Spring 4-20-2011

USING A GEOGRAPHIC INFORMATION SYSTEM TO DEFINE REGIONS OF GRAPE-CULTIVAR SUITABILITY IN NEBRASKA

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USING A GEOGRAPHIC INFORMATION SYSTEM TO DEFINE REGIONS OF GRAPE-CULTIVAR SUITABILITY IN NEBRASKA

By

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A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Arts

Major: Geography

Under the Supervision of Professor Donald Rundquist

Lincoln, Nebraska

May, 2011

USING A GEOGRAPHIC INFORMATION SYSTEM TO DEFINE REGIONS OF GRAPE-CULTIVAR SUITABILITY IN NEBRASKA

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University of Nebraska, 2011

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The thesis was undertaken to develop a methodology and digital tool, based upon the use of Geographic Information System (GIS) technology, for delineating specific regions within the state of Nebraska that are suitable for the cultivation of two selected grape hybrids. The successful cultivation of grapes for producing wine requires knowledge of the physical and environmental conditions characterizing the local landscape. GIS technology allows the integration of multiple layers to be analyzed simultaneously, which can provide prospective grape growers with necessary information upon which to base their management decision. In the study, nine GIS variables/layers including growing degree days, length of frost-free period, minimum winter temperature, aspect, slope, soil drainage, soil pH, organic matter and land use were analyzed in order to determine agricultural suitability in Nebraska for Edelweiss and Cynthiana/Norton cultivars.

There are three primary outcomes of the study: 1) a comprehensive database and map of current vineyard operations in Nebraska; 2) a model / tool, which may prove useful regarding future efforts dealing with potential suitability for viticulture; and 3) a series of suitability maps for highlighting areas where Edelweiss and Cynthiana/Norton should be grown. The research may be beneficial to those involved in Nebraska's grape and wine industry.

ACKNOWLEGEMENT

Many people have assisted me, both directly and indirectly, in the completion of this thesis. First, I would like to thank my advisor - Dr. Don Rundquist. Without his guidance, the completion of this thesis would not have been possible. I thank him for helping me throughout the entire research, writing process and support in all aspects. I would also like to thank my other committee members, Dr. James Merchant, Dr. Paul Read and Dr. Stephen Lavin for their advice and support during the research. Thanks are also due to Nebraska Department of Agriculture for their funding to support me through the research and thesis writing process.

Other recipients of my eternal gratitude are my fellow graduate students, Leslie Rawlings and Paul Merani. I greatly appreciate Leslie's willingness to answer all my questions on GIS and Paul's critical advice during every group meeting. Finally, I would also like to thank my friends, Ruopu Li and Yi Peng, for their help during the data collection portion of the research.

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CHAPTER 1: INTRODUCTION

1.1 Background

The wine and grape industry in the U.S. has a history of over 300 years. Today, the United States is the fourth largest wine producing country in the world after France, Italy, and Spain (Read, 2008) and, wine and grape production occurs in all fifty states, with California leading the way followed by Washington, New York and Oregon. The production in California alone is more than double the production of the entire country of Australia. The United States wine, grape, and grape products industries contribute more than $162 billion annually to the American economy (see Table 1.1), and provide more than one million jobs (MKF Research, 2007). Less tangible but equally important are the many contributions the industry makes in preserving agricultural land, revitalizing rural communities, and enhancing the quality of life. The grape and wine industry in the U.S. is clearly significant, with new developments occurring in numerous other states, including Nebraska.

Table 1.1 Impact of the wine and grape industry on the U.S. economy. (Source: MKF Research, 2007)

	ECONOMY IMPACT
Full-time Equivalent Jobs	1.1 million
Wages Paid	33 billion
Number of US Wineries	4929
Number of Grape Growers	23,856
Grape Bearing Acres	934,750
US Winery FOB Revenue	11.4 billion
Retail and Restaurant Share of Revenue from Sales of US Wine	9.8 billion
Distributor Share of Revenue from Sales of US Wine	2.7 billion
Grape Sales	3.5 billion
Retail Value of Table Grape Sales	3 billion
Retail Value of Raisin Sales	560 million
Retail Value of Grape Juice and Juice Product Sales	2.8 billion
Number of Wine-Related Tourist Visits	27.3 million
Estimated Wine-Related Tourism Expenditures	3 billion
Federal Taxes Paid	9.1 billion
State and Local Taxes Paid	8 billion

The wine and grape industry in Nebraska began in the late 19th century, and by the beginning of the 20^{th} century, some 5,000 acres of grapes were in production, with most vineyards located in the eleven eastern counties adjacent to the Missouri River (Read, 2008). However, the Nebraska wine industry, like that of other states, was devastated in 1919 by the passing of Prohibition legislation. When finally repealed in 1933, little of the commercial grape industry remained in Nebraska, and that which did exist was destroyed by a storm in November of 1940.

Although the wine and grape industry in the state was dormant until the mid 1980s, it was revitalized by the passage of the Nebraska Farm Wineries Act in 1985. The new law increased the amount of juice that a winery could produce from 200 to 50,000 US gallons. Even so, in the early 1990s, fewer than 10 acres of commercial vineyards were in cultivation across the state. The Nebraska industry grew rapidly, however, after the first post-Prohibition winery was established. Cuthills Vineyards, located in Pierce, opened for business in December 1994, and provided growers with a market for their viticultural produce. Thus, an incentive existed for enterprising individuals to begin growing and harvesting wine grapes. A second winery, James Arthur Vineyards, began commercial operations in September 1997. Since then, 20 additional licensed farm wineries have initiated business activity, with most located near Omaha and Lincoln (see Figure 1.1). Compared to its humble origins from about a decade and a half ago, the state's wine industry has made substantial progress. To date, approximately 400 acres of grapes are grown in Nebraska, most of which are used for wine production.

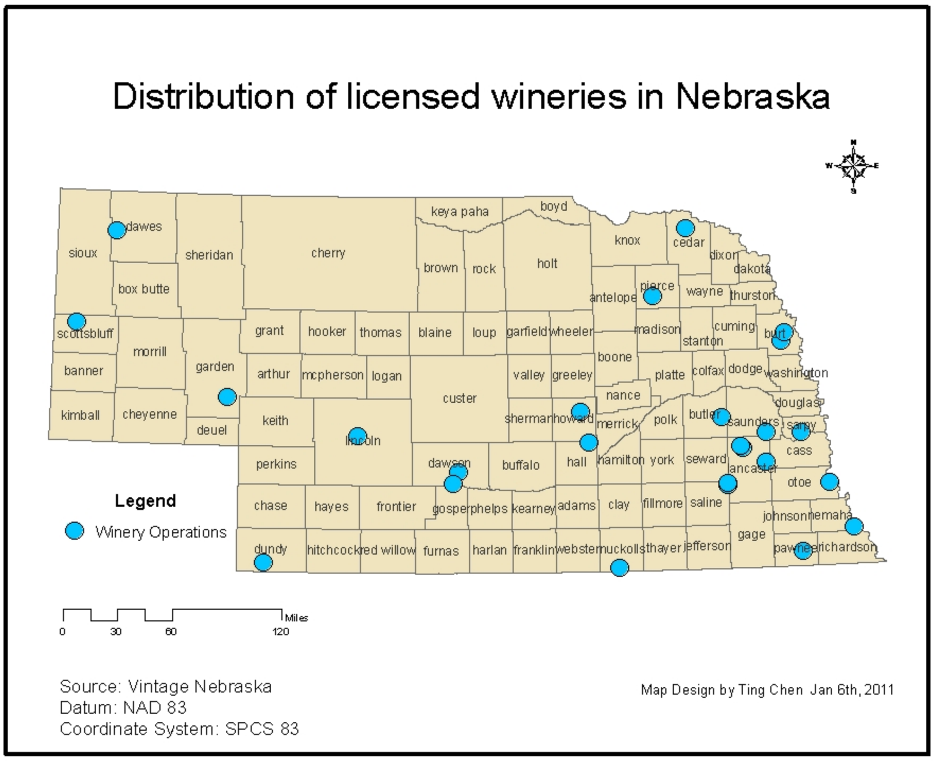

Figure 1.1: The spatial distribution of licensed wineries in Nebraska (Source: www.nebraskawines.com)

As an indication of the progress achieved in a relatively short period of time, some Nebraska wineries have already gained national recognition for their value-added products. In 2006, "Dragons Red," produced by Soaring Wings Winery near Louisville, was awarded the title of "best hybrid red" in the Best Of The East competition, which hosts competition among wineries located east of the Rocky Mountains. Since then, the state's wineries have garnered over 120 awards in various national and international competitions.

With the recognition and rapid expansion of the Nebraska wine and grape growing industry, there has been a subsequent impact on the economy of the state. Like all other industries, this one also creates employment opportunities. It has been noted that the impact from Nebraska's wine and grape growing industry in 2006 was $5.3 million, including $1.6 million in workers' wages spread over an estimated 82 jobs. The employment figure included part-time workers, but excluded seasonal workers and proprietors (besides owners of wineries) involved in the industry (Thompson and Freudenburg, 2007). This study also estimated that there were 110,000 visitors to Nebraska wineries in 2006. One can only expect the economic impact to increase as the industry matures and expands further.

Wine grapes are a product of high value, as indicated by gross receipts per acre, which average between $3000 and $6000 (Wolf, 1998). That figure is much higher than for most other agricultural products (tobacco being an exception). Therefore, an investment in viticulture is made even more alluring given that productive vineyards have an average life span of 20 to 30 years, and include on-going fiscal return with routine maintenance. With the year-to-year financial rewards, along with a high per-acre value, grape production is not only competitive with other types of crops but also with non-agricultural land uses such as residential and commercial activity. Expansion of Nebraska viticulture seems all but certain.

1.1.1 Statement of the Problem

An important issue relating to the wine industry, whether in Nebraska or elsewhere, is where to locate a potential new vineyard. Because the establishment and maintenance costs are high for a grape-growing operation, and because vineyards have a long life span, as noted above, it is critical that a potential grape grower makes locational decisions based upon sound information. There are many questions to be answered before initiating vineyard development. For example, exactly how does one determine if the land is suitable for growing grapes? What types of soils are needed for successful grape and wine production? Are there any topographic constraints that apply to the commercial growing of grapes? What about the climate, especially cold temperatures in the winter? Of course, potential growers generally have many other questions outside the realm of location, including the specific costs associated with the initial establishment of a vineyard operation. The latter types of questions, however, are beyond the scope of this thesis.

It is clear (especially to a Geographer) that much of the information related to a grower’s decision about potential vineyard location is grounded in geography. In a strict “conceptual sense,” it is an issue of comparing maps; for example, those of soils and topography, at minimum. These types of maps are certainly available on paper for most locations in the U.S., and climatic information is also readily available. Behind every map, however, is a wealth of additional or more detailed information not included on the printed document. This is one of the problems with paper based maps; they are static, address a single theme, and are current only at the time they are drafted. More importantly, there is no underlying database, and it is therefore impossible to “query” a paper map in the manner of a digital archive. One potential solution is the automated Geographic Information System (GIS), which is not only capable of overcoming the limitations of the paper map, but it also allows for sophisticated forms of spatial analysis. Thus, this project makes use of GIS technology to address the issue of locating the portions of Nebraska that have potential as future grape-producing regions.

1.1.2 Literature Review

Other researchers have attempted to deal with the matter of vineyard location. Brooker and Gray (1990), for example, used a GIS to construct a temperature/crop map to depict areas of Tennessee best suited for growing groups of vegetables with specific temperature requirements. Their method combined weather station heat units, soil type (classed by potential for vegetable production), and soil-slope information.

Myers (1993) used GIS technology to create suitability maps for amaranth (*Amaranthus cruentus L.*) and canola (*Brassica napus L.var. napus*) based on soil classification, traditional crop production and estimated probability of disease in Missouri. Myers recognized that the suitability map for canola could be improved with greater understanding of the weather events associated with winter survival and the need to validate suitability maps.

Boyer (1998) analyzed data for the State of Virginia to establish suitability for grape culture in his Master thesis. His research occurred in two phases: a small scale analysis that encompassed the entire state, and a large scale analysis which focused on site selection at the local level. In the small scale analysis, weather station data (minimum winter temperatures, maximum summer temperatures, precipitation, length of growing season) were collected, and elevation and slope models were constructed to complement the climatic variables in delineating regions across Virginia that had greater or lesser viticulture potential from a physical and climatological basis. Secondly, at the local scale, a GIS approach was used to identify sites at the county scale that possessed greater or lesser viticulture potential from a physical basis. Each physical feature layer was given a numerical classification; then all layers were combined to produce a 0 to 100 scale in the final, composite image. Employment of a GIS approach was shown to be an effective tool for site selection at the local scale.

Smith and Whigham (1999) demonstrated that the spatial and temporal variables associated with the growth of grape vines and management of vineyards were ideally suited to the application of spatial information systems. The paper highlighted those aspects distinctive to viticulture that were amenable to support from a spatial systems perspective. Issues that were addressed included scale variation, significance of location, factors which affected production and quality, vintage, the annual cycle of the vine and harvest of fruit, extreme events, risks (e.g., frost, pests, diseases), trans-seasonal and intra-seasonal cycles, sustainability, quality and integrity of the final product, traceability and the reputation and value of the final product. Though the authors stated the potential pitfalls of using a spatial information system in vineyards (e.g., costly data gathering and management), they still believed that the identification of significant factors that influenced the development of fruit and were included in an automated system would provide growers and producers with better information and therefore support better decision making and the quality of results.

Young et al. (2000) used GIS to identify the suitability of the Wyoming Bighorn basin to grow 28 alternative crops. Their study included summer temperatures, precipitation, growing-degree days, length of frost-free season, and soils data developed using a predictive model based on bedrock geology and elevation.

Bowen and Hollinger (2004) developed a simple model using crop edaphic requirements and climate and soil information in a GIS format to evaluate the suitability of a region's conditions for a large number of crops. Their model included crop requirements and geographic distribution of soil properties (soil texture, soil pH, and soil drainage) and climate variables (daily maximum and minimum temperatures, precipitation, extreme minimum winter temperature, and growing degree days) to characterize the suitability of regions in Illinois for 414 crops. In their work, map data and algebraic routines operating within a GIS were used to compute the overall suitability of 2442 separate areas in the state. The model demonstrated its utility for evaluating numerous crops using limited soil and climate characteristics, and the model can be expanded to any geographical area in the world with adequate soil and climate data.

Jones et al, (2004) analyzed the terroir of the Umpqua Valley. A multi-stage GIS analysis was set up to incorporate factors related to the topography, soils, land zoning, and climate. This research attempted to define and map "terroir" (the distinctive attributes of a place that define the character of a wine) potential by examining the grape-growing landscape in the Umpqua Valley AVA of Oregon through the spatial analysis of the variables noted above. The research concluded that Douglas County and the Umpqua Valley AVA have a large percentage of land zoned for agriculture, farm/forest transition, or rural residential that can easily be developed into vineyard sites.

Day et al, (2006) developed a vineyard site assessment model using GIS data layers for southeastern Pennsylvania. Their study included topography, soil, land use and climate parameters to develop viticulture suitability. Twenty-three existing vineyards were field-visited for model validation.

Greene (2007) highlighted web-based GIS tools that were currently available to support new crop development. The intent of his work was to illustrate how the web was rapidly becoming a vital resource for casual users to capitalize on GIS tools without the traditional steep learning curve. This article explored tools that: (1) provide users with location specific information; (2) help predict which crops grow best where; and (3) help predict where useful plant germplasm might occur. The work illustrated a few user-friendly GIS tools available on-line to help support new crop development. The key point was that GIS tools were becoming increasingly user-friendly, especially those applications designed to be used on the web. The future should only bring even more user-friendly GIS tools that are increasingly more sophisticated and powerful. On-line access to those tools, and the ever increasing amount of online environmental data will support researchers developing new crops.

