Viticultural Site Selection: Testing the Effectiveness of North Carolina’s Commercial Vineyards

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Abstract:

Prohibition destroyed North Carolina's once thriving wine industry (Mills & Termey, 2007). Since the mid-1970s, however, the state has rebounded to become the nation's twelfth largest producer of wine (TTB 2015). As of September 2017, North Carolina is home to 186 wineries. This represents a significant increase from the 21 wineries that were present in the year of 2000 (Fuller, 2017; Winslow, 2014, 2016). The economic impact of the wine industry in North Carolina has been estimated at $1.97 billion in 2016 (Frank, Rimerman + Co. LLP 2017). The young but rapidly growing wine industry is poised for continued growth and will likely have a significant impact on the North Carolina's economy into the future.

Keywords: North Carolina | agricultural sustainability | viticulture | vineyard site selection | Pierce's disease

Article:

1. Introduction

Prohibition destroyed North Carolina's once thriving wine industry (Mills & Termey, 2007). Since the mid-1970s, however, the state has rebounded to become the nation's twelfth largest producer of wine (TTB 2015). As of September 2017, North Carolina is home to 186 wineries. This represents a significant increase from the 21 wineries that were present in the year of 2000 (Fuller, 2017; Winslow, 2014, 2016). The economic impact of the wine industry in North Carolina has been estimated at $1.97 billion in 2016 (Frank, Rimerman + Co. LLP 2017). The young but rapidly growing wine industry is poised for continued growth and will likely have a significant impact on the North Carolina's economy into the future.

The primary risks to yields and profitability for viticulture in North Carolina are climatological. The long, warm, and humid growing season can promote fungal diseases in susceptible varieties such as *Vitis vinifera* and many French-American hybrids (Wolf et al., 2011). In addition, winter minimums in higher elevations can reach temperatures low enough to kill the vine wood of *V. vinifera* (Pool, Wolf, Welser, & Goffine, 1992; Wolf & Boyer, 2003). In contrast, winter minimums in lower elevations are often too mild to significantly reduce the presence of vectors associated with Pierce's Disease (PD) (Anas, Harrison, Brannen, & Sutton, 2008; Sutton, 2005). Tropical cyclones are also problematic since high winds and heavy rain can ruin an otherwise healthy crop, and late spring frosts can damage vines and limit the profitability of growing varieties that emerge early (Poling 2008).

Installing and operating a vineyard is expensive. A hypothetical 4-ha (10 acre) Chardonnay vineyard in North Carolina has been estimated to cost $31,816 per hectare ($12,876 per acre) after three years of establishment (Poling 2007). According to a vineyard installer (Hobson Jr., F.W., owner of Rag Apple Lassie Vineyards), more recent costs for a typical vineyard was estimated at $49,421 per hectare ($20,000 per acre). The estimate, however, does not account for the costs associated with land preparation, mowing, herbicides, insecticides, fungicides, soil nutrient adjustment, or labor in the first three years (Nowlin, 2013). For many North Carolinian grape growers, savings that could have otherwise been used in retirement are often used to cover startup costs for a vineyard. Others might decide to plant grapes on land already owned, often a long-held family farm, rather than seeking the most suitable land. Poor site location can compromise the entire vineyard operation and lead to the failure of the business and the loss of the family farm.

The risks presented by the environment, along with the high cost of establishing a vineyard, highlights the importance of conducting a site suitability analysis (Poling & Spayd, 2015; Wolf & Boyer, 2003; Wolf, 2008). Regional extension advice is connected to local knowledge. In many cases, local knowledge can be used to address issues that are unique to crop production in the region (Debolini, Marraccini, Rizzo, Galli, & Bonari, 2013). The North Carolina Cooperative Extension Service (CES) provides agricultural suitability guidance to the viticultural industry. The advice is summarized in a document titled the North Carolina Winegrowers Guide (NCWGG) (Poling 2007; Poling & Spayd, 2015). In North Carolina, this document forms the basis of government guidance to the wine industry on vineyard establishment and operation.

