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USE OF REMOTE SENSING FOR AGRICULTURAL STATISTICS: THE U. S. EXPERIENCE

by
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I. INTRODUCTION

The National Agricultural Statistics Service (NASS) of the U. S. Department of Agriculture is responsible for conducting the Census of Agriculture a 5-year intervals (1997 is the current Census year) and an extensive survey program to support the publishing of all official current agricultural statistics for the United States (U.S.). In order to fulfill its complex mission, the NASS staff has utilized numerous statistical and technological tools over the last 135 years of its existence. Some important tools used by NASS staff over time include: rural postal route postcard surveys, mechanical crop meters which calculated percent of different crops along rural road routes, area sampling frames, objective yield survey and measurement techniques, list sampling frames, combination of list and area sampling and estimation techniques known widely as multiple frame sampling, off-the-shelf statistical software systems, computer assisted data collection techniques, and space-borne remotely sensed data for area frmae construction, crop area estimation and monitoring. Even with all these tools added to the toolkit over the decades, the primary source of data remains farmer and agribusiness reported data. The remainder of this paper will describe the role of space-borne remotely sensed data in the NASS survey program.

II. GENERAL ROLE OF REMOTELY SENSED DATA in NASS

Space-borne remotely sensed data, such as that from Landsat 1 which was launched in 1972, has played a role in the NASS survey program. There are four major areas in which it has contributed to the NASS survey program or the survey research program. Those four areas are: area sampling frame development and maintenance, crop acreage estimation for a subset of major crop producing states, crop condition monitoring with vegetative index data, and with vegetative index data as an input to crop yield model research. For each topic area, there is a different story and timeframe.

III. AREA SAMPLING FRAME DEVELOPMENT AND MAINTENANCE

NASS has used area frame sampling on the national level since 1945. The master sample of agriculture was based on an area frame stratified geographically. Then, in the mid-1960's, aerial photography mosaics became available on a large area coverage basis. NASS staff photo-interpreted the black and white aerial photo mosaics in order to develop broad land cover strata, similar to those in use today. Research on the use of Landsat for area frame stratification was done in the mid-1970's by NASS research staff and then successfully transferred to an operational basis in 1979. In the late 1980's, NASS staff worked jointly with the National Aeronautics and Space Administration (NASA) Ames Research Center to convert the process of area frame construction to a digital process. The system developed was referred to as the Computer-Assisted Stratification and Sampling (CASS) system. Now, in the late 1990's, the system is being converted to commercial off-the-shelf software.

Remote sensing paper image products, primarily from Landsat Multi-Spectral Scanner (MSS) and Thematic Mapper (TM), were used from 1979-1990 as the primary input to land cover stratification. From 1990, digital Landsat and some French SPOT has been used as the primary input to area frame stratification.

IV. CROP ACREAGE ESTIMATION

NASS staff have been estimating crop acreage in some fashion since its first Crop Report in July 1863. The master sample of agriculture in 1945 was an instrumental step in the use of area frame sampling for crop acreage estimation. The closed segment estimator has been a reliable statistical indicator of crop acreage at the national and state level for nearly half a century now. In the mid-1980's, NASS staff developed and utilized multiple frame sampling for acreage estimation, in addition to area frame estimators. The relative sampling errors of the multiple frame are lower, but the nonsampling error characteristics are also different and perhaps higher in general for the multiple frame.

What has been the role for space-borne remotely sensed data in crop acreage estimation in the U.S.? As mentioned previously, the area frame stratification is done with Landsat and SPOT as major inputs. Thus, the crop acreage estimates coming from the area frame benefit from the more current stratification of land cover than the previous aerial photo mosaics, which were often 5-10 years old.