Jayasinghe and Machida (2009) developed an interactive web-GIS on-line system with crop-land suitability analysis, which provided information on tomato and cabbage suitability in the Kandy, Matale, Nuwaraeliya and Badulla districts of Sri Lanka. In their study, analysis of topographic factors, soil properties, and climate factors were considered as important criteria to determine crop-land suitability for growing tomatoes and cabbage. They used spatial analysis tools to create suitability maps under four criteria: highly suitable, moderately suitable, marginally suitable, and not suitable. Then, a combination of GIS, Map Server, and Web Server components were used to develop a flexible and user-friendly online crop suitability consultation system. By using their web-GIS tools, users would get the information on the crop suitability rank, suitability category, suitable land area for that crop, current vegetation and statistics data.

The application of GIS as an approach in the prediction of vineyard suitability has been widely accepted over the past two decades. However, most research on vineyard suitability does not deal with specific cultivars of grapes. There are over 5,000 cultivars of wine grapes all over the world, and each has a unique requirement for climate, soil and other physical factors. For example, American and French hybrid types are best suited to northern growing conditions because they tend to be winter-hardy. Investigations of vineyard suitability would be more precise and of a greater value if the particular grape cultivar is taken into the consideration. My research focuses on two selected individual grape cultivars and their growth potential as assessed on a statewide basis. An important output of my research is a series of suitability maps for those well-selected grape hybrids, as examined within the spatial framework of the State of Nebraska. My research should add to the limited existing literature on the suitability of grape cultivars in Nebraska.

1.1.3 Objectives

The primary goal of this study is to develop a methodology and digital tool, based upon the use of GIS technology, for identifying specific geographic areas within the State of Nebraska that are suitable for the cultivation of well-selected grape hybrids. For the purpose of this project, the term “suitable” refers to a location that possesses the physical characteristics of the environment (climate, topography, soil) that allow for successful viticulture; i.e., high quality fruit, minimal risks to vine survival, and relatively low maintenance costs. While some physical and cultural factors (e.g., distance to market) are important with regard to the commercial success of a winery, they do not have a direct influence on the success or failure of grape growing. Therefore, such factors are not considered in this work.

My study is undertaken within the framework of a Geographic Information System (GIS). The integration of other related geospatial technologies including Global Positioning Systems (GPS) and remote sensing, beyond the scope of the thesis, would allow a grower to track information relating to the crop condition as well as mapping the location of specific features that affect crop productivity. The ability of a GIS to integrate information from many sources makes it particularly attractive for use in vineyard site assessment. Factors that define geographic origin can be described discretely using a GIS and include soils, slope, aspect, growing season and growing-degree days. When combined, a specific variety of wine grape best suited to the site can be determined. Storing this information in a GIS provides growers a means to manage more effectively the inputs applied to a crop. The location can be tracked and mapped for reporting purposes to governing agencies, thus relieving the grower of hours of tedious paper work by automating the task. Until recently, this technology has been used to maximize vineyard productivity for a given site. By combining these geo-technologies, growers can implement a cost effective management solution that improves profitability of the operation as well as minimize the amount of inputs necessary.

The study began with the mapping of existing vineyard operations in the State of Nebraska, which was used to compare and validate the results of the GIS model for vineyard suitability. Then a geographic analysis of the influence of physical environments on statewide viticulture potential was offered. As noted above, the major element of this work was to identify potential areas in Nebraska for the growth of two particular grape hybrids. I analyzed the climatic, soil and topographic features of Nebraska in terms of their regional potential for specific hybrids. From this analysis, I identified and ranked regions based upon their potential for viticulture. I also aimed to build a prototype geographic information system (GIS) for Nebraska vineyards that would serve as a framework for on-going efforts related to the growth of the industry. Factor layers, constructed at the state scale, were produced from a series of physical databases, representing viticulturally important features of the landscape. A ranking system was developed for each layer and, in turn, all layers were combined to create a single image displaying suitability scores (0 to 10, with 10 as a perfect score) for every 30m cell in the state.

The final step in this work entails validation of this Geographic Information Model. Results from the model were compared to the currently operating vineyard locations, and to ancillary relevant data from those sites. Concluding remarks on the utility and effectiveness of this approach will complete the thesis.

To summarize, the thesis is developed around three specific objectives:

1. To map the existing spatial distribution of vineyards in Nebraska;

2. To develop a prototype geographic information system (GIS) tool for Nebraska vineyards that will serve as a framework for on-going efforts related to site-location for development of vineyard operations within the state;

3. To employ GIS techniques to produce prototype vineyard-suitability maps for the state, with emphasis given to climatic factors. The suitability maps will be oriented to two specific wine-grape cultivars.

1.2 Anticipated Outcomes of the Current Study

One of the final tasks related to this study will be to compare the actual, currently operating vineyard locations with the potential viticulture-development areas identified by the developed model. If the model is valid and successful, discrepancies between the actual and the potential would perhaps need to be considered by the individual growers. Such a result points to the possibility of faulty decision-making. When tools such as that which I aim to develop are made available to farmers, agriculture extension agents, and others, the spatial pattern of viticulture acreage in the state could in time be fundamentally changed. Identification of promising viticulture areas could stimulate interest in local economic growth, both from internal and external potential investors. As Johnson and Wade (1993) noted, expansion of the wine industry is a viable, and sustainable economic development strategy for rural areas, since total income and employment opportunities may be increased without damaging the rural character and environmental quality of the region. Investment and expansion of viticulture equates to more jobs, more money invested in local economies, and presents a viable supplementary income to rural landowners. My study could also assist in minimizing unnecessary and unexpected expenses associated with the high maintenance costs of poorly located vineyards.

This study should add to the growing literature on the importance of detailed examination of the physical environment as agricultural landscapes adjust to their optimal locations. It represents an integration of high resolution digital data, location characteristics, and qualitative grower data into one database.

CHAPTER 2: THE NEBRASKA STATEWIDE VINEYARD MAPPING PROJECT

2.1 The Importance of Mapping Vineyard Locations

One objective of my study is to map the spatial distribution of vineyards currently operating in Nebraska. A “vineyard,” by definition, is an agricultural enterprise aimed at the cultivation of grape-bearing vines, grown mainly for winemaking, but also raisins, table grapes and non-alcoholic grape juice. The size of a vineyard may vary from a few vines to thousands, but for the purpose of the current study, only vineyards which have at least 50 vines are included in the compilation and mapped.

Like other major grape-growing states, such as California and New York, Nebraska has a professional growers association; i.e., the Nebraska Winery and Grape Growers Association. That group has, in the past, made an effort to compile a comprehensive list of vineyard locations in the state. Despite good intentions and for a variety of reasons, that undertaking has, up to now, led to only a partial list of vineyard operations in Nebraska. It seemed necessary, therefore, to make an attempt to develop an accurate database of vineyard locations not only as an aid to viticultural specialists and extension personnel in the state but also because such a compilation is required to compare and validate the results of the GIS model for vineyard suitability, a primary outcome of the current study.

2.2 Methodology Related to the Mapping Activity

In order to map the spatial distribution of existing vineyards in Nebraska, the location of each grape-growing enterprise needs to be referenced according to some standard coordinate system (e.g., latitude and longitude). Thus, each vineyard must be "geo-located" whether by comparing locational "descriptive information" as provided by growers to existing maps (e.g., USGS quadrangles) or by data acquired using a Global Positioning System (GPS). The vineyard database used for my work was developed by means of two primary sources of information. First, a hard copy of the "Vineyard Location List" (dated February, 2006) was obtained from the Nebraska Winery and Grape Growers Association (NWGGA). That list contained only a legal description (section/township/range) for the vineyards, and surely was incomplete according to information obtained from informed extension and agricultural specialists. Therefore, with support from the Pesticide Division of the Nebraska Department of Agriculture (NDA), an effort was undertaken to add missing data to the resulting file as well as to improve the accuracy of the existing list. That agency was in need of vineyard locations for the purpose of providing aerial-spray personnel with that information to prevent legal confrontations due to the drift of pesticides onto sensitive crops (e.g., grapes). Therefore, I worked in conjunction with NDA personnel (Mr. Craig Romary) to develop a questionnaire that was distributed widely via extension offices as well as directed mailings. The questionnaire was accompanied by a cover letter, signed by Drs. Donald Rundquist and Paul Read, explaining the rationale for the survey. Self-addressed and stamped envelopes were also provided, and the respondents were asked to mail the envelopes to me at my UNL address. Please see Appendix A and B for further details related to the questionnaire and cover letter.

2.2.1 Obtaining Geographic Coordinates for Nebraska Vineyards

The question of primary significance on the mailed document, of course, was oriented to where in Nebraska one's vineyard is located. We were hoping for coordinate information in some form (either latitude and longitude or township and range), but the various growers offered a wide variety of (sometimes anecdotal) locational descriptions.

Many of the grape growers responding to our survey did provide a legal description in township, range, section, and quarter section (e.g., N 1/2 SE 1/4, SW 1/4, S24, T32N, R18E) for their vineyards. Such a response meant that my first task was to convert the legal description to the corresponding latitude/longitude coordinate for the center of the section. A screen image from the software program TRS2LL, obtained from http://wefald.com/download.html, is shown as Figure 2.1.

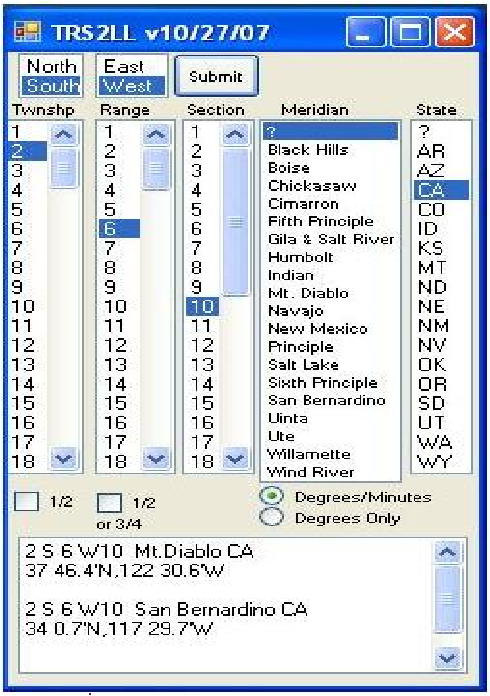

Figure 2.1: A screen image from the software program TRS2LL used to convert Public Land Survey Coordinates to latitude/longitude

In the TRS2LL program, the user selects the State/Meridian and directions, and then inputs the township, range, and section numbers. The program then provides the corresponding latitude and longitude information, as shown at the bottom of the graphic.

Far too many of the survey respondents provided only a street address for their vineyard (e.g., 55611 885 Rd, Fordyce, NE 68736-4018). In this case, Google Earth was employed to obtain the latitude and longitude by typing the street address in the Search column (see the upper red circle in Figure 2.2). The program output was the latitude and longitude displayed at the bottom of the map (See the red circle on the map proper in Figure 2.2).

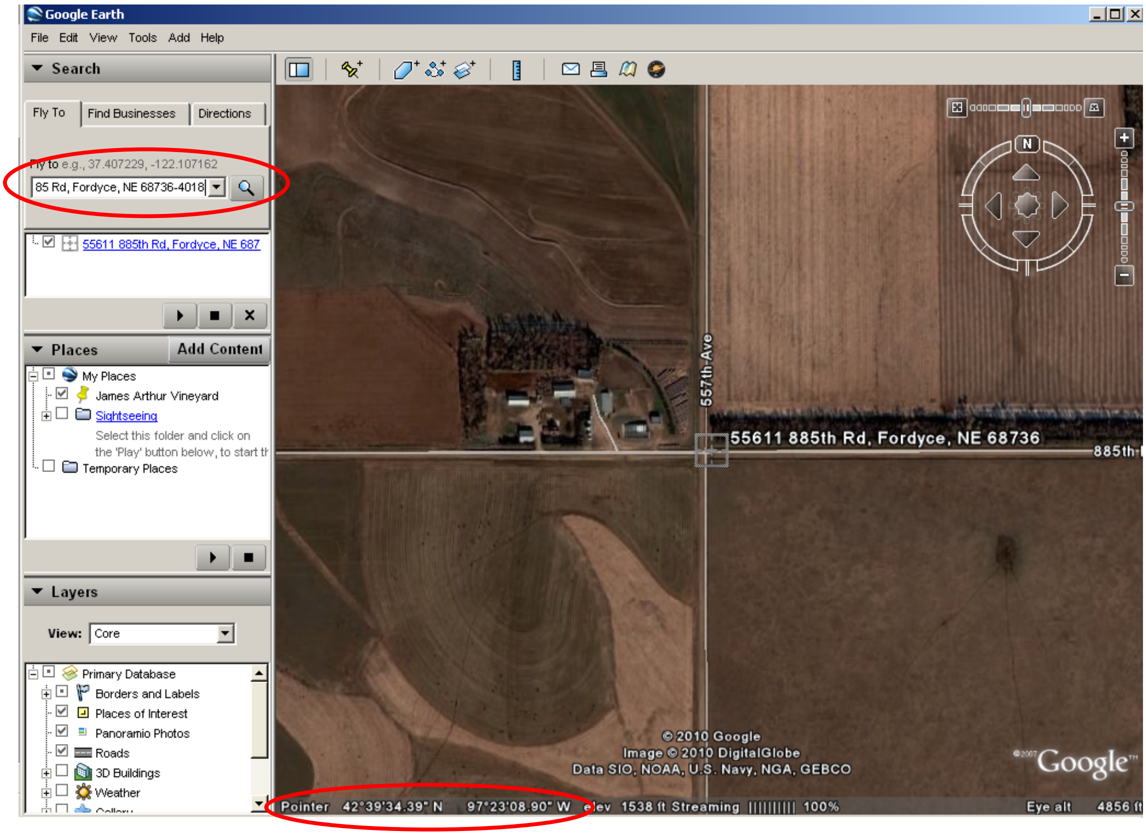

Figure 2.2 Google Earth interface

Unfortunately, some growers provided only a vague description of their vineyard location (e.g., Devils Nest, NE). This type of response made the geolocating very difficult as it can neither be converted to coordinates using the TRS2LL program nor pinpointed by Google Earth. My solution to the problem of such a vague description was to search the 2006 FSA (Farm Service Agency) imagery of the general area alluded to in the description in an attempt to identify a vineyard operation. Given the high spatial resolution of the FSA imagery (1 meter resolution), it was not difficult to visually discriminate a grape-growing operation from the typical surrounding corn and soybean operations. Figure 2.3 provides an example of the appearance of a vineyard on an FSA image.

Figure 2.3: SchillingBridge Vineyard, Pawnee City, Nebraska

2.2.2 Creating the Digital Database

Once a vineyard was accurately geolocated, the coordinate information, along with other related data provided in the survey, were compiled in a digital database consisting of two parts. The locational data were placed separately from the "related information," which included such things as acreage encompassed by the vineyard, vineyard location, grower-contact telephone and email, and grape cultivars planted.

An open source tool called PhpMyAdmin, which was written in PHP and intended to handle the administration of MySQL over the World Wide Web, was employed to perform the various data-management tasks such as creating, modifying or deleting database, tables, fields or rows. The two separate tables are connected by an ID, which is the name of the vineyard owner. Table 2.1 and Table 2.2 illustrate the structure of this relational database.

