Exploring Continuous Corn Cropping Patterns and Their Relationship with Geographic Factors

Weiguo Han, Liping Di, Ali L. Yagci
Center for Spatial Information Science and Systems
George Mason University
4400 University Drive, MS 6E1, Fairfax, VA 22030, USA
whan@gmu.edu, ldi@gmu.edu

Zhengwei Yang
US Department of Agriculture
National Agricultural Statistics Service
3251 Old Lee Highway, Fairfax, VA 22030, USA
zhengwei.yang@nass.usda.gov

***Abstract*— Continuous cropping is one of main planting methods in the cropping systems. Discovering the continuous planting patterns and their relationship with geographic factors is a very meaningful research subject to support agricultural decision making. The Cropland Data Layer (CDL) data is one of useful land cover data resources to study the crop planting patterns of any area of interest in the Contiguous United States. In this paper, the CDL data of Iowa for the years of 2006-2012 are retrieved directly from CropScape, and planting patterns of continuous corn cropping is discovered from these CDL files. The raster layer of these planting patterns will be overlaid and analyzed in combination with other geospatial datasets, like digital elevation model data, average annual temperature, average annual precipitation data, and soil classification data to identify the important physical factors that impact on the patterns. Spatial relationships between continuous corn planting patterns and these geographic factors are also investigated and presented in this paper.**

Keywords- Cropland Data Layer; CropScape; Planting Pattern; Continuous Cropping; Overlay Analysis

I. INTRODUCTION

Continuous cropping and crop rotation are two main planting methods in the cropping systems [1]. Continuous cropping means that the same crop is continuous cultivated for multiple years on the same land [2], like wheat in the Central and Southern Plains. Crop rotation is to plant specific groups of crops over years on the same land [3], like corn-soybean rotation in the Midwest. Discovering these planting patterns and their relationships with geographic factors is a very important issue in the research fields of water resources assessment, soil fertility maintenance, crop yield estimation, pesticide control, land cover monitoring, agricultural sustainability, etc.

The Cropland Data Layer (CDL) data is one of useful land cover data resources to study the planting patterns of any area in the Contiguous United States (CONUS). The CDL data product is produced from mid-resolution satellite data and high quality ground truth data [4]. This geospatial product presents the detailed information on agricultural and non-agricultural landscapes [5].

In this paper, the state of Iowa is selected as the study area because it is the No. 1 corn producing state in the United States. The CDL data for the crop years of 2006-2012 of Iowa are extracted directly from the popular Web portal of CropScape [6]. Next, the planting pattern of continuous cropping is generated from these CDL files. Like in other Midwest states, high value crop of corn is continuously cropped over years in many areas of Iowa. The continuous corn cropping patterns will be discovered through the method of spatial analysis. Then, these spatial patterns will be overlaid and analyzed in combination with other geospatial datasets like digital elevation model (DEM) data from National Elevation Datasets (NED), average annual temperature data, average annual precipitation data, and soil classification data from Digital General Soil Map of the United States. And the important physical factors that impact on planting patterns will be identified. These datasets are freely obtained from United States Department of Agriculture (USDA), United States Geological Survey (USGS), and other federal agencies or organizations. Finally, spatial relationships between continuous corn planting patterns and these environmental factors will be investigated and presented in thematic maps, graphs, as well as tabular reports. Geoprocessing tools of Spatial Analyst in ArcGIS® software will be utilized and executed to analyze spatial relationships.

The remainder this paper is organized as the following: the geographic datasets and spatial analytics functions are introduced in Section 2. The continuous corn planting patterns and their relationships with other geographic factors are discussed in Section 3. Finally, future works are described and the conclusions are summarized in Section 4.

II. DATA AND METHODS

2.1 *Geospatial Datasets*

1) CDL Data

USDA National Agricultural Statistics Service (NASS) has produced the CDL data annually since 1997. This geo-referenced cropland product provides specific land cover classifications crossing the CONUS. It covers all 48 conterminous states and District of Columbia from the crop year of 2008. This valuable geospatial data has been served as one of the important sources in the official reporting process of agricultural statistics information, and can be leveraged to explore land cover and land use changes and agricultural geo-information of the CONUS.

