AGRICULTURAL STATISTICS BOARD AVHRR AND GIS PRODUCT DEVELOPMENT

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ABSTRACT

USDA National Agricultural Statistics Service's (NASS) Agricultural Statistics Board (ASB) meets monthly during the crop growing season to establish crop acreage and yield estimates for the United States. The Remote Sensing Section (RSS) of NASS's Research Division has worked closely with the ASB and NASS's Crops Branch in developing Advanced Very High Resolution Radiometer (AVHRR) maps and GIS products to display crop development and condition as supplementary information to the standard NASS collected survey data. The AVHRR maps display vegetation indices for biweekly composite data from EROS Data Center, Sioux Falls, South Dakota. The AVHRR maps are being used by ASB and Crops Branch as an additional tool to gather near real-time information about crop condition. The GIS maps display crop condition and crop growth stage information at the State level (county maps for some States are under development) with frost-line contours to aid in evaluating possible loss from freezing in late maturing crops.

INTRODUCTION

NASS's Remote Sensing Section (RSS) is working with the ASB crop analysts to provide timely and useful imagery and data products. The primary purpose of this project is to provide near real-time capability using satellite data to monitor crop growth and progress in the major production areas of the United States. The satellite data provided an independent source of supplementary information to that collected by enumerators. Crop analysts use the satellite imagery integrated in a geographic information system (GIS) to help in their assessment of current crop condition and vegetation vigor.

NASS uses Arc/Info running on a Sun SPARCstation network as the Agency's GIS software. Map composition capabilities allow rapid creation of AVHRR vegetation index maps and other GIS map products using Arc/Info's macro language AML's, along with Arc/Info's Grid module. NASS uses its Arc/Info GIS capability to combine diverse layers of information to overlay image data with State and county boundaries, frost isoline data, and crop information.

The NASS Agency estimation program and the role of the ASB is described below. This research concentrates on GIS map products developed for the ASB: County estimates, AVHRR image data integrated with GIS, crop progress of the specific stages of crop development, frost isolines, and Monthly Agriculture Yield Surveys.

NASS AGENCY BACKGROUND

NASS has the responsibility for monitoring crop conditions in the United States, and providing monthly forecasts and estimates on seasonal production. The ASB consists of a permanent chairperson and secretary, and other NASS staff members chosen to participate in the preparation of a specific report based on their detail knowledge of a particular topic. NASS collects crop information from many different sources, of which the farmer surveys are the most important. Major NASS surveys include: The Quarterly Agriculture Surveys (QAS), Monthly Agriculture Yield Surveys, Objective Yield Surveys, and the Weekly Crop Weather Surveys (Allen *et al.* 1994). June Agriculture Surveys (part of the QAS), which are multiple frame surveys based on both area and list samples, provides several significant indications for estimation of crop acreage. The Monthly Agriculture Yield Surveys, which are based on a list sample, are conducted between quarters to gather information on crop condition and yield. Objective Yield Surveys, mainly area based, produce additional information that statisticians can use to forecast crop yield per acre. The Weekly Crop Weather Survey collects information on crop progress and condition during the growing season. A large list sample is contacted at the end of the crop season, this data is used for county estimates.

NASS uses the collected data for monthly reports on farmers' planting intentions, estimates of crop acreage planted and expected to be harvested, and forecasts of crop yield and production during the growing season. After crop harvest, NASS estimates harvested crop acreage, crop yields, and crop production using the above surveys. The ASB combines survey data indications, administrative data, and all other known information to produce official estimates.

COUNTY ESTIMATE MAPS

The county estimates program uses data collected through cooperative agreements with each State individually. The States cooperate with NASS in exchange for data that provide estimates of their agricultural economies at the county or agricultural statistic district (i.e., multiple counties) level. These estimates usually include information on crops that are particularly important to the State and their local economies.

County crop estimates are usually prepared from surveys mailed to a large sample. Samples for these surveys accomplish several important objectives. Measuring year-to-year change is possible since many respondents are included in the sample from one year to the next. Since most operators are not in the sample earlier in the year, the response burden for an individual operator is less. The list frame is updated from the farm operation changes detected in the county estimates program (U.S.D.A., National Agricultural Statistics Service, 1995, p. 9).

RSS uses county estimates to develop choropleth maps for NASS Headquarters and State Statistical Offices (SSO's). The SSO's are responsible for setting the county estimates for acreage, yield, and production. They submit their county estimates to Headquarters during February and March. Commodity statisticians decided appropriate groupings for the crop yield and harvested acreage.

Currently, nine commodities were produced for distribution, including: all wheat, barley, corn, durum wheat, oats, sorghum, soybeans, spring wheat, and winter wheat. These maps are available at NASS's Internet site: **www.usda.gov/nass**.

The use of choropleth maps to analyze crop statistics can be quite valuable. For example, Figures 1 and 2 show the national distribution of yields for corn and soybeans. Note how corn yields vary greatly even for States in the traditional Corn Belt of Iowa, Illinois, Indiana, and Ohio.

Figure 2 shows that many counties in the Corn Belt States had soybean yields greater than 45 bushels per acre in 1994. Unlike corn, soybeans have the greatest concentration of high yields in the Corn Belt States.

AVHRR MAP PRODUCTS

The EROS Data Center (EDC), U.S. Geological Survey, calculates a conterminous U.S. biweekly Normalized Difference Vegetation Index (NDVI) (Goward 1985) image from the Advanced Very High Resolution Radiometer (AVHRR) sensor on the National Oceanic and Atmospheric Administration (NOAA) satellite NOAA-14. EDC produces standardized AVHRR digital images and map products that display vegetation indices for the biweekly composite data. EDC creates the composite images by selecting the maximum NDVI value for each image pixel from the given biweekly period. This method produces frequent clear observations of the Earth's surface (Holben 1986; Eidenshink 1992a).

