Analyzing Rice Production Potential in the Midwest and Great Plains states of the United States: a geographic information system approach

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Abstract

A geographic information system (GIS) approach has been developed to search for areas that meet the requirements of environmental conditions such as temperature, precipitation, and slope for rice production. These environmental conditions, are spatial in nature, meaning that their distributions are related to positions on the earth. As a result, the use of GIS tool is appropriate.

This study focused on an area corresponding to the United States Midwest and Great Plains states, including Wisconsin, Illinois, Iowa, Missouri, Nebraska, Kansas, and Oklahoma. Temperature and precipitation data from six hundred fifty nine (659) weather stations within the study area were collected. The climate data have been compiled into a database format that is compatible with other GIS database. Temperature isolines were generated, and areas that meet the rice production potential requirement (e.g., minimum monthly temperature in April > 41°F or 5 °C) were identified. Digital elevation models (DEM) at one-hundred-meter spatial resolution were collected to produce the slope information. Areas with small slopes (e.g., slope<1%) were extracted from the DEM. GIS overlay analysis was used to identify the potential areas for rice production that meet both slope and climatic requirements. A conceptual model of GIS was also developed to demonstrate the process of identifying potential areas if considering other environmental factors such as soil types, rivers, and current land use/land cover. The researcher would suggest that the GIS approach demonstrated in this study be applied in other areas at a continental or global scale.

Introduction

Geographic information system (GIS) is a computer-based information system for the capture, storage, retrieval, analysis and display of geographic features tied to a common geographic coordinate system (Goodchild, 1992; Clarke, 1997). Within the framework of GIS, data are logically divided into two categories: spatial (geometric) data and attribute (non-spatial) data. The range of spatial data types currently used in most GIS is largely dictated by the data models they implement, namely vector and raster (Burrough, 1986; Goodchild, 1992). In a vector data model, cartographic representations (i.e., points, lines and polygons) are used and the relationship among different features are maintained by spatial topology in a GIS. In the raster data model, a grid-cell or pixel representation is used. Digital elevation model (DEM), and scanned aerial photographs are good examples of raster data. These vector and raster representations of geographical features in GIS focus on database management, query and spatial analysis (Rhind, 1990). Attribute data are the characteristics about the geographic features. In both vector and raster data presentations, links are established between attribute information and spatial features. In the typical vector data model, the relational database management system (RDBMS) is most favorably incorporated for manipulation of feature attribute information. Links are established by arranging unique identifiers (or Ids) for each spatial feature (or IDs) to be recorded in the key fields of the appropriate database table(s) employed to store the attribute information. Data can be retrieved and associations developed based on the identifiers. In the raster model, by contrast, the links are implicit in the way that specific attributes are assigned to individual layers, and the values specified for the pixels or cells in each layer. By allowing links between spatial and attribute databases, a series of operations such as search, overlay, and select can be performed (Rhind, 1990). The linkage between spatial and attribute databases makes it possible for decision-makers to access location and attribute data simultaneously to simulate the effects of management and policy alternatives. Today, using GIS, land managers, planners, resource managers, engineers and many others can use geographic data more efficiently than ever before to analyze management and policy issues.

The application of GIS in agriculture is not new. GIS techniques have been applied for agricultural studies at local, regional and national scales for long time (Usery et al 1995). Combined with geographical data and satellite imagery, these techniques could support the studies of land capability, crop condition and yield, flood and drought, soil erosion, and climate change impacts (Carbone et al 1996; Korporal and Hillary 1993; Wade et al 1994; Korporal and Hillary 1993; Wade et al 1994; Desmet and Govers 1995; Wilson and Gallant 1996; Corbett and Carter 1996; Kern 1994, 1995). According to Hutchington et al (1996), GIS-based climate and land cover databases, and topographic, soil, and land cover databases have been generated at the regional and global scales. However, few attempts have been made to develop a GIS model for agricultural suitability analysis at such scales.

The objective of this study was to develop a GIS-based model for rice potential production. There are many factors that influence how well rice grow and develop. It is beyond the scope of this study to list every factor that affects rice's production, but a basic list of types of factors is attempted.

