NEW METHODS AND SATELLITES: A PROGRAM UPDATE ON THE NASS CROPLAND DATA LAYER ACREAGE PROGRAM

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Commission VIII, WG VIII/10

KEYWORDS: AWiFS, Landsat, See5, Agriculture, Classification, Cropland Data Layer

ABSTRACT:

The United States Department of Agriculture (USDA), National Agricultural Statistics Service (NASS) annually produces crop specific classifications and acreage estimates over the major growing regions of the United States using medium resolution satellite imagery. The classifications are published in the public domain as the Cropland Data Layer (CDL) after the release of official county estimates. This program previously used; Landsat TM and ETM+ imagery, the NASS June Agricultural Survey (JAS) segments for ground truth information, and Peditor software for producing the classification and regression estimates. The unpredictability of the Landsat program, the labor intensive nature of JAS digitizing for the CDL program, and the potential efficiencies gained by using commercial software warranted investigations into new program methods. NASS began investigating alternative sensors to the Landsat platform in 2004, acquiring ResourceSat-1 Advanced Wide Field Sensor (AWiFS) data over the active CDL states. Additionally, evaluations were performed on alternative ground truth methodologies using data collected through the USDA/Farm Service Agency (FSA) Common Land Unit (CLU) program and testing began with See5 software to produce the CDL.

NASS began pilot AWiFS studies for the State of Nebraska in 2004 and followed up with studies of Arkansas, Louisiana, Mississippi, Missouri, Nebraska and North Dakota in 2005. Accuracy assessments and acreage indications determined that the AWiFS results positively reduced the statistical variance of acreage indications from the JAS area frame, delivering a potential successor to the Landsat platform. In 2006 pilot testing was complete and the AWiFS sensor was selected as the exclusive source of imagery for the production of the CDL and acreage estimates. The FSA CLU program provides a comprehensive national digitized and attributed GIS dataset collected annually for inclusion into programs like the CDL. Commercial image processing programs such as See5 were tested in 2006 against the AWiFS imagery and CLU datasets, providing evidence of efficiency gains in statistical accuracy, scope of coverage and time of delivery to make further investigation warranted. The results of these program updates are presented.

INTRODUCTION

The Cropland Data Layer (CDL) Program at the National Agricultural Statistics Service (NASS) has been in production for over 10 years in its present state. The CDL is produced annually using available medium resolution satellite imagery such as the Landsat 5, Landsat 7 and IRS-1C LISS 3 satellites, the NASS June Agricultural Survey (JAS) for ground truth training data, and NASS developed and maintained public domain image processing software Peditor. The CDL program has expanded into many States through partnerships and cooperative agreements with interested federal and state governments and universities. Expansion has been supported by efficiencies with faster microcomputers, enhanced Peditor algorithms (Ozga 2000, Mueller and Ozga 2002) optimum staffing and employee training. This has allowed NASS to expand coverage while maintaining requirements of timely, accurate, unbiased state and county level acreage estimates delivered to decision makers in NASS with measurable error.

The program is a public domain product after publication of official county estimates. It is released in mid-March of the following year for wheat, corn and soybean States of the Midwest and in early July for the Mississippi Delta States with rice and cotton estimates. The uses of the CDL product are diverse and unique such as: agribusiness planning, environmental and ecological modelling, land use studies, crop rotational analysis, water usage, precision farming, epidemiological, alternative fuels, demographic, carbon, nutrient, pesticide and conservation research to name a few. The NASS CDL is widely viewed in the geospatial community as a one-of-a kind product useful for identifying crop specific land use cover types and can be used to mask out agricultural lands for modelling purposes.

The complete inventory of CDL states is depicted in Figure 1. The shade of green indicates if the program was a one time, annual, or potential project state, while the year shows either the crop year that the program started or the one year that it was performed. The dark green states are repeated annually, while the medium green states were performed either under contract or with program cooperators who created the CDL product. NASS is currently seeking active partnerships with the light green states.