Land use decisions for agriculture involve many factors (Gomes et al., 2018; Vinatier & Gonzalez Arnaiz, 2017). Some vineyard operators in North Carolina have made good site selection choices, however, there has been no research conducted on how well vineyard site locations connect to agricultural extension advice (Nowlin & Bunch, 2016a). The objective of this study is to examine the degree to which North Carolina vineyard site locations conform to the advice given by the CES in the NCWGG.

2. Geospatial modeling of viticultural site suitability

The European wine grape, known scientifically as *Vitis vinifera*, has been cultivated by humans for more than 8000 years (McGovern, 2007; McGovern, Hartung, Badler, Glusker, & Exner, 1997). The challenge of identifying areas suitable for grape growing came to the forefront as the practice of commercial viticulture moved out of Europe. Potential locations can be objectively compared by analyzing the physical character of wine growing areas (Bonfante, Basile, Langella, Manna, & Terribile, 2011; Bowen et al., 2005; Hellman, Takow, Tchakerian, & Coulson, 2011). Multi-factor spatial analysis, for example, has been used to describe regions and model site suitability (Foss, Ravenscroft, Burnside, & Morris, 2010; Irimia and Patriche 2010, 2011; Jones et al. 2004, 2006). Modeling the related effects of latitude, regional climate, soil, and topography makes viticultural site selection computationally complex.

Site suitability models for viticulture have been applied to many areas throughout the world. Vaudour and Shaw (2005), for example, examined viticultural zoning from a worldwide perspective. Other researchers have focused on regions of countries such as Southern England, Australia, Canada's Okanagan and Similkameen Valleys, Valle Telesia in Italy, and Romania's Huşi vineyard region (Bonfante et al., 2011; Bowen et al., 2005; Foss et al., 2010; Hall & Jones, 2010; Irimia and Patriche 2010, 2011). In the U.S., site suitability models for viticulture have been applied to Oregon's Umpqua Valley and Rogue Valley, West Texas, and Rockingham County, North Carolina (Hellman et al., 2011; Jones et al. 2004, 2006; Nowlin, 2013; Nowlin & Bunch, 2016a).

Previous research has organized elements of site suitability models by spheres of the Earth (i.e., lithosphere, atmosphere, pedosphere, and anthroposphere). Geospatial data representing topography, soil, and climate are often used to group and delineate important elements. The most common source of topography, soil, and climate data are Digital Elevation Models (DEMs), SSURGO and STASGO, and PRISM respectively (Nowlin, 2017). Soil surveys are readily available as three distinct geospatial datasets. The vector datasets known as STASGO and SSURGO, for example, are suited to scales of 1:250,000 and from 1:12,000 to 1:63,360 (typically 1:24,000) respectively (Mednick, 2010). Most recently, a raster version of SSURGO called gSSURGO has been made available at 10 m spatial resolution. The use of PRISM and Daymet climate data has been used in various site suitability studies at various spatial resolutions (Foss et al., 2010; Hellmen et al., 2011; Jones et al., 2006, 2004). PRISM monthly and 30-year climate normal data are available at 800 m while daily data are available at 4 km for the continental U.S (Nowlin & Bunch, 2016b).

Pierce's disease (PD) is a problem that has not been fully incorporated into site suitability models. PD is a plant disease caused by *Xylella fastidiosa*, a bacterium, which clogs the xylem of the grapevine producing water stress. The disease is usually fatal to *V. vinifera* and most French American hybrid grapes. The disease is known to be spread by insects like the Glassy Winged Sharpshooter (*Homalodisca vitripennis*). The disease is the primary limiting factor for viticulture across the Southeastern U.S. The boundary between the zones of low and high risk for PD bisects North Carolina. These zones are defined by areas with colder winters that have lower risk and areas with mild winters that have higher risk (Nowlin & Bunch, 2016a). One PD control program report from California found many plants that act as hosts, from Oleander to Bermuda Grass to wild grapes (Almeida & Purcell, 2002, pp. 295–302). These plants are also common in North Carolina. A PD risk assessment method has been developed (Anas et al., 2008; Sutton, 2005).

