Vineyard Site Suitability in Minnesota USA

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Abstract

The number of vineyards and wineries in Minnesota has increased dramatically in the past decade and the industry will continue to grow according to recent research. Grape growers entering the commercial grape industry in Minnesota need to locate suitable areas for new vineyards. This study identified three major regions in Minnesota with suitable areas based on a set of environmental criteria. Proximity to existing wineries has economic ramifications on wineries and may determine how a winery prices its wines. In addition to the environmental suitability analysis, an analysis was conducted to determine if the average price of a bottle of wine is clustered within Minnesota. This information can aid those beginning to grow commercial grapes in the developing grape industry in Minnesota.

Introduction

The number of wineries in Minnesota has increased over the last 20 years. During the 1990s, less than a dozen wineries existed in Minnesota (Monaghan, 2008). However, Minnesota's wine industry has experienced growth over the past decade; Tuck and Gartner (2013) determined 44% of wineries existing in Minnesota today have been established since 2007. Currently, there are 40 wineries and 26 vineyards, which are members of the Minnesota Grape Growers Association (MGGA) plus two private wineries (Figure 1).

The success of wineries has a direct impact on local and state economies. The Northern Grapes Project, a 2011 survey funded by the United States Department of Agriculture, asked members of the MGGA, as well as individual growers, and others not directly involved in growing grapes, to answer a questionnaire about their sales data and their thoughts on the future growth in Minnesota (Tuck and Gartner, 2013). Of the hundreds of answers submitted for the survey, the researchers found Minnesota wineries grossed $13.7 million in sales, $12.0 million of which were earned from wines produced from cold hardy wine grapes grown in Minnesota (Tuck and Gartner, 2013). The MGGA (2014) stated one acre of grapes grown in Minnesota will produce approximately 2,800 bottles of wine and contribute approximately $3,350 in total taxes to the State of Minnesota.

Wineries also contribute to Minnesota's employment. Tuck and Gartner (2013) emphasized the wine and grape growing industry contributed a total of $59 million to Minnesota's economy and provided $19.7 million in labor income.

The trend of new wineries appears to be positive. Tuck and Gartner (2013) indicated Minnesota winery owners expect to expand and vineyard owners plan to

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increase the acreage used in growing wine grapes in the near future. With grape research progressing and varieties of cold hardy grapes increasing, grape growers will continue to have the opportunity to develop new vineyards in Minnesota (Monaghan, 2008).

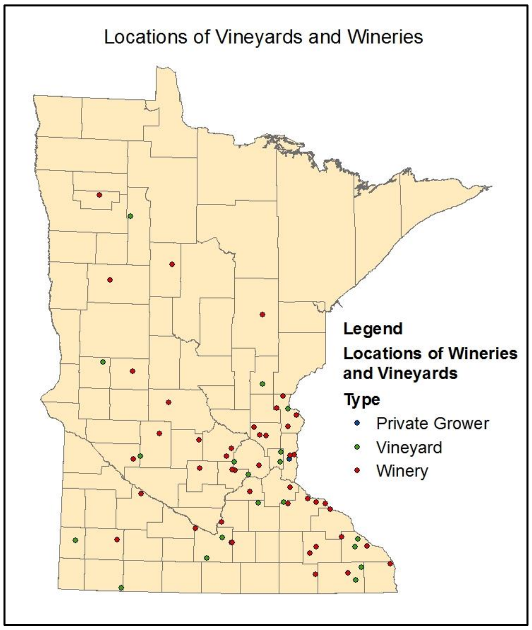

Figure 1. Existing winery and vineyard locations in Minnesota.

Background

Several factors determine vineyard suitability. Variables such as aspect, slope, soil drainage, climate, and land use need to be examined in order to determine whether or not wine grapes will grow in an area (Jones, Snead, and Nelson, 2004).

Aspect is essential in determining the amount of solar radiation a vineyard will receive at certain latitudes; at higher latitudes the sun's rays pass through a larger layer of the atmosphere (White, 2009). Thus, the strength of the sun's rays will be less at higher latitudes. Since there is less sun intensity in northern latitudes, the amount of direct sun is important. Slopes which face southward will be warmer than slopes facing northward (White, 2009). As a result, southward-facing slopes are preferred because these slopes receive the most warmth from the sun (Jones *et al*., 2004) and will be more conducive to growing grapes than those slopes that face west, north, and east.