The CDL program is moving to expand to additional states. New expansion efforts will prioritize states based on an individual crop's value of production. The following is a list of commodities ranked in order of importance to the U.S. agricultural economy: 1. corn, 2. soybeans, 3. winter wheat, 4.

cotton, 5. spring wheat and 6. durum wheat. These commodities are traded on U.S. commodity markets and are one of the USDA's "Program Crops". These crops total production and/or value of production for a state places it within the top 5-10 producing states for the U.S. Based on this economic data, future efforts will target the remaining non-CDL corn and soybean states listed in Table 1 to capture the high value States of Kansas, Minnesota, and Ohio for corn and South Dakota for soybeans.

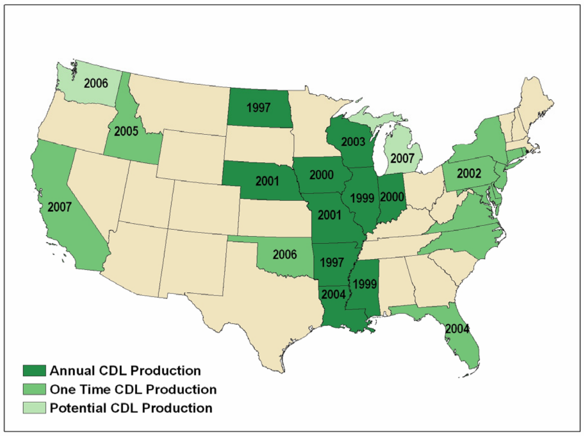

Figure 1. Cropland Data Layer inventory. Note the year indicates project start-up and the shade of green indicates project status.

Recent advancements in commercial software applications, newer multispectral satellite systems, ground truth alternatives to the JAS, and the ability to integrate other ancillary data sets into the analysis have offered research opportunities to improve on the recent CDL program efficiencies. See5* software integrated with ERDAS Imagine offers the opportunity to perform rapid state wide classifications and spatial smoothing of results and provide estimates to decision makers in NASS for consideration in setting early season state level estimates.

The launch of the IRS-P6 Resourcesat-1 Advanced Wide Field Sensor (AWiFS) in October of 2003 offered an alternative to the failing Landsat program. Research efforts began in 2004 to move CDL operations from the Landsat platform to that of the AWiFS. The Resourcesat-1 sensor is an operational program where the USDA is receiving domestic AWiFS imagery within five days of acquisition from commercial vendor GeoEye.

The JAS has been the backbone of the acreage estimation and CDL program since its inception in the 1970's (Allen and Hanuschak 1988, and Ozga and Craig 1995). The Farm Service Agency (FSA) of USDA partnered with NASS to deliver their enterprise-type GIS data layer called the Common Land Unit (CLU) program. The CLU layer is part of a national program that includes all farms that voluntarily participate in the program. The CLU program supports farm commodity and conservation programs and disaster response (Boryan 2007). The CLU is a comprehensive alternative ground truth dataset that can be utilized earlier than the JAS.

* Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the US Government.

These new developments have created a variety of research opportunities to shorten the delivery times of acreage estimates, from mid-December to mid-October and to expand coverage to additional states as capacity is built out, while AWiFS offers new capabilities not previously experienced in the medium resolution marketplace.

Numerous Midwestern and Mississippi Delta States were processed with these new methods, techniques and data sources for crop year 2006. The various methods, procedures and estimation tests are discussed in detail for Iowa. Iowa is currently ranked number one in corn acreage with over 4.5 million hectares and second in soybean acreage with over 4.1 million hectares in the U.S.

CORN	SOYBEAN
Illinois	**Arkansas**
Indiana	**Illinois**
Iowa	**Indiana**
Kansas	**Iowa**
Minnesota	Kansas
Nebraska	Minnesota
Ohio	**Missouri**
Wisconsin	**Nebraska**
	North Dakota
	Ohio
	South Dakota

Table 1. The "Program Crops" corn and soybean states. Bolded states are already in the CDL program.

