On the 2012 Drought in Midwest, USA

[1]G. Mallya, [2]L. Zhao, [3]X. C. Song, [4]D. Niyogi, and [5]R. S. Govindaraju

Introduction:

The 2012 North American Drought may be the costliest and one of the most widespread natural disasters in United States (US) history (USDA-ERS, 2012). While several states across the US were experiencing drought conditions to varying degrees of severity, the Midwest and Northern plains were perhaps the most affected. The drought severely impacted agricultural activities across the US, particularly corn and soybean crops, prompting federal agencies including U.S. Department of Agriculture to declare disaster areas (USDA, 2012b) and to provide assistance to those affected by this calamity. This article utilizes existing and new techniques to provide insights into the severity of the 2012 Midwest drought and its impacts over the region.

Potential Causes:

The weak winter storms across the US during winter of 2011 due to natural climate fluctuations, La Niña, are considered to be the primary cause of the 2012 drought. La Niña conditions prevail when the sea surface temperatures in the Pacific Ocean are lower than their long-term average value. While La Niña is known to affect the weather in different parts of the world, it is generally associated with dry conditions over the US. The areal extent of snowfall during winter of 2010 (11.25 million sq. Km) was nearly 12% less than mean areal extent (12.75 million sq. Km) observed over the period of 1967 to 2012. The lack of snowfall during the winter of 2010 resulted in lower snow melt in the early part of spring 2011 (Fig. A1; GSL, 2012), leaving behind drier soils. This further lead to the vicious cycle of reduced evaporation and decreased rainfall all through Spring, 2012. Record temperatures were also observed at several locations across the Midwest and other parts of the US during 2011 and 2012 (NOAA, 2011b; NOAA, 2012b). While

[1] Ph.D. student, School of Civil Engineering, Purdue University, West Lafayette, IN 47907, USA.
[2] Research Scientist, Rosen Center for Advanced Computing, Purdue University, West Lafayette, IN 47907, USA.
[3] Senior Research Scientist, Rosen Center for Advanced Computing, Purdue University, West Lafayette, IN 47907, USA.
[4] Associate Professor and Indiana State Climatologist, Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN 47907, USA.
[5] Professor, School of Civil Engineering, Purdue University, West Lafayette, IN 47907, USA.

the summer of 2011 was the second warmest (i.e. $74.5^{\circ}F$, or $2.4^{\circ}F$ above 20th century average) in US history after Dust Bowl era of 1936 ($74.6^{\circ}F$), the summer of 2012 was the third warmest at $74.4^{\circ}F$ (Figure A2-A3; NOAA, 2011a; NOAA, 2012a). This intense heat wave contributed towards the intensification of the drought particularly over the Midwest and the Northern Plains. Figures 1a-b show the percentage deviation of monthly mean temperatures from their long term average values during July 2011 and July 2012, respectively. In general, the temperatures across the Midwest were approximately 20-30% higher than long term average values for the two summer months.

Drought monitoring:

Drought indices are used to monitor the onset, severity and duration of droughts. Detailed reviews of different indices used to characterize droughts are available in the literature (Dracup et al., 1980; Heim, 2002; Mishra & Singh, 2010; Dai, 2011). In this study, drought characteristics such as severity and extent were analyzed over the Midwest using the standardized precipitation index (SPI; McKee et al., 1993), the hidden Markov model-based drought index (HMM-DI; Mallya et al., this issue), and U.S. Drought Monitor maps (Svoboda et al., 2002). While SPI and HMM-DI use precipitation as the input variable to characterize droughts, the U.S. Drought Monitor uses a blend of drought indices and inputs from experts while generating drought severity maps (details in Svoboda et al., 2002). Since the drought indices differ in their mathematical formulation, the drought characterization does vary between indices.

Monthly precipitation and temperature data for the Midwest were obtained for co-operative (COOP) stations from National Climatic Data Center (NCDC). A total of 1286 COOP stations were available with data record length greater than 50 years (Fig. 2). SPI and HMM-DI were computed for different time windows (1, 2, 3, 6, and 12 months) that represent the typical time-scale of droughts. To conform to the US Drought Monitor classification scheme, both SPI and HMM-DI classify droughts into 5 classes (D0-D4) as in Table 1. As agriculture is one of the major drivers of local economies in the Midwest and are susceptible to droughts, results for 1-month time window are discussed here. SPI and HMM-DI gridded maps $\left(0.1^{\circ}\text{ resolution}\right)$ were generated using linear interpolation to help visualize the spatial extent of droughts.

During June 2012, the SPI (Fig. 3a) shows that majority of Midwest was experiencing drought conditions. According to this index, large extents of Indiana, Illinois and Kentucky were experiencing D3-D4 category droughts. Parts of other Midwestern states such as southern Wisconsin, northwest Ohio, and southwest Minnesota experienced D2-D4 category droughts. Figure 4 shows the percentage area of Midwest experiencing different drought categories for the period of January 2009 to September 2012. The percentage area experiencing D0-D4 category droughts showed a significant increase during the summer months (June to August) of 2012. For example, during June 2012, 65% of the Midwest was experiencing drought (D0-D4) with nearly 30% of the area experiencing D2-D4 category droughts. The HMM-DI plots (Fig. 5) show the probability of a region experiencing different drought categories (D0-D4). During June 2012, according to HMM-DI index (Fig. 5a), large extents of Midwest were experiencing drought. Specifically Indiana, Illinois, Kentucky and southern parts of Wisconsin showed high probabilities of D4 category drought. Parts of Missouri, northwest Indiana and Ohio were experiencing D2-D3 category droughts. The probabilistic framework of HMM-DI reveals the model uncertainty in assigning drought classes to a region (Mallya et al., this issue). Figure 6 shows the percentage area of Midwest experiencing different drought severities according to HMM-DI. Drought conditions prevailed over the Midwest as early as July of 2011, with D3-D4 category droughts intensifying during June-August 2012. Specifically, during June 2012, 52% of Midwest was experiencing droughts (D0-D4) with nearly 36% of the area experiencing D2-D4 category droughts. The drought map released by U.S. Drought Monitor during the last week of June 2012 (Fig. 7a) shows that large extents of the Midwest were experiencing D1-D2 category droughts. Southern Illinois, southwest and northeast Indiana, and western parts of Kentucky were experiencing D3 category drought.