Slope is also a key component in vineyard site suitability. Plocher and Parke (2008) found cold air more often moved out of vineyards with slopes of 1.5 to 3 percent instead of settling; when cold air settles in a valley, frost is more likely to occur and damage the plant.

Vineyards can be grown on a large assortment of soil types because the effects soils have on the growth of the grape vine are complex (van Leeuwen and Seguin, 2006). Drainage is a critical characteristic associated with soil when choosing a site (Berry, 1990). In regards to drainage, there are three important characteristics for soils in a vineyard: hold water but not waterlog, drain well, and be permeable (Halliday, 1993).

There are numerous climatological variables that are crucial to the implementation of a new vineyard, including winter temperature and the number of frost-free days.

Winter survival of grapevines is necessary for the long-term success of vineyards. Plocher and Parke (2008) found that when an area receives an annual minimum temperature colder than -31° F more than one out of ten years, only the hardiest grapes should be chosen and more winter protection will be needed in order for grapes to grow.

There are two important dates for the growing season of grapes: when the grape buds (bud break) and when grapes are picked (harvest date). Since there are a variety of Minnesota cold hardy grapes, there are multiple bud break dates and harvest dates for the wine grapevines. Early season grapes usually bud in the middle of May; mid-season grapes will bud a few weeks later. The average harvest date for cold hardy grapes ranges from September 19 to September 30 (University of Minnesota, 2014). The length of the growing season determines whether or not grapes can survive in Minnesota. Growing season length is measured by the number of days between the last spring freeze date and the first fall freeze date (Jones *et al.*, 2004). The minimum growing season for grapes is 127 days. However, according to the University of Minnesota, there should be 160 consecutive frost-free days in Minnesota for the grapevines to thrive (Luby, 2012).

Land use is important when choosing a new vineyard location; agricultural or rural residential are the best locations (Jones *et al.*, 2004). Conversely, urban areas are unwanted locations (Jones *et al.*), because the density of buildings, roadways, and other structures limit the available land required to grow a vineyard.

Spatial relationships amongst wineries have an important economic impact on each winery. Panzone and Simões (2009) stated a reputable winery could impact other wineries' perceived quality within a clustered region. Isolated wineries will not have neighboring wineries to learn from, they will be unable to share labor costs with other wineries, and they will face difficulty attracting tourists who want to participate in wine tours with minimal travel (Yang, McCluskey, and Brady, 2012). Wineries can set their prices higher based on the good reputation of neighboring wineries (Yang *et al.*, 2012). As a result, wineries that are clustered with notable wineries will have a simpler time marketing their wine when compared to an isolated winery (Yang *et al.*).

Methods

Necessary Data

Elevation

There were many data sets required to determine suitable vineyard locations. First, digital elevation models (DEM) were used to extract slope and aspect information. The DEMs were obtained in sections from the National Elevation Dataset in a 1/3 arc second (approximately 8 meter resolution) raster.

Soils

In order to ascertain drainage data, the Soil Survey Geographic Database (SSURGO) was downloaded from the National Resource Conservation Service for each county in Minnesota. Each dataset included a shapefile of soil polygons and corresponding tables of information, including a drainage classification.

Climate

The Plant Hardiness Zoning Map (PHZM) was obtained from the United States Department of Agriculture. The original PHZM was delineated into 5° F zones showing annual extreme minimum temperatures from 1976-2005. The image was downloaded, georeferenced, and digitized for the zones needed.

Growing season data was calculated after obtaining frost-free probability data from Minnesota weather stations. This dataset used daily averages from 1981 to 2010 and calculated the probability of each weather station having 160 frost-free days each year. The data included every weather stations' probability with its x, y coordinates and was provided by the National Climate

Data Center from the National Oceanic and Atmospheric Administration. Once data from 35 weather stations in Minnesota were collected, a table containing each weather station location and corresponding frost-free days probability figure was imported into Esri's ArcMap. The data were then mapped using the x, y coordinates into a point feature class.

Land Use

The statewide cropland data layer was downloaded from the United States Department of Agriculture and was used to obtain information about land use. Data included 46 classes of land use found in Minnesota and was supplied in a 30 meter raster.