METHODOLOGY

AWiFS Studies

There have been numerous studies by NASS remote sensing analysts evaluating the possibility of using AWiFS imagery for the CDL program. In 2004, 142 scenes were collected by SpaceImaging Inc. on behalf of USDA during the month of August and NASS performed a feasibility study to determine if the AWiFS sensor would be a suitable Landsat replacement. In 2005, SpaceImaging Inc. collected 100 AWiFS scenes over the U.S. to use for comparisons with TM classifications. In 2006, USDA moved all image acquisition activities to AWiFS, collecting over 1,400 images and ceased active acquisition of Landsat imagery.

A Nebraska 2004 study, (Boryan and Craig 2005) compared a unitemporal AWiFS with a multitemporal and unitemporal TM classification. The results demonstrated that the TM multitemporal classification was the most accurate as expected. The unitemporal AWiFS classification while not as accurate as the unitemporal TM showed that despite lower accuracy assessments the AWiFS performed well for acreage estimation of corn and soybeans and the coefficients of variation (CV's) were only slightly worse than those of the TM sensor, and AWiFS performed better than the initial JAS estimates. In a pending article (Johnson 2007) discussed three co-incident AWiFS and TM collections in the central and southern parts of the U.S. in 2005. The classification assessments demonstrated that TM outperformed AWiFS in two out of three assessments with the exception of one area in Iowa. The Iowa case was the smallest of the three study areas, had extreme AWiFS viewing geometry and was angled toward the sun. An analysis of Nebraska 2005 (Seffrin 2007) produced separate AWiFS and TM classifications that showed both sensors produced equally good estimates for corn and soybeans when compared to the official crop estimates. However, the state level CV's were larger for AWiFS than Landsat, but closer than the initial JAS estimate. These results were consistent with each other, and demonstrate that AWiFS crop indications were useful for crop acreage estimation, especially at the state and county level.

The AWiFS satellite was launched in October of 2003 and is backed by the Indian Space Research Organization and commercial partner GeoEye. This satellite provided an opportunity for breaching the Landsat data gap that is now in existence. Despite lower spatial and spectral resolution, the benefits of AWiFS outweigh the drawbacks; with the large swath width (740 km), an orbital repeat path of 24 days with repeat coverage every five days over 80 percent of the path, increasing the potential for in-growing season cloud free imagery, the ability to analyze larger amounts of training data that were not previously available with other systems with smaller coverage footprints, and near Landsat like spectral resolution (TM bands 2, 3, 4, 5) including the critical SWIR band, makes the AWiFS sensor an attractive Landsat alternative. The 56 meter spatial resolution does not appear to impact classification accuracy and acreage estimates while not as accurate as TM, they are statistically relevant. There also appears to be no negative affects (i.e., distortion) at the edges of the large AWiFS footprints (Johnson 2007). One potential limiting factor could be field size, as the CDL program typically targets states that contain large fields, usually with the average size greater than 20 acres and areas with smaller fields could provide less than optimum results, because of spatial resolution.

FSA/CLU Data

The USDA/Farm Service Agency (FSA) has established a Common Land Unit (CLU) standardized national GIS layer that managers land records, field locations and soils information. This program is maintained at the county level in over 2,300 FSA field offices, in a distributed data environment. The program's goal is to map and track all fields included in FSA programs on a near real time basis in part for compliance and administration purposes.

During the growing season, producers report their growing intentions, crops and acreage to the FSA offices and it is input into the GIS. A CLU is defined as the smallest unit of land with a permanent contiguous boundary and land cover. The CLU's are digitized in ESRI's shapefile format, while associated administrative attribute information is maintained in a separate database known as 578 Administrative Data. There are five main drawbacks to using the FSA CLU/578 datasets: 1) many CLU's have multiple crop types (mixed fields) within each field and are not suitable for training, only single use fields are used for training, 2) not all crop types are included in the program, only "program crops" are included and specialty crops are excluded, where the CLU program is not a true probability based sample of land cover and has bias toward subsidized "program crops", 3) every producer does not sign up for this program and non-agricultural areas are excluded too, leaving holes in the dataset, and 4) since the CLU's are maintained at the county level, a producer can report all of their farming operations in one office, regardless if their operations reside physically onto adjacent counties (Boryan 2007) and 5) the ability to data mine through multiple years of CLU data, is not possible at this juncture, as the CLU's are a live dynamic GIS dataset and are updated each year as producers report on their operations, overwriting the prior year's CLU dataset. However, this comprehensive and robust CLU/578 dataset is timely and accurate enough to support NASS' remote sensing operations, reduce labor costs and potentially speed up analysis.