In addition to area frame stratification, construction and maintenance, NASS research staff developed a new method that used a regression estimator, area frame sample-ground reported data and Landsat data combined, in the late 1960's and early 1970's. The use of this method was applied operationally in Iowa in 1979. The program peaked in 1987 with an eight-state project covering a substantial percentage of U.S. corn, soybeans and winter wheat. Then due to budget pressures and a change from the MSS to the TM Landsat sensors, the program was changed back to a research only program. In the 1990's, the level of the program has ranged from one county to a three state level. The program is currently at the three state level and covers Arkansas, North Dakota and South Dakota. The relative efficiency of the regression estimator averages around 3.0 and ranges from 1.5 to 6.0. The meaning of this is that to get a relative effifiency of 3.0 using only the area frame ground system, the sample size would need to be tripled in order to match the regression estimator that uses the operational area frame sample. In addition, county level estimates with measurable statistical precision can be calculated as well. Because of satellite imagery dates and required processing time, the estimates are only available after the crop harvest.

V. CROP CONDITION MONITORING

In the late 1980's, NASS staff began the research to evaluate vegetative index data from the National Oceanic and Atmospheric Administration (NASA) polar orbiting weather satellites. Canada had already begun a program to monitor crop conditions using NOAA's Advanced Very High Resolution Radiometer (AVHRR) data, using the Normalized Difference Vegetation Index (NDVI). The U.S. was interested in developing a similar program for crop monitoring as a supplemental aid to the operational weekly expert opinion survey program. The NASS operational program involves weekly expert opinion data published in the joint USDA/NASS and NOAA Weekly Weather and Crop Bulletin. USDA extension agents in county or regional level offices are the main source for the weekly data on crop stage and crop condition.

The research in the late 1980's was successful and the NDVI images were first widely spread among policy makers and data users during the massive flooding of cropland in the U.S. Midwest region in 1993. The images are now available on a bi-weekly basis from the NASS home page on the Internet Web site, http://www.usda.gov/nass. The other major event observed on the images to date was the dry winter and early spring drought in the winter wheat region in the U.S. in 1996.

This is the capability that Morocco's Royal Center for Remote Sensing is currently developing. The capabilty should be quite valuable to Morocco as one of the real strengths of NDVI monitoring is early detection of moisture stress in rain-fed small grains production regions. In addition, one AVHRR scene covers all of Morocco and thus, complex mosaicing of images won't be required.

VI. CROP YIELD FORECASTING AND ESTIMATION

NASS has several sources of survey information for crop yield forecasting and estimation. First for forecasting, there is a monthly probability based sample selected of individual farmers and producers to give their opinion on yield potential to date during the growing season. In addition, there are objective yield samples. Objective yield samples are small randomly selected plots within a randomly selected crop field. For the small plots (plot size and shape varies by crop), plant counts and row spacing measurements are taken after crop emergence, but early in the season. As the season progresses, fruit counts and size measurements are also taken. Near harvest, destructive samples are taken to a regional laboratory where they are weighed and counted and converted to a standardized moisture content level. Linear models are used to forecast the current season yield, based upon field measurements taken during the season. The model outputs are summarized at the state and regional levels. Based upon the data from the farmer reported surveys and the objective yield surveys, the NASS Agricultural Statistics Board interprets the data and publishes one official crop yield forecast or estimate.

For decades, researchers have spoken of crop yield forecasting models based on inputs such as weather data, remotely sensed data and crop calendar like data. In addition, more complex physical based models, like plant/fruit process models, have been evaluated. USDA/NASS has not adopted any of them for operational use, despite substantial research investments, especially in the mid-1970's to the mid-1980's. There are currently some small scale research efforts in this topic area. The first one is a joint effort with USDA's Agricultural Research Service. A three year project is beginning in 1998 to develop and evaluate spring wheat yield models for end of the season county level estimates. The outputs of these yield models will be compared to the operational county level yield information, which is usually a large non-probabilty based sample of farmer reported data at the county level. The non-probability based sample results are usually used to partition or break down the state acreage and yield estimates, which are probability survey based. The new model will use a crop specific categorized Landsat TM data as a mask for the lower resolution AVHRR/NDVI data. In addition, a version of the Erosion Productivity Impact Calculator (EPIC) model, adjusted for the inclusion of remotely sensed inputs as well, will be used and evaluated for performance at the county level.