3. Study area

The study area for this research is North Carolina. The state has vineyards distributed throughout the three physiographic regions (Nowlin and Bunch, 2016b) (Fig. 1). There are five official American Viticultural Areas (AVAs) approved in the Code of Federal Regulations (CFR) Title 27 § Part 9, 2017; (Code of Federal Regulations, 2002, 2008, 2009, 2014, 2016). These include the Yadkin Valley AVA (2002), the Swan Creek AVA (2008), the Haw River Valley AVA (2009), the Upper Hiwassee Highlands AVA—shared with Georgia (2014), and the Appalachian High Country AVA—shared with Tennessee and Virginia (2016).

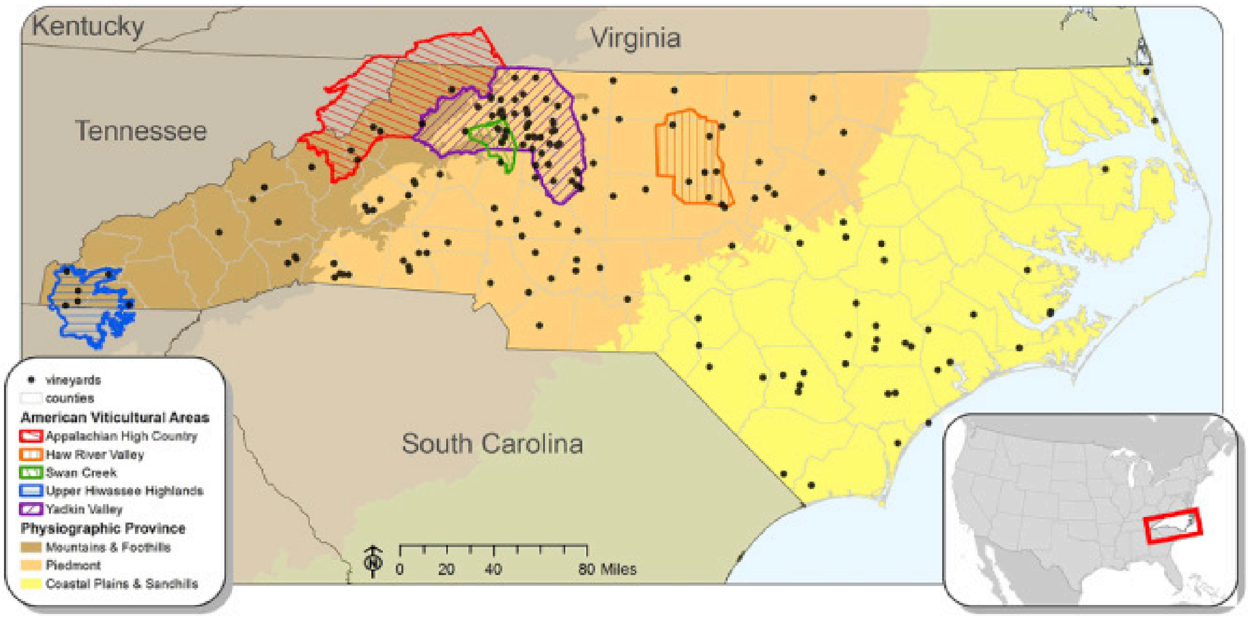

Figure 1. North Carolina physiographic regions and American viticultural areas as of December 2016.

4. Materials and methods

A pass/fail physical capability model was constructed using a GIS and site selection guidance from the NCWGG. The parameter class boundaries were guided by the NCWGG, while the methodology for generating the surfaces were guided by viticultural site suitability and terroir analysis literature. Parameter related to climate, topography and soil were used as model inputs (Fig. 2). The following provides a discussion on the physical parameters and elements of the model.