Economic Impact

Existing winery and vineyard address information was provided by the MGGA. A vineyard is the location where grapes are grown and converted into wine, while a winery markets and sells wine. Sometimes the winery and its vineyard will be located at the same address. When a winery and vineyard had the same address, one winery point was created. Addresses of existing wineries and vineyards were compiled into a table and geocoded to generate a point feature class. The point feature class was then joined with Minnesota county boundaries via the Spatial Join tool in Esri's ArcGIS; this allowed the results of the Hot Spot Analysis to be viewed at the county level. The average price of a bottle of wine was included as an attribute in the county feature class to test for clustering and calculate hot spots. The average price for a bottle of wine was calculated after finding bottle prices on every winery's website or by contacting the winery directly. When multiple wineries were found in a county, the average bottle price was manually calculated and edited in the attribute table of the county feature class.

Coordinate System and Resolution

Before the final suitability analysis was undertaken, every data layer needed to be formatted correctly; this procedure included ensuring all layers had the same projection, NAD 1983 UTM Zone 15, and the same resolution. Many datasets had different resolutions. The highest raster resolution of all data layers was 8 meters from the elevation data, while the lowest resolution data was 30 meters from the land use layer. In order to be able to overlay datasets and maintain the accuracy of the elevation data, the land use layer needed to be resampled to an 8 meter cell size. The rest of the layers were converted from vector to raster in an 8 meter cell size.

Reclassification

Before the overall suitability raster was calculated, each criterion dataset (Aspect, Slope, Frost-Free Days, Minimum Temperature, Soil, and Land Use) was reclassified into values 0 and 1 using the Reclass tool found in the Spatial Analyst toolbox. A value of 1 represented suitable areas and a value of 0 represented unsuitable areas according to the criteria described below. The tools used are found in Esri's ArcGIS 10.2 Desktop software.

Slope and Aspect Layers

Slope and aspect data were ascertained from the DEM data. The Aspect tool was used to calculate aspect. South facing slopes were represented with values between 157.7 and 202.5. A condition statement in the Raster Calculator tool was used to derive south facing slopes.

The Slope tool was applied to each DEM. Slopes of 1.5% to 3% were extracted using a condition statement in the Raster Calculator. Both the aspect and slope rasters were projected from Geographic Coordinate System (GCS) North American 1983 to NAD 1983 UTM Zone 15 to maintain continuity amongst data layers.

Soils Layer

The soil data layer was used to obtain information about drainage. The component table held the drainage class attribute and was related to the soil polygons. A Select Layer by Attribute query was performed to ascertain only well-drained soils. Once this process was completed for each county, the polygon feature classes were merged together to create one soils polygon feature class for the state. To ensure all the layers would overlay with the same projection, the well-drained soils polygon was projected from GCS North American 1984 to NAD 1983 UTM Zone 15.

Climate Layer

The climate-related criteria dealt with winter temperatures and the probability of the plant surviving the winter. The PHZM was divided into 5° F zones. Zones 4a, 4b, and 5a represented areas of -30° F or warmer and were extracted to a new raster, because Plocher and Parke (2008) determined areas colder than -31° F would limit the growth and productivity of grapes.

Once the point feature class containing frost-free days data was imported into ArcMap, the coordinate system was defined as WGS 1984. The feature class was then projected into NAD 1983 UTM Zone 15 to maintain uniformity throughout all layers. The Spline tool interpolated the values of the frost-free days attribute in the weather stations point feature class into a smooth raster that represented the probability of an area having 160 frost-free days. Weather stations that record 160 consecutive frost-free days at least 50% of the time were considered suitable for this project. While 160 frost-free days is recommended for a grape to thrive, the minimum number of days for grape survival is 127 frost-free days; therefore, a 50% probability of 160 frost-free days was used to capture areas that might meet 160 frost-free days but should meet the minimum 127 frost-free days.

Land Use Layer

The land use layer provided information regarding which areas were considered agricultural or developed. The raster classified Minnesota into 46 different land use classifications ranging from barren land to developed land. Any classification concluded to be agricultural was extracted to a new raster. The raster was then resampled to a cell size of 8 to maintain cell size consistency throughout all the data layers.

