which were surveyed provides information between ground data and classified satellite data. The key variable is not pixel to pixel classification accuracy but is the correlation between crop area and numbers of pixels classified into each crop at the sampling unit level. This information is used in a regression estimator or for the scene (or the satellite pass) that is being analyzed. The classification of all pixels within the scene or the pass gives the average number of pixels classified into the crops of interest per sampling unit. The relationship between the average number of pixels classified into a crop in the sample of sampling units visited versus the average number for all sampling units in the scene provides an adjustment factor for that scene. Thus, if the random sample of ground sampling units was not totally representative of the entire area the expansion approach enables an adjustment of that estimate.

If there is good correlation between satellite data and ground data, the variance of this combined crop area estimate is reduced. With good quality satellite data during the growing season SRS has experienced results equal to the precision obtained by collection of 3 or 4 times as much ground data as are presently collected in the regular survey. Refer to table 1 for comparison of results.

There are, of course, limitations to this approach. As mentioned above, fairly large fields are needed because the training approach uses only "pure" pixels (those within field boundaries) for training. Thus, the size of field needed for training is related to the spatial resolution of the satellite. Higher resolution imagery available in the future will allow the use of smaller fields for training, and perhaps enable the improvement of estimates for minor crops. A second factor which is often a limitation is that prime agricultural areas usually have considerable moisture and cloudy conditions during the growing season. The presence of clouds, coupled with the rather long repeat cycle of the present LANDSAT series, means that satellite coverage of many prime growing areas might be missed during a ·ticular season. The SRS approach does still enable a .l probability estimate since areas lost due to cloud cover are estimated for by the probability ground data from the regular SRS area frame survey.

Timing of estimation from this SRS approach depends upon obtaining satellite data during the midst of the growing season. Therefore, the satellite is not helpful for an early season estimate, although this estimate can be generated from the ground data survey itself. Once satellite data is obtained, the process to properly register it to ground locations, to conduct training, and to perform all the steps of analysis is a somewhat time consuming procedure for large areas. Care must be taken in each stage to be sure that operations are properly done. Presently, these procedures are best implemented if a very large computer is utilized for classification, but smaller computers can be used if the data can be somewhat subdivided for classification and if more time is available for creating the computer runs.

6. INTERPRETATIVE USE OF REMOTELY SENSED DATA

The discussion and examples above have all dealt with situations in which ground data were available for training and calculation of agricultural statistics estimates with known sampling errors. There is another set of approaches which might be called "interpretative" uses of remote sensing.

In interpretative utilizations no ground data are available for training or some data are available but not ·tatistical sample of the area of interest. The ·otely sensed data are examined and estimates are made by photo interpretation type determinations and area calculation or by machine expansion, in the case of digital data.

This interpretative approach is useful in a situation where remotely sensed data are available on a recurring basis but ground data for training is not possible. In the case of satellite collected data, a transformation such as the Kauth-Thomas approach can be used to standardize responses on different dates of imagery. This standardization adjusts for most of the atmospheric differences between dates and allows an interpretation of relative "healthiness" between two dates or of differences in planted acreages.

Interpretative approaches are particularly applicable in a mono-culture situation or in an agricultural area where there is one major crop and the percentage of that crop to total planted area does not vary much from year to year. In those situations, the key interpretation is one of "crop or non-crop" and there is not a requirement to try to identify particular crops within the study area. This approach was the main basis for wheat acreage and condition estimates out of the Large Area Crop Inventory Experiment (LACIE) Program in the United States. (Ref. 4)

It is important to point out that remotely sensed data, such as LANDSAT data, can be statistically sampled for interpretation purposes. This will help improve the judgements made from the data but if no ground data are available for training or testing the resultant estimates ·ot probability estimates since sampling errors are ·valid.

If the interpretations made are of condition or potential production levels during the growing season the key element is availability of coverage. For this reason the Early Warning/Crop Condition Assessment (EW/CCA) Project of the Agriculture and Resources Inventory Survey Through Aerospace Remote Sensing (AgRISTARS) Program has explored the use of meterological satellite data as a supplement or possible replacement for LANDSAT data. The EW/CCA approach is one of "indexing" data based on a vegetative index transformation over a geographic grid. Even though the resolution of metrological data is much coarser (one kilometer versus 80 meters) than LANDSAT data, since data are converted to an index value anyway the coarser data can be easily substituted. The meterological satellite data can be available on a much shorter repeat cycle which is a important consideration in the EW/CCA desire to monitor crop conditions and stresses.