4.1. Vineyards

Vineyards were mapped using GIS. The locations (as of 2017) were taken from a list of NC commercial vineyards generated by NC Wine and the North Carolina Muscadine Grape Association (NMGA). Additional information on vineyards locations also came from the research conducted by Nowlin and Bunch (2016a; 2016b). Polygons of the vineyard boundaries were digitized using aerial imagery from the National Aerial Imagery Program (NAIP) and imagery from Google Earth. The dataset compiled by this research is only known and complete set of vineyard boundaries for North Carolina.

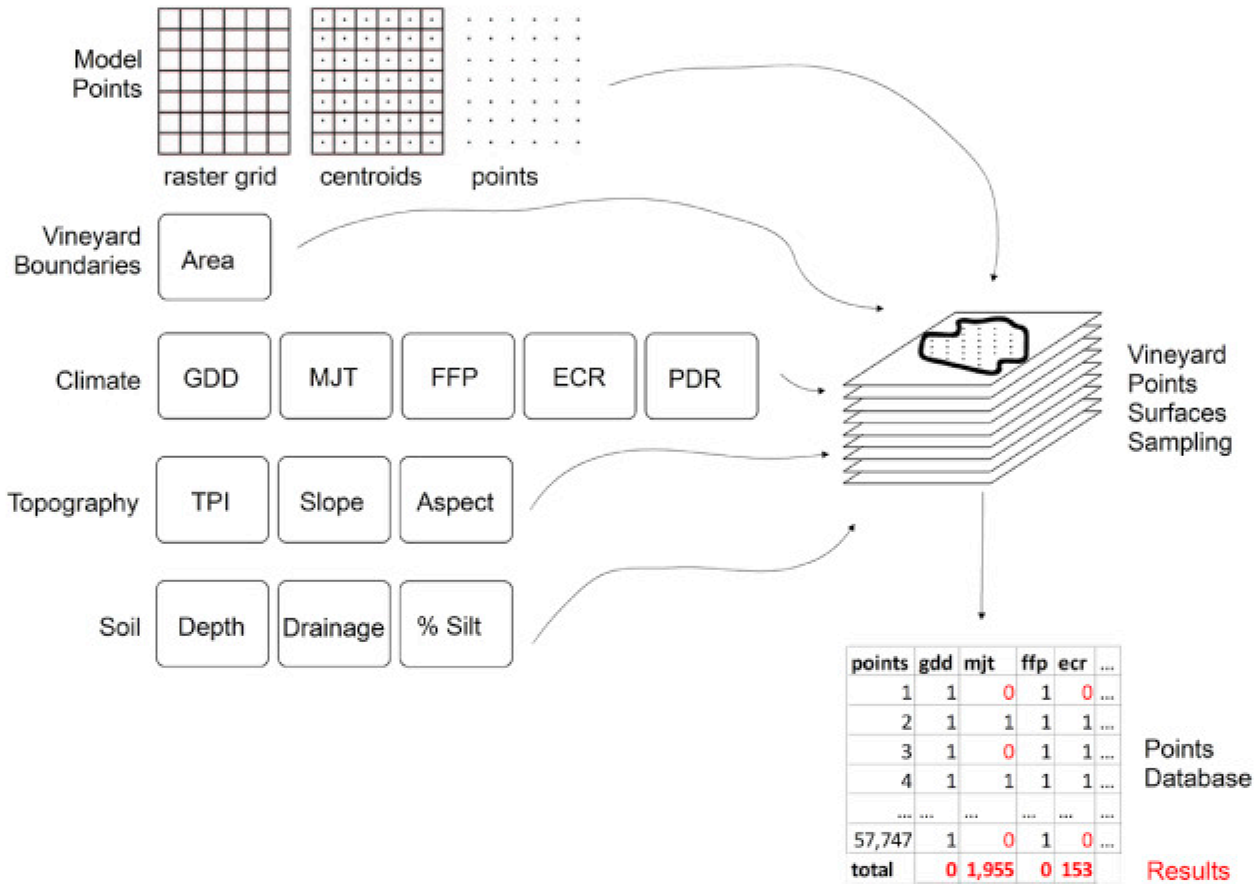

Figure 2. Model testing Vineyard site selection capability/suitability.