Raster Calculation

Once the necessary information was extracted and calculated individually for each criterion, the final analysis took place; all the rasters with a value of 1 represented the desirable criteria and a value of 0 represented unwanted criteria. The rasters were multiplied together using the Raster Calculator tool. The calculated output resulted in the location of suitable areas and unsuitable areas for new vineyards based on the criteria found in Table 1. For a location to be suitable, all criteria needed to be met.

Table 1. Criteria used in analysis.

Layer	Value Extracted
Aspect	Southward-facing hillside
Slope	1.5 - 3%
Frost-Free Days	160 days
Minimum Temperature	Temperatures warmer than -31° F
Soil	Well-drained
Land Use	Agricultural, rural residential, farm/forest transition

Suitability

In order to test the model used in this study, the 68 existing wineries and vineyards were compared to the suitability map and each criterion. The goal was to determine if the suitability model reflected areas actually selected by grape growers, and if not, define which criteria might be too restrictive. The existing winery and vineyard locations were overlaid onto the suitability map and each criteria layer. The percentage of the number of wineries and vineyards that fell within each suitable area were calculated.

Economic Impact Analysis

After the wineries point feature class was joined to the Minnesota counties feature class, a cluster analysis test was chosen to discover the spatial relationship amongst existing wineries. Cluster analysis was used to answer: based on the average cost of a bottle of wine does statistically significant clustering exist within Minnesota amongst wineries? The Spatial Autocorrelation (Global Moran's I) tool used the location and the average price with the Moran I formula to evaluate whether or not the pattern in wine pricing was random, clustered, or dispersed.

Since the Global Moran's I tests spatial patterns on a global level, a hot spot analysis was performed to visualize clustering patterns on a local level. The Hot Spot Analysis (Getis-Ord Gi*) used z-scores, p-values, and neighboring features to prove or disprove significant clustering on a local level (ESRI, 2014); in order for a hot spot to be present, a county needed to have a high average wine price and be surrounded by counties with high values. The tool gave a z-score to signify hot and cold spots. As a result, a higher z-score indicated more intense clustering (hot spot), while a lower z-score signified clustering of low prices (cold spot) (ESRI, 2014). The county polygon with the average price for a bottle of wine was used for the Hot Spot Analysis tool. The "Conceptualization of Spatial Relationships" parameter was set to fixed distance band with no distance threshold. The fixed distance band analyzed each feature in relation to its neighbor and weighted each feature according to intensity. When a distance threshold is not specified, a default value, the Euclidean distance, is computed; this guaranteed all features had at least one neighbor. Since hot spot analysis is not an environmental factor, the output did not contribute to the final suitability analysis. Instead, the hot spot analysis served as an aid in understanding how a new vineyard or winery would interact with existing wineries.

Results

Environmental Suitability

This project took into account aspect,

slope, drainage, land use, frost-free days, and winter survival likelihood. South-facing slopes, slopes of 1.5-3% (Figure 2), and areas with well-drained soils were found statewide (Figure 3).

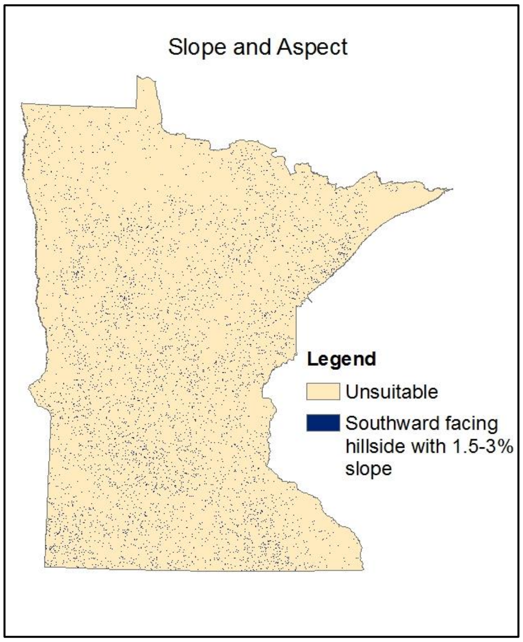

Figure 2. Map of slope and aspect. Slope and aspect were multiplied together because it was difficult to distinguish suitable from unsuitable areas on each individual map.