In order to obtain the current years' CLU information, a request is sent out by NASS through a liaison agent, who then sends the request to each FSA county field office within a state to pull their CLU datasets and send them back to NASS Headquarters for distribution. This request is quite burdensome for the FSA offices, and requests are limited to August and January of each year. The data is organized in ESRI shapefile format by county. The 578 Administrative Data is maintained in a separate centralized database, and NASS can query and extract data directly at any time. The merging of the CLU and 578 datasets occurs through a common Administrative ID, allowing for prior years' CLU's to be joined to the current years' 578 data using ArcGIS scripts.

The FSA comprehensive CLU dataset provides for the opportunity to have both an independent training and testing dataset that NASS never had with the JAS, as all JAS segments were previously used for both operations. The CDL program was operational in ten states in 2006, with the potential of even more in 2007. Each NASS Field Office that participates in the CDL program contributes hundreds of hours to digitizing the JAS field boundaries annually. While the JAS provides systematic probability based random samples, the CLU's include nearly the whole agricultural domain (Figure 2), and only require a few hours of an experienced GIS analyst to merge the CLU and 578 datasets together for each state. Once the datasets are merged, only single use fields with a one to one correspondence between polygon and field record are retained, multi-use CLU fields are omitted. The labor and cost savings to NASS are significant, and the remote sensing program will benefit from this comprehensive dataset. The JAS outer field boundaries are still needed for the remote sensing regression estimator, and that is already being maintained and provided by the NASS Area Sampling Frame Section to support the JAS.

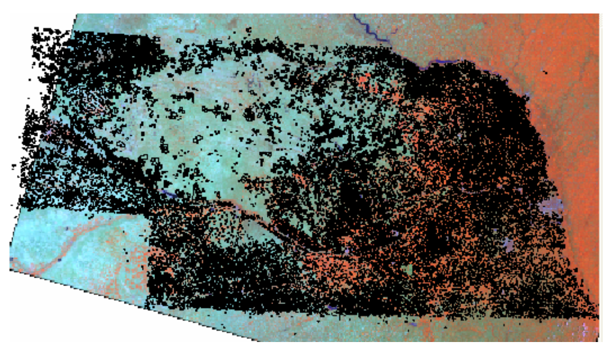

Figure 2. FSA CLU layer draped onto a July 15, 2006 Nebraska single date AWiFS image.

NASS' remote sensing intentions are to leverage the 578 data in mid-July with database queries from the liaison agent, and merge the current year's records with prior year's CLU's, as the likelihood of the Administrative ID changing is small, and the chances of a successful match are high. Preliminary selection of useable AWiFS scenes will begin at this point. An early season classification can be run, to check ground truth validity and evaluate scene quality. In prior years, JAS digitizing would finish in September or October depending on available resources at the NASS Field Offices, thereby prohibiting an early season estimate. The new year's CLU's will be updated with the most recent certified 578 data in mid-August, and processing will begin on the mid-season estimate.

Ancillary Data

There are a variety of raster based data layers available from the U.S. Geological Survey (USGS) and now prior CDL products that can be included in the remote sensing analysis. Ancillary datasets from the U.S. Geological Survey, National Land Cover Dataset program (Homer 2004) were incorporated into the process to help separate non-agricultural land uses. The following data layers were utilized for the production of the 2006 CDL: elevation, forest canopy, impervious surfaces, the 2001 National Land Cover Dataset (NLCD) and prior CDL's. New program methods allow for the inclusion of these datasets improving classification accuracy especially in the non-agricultural areas.