Table 2.1 User Information

ID	Owner	Phone	Email	Mailing Address	State
DonCox	Cox, Don	3085462853	ccvinyards@neb-sandhills.net	35181 Calf Creek Rd, Mullen, NE	NE
Harmony	Billings, Ron	4023763739	harmony@shwisp.net	801 Candice, Valentine, NE	NE
Jehorn	Horn, Jerry	4028832363	jehorn@sentco.net	PO Box 96, Shubert, NE	NE
……	……	……	……	……	……

Table 2.2 Vineyard Information

ID	Business Name	Township	Section	Range	County
DonCox	Calf Creek Vineyard	25	25	33	Cherry
Harmony	Harmony Vineyard	34	31	27	Cherry
Jehorn		3	12	15	Richardson
……	……	……	……	……	……

The following is the link that can be used to access and/or query the vineyard database. (http://snr12b.unl.edu/vineyard_database/index.php)

2.3 Map Result: The Spatial Distribution of Vineyards in Nebraska

While it is certain that our database is not exhaustive because some vineyard operators apparently do not wish to provide their locational and other information via the web, I believe that the dataset provided to the NDA is the best possible given current time and funding constraints. All the information, both locational and related, was saved as a .dbf4 (dBASE IV) file. A layer in shapefile (.shp) spatial data format was produced by importing the .dbf file into ArcMap. Figure 2.4 shows the current spatial distribution of vineyards in Nebraska with the county boundary as the base map. (County boundary map was downloaded from Nebraska Department of Natural Resources)

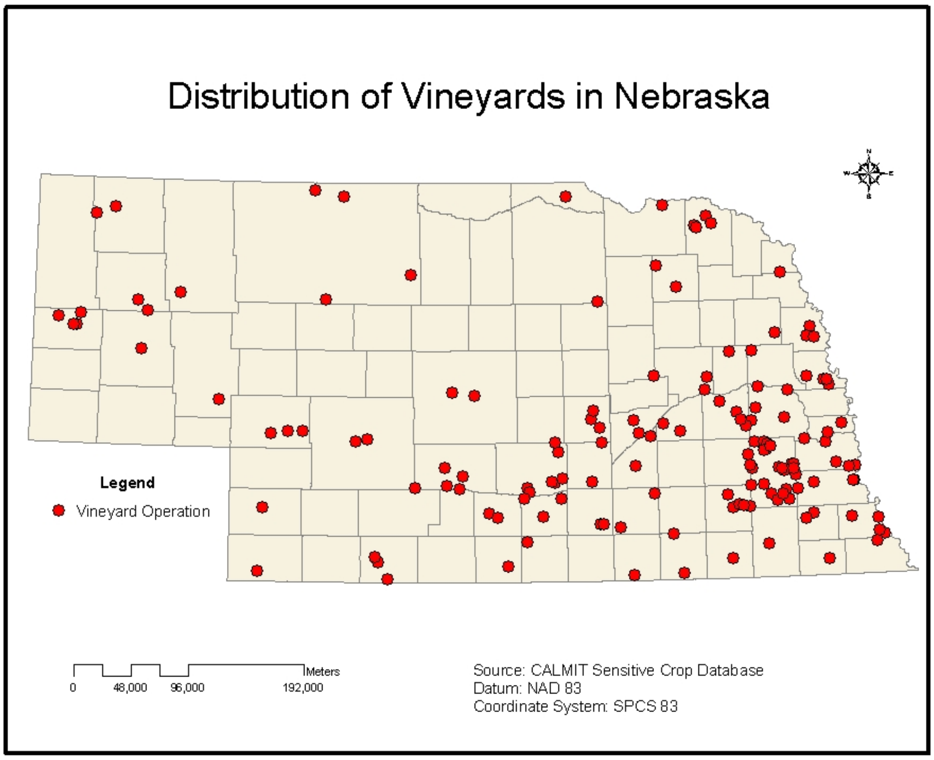

Figure 2.4: Current (2011) spatial distribution of vineyards in Nebraska

By my estimate, there are 152 vineyards distributed across the state. From the Figure 2.4, it is very obvious that most vineyards are concentrated in the southeastern part of

Nebraska. Lancaster County, with 22 vineyards, has the highest concentration of growing operations. Table 2.3 provides the per-county summary of vineyards in Nebraska.

Table 2.3 Per-county summary of vineyard in Nebraska

County	Number	County	Number	County	Number	County	Number
Boone	1	Dakota	1	Johnson	2	Platte	2
Box Butte	2	Dawes	3	Kearney	3	Polk	1
Boyd	1	Dawson	5	Keith	3	Red Willow	3
Buffalo	7	Dodge	1	Knox	1	Richardson	1
Burt	5	Dundy	1	Lancaster	22	Saline	5
Butler	5	Franklin	1	Lincoln	2	Sarpy	2
Cass	5	Gage	1	Merrick	2	Saunders	7
Cedar	4	Garden	2	Morill	1	Scotts Bluff	4
Chase	1	Hall	2	Nemaha	4	Seward	2
Cherry	4	Hamilton	2	Nuckolls	1	Sheridan	1
Clay	3	Harlan	1	Otoe	5	Thayer	2
Colfax	1	Holt	1	Pawnee	1	Washington	4
Cuming	1	Howard	3	Phelps	2		
Custer	2	Jefferson	1	Pierce	2		

2.4 Summary

The goal of this chapter was to map the vineyard locations in Nebraska and develop an updated, hopefully accurate database. Figure 2.4 and Table 2.3 provide the “vineyard geography” of our state. The link provided above allows users to access the compiled database. The spatial distribution of vineyards in Nebraska will be used in a following chapter to compare with the results of the GIS-based suitability model.

CHAPTER 3: DEVELOPING A PROTOTYPE GIS-BASED MODEL TO ASSESS VINEYARD SUITABILITY IN NEBRASKA

In order to construct a Geographic Information System (GIS) model which will delineate sites as having either suitable or unsuitable viticulture potential, factors that influence the proper growth and development of grapes have to be determined. Numerous researchers have examined the many factors related to grapevine culture, providing some insight into the complex interrelationships comprising viticultural practice (growing grapes), enology (the production of quality wine), and the site characteristics. Wilson (1998) analyzed the importance of various factors, and his discourse provided recognition that geology and geological processes are relevant to wine quality. Haynes (1999) further discussed the importance of the interrelationships among all the grapevine-related factors and concluded that soil and subsoil were the determining factors controlling the grape growth and wine taste. Numerous articles have dealt with the various physical factors associated with site selection for vineyards, and although there is some disagreement about which factors should be included and be the most important, most research focuses mainly on climate, topography, and soil factors (e.g., Shaulis and Dethier, 1970; Dry and Smart, 1988; Gladstones, 1992; Wolf, 1997; Jones and Hellman, 2003). Therefore, climate, soil, and topography were the variables selected for inclusion in the model developed for this study. Land use is also considered in this analysis due to the fact that the land use can significantly affect costs though it does not directly affect potential for the growing of wine grapes.

3.1 Site Considerations

A literature search (Duke, 1981; Brooker and Gray, 1990; Janick and Simon, 1993; Myers, 1993; Boyer, 1998; Smith and Whigham, 1999; Jones at al, 2004) and numerous Internet Web pages were used to identify the physical requirements (climate, soil, topography and land use) for the cultivars of wine grapes suitable for growing in Nebraska. Soil requirements included the range of pH, soil drainage characteristics, and amounts of organic matter. Climate requirements included length of frost-free period, extreme minimum winter temperatures, and growing-degree days. While other climate (e.g., humidity and solar radiation) and soil (e.g., soil depth to rock) characteristics may limit crop growth at a location, they were not included in this study because these specific crop requirements were generally unknown with regard to the cultivars selected.

3.2 Data Collection and Processing

The majority of the data described above were acquired from the Nebraska Department of Natural Resources (NDNR) via their online archive. The data acquired for the development of the GIS database were in multiple formats including shapefiles (.shp), DEM files (.dem) and raster grid files (.grid). All these files were converted into .grid files for ease of overlay analysis. Once all of the digital datasets were collected for use with the GIS, they were projected into a single coordinate system based on a common datum and coordinate system in order to ensure spatial accuracy and cohesion between and among layers in the database. The datum and coordinate system chosen for the current study was the North American Datum of 1983 (NAD 1983) and SPCS83. All data have a resolution of 30 meters, a decision due to the fact that the preponderance of the available information were already at 30 meters.

3.2.1 Climate

Climate is a very important factor in choosing a site for vineyard development. The climate of Nebraska is classified as Continental, according to the Koppen classification system (Strahler, 2006). A continental climate is characterized by having hot summers and cold winters with the majority of the precipitation coming in the spring and summer months. For this study, climatic data were obtained from the High Plains Regional Climate Center (http://www.noaa.gov) and the National Oceanic and Atmospheric Administration (http://www.hprcc.unl.edu).

3.2.1.1 Length of Frost-free Period

The length of frost-free period is important in determining whether grapes will ripen or not. Decreasing temperatures in the fall reduce the capacity of the vine to synthesize sugar and ripen grapes. Ultimately, frost will kill leaves that have not naturally senesced, preventing further sugar accumulation in fruit and perennial portions of the vine (Wolf and Boyer, 2003). Vineyard sites, therefore, must have not only sufficient heat but also the duration of heat to ensure ripening of the crop. A minimum of 160 frost-free days is recommended for vineyards in Nebraska (Read, 2008), although very early-maturing varieties, such as Cabernet Franc, may ripen with a season as short as 150 days. The average period from budbreak to fruit harvest ranged from 144 to 179 days for diverse varieties evaluated at Winchester, Virginia (Wolf and Warren, 2000; Wolf and Miller, 2001). In this study, data summarizing the length of frost-free days above -32°F were collected from the High Plains Regional Climate Center's Frost Statistics, based upon 96 weather stations across the State of Nebraska (and a surrounding area outside the state border). Continuous spatial estimates of the length of frost-free days were interpolated using the Spline method, which assumes a minimum curvature between nearby points (see Figure 3.1).

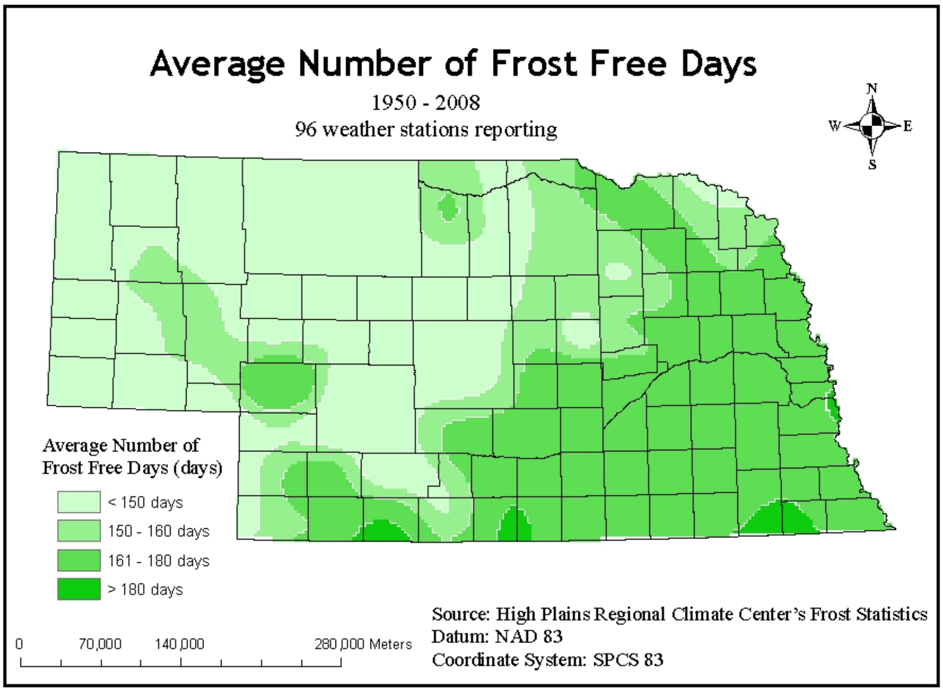

Figure 3.1: Nebraska's average number of frost-free days

Figure 3.1 illustrates patterns in number of frost free days across the state, but of course, specific sites in the region may have slightly longer or shorter growing seasons due to micro- and mesoclimatic anomalies. Notice that the general trend is for the number of frost-free days to increase from west to east, with the maximums in the Southeastern portion of the state, and along the Kansas border.

3.2.1.2 Growing Degree Days

Grapes obviously need warm temperatures to ripen during the growing season. The concept of growing degree days (GDD) is used to quantify heat available for grapevine development (Wolf and Boyer, 2003). By convention, the number of growing degree days is tallied from April 1 to October 31, with the calculation using a base temperature of 50 degrees Fahrenheit (Wolf and Boyer, 2003). This is due to the fact that photosynthesis and respiration cease, for all practical purposes, at temperatures lower than 50°F. The following is the equation used in calculating growing degree days:

GDD =Sum of [(Daily Max Temp + Daily Min Temp)/2-50] for all days from April 1 to Oct 31.

In this study, data for growing degree days were collected from the High Plains Regional Center’s Historical Data Summary from 103 weather stations across the State of Nebraska and the surrounding area outside the border. Continuous spatial estimates of the growing degree days were interpolated using the Spline method, which assumes a minimum curvature between nearby points (see Figure 3.2).

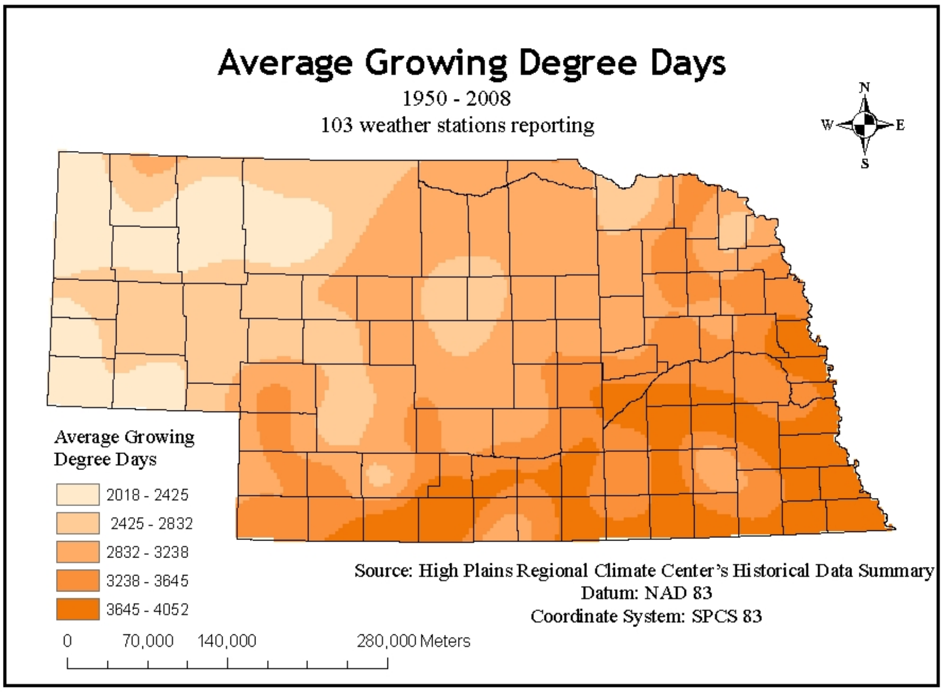

Figure 3.2: Nebraska's average growing degree days

Figure 3.2 illustrates patterns of growing degree days across the state, although specific sites in the region may have slightly higher or lower growing-degree days based on micro- and mesoclimatic influences. Again, notice that the numbers increase from west to east, with the Southeast appearing to be most desirable.

3.2.1.3 Frequency of Extreme Winter Temperatures

Temperature varies markedly in Nebraska because of its inner continental location. Grapes grown in the state are often exposed to climatic stresses that can reduce fruit quality and yields, and injure or even kill grapevines. Certainly, vines can be severely damaged or killed by extremely low winter temperatures, not to mention frosts occurring in late spring or early fall, as well as the high summer temperatures. Injury to grapevines may include death of overwintering buds, or damage to the vascular tissues of canes, cordons, and trunks (Wolf and Boyer, 2003). The frequency of damaging low winter temperatures determines whether or not grape production is possible and, if it is, what species and varieties have a chance of withstanding the cold. Due to the dynamics of vine cold hardiness (Howell, 2000), it is difficult to say precisely what specific temperature will cause cold injury to a particular grape cultivar on an individual date.