When observing agriculturally intensive areas, low NDVI values delineate those areas that are likely to be under stress due to drought, excessive moisture, or disease. Higher NDVI values pinpoint areas with improved crop development. Although the AVHRR sensor has a 1.0 square kilometer spatial resolution (after processing by EDC), the (in some case daily) observations make the AVHRR a good resource for vegetation monitoring (Eidenshink *et al.* 1992b). The NDVI images produced every two weeks by EDC, and then reprocessed by RSS, provide a valuable view of U. S. vegetation for crop analysts and statisticians. The ASB uses the AVHRR maps as a supplementary data source since NDVI values have been shown to have a close relationship to the phenological growth stages of crops (Perry *et al.*, 1984; Goward *et al.*, 1985; Tucker *et al.*, 1985). Consequently, the maps aid in seeing relationships between NDVI values, the crop estimates, and projections of the final yield.

<u>Difference Image</u>

Another product produced by NASS, developed with assistance from the Agricultural Research Service (ARS), is that of the AVHRR difference image. While the NOAA-11 satellite was operating during 1993 through 1994, NASS generated difference image maps by subtracting the previous year's corresponding biweekly data from the current biweekly image. A median of the earlier four years of data for the corresponding biweekly period was also created and subtracted from the current biweekly period (Wade *et al.*, 1994).

USDA policy makers used the AVHRR difference image map products to compare the 1993 crop conditions in the Midwest flood and Southeast drought areas with the same areas during the 1992 growing season (Wade *et al.* 1994). Doraiswamy (Doraiswamy *et al.* 1994) discussed use of AVHRR imagery to estimate the acreage of vegetation classes damaged by the Midwest flood of 1993. Frequent and timely delivery of the biweekly difference images provided in map form made the AVHRR difference images more useful to the policy makers when they evaluated the changing crop conditions in areas affected by flood and drought.

<u>NDVI Image</u>

The launch (December 1994) of the new NOAA -14 satellite to replace the failed NOAA-11 satellite prevented comparing the satellite data from two sensors with different radiometric characteristics by simply subtracting the two sets of data. Now only the standard NDVI images are available for use by NASS statisticians who compare the indices over time to detect and monitor crop development. Developmental work is currently underway to develop a difference and ratio image product for the current satellite's data.

RSS uses the biweekly composite NDVI image product as the basis for overlaying additional GIS products. Arc/Info AML routines help to simplify the processing of the biweekly AVHRR data. The Grid module of Arc/Info provides the image processing functionality. The following provides RSS's method for processing AVHRR data:

1) Sum the values for AVHRR channels one and two.
2) Assign values of the sum greater than 230 to be clouds.
3) Mask all international and water areas to display only the continental U.S. by using EDC's Land Cover Characteristics data set (Brown *et al.* 1993).

Another use of the data was that made by the North Dakota State Statistical Office (SSO). By comparing data from Weekly Crop Weather reports with color slides of the tri-State (consisting of North Dakota, South Dakota, and Minnesota) AVHRR maps, North Dakota's State Statistician showed a meeting of North Dakota's State Food and Agriculture Committee and Emergency Board the progress of the 1995 crop season. Late crop planting, followed by extreme heat during the critical heading and pollination period for an already very late crop, were clearly visible on the AVHRR maps (Beard 1995). The AVHRR data clearly supported Natural Disaster Damage Assessment Reports filed by 35 North Dakota counties. Those Counties requesting disaster assistance were easily predicted using the biweekly AVHRR maps and slides. The board members required no discussion to approve disaster designation for the effected counties.

Additional map products were developed using the NDVI image. A nine-image "small multiples" (Tufte 1990) reduced scale map of U.S. vegetation condition provided a time series of an entire season by combining biweekly periods that span from May through September. A small multiple comparison of NDVI values for three years from 1993 through 1995 for the same three periods was another geo-spatial product provided to the ASB. This product encompassed a six-week time span to show biweekly periods during the growing season compared with that of the previous two years of corresponding biweekly periods.

NDVI Image Mask

The county acreage statistics for corn, soybeans, and wheat provide a mask for AVHRR maps that allow focusing on the vegetation indices of specific crops by excluding other areas. NDVI image masking uses all of the three previously mentioned processing steps, and adds a polygon mask to counties with crop acreage less than a predetermined limit. Figure 3 shows an example of the corn mask applied to the period 34 (9/1 - 9/14) 1995 composite biweekly image. The mask excludes all counties that harvested less than 50,000 acres of corn during 1994.

Map products produced for the ASB included the following vegetation condition maps:
(1) corn area vegetation condition
A map of NDVI values for only those U. S. counties with a minimum of 50,000 acres of harvested corn;
(2) soybean area vegetation condition
A map of NDVI values for only those U. S. counties with a minimum of 50,000 acres of harvested soybeans; and
(3) wheat area vegetation condition
A map of NDVI values for only those U. S. counties with a minimum of 25,000 acres of all wheat harvested (which includes durum, spring, and winter wheat).

CROP PROGRESS MAP PRODUCTS

To enhance the value of the vegetative index data products mentioned above, RSS developed additional GIS maps to display specific stages of crop development. This map product helps commodity specialists monitor the crop growth. Weather data such as frost information and precipitation can provide supplemental information to analyze the current crop condition. Providing frost isolines for the mean first fall freeze date as a map overlay helps in evaluating possible crop damage from freezing in late maturing crops.

A National Agricultural Summary of crop progress and condition tables is in the Weekly Weather and Crop Bulletin published each week. The joint cooperators for this publication are the following: the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), the National Weather Service (NWS), and the Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS) and the World Agricultural Outlook Board (WAOB). NASS Headquarters releases a separate Crop Progress report during the growing season. The report contains tables which show planting, phenological and harvest progress, and crop condition percent by categories for the major producing States.

The crop progress is monitored for maturity phases of a particular crop. For example, both corn and soybeans go through various phenological stages of maturity. See Table 1 for a brief description of the major crop stages for both corn and soybeans (U.S.D.A. National Agricultural Statistics Service 1990). The dates given provide the period during which the crop stages should generally occur.

Table 1. Corn and Soybean Phenological Stages.