4.2. Climate

Regional CES site selection advice relates to climate variables of temperature. This includes growing degree day (GDD), mean July temperature (MJT), extreme cold risk (ECR), frost free period (FFP), and the PD risk (NCWGG).

The GDD index is a reflection of growing season heat accumulated above 0 °C (50 °F) from the beginning of April to the end of October. Classifications of GDD known as Winkler Regions for California have been widely reported in the literature (Amerine & Winkler, 1944). They have been further updated by Jones, Duff, Hall, and Myers (2010) and Anderson, Jones, Tait, Hall, and Trought (2012) to account for other regions worldwide, for lower and upper limits not originally specified, and a division of Region I into two classes (Table 1). It should be noted that the beginning and end of the growing season being understood by Amerine and Winkler as April 1st and October 31st might not apply to very warm viticulture areas with long growing seasons, and the months would change in the Southern Hemisphere.

The average temperature of the warmest month was represented by MJT (Smart & Dry, 1980). The NCWGG only cites three classes for MJT. These include <21 °C (warm), 21 °C–23 °C (hot), and >23 °C (very hot) while Smart and Dry (1980) also included <17 °C (cold) and 17 °C–19 °C (cool). This study has incorporated two additional classes termed 25 °C–27 °C (exceptionally hot) and ≥ 27 °C (too hot for *V. Vinifera*). The MJT classes are listed in Table 2.

Table 1. Growing Degree-Days, 1981 to 2014, classified into updated Winkler Regions (Anderson et al., 2012; Jones et al., 2010).

Growing Degree-Days (10 °C base)	Winkler Regions
<850	Too Cold
851 to 1111	Region Ia
1112 to 1389	Region Ib
1390 to 1667	Region II
1668 to 1944	Region III
1945 to 2222	Region IV
2223 to 2700	Region V
>2701	Too Hot

Table 2. Mean July Temperature, 1981 to 2014, Classified by Smart and Dry (1980), with the addition of two hotter classes using the same class intervals.

July Mean Temperature (°C)	Class
<= 17	Cold
17 to 19	Cool
19 to 21	Warm
21 to 23	Hot
23 to 25	Very Hot
25 to 27	Exceptionally Hot
>= 27	Too Hot for *V. Vinifera*

A conservative measure for the growing season length used in Virginia is the FFP (Wolf & Boyer, 2003). The NCWGG states that the growing season should be at least 165 days with muscadines requiring 200 days. Using these figures, a classification of growing season length was derived (Table 3).

Table 3. Frost free period, 1981 to 2014, 10-day interval classes (after 170 days), with ordinal terms.

Frost-Free Period (days)	Class
<165	Very Short
166–170	Short
171–180	Intermediate
181–190	Sufficient for Most *V. vinifera* Varieties
191–200	Long
201–210	Very Long; Sufficient for Most Muscadine Varieties
>211	Extremely Long

The Virginia, Wolf and Boyer (2003) study assessed extreme cold risk using the decadal incidence of vine wood damaging cold events. They defined risk in terms of the count of days per decade that are ≤ −22.2 °C (−8 °F). Three or more days per decade was considered high risk.

Since most bunch grapes are not PD resistant, the CES guidance suggests avoiding areas that are prone to the disease. The problem areas have been shown to follow a geographic pattern that closely follows two sets of temperature thresholds. Areas of very high, high, medium, and low risk are shown to be separated by the number of days where winter minimum temperatures occur for three, four, or five days ≤ −9.4 °C (15 °F) and alternatively one, two, or three days ≤ −12.2 °C (10 °F). These two sets of temperature thresholds hint at enviro-biotic controls on the overwintering of the disease vectors and/or the survival of the bacterium itself (Anas et al., 2008; Sutton, 2005).