For July 2012, SPI (Fig. 3b) shows reduction in drought severity across Kentucky, Ohio and parts of Indiana. During the same period, drought intensified over Illinois, Iowa, Wisconsin and Minnesota, thereby showing a spatial shift towards the Northern Plains. Similar conclusions can be drawn using HMM-DI (Fig. 5b), with droughts showing a clear shift towards the west. Large parts of Illinois and Iowa were experiencing D3-D4 category droughts. For the same period, the

U.S. Drought Monitor (Fig. 7b) shows that southern Illinois and southwest Indiana were experiencing a D4 category drought; large extents of Indiana, Illinois and Missouri were experiencing a D3 category drought; Iowa, parts of Wisconsin and Michigan were experiencing a D2 category drought; and Kentucky showed improvement in drought conditions. The temperatures were warmer over Illinois, Missouri and Iowa during this period.

Finally for August 2012, SPI (Fig. 3c) shows that central region of Missouri and Kentucky, northern parts of Minnesota, Wisconsin and Michigan, and southern Ohio were experiencing D3-D4 category droughts. Large parts of Illinois and Indiana saw relief from droughts during this period. HMM-DI (Fig. 5c) also shows that Missouri, Kentucky, Minnesota, Wisconsin and Michigan experienced D2-D4 category droughts. According to U.S. Drought Monitor release (Fig. 7c) at the end of August 2012, D4 conditions continued to prevail over southwest Indiana, southern part of Illinois, and western Missouri. Large extents of Iowa, Illinois and Indiana experienced a D3 category drought. Drought severities either remained same or improved in Minnesota, Wisconsin and Michigan during this period. The temperature distribution (Fig. 1c) shows that Missouri and southern Illinois experienced relatively warmer temperatures.

From the foregoing discussion, it is clear that both SPI and HMM-DI provide similar drought classification for the three summer months. However, U.S. Drought Monitor classification was a little different because these maps are produced based on a variety of inputs - drought intensity blend from five key indicators (Palmer Drought Severity Index, CPC Soil Moisture Model percentiles, USGS Weekly Streamflow percentiles, SPI, short and long-term drought indicator blends); supplementary indicators; use of region specific weights for drought indicators; expert local inputs such as soil moisture levels, reservoir levels and so on (Svoboda et al., 2002). A drought index, such as SPI, is generally calculated for several time scales, ranging from one month to 24 months, to capture the various scales of both short-term and long-term droughts. However, Palmer Drought Severity Index (which is one of the five key indicators used in U.S. Drought Monitor) is not able to depict drought for time scales shorter than 12 months (Vicente-Serrano et al. 2011).Therefore, the inherent time scales used for different indicators that contribute to the U.S. Drought Monitor map differ based on their definition. The U.S. Drought Monitor clearly states that the maps are designed to provide the 'big picture' so the public, media, and federal and state agencies can remain updated on the drought condition across the United States (USDM 2008).

Drought Impacts:

Drought, a form of moisture deficit, can have negative impacts on society, the environment, and the economy of the region (Dracup et al., 1980). However, reporting and quantifying the impacts due to droughts remains a challenge even today. In United States, several agencies such as NOAA, USDA, USGS, NIDIS, and US Drought Monitor publish reports periodically that list different types of drought impacts. Some of the most commonly cited drought impacts include: reduced agricultural yield, forest fires, and water scarcity in the form of low - streamflow, reservoir, lake and groundwater levels.

The drought of 2012 had severe impacts over the Midwest region. The Drought Impact Reporter (DIR; Wilhite et al., 2007) launched by National Drought Mitigation Center (NDMC) provides a comprehensive database for the different types of impacts, as well as the sources that reported the impacts. Figure 8a shows a bar graph of the number of drought impacts that were reported in the Midwest between 2000 - 2012. A record number of impacts were reported during 2012, with agricultural impacts being predominant. Figure 8b provides insight into the number of drought impacts reported in the Midwest from January 2012 to October 2012. While agricultural impacts dominated all other impact categories during each month, the largest number of impacts were reported in July 2012. One may recall that during July 2012, large extents of Midwest were experiencing D2-D4 category droughts and record temperatures were also reported in many parts due to an intense heat wave over the region. Figures 9a and 9b show the sources that reported the drought impacts over the Midwest.

According to USDA-ERS drought outlook (USDA-ERS 2012), nearly 60% of the farms in the United States were experiencing droughts during summer of 2012. Although drought conditions showed signs of improvement since September 2012, most of the crops were severely impacted due to extreme drought conditions in summer. The low yields and quality of crops were discussed in the media (AGWEB 2012). Since agricultural impacts were reported frequently during the 2012 drought, crop data available for the period were studied. Annual yield and production data for corn and soybean were collected from National Agricultural Statistics Service (NASS) for the period 2011 and 2012. Figure 10a shows the total corn production in each Midwestern state during 2011 and 2012. Except for Minnesota, all Midwest states showed a decrease in total corn production in 2012 compared to 2011. Figure 10b shows that the average corn yield per acre decreased significantly during 2012 in comparison to 2011 in all Midwest states except Minnesota. As a result of reduced corn yield, season-average corn prices for the 2012/13 marketing year were forecasted to fall within a range of $6.95-$8.25 per bushel, up from the average of $6.22 for 2011/12 (USDA-ERS 2012). Figure 10c shows the total soybean production in each Midwest state during 2011 and 2012. Again with the exception of Minnesota, soybean production showed a decline in all Midwest states during 2012. The average soybean yield per acre also showed a decrease during 2012, except in Minnesota (see Fig. 10d). Reduced soybean yield for the 2012/13 marketing year pushed prices to record highs. Season-average prices for 2012 were forecasted to be between $13.90-$15.90 per bushel. For 2012/13, soybean oil prices were expected to average 51-55 cents per pound, compared with 52 cents per pound estimated for the 2011/12 marketing year, while soybean meal prices were projected at $455-$485 per short ton, up from an estimated $394 per ton for the 2011/12 marketing year (USDA-ERS 2012).

U.S. livestock sectors were also hard hit due to drought. According to USDA-ERS (2012), higher feed prices, low crop yields, poor pasture conditions, and higher temperatures had a negative impact on cattle, hogs, poultry and milk production. A combination of impacts on the agricultural farms and livestock sector resulted in the increase of food prices. Retail prices of poultry (10%), beef (16%), pork (15%), dairy products (2%), packaged and processed corn products also saw an increase due to droughts.