- Soil factors include level of nutrients, availability of nutrients, moisture level of soil, and soil compaction.
- Pest factors include historical or current infestations of soil fungus, bacterial diseases, insects or weeds.
- Management factors include crop history, past fertilizer applications, pesticide applications, and tillage practices.
- Weather factors include rainfall, temperature and humidity.
- Climatic factors include long range weather patterns such as 1st frost, length of growing season, and degree days.
- Topographic requirements include slope and aspect

The majority of those factors are spatial, meaning that their distributions are related to positions on the earth. As a result, the use of GIS tool is appropriate. To simplify the process of developing a GIS-based model, and to take into consideration of the available data, this study focused on only a few environmental factors, including temperature, precipitation, and slopes.

Study area

This study focused on an area corresponding to the Midwest and the Great Plains states, including Wisconsin, Illinois, Iowa, Missouri, Nebraska, Kansas, and Oklahoma (Figure 1). The study area occupies a large extent of geographical settings (33° N to 47° N latitudes), and has long farming history. Wisconsin is known as “America’s Dairyland.” The low-lying, rolling plains with their lush pastures are ideal for dairy cattle, and Wisconsin produces much of the nation’s milk, cheese, and butter. Within the state there are more than 8,000 lakes., which provide sufficient water for agriculture (e.g., corn, soybean and wheat).

Illinois is known as “Prairie State”. The fertile soil and long growing season make it an important agricultural state. It is among the leading producers of soybeans and corn. Wheat, oats, barley, rye, and sorghum are also grown in large quantities.

Iowa is a rich farming state of the Midwest. Around 90 percent of the state is farmland. The gently rolling land and fertile soil produce high output of agricultural crops, most noticeably corn and alfalfa. The eastern border of Iowa is Mississippi River, while its western border is formed by the Big Sioux and Missouri rivers. These rivers provide irrigation water.

Missouri is a prosperous state, in both agriculture and industry. The two great rivers, the Mississippi and the Missouri, flow through the state and provide irrigation water for agriculture. However, agriculture in this state is not as important as industry (e.g., manufacturing).

Nebraska is known as “Cornhusker State”. Most of Nebraska is prairie land, which is ideal for farming. Nebraska ranks behind only Texas and Iowa in the number of cattle and calves, about 6 million raised in the state each year. After corn, the most valuable crops are hay, oats, wheat, sorghum, soybean, and sugar beets.

Kansas is the number one wheat growing state in the US and is also a leading sorghum producer. Large farms dominate the flat central plain, where rich soil made fertile land for farming.

And finally, Oklahoma supports some 70,000 farms. Cattle are the state’s most valuable agricultural product, and livestock ranks first in terms of farming incoming. Red River region in the southeast corner of the state forms part of the fertile lowlands for growing cotton.

Data sets

In relation to these states, several different types of data were collected. The first type of data included locations of weather stations in latitude and longitude. Six hundred fifty nine (659) weather stations in the study area were selected. For each station, information such as the station identification number, the station name, and the period of record, along with temperature and precipitation, was downloaded from the official websites of the U.S. National Weather Service (NWS) or the National Oceanic and Atmospheric Administration (NOAA).

The second type of data was temperature and precipitation. For each weather station, minimum monthly temperatures for April and May, maximum monthly temperatures for June through October, and monthly precipitations for April through October were collected.

The third data type is the elevation data, namely digital elevation model (DEM). This data set was purchased from a commercial vendor, Earth Resources Mapping, Inc., and has a grid size (i.e., spatial resolution) of 100 meters by 100 meters

Data Analysis in GIS

The primary software package used to implement spatial analysis is ArcView GIS produced by Environmental Systems Research Institute (ESRI). ArcView provides ready-to-use functions to display, browse and query geographically-referenced data (ESRI, 2000).

A point coverage (i.e., map) of weather stations was generated in ArcView from the first type of data set, locations of weather stations in latitude and longitude (Figure 2). The information such as temperature and precipitation was entered as attributes for each weather station. Then, temperature contour lines (also called isolines) were created through ArcView GIS spatial analysis functions. Figure 3 displayed the temperature isolines generated from the April minimum monthly temperatures for all weather stations. Areas that meet the temperature criteria for rice production (e.g., minimum monthly temperatures above 41 °F or 5 °C in April) can be extracted through GIS query analysis and highlighted in yellow color. Similarly, other contour lines, such as May minimum temperature isolines, June through October maximum temperature isolines, and April through October precipitation isolines, can also be generated in ArcView GIS.