4.2.1. Climate model

The data source for the climate layers was the 2016 PRISM Climate Group daily data from between 1981 and 2014 at 4 km resolution (Daly et al., 2000; Daly et al. 2008; Daly, Widrlechner, Halbleib, Smith, & Gibson, 2012; PRISM 2016). The PRISM metrics used in the study were the daily minimum, maximum, and mean temperature surfaces from a period spanning over 33 years (33 years × 365 days x 3 metrics = 36,135 maps). These data were used to compile gridded raster surfaces for the following parameters (GDD, MJT, FFP, ECR and PD risk {PDR}).

- GDD – Growing degree-days were calculated by summing all daily mean temperatures over 10 °C (50 °F) between 1 Apr and 31 Oct, and failing those below Winkler Region Ia (less than 851 GDD) or those above Winkler Region V (greater than 2700 GDD).
- MJT – Mean July (January in the southern hemisphere) temperatures were failed if the mean was ≤ 17 °C or ≥ 27 °C. (muscadines only).
- FFP – The growing season length was calculated using the mean Frost-Free Period, which is the average span of days between the last vernal frost and the first autumnal frost. Those regions with less than 165 days FFP were failed.
- ECR – Extreme cold risk was considered by counting the mean number of days per decade with an incidence of ≤ −22.2 °C (−8 °F), and failing those with ≥3 days.
- PDR – The risk presented by PD was considered by summing the annual count of days at or below Turner Sutton's two PDR thresholds. These include the mean annual incidence of days ≤ −9.4 °C (15 °F) with those ≤ −12.2 °C (10 °F).

4.3. Topography

The topographic factors cited in the CES documentation include measures of absolute and relative elevation, slope and aspect. Extremely high elevation sites are not suitable because of their short growing seasons, extreme cold, and high advective frost risk (Wolf & Boyer, 2003). North Carolina has a broad range of elevations, beginning at sea level and rising to the highest point in the U.S. east of the Mississippi River, 2037 m (6684 ft) on Mt. Mitchell. Absolute elevations ≥610 m (2000 ft) are cited as high risk in the NCWGG due to the very cold conditions (Poling 2007; Poling & Spayd, 2015). In calm, clear conditions, radiative frosts cause severe risks, especially in the spring after bud break. To reduce the impact on vineyards, being located above the valley floor at a site with prominent relative elevation is a way to ensure that cold air can drain away from the vineyard. (Poling & Spayd, 2015, Fig. 3).