To enable better understanding of the causal factors for short and long term droughts and to disseminate local to regional scale drought information, a web-based geospatial drought assessment platform Drought Information Network (DRInet; Zhao et al., 2011) has been developed at Purdue University. The goal of DRInet (http://drinet.hubzero.org) is to encourage increased communication and cross-synthesis of different data sources to better explain the role of hydrologic and meteorologic variables on droughts, and to quantify and evaluate drought impacts for different stakeholders. DRInet contains an Indiana drought information web page that provides a summary of the current drought related parameters for the state. The parameters include precipitation, soil moisture, air and surface temperature, stream flow, crop moisture index and greenness as measured by satellite sensors plus related outlooks maps. For example, it provides the images of greenness deviation from coverage created from satellite data to illustrate weekly changes during 2012.

DRInet is home to researchers and students allowing them to publish their own models and tools, datasets, analyses, visualization, training and educational materials for studying droughts. Tools published on DRInet can be accessed from a web browser. For example, Drought Impact Viewer tool uses three layers of information to evaluate drought impact. One is a NASS crop data layer for a specified year. The second is a drought index layer from the Midwestern Regional Climate Center that is released weekly. The third layer is the county boundaries for Indiana. The NASS crop data layer represents 13 categories of crops and other land uses. The tool provides a breakdown of crops affected by different levels of drought in Indiana. Figure A5 shows the extent to which crops were affected by different drought levels in Indiana during July, 2012. Nearly 77% of corn and 71% of soybean that were grown in Indiana were affected by D2-D4 category droughts during July 2012. Other tools that are available on DRInet include: Water Balance Viewer that is designed to display the water balance for the selected hydrologic unit code within Indiana; JDI-Precipitation-Viewer helps visualize the Joint Deficit Index (JDI; Kao & Govindaraju 2010; Govindaraju & Tripathi 2009) of precipitation by providing an objective (probability-based) description of the overall drought status and allows a month-by-month assessment for drought recovery; Stream Deficit Viewer depicts drought state of streams in Indiana using JDI (Kao & Govindaraju 2010) and also shows the probability of recovering from an existing drought state; HMM-based Drought Index Viewer graphs the probabilistic classification of drought by HMM-DI (Mallya et al., this issue) and discrete classification of drought by SPI (McKee et al., 1993); Water Deficit Viewer (Govindaraju et al., 2009) shows the amount of precipitation required to recover from an existing drought and the probability of such recovery for a chosen time-scale of drought. These online tools can help decision makers at drought mitigation agencies in evaluating droughts and carrying out effective relief efforts.

Drought relief:

To cope with the many negative effects of droughts, several federal and state agencies made drought relief funds available to affected areas. NRCS for example, released a combined total of $8.5 million (NRCS 2012) as drought assistance to several Midwest states as of September 2012. These funds were provided to implement conservation practices, including conservation tillage, cover crops, nutrient management, prescribed grazing, livestock watering facilities and water conservation practices. USDA offers several drought assistance programs that provide credit assistance, crop insurance and assistance, livestock assistance, and watershed protection assistance. During the 2012 drought, USDA announced (USDA 2012) $16 million in technical and financial assistance to help crop and livestock producers to cope with droughts. In addition, USDA made available $14 million in unobligated funds to Emergency Conservation Program. This fund will be used to make water and emergency forage available to the livestock in need, and to rehabilitate lands that were severely impacted by the drought.

Current drought outlook over the Midwest:

While the Midwest was in the grip of extreme drought during summer of 2012, signs of improvement were visible since September, 2012. As of November 2012 (the writing of this article), Moderate to Extreme drought (D1-D3) conditions were still prevalent in upper and western Midwest (see Fig. A4), with above normal temperatures being reported in several areas.

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Tables:

Table 1: US Drought Monitor classification scheme

Category	**Description**	**SPI Range**
D0	Abnormally Dry	-0.5 to -0.7
D1	Moderate Drought	-0.8 to -1.2
D2	Severe Drought	-1.3 to -1.5
D3	Extreme Drought	-1.6 to -1.9
D4	Exceptional Drought	-2.0 or less

Figures:

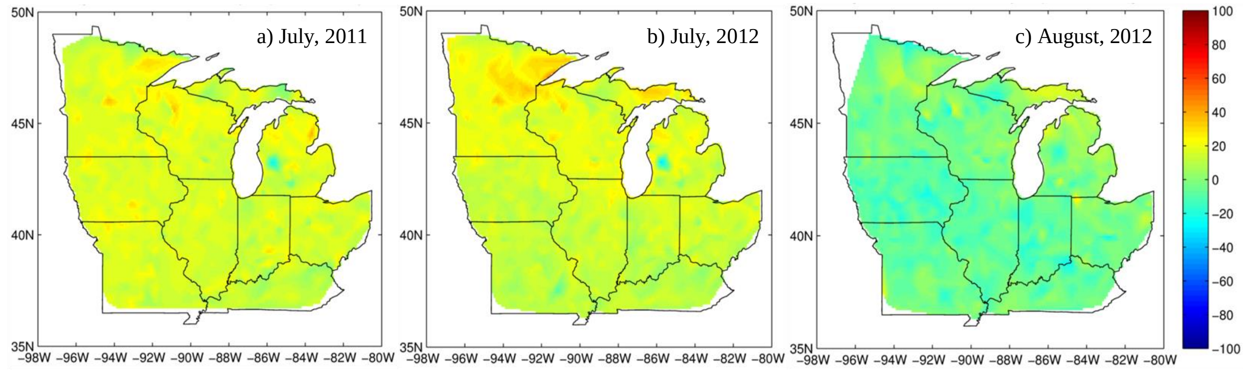


Figure 1: Percentage deviation of monthly mean temperature from long term average during: a) July 2011, b) July 2012, and c) August 2012.

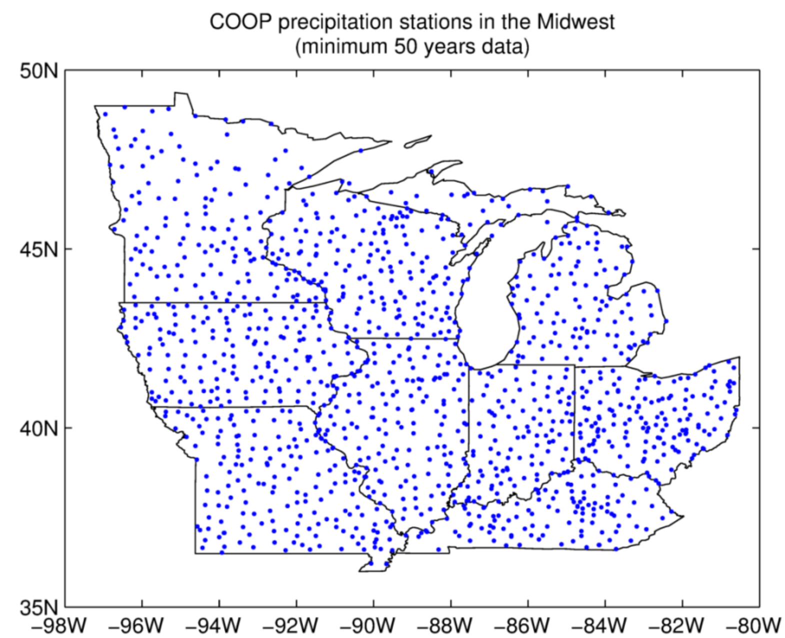


Figure 2: COOP precipitation stations across the Midwest with data record length greater than 50 years.