Corn						
Stages	Planting	Silking	Dough	Dent	Mature	Harvest
Definition		Silk Emergence	Kernels Half Dented - Dough Like	Fully Dented Kernels	Shucks Opening, No Green Foliage	
Dates	Apr 8 - Jun 3	Jul 8 -Aug 12	Jul 22 - Sep 2	Aug 12 - Sep 16	Aug 19 - Oct 14	Sep 9 - Nov 25
Soybeans						
Stages	Planting	Blooming	Setting Pods	Dropping Leaves	Harvest	
Definition		At Least One Bloom	Pods Developing on Lower Nodes	Leaves Turning Yellow		
Dates	May 6 - Jul 1	Jul 1 - Aug 26	Jul 15 - Sep 9	Aug 26 - Oct 21	Sep 16 - Nov 25	

The percentage reported for a given phenological stage shows the progress of crop development or of field work. If half the expected soybean acreage is planted, a value of 50 percent should be used. Should weather conditions alter planting prevent planting of intended acreage, a figure of 100 percent gives the time when planting stops. Progress percentages are related to the percentage of plants within a given acre that are currently in (or beyond) a given phenological stage. Specifically, an acre of crop is in (or beyond) a phenological stage when 50 percent or more of the plants in that acre are in (or beyond) that stage. Generally, a given field is considered in a particular stage when 50 percent or more of the plants within the field have reached (or gone beyond) that stage.

RSS developed a pilot project using NASS's crop progress information on a county level by preparing a map for the ASB members to show percent silking for corn in three States. The ASB found that the map gave valuable insight into the prospects for the 1995 corn crop. Consequently, the ASB decided that percent dented by county for the four major corn States (Illinois, Iowa, Minnesota, and Nebraska) could be mapped to evaluate what areas would be affected by a normal frost. Therefore, the Crops Branch requested that these States submit their county average percent dented from their September Crop Weather Bulletin (a weekly bulletin published by the State Statistical Offices). The States submitted their data files to the RSS as requested. RSS used Arc/Info to join crop progress data with county boundaries of the specified States. Appropriate percent breaks were provided by the corn commodity statistician.

Preliminary reports confirmed the crop progress map to be a useful ASB tool for the first group of States examined. This project might be expanded to include more States for next summer. Cooperating States must submit their county level crop progress for corn and soybeans in a predefined format weekly for use by the ASB.

HISTORIC AND CURRENT FROST ISOLINES

Displaying frost isolines can aid in evaluating possible crop damage from freezing in late maturing crops. Frost isolines also can provide another overlay or GIS layer to the NDVI images. Analysts can use these isolines to locate areas where the first frost might produce possible crop damage. The crops' development was analyzed and compared with the historic dates calculated from thirty years of historic data of the first frost, derived from the Weekly Weather and Crop Bulletin. Historic frost lines were overlaid onto the crop progress maps during August and September to monitor both corn and soybeans. The percent corn denting shown in Figure 4 shows that for the week ending September 3, 1995, crops for some counties in the four State area are not yet in danger of frost damage according to historic frost isolines.

Evaluating the effect of subfreezing temperatures forecast across the U.S. Midwest on the corn and soybean crop at risk for frost damage is another interest of policy makers who find such maps useful to examine. Current frost lines provided by the Crops Branch showed freezing temperatures provided by the National Weather Service for an average of the previous two days ending on September 22, 1995. After overlaying frost isolines onto the map displaying corn and the percent dented for four major corn States, these frost lines reflected the coldest temperatures recorded for the current season (See Figure 5). These frost isolines were also overlaid onto the map displaying soybeans percent dropping leaves (See Figure 6). Clearly, these Figures show a much greater potential for freeze damage to those counties of corn and soybeans that are not yet mature as of September 17. These maps were available to crop analysts to provide a useful visual interpretation of possible areas for crop frost damage monitoring for the October ASB report.

MONTHLY AGRICULTURE YIELD SURVEY

Survey data is also being mapped to provide a supplemental visual tool for the ASB. Currently, maps for some Monthly Agriculture Yield Surveys can display the weighted average by county by using the same bushels per acre yield groupings as for the county estimate maps. This technique allows for the ability to compare the survey data with the county estimates' maps.

Agricultural Yield Surveys are conducted monthly during May through November. All States, except Alaska and Hawaii, participate in the survey. The months for which individual States participate will depend on the estimating program needs for that State. This survey provides the primary indications for the monthly Crop Production report that provides forecasts of production during the growing season. The crop acreage and yield data are collected by mail and telephone. The sample consists of a sub-sample of operators who reported the crop of interest during the March and June Agricultural Surveys.

RSS received the survey data from Headquarters during the months of September, October, and November 1995. Headquarters created a SAS dataset of survey data. After transfer of the data files from the Sun to the PC, RSS generated summary statistics in Arc/Info to produce county level harvested acres by summing of individual responses for a county. A weight for each individual observation was created by dividing each respondent's harvested acreage by the county total. After multiplying the weight times each respondent's corn and soybeans yield, RSS summed the weighted yield responses to the county level.

An Arc/Info AML joined the weighted yield data with the county boundary file, and created the final map product. Figures 7 and 8 show corn for grain and soybeans, from Monthly Agricultural Yield Survey data for September 1995 respectively. These choropleth maps can be provided to the ASB to monitor year to year differences of yield data.

FUTURE GIS PRODUCTS

Plans are to continue focusing on corn and soybeans to evaluate growing degree days as a useful GIS ASB product. Growing degree day units is a method to relate the cumulative effects of temperature above a given base to plant growth. The base temperature varies with the type of crop.

Growing degree days can be a tool in describing the relative maturity of a plant as opposed to tracking the days a specific variety requires to reach maturity. Growing degree days are calculated for each 24-hour day and accumulated from the time the crop is planted until maturity (Aldrich, 1986). Therefore, growing degree days could be a useful indicator of the total effect of temperature during the growing season. Although growing degree days are not a perfect tool for monitoring corn maturity, degree days can be provided with the phenological stages for a commodity. Growing degree days can be a useful tool in providing a more thorough picture of crop maturity stages and provide additional insight.