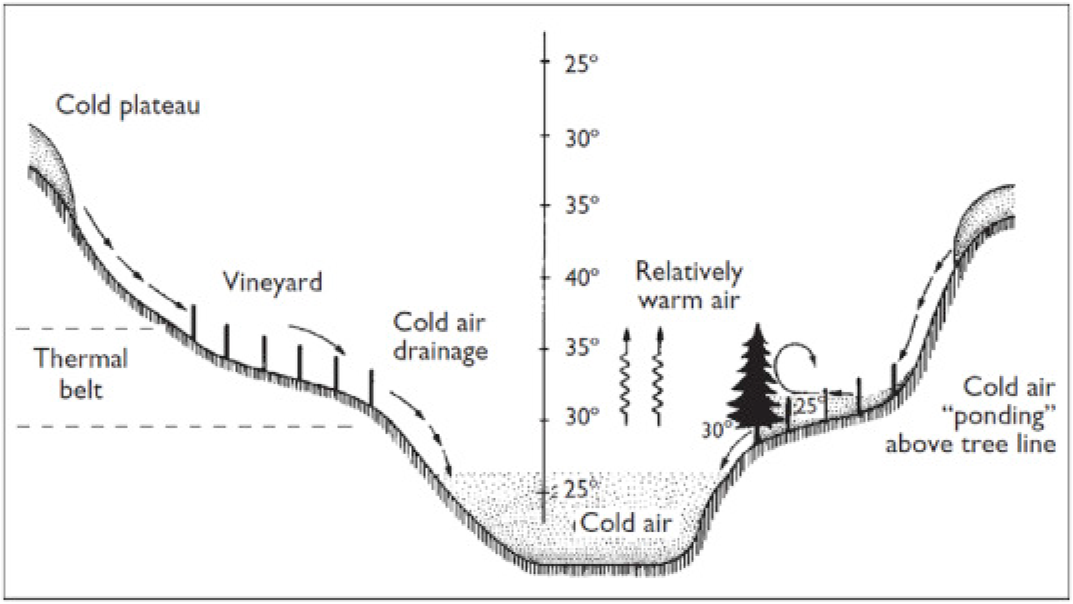

Figure 3. Cold Air Drainage, image originally from Mid-Atlantic Winegrape Production Guide (Wolf & Poling, 1995), used by permission.

Relative elevation, topographic prominence, and topographic position can be used to understand the relationship between a vineyard location and its potential for cold air drainage. A ratio of these elevations is a metric describing the local topographic prominence. The major complicating factor influencing the interpretation of topographic prominence is the notion of scale. If a vineyard is on a small hill within a large valley, the topographic prominence will be high locally. If you look only at the scale of the valley floor, however, it will be low if you extend the horizontal scale to include the ridges defining the valley. While the physics of cold air drainage may be understood in a closed simple system, the complexity of terrain across a broad area such as a state makes the choice of a common scale for relative elevation even more problematic. Building on the work of Guisan, Weiss, and Weiss (1999), Weiss (2001) developed a method of classifying slope position, which has been refined in the literature (De Reu et al., 2013). This method utilizes a series of annuli at three distances and taking the focal mean Z score of topographic position. The method classifies the Z score surface into slope position (Table 4).

Table 4. Weiss (2001) Topographic position index, slope position using 2016 national elevation dataset.

Slope Position	Z score
Ridge	> + 1 STDEV
Upper Slope Position	>0.5 STDEV ≤ 1 STDEV
Middle or Flat Slope Position	≥ −0.5 STDEV, ≤ 0.5 STDEV
Lower Slope Position	≤ −1.0 STDEV, < 0.5 STDEV
Valleys	< −1.0 STDEV

Slope, a measure of the inclination of the land, is an important practical consideration since a tractor can easily turn over or slip on steep slopes. Another consideration of slope relates to sustainability. Soil erosion, for example, becomes a problem in regions where rainfall rates and slope are high. The NCWGG suggests that vineyard sites not exceed the 15% gradient threshold.

Aspect, the cardinal-ordinal direction of slope (East, West, North, South—Northeast, Southeast, Southwest, and Northwest), is often expressed in degrees from North (clockwise). Aspect is important to the local climate of the vineyard because it relates to the orientation of the slope and the seasonal/diurnal relationship to the sun's rays. In this way, aspect can impact the insolation potential of the vine. In the Northern Hemisphere, for example, a facet of land might be oriented to the South where it would have warmer days because of the more direct angle of sunlight and the greater insolation incident along each unit area. If oriented to the East, it would receive the first sunlight in the morning, which might burn off early dew and lower fungal disease pressure. If oriented North, the area would stay cooler in the spring longer, delaying bud break, which could be useful in a Chardonnay vineyard since it is one of the first varieties to break bud in the spring. Delaying this developmental milestone can lower the risk that a killing frost will damage the green shoots of varieties which break bud early. This has happened recently in the north and west portions of the Haw River Valley AVA of the Upper Piedmont region in North Carolina (Table 5).