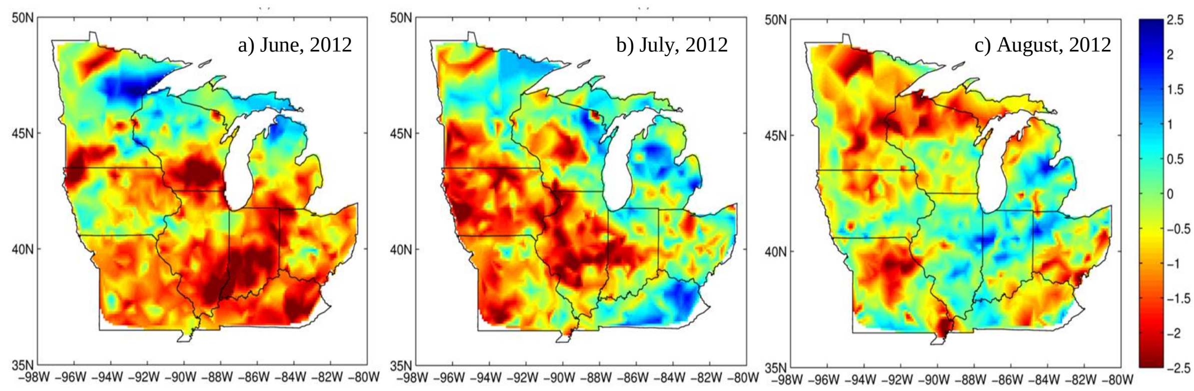


Figure 3: SPI values for 1-month time window across the Midwest during: a) June 2012, b) July 2012, and c) August 2012.

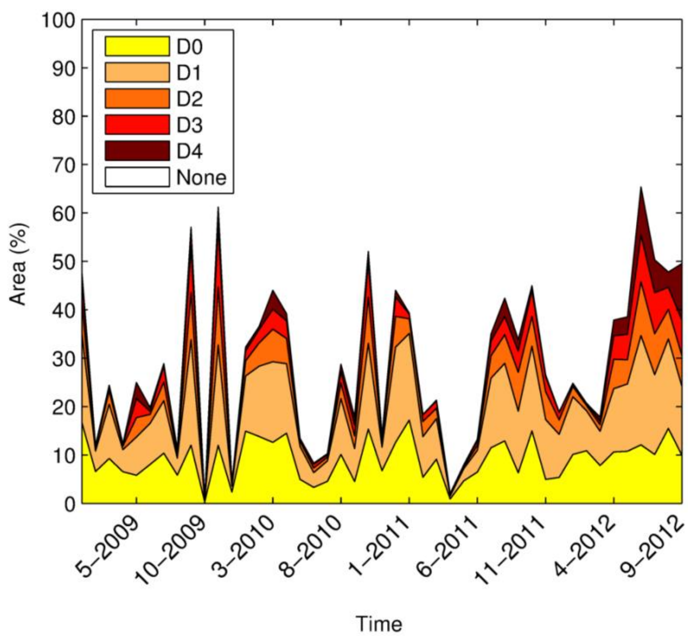
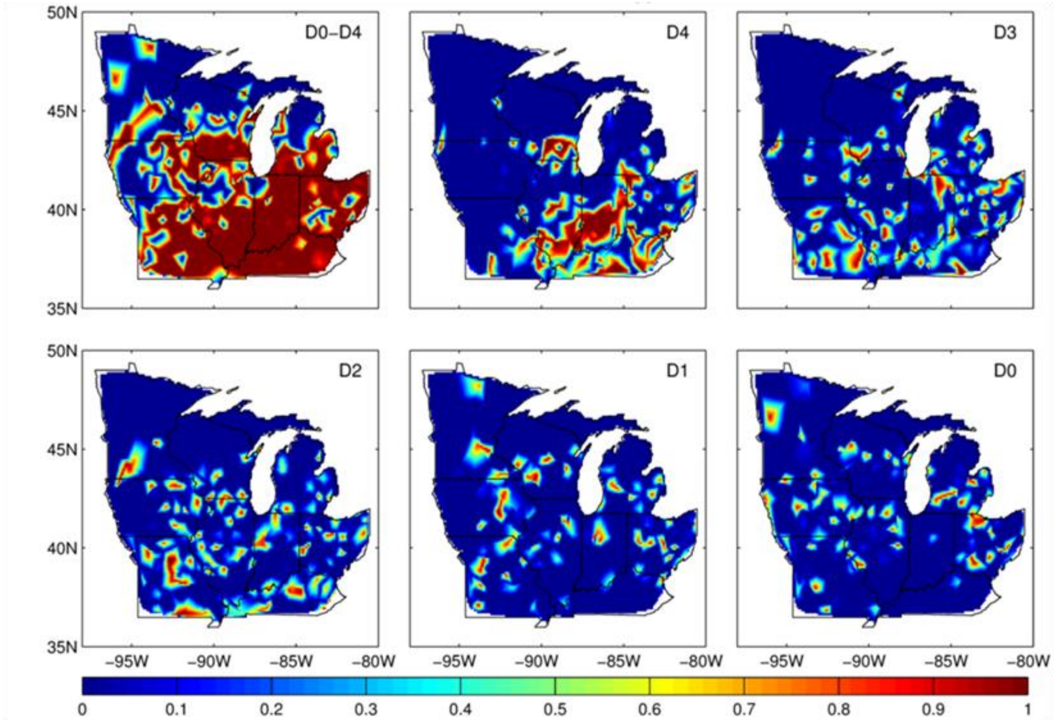
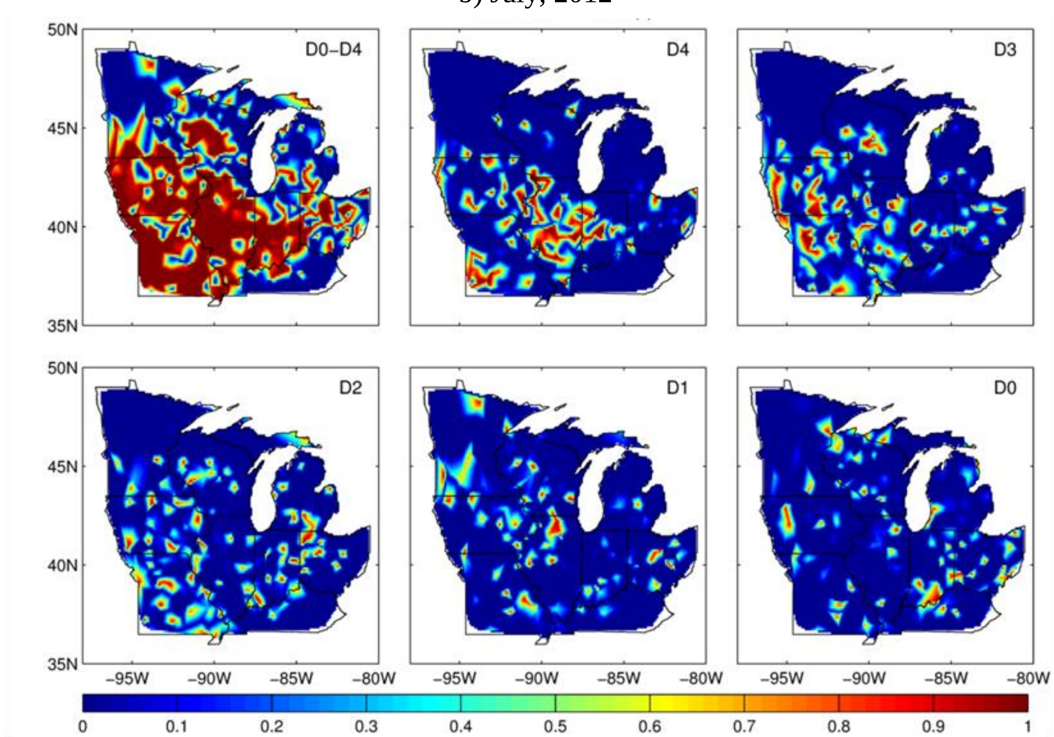