Future ASB products under consideration using our GIS would include growing degree days for a current week based on historic normals and growing degree days for the current week calculated from a weekly average of growing degree days. These could be categorized based on historic normals as below normal, average or above normal. NASS plans to continue to evaluate use of current and historic frost isolines overlaid on crop progress data at a county level, and new variables such as crop condition and soil moisture at a county level.

CONCLUSION

NASS will continue to investigate other uses of AVHRR data, along with ancillary data sources to help monitor crop growth and progress. Frequent satellite overpasses is a necessary requirement for observing changing weather, agricultural conditions, and providing a timely image. The use of vegetation indices provides an additional independent tool for crop analysts to help in their crop forecasts. Development of additional map products for the crop analysts will continue as RSS researches the relationships of NDVI values to crop growth and progress.

RSS is exploring the possibility of using data collected by NASS with that of the new AVHRR 14 sensor to create integrated products from the following: county estimate maps, crop masks, crop progress data, frost isolines, and Monthly Agricultural Yield Surveys. Integrating the use of satellite data with that of weather and NASS collected data should be a valuable tool for crop analysts to monitor crop progress. Also, additional research is being focused on tracking corn and soybean progress for growing degree days. Future research will investigate further uses of the NOAA AVHRR 14 sensor to produce difference/ratio products comparing 1996 with 1995 for a comparable period.

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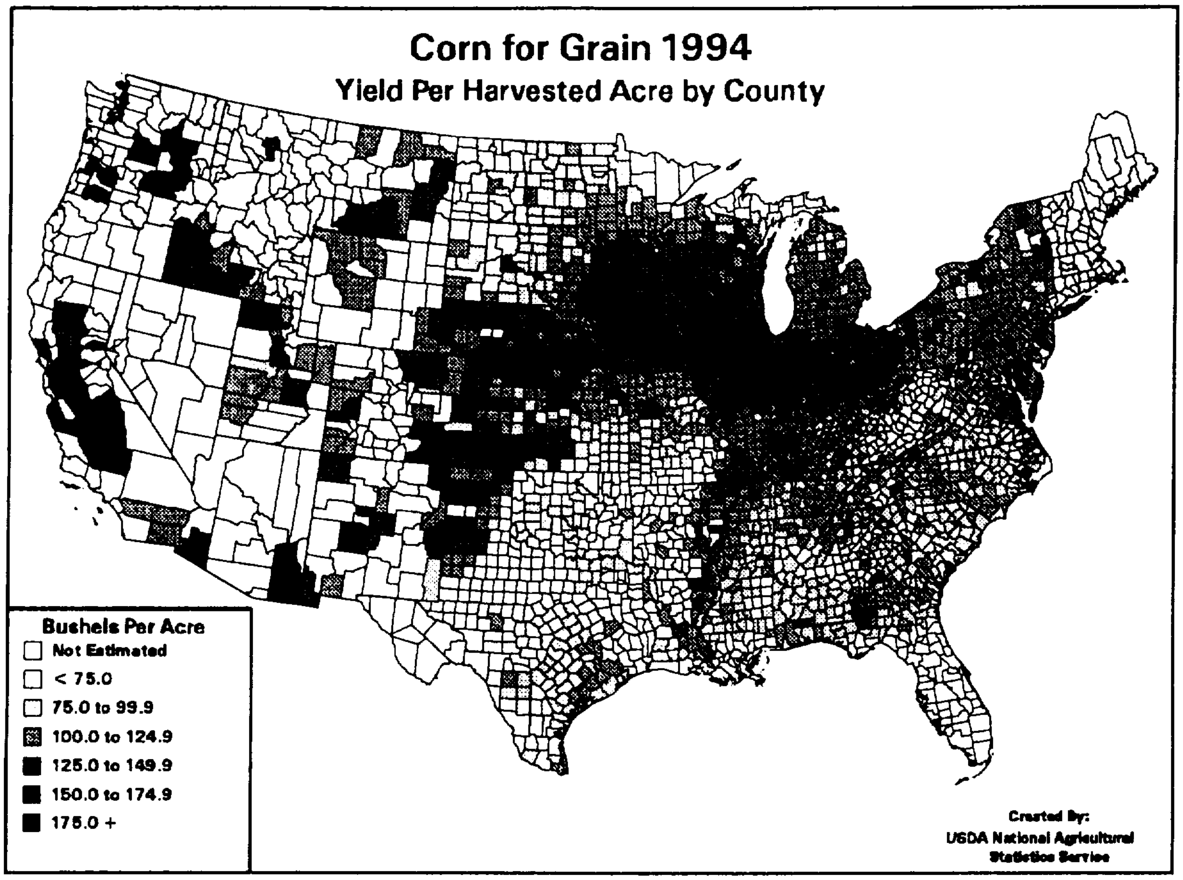