VII. CONCLUSIONS AND SUMMARY

The use of space-borne remotely sensed data has definitely contributed to the agricultural statistics program of the U.S. Operational use began in 1979 with land cover stratification in area sampling frame construction and for end of season corn and soybean acreage estimates in Iowa. The crop acreage program size has varied from one county to eight major crop producing states. Positives for the acreage program are: state estimates with substantially improved statistical precision levels, county level estimates with measurable precision, and crop specific categorized theme maps (paper or as GIS data layer). Negatives for the acreage program have been: cloud cover affects coverage of regression estimator (differently each year), only end of the season estimates are available, and costs of satellite data. The crop acreage program using space-borne remotely sensed data is currently done in three major crop producing states. The use of coarse resolution AVHRR and NDVI vegetative index has been a complement to the long existing Weekly Weather and Crop Bulletin. The NDVI maps are good for viewing vegetative conditions over large areas such as regions or the 48 contiguous states. Positives are : very infrequent cloud cover on the bi-weekly composites, and moisture shortage related crop stress over large areas is often apparent. Negatives are : when cloud cover is apparent, often the NDVI values near the cloud covered zone appear to have artificially low values as well, knowledge of crop phenology and crop calendar like information, as well as the remote sensing characteristics is necessary to properly interpret the images. The NDVI maps have been used on several major events to display to the public the spatial extent and location of the events. The massive flood in the U.S. Midwest region in 1993 which had a quite negative impact on corn and soybean production and the large area dry, windy and cold winter and early spring drought for winter wheat in the Southern Great Plains in 1996 were two of those events. For crop yields, the two major sources of data for official statistics remain as farmer reported and objective counts and measurements in the field and in the laboratory. Research on a small scale is being conducted to evaluate yield models that use soils and weather data and remotely sensed data and crop calendar like information as inputs.

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IX. REFERENCES

Allen, J.D., Hanuschak, G.A. (1988) "The Remote Sensing Applications Program of the National Agricultural Statistics Service: 1980-1987," U.S. Department of Agriculture, NASS/R&AD SRB Staff Report Number SRB-88-08.

Allen, R., Hanuschak, G., Craig, M. (1994) "Forecasting Crop Acreages and Yields in the Face of and in Spite of Floods," in Proceedings of the Seminar on Yield Forecasting, Food and Agriculture Organization, Villefranche-sur-Mer, France, October 21-24, 1994, pp. 99-138.

Bellow, M.E., Graham, M.L. (1992) "Improved Crop Area Estimation in the Mississippi Delta Region Using Landsat TM Data," in Proceedings of ASPRS/ACSM/RT'92 Convention, Washington, D.C., pp. 423-432.

Bouzaffour, Seghir; Hanuschak, G. (1998) "Crop Monitoring in Morocco Using Remote Sensing and Geographic Information Systems: From a Management Perspective", Proceedings of the Agricultural Statistics 2000 Conference, Washington DC, 3/98

Caudill, Charles E. and Hanuschak, G. (1983) "Management Issues of Integrating Earth Resources Satellite Data Into The United States Department of Agriculture's Domestic Crop-Area Estimation Program," Semi-Annual Meeting of the Institute of Management Science / Operations Research, Orlando, Florida, November, 1983.

Cook, P.W., Mueller, R.W., Doraiswamy, P. (1996) "Southeastern North Dakota Landsat TM Crop Mapping Project", 1996 ASPRS/ACSM Annual Convention Technical Papers, Volume 1, pp. 600-614, Baltimore, MD, April 1996.

Cotter, James and Cathy Tomzyak, 1994. “An Image Analysis System to Develop Area Sampling Frames for Agricultural Surveys,” USDA, NASS, Washington, DC.

Craig, Michael. "Applications of Advanced Technology For Agricultural Statistics." ISIS'92 Seminar, Statistical Commission and Economic Commission for Europe, Conference of European Statisticans, United Nations, Bratislava, Czeck and Slovak Federal Republic, May 1992.

Crop Production Report. May 10, 1996. USDA, National Agricultural Statistics Service, Washington, DC.