In this research, daily temperatures over a ten-year period were recorded. New values (numbered 1 through 4, with 4 being the most suitable for grapevine growth and 1 being the least suitable) were assigned to daily temperatures based on their potential damage to the vineyard. For example, the minimum winter temperature an Edelweiss vine can stand is -32°F (Smiley, 2008). I then assigned the value 4 to all temperatures that were above 0°F; value 3 to temperatures above -15°F but below 0°F, value 2 to temperatures that were above -32°F but below -15°F, and value 1 to temperatures below -32°F. The next step was to apply the following equation:

$(N \times 4 + M)/D$

Where N = the number of days whose minimum temperatures were above 0 °F as measured over the entire ten-year period.

M = the sum of the new assigned values (1 to 3) for daily minimum winter temperature below 0 °F for the entire ten-year period.

D = the total number of days in January (31 days), February (28 days), March (31 days), November (30 days) and December (31 days) for a ten-year period, which is 151*10 days or 1510 days.

Finally, the final result was transformed (e.g., 3.70125 to 4.0638) to a scale ranging from 1 to 10 by linearly stretching the data using the following equation:

$$(y - 1) / (10 - 1) = (x - 3.70125) / (4.0638 - 3.70125)$$

By doing a 1 to 10 normalization, the dataset is capable of better depicting variability across the state. When interpreting the result, if an area achieved a score of 10, then it will be considered to be optimally suitable for grape vine growth. But, if an area has a score of 1, it is considered very poor for the potential growing of grapevines. Figure 3.3 depicts the result of the scaling.

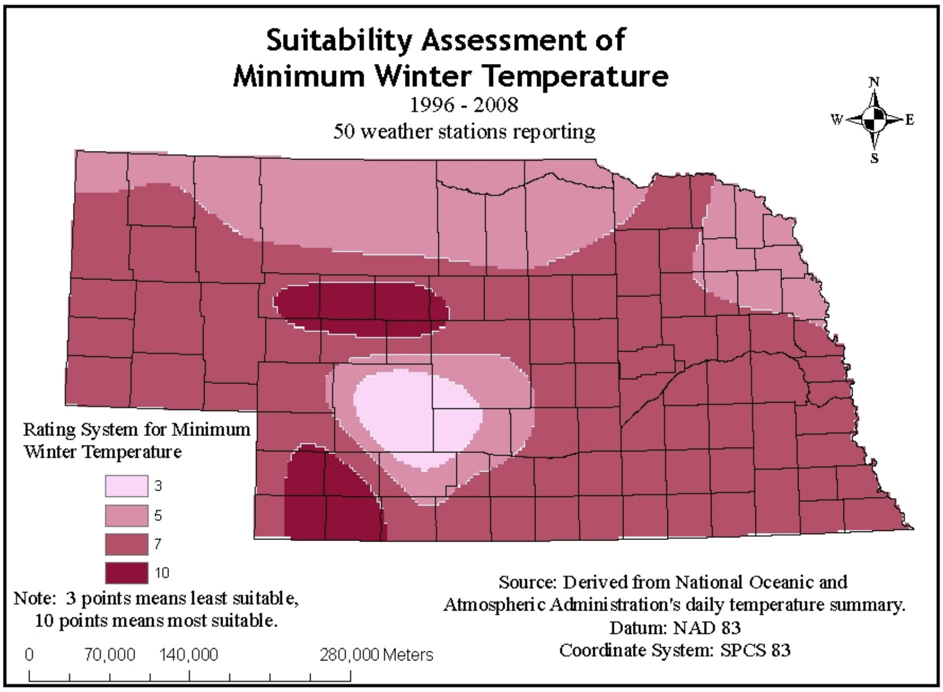

Figure 3.3: Nebraska’s suitability assessment of minimum winter temperature

Figure 3.3 illustrates patterns in minimum winter temperature across the state, although specific sites in the region may have slightly longer or lower winter temperatures based on micro- and mesoclimatic influences. Not surprisingly, the general pattern is one of greater suitability toward the southern boundary of the state.

3.2.2 Soil

Soil obviously influences grapevine productivity and wine quality. However, like climate, soil is comprised of many components such as texture, hydrology, depth of profile, origin of parent rock, organic matter content, chemical properties, and other factors including the density and diversity of invertebrate fauna. Though the precise manner as to how these soil variables influence grapevine productivity and wine quality has not been well characterized, some properties are either decidedly more important than others by virtue of their known influence on vine performance, or because some are more easily improved upon than others. One should realize, however, that like above-ground features, few soils will be ideally suited with regard to all potential criteria. Soils cannot be evaluated independently from the other vineyard site considerations discussed in this work, and some compromises in soil quality may be necessary so that the vineyard site selection process does not become too biased toward soil considerations (Wolf and Boyer, 2003).

3.2.2.1 Sources of Soil Data

The source of detailed soil data was the U.S. Department of Agriculture (USDA) Soil Conservation Services soil survey. This information can be found through the USDA Natural Resources Conservation Service (NRCS) Website (http://soils.usda.gov/). STATSGO data, which consist of geo-referenced locations and a complicated database with more than 50 tables, were downloaded from the above website. Each soil map unit, typically a set of polygons, may contain multiple soil components that have different use and management. The thematic soil maps were created using Soil Data Viewer and then converted to a raster format in ArcGIS at a resolution of 30 meters. Soil Data Viewer is a tool built as an extension to ArcMap that allows a user to create soil-based thematic maps. Soil Data Viewer makes it easy to compute a single value for a map unit and display results, relieving the user from the burden of querying the database, processing the data and linking to the spatial map. In my thesis, I used Dominant Component methods to create soil based thematic maps. This aggregation method returns the attribute value associated with the component with the highest percent composition in the map unit. If more than one component shares the highest percent composition, the corresponding "tie-break" rule determines which value should be returned.

3.2.2.2 Soil Drainage

The single most important soil trait to consider in terms of grapevine health is internal water drainage or permeability (Cass, 1999). “Good drainage” refers to the speed with which free moisture drains from the soil profile. Well-drained soils are more desirable than poorly drained ones because waterlogged soils increase the occurrence of root rot, fungus, and pathogens (Childers, 1976; Barden, 1998; Marini, 1998). In addition, vines allowed to grow in water-saturated soils develop shallow root systems because there is not enough oxygen to support deep root growth, and all of the plant’s water requirements are met near the surface. This type of growth quickly becomes problematic during even moderate droughts, as the shallower rooting system is immediately water starved (Wolf and Boyer, 2003).

Data from soil surveys refer to soil drainage in ranges from excessively drained to poorly drained. Generally, a moderately well-drained soil is suitable for grapevines and a well-drained soil is ideal. Figure 3.4 depicts the patterns of Nebraska’s soil drainage classes.

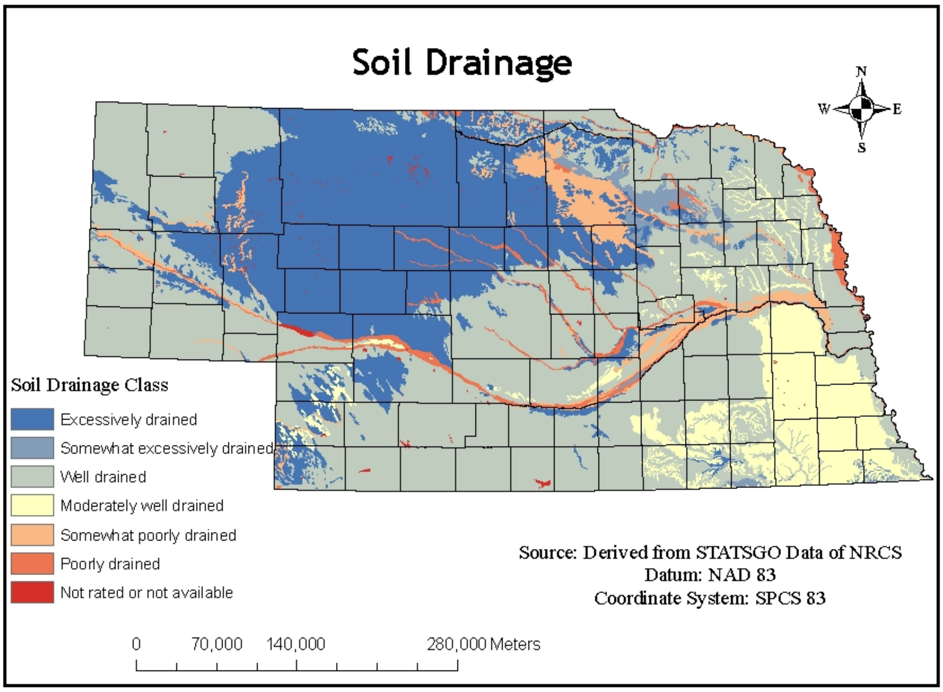

Figure 3.4: Nebraska's soil drainage classes

Figure 3.4 illustrates the soil drainage pattern across the state. From the map, we see that the Northcentral part of the state (the Sandhills region) falls within the category of excessively drained soil, but most areas in the state are well drained and moderately well drained.

3.2.2.3 Organic Matter

Organic matter contributes porosity, structure, nutrients, and moisture holding ability to a given soil. It also aids in supporting a diverse microbial and invertebrate (e.g., earthworms) ecology. Organic matter provides a pool of slowly available nitrogen to support vine growth, and content values greater than 5% may be counter-productive in that excessive nitrogen that is released by decomposition may lead to supra-optimal vine growth. However, soils that have been exploited by deficit farming or that are inherently low in organic matter can be profitably amended with compost, green manures, or other forms of organic matter and, therefore, should not be rejected as vineyard soils (Wolf and Boyer, 2003). Figure 3.5 depicts the percentage of soil organic matter over the state.

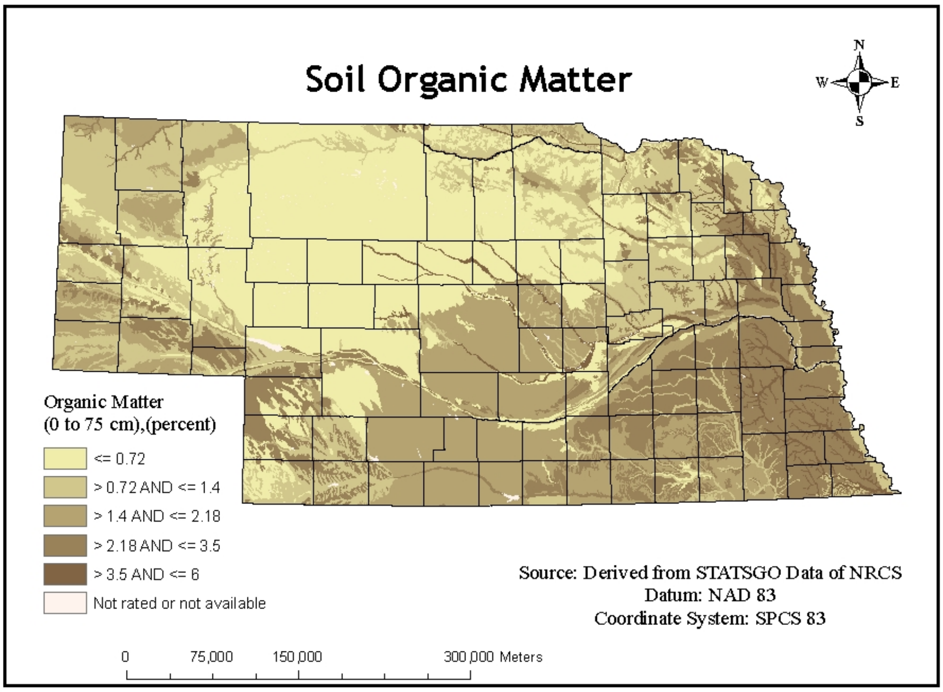

Figure 3.5: Nebraska's soil organic matter

Figure 3.5 illustrates patterns in soil organic matter across the state. From the map, we see that the soil with highest percentage of organic matter is distributed throughout the southeastern part of Nebraska while the north central part of the state ranks lowest in percentage of soil organic matter.

3.2.2.4 Soil pH

Soil pH is an important consideration for grape cultivar siting. Acidic to neutral soils with pH values between 5.5 and 7.0 are best, although grapes tolerate a wide range of soil pH. Soils with pH values greater than 8.0 can create nutritional problems, such as iron chlorosis, in the grape vines. In addition, some diseases tend to thrive when the soil is alkaline or acidic. Soil pH can also affect the availability of nutrients to the plant.

Figure 3.6 depicts the soil pH information across the state.

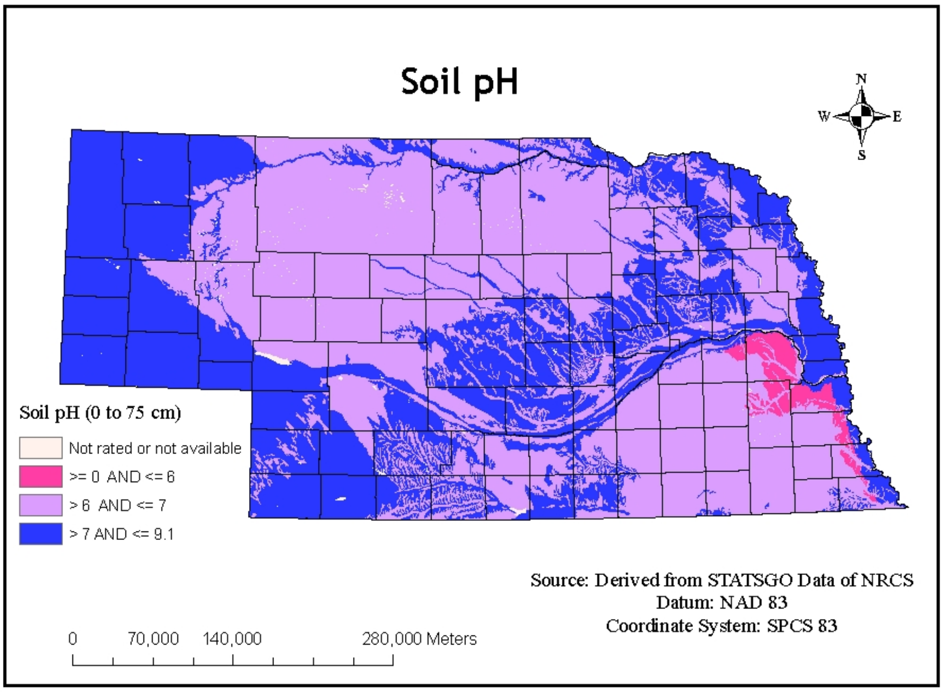

Figure 3.6: Soil pH

From the map, it is clear that the soil with highest pH value is distributed throughout the western, central, and eastern part across Nebraska; while a minor area in the southeastern part ranks lowest in pH value. It can be inferred from Figure 3.6 that the areas with the most desirable soil pH (between 5.5 and 6.8) are located in the Southeastern and North Central part of the state.

3.2.3 Topography

The topography of a site is recognized as having an influence on grape production by affecting its mesoclimate (Gladstones, 1992). From an analysis of “premium vineyards” from around the globe, Gladstones (1997) found that they tended to have a reduced diurnal fluctuation in temperature due to two or more of the following topographic characteristics: 1) they are located on slopes with excellent air drainage and situated above the fog level; 2) the slopes are on projecting or isolated hills and have outstanding air drainage; or 3) they directly face the sun during part of the day (easterly aspects are desirable). Therefore, the dominant topographic characteristics that influence grapevine performance appear to be elevation, slope, and aspect.

3.2.3.1 Elevation

Most of Nebraska is composed of gently rolling hills with very few steep slopes. Therefore, elevation may not be an important factor for site selection of vineyards in Nebraska.