Figure 4: Percentage Area under drought using 1-month SPI values.

a) June, 2012



b) July, 2012



c) August, 2012

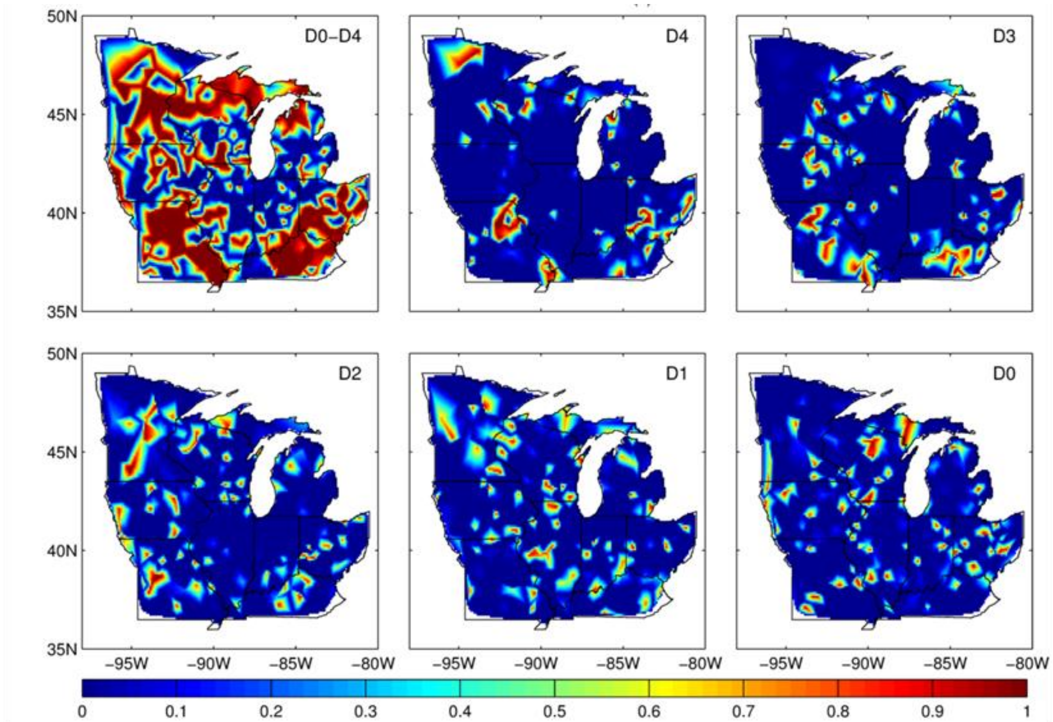


Figure 5: HMM-DI probabilities for 1-month time window across the Midwest during: a) June 2012, b) July 2012, and c) August 2012.

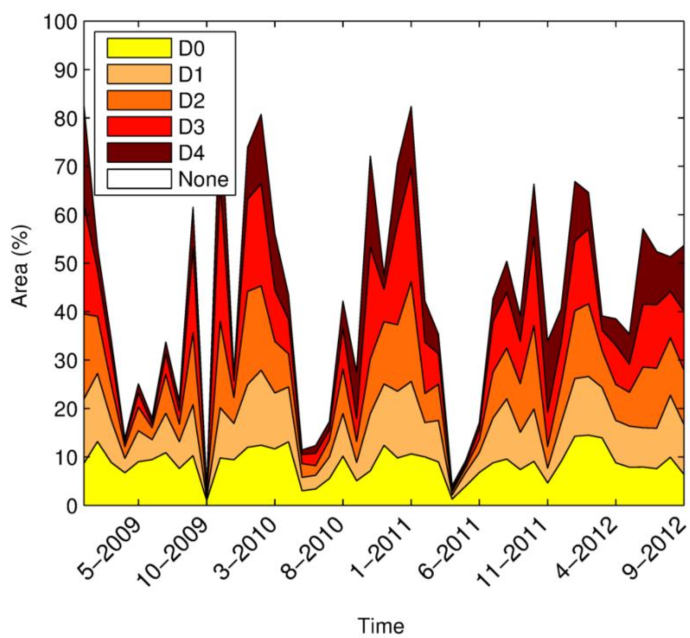


Figure 6: Percentage Area under drought using 1-month HMM-DI.