Figure 1. 1994 U.S. County Corn for Grain Yields per Harvested Acre

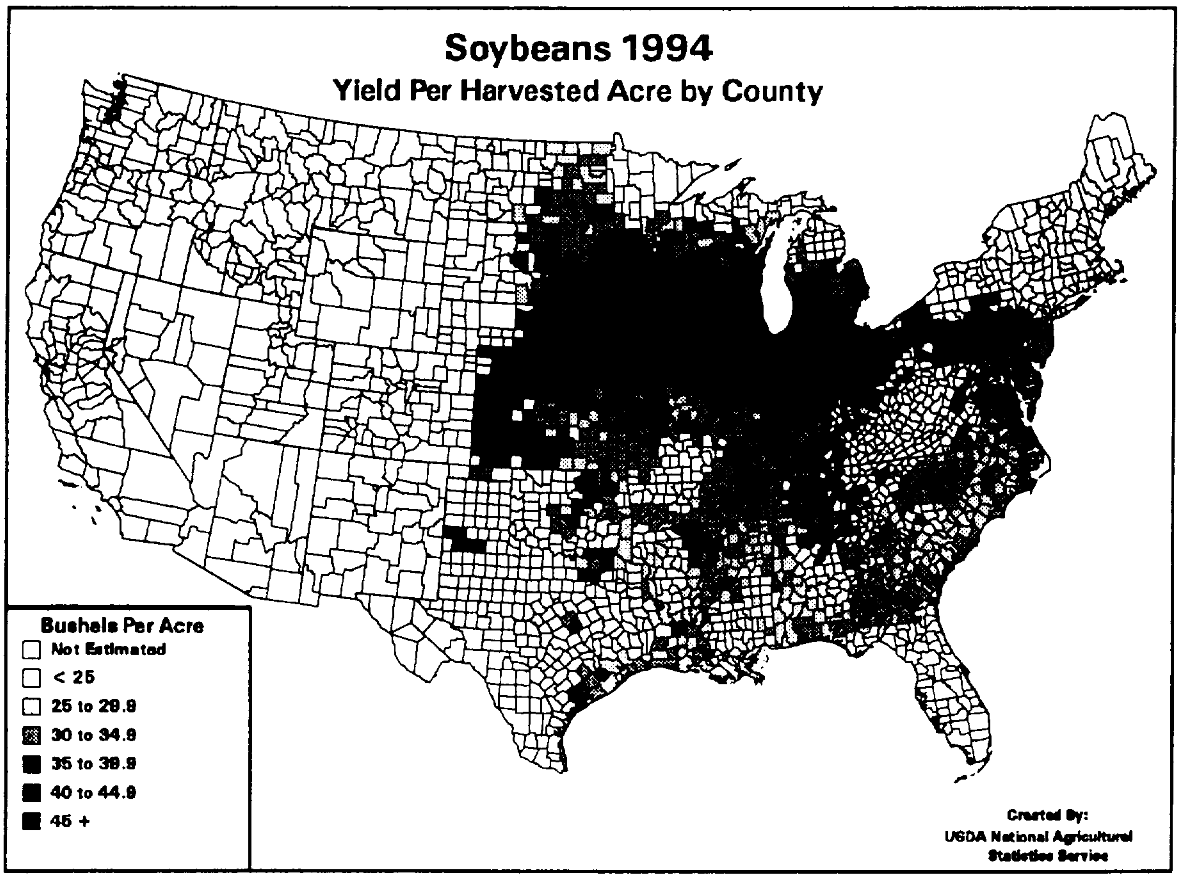

Figure 2. 1994 U.S. County Soybean Yields per Harvested Acre

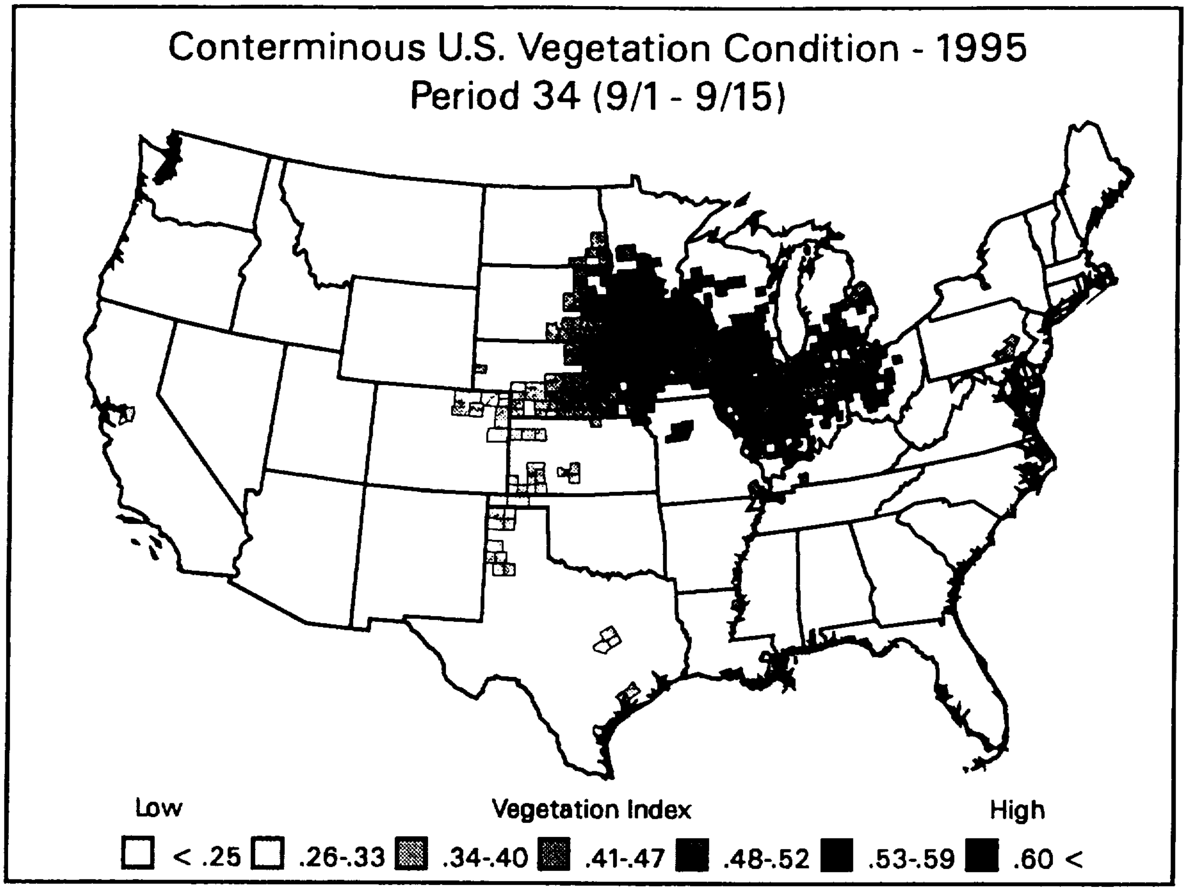

Figure 3. Period 34, (9/1 - 9/14) 1995 biweekly composite image overlaid with corn mask. Mask excludes counties with harvested acres less than 50,000 acres