3.2.3.2 Slope

Slope is also important for surface and, to some extent, for internal soil water drainage, both of which are critical in the growing of grapevines. Slopes steeper than 15% are not recommended because of risk of roll-over or the downhill drift of towed equipment into the vineyard row (Wolf and Boyer, 2003). Though terracing slopes is possible, it adds difficulty to vineyard establishment and management costs. The risk of soil erosion is also increased when soils are cultivated on steep slopes. Slope data were calculated based on Digital Elevation Model (DEM) data using Surface analysis in ArcGIS. The DEM is a digital file consisting of terrain elevations for ground positions at regularly spaced horizontal intervals. Figure 3.7 provides a summary of slopes in Nebraska.

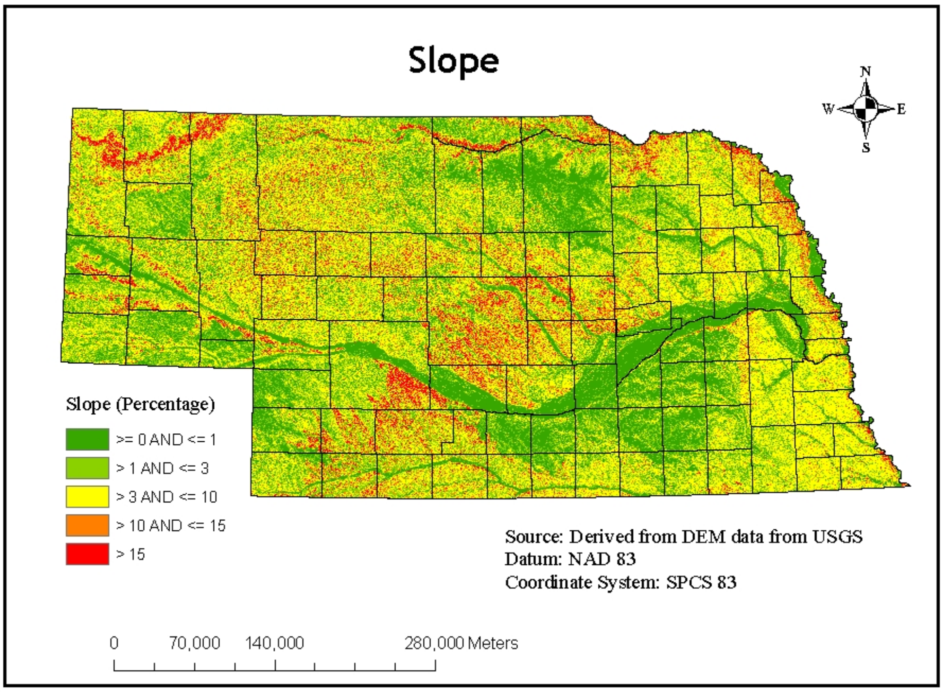

Figure 3.7: Slope (percentage)

Figure 3.7 illustrates slope ratings across the state. It is difficult to recognize a general pattern, but one can still concludes from Figure 3.7 that the sites with desirable slopes (between 3% and 10%) are mostly located in the Southeastern part of the state.

3.2.3.3 Aspect

Aspect refers to the predominant directional orientation of a slope, and it is important in that it affects the total heat balance of a vineyard. Aspect also has a slight, but measurable effect on winter temperatures. In a long-term Georgia study, minimum temperatures on northerly slopes were 1.0°F to 2.5°F cooler than on the corresponding elevations of southerly slopes during freezes with temperature inversions (Johnstone et al, 1968). In the same study, the frost-free growing season was, on average, about two weeks longer on slopes with southern aspects than on those with northern aspects.

There are advantages and disadvantages to most vineyard aspects. Fortunately, aspect is probably the least important physical factor of vineyard site considerations (Wolf and Boyer, 2003). In practice, other factors such as elevation, current land use, and soil characteristics typically dictate which aspect will be planted with vines. Figure 3.8 depicts the aspect data for the state. Of course, the results are much localized, so it is difficult to verbalize a general pattern. East-facing slopes, the most desirable as noted above, are found in many places throughout Nebraska.

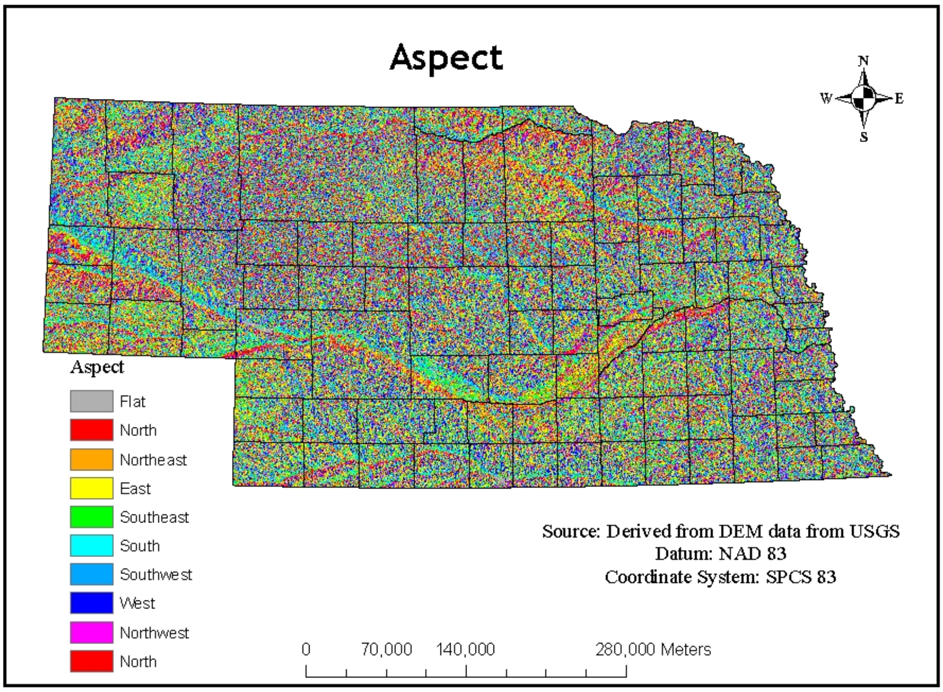

Figure 3.8: Aspect

3.2.4 Land use

Land use does not directly affect the potential for grapevine growth, but is an issue in that some areas are simply not available for vineyard development. For example, urban areas and water bodies are obviously quickly eliminated as potential sites for commercial vine cultivation. Therefore, land use must be considered as a factor in identifying locations for viticulture. Figure 3.9 depicts the land use classes as distributed across the state.

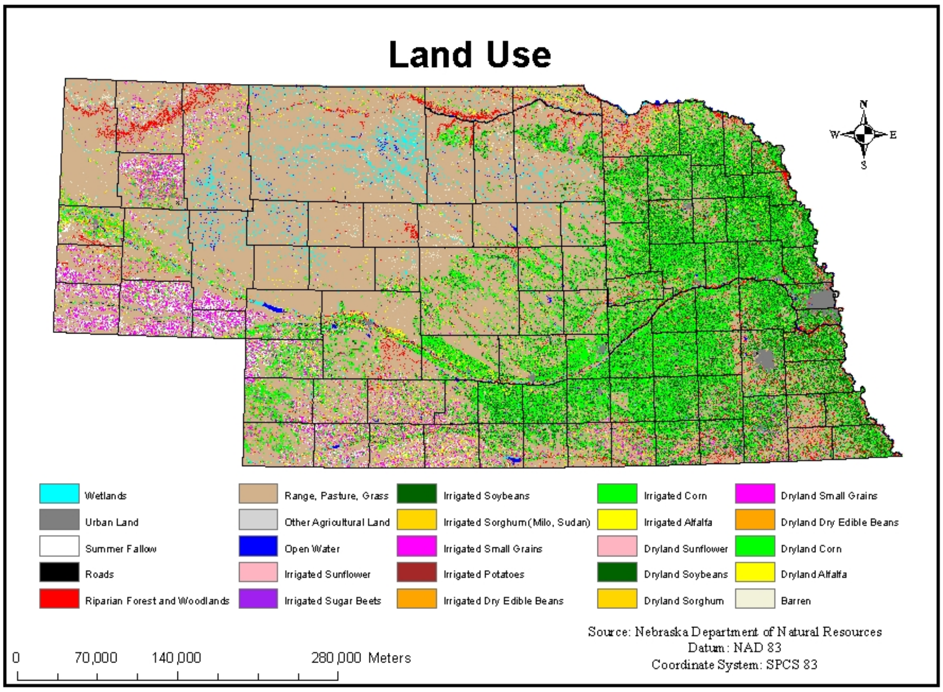

Figure 3.9: Land use

Summary

The variables summarized in preceding paragraphs were compiled and geo-registered for inclusion in the GIS model. The methods employed in the development of that model are outlined in the next chapter.

Chapter 4: Methods Used in Developing a GIS-Based Model to Assess Vineyard Suitability

The purpose of this chapter is to describe the procedures implemented in developing a GIS-based model that was used in assessing the suitability of growing grapes in various parts of Nebraska. It is impossible, however, to treat this problem in a "crop-wide" manner; i.e., one cannot simply assess the general location suitability of growing grapes. More specifically, because grape cultivars vary greatly in terms of their cold hardiness, tolerance to disease, and canopy vigor, it is necessary to evaluate individual cultivars in terms of the considerations (e.g., climate) noted in Chapter 3. For purposes of developing the model, therefore, two specific grape cultivars were selected for use.

4.1 Grape Cultivars Used for Model Development and Testing

Many grape cultivars are grown over the world for the purpose of making wine, and some of the most popular, widely recognized types include Chardonnay, Cabernet Sauvignon, Riesling, Merlot and Pinot Noir. None of these, however, are suited for growing in Nebraska due to the climatic extremes experienced here. Because of its continental location, conditions in Nebraska are not as temperate as many of the well known grape-growing regions of the world, and our state has both a relatively short growing season and winters occasionally producing extremely cold temperatures (Smith, 2006). In order for a grape cultivar to be grown successfully in Nebraska, it must be "winter hardy," meaning that it is able to withstand occasional very cold temperatures. To allow the growing of wine grapes in cold climates, plant breeders created hybrids by crossing wild, winter hardy American vines with established European wine grapes (Smith, 2006). The resulting cultivars have been named "French-American hybrids." A few examples of the major grape cultivars that are cultivated in Nebraska, as reported in the 2004 Nebraska Grape Census, are described below. Note the breeding process needed to bring the climatic resistance to the resulting vines.

De Chaunac

De Chaunac is a French-American hybrid wine grape cultivar used to make red wines. It was developed by Albert Seibel circa 1860. It is also known as Seibel 9549 and is a cross of Seibel 5163 and possibly Seibel 793 (http://en.wikipedia.org/wiki/De_Chaunac). It is productive, winter hardy, and can withstand temperatures as low as -25°F. *De Chaunac* has a good resistance to powdery mildew and downy mildew (Reisch et al., 1993). It is grown in varying amounts for wine production across the northeastern portion of North America, especially in the winegrowing regions of New York, Pennsylvania, Nova Scotia, Ontario, and other similar wine growing areas.

Frontenac

Frontenac is a French-American hybrid grapevine grown from a crossing of the complex inter-specific hybrid Landot 4511 and a very cold hardy selection of *Vitis riparia*. *Frontenac* is winter hardy and able to withstand temperatures as low as -35°F (Reisch et al., 1993). The vines are highly resistant to downy mildew, and also to powdery mildew and botrytis. *Frontenac* is a grape cultivar that ripens late in the growing season.

LaCrosse

LaCrosse is a hybrid cultivar, mostly grown in North America. *LaCrosse* is a hybrid of Seyval Blanc and Minnesota 78 x S.1000. It produces grapes suitable for making fruity white wines similar to Riesling, or as a base for blended wines. It is another winter hardy cultivar suited for the Midwest and it has been successfully grown in Minnesota and Nebraska. *LaCrosse* grape can withstand at least -25° F (Reisch et al., 1993).

Saint Croix

Saint Croix is a hybrid red wine grape cultivar which can tolerate temperatures from -20°F to -31°F (Domoto, 2007). It was released by Elmer Swenson in 1981 by cross breeding (Minnesota 78 x S. 1000) and (Minnesota 78 x Seneca). *Saint Croix* is a productive grape cultivar (Bordelon, 2005).

Edelweiss

Edelweiss is an American hybrid derived from cross breeding the Minnesota 78 and Ontario grapes (Smith, 2006) and it is very winter-hardy (as low as -32°F). It is an early maturing cultivar, so early harvesting is essential for making good wine. This grape cultivar also has strong resistance to grape diseases and fungus. *Edelweiss* is one of the major grape cultivars cultivated across Nebraska, and is probably the best selling of the state's wines.

Cynthiana/Norton

Cynthiana-Norton is a native American grape cultivar. *Cynthiana/Norton* originated from *Vitis aestivalis*, and was given different names, 'Norton' in Virginia and 'Cynthiana' in Arkansas. In the following text, Norton will be used instead of Cynthiana/Norton. It is moderately winter-hardy (-10°F to -15°F), has a late maturity, and can only adapt to long frost-free sites of 180 or more days (Smiley, 2008). This grape cultivar also has strong resistance to grape diseases (Smiley, 2008). As such, Norton is a minor grape cultivar cultivated in Nebraska, despite the excellent wine that it can yield.

For my research and model testing, I chose to examine only two cultivars; Edelweiss and Norton. Hence, the model development which is summarized below was oriented to those two cultivars.

4.2 Methodology

As noted in my earlier literature search, numerous researchers have addressed questions of geographic suitability for wine-grape cultivation (e.g., Brooker and Gray, 1990; Myers, 1993; Boyer, 1998; Smith and Whigham, 1999; Young *et al*, 2000; Bowen and Hollinger, 2004; Jones *et al*, 2004; Smith, 2006; Day *et al*, 2006), and all attempted to define and map potential areas suited for growing grapes by analyzing the climate and soil variables, considered by most to be the critical physical factors for grapevine growth. In this study, however, I deviated from those approaches in that I attempted to be more specific and address the fact that various grape cultivars have different thresholds or limits with regard to cold hardiness. Therefore, I consider cold hardiness to be the most critical factor to be considered in my attempt to model the suitability of various Nebraska regions for the growing of wine grapes. Thus, for purposes of testing my GIS-based model in the state, I chose, as noted above, two grape cultivars that have very different levels of cold hardiness; Edelweiss and Norton.

The examination of location suitability for these two cultivars allows for assessing not only whether current growers have placed their crops in logical geographic locations but also for potential growers to recognize that ideal places exist for growing that cultivar.

