Vineyard Suitability Analysis of Adams County, PA

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Introduction

Studying the agricultural land use of an entire county can be beneficial for economic development and planning for future challenges. In the case of most forms of agriculture, planning ahead to make the most from a crop is imperative; however, this is especially so for grapes. When wine-production grapevines are planted, many different aspects of the geography should ideally be analyzed due to the impact that environmental factors can have. Many publications have been produced on this topic including journal articles, cooperative extension guides, and various books. Divulging the secrets to producing excellent wine has been a focus of many studies, mostly publishing in the Journal of Wine Research. Many of these publications acknowledge a term, "Terroir," as an important factor in wine quality, which is defined by an interactive system in a location, including aspects of climate, soil, and the grapevine (cultivar) (Leeuwen, et al. 2004).

While this concept mostly pertains to European vineyards, Terroir has made lasting impacts on wine culture worldwide. Many people unknowledgeable of wine origin consider French wine to be iconic (given wine is one of France's largest agricultural products). On the other hand, South African, Australian, Chilean, ect. origin wines are not so well known, despite producing significant impacts on their respective economies. This is a cultural impact of the concept of Terroir (Trubek, 2008) and has had a tremendous impact on marketing. While the concept of terroir has indeed impacted the culture and economic dynamics of wine production, it has also sparked curiosity in the scientific world, which wish to expose what exactly creates quality in wine, and how specific aspects of production affect wine quality.

Many in the scientific world of viticulture have led into many venues of analysis including chemical analyses, the impacts of soil type, climate parameters, production methods, and many others (Cuneo, et al, 2013; Baciocco et al. 2014; Leeuwen et al. 2004). These studies have all attempted to define what parameters would make decent wine. Ideally, and most likely, this information will be utilized by vineyards to improve decision making when preparing to invest in new property and choosing varieties to plant. While there are many studies which suggest climate change is a factor to consider when planning a vineyard, a potential application for these studies on terroir is the current development of vineyards. The concept of terroir has been assessed using cartographic data from New Zealand, in order to construct models for predictive and analysis of vineyards (Shanmuganathan 2010). Another article has used the concept of terroir to put viticultural zoning in a world perspective, suggesting that the close relationship between the grape ecology and geography encourage (Vaudour and Shaw 2005).

In Pennsylvania, specifically, wine grape production had a considerably late debut. During the alcohol prohibition in the 1920's, Pennsylvanian farmers turned to the concord grape variety which was fairly popular and profitable. After the federal prohibition ended, and due to the residual laws of Pennsylvania, wine grape production was unpopular in PA until

1968, when the Pennsylvania Limited Winery Act was passed (Carroll, 2006). This pattern of development has created an environment with a lack of scientific exploration into viticulture in this area.

This study attempts to bridge the gap between geographical wine studies and the study area, Pennsylvania, by following a rating index for vineyard suitability in Nebraska. This study will outline the methodology for the technique in order to display information gained from the study of land cover sciences. If there is sufficient data, then the research question can be answered: what areas of Adams County, PA are suitable for Edelweiss and Cynthiana-Norton wine grape varieties?

Methods

This study focused on the state of Pennsylvania due to its relatively new wine-viticultural industry and lack of study. In order to reduce the amount of time required to complete the assessment, the study area was reduced to four counties within south central PA, Adams, Cumberland, Franklin, and York. Since this project's main objective was to determine the soundness of the methodology, reducing the area of study will not drastically impact the results.

This assessment utilized available raster data compared to available information on viticultural prime areas to determine areas of south central Pennsylvania that are ideal for viticulture. The first step of this assignment was largely based on a literature review in order to determine what parameters are ideal for grape vine growth. General parameters were gathered through research into the concept of terroir. This concept outlines general details of grapevine production which influences the individuality and quality of the final product. It was found that among other criteria, grapevines are greatly influenced by climate, soil, production techniques, and elevation-based parameters. While these parameters can influence the location of a vineyard, there are also some other, more logical parameters than can be tested. Obviously, unless the areas were modified, vineyards cannot develop on wetlands of any sort. Additionally, vineyards will have difficulty developing over urban land use, and will have a range of difficulty being established based on a general land uses also including agriculture, open, forested, or water.

During the research of this topic, a thesis researching vineyards site suitability using a GIS for the entire state of Nebraska was found (Chen 2011). This study outlined the methodology used to grade the suitability for Edelweiss and Cynthiana-Norton grape varieties based on criteria associated with the concept of terroir. An equation including many parameters, weighted by influence on quality, was created to map the suitability for the entire state. This study was used as a model for assessing Pennsylvania vineyard suitability. Use of this methodology was further encouraged because some of the sources of information used to rate viticultural suitability were from Pennsylvanian grape farmers.