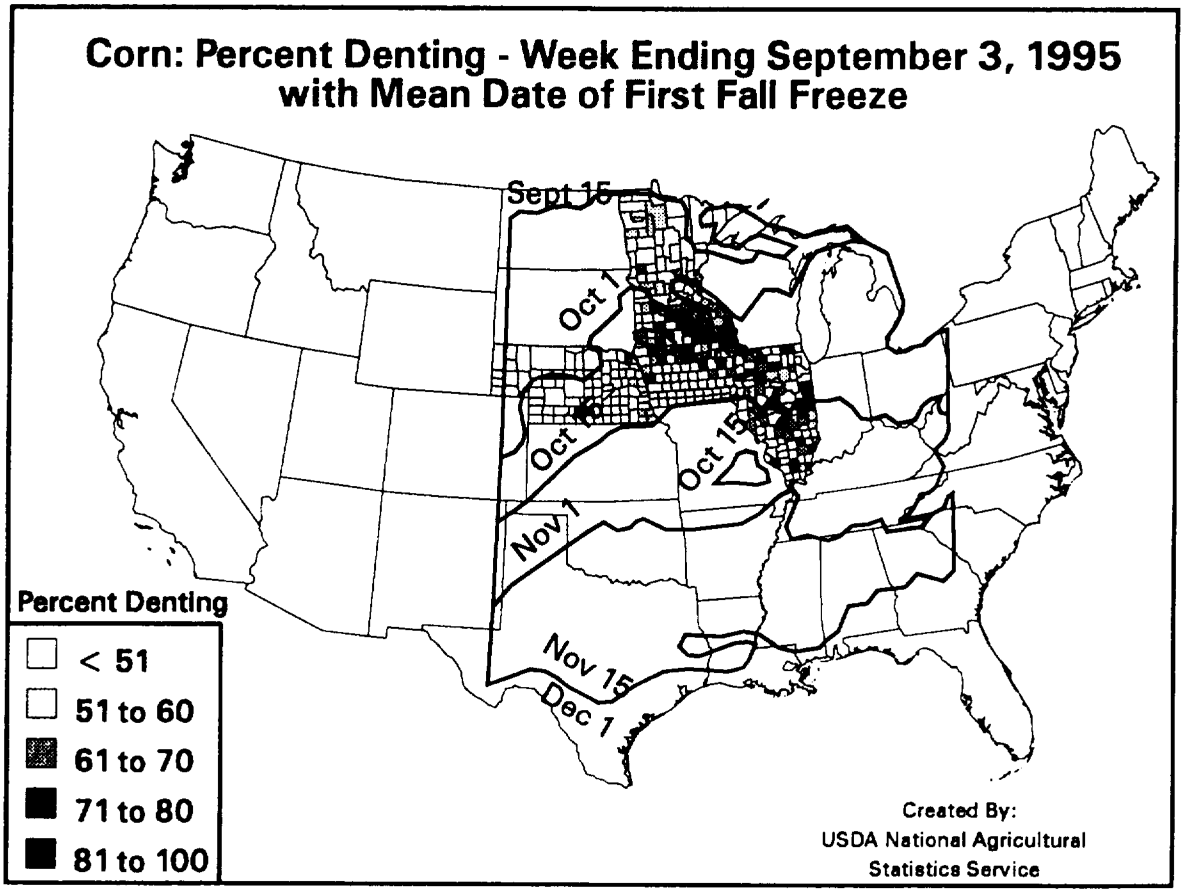

Figure 4. County Percent Corn Denting for Week Ending Sept. 3, 1995 with Historical Isolines