Users can access, visualize, retrieve, and analyze the CDL data within area of interest (AOI) at any geographic level through CropScape to answer cropland related questions

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having local, regional, state, or national implications. As the top corn producing state in the United States, Iowa is selected as a case study to investigate the continuous corn planting pattern in the state. User can explore the CDL data within this state directly by inputting CropScape link plus its abbreviation (i.e. http://nassgeodata.gmu.edu/CropScape/IA) in the common internet browsers. For the reason of original data quality, only the CDL data for the years of from 2006 through 2012 are downloaded from CropScape easily for further analysis.

2) NED Data

The study shows that crop yield is correlated with several terrain attributes, like elevation, slope, and curvature [7]. There are numerous sources of DEM datasets shared freely over the Web. USGS NED data is selected in this study because it provides the best raster elevation data of the CONUS for research and GIS applications [8].

The Geospatial Data Gateway (GDG) of USDA offers environmental and natural resources data to general public [9], including NED data at 3 meters, 10 meters, and 30 meters. The state of Iowa includes 1137 3-meter maps (size 74266.332 MB), 1141 10-meter maps (size 9306.911 MB), and 26 30-meter maps (size 1571.143 MB) covering the whole state. The DEM data will be reclassified to define as multiple elevation categories, so 26 30-meter DEM tiles are downloaded in GeoTIFF format from GDG, and will be mosaiced and rasterized into one DEM file. The primary terrain attributes of aspect and slope will be calculated from this DEM file.

3) Temperature Data

The weather variables like temperature have important impacts on crop growth, development, and yield [10]. The annual average temperature data by state can be obtained in ESRI® Shapefile format from GDG.

The latest 1981-2010 annual average maximum temperature data for Iowa is customized, ordered, and retrieved from GDG portal. It contains 11 polygons which represent the areas of average maximum temperature from 53°F to 63°F (as seen in Figure 1-1).

4) Precipatation Data

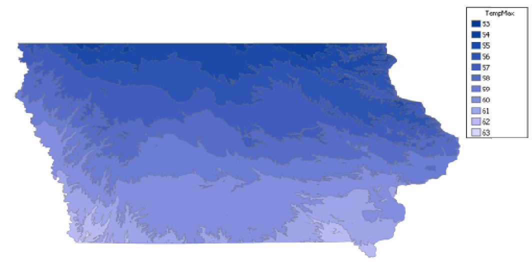
The yield of corn, especially planting in the dry-land areas, is highly dependent on precipitation [11]. GDG provides the 1961-1990, 1971-2000, and 1981-2010 monthly and annual average precipitation data by state in ESRI® Shapefile format. These data are derived from point precipitation and elevation data for the 30-year period in a model.

The 1981-2010 Iowa annual precipitation data is downloaded from GDG portal. There are 15 features in this vector file which represent the areas of annual average precipitation from 25 inches to 39 inches, as seen in Figure 1-2.

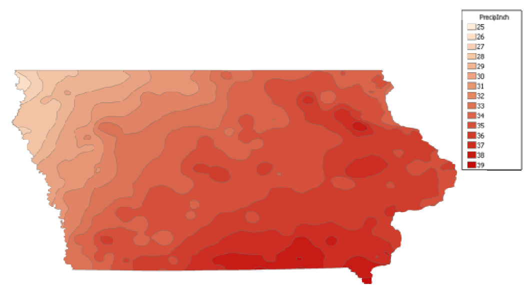
5) Soil Type Data

The soil types affect how well corn responds to residues on the surface of the soil [12]. The U. S. General Soil Map (STATSGO) data and the Soil Survey Spatial and Tabular Data (SSURGO) data are records of map unit locations and soil classifications collected and produced by National Cooperative Soil Survey (NCSS). The former one is designed for geographic display and analysis at the state, regional, and state level, it is composed of general map units associated with soil features.