Table 1 shows each criteria used in the model study along with the assigned weight for the importance. This system was used, as it was confirmed that these parameters are indeed reasonably ranked and assembled. In order to conduct this study in Adams County, PA, data for each or table 1's criteria needed to be gathered.

Table 1. Weights for each layer of the GIS used in the analysis. (Chen, 2011).

Variable	Weight	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

The Slope and Aspect data for Adams County was collected through the use of the National Elevation Dataset (NED) (USGS 2009). Contiguous digital elevation models (DEMs) for the entire county of Adams was gathered, georeferenced to NAD 1984 State Plane PA South, merged into a single raster image, then clipped by the perimeter of Adams County. To calculate the slope and aspect for each pixel, the functions Slope and Aspect were used in ArcGIS.

The USGS Web Soil Survey (WSS) was a major source of data for this project. Using the SSURGO soils database for Adams County, PA to link the data to a location, the WSS provided soil pH, calcium carbonate, organic matter content, drainage class, and even frost free days. Once the tabular data was downloaded, it was linked to the SSURGO soils layer in order to enter the information into the equation. The single most important soil trait to consider is water drainage (Cass, 1999). Drainage refers to the speed in which free moisture drains from the soil. Grapevines prefer well drained soil, due to the increased likelihood of pathogens like root rot (Childers 1976; Chen 2011).

The final pieces of information regard climatic data, including growing degree days and minimum winter temperatures. Extremely cold temperatures can damage or even kill grape vines. Reduction in crop yield or in total plants from cold damages is a serious influence on vineyard placement. In order to determine minimum winter temperatures, it was momentarily considered to download a dataset containing historic data for the county. However, before this was started, it was discovered that the entire county of Adam's County is with the same USDA plant hardiness zone. The average minimum winter temperature between 1976 and 2005 was between -5 and 0 degrees Fahrenheit. This made the calculation of this measure pointless

because the results are relative to the entire county. This measure was excluded from the calculation.

Data containing maximum and minimum temperatures of Adam's County for 2014 was downloaded from the National Climatic Data Center (NOAA 2014). The most recent year was chosen to minimize the processing time and to ensure that the climatic data representing the county was recent.

Following the equation from Chen 2011,

$$\sum_{t=1}^{n}(Wt\ x\ Vj)$$

Where Wt=weight of the t variable (table 1)

Vj= score of the j criteria in the t variable (tables 2-8)

To clarify the use of this formula. (Wt x Vj) will be calculated for each criteria (table 1). Each criteria will be summed per geographic mapping unit (Pixel) to create a model representing agricultural suitability for grapes.

To determine the Vj score for each parameter being assessed, the rating system from Chen 2011 was also used. Tables 2 through 8 list the scoring for both the Edelweiss variety and the Cynthiana-Norton vine cultivars.

Table 2. Weighting system for both grape varieties for GDD (Chen 2011).

	Growing Degree Day Points	
Range	Edelweiss	Cynthiana-Norton
2018-2425 GDD	3	3
2425-2832 GDD	5	5
2832-3238 GDD	7	7
3238-3645 GDD	9	9
3645-4052 GDD	10	10

The determination of the growing degree days required much more effort. Growing degree days refers to the number of days that the grapevine will have to develop. This measure is generally used as a predictive measure to estimate development time, however, in this case, the data has been assimilated and repurposed. A longer growing season with higher temperatures will create better wines because of the influence on grape and vine growth/maturity (Wolf and Boyer 2003). In order to calculate this, the equation from Chen 2011 was followed:

$$GDD = \sum_{Apr\ 1-Oct\ 31}^{n} [((\text{Daily Max Temp (F)} + \text{Daily Min Temp (F)})/2) - 50\ (\text{F})]$$

The four weather stations from the NCDC downloaded data were used to calculate GDD in Microsoft Excel (NOAA 2014). Since the weather stations were reported in decimal degrees, the data needed to be transformed to fit the US survey feet of the State Plane Coordinate System. The GDD from each of the four weather stations were used as an input to interpolate a continuous raster. The values of this raster were reclassified as the point value for the suitability equation.

Table 3. Weighting system for both grape varieties for number of Frost Free Days (Chen 2011).

	Number of Frost Free Days	
Range	Edelweiss	Cynthiana-Norton
< 150 Days	0	0
150 to 165 Days	5	0
165 to 180 Days	7	0
>180 Days	10	10

It is recommended that grapevines in Nebraska at least 160 frost-free days (Read 2006). Since this parameter is not specific to Nebraska, using this figure for an analysis in Pennsylvania is reasonable.

Table 4 Weighting system for both grape vine varieties for slope (Chen 2011).