4.2.1 The Input Variables and Their Weights

The concept behind the grape suitability analysis process is very simple. Individual variables considered in the previous section—growing degree days, frost free period, minimum winter temperature, aspect, slope, soil drainage, soil pH, and organic matter--each comprise a separate layer in the GIS analysis. Referring to the methods and models developed for viticulture potential in Virginia (Boyer, 1998), vineyard selection for Maryland Southern and Eastern Shores (Joseph A. Fiola, 2007), analysis of the terroir potential in the Umpqua valley of Oregon (Gregory *et al*, 2004), the Pennsylvania vineyard site assessment system (Day, 2006), and other literary sources, the model employed in the current study is an index model (Weight-rating Score Model). It can be expressed as:

$$\sum_{i=1}^{n}(Wi \times Vj)$$

Where W_i = weight of the i^{th} variable

V_j = score of the j^{th} class in the i^{th} variable

For my study, there were eight variables involved in the analysis (growing degree days, frost free days, minimum winter temperature, aspect, slope, soil drainage, soil pH and soil organic matter). Therefore, the model can be expressed as follows:

$$\text{Total Score (Index value)} = W_{gdd} \times V_{gdd} + W_{ffp} \times V_{ffp} + W_{mwt} \times V_{mwt} + W_{slope} \times V_{slope} + W_{aspt} \times V_{aspt} + W_{soldrng} \times V_{soldrng} + W_{pH} \times V_{pH} + W_{orgmttr} \times V_{orgmttr}$$

Where:

W_{gdd} = weight of growing degree days and V_{gdd} = value of classes in growing degree layer

W_{ffp} = weight of the frost free period and V_{ffp} = value of classes in frost free period layer

W_{mwt} = weight of minimum winter temperature and V_{mwt} = value of classes in minimum winter temperature layer

W_{slope} = weight of slope and V_{slope} = value of classes in slope layer

W_{aspt} = weight of aspect; and V_{aspt} = value of classes in aspect layer

$W_{soldrng}$ = weight of soil drainage and $V_{soldrng}$ = value of classes in soil drainage layer

W_{pH} = weight of pH and V_{pH} = value of classes in pH layer

$W_{orgmttr}$ = weight of soil organic matter and $V_{orgmttr}$ = value of classes in soil organic matter layer

As can be seen from the above equation, each variable (layer) was assigned a weight (W_i) depending on its influence on the growth of each of the two selected cultivars. Numeric ratings (weights) assigned to each layer were determined by means of both literary sources and consulting with my committee members. Each layer was given a numerical value, ranging from 1 to 10. That assigned value was determined by its relative importance to the growth of Edelweiss and Cynthiana-Norton, respectively. For example, the role of the frost free period was determined to be more important to a site than soil pH, so the former received a higher total point value than the latter.

Of all the factors specific to the site (e.g., climate, topography, soil), climate exerts the most profound effect on the ability of a region or site to produce quality fruit (Jones et al, 2004). Climate factors included minimum winter temperature, frost free period, and growing degree days, among which the minimum winter temperature was considered to be the most important factor influencing the distribution of grape cultivation (Kurtural, 2005). Even in established grape growing areas, temperatures occasionally reach critically cold levels and cause significant damage. Freezing injury, or winter kill, occurs as a result of permanent parts of the grapevine being damaged by sub-freezing temperatures. This is different than damage due to late spring frost, which kills the young shoots and flower buds, and therefore reduces the crop yield. Thus, winter kill can be costly, as entire plants can be destroyed, not just the buds which affect the crop for a single year. Therefore, minimum winter temperature received the highest value; 10 points. Referring to the literature and the Pennsylvania Vineyard Site Assessment Model (2009), the frost free period was determined to be the second most important, and thus it received 9 points.

Growing degree days is another consideration in selecting a suitable site for a certain grape variety. That metric has been used to predict a vine's ability to mature and produce a high quality crop in the northern hemisphere (Amerine and Winkler, 1944), but it probably should not be considered more important than the minimum winter temperature and frost-free period. The former only affects the vine's ability to mature a quality crop, while the latter two parameters can injure or even kill the crops. The literature suggests that growing degree days should receive 8 points on a 10-point scale (Boyer, 1998).

The soils of a site also play critical roles in grapevine growth and quality. The best vineyard soils are those that permit deep and spreading root growth, and provide a steady, moderate supply of water (Kurtural, 2005). As noted previously, the internal water drainage is the most important soil physical property. Though it can be modified during site establishment, the result of doing so increases the cost of vineyard development. Thus, soil drainage received 10 points based on both the above reason and the Pennsylvania Vineyard Site Assessment Model (2009). The soil organic matter and soil pH seem not to be as important as soil drainage, and they can also be modified easily during site preparation. Soil organic matter can be improved by amending the soil with compost, green manures, or other forms of organic material, while soil pH can be adjusted with lime or sulfur applications. Due to the above discussion, and referring to the Pennsylvania Vineyard Site Assessment Model (2009), soil organic matter and soil pH received only 4 points in the analysis.

Topography is the last, yet not the least important, factor that exerts influence on the growth of vine grapes, and it has interactive effects with climatic elements. Topography, in the current study, was considered to include both aspect and slope. The effect of aspect on grape varieties is somewhat variable and complex, plus there is a general lack of research data to support claims of its importance. Some authors, in fact, consider aspect to be the least important among the set of topographic factors related to vineyard siting (Wolf and Boyer, 2003). Therefore, aspect was weighted at 5 points for purposes of the model. Slope was weighted at 6 points, as suggested by the Pennsylvania Vineyard Site Assessment Model (2009).

Based on the above considerations and weighting, the numeric ratings for each layer comprising the current analysis are as follows (see Table 4.1):

Table 4.1 Weights for each layer of the GIS

Variables	W_{scale}	$W_{normalized}$
Growing Degree Days	8	14.3%
Frost Free Days	9	16.1%
Minimum Winter Temperature	10	17.9%
Aspect	5	8.9%
Slope	6	10.7%
Soil Drainage	10	17.9%
Soil pH	4	7.1%
Soil Organic Matter	4	7.1%
SUM	56	100%

Note: W_{scale} refers to the scale from1 to 10.

$W_{normalized}$ is the percentage effect each layer has during model calculation.

At this point in the procedure, each layer received a weight ranging from 1 to 10 points. Taken together, the points assigned to the eight layers add up to a total of 56 possible points. By dividing the points each layer received by all 56 points, the percentage of influence each input layer has on the grapevine growth can be derived. The final percentage rate for each variable is summarized in Table 4.1.

4.2.2 The Method for Determining Class Ranking for Edelweiss Vines

After assigning weights (W_i) for all input raster layers, the next step was to determine the V_j value of the classes or sub-groups within each variable/layer. I refer to this as the "individual class ranking within a layer." As noted above, for each layer, a total point value (10 points) was distributed across the range of possibilities, and each range was valued according to the relative importance of that variable in successfully growing a particular grape cultivar. With regard to the class ranking, however, further quantitative scaling was required. For example, with regard to the frost-free-period layer, a maximum score is 10 points. It was decided (see below) that a frost free period of more than 180 days earned all 10 points while a frost free period with less than 150 days should receive only 1 point. The ratings among the classes within each layer (V_j) were determined by both the literature sources noted above and in the previous chapter, and by consulting with members of my supervisory committee.

The individual class ranking for Edelweiss is explained in the subsequent paragraphs.

Growing Degree Days

According to Winkler and Amerine (1944), a sound rating system for growing degree days is as follows:

2018 GDDs – 2425 GDDs = 3 points

2425 GDDs – 2832 GDDs = 5 points

2832 GDDs – 3238 GDDs = 7 points

3238 GDDs – 3645 GDDs = 9 points

3645 GDDs – 4052 GDDs = 10 points

Total Number of Frost Free Days

As noted in Chapter 3, a minimum of 160 frost-free days is recommended for vineyards in Nebraska (Read, 2008). However, because Edelweiss is an early maturing variety, it may ripen with a season as short as 150 days. Hence, the rating system for the total number of frost free days was established as follows:

< 150 days = 0 points

150 to 165 days = 5 points

165 to 180 days = 7 points

>180 days = 10 points

Minimum Winter Temperature

For the Edelweiss suitability analysis, the daily temperature data averaged over a ten-year period were recorded. Then, new values (numbered from 1 to 4, where 4 means most suitable for growing Edelweiss and 1 least suitable) were assigned to the data based on their influence on Edelweiss growth. I assigned: 4 points to any minimum winter temperature that was above 0°F; 3 points to any minimum that was above -15°F but below 0°F; 2 points to any minimum that was above -32°F but below -15°F; and 1 point to any minimum that was below -32°F. Then, I applied the following equation:

$(N\times4+M)/D$

Where N = the number of days whose minimum temperatures were above 0 °F as measured over the entire ten-year period.

M = the sum of the new assigned values (1 to 3) for daily minimum winter temperatures below 0 °F for the entire ten-year period.

D = the total number of days in January (31 days), February (28 days), March (31 days), November (30 days) and December (31 days) for a ten-year period, which is 151*10 days or 1510 days.

The final result ranged from 3.7404 to 3.9748. This result was then transformed to a scale between 1 and 10, with 10 being optimally suitable for Edelweiss growth and 1 being generally unsuitable for growing Edelweiss.

Aspect

As discussed in Chapter 3, the frost-free growing period was, on average, about two weeks longer on slopes with southern aspects than on corresponding slopes with northern aspects. Western aspects are considered somewhat undesirable due to the potential for excessively high temperatures, as well as potential drastic differences between winter day versus winter night temperatures, so northern slopes are unsuitable for obvious reasons. Based on discussions in Chapter 3 and literature sources, the rating system for aspect was established as follows:

Flat, No Aspect = 5 points

Southwestern (202.5°-247.5°) = 7 points

Southern (157.5°-202.5°) = 9 points

Western (247.5°-292.5°) = 5 points

Northwestern (292.5°-337.5°) = 2 points

Southeastern (112.5°-157.5°) = 10 points

Northern (0°-22.5°, 337.5°-360°) = 2 points

Eastern (67.5°-112.5°) = 7 points

Northeastern (22.5°-67.5°) = 4 points

Slope

Based mostly on the desire to have a moderate slope to facilitate air drainage, but not so much as to both incur soil erosion and experience difficulty with using tractors and other related equipment (Smith, 2006), the rating system for slope was developed as follows:

Flat land = 3 points

1 to 3% = 5 points

3 to 10% = 10 points

10 to 15% = 7 points

>15% = 1 points

Soil Drainage

Because grape vines prefer well-drained soils, drainage was given the highest priority among the soil variables. The rating system was established, somewhat arbitrarily, as follows:

Poorly drained = 0 points

Somewhat poorly drained = 3 points

Moderately well drained = 8 points

Well drained = 10 points

Somewhat excessively drained = 6 points

Excessively drained = 5 points

Soil pH

Based on the literature sources, the rating system for soil pH layer was developed as follows:

< 5 = 0 points

5 to 7 = 10 points

>7 = 3 points

Soil Organic Matter

Organic matter values greater than 3% to 5% may be counter-productive for grape vines in that excessive nitrogen released by organic matter decomposition may lead to accelerated vegetative growth (Kurtural, 2005). The result is that the vines produce excessive foliage and poor or few fruit clusters. The rating system for the soil organic matter layer was organized (rather arbitrarily) as follows:

<1% = 3 points

1 to 3% = 10 points

3 to 4% = 3 points

>4% = 0 points

4.2.3 The Method for Determining Class Ranking for Cynthiana-Norton Vines

Although grape cultivars vary greatly in their tolerance of cold winter temperatures, a wide range of soil types are satisfactory for their cultivation. The exception, of course, is poorly drained soil (Andales, 2009). Soils capable of supporting grapevine growth possess at least reasonably good drainage, moderate fertility, and acceptable depth. In addition, grapes can grow over a relatively wide range of soil pH, organic matter and fertility level (Andales, 2009). Even if there are minor differences in the soil drainage, pH, and organic matter between Edelweiss and Norton, they can be adjusted easily during the site establishment. Therefore, it is reasonable to assume that soil has the same percentage of influence for successful Norton growth as for Edelweiss. As noted previously, the variables chosen as surrogates for topography are aspect and slope. During vineyard establishment, a moderate slope (3% to 15%) has been recommended to facilitate air drainage, but not so much as to incur soil erosion and difficulty in using tractors and associated equipment. Unlike slope, the effect of aspect on grape cultivars is somewhat uncertain. Unfortunately there is a general lack of research documenting the impact of variable aspects on the growth of grapes, and there may be differences from one cultivar to the next. Hence, the quantification of aspect in terms of growing Edelweiss and Cynthiana-Norton is beyond the scope of the current study. Therefore, similar values of aspect were used for both Edelweiss and Norton in the current analysis. With regard to recommending locations for the growth of Norton vines, however, the rating system for both the frost-free period variable and minimum winter temperature variable need to be changed, while the rest (growing degree days, aspect, slope, soil drainage, soil pH, and organic matter) were held constant with those used for the Edelweiss suitability analysis.

Frost Free Days

Norton can only grow in frost-free sites of 180 or more days (Smiley, 2008). Therefore, the rating system for frost free days for Norton was as follows:

< 180 days = 0 points

>=180 days = 10 points

Minimum winter temperature

For the Norton suitability analysis, the averages of the daily temperature data over a ten-year period were recorded, and new values were assigned. I assigned: 4 points to any temperature that was above 0°F; 3 points to any temperature that was above -10°F but below 0°F; 2 points to any temperature that was above -15°F but below -10°F; and 1 point to any temperature that was below -15°F. I then applied the following equation:

$$(N\times4+M)/D$$

Where N = the number of days whose minimum temperatures were above 0 °F as measured over the entire ten-year period.

M = the sum of the new assigned values (1 to 3) for daily minimum winter temperature below 0 °F for the entire ten-year period.

D = the total number of days in January (31 days), February (28 days), March (31 days), November (30 days) and December (31 days) for a ten-year period, which is 151*10 days or 1510 days.

The final result ranges from 3.847 to 3.966. I next did a linear stretch on the resulting range to a where 3.847 was set to 1 and 3.966 was set to 10.

4.3 Prototype Model for Grape Cultivar Suitability

Finally, after all the weights for each layer and among classes within each layer were determined, all layers were introduced into the prototype model (see Figure 4.1) created using Model Builder in ArcGIS.

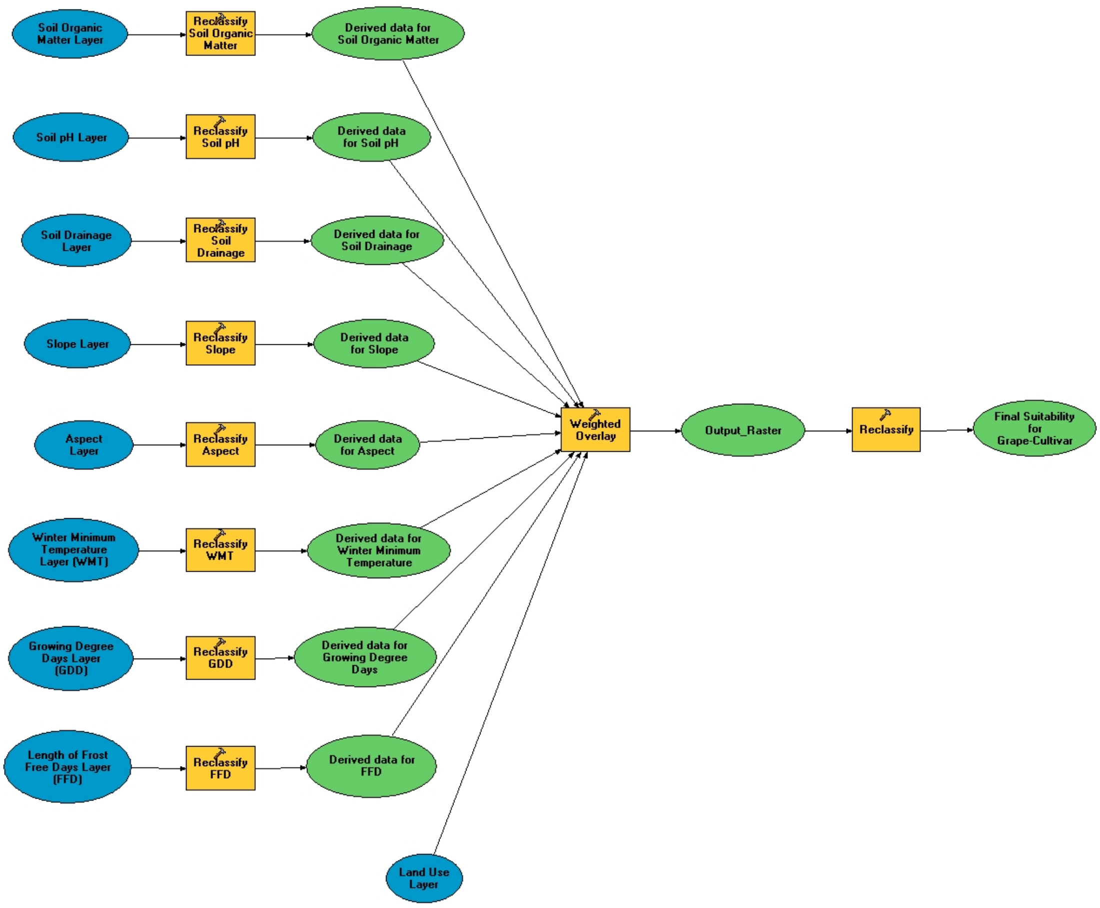

Figure 4.1: Prototype model for grape site assessment

The model tool was designed to produce a final composite image which numerically ranks each 30-meter site (pixel in the array) based on the combined attributes of the individual variables. This was accomplished by each cell in the grid having a unique location attribute. Thus, cells with the same ‘location’ on different layers are associated to each other across layers, and can be overlaid together to produce a final composite image of grape cultivar suitability. Data manipulations and map creation were conducted using ArcGIS (Environmental Systems Research Institute, Inc.)