The National Elevation Dataset (NED) (seamless.usgs.gov) is 30 meters in resolution, with the elevation model deriving slope, aspect, and topographic positional index (TPI) layers that can be used for training. The NED can be used to derive rules on whether potential agriculture production could exist based on topography and elevation data. The 2001 NLCD (www.mrlc.gov) was a national product completed in January of 2007, and included 21 land cover classes; percent tree canopy and percent urban imperviousness derived from Landsat imagery at 30 meters resolution. These products were used to derive extra signatures to improve the non-agricultural classification. Prior CDL's were used to focus the classifier on crop production/intensive areas and crop rotational patterns could be used for decision support. These datasets were resampled to 56 meters resolution using nearest neighbour rigorous transformation to match the native AWiFS pixel resolution.

Software Updates

NASS began using See5 (www.rulequest.com) software for the production of the 2005 Mississippi Delta CDL. For testing purposes only the agriculturally intensive Delta Region was classified with See5, as the rest of the domain was stamped in with Peditor classifications. The Florida 2004 CDL was produced next and it was the first full state CDL to be processed using See5. From the success of these pilot projects, additional See5 CDL's were processed for crop year 2006. The CDL States of Iowa, Nebraska, North Dakota, Washington and Wisconsin were tested with See5. Additionally, Nebraska and North Dakota were produced with FSA/CLU data only, while Iowa was produced with both Peditor and See5 software and JAS and FSA CLU training data.

Investigations began in late 2004 to determine if there existed an affordable, efficient and accurate classification alternative methodology to Peditor. Decision tree software was investigated based on recommendations from EROS Data Center researchers and literature reviews (Hansen et al., 1996; Friedl and Brodley, 1997 and Lawrence et al., 2004). Decision trees offer several advantages over the more traditional maximum likelihood classification method. The advantages include being: 1) non-parametric by nature and thus not reliant on the assumption of the input data being normally distributed, 2) efficient to construct and thus capable handling large and complex data sets, 3) able to incorporate missing and non-continuous data, and 4) able to sort out non-linear relationships. These reasons combined usually lead to improved classifications over the maximum likelihood method. Additionally, there are several varieties of decision tree classifiers but See5.0 stands out because it further employs a statistical technique known as "boosting" which has been shown to improve results even further.

IOWA PROGRAM RESULTS

Ancillary Data Preparation

To prepare for the remote sensing analysis of Iowa, the ancillary data incorporated into the analysis was downloaded, including: forest canopy, impervious surfaces, and land cover. The project study area was defined by a polygon that extended 10,000 meters beyond the Iowa state boundary. This was used to clip subsequent data sets to the same extent. To capture the extent of Iowa and beyond, the USGS grouped the continental US into 17 zonal areas for ease of downloading and distribution. The ancillary layers covering Iowa in superzones 6, 8, 9, and 11 were downloaded from ftp://edcftp.cr.usgs.gov/pub/data/landcover/nlcd2001/superzones/ and were then mosaicked, resampled to 56 meters using a nearest neighbor rigorous transformation, and clipped to the study area. The NLCD land cover layer was used as ground truth for non-agricultural areas. These data sets were projected in Albers and no reprojection was necesary. The elevation data was downloaded in 1.5º x 2.0º tiles from the seamless data server (seamless.usgs.gov) in BIL format to cover Iowa and the surrounding area. It was then mosaicked, reprojected to Albers, resampled to 56 meters using bilinear interpolation using rigorous transformation, to a 16-bit unsigned integer ERDAS Imagine format image. This formatted Digital Elevation Model (DEM) was an input to deriving slope, aspect, and topographic positional index (TPI) layers that were also used for training.

AWiFS Scene Preparation

There were ten AWiFS scenes chosen to cover Iowa for crop year 2006. Figure 3 shows the AWiFS scene footprints divided into two Analysis Districts. Analysis District 01 (blue) was observed on May 19 and July 30 and Analyst District 02 (red) had observation dates of July 16 and September 26.