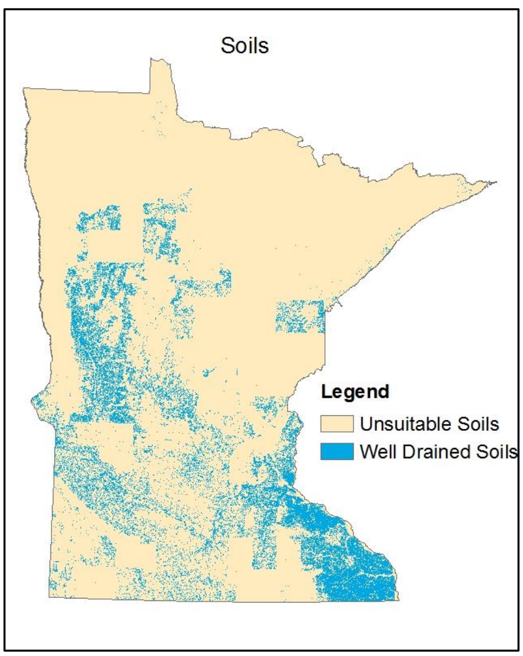

Figure 3. Well-drained soils map.

The land use map found most areas in western and southern Minnesota were agricultural (Figure 4). Suitable plant hardiness zones were found in the far western portion of Minnesota, as well as south of Brainerd and Hinckley (Figure 5).

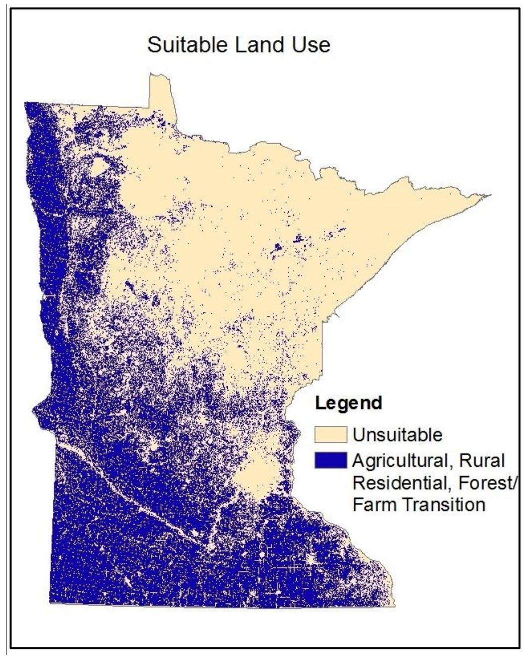

Figure 4. Areas deemed agricultural.

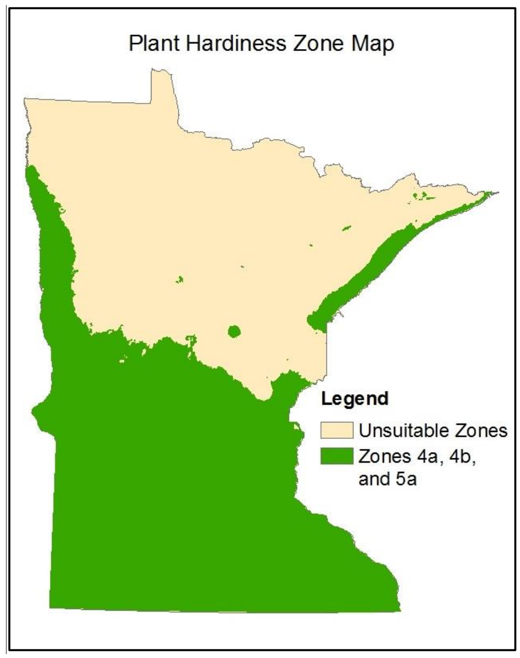

Figure 5. Map of zones 4a, 4b, and 5a from the plant hardiness zone map.

Frost-free days were found in southeastern Minnesota and a small area near Appleton (Figure 6).