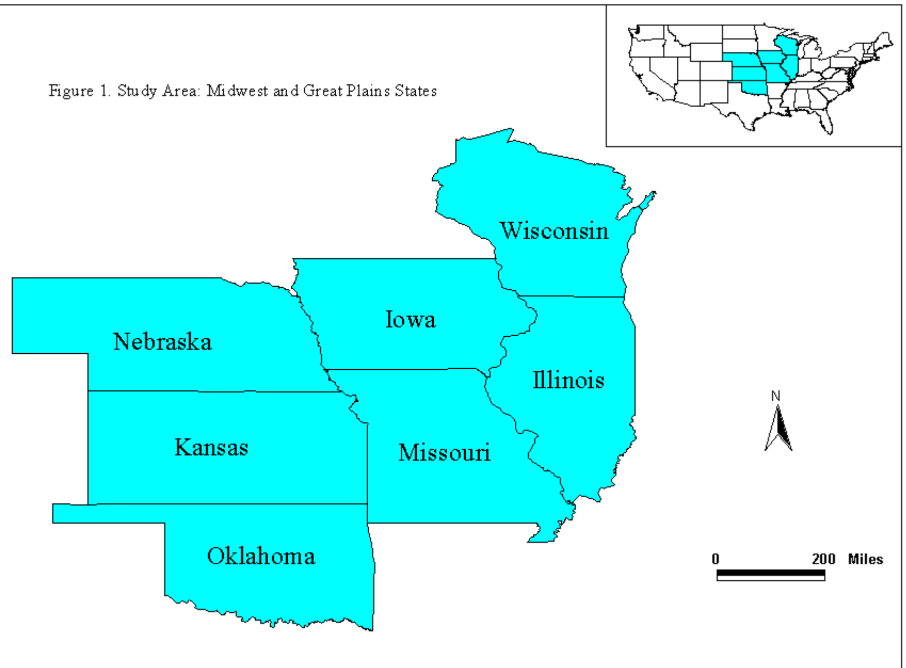
Digital elevation model is used by most GIS professionals to extract topographic information such as slope and aspect. Finding very low slope (e.g., 1% or less) is essential to the cultivation of a rice crop. With the DEM data for the study area, a grid file is generated in ArcView first, and then a slope file. A spatial query in ArcView was used to search for areas with slope less than 1 percent. Because the DEM data for the entire study area is more than 1 Gigabytes in file size, a subset of the DEM data for each state was used instead to create slope map. A sample map for the state of Wisconsin with slope less than 1 percent, supper-imposed with April minimum monthly temperature isolines, is displayed in Figure 4.

There are totally fourteen (14) isoline maps generated from the temperature and precipitation data and one (1) slope map created from the DEM data. GIS overlay analysis functions further allow to display all fifteen maps together. Areas that meet all temperature and precipitation requirements as well as slope requirement for rice production can then be determined.

Conclusions and Discussions

As for the final results of this study, it could be said that there is a rather expansive area where rice cultivation could be sustainable with the study area of this project. Taking into account only temperature and precipitation requirement, the areas that could sustain

Figure 1. Study Area: Midwest and Great Plains States



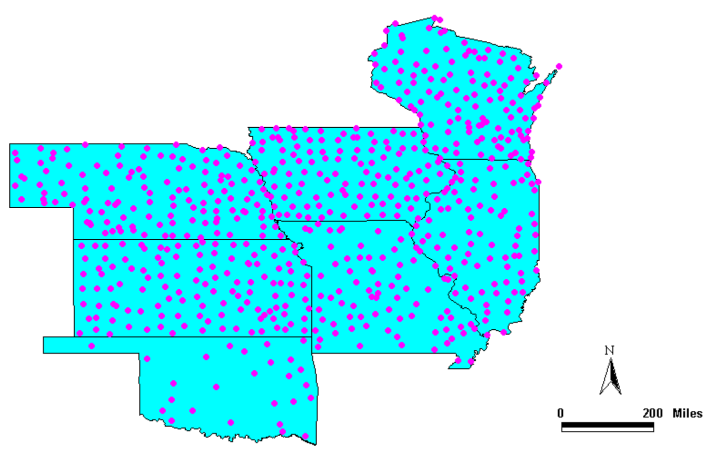


Figure 2. Locations of the National Weather Stations in the Midwest and Great Plains States