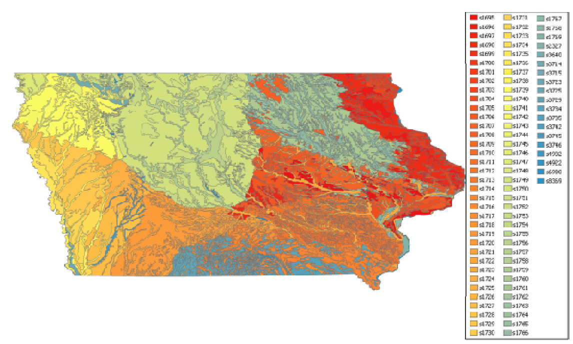
The STATSGO data for Iowa is ordered and retrieved from GDG portal. The compressed file includes tabular information in pure text which can be imported in Microsoft® Access® databases and spatial information in ESRI® Shapefile format. Figure 1-3 illustrates that the map units in this state are mainly covered by 83 different types of soil.



(1) Annual Average Maximum Temperature



(2) Annual Average Precipitation



(3) General Soil Types

Figure 1. Geographic Datasets of Iowa

2.2 *Data Processing*

In this study, ArcGIS® software is utilized to process and analyze geospatial data. The CDL files for the years of 2006-2009 are at 56m resolution, and the others at 30m resolution. So the re-sampling processing is required to make all files at the same resolution (56m) for raster calculation on a per-cell basis. *Raster Processing* of *Resample* in the *Raster Data Management Tools* is utilized to fulfill this operation.

The 26 NED DEM files are mosaiced into a single file using *Mosaic* of *Raster Dataset* in the *Raster Data Management Tools*. And the single file is rasterized within the state boundary of Iowa using *Clip* of *Raster Processing* in the same toolset. The boundary file can be obtained from United

States Census Bureau website [13]. The whole process is as seen in Figure 2.

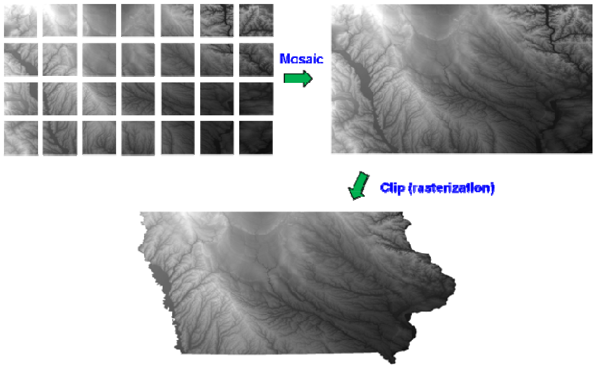


Figure 2. DEM Data Processing

2.3 *Spatial Analysis*

Spatial analysis functions of slope, aspect, raster calculator, reclassification, and overlay analysis are performed on the above geospatial datasets and the derived files to explore the continuous corn platting patterns during the period of 2006-2012 in the state of Iowa and investigate their relationships with geographic factors. *Spatial Analyst Tools* in ArcGIS® provide the corresponding geoprocessing tools in several toolsets, including *Map Algebra*, *Surface*, *Reclass*, and *Zonal*, to perform these analytical functions.

Raster Calculator in *Map Algebra* toolset is used to generate the raster file of continuous corn planting patterns during the seven years from the re-sampled CDL files.

Slope and *Aspect* in *Surface* toolset are performed on the processed DEM file to calculate the terrain attributes of slope and aspect of the entire state.

Reclassify in *Reclass* toolset is executed to reclassify the DEM data and the derived slope data into several categories which stand for the specified value ranges of elevation and slope. Other geospatial data mentioned above are not needed to do this because they have been grouped into categorical datasets.

Zonal Statistics in *Zonal* toolset is utilized as an overlay analysis tool to calculate the raster values of the 7-year continuous corn cropping within the categorized areas of several geographic datasets.