In Figure 4.1, the blue oval represents the data that one submits to the model for processing, such as growing degree days, length of frost free period, minimum winter temperature, soil drainage, soil organic matter, soil pH, slope, and aspect. The yellow rectangular box represents the Reclassify tool used for converting the input cell values of the input layers to values describing the range from least suitable to most suitable for the chosen grape cultivars. The green oval represents the derived result of the previous step. Then, all the derived data are assigned a weight (described in previous paragraphs) and integrated together using the Weighted Overlay tool, which overlays several raster layers using a common measurement scale and weights (each according to its importance) in order to perform the calculation of a multiple criteria analysis among raster layers. Finally, the derived data from the overlay analysis are classified to produce a final suitability map for the selected grape cultivar, with the output categories ranging from least suitable to most suitable.

CHAPTER 5: MODEL RESULTS AND EVALUATION / COMPARISON WITH EXISTING VINEYARD DISTRIBUTION

5.1 Output

5.1.1 Modeled Suitability for Edelweiss

Figure 5.1 illustrates the model output regarding Edelweiss suitability across the entire State of Nebraska. From the map, we can see that Western Nebraska appears not to be an ideal region for the cultivation of the Edelweiss grape variety. The model suggested that the best areas to cultivate Edelweiss are in the Southern and Southeastern portion of the state where the overall climate condition is warmer than in areas further north and west.

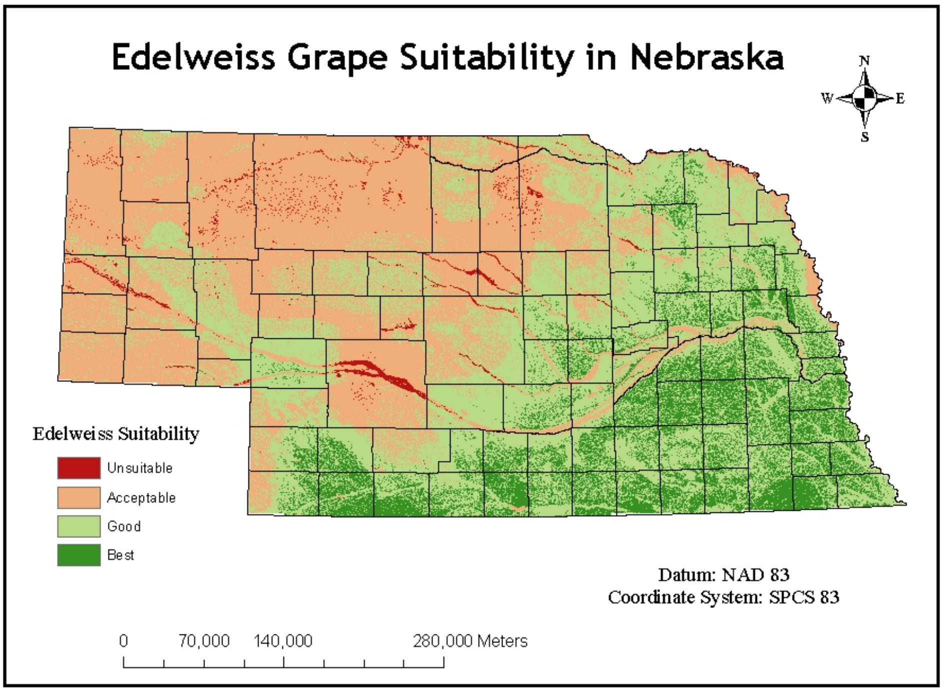

Figure 5.1: Suitability assessment for Edelweiss

5.1.2 Modeled Suitability for Norton

Figure 5.2 illustrates the spatial distribution in Nebraska of the calculated (pixel-by-pixel) suitability for the growth of Norton grapes. From the map, we can see that most areas of the state are not suitable for Norton cultivation. According to my model, only a few small zones along the Kansas border are suitable for growing Norton vines. This spatial distribution no doubt underscores the importance of climate in the calculation of the model output.

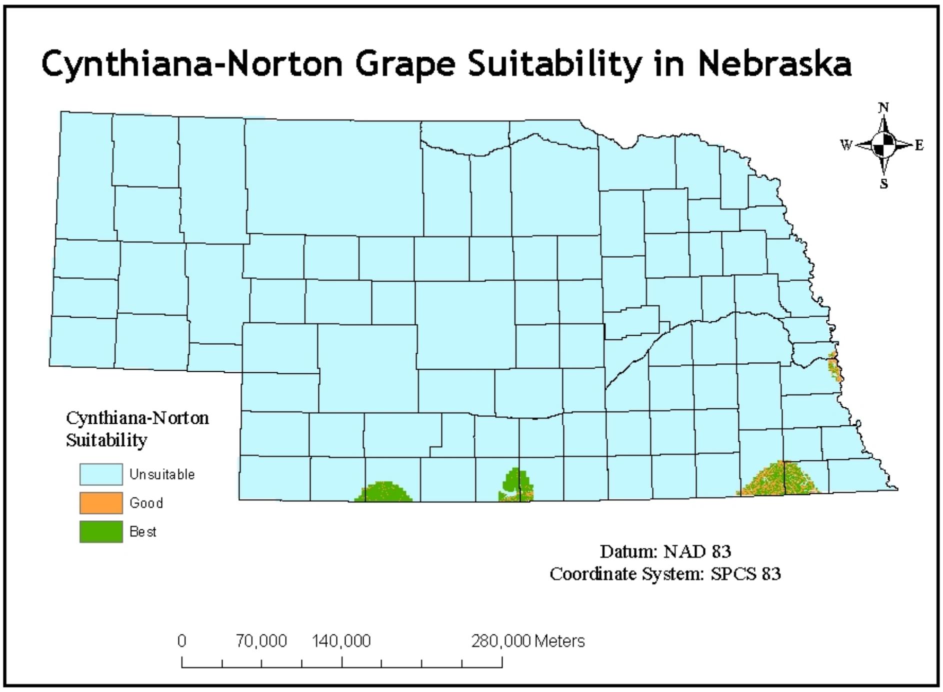

Figure 5.2: Suitability assessment for Cynthiana-Norton

5.2 Evaluating Results: The Rationale

Once the GIS-based model was run using the various geo-referenced layers of pertinent information, it was considered important to evaluate the final map product for each of the selected grape cultivars. As noted previously, the final map serves two useful purposes: 1) to highlight, for the potential grower, areas in the state where the cultivation of Edelweiss and/or Norton is considered feasible; and 2) to consider it within the context of the spatial distribution of existing Nebraska vineyards. The former should have utility as a tool for directing interested individuals to geographic regions of suitability and the latter for evaluating the decision-making thus far in developing the grape-growing industry in the state.

5.2.1 Evaluating Results for Edelweiss

Recall that location data relating to the Edelweiss cultivar were collected by questionnaire, and then integrated into the GIS for analysis. Figure 5.3 illustrates the distribution of vineyards growing Edelweiss in Nebraska as of summer, 2010.

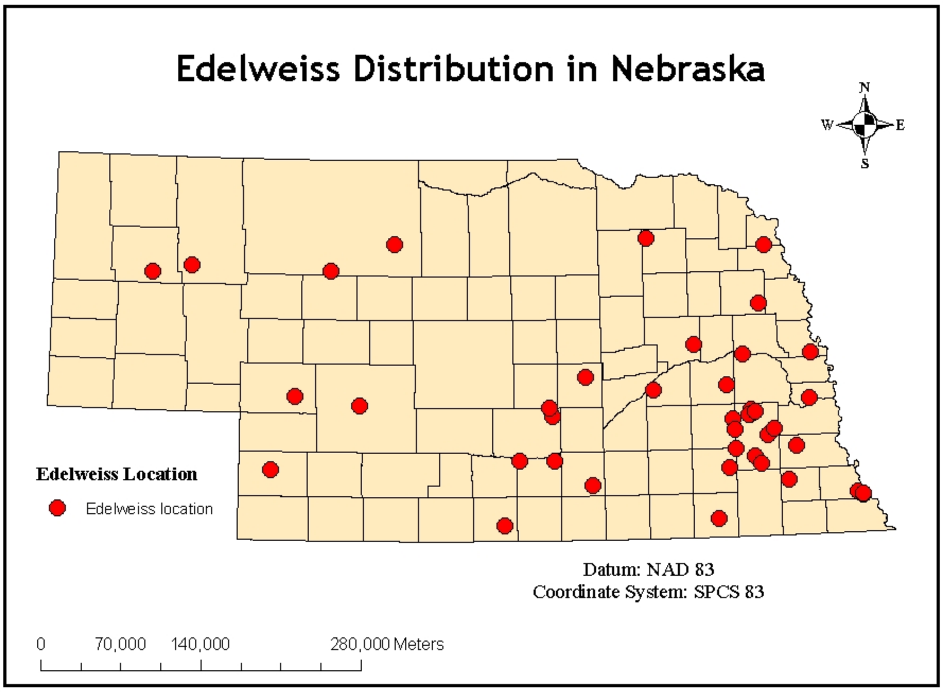

Figure 5.3: Spatial distribution of vineyards growing Edelweiss in Nebraska

There are currently 42 vineyards growing Edelweiss, and as can be seen in Figure 5.3, most of them are located in the southeastern part of the state, with a few others scattered around the western part of the state. In order to conduct the evaluation and comparison, the next step was to integrate the Edelweiss location data (shown as Figure 5.3) into the GIS, and overlay it upon the Edelweiss suitability map, highlighted above. Once in the GIS, statistics can be generated from the patterns identified. Figure 5.4 illustrates the spatial distribution of Edelweiss-growing vineyards overlaid on the Edelweiss suitability layer.

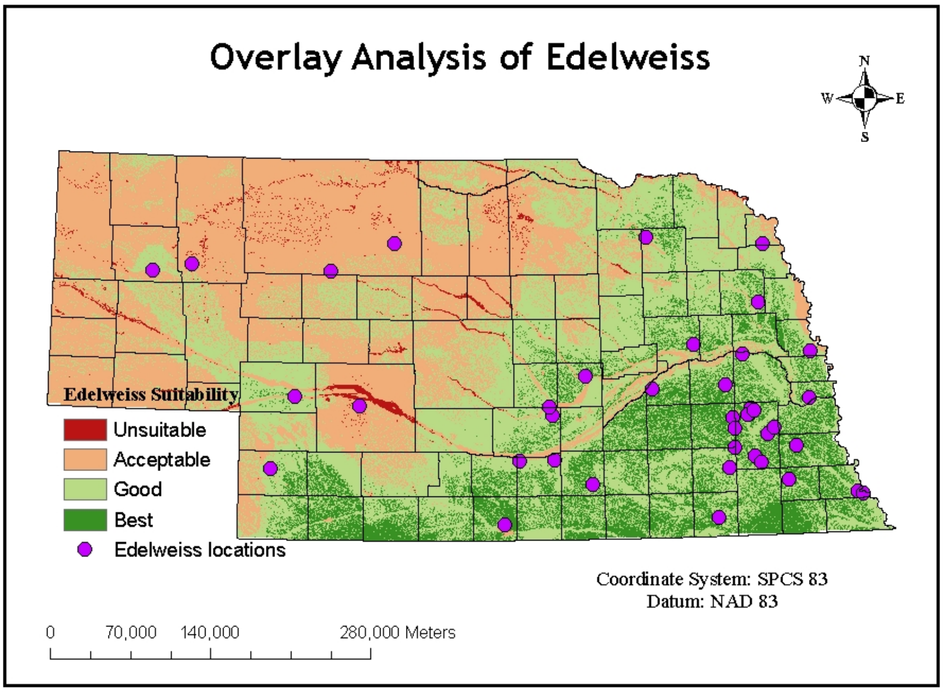

Figure 5.4: Spatial distribution of Edelweiss-growing vineyards overlaid on the Edelweiss suitability layer

It is clear from Figure 5.4 that most of the current vineyards growing Edelweiss are located within suitable locales; in fact, all 42 locations are so positioned. According to the graphic, only 4 vineyards (roughly 10% of the Edelweiss-growing operations) fall within the ranked category of acceptable suitability, 38% of the locations fall within the ranked category of good suitability, and 52% of vineyard locations growing Edelweiss fall within the highest ranked category of best suitability. Figure 5.5 shows the percentage number of vineyards growing Edelweiss in each ranked category.

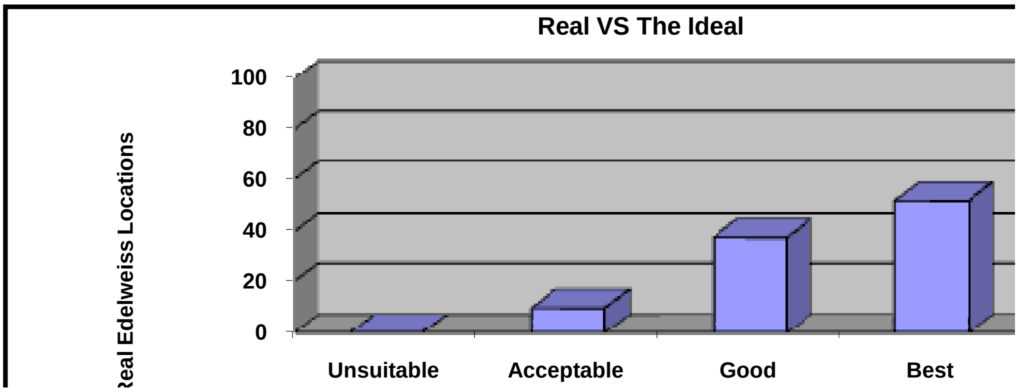

Figure 5.5: Percentage number of vineyards growing Edelweiss in each ranked category

From Figure 5.5, it can be inferred that the viticulture assessment model for Edelweiss provided a reasonable result for as compared to the vast majority of actual Edelweiss locations.

5.2.2 Evaluating Results for Cynthiana-Norton

Location data for vineyards growing Norton were also collected by the mailed survey instrument, and then integrated into the GIS for analysis. Figure 5.6 illustrates the distribution of vineyards growing Cynthiana-Norton vines in Nebraska.