Crop Production Report. June 12, 1996. USDA, National Agricultural Statistics Service, Washington, DC.

Crop Production 1996 Annual Summary Report. USDA, National Agricultural Statistics Service, Washington, DC.January 1997.

Crop Production Report. June 12, 1997. USDA/NASS Kansas Agricultural Statistics Service, Topeka KS.

Doraiswamy, P.C.; Stern, A.J.; and Zara, P. "Monitoring Crop Progress Using NOAA AVHRR Data Adjusted for Seasonal Climatic Variation", 1997 ASPRS/ACSM Annual Convention Technical

Papers, Volume 3, pp. 625-635, Seattle, Washington, April 1997.
Hanuschak, George. "The Effect of the Landsat Cloud Cover Domain on Winter Wheat Acreage Estimation in Kansas During 1976." Fourth Symposium on Machine Processing of Remotely Sensed Data, LARS 77, Purdue University, West Lafayette, Indiana. June 1977.
Hanuschak, G., K. Morrisey, 1977. Pilot Study of the Potential Contributions of Landsat Data in the Construction of Area Sampling Frames, Statistical Reporting Service, USDA, Washington D.C.
Hanuschak, G., Wade, G. and Craig M. (1997). "Using Geographic Information Systems for Dissemination of U.S. Agricultural Statistics, Proceedings of the United Nations Economic Commission for Europe sponsored workshop on Geographic Information Systems, Brighton, UK.
Hanuschak, G.A., Craig, M.E. (1993) "Remote Sensing Program of the National Agricultural Statistics Service: From A Management Perspective," Survey Methods for Businesses, Farms, and Institutions, ICES Part II, U.S. Department of Agriculture, NASS Research Report Number SRB-93-11.
Hanuschak, G.A., Allen, R.D, Wigton, W.H. (1982) "Integration of Landsat Data Into The Crop Estimation Program of USDA's Statistical Reporting Service", 1982 Machine Processing of Remotely Sensed Data Symposium, Eighth International Symposium, LARS, Purdue University, July 1982.
Holko, Martin L., R. Sigman. "The Role of Landsat Data in Improving U.S. Crop Statistics." Paper presented at the Eighteenth International Symposium on Remote Sensing of Environment, ERIM, Paris, France. October 1984.
Houseman, E.E., 1975. "Area Frame Sampling in Agriculture." Statistical Reporting Service, SRS No. 20, USDA, Washington D.C.
Korporal, Kenneth D, and N.M. Hillary, 1993. "The Statistics Canada Crop Condition Assessment Program," Statistics Canada Publication, Ottawa, Canada..
Mueller, R.W., Wade, L.G., Cook, P.W. (1996) "Agricultural Statistics Board AVHRR and GIS Product Development", 1996 ASPRS/ACSM Annual Convention Technical Papers, Baltimore, Md.
Nealon, Jack and James Cotter, 1987. "Area Frame Design for Agricultural Surveys." NASS, USDA, Washington D.C.
Ozga, M., Mason, W.W., Craig, M.E. (1992) "PEDITOR -- Current Status and Improvements," in Proceedings of ASPRS/ACSM/RT'92 Convention, Washington, D.C., pp. 175-183.
Sigman, Richard and Gail Walker. "The Use of Landsat for County Estimates of Crop Areas: Evaluation of the Huddleston-Ray and Battese-Fuller Estimators," SRS Staff Report No. AGESS820909, September 1982.
Stakenborg, Jacques, 1989. "Data Treatment for Crop Statistics", European Communities Joint Research Center, Institute for Remote Sensing Applications Conference on the Application of Remote Sensing to Agricultural Statistics, Varese, Italy.
Winings, Sherman B. "Landsat Image Availability of Crop Area Estimation," Presented at Eighth Symposium on Machine Processing of Remotely Sensed Data LARS 82, Purdue University, West Lafayette, Indiana. July 1982.
Vogel, Fred, 1986. "Applications of Remote Sensing." USDA, NASS, Washington, DC.