	Slope	
Range	Edelweiss	Cynthiana-Norton
Flat	3	3
1-3%	5	5
3-10%	10	10
10-15%	7	7
>15%	1	1

Slope can be an important aspect to study when considering where to plan a vineyard because of its close relationship with water drainage, erosion, and equipment access. Flat or slight slopes are easy to manage with little erosion, but are more prone to cool air inversions. Steeper slopes allow for more air flow but as little as 2% slope can cause increased erosion concerns. Slopes greater than 5% present risks for tractors and other equipment and slopes greater than 7.5% present concerns with severe nutrient loss, run off, and equipment rollover concerns (Smith 2006).

Table 5.Weighting system for both grape variety for aspect (Chen 2011).

	Aspect	
Range	Edelweiss	Cynthiana-Norton
Flat	5	5
202.5°-247.5°	7	7
157.5°-202.5°	9	9
247.5°-292.5°	5	5
292.5°-337.5°	2	2
112.5°-157.5°	10	10
0°-22.5°, 337.5°-360°	2	2
67.5°-112.5°	7	7
22.5°-67.5°	4	4

Aspect, the orientation of a slope, effects the heat balance of a vineyards, with a slight impact on winter temperatures. While it was found to have some impact on vineyards, aspect is not an exceedingly important variable to consider when planning a vineyard, compared to other criteria (Wolf and Boyer 2003).

Table 6. Weighting system for both grape varieties for soil drainage (Chen 2011).

	Soil Drainage	
Range	Edelweiss	Cynthiana-Norton
Poorly Drained	0	0
Somewhat pporly drained	3	3
Moderatrely Well Drained	8	8
Well Drained	10	10
Somewhat excessively drained	6	6
Excessively drained	5	5

In order to calculate the area for soil drainage, the ranges needed to be renamed to fit the classification scheme. Since the value "very poor drainage" was listed, and the lowest classification for drainage was "poor drainage," a look-up table was created to both adjust the naming to fit table 6, and to assign the corresponding Wt point values. By keeping only matching records, polygons that with blank drainage fields were excluded. This is beneficial, as these polygons were bodies of water, where vineyards are unlikely to develop.

Table 7. Weighting system for both grape varieties for Soil Organic Matter (Chen 2011).

	Soil Organic Matter	
Range	Edelweiss	Cynthiana-Norto
<1%	3	3
1 to 3%	10	10
3 to 4%	3	3
>4%	0	0

Table 8. Weighting system for both grape varieties for Soil pH (Chen 2011).

	Soil pH	
Range	Edelweiss	Cynthiana-Norton
<5	0	0
5 to 7	10	10
>7	3	3

Each separate weighted score for each variable was mapped before being summed in order to develop an understanding of the outcome. As an added note found in research, soils containing calcium has an added benefit to wine grapes due to the neutralization of acids that can lower the quality of wine in abundance. According to a highly regarded book in viticultural study, Wine and the Vine, growing in karst environments could be beneficial. This was the original consideration when downloading the calcium carbonate layer from the USGS Web Soil Survey. CaCO3 was not included in this study because, 1.) this chemical property might already be displayed in the pH measure, and 2.) unlike the surrounding counties, Franklin and Cumberland, Adams county does not have an abundance of carbonate lithology.

Figure 1 shows the final results of all of the data collection and calculation before the final suitability score was calculated. Each individual layer was analyzed to ensure that urban and aquatic areas are less suitable, and to estimate the final result. This figure was also beneficial during the analysis stage of this assessment in order to better understand the final result. In order to get a better idea of what areas are suitable, the raster was reclassified into three classes. This defined areas that are suitable and unsuitable.