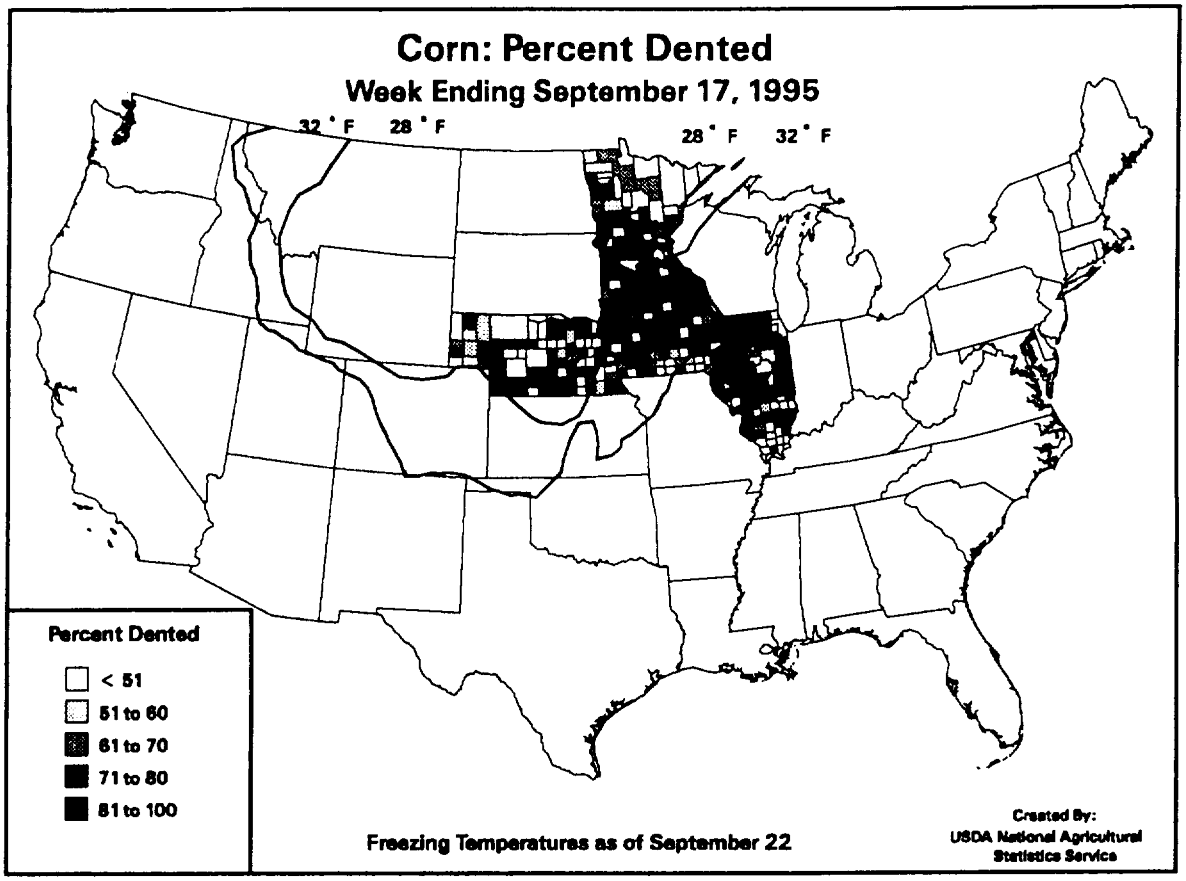

Figure 5. County Percent Corn Dented for Week Ending September 17, 1995 with 48 Hour Freeze Isolines

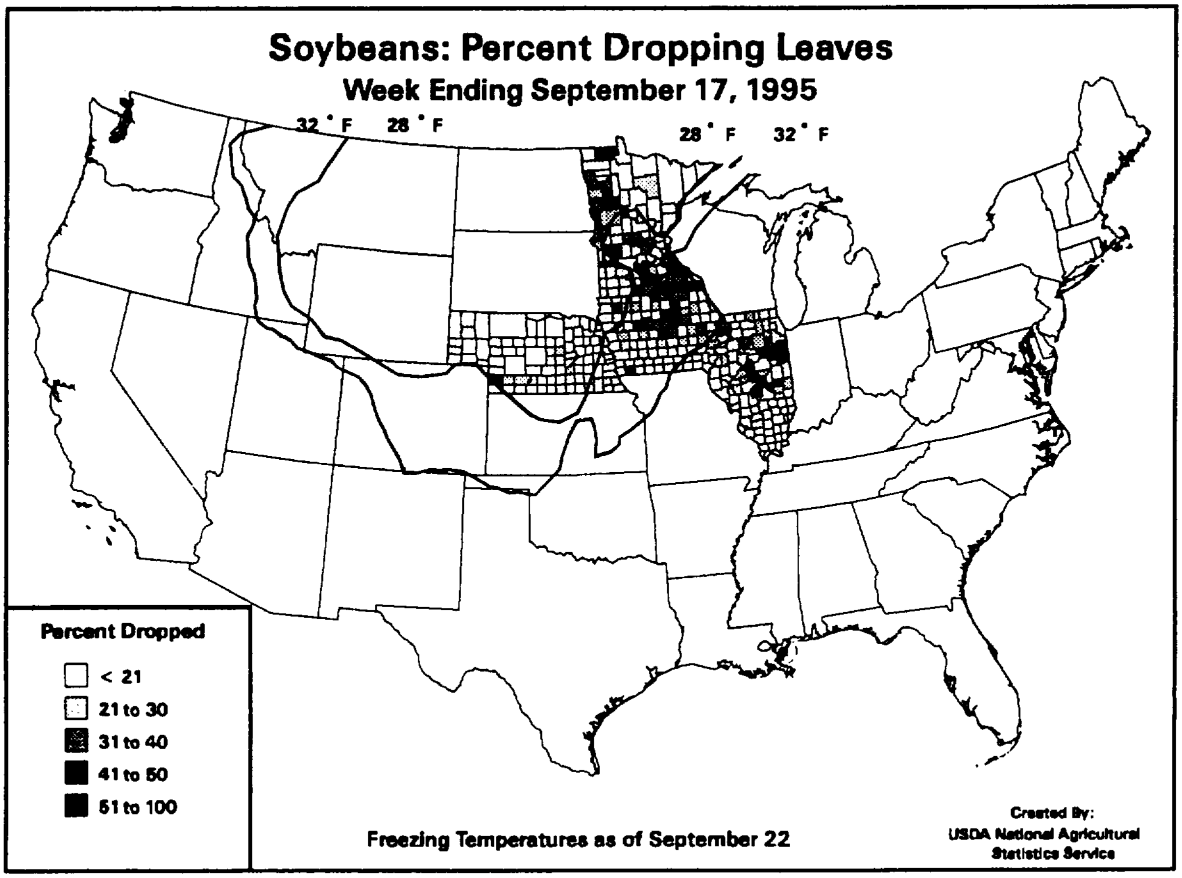

Figure 6. County Percent Soybeans Dropping Leaves for Week Ending September 17, 1995 with 48 Hour Freeze Isolines

