A phenological atlas of major crops from the United States Heartland

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4/13/09

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National Agricultural Statistics Service

The following time-series charts describe the phenology, or seasonal life cycle, in terms of satellite observed Normalized Difference Vegetation Index (NDVI) for primary crops across 15 intensively cultivated states of the interior United States. They were derived by intersecting known field location and crop type information from the Farm Service Agency (FSA) against remotely sensed imagery from the National Aeronautics and Space Administration's Terra polar orbiting Earth observing satellite. These charts help objectively portray the growth and senescence cycles of crops regionally in recent years. They may also be useful for analysis against crop progress, condition, or yield information.

States included are Arkansas, Illinois, Indiana, Iowa, Kansas, Louisiana, Minnesota, Mississippi, Missouri, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota, and Wisconsin. Years covered are 2006, 2007, and 2008. Crops analyzed are alfalfa, barley, corn, cotton, oats, rice, sorghum, soybeans, and wheat (durum, spring, winter).

NDVI is a biophysical measurement of the amount of biomass and vigor of vegetation and calculated from multispectral imagery channels as

$$\text{NDVI} = (\text{Near-infrared} - \text{Red}) / (\text{Near-infrared} + \text{Red}).$$

Theoretical values range from -1.0 to 1.0 but more practically 0.1 is typically close to the minimum (correlated with bare soil) while 0.9 is near the maximum (representing dense, fully leafed-out vegetation). Because NDVI is normalized it allows for consistent comparison of vegetation conditions across differing imagery dates and thus ideal for time-series analysis.

The imagery data utilized was collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra satellite. Specifically analyzed was the derived 16-day composited, 250 meter resolution, NDVI layer from the freely available "MOD13Q1" science product. The data is a "best of" single image mosaic derived through an algorithm which chooses the best image pieces, from dozens possible, within set 16-day time spans. Effectively created is an image every 16 days with little contamination from atmospheric obstructions (*e.g.* clouds and haze) or ground cover anomalies (*e.g.* snow or standing water). The image mosaics ranged from March 22 to December 3, for a total of 16 each year, and were adequate to document both fall and spring planted crops.

Ground information needed to ascertain which portions of the images pertained to what crops was gathered from the FSA. FSA's "form 578" farmer crop reporting data was matched with FSA's Common Land Unit (CLU) polygon based geographic information system (GIS) data. Next, the matching GIS records were spatially "buffered" inward by 250 meters, or a MODIS pixel size, to assure that no field edge pixels, which likely contain mixed cover types, were included. The remaining buffered FSA areas were then overlaid with the MODIS time series and averaged for each crop by state to provide the representative phenological curve. Crops found in abundance have more samples going into the mean (the number of pixels used are displayed in the legend's parentheses) and are thought to be more accurate. Any crop that did not contain at least 10 samples within a state, in a given year for all years, was excluded. The time series profile for all pixels within the state, regardless if cropland or not, was also included for reference.