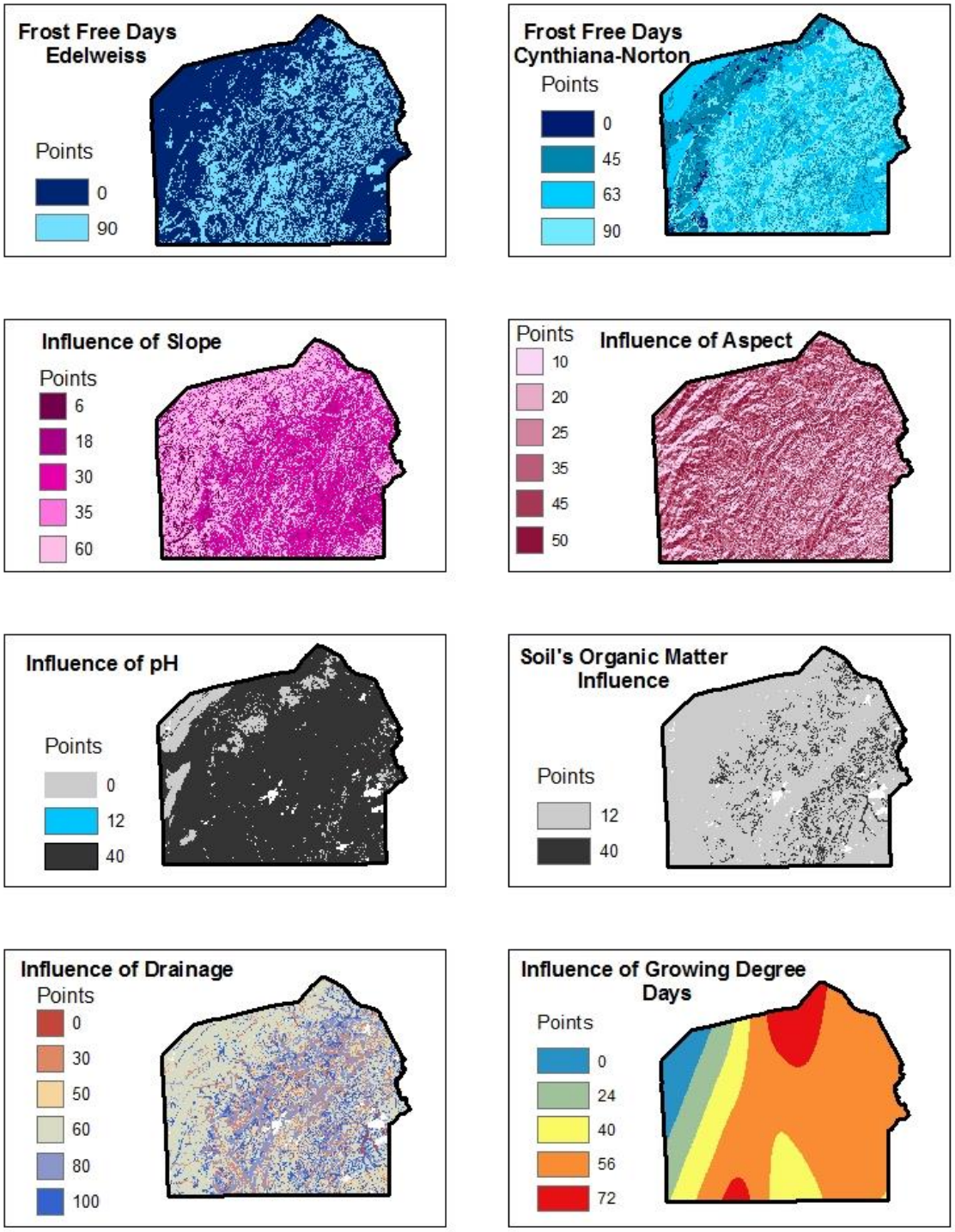

Figure 1. All of the rasterized criteria reclassified and calculated for the calculation of vineyard suitability. The more points, the more suitable an area is.

Results

After the criteria was summed, the general results were inspected. For the Edelweiss assessment, the maximum value was 437 and the minimum was 148. A perfect score is 460. This shows that, for some areas of Adams County, Edelweiss is suitable, according the modern understandings of viticulture. The results from the Cynthiana-Norton variety show that the max is 452 (even more suitable) and the min was 88. This shows that the Cynthiana-Norton variety is more location sensitive than Edelweiss.

Figure 2 shows the results from the summation of the criteria using the Edelweiss variety specifications. As the figure shows, the most suitable areas are in the central valley of Adams County, while the least suitable are in the mountains to the northwest. Areas that were urban, like Gettysburg in the center of the map, displayed as white, which was a convenient and unintentional outcome of some layers marking these areas as NODATA (because they are Urban or Wetlands). It seems that the influence of slope, organic matter, and drainage has created two distinct ridges where suitability is much higher.