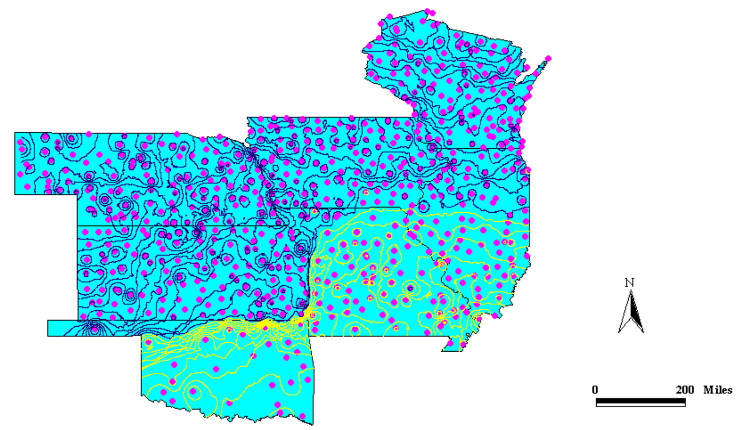


Figure 3. Isolines showing areas with minimum monthly temperatures in April above 5 degrees (yellow lines) and below 5 degrees (dark blue lines)

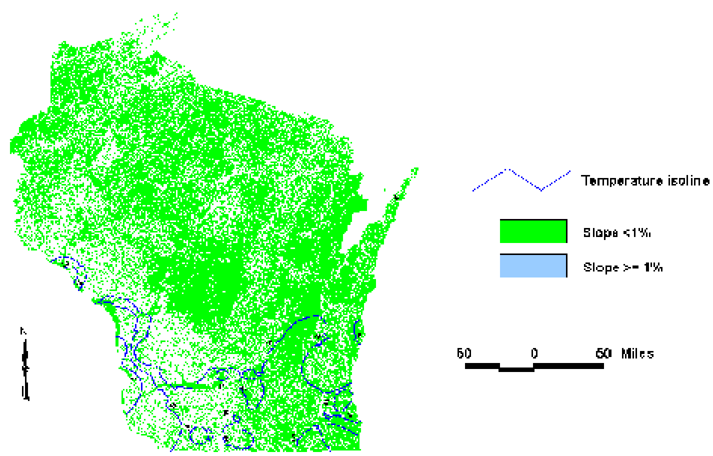


Figure 4. Area that meets temperature requirement (April minimum monthly temperature equal to or greater than 35 °F) with slope less than 1 percent

rice cultivation include the following: most of Oklahoma, the extreme southeastern part of Kansas, most of Missouri, the southern three fourths of Illinois, and the southeastern quarter of Iowa. After considering slope characteristics as well, the main areas that would appear to be able to sustain rice cultivation in the regions mentioned above would appear to be mainly in the valleys of major rivers, such as the Missouri and the Mississippi, as well as in randomly scattered areas throughout the region.

This promising result, however, will probably be diminished by several other factors. First, there is a possibility that such regions where rice cultivation could be most successful from the GIS analysis may be occupied by major cities and large lakes because of their flat terrain. Secondly, environmentally sensitive areas such as wetlands and marsh , although not impossible, greatly reduce the feasibility of farming. Thirdly, the type of soil as well as the level of nutrients, availability of nutrients, and soil compaction are also key factors. Other temperature data, such as the length of growing seasons and degree days, can be used to determine the best cultivation time of rice because rice needs to be sustained at a certain temperature for a certain period of time to grow successfully and be economically productive. It is also important to know the first and last frost for each area since that would give farmers an indication of when rice can be planted and when it must be harvested by.

To overcome these problems that affect the final selection of potential areas for rice production, it is necessary to include current land use/land cover data and digital soil map for the study area in the GIS spatial analysis, which can be done in the next stage of this research. For this reason, the author made a flowchart or cartographic model that could be possibly used by other researchers to conduct similar study in searching for potential areas of rice cultivation (Figure 5).