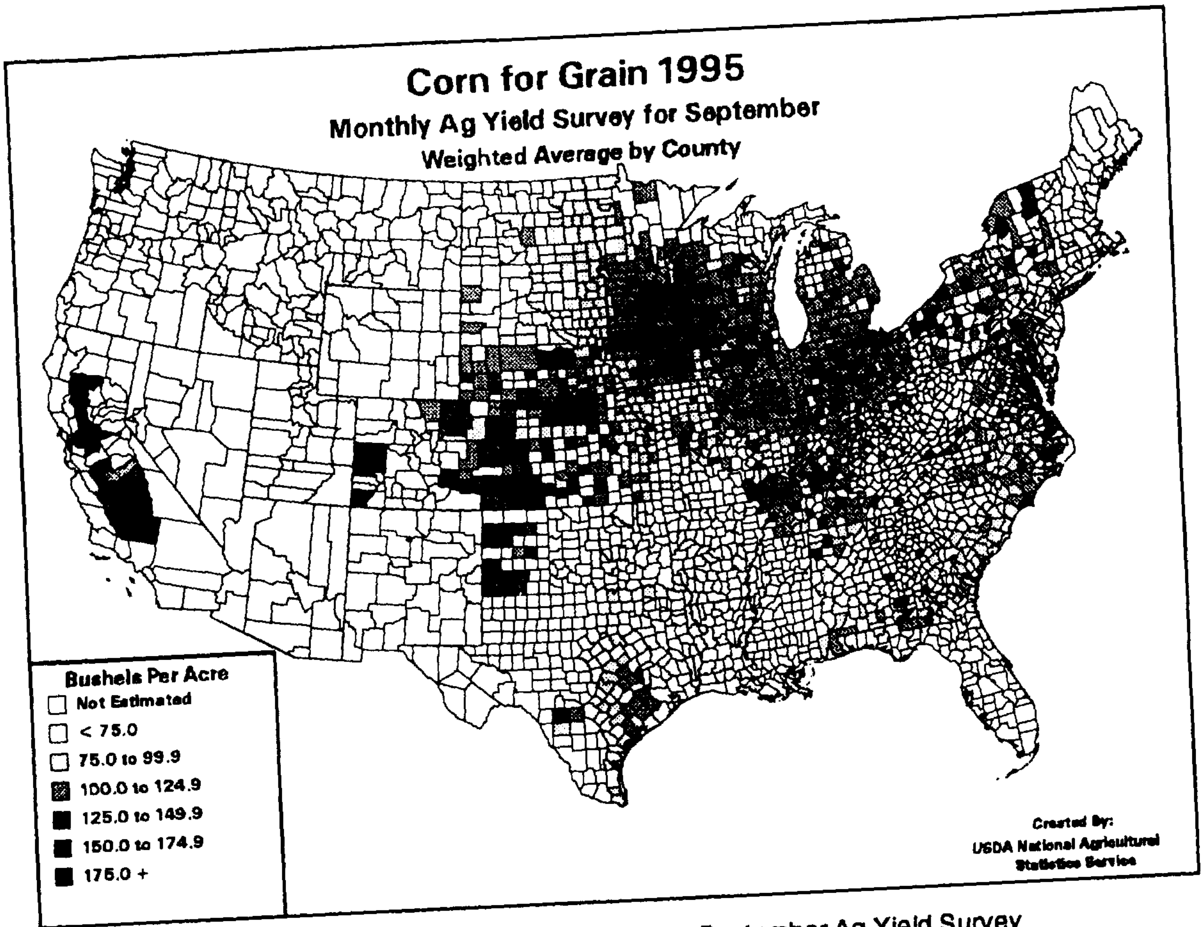

Figure 7. 1995 U.S. County Corn for Grain Yields from September Ag Yield Survey

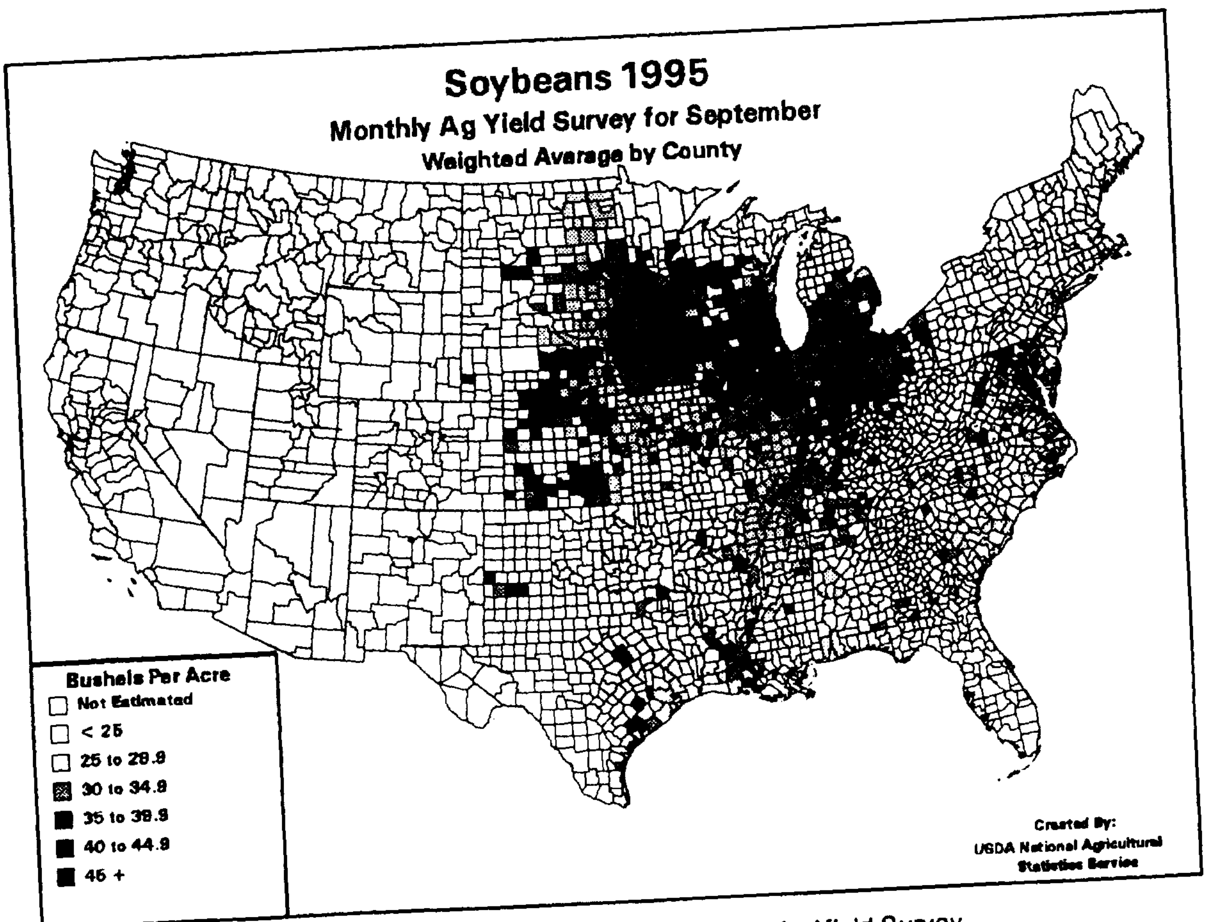

Figure 8. 1995 U.S. County Soybean Yields from September Ag Yield Survey