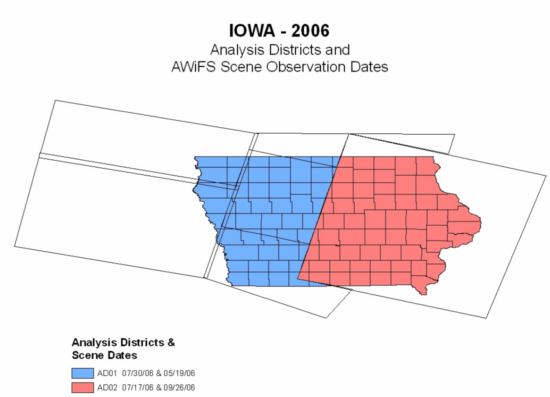

Figure3. Iowa 2006 AWiFS Analysis District map.

All AWiFS scenes were purchased ortho-rectified from GeoEye. The individual AWiFS scenes were reprojected to Albers from the native Lambert Conformal Conic projection, using nearest neighbor resampling. Scenes of the same date were mosaicked and clipped to the study area using ERDAS Imagine.

FSA/CLU Ground Truth

The FSA common land unit (CLU) data were used as ground truth. Preprocessing of the shapefile data removed duplicate polygons and correctly assigned state and county identifiers. The shapefile attributes and the 578 crop data were imported into Statistical Analysis Software (SAS) and filtered for usable CLUs. CLUs were excluded if they had more than one crop type, were smaller than 10 acres, or had a difference in size of more than 10 percent between the shapefile and 578 data. A sample of the data was created by selecting one-fifth of the CLUs if a crop had more the 10,000 usable CLUs and selecting one-half of all other covers. To improve the classification of a severe drought area and the valley along the west of the state, the counties of Ida, Sac, Woodbury, Monona, Crawford, and Harrison had three-fifths of the corn and soybean CLUs sampled. The selected CLUs were rasterized to 56 meters and the categories recoded to match the published set of CDL master categories.

To calculate the number of non-agricultural training pixels to collect, the NLCD land cover layer was clipped to the state boundary and pixels tabulated by category. The proportion of agricultural to non-agricultural pixels was used to determine the number of non-agricultural pixels to select after the agricultural sample was selected. This will reduce the possibility that a category will over classify because it is disproportionately represented in the training data.

See5 Classification

Training data were created using the NLCD Sampling Tool in ERDAS Imagine for the entire state all at once. All of the sampled crop pixels were chosen for training. The sampling tool was run again to select a stratified sample from the non-agricultural categories of the NLCD land cover layer. The data files were merged and the names file adjusted to include dependent categories from both inputs.

See5 was run on the training data using the boost 10 option (Quinlan 1996). The resulting decision tree was input to the NLCD See5 classifier in Imagine to create a classification and confidence map. The classification results were post processed using a minimum mapping unit (MMU) filter to eliminate individual misclassified pixels. The Imagine NLCD "Smart Eliminate" tool was applied with a MMU of 20 acres (26 AWIFS pixels) for corn and soybeans and a MMU of 2 acres was used for all other covers for the final CDL and estimates.

See5 decision tree results can appear quite complex and difficult to interpret, the operations appear to be "black box" like, as the results are accurate, and there are hundreds if not thousands of "leaves" which represent box-like containments of pixels and no tools to manipulate them directly. However, there are ways to edit and improve the See5 classification. When a classification was run using the See5 classifier tool under the NLCD menu in ERDAS Imagine, the option to "Create Error or Confidence Layer" was chosen. This was the predicted confidence associated with each output pixel based on the input rules (MDA Federal Inc. 2006) Bad ground truth could be reduced by only keeping ground truth pixels in the next See5 training where the input and output class match and have a high confidence.

For the Iowa 2006 project using FSA training data, the See5 boost function had the effect of reducing the decision tree error from 5.8% to 0.4% and reducing the size of the tree file to one-third the size of the original. Visually this made no change or improvement in the classification besides shifting a few pixels around. This may be a more useful technique when there is limited imagery (unitemporal) or less ground truth. In the future, development of a two step process may be required: step one evaluates all of the reps of ground truth based on the training of one rep of data; and step two retrains and reclassifies on a separate rep of data than used in the first training (with 'bad' ground truth eliminated during the first step).

Acreage Estimates

Pocahontas County (Figure 4), is located in northwestern Iowa, where agriculture is the dominant land use. Pocahontas land area encompasses a total of 150 hectares, with 71 and 62 hectares of corn and soybeans respectively in 2006 leaving only 13 hectares for other land usage, with 89 percent of the total land cover in either corn or soybean production.