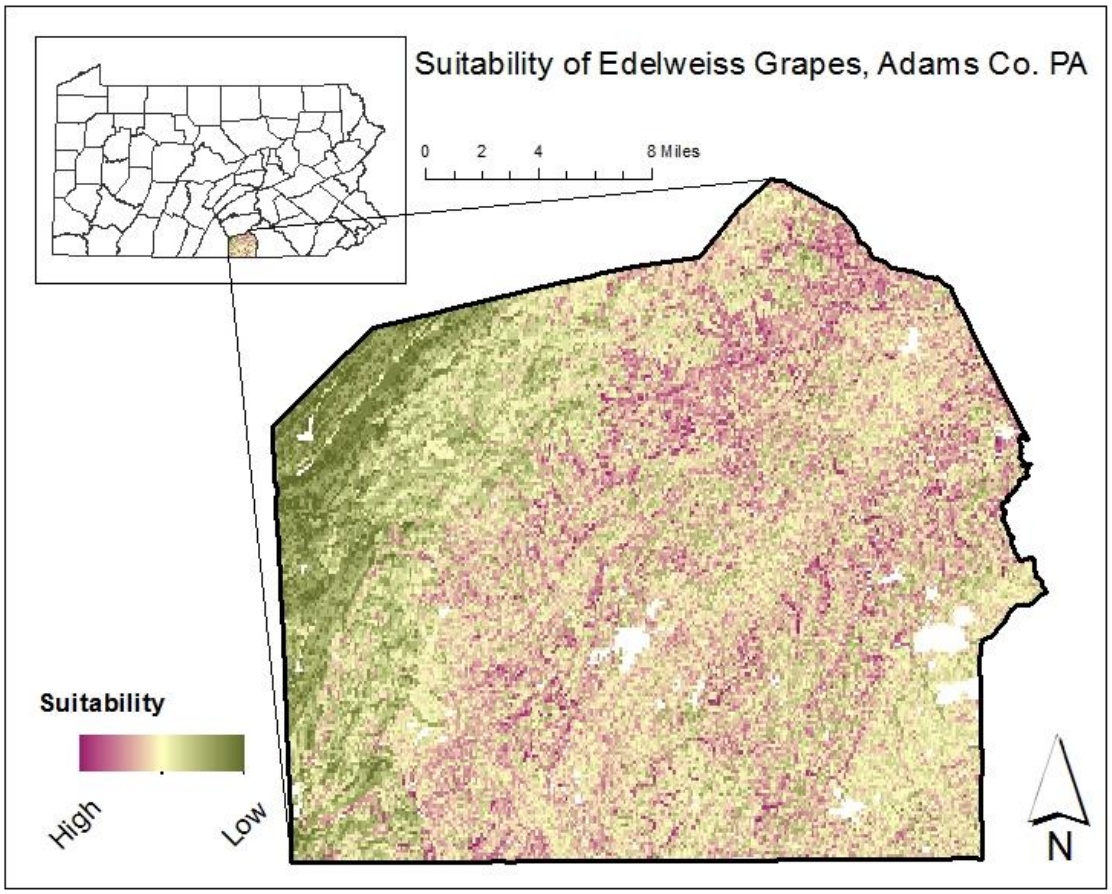

Figure 2. Resulting raster from the summation of all of the criteria involved in the analysis.