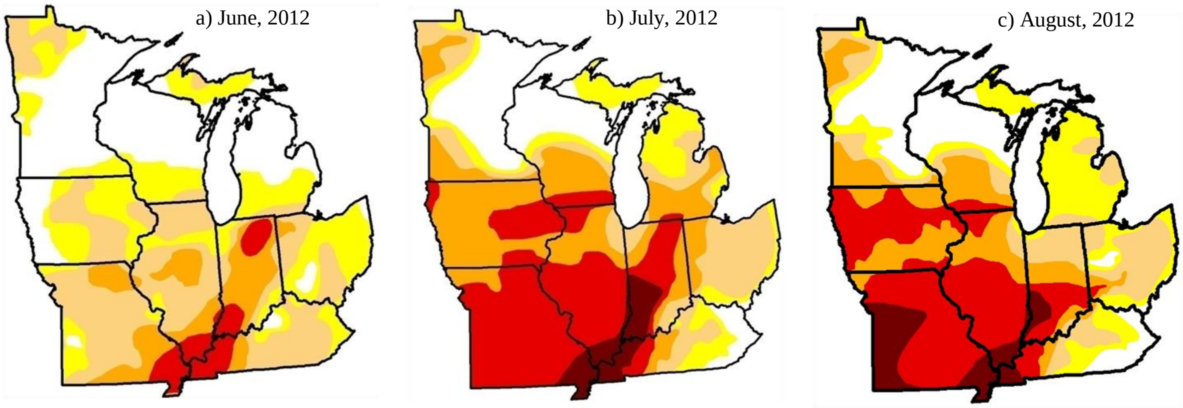


Figure 7: U.S. Drought Monitor maps for the Midwest during: a) June 2012, b) July 2012, and c) August 2012. (Source: National Drought Mitigation Center, University of Nebraska-Lincoln)

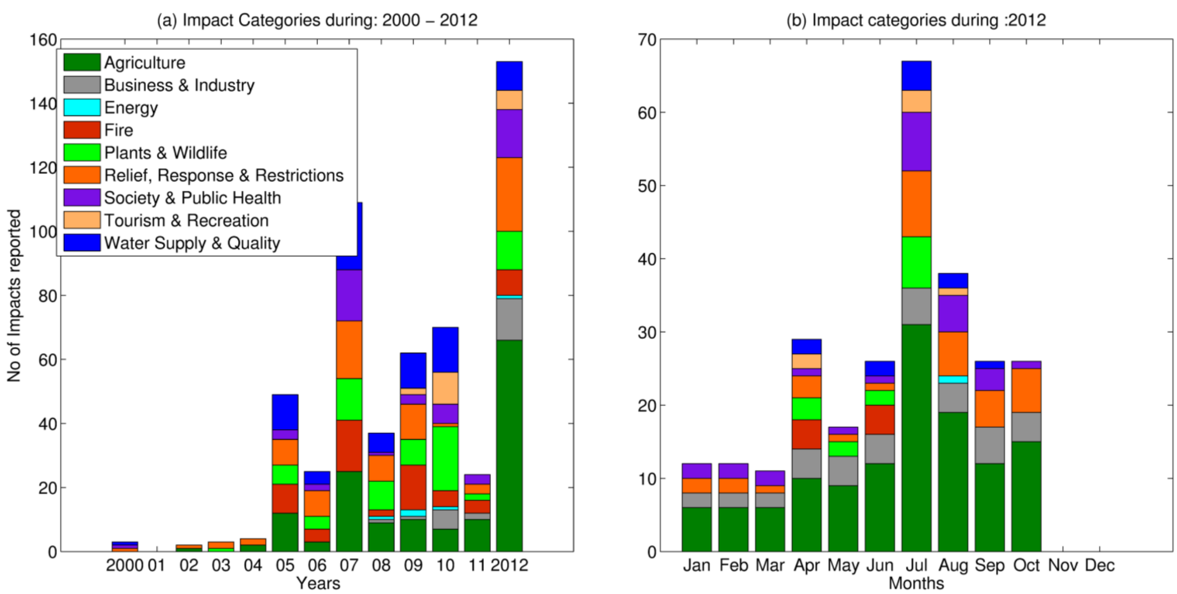


Figure 8: Drought Impact categories reported for Midwest. (Source: Based on data obtained from Drought Impact Reporter, National Drought Mitigation Center, University of Nebraska-Lincoln)

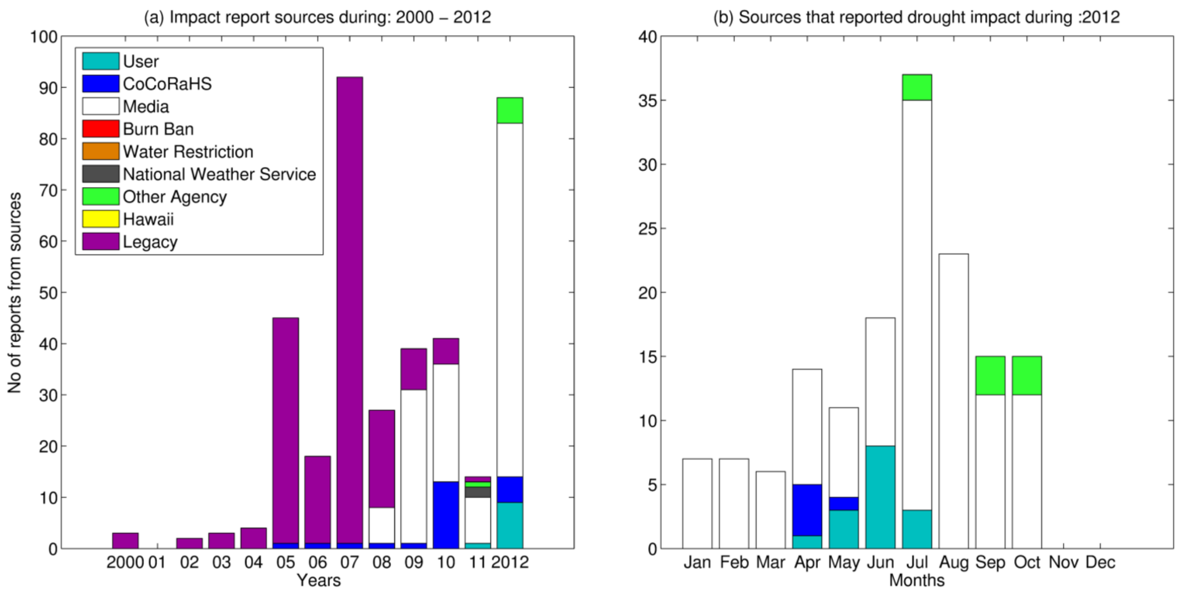


Figure 9: Sources that reported drought impact for Midwest. (Source: Based on data obtained from Drought Impact Reporter, National Drought Mitigation Center, University of Nebraska-Lincoln)