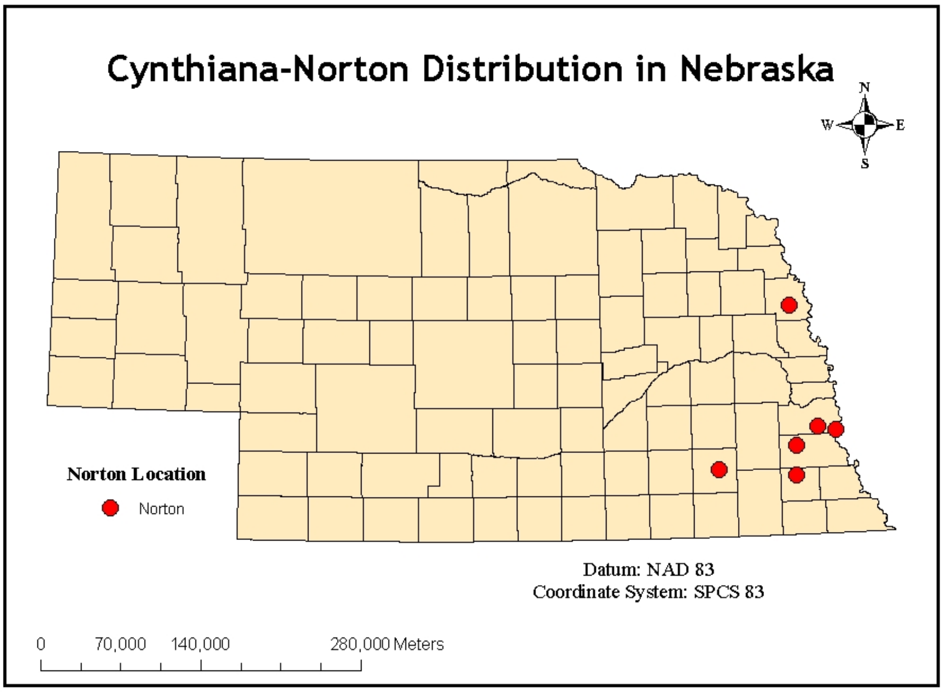

Figure 5.6: Spatial distribution of Norton-growing vineyards in Nebraska

It can be seen from the map that there are only six locations where the Norton grape is cultivated in Nebraska, and all are located in the Southeast. The spatial data for Norton were integrated into the GIS and overlaid upon the Norton suitability layer. Once in the GIS, the statistics can be generated from the patterns indentified. Figure 5.7 illustrates the spatial distribution of Norton-growing vineyards as overlaid on the Norton suitability layer.

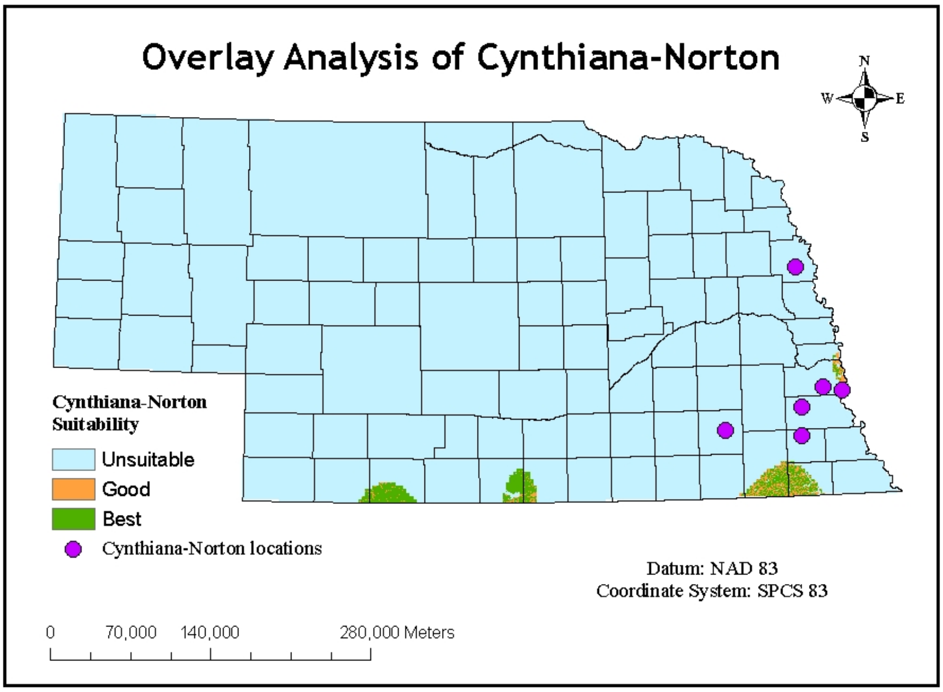

Figure 5.7: Spatial distribution of Norton overlaid on the Norton suitability layer

From Figure 5.7, it can be seen that none of the six Norton locations fall within the suitable areas for that cultivar. Figure 5.8 illustrates the percentage number of vineyards growing Norton in each ranked category.

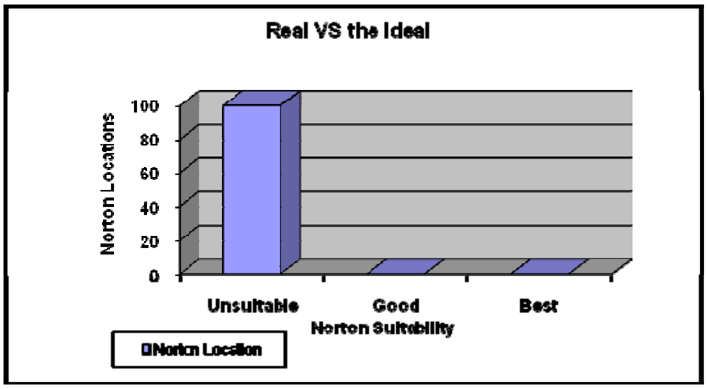

Figure 5.8: Percentage number of vineyards growing Norton in each ranked category

One can see that the suitable areas in Nebraska for growing Norton are almost non-existent, with only a few small sites along the southern border. The reason for this, as noted above, is because very few areas can meet the required frost free period of more than 180 days. However, Norton-growing vineyards are in relatively close proximity to the defined “suitable” areas, so there may well be a possibility of successful cultivation, but those growers may well be someday faced with a significant loss of vines.

CHAPTER 6: FINAL SUMMARY

6.1 Evaluation of the Thesis Project

Three major research tasks were completed in this thesis: (1) collecting and compiling data dealing with the locations of vineyard operations in Nebraska, mapping their spatial distribution, and compiling a database of pertinent information associated with each grape-growing operation of record; (2) developing and testing a prototype GIS-based model intended to be used as a tool for statewide vineyard-suitability assessment; and (3) producing suitability maps highlighting portions of the state where potential exists for growing two selected wine-grape cultivars; Edelweiss and Norton.

6.1.1 Evaluation of the Statewide Vineyard Mapping Segment of the Project

In the first task, the mapping of vineyard locations over the entire State of Nebraska, a database of grape-growing locations was built based on both existing information from the state growers' group and results obtained from the request for locational data which we created and distributed through extension and other public mechanisms. The final compilation is probably the best available and most accurate listing of vineyard operations in the state. The resulting map (Figure 2.4 in Chapter 2) is important in that not only is it an aid for viticulture specialists and extension personnel in the state but also it can be linked to economic development initiatives related to the wine industry. For my specific purpose, the map was used to compare and validate the GIS model as discussed in Chapter 5. The data compilation and mapping exercise led to the conclusion that there are currently 151 vineyard operations in Nebraska, with most clustered in the southeastern region, a not unexpected finding given general knowledge about our state's climate and topography. Nevertheless, it is quite probable that more than 151 vineyards are currently operating in Nebraska because of the likelihood that a number of growers did not respond to the request for information which we sent out. Additionally, it seems likely that the mailing did not reach every grape grower in the state. Given that the Nebraska wine and grape growing industry is expanding rapidly (Thompson & Freudenburg, 2007), there is a good reason to continue with attempts to improve and update the vineyard database from time to time.

A product related to the mapping exercise was the creation of a digital dataset served via a web site (http://snr12b.unl.edu/sensitivecrop/index.php) aimed at documenting locations of Nebraska's pesticide-sensitive crops, thanks to funding provided by the Nebraska Department of Agriculture. Here, grape growers have a mechanism for providing information on-line related to their vineyards. On the positive side, we occasionally receive new inputs to the database from Nebraska grape growers. Thus, the mapping exercise, and the associated web-site development, have made a contribution to our understanding of the viticultural-development phenomenon as it relates to the State of Nebraska.

6.1.2 Evaluation of the Prototype GIS-Based Model Tool

The second research task involved developing a GIS-based model / tool, (Chapter 4) for highlighting portions of Nebraska that are suitable for the development of vineyards growing two selected grape cultivars. The algorithm was based upon the Model-Builder function in ArcGIS software. The concept, as developed, requires eight layers in raster format, each one representing one of the selected variables input to the analysis. The inputs included growing degree days, length of frost free period, minimum winter temperature, soil drainage, soil organic matter, soil pH, slope, and aspect. All eight layers were generated at a resolution of 30 meters. The application of the model / tool requires a basic knowledge of ArcGIS and a thorough knowledge of the requirements of each grape cultivar with regard to climate, soil, and topographic settings. It should be noted that a set of constraints, specific to each cultivar of interest, must be input to the model before it can be used in a practical manner.

No matter how well-constructed the model, the result is, of course, an immense simplification of reality. My intent was merely to develop a prototype model / tool that might serve as a basis for on-going efforts dealing with grape cultivar suitability. The generalized nature of model output limits its use for thorough site evaluations in very localized settings.

Regarding my modeling effort, eight factors, which were most frequently employed in previous studies of grape cultivar suitability as reported in the literature, were included in the analysis. These factors may not be the absolute best indicators for suitability analysis but they are the most readily quantifiable and generally available. Other growth-limiting variables were not considered; for example, local weather patterns, elevation, soil texture and others, which also play a role in grape growth. Thus, the reader must understand that the outcome of this project may well have been different if the suite of variables input to the model were varied.

6.1.3 Evaluation of the Suitability Maps for Edelweiss and Norton

The final project task dealt with the production of location-suitability maps generated by the model / tool for two specific cultivars; Edelweiss and Norton. The resulting maps for these two cultivars are designed to be an example as to how the tool might be used.

A problem associated with the research includes the fact that the sources for the climate data collected for the analysis are limited, despite the fact that approximately 227 weather stations are spread throughout the State of Nebraska. More specifically, some weather stations have missing data for individual years. These were excluded from the analysis. In my study, climate data were collected from only 97 stations, one for each county, on average. These data were interpolated in ArcGIS to yield maps of weather patterns, and then resampled to output layers with a finer resolution (30 meters), which made the result very generalized at the expense of obscuring localized weather patterns. Thus, the final suitability maps are not useful for a thorough evaluation at a localized site.

Another limitation associated with the final suitability maps for Edelweiss and Cynthiana-Norton was caused by the inconsistency in the period over which climate data were collected. For example, data for growing degree days and length of frost free period, averaged over a fifty-year period, were collected and employed in the analysis, while a dataset of only an averaged ten-year period was available for daily temperature, which was used to derive the minimum winter temperatures. In order to obtain data for minimum winter temperature, which are not readily available, the daily temperature data over a certain temporal period should be collected first, followed by derivation of minimum winter temperature (as discussed in Chapter 4). This procedure would involve a massive investment of time and effort for a fifty-year period. Considering that the intent of the current study is to develop a prototype GIS-based model to assess grape cultivar suitability in Nebraska, such an undertaking was impractical. Similar future models must, among other things, address the issue of compiling and improving the quality of climatic inputs.

Finally, pH is a very important factor for the growth of the Edelweiss grape. In my study, I made the assumption that a pH value can be adjusted before the establishment of a vineyard by means of soil additions, My works showed that the soil pH factor exerts only a 7.1% influence on suitability for the Edelweiss grape, as it also did for Norton. But, perhaps the weight should be adjusted for Edelweiss to underscore the critical influence that soil pH has on Edelweiss.

6.2 Conclusion

This project represents the first comprehensive effort to compile data about the grape and wine industry in Nebraska. Along the way, maps of both vineyards and wineries were produced. The development of a digital database and associated Internet tools for producer input comprise useful outcomes for the work. The related web-based “pesticide sensitive crop locator” will no doubt serve to assist producers in avoiding the drift of damaging or destructive chemicals onto grape vines.

The research also attempted to define and map the potential for growing two specific grape cultivars in Nebraska by means of the spatial analysis of relevant topography, soil, and climate parameters. By comparing the distribution of vineyards growing Edelweiss and Norton to the modeled suitability map of those grape cultivars, one can see that there are some vineyard operations growing Edelweiss and Norton in areas that were not identified as optimum by my model. I, of course, have no means of knowing whether vines outside the identified optimum areas are being grown successfully, so the "precision" of the model, in that sense, cannot be verified. There are no doubt many variables that lead a grower to plant a particular grape cultivar, most of which do not lend themselves to being input to a model such as developed herein. Such uncertainties of human behavior, and other related factors (e.g., economic, etc.) that lead people to plant particular cultivars are difficult to predict, and such variables may limit the ultimate real-world application of my study.

This study provides only a first step in developing a GIS-based mechanism for locating suitable areas in Nebraska for growing specific wine-grape cultivars. Geographic analysis at the statewide scale, allows one to visually assess the distribution patterns of important climatic, topographic and soil factors. Integrating GIS and related technologies into site identification will become even more powerful as more climatic data are collected and made available to modelers. For now, perhaps the most positive outcome of this research is for educating not only current but also future grape growers to the importance of a careful site evaluation prior to expending resources to initiate a vineyard operation.

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APPENDIX A COVER LETTER

University of Nebraska Lincoln

Center for Advanced Land Management Information Technologies (CALMIT)
School of Natural Resources

March 2008

Dear Vineyard Owner:

Funding from the U.S. Environmental Protection Agency, via the Nebraska Department of Agriculture, has allowed development of a project aimed at creating a database containing the locations of Nebraska's pesticide-sensitive crops. The initial effort is focused on the vineyards of our state, but once the prototype system for grapes is operational, project leaders will seek input from growers of other pesticide-sensitive crops. The vineyard mapping project is being conducted under the joint supervision of the Center for Advanced Land Management Information Technologies (CALMIT), a unit of the School of Natural Resources, and the Viticulture Program of the Department of Agronomy and Horticulture. Both groups are part of the Institute of Agriculture and Natural Resources at UNL.

The fundamental reason for undertaking the vineyard-mapping effort is to increase compliance with pesticide laws and regulations. That compliance should be facilitated by making useful, location-specific information, such as maps and aerial views of pesticide-sensitive vineyards, available to applicators by means of Internet delivery. Thus, instances of pesticide drift onto grapes should be reduced or even eliminated.
The specific objectives of the new project are: 1) to construct a database of Nebraska vineyards, including pertinent information such as the geographic location of each; and 2) to create a web-based Internet mapping capability as a means of providing maps and aerial views of vineyards in the state, along with a tool for growers to input new information.

Please examine the information recorded on page 2 of this communication. First, verify the accuracy of all the entries. If there is an error, please make a correction. Second, if you agree to include your information in the web-based database so that pesticide applicators will be aware of your vineyard location, please sign your name in the designated place on the form. If you decide not to participate in this effort, please return the form unsigned, and we will not include your information in the database. A self-addressed stamped envelope has been provided for your use. If you have any questions about this letter or the attached information sheet, feel free to call Don Rundquist at 402-472-7536 or Paul Read at 402-472-5136.

Thank you in advance for any assistance you might give us regarding this important project designed to protect vineyard owners from pesticide drift.

Sincerely yours,

Donald C. Rundquist, PhD
Professor, School of Natural Resources
Director, CALMIT

Paul E. Read, PhD
Professor, Agronomy & Horticulture
Director, Viticulture Program

3310 Holdrege Street / P.O. Box 830973 / Lincoln, NE 68583-0973
(402) 472-8197 / FAX (402) 472-2946 www.calmit.unl.edu/calmit.html

APPENDIX B QUESTIONNAIRE

Vineyard Information Sheet

Name of vineyard (if applicable) -

Name of vineyard owner -

Location of vineyard (legal or street) -

County where vineyard is located -

Mailing address of vineyard owner -

Telephone number or email address of vineyard owner -

Total acres planted to grapes -

Total number of vines in your vineyard(s) -

Year of first planting -

Years of subsequent planting -

Grape cultivars planted -

Other pesticide-sensitive crops grown -

Signature____