III. Results

3.1 *Continuous Corn PlantingAreas*

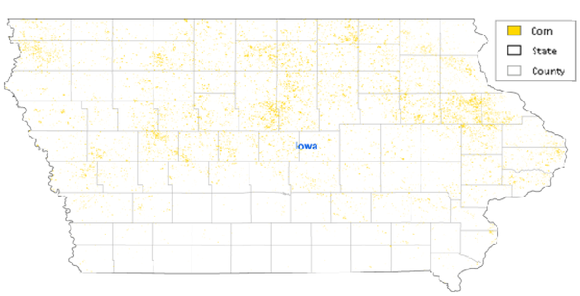
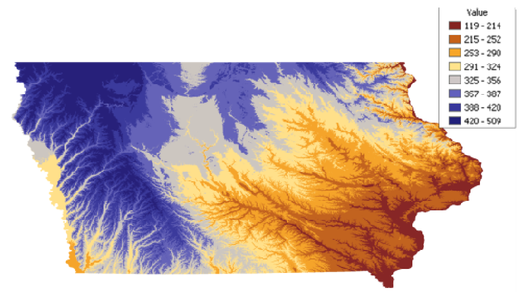


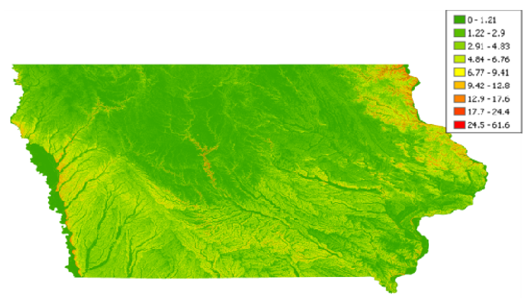
Figure 3. 7-year Continuous Corn Planting Areas in Iowa

An expression with logical operators (i.e. Equal To: "==" and Boolean And "&") and numerical value (i.e. 1, corn value) using the 2006-2012 Iowa CDL data as the inputs is built and executed in *Raster Calculator* to create the raster data representing the 7-year continuous corn planting areas. The output raster layer is shown in Figure 3. In this file, value 1 means that the crop values of this cell during the period of 2006-2012 are always the one of corn, value 0 means not all and is set as NoData value. It can be seen that most of continuous corn planting areas are located in the north and middle of Iowa.

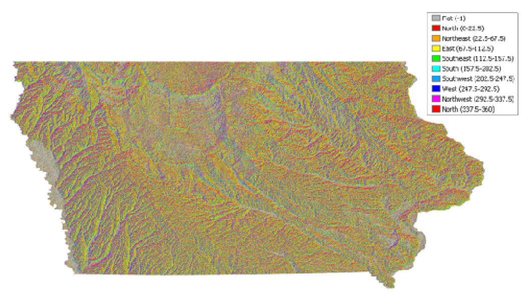
3.2 *Terrain Attributes*



(1) Reclssfied Elevation



(2) Reclssfied Slope



(3) Aspect

Figure 4. Terrain Attributes of Iowa

The DEM file is reclassified into eight categories according to elevation value ranges: [119, 214], [215, 252], [253, 290], [291, 324], [325, 356], [357, 387], [388, 420], and [421, 509] (unit: meter). The reclassified DEM file is shown in Figure 4-1.

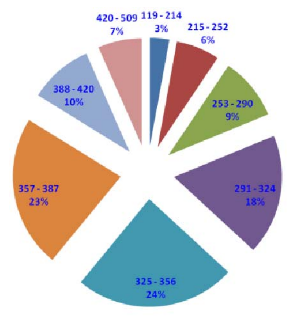
The output slope data is grouped into nine classes based on the intervals: [0, 1.21], [1.22, 2.9], [2.91, 4.83], [4.84, 6.76], [6.77, 9.41], [9.42, 12.8], [12.9, 17.6], [17.7, 24.4], and [24.5, 61.6] (unit: degree). Figure 4-2 displays the reclassified raster data of slope.

The output aspect data contains nine categories representing the aspect of each cell, including Flat, North, Northeast, East, Southeast, South, Southwest, West, and Northwest (as shown in Figure 4-3).

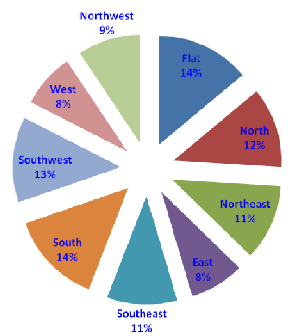
3.3 *Overlay Analysis*

Overlay analysis combines the features of several geospatial datasets together to create the detailed areas which have the specified attributes. ArcGIS® offers vector and raster overlay tools to overlay multiple vector and raster layers respectively.