In addition to the inability to calculate sampling errors from interpretative approaches there are other drawbacks. If no transformations are made to the data, direct interpretation is very heavily affected by atmospheric differences from date to date. Misinterpretation can easily result from differing levels of haze or illumination of satellite data from two different dates.

If an interpretative approach is used no valid estimate can be made for areas which are cloud covered on a particular pass. In these cases the approach is normally to expand interpretations from the non-cloud covered areas for thoses cloud covered but this will add an additional bias to any estimates created. This varies from the ground training data approach above in which the area frame data provided an independent estimate for clouded areas.

It may be necessary to combine several dates of imagery in order to make a proper interpretation. For example, if estimates of winter wheat are desired in the Spring the "healthiest" fields may be obvious in the first images available but fields of poorer stands may be later to "green up" and might not be detected through early season interpretation. If random ground data are available the fields of poorer stands would be represented by additional clusters of wheat and would be included in the early season estimate.

The other drawback to interpretative approaches is the heavy labor input required for most techniques. In spite of automation efforts success still depends on individuals reviewing image products to "identify" fields of the desired crop or condition level. A high skill level in terms of knowledge of the agriculture cropping practices in the area studied is also required in order to make best use of the approach.

7. FUTURE SENSORS FOR AGRICULTURE STATISTICS

Great things have been predicted for agriculture in the future from new sensors and new satellites. Satellites such as the French SPOT series and LANDSAT D with its Thematic Mapper will offer new opportunites for improvement of agricultural statistics. These developments offer more spectral bands, bands perhaps better suited to interpretation of agricultural targets, and much finer spatial resolution. Each of these factors should be helpful but they may also require some new approaches to take advantage of them.

The Thematic Mapper (TM) to be aboard LANDSAT D offers improved ground resolution (30 meters versus 80 meters) over LANDSAT multispectral scanners (MSS) on earlier LANDSATS or the one aboard LANDSAT D. TM bands provide wider coverage of the electromagnetic spectrum then do the four MSS bands. TM also has [illegible]ter radiometric precision (256 usable levels versus [illegible]) than MSS data. There are also better geometric parameters such as detector-to-detector and band-to-band registration (Ref. 6). Each of these advances may be of value to agricultural statisticians. Sigman and Craig (Ref. 5) found in a Thematic Mapper Simulation study a three-fold improvement in statistical precision over using MSS data for corn acreage estimation. In the same study, precision improvement for soybean acreage (for which MSS performed better than for corn) the improvement factor was 1.4. The improvement for corn came from the interaction of the effects of the increased number of bands and the increased spatial resolution. The soybean improvement was primarily due to the increased resolution.

The instrument package of the French SPOT satellite series to be launched in 1984 offers another advance in resolution over even the TM. The three multispectral bands of SPOT will have 20 meter ground resolution (at nadir) and the panchromatic mode will have 10 meter resolution (at nadir). The SPOT satellite will also offer the opportunity to obtain off-nadir observations to increase the frequency of coverage of important ground targets or to acquire stereoscopic pairs of images. The SPOT instrument will utilize a linear array of solid state detectors which collects data without mechanical scanning.

SPOT offers some very interesting new possibilities for agricultural statisticians. The improved resolution and the stereoscopic feature may allow the utilization of SPOT data as "ground truth" for some applications. T[illegible] features will particularly be of value to those in[illegible]ested in forestland inventories. Since losses of data due to cloud cover is the major limitation to the SRS approach described above for improving sampling errors of major crop area estimates, the pointable feature of SPOT might be used to increase the likelihood of coverage of sample units.