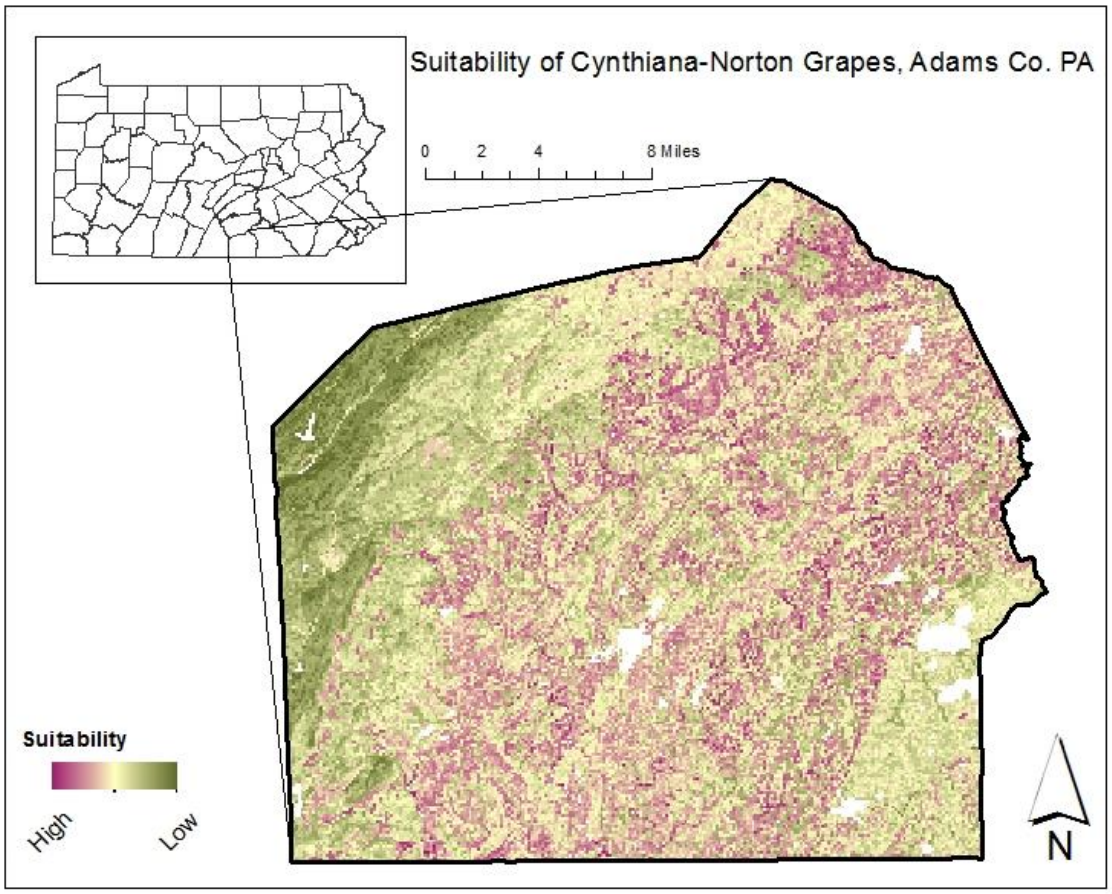

Figure 3. Resulting raster from the summation of the criteria. Note the slight differences between this figure and figure 2 caused by the varietal preferences of FFD.

Figure 3 shows the results from the other variety, Cynthiana-Norton. This warm-weather grape variety shows the same general pattern as the Edelweiss variety, however, the contrast between zones were much more exaggerated, showing some areas being extremely suitable for the Cynthiana-Norton variety. With this noted, it is also worth mentioning that there are some areas that change suitability dramatically over a short area. Figure 4 shows how stark the suitability can be over a short distance.

Figure 5 shows the results from the Cynthiana-Norton suitability index, only it has been reclassified into suitable and unsuitable areas. The white areas, are areas with the "NODATA," as mentioned before.

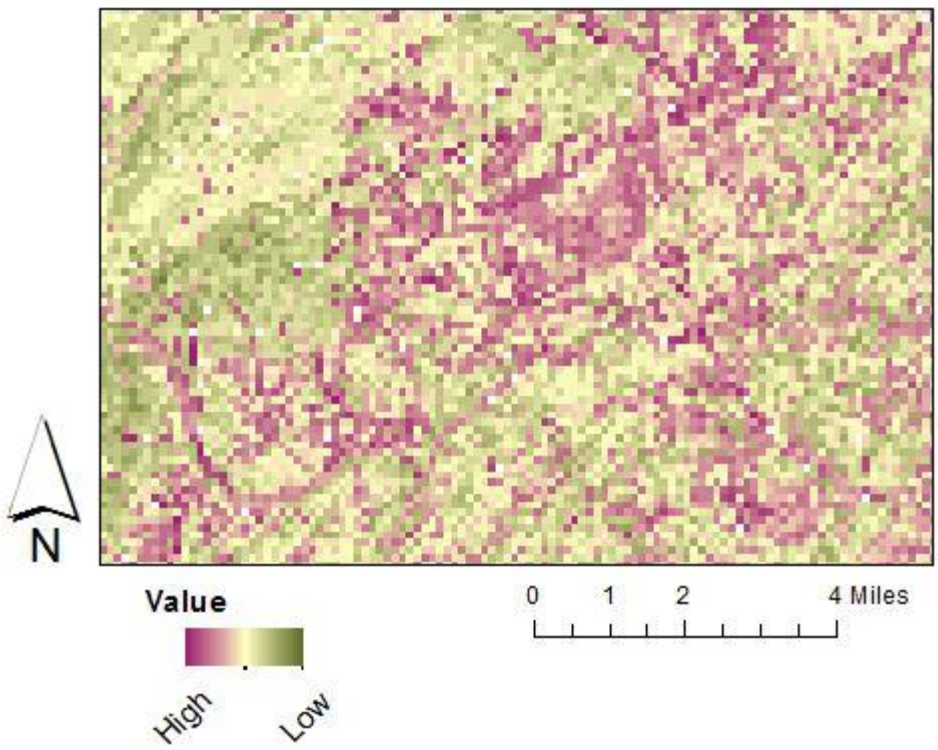

Figure 4. High-Scale image of Cynthiana-Norton variety to show how the suitability can change quickly.