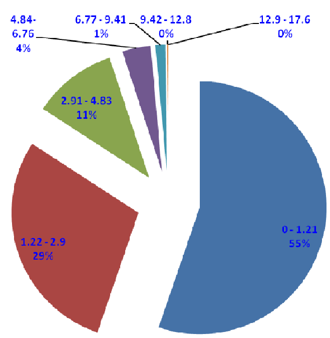
In this study, *Zonal Statistics as Table* is adopted to overlay the raster layer of the 7-year continuous corn planting with other categorized vector and raster layers and summarizes its values within the categorized zones of these layers. The statistics results are outputted into tables, and visualized in graphs. The pie charts in Figure 5 illustrate how much these geographic factors impact on continuous corn cropping of Iowa.



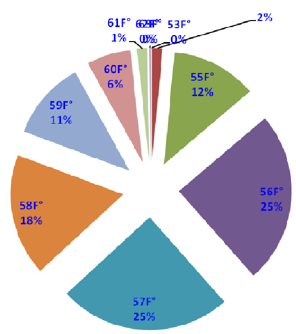
(1) By Elevation Ranges



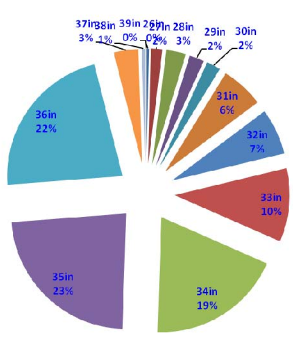
(2) By Aspect



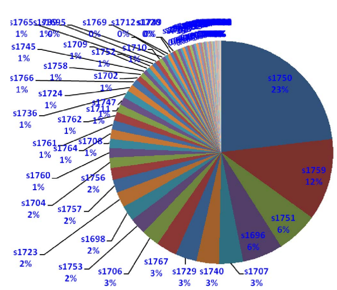
(3) By Slope Ranges



(4) By Annual Maximum Temperature



(5) By Annual Precipitation



(6) By Soil Types

Figure 5. Display of Zonal Statistics Results

1) *Relationship with elevation attributes*

Figure 5-1 displays that the elevations of nearly 85% of continuous corn planting areas are between 253 meter and 420 meter. The areas with elevation ranges of 325m-356m, 357m-387m, and 291m-324m are the top three ones.

Unlike other charts with obvious differences between categories, the percentage of continuous corn planting areas in each aspect is roughly similar, as shown in Figure 5-2. So, it can be concluded that there is no correlation between aspect and continuous corn planting.

Overall, about a very large majority of continuous corn planting areas are located in the lower slope areas (0 through 4.83 degree slope), as seen in Figure 5-3. The flat areas (slope <1.21 degree) is the biggest segment, about 55% of total areas.

2) *Relationship with climate factors*

At first glance of Figure 5-4, it is clear that the annual average maximum temperature of approximately 97% of continuous corn planting areas is between 55°F and 60°F. The remaining segments account for about 3% in total. The cropping areas with annual average maximum temperature of 56°F and 57°F are roughly half of the total ones.

The continuous corn planting areas with the annual average precipitation between 31 inches to 36 inches account for about 87% of the total areas, as shown in Figure 5-5. The proportions of areas with 34 inches, 35 inches, and 36 inches are approximately 19%, 23%, and 22% respectively.

3) *Relationship with soil types*

Figure 5-6 shows the proportion of continuous corn planting areas by soil types. The biggest four soil types of the areas are *s1750* (about 23%) that represents one of the poorly drained soil types (Webster-Nicollet-Clarion-Canisteo), *s1759* (nearly 12%) that indicates one of the somewhat poorly drained soil types (Kenyon-Floyd-Clyde), s1751 (almost 6%) which means another poorly drained soil type (Nicollet-Clarion-Canisteo), and s1696 (around 6%) which stands for one of the well drained soil types (Fayette-Downs) .