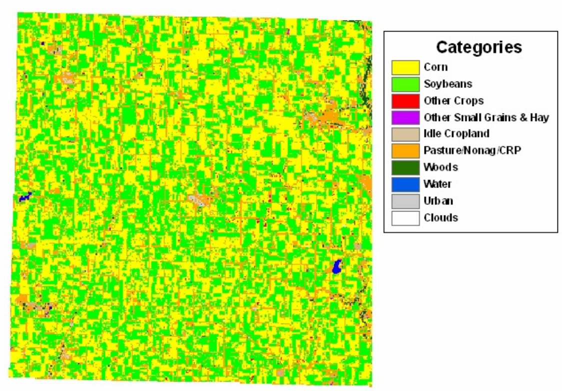

Figure 4. The Pocahontas County, Iowa 2006 Cropland Data Layer.

A comparison of the JAS and AWiFS estimates is depicted in Figure 5 using JAS and Peditor, JAS and See5, FSA and See5, FSA and See5 with smart eliminate set to 20. The zero line is the ASB Iowa State level final number with +/- 2% CV. All estimates are compared to the ASB for analysis purposes. For each of the estimates and crops in Figure 5 the black line represents the percentage difference that the estimate was from the ASB number. The yellow and green lines surrounding the bars are the +/- 2% CV's centered from the black line. The JAS for corn was quite accurate while the soybean number was around four percent under. The CV range difference between the JAS and remote sensing estimates are because of the benefits of the regression estimator. The FSA/See5-smart eliminate 20 produced the most accurate remote sensing corn estimate, while the JAS/Peditor estimate was a close second. The JAS/Peditor estimate performed best of all estimators for soybeans. The JAS/See5 estimate was the least accurate remote sensing estimate, While the JAS/Peditor and FSA/See5 were the most accurate overall of all estimates.

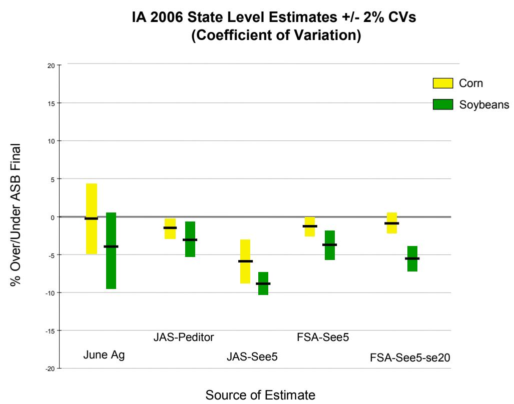

Figure 5: A comparison of the June Agricultural Survey and AWiFS estimates for Iowa crop acreage.

Numerous state level estimation tests were run on the Iowa 2006 dataset, to measure the accuracy of remote sensing estimates versus the JAS and the final Agricultural Statistics Board (ASB) results. All estimates for corn and soybeans were calculated by importing and processing the data in Peditor. After regression analysis at the Analysis District level, estimates were accumulated to the state level.

CONCLUSION

The opportunity to expand the remote sensing program to the "Program Crops" corn and soybean states and deliver operational state level estimates two months earlier would not be possible without a major overhaul in technologies and methods. The Resourcesat-1 AWiFS sensor was critical in proving rapid revisit times, large footprints, near Landsat like spectral bands and adequate spatial resolution. The ability to obtain the FSA CLU layer in early July and a final certified CLU in mid-August will enhance the program's chances of delivering an early season estimate and relieve the NASS Field Office from digitizing duties. The ability to include ancillary data for training, such as elevation, and non-agricultural land covers improves overall classification accuracy and appearance. The utility of See5 software provides a means for efficiently and accurately producing acreage estimates at the state level to the Agricultural Statistics Board a month or two earlier. It is hoped that the modernization effort will improve the estimate delivery time, accuracy and expand the program scope to include the major "Program Crops" of US agriculture, and make the NASS remote sensing program truly operational.

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