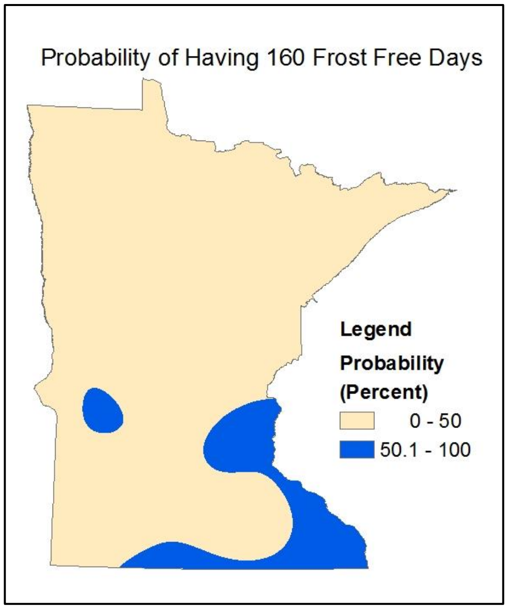

Figure 6. Frost-free days after the Spline Tool was used.

Final suitable and unsuitable areas for new vineyards are shown in Figures 7 and 8.

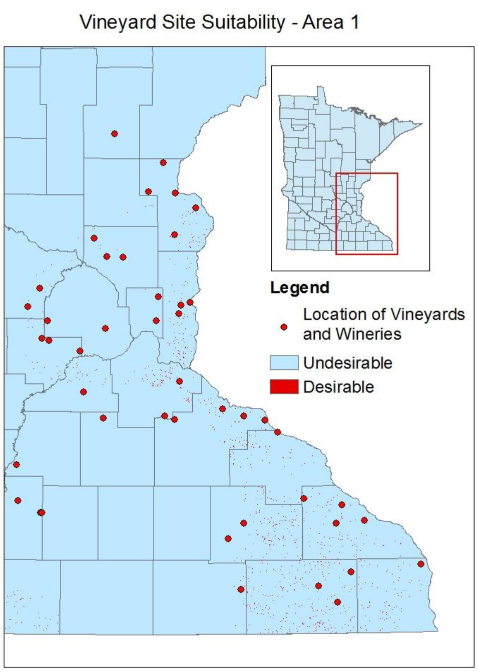

Figure 7. Area 1 of suitable areas for new vineyards.

Total acreage was calculated by multiplying the count of suitable cells by the square of the cell size. The total acres of desirable sites were 39,789.84 or 62.17 square miles.

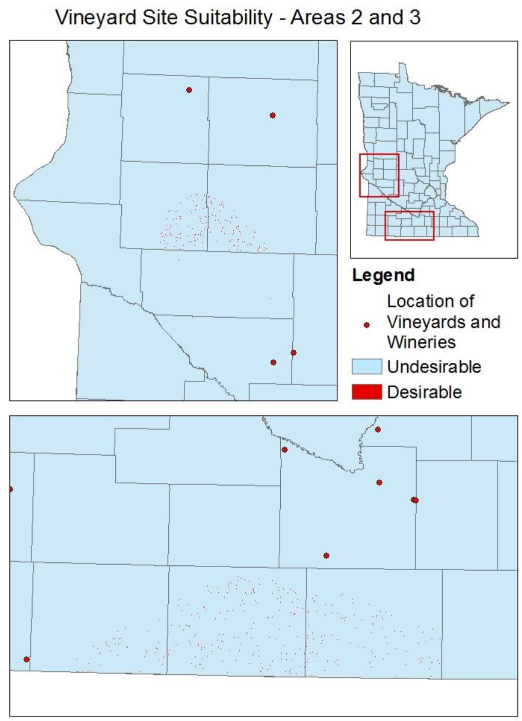

Figure 8. Areas 2 and 3 of suitable areas for new vineyards.

Economic Impact Suitability

The output from the Global Moran's I tool gave an average z-score of 0.475397 and a p-value of 0.634504. Since the p-value from the Global Moran's I tool was not statistically significant (<0.05), the null hypothesis cannot be rejected; wineries based on the average price of a bottle of wine were not clustered on a global level.

The Getis-Ord Gi* tool produced minimal areas of statistical hot spots. Regions with a larger z-score had more intense clustering of high values and were mapped as a hot spot. Areas around Minneapolis-St. Paul had significantly high z-scores, implying an area of higher wine prices (Figure 9). Lower prices were found in northern Minnesota where isolated wineries are located.