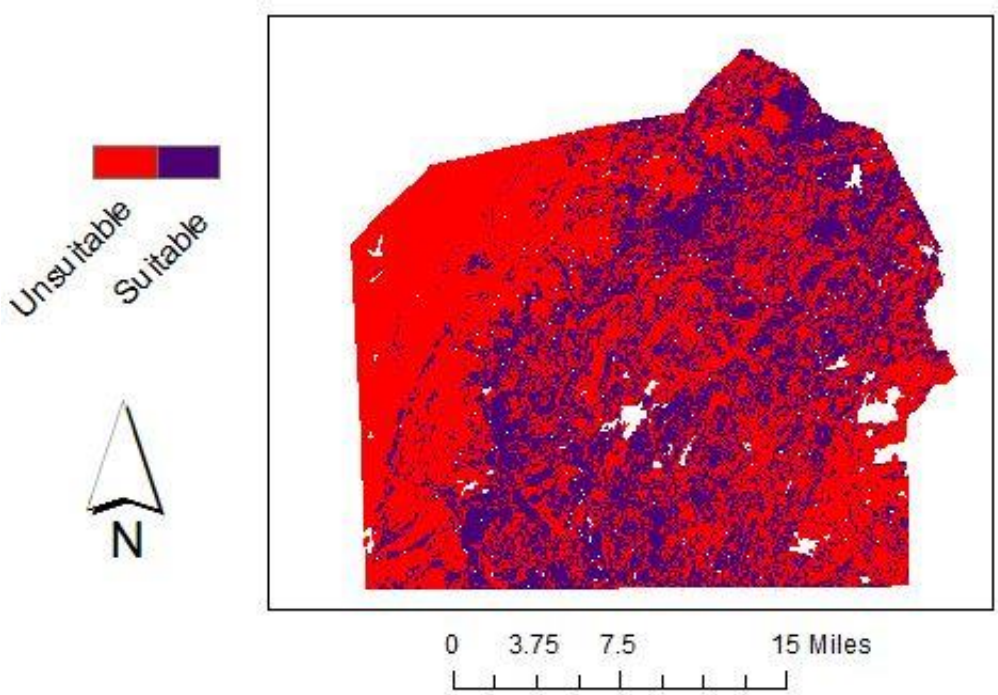

Figure 5. Cynthiana-Norton suitability index reclassified into two classes. Not that there are more areas that are unsuitable than suitable.

Discussion and Conclusion

While the study of viticulture might have a fixation on dispelling the mystery behind terroir, these results have actually been able to be utilized in a productive manner. Understanding what makes a decent wine can obviously be beneficial for vineyards to sell a higher quality product; however, it also presents an opportunity to examine geographic associations regarding wine. While this study is largely based on the methodology of Chen 2011, its application to Pennsylvanian vineyards expands on the research. By conducting the same research in a new area, not only do I develop my understanding of the local geography, but I also can understand the benefits and limitations to this study.

When studying this topic on "quality wine" it is worth mentioning that, while some criteria are subjective, many aspects of terroir are backed through chemical and economic research. While Pennsylvania is still developing a name for itself in the wine world, understanding ideal locations for vineyards could help improve the quality of Pennsylvania wine and could influence land use planning. Many studies focus of wine grapes with the intention of understanding the impact that climate change will have on the industry (Quiroga and Iglesias 2009; Jones et al. 2005, Jones and Webb 2010). Since many of the criteria used in this study are based on climatic parameters, it is considerable to continue the study with the use of climate models. This data could be used to project the anticipated changes to the environment, and therefore the suitability for wine grapes for both economic preparation or investment. Since terroir has been so deeply ingrained into geographic locations, changing in weather can threaten the quality of historic viticultural zones.

Figures 5 and 6 show the results from the model study, Chen 2011. While the classification scheme used by Chen was not the same as this study, it was still worth-while to compare the two study's results. Between the two Edelweiss analyses, it was difficult to discern notable differences. Both figures display a static pattern of suitability, with obvious zones of transitions. While the results from Chen 2011 were more smooth, it was also over the span of an entire state. The differences between the two Cynthiana-Norton analyses were much more dramatic. In Nebraska, most of the state was unsuited for this variety, while in Pennsylvania, much more land was suitable.