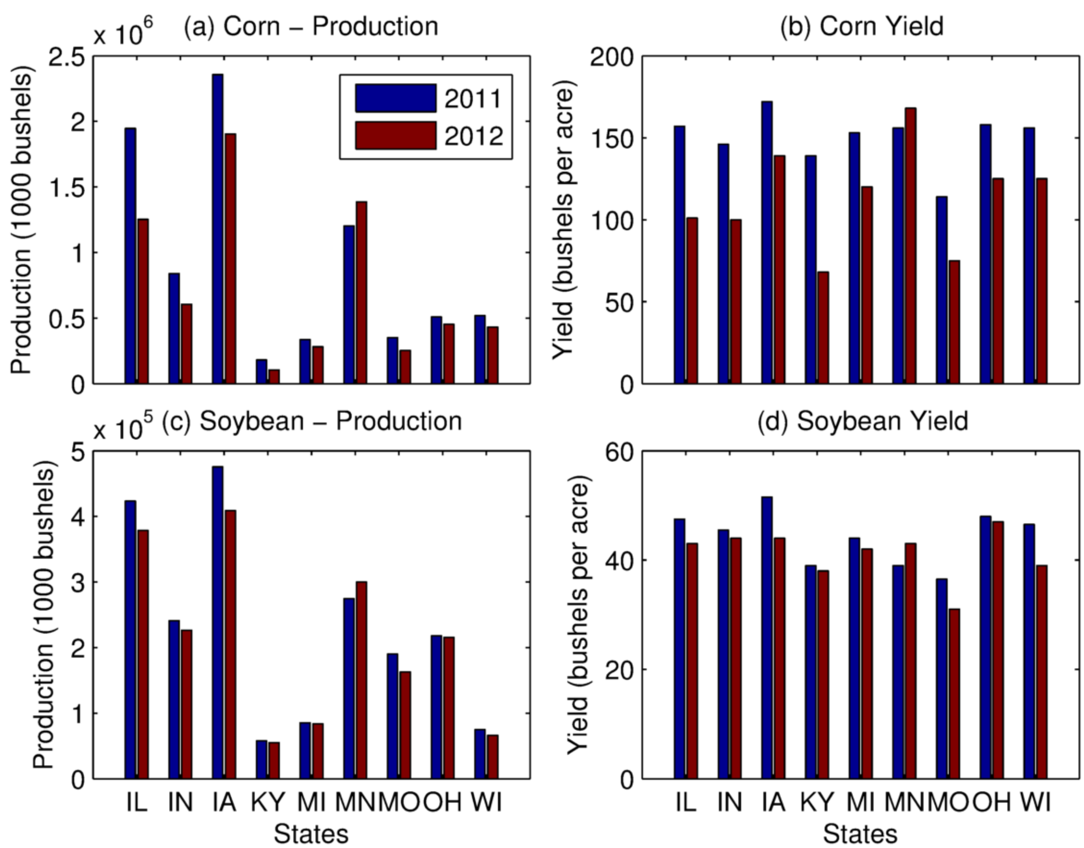


Figure 10: Crop yield variation for Midwest states during 2011 and 2012.

Appendix A:

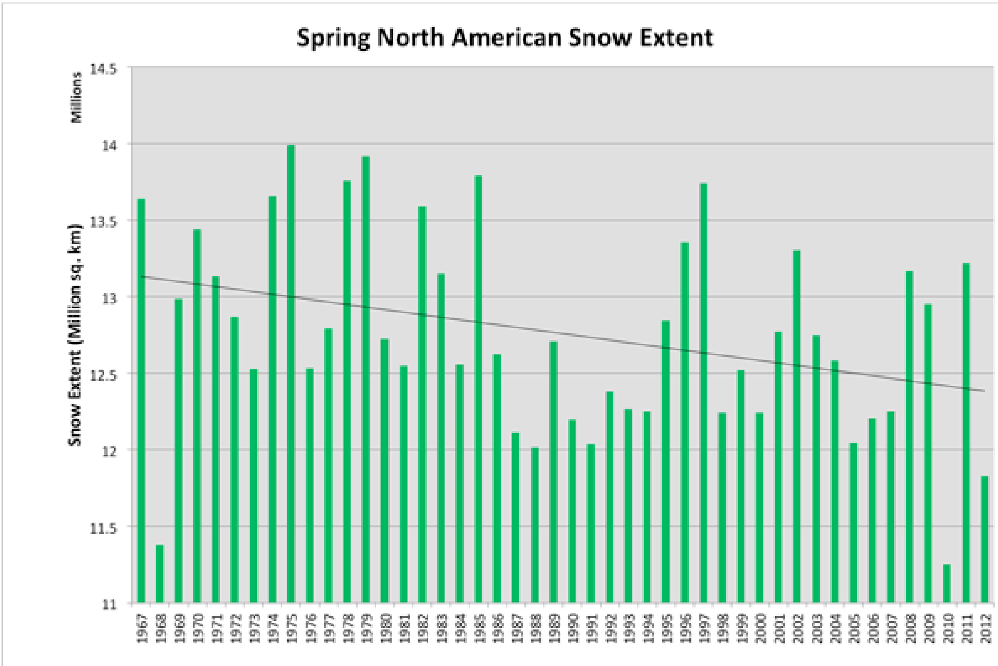


Figure A1: Areal extent of snowfall during Spring over United States. (Source: Global Snow Lab, Rutgers University)

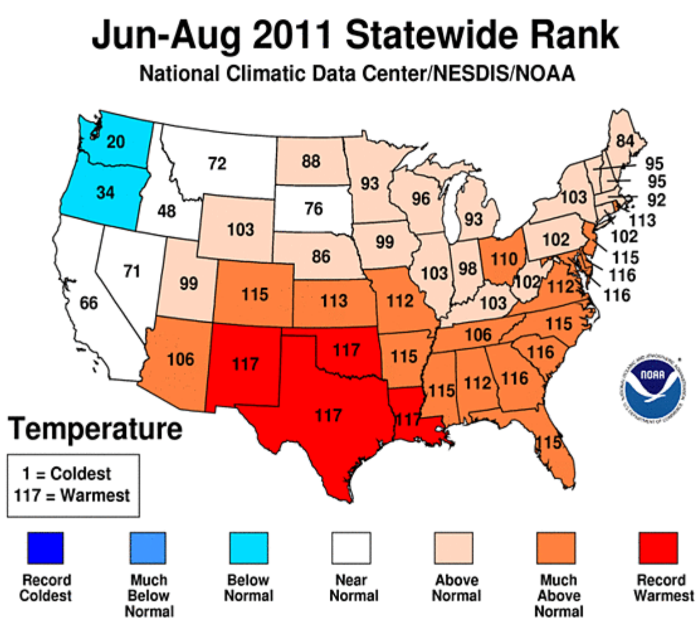


Figure A2: Maximum recorded temperatures across United States during summer of 2011. (Source: National Climatic Data Centre, NOAA)