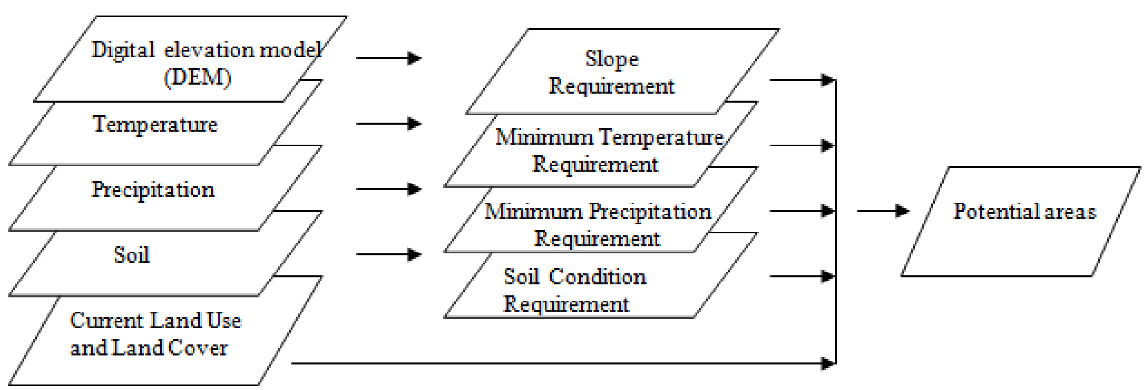


Figure 5. A cartographic model of using GIS to identify potential areas for rice production

There is, however, a very promising future for this study, which can be further investigated by expanding the scope of this project both geographically and by the data sets that could be employed in this project. Some of the areas that could be expanded upon include the project's geographical scope, especially to other parts of the United States as well as to Europe and Asia. A data set similar to the data set used for this project has already been created in California, which is a state that has a very large Asian population that may very well see a benefit to growing, domestically, the crop that had sustained their forefathers for centuries.

References

Burrough, P. A., 1986. *Principles of Geographical Information Systems for Land Resources Assessment*, Oxford Science Publications, New York, New York, 193 pp.

Carbone G. J., S. Narumalani, and M. King, 1996. Application of remote sensing and GIS technologies with physiological crop models, *Photogrammetric Engineering and Remote Sensing*, 62:171-9.

Clarke, K. C, 1997. *Getting Started with Geographic Information Systems*, Prentice Hall, Upper Saddle River, New Jersey, 353 pp.

Corbett, J. D. and S. E. Carters, 1996. Using GIS to enhance agricultural planning: the example of inter-seasonal rainfall variability in Zimbawe, *Transactions in GIS*, 1:207-18.

Desmet, P. J. J., and G. Govers, 1995. GIS-based simulation of erosion and deposition patterns in an agricultural landscape: a comparison of model results with soil map information, *Catena*, 25: 389-401.

Environmental Systems Research Institute (ESRI), 2000. *ArcView: The Geographic Information System for Everyone*, ESRI, Redlands, California, 98p.

Goodchild, M. F., 1992. Geographical Information Science, *International Journal of Geographical Information Systems*, Vol. 6, No. 1, pp. 31-45.

Hutchinson, M.F., H.A. Nix, J.P. Mcmahon, and K.D. Ord, 1996. The development of a topographic and climate database for Africa. *Proceedings, Third International Conference Integrating GIS and Environmental Modeling*, Santa Fe, New Mexico, January, Santa Barbara, NCGIA. CD-ROM

Korporal, K. D. and N. M. Hillary, 1993. *The Statistics Canada Crop Condition Assessment Program*, Ottawa, Statistics Canada.

Kern, J. S., 1994. Spatial patterns of soil organic carbon in the contiguous United States, *Soil Science Society of America Journal*, 58: 439-55.

Kern, J. S., 1995. Geographic patterns of soil water-holding capacity in the contiguous United States, *Soil Science Society of America Journal*, 59: 1126-33.

Rhind, D. P., 1990. Global Databases and GIS, *The Association for Geographical Information Yearbook 1990*, Foster, M. J. and P. J. Shand (eds.), Laylor & Francis and Miles Arnold, London, pp. 218-233.

Usery, E. L., S. Pocknee, and B. Boydell, 1995. Precision farming data management using geographic information systems, *Photogrammetric Engineering and Remote Sensing*, 61:1383-91.

Wade, G., R. Mueller, P. Cook, and P. Doralswamy, 1994. AVHRR map products for crop condition assessment: a geographic information system approach, *Photogrammetric Engineering and Remote Sensing*, 60:1145-50.

Wilson, J.P., 1999. Local, national, and global applications of GIS in agriculture, In *Geographical Information Systems: Management Issues and Applications*, P.A. Longley, M.F. Goodchild, D.J.Maguire and D.W.Rhind (eds.), pp. 981-998. John Wiley & Sons.

Wilson, J. P., and J. C. Gallant, 1996 EROS: a grid-based program for estimating spatially-distributed erosion indices, *Computers and Geosciences*, 22:707-12.