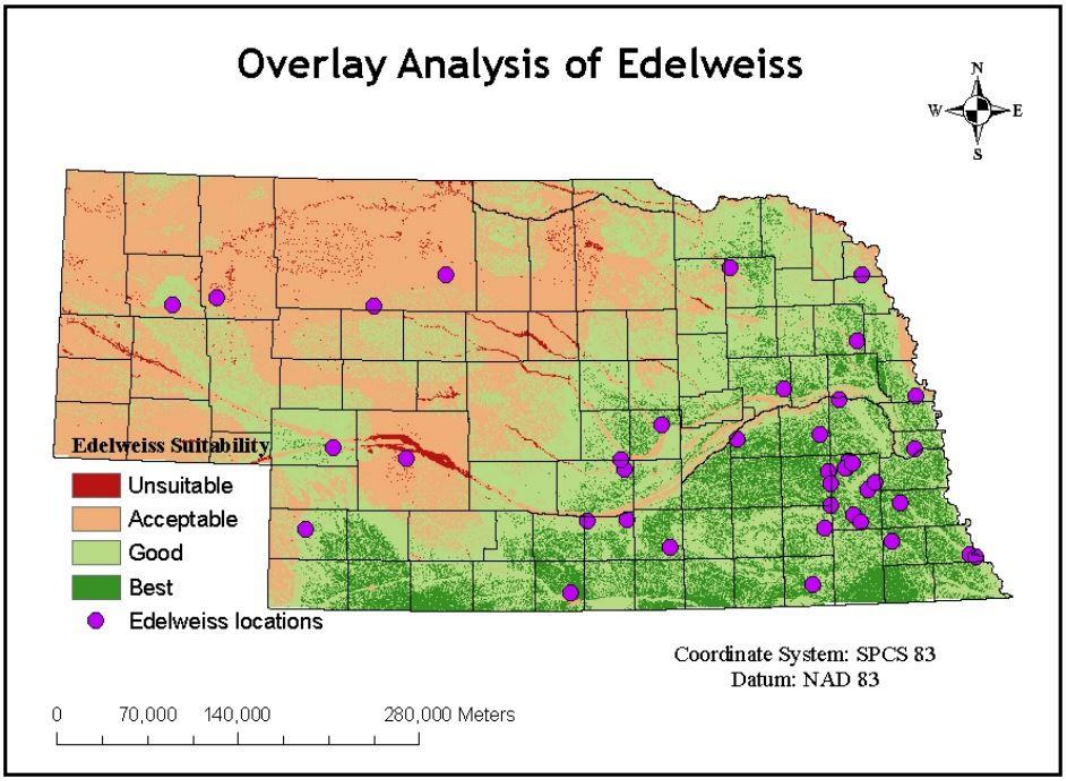

Figure 6. Results of the Edelweiss suitability analysis from Chen 2011.

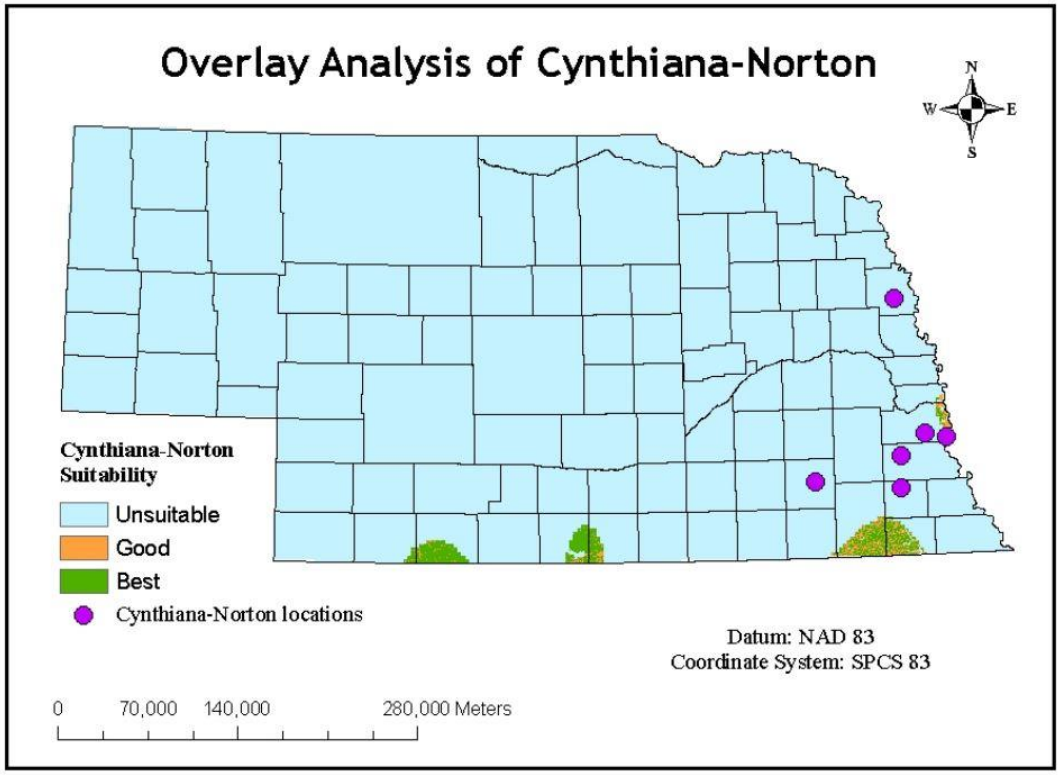

Figure 7. Results of the Cynthiana-Norton suitability analysis from Chen 2011.

The limitations to the study area and inclusion of available data were major drawbacks to this study. While this was an excellent preliminary step, an increase in the general picture can always provide more answers. One specific reason why expansion into other counties would be ideal was the calculation of the growing degree days. If more weather stations from other counties were included, the interpolation operation (spline) would have been more accurate, especially in the northwestern corner of Adams County (figure 1). In addition to including more weather stations, it would also include a reason to include the severe minimum temperatures into the study. Additionally, it would be worth exploring the impact of Calcium Carbonate, by including Franklin and Cumberland Counties. In addition to including the other counties, also including other facts, such as current land use, to remove urban and water land cover from the map.

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