However, the new advances in sensors will necessitate research into new procedures to best utilize these features. The improved resolution of the TM aboard LANDSAT D means an increase of 5.7 times the MSS data rate. Few data users currently handle entire scenes of LANDSAT MSS data and some users may presently be "locked in" to processing systems that are set up for only a fixed number of pixels. Users will need to carefully evaluate their processing needs and decide what adjustments should be made. The adjustments may not be obvious. For example, the Statistical Reporting Service already has the capability for handling up to eight channels of satellite data and has access to a large mainframe computer which should be able to process entire frames of LANDSAT TM data. The higher resolution of the TM will most affect SRS's small scale processing for training and testing against ground data which is currently performed on a much smaller mainframe computer. The result may be that only a sample of TM data will be used for training and estimation (some research of these procedures has already been done) or the mix of operations performed on the two mainframe machines may be altered. It is also likely that SRS after testing may utilize only a subsample of the TM bands (such as four of the seven) if it a[illegible]ars that the marginal improvement from added bands is slight compared to additional time and cost requirements.

Utilization of the SPOT satellite capabilities for digital processing will definitely bring in new adjustments for agricultural statistics users. If the off-nadir observation mode is used, the pixel sizes will vary within the scene. Users will likely have to develop their own algorithms to adjust for this variation and to be able to match sampling unit ground data with the satellite data locations. Using the off-nadir observation feature to observe an important area missed earlier due to clouds does mean that the at-nadir image for that pass will be sacrificed. Thus, the SPOT capabilities will mean that new management and prioritization structures will be needed which can make decisions on a nearly daily basis.

It is possible that many people interested in utilization of the SPOT satellite may have not fully realized the effect of the smaller SPOT swath width. The LANDSAT swath width is 185 km. The SPOT swath width of each High Resolution Visible (HRV) instrument is 60 km or both can be used to provide a total swath width of 117 km (3 km overlap). This smaller coverage width may affect drastically present procedures for utilizing satellite data. Presently, nearly every LANDSAT data scene has enough randomly selected ground sampling units (30 or more) for SRS to use its procedures described above in Section 5. Each 60 km by 60 km SPOT scene will be only about one-ninth of present LANDSAT size and there will not be adequate data available for training from the present ground survey. For SRS to utilize SPOT data in a similar fashion to that used now a sampling scheme of selecting random SPOT acquisition locations might be needed for which additional ground data could be collected. Precision improvements might be great for the selected sample but a new level of sampling variation will be introduced because of the swath width differences. Cost will also be a consideration since some estimates have predicted that data costs for SPOT scene may be comparable with that of LANDSAT scene covering nine times as much land area. For these reasons users interested in large scale estimation may adapt a multi sensor sampling approach with LANDSAT (or even meterological satellite data) data as the main source and SPOT data used for only a portion of the area or used as a fillin data source.

8. REFERENCES

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Table 1 - Percentage of Usable LANDSAT Imagery and Ratios of Statistical Improvement In Crop Acreage Estimation - United States

State	Year	Crop	Percentage Of Area Covered 1/	Relative Efficiencies 2/	
				Substate	State Level
Iowa	1978	Corn	87.9	1.0-6.0	2.4
Iowa	1978	Soybeans	87.6	2.7-7.6	2.4
Kansas	1980	W.Wheat	50.8	1.2-3.0	1.3
Iowa	1980	Corn	73.6	1.8-3.0	1.8
Iowa	1980	Soybeans	75.3	1.4-6.4	1.5
Kansas	1981	W.Wheat	83.4	1.9 -5.5	2.3
Oklahoma	1981	W.Wheat	73.8	1.2 -4.0	1.3
Iowa	1981	Corn	62.2	1.2 -5.1	1.6
Iowa	1981	Soybeans	62.8	2.9-15.8	1.6
Missouri	1981	Corn	71.7	1.9 -5.8	2.2
Missouri	1981	Soybeans	74.9	1.3 -4.9	2.1
Missouri	1981	Rice	100.0 3/	6.0	6.0

1/ Cloud free imagery of individual counties within scenes during an approximate two month period of peak growth is needed. Some data may have been lost due to mechanical problems in addition to cloud cover.

2/ Relative Efficiency is a measure of statistical precision. It represents the adjustment in ground survey sample size to equal the precision of the combined ground data LANDSAT data estimate. Relative efficiencies are lower at the State level since no improvement in precision is possible for substate areas with no LANDSAT coverage.

3/ Rice growing area in Missouri is contained on one LANDSAT scene.