IV. Discussions and Conclusions

This paper explores the continuous corn planting patterns during the period of 2006-2012 in the state of Iowa, and investigates these patterns relationships with environmental factors, including elevation, aspect, slope, temperature, precipitation and soil type. To generate the relationships, multiple geographic datasets are collected and organized in GIS software. These data are processed and analyzed to allow the continuous corn planting patterns and their relationships with geographic factors to become apparent. In a conclusion, the generated maps and graphs show that there are strong relationships between continuous corn planting and elevation, slope, temperature, precipitation, and soil types. Moreover, the CDL data provided by CropScape is one of the useful agricultural spatial data sources to discover crop planting patterns. Open access geospatial data from multiple sources can be served as explanatory variables of spatial analysis.

However, the relationships with soil types need to be further investigated. The detailed soil type data (i.e. SSURGO) will be utilized in the analysis. Other geographic factors, like national wetland inventory data, water resource points and stream network, will be considered as explanatory variables. In addition, the relationships between crop patterns census, social and economic data, such as crop production, yield and price, will also be explored, and a classification tree will be built from the relationships of crop planting patterns with these various types of factors. Furthermore, new standard geoprocessing services of raster calculator and overlay analysis will be implemented and integrated in CropScape to extend its functionality. These geoprocessing services will facilitate users' analysis in their research and applications, and can be integrated in their scientific workflow.

REFERENCES

[1] C. C. Sheaffer, K. M. Moncada. Introduction to Agronomy: Food, Crops and Environment. Delmar Cengage Learning. New York: Clifton Park, 2008.

[2] A. Deberman, D. Dawe, R. P. Roetter, and K. G. Cassman, "Reversal of rice yield decline in a long-term continuous cropping experiment", Agronomy Journal, Vol. 92, pp. 633-643, 2000.

[3] M. Liebman, E. Dyck, "Crop rotation and inter-cropping strategies for weed management", Ecological Applications, Vol. 3, pp. 92-122, 1993.

[4] United States Department of Agriculture National Agricultural Statistics Service, "Cropland Data Layer", http://nassgeodata.gmu.edu/CropScape, 2013.

[5] C. Boryan, Z. Yang, R. Mueller, and M. Craig, "Monitoring US agriculture: the US Department of Agriculture, National Agricultural Statistics Service, Cropland Data Layer Program", Geocarto International, Vol. 26, No. 5, pp. 341-358, 2011.

[6] W. Han, Z. Yang, L. Di, and R. Mueller, "CropScape: A Web service based application for exploring and disseminating US conterminous geospatial cropland data products for decision support", Computers and Electronics in Agriculture, Vol. 84, pp. 111-123, 2012.

[7] T. C. Kaspar, T. S. Colvin, D. B. Jaynes, D. L. Karlen, D. E. James, D. W. Meek, D. Pulido, and H. Butler, "Relationship between six years of corn yields and terrain attributes", Precision Agriculture, Vol. 4, No. 1, pp. 87-101, 2003.

[8] United States Geological Survey, "National Elevation Dataset", http://ned.usgs.gov, 2013.

[9] United States Department of Agriculture National Resources Conservation Service, "Geospatial Data Gateway", http://datagateway.nrcs.usda.gov, 2013.

[10] D. T. Coelho, and R. F. Dale, "An energy-crop growth variable and temperature function for predicting corn growth and development: planting to silking", Agronomy Journal, Vol. 72, No. 3, pp. 503-510, 1980.

[11] D. C. Nielsen, M. F. Vigil, and J. G. Benjamin, "The variable response of dryland corn yield to soil water content at planting", Agricultural Water Management, Vol. 96, No. 2, pp. 330-336, 2009.

[12] J. A. Tolk, T. A. Howell, and S. R. Evett, "Effect of mulch, irrigation, and soil type on water use and yield of maize", Soil and Tillage Research, Vol. 50, No. 2, pp. 137-147, 1999.

[13] Uinted States Census Bureau, "The 2010 TIGER/Line® Shapefiles", http://www.census.gov/cgi-bin/geo/shapefiles2010/main, 2013.