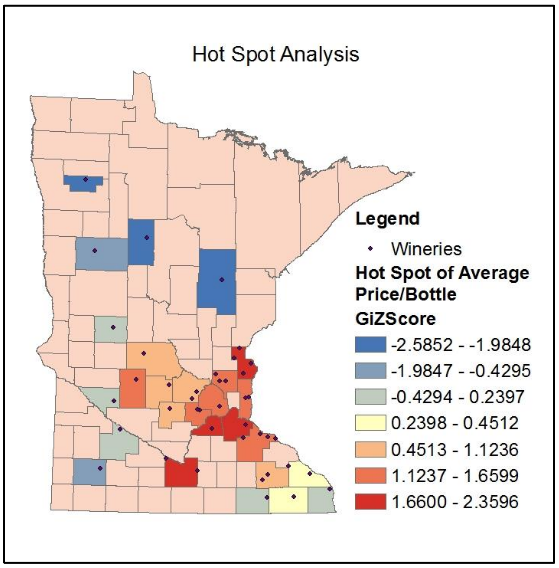

Figure 9. Significant hot spot locations by county for average bottle of wine prices.

Discussion

In total there are approximately 80,000 square miles of land in Minnesota and this study found nearly 62 square miles of suitable land for new vineyards. As a result, the suitable sites cover approximately 0.07% of the state. Since one acre of grapes produces 2,800 bottles of wine and contributes $3,350 in taxes (MGGA, 2014), the number of bottles that could be produced from the areas found in this study is over 111 million, while the amount of taxes gained for the state would be approximately $133 million.

There are many existing wineries and vineyards within the suitable areas found in this study. Twenty-three existing wineries and vineyards (about 1/3) were within 2 miles of land deemed suitable for vineyards. Thirty-four existing wineries and vineyards were within 30 miles of suitable areas, while nine wineries and vineyards were located more than 30 miles from suitable areas. The fact wineries and vineyards exist outside the suitable area result suggests the model might be too limiting. Other areas may be successful in producing grapes, but this model is highlighting the most suitable areas. Comparing existing wineries with the individual criteria helped explain why 2/3 of the existing wineries and vineyards fell more than 2 miles outside the model (Table 2).

Table 2. Results of the suitability analysis.

Layer	**Percentage of Existing Wineries within Each Layer**
Aspect and Slope	15%
Frost-Free Days	45%
Minimum Temperature	91%
Soil	38%
Land Use	35%

Since 15% of existing wineries and vineyards fell within the suitable aspect and slope variables, these criteria were the most restrictive and should be considered for modification in future suitability models. Areas with southwestern and southeastern aspects could be integrated to include all southern facing hills in future models. Also, a range of 1.5% for the slope variable is narrow; a larger range for the slope variable could have increased the likelihood of more results for the aspect and slope.

The results of the cluster analysis are a marketing aid when choosing a location. Since Global Moran’s I tool determined there is no global clustering of wine prices in Minnesota, the hot spot analysis is less important in Minnesota than in other states, such as California, which are known for their wine. For a prospective vineyard owner, it is not critical to be within the clustered areas, but it could help when pricing wines.

Originally, land use was classified using ERDAS software and supervised classification. However, after performing the supervised classification on four counties, it was concluded the time spent did not result in a significantly improved outcome to justify proceeding.

Future work could include regression analysis, such as using the Geographically Weighted Regression tool and the variables used in this project to refine the criteria. The model in this study provided a starting point for which variables to use and which criteria should be modified in future iterations. Future projects could use the results from the suitability test to broaden the variables and narrow the results after several tests of the Geographically Weighted Regression tool.

Also, understanding relationships between wine prices and locations of wineries on a broader scale could be further investigated. Future projects could investigate how reputations of wineries impact bottle prices. Surveys asking respondents to rate a winery's quality of wine, as well as the winery overall, would determine whether or not the reputation of a winery is correlated to wine prices.

Conclusions

Conclusions found in this research are beneficial to prospective vineyard owners and current vineyard owners contemplating expansion. With a steady increase in wineries in Minnesota over the past decade, identifying potential locations for new vineyards is important. This process can be simplified when using GIS. This study extracted information from many sources and combined criteria in ArcMap in order to establish where the best locations for new vineyards would be located. The study found many areas in Minnesota that met the criteria described in this project and would allow grapes to thrive.

Disclaimer

The pricing data for an average bottle of wine was gathered with the best information available at the time of this study.

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