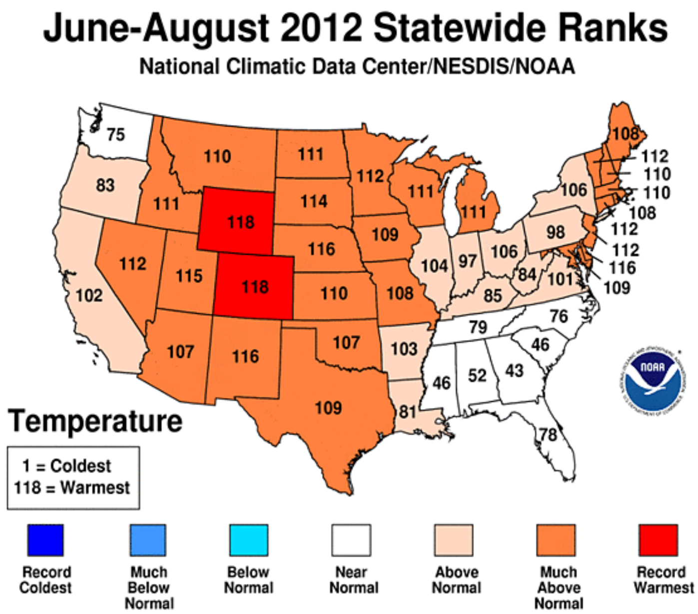


Figure A3: Maximum recorded temperatures across United States during summer of 2012. (Source: National Climatic Data Centre, NOAA)

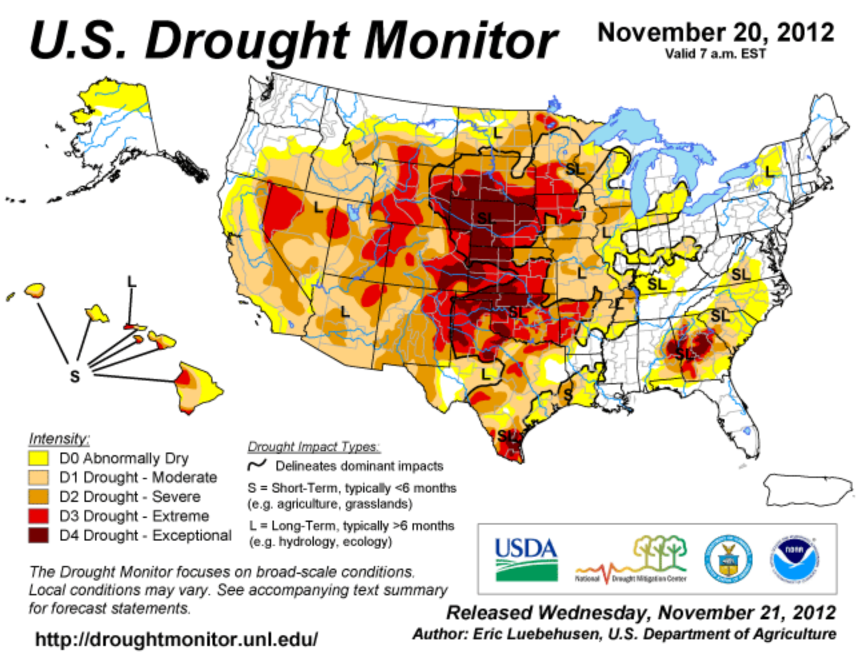


Figure A4: U.S. Drought Monitor map during November, 2012. (Source: National Drought Mitigation Center, University of Nebraska-Lincoln)

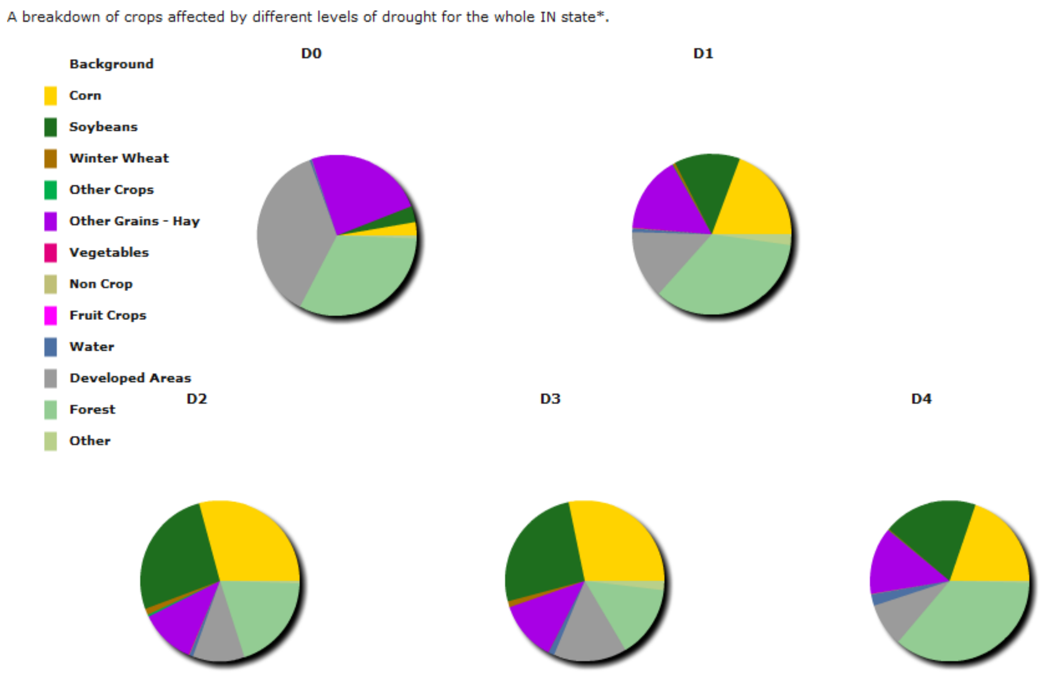


Figure A5: Drought Impact Viewer output for Indiana during July 2012 (Source: DRInet)