Table 5. Recent late spring frosts occurring after warm periods (preceding 21-day running mean > 60 °F) after April 7th, recorded at the GSO airport in greensboro, NC.

Date	Warm Period: Average Temperature °C (°F)	Daily Low Temperature °C (°F)
4/20/1988	21.1 (70)	−1.1 (30)
4/12/1989	16.8 (62.4)	−1.7 (29)
4/8/1990	16.6 (61.9)	−2.2 (28)
4/12/1990	17.1 (62.7)	−1.1 (30)
4/10/1997	19.5 (67.2)	−1.1 (30)
4/7/2002	17.3 (63.2)	−1.1 (30)
4/18/2001	20.6 (69.1)	0 (32)
4/19/2001	20.6 (69)	−0.6 (31)
4/7/2007	21.7 (71)	−1.1 (30)
4/8/2007	22.2 (71.9)	−3.8 (25)
4/16/2014	20.7 (69.3)	−1.1 (30)
4/10/2016	18.8 (65.8)	−1.7 (29)

4.3.1. Topography model

The most recently available data from the National Elevation Dataset (NED) was acquired as 10 m raster digital elevation models (DEMs) (USGS, 2015). The datasets were used to compile a gridded raster surface for the Topographic Position Index (TPI), Slope and Aspect.

- TPI – Topographic Position Index was used to classify cold air drainage risk zones, such that the mean Z score across the combined TPI annulus ranges below Z scores of −1 standard deviations were failed. In accordance with Weiss's (2001) “Slope Position” methodology, Z scores below −1 represent low relative elevation, also known as low topographic prominence. Three annuli of the following radii were used: close = 50–200 m, medium = 500–650 m, and far = 1850–2000 m. The annulus ranges were based on a survey of regional landforms that were calculated by measuring from ridge to ridge across drainages at different local scales.
- Slope – Slopes above 15% were failed due to the risk of soil loss from erosion and the danger of operating heavy machinery steep slopes.

- Aspect – Aspects between due South (180°) and due West (270°) were failed due to the potential of early bud break in the spring and/or winter injury attributed to the lack of cold hardening in the late fall.

4.4. Soil

Soil provides an important set of factors in vineyard suitability. It delivers the basic plant nutrients, provides access to water, and acts as the anchoring medium for the roots. The three soil factors that are emphasized in the NCWGG are soil drainage class, soil depth, and fertility. There is no substitute for on-site soil samples and inspection via soil pits and testing of infiltration rates, however, USDA-NRCS soil surveys provide a suitable alternative for broad generalizations over large areas. Over-vigor is where the vine emphasizes wood and leaf growth at the expense of fruit quality. It is associated with high soil water and fertility. The increased density and size of the canopy resulting from an over-emphasis on making leaves reduces light infiltration and air flow. This increases the risk for fungal diseases, and promotes inconsistent fruit ripeness and rot. North Carolina experiences high average annual precipitation ranging from 1000 to 1300 mm (39.4–51.2 inches) annually. This makes soil drainage important for vine health. Soils should be at least "Moderately Well Drained" and at least 76.2 cm (30 in) deep. Soils that are high in fertility should also be avoided to reduce the likelihood of developing large dense canopies (Wolf & Boyer, 2003).

4.4.1. Soil model

The source for the soil data was gSSURGO (10 m spatial resolution). This dataset was used to compile a gridded raster surface for depth, drainage class, and percent silt.

- Depth – Soil depths <76.2 cm (30 in) failed.
- Drainage – Soil Drainage Classes that were not at least "Moderately Well Drained" were failed.
- Percent Silt – Since silt is a good measure in North Carolina for fertility, it was used as a proxy; soils with >50% silt were failed.

4.5. Model function

A raster to feature function was used to create a set of points from DEM grid cell centroids for all locations within the vineyard boundary polygons. There was a total of 57,747 points that fell within the boundaries of the state's 160 vineyards. The raster parameter surfaces were sampled using these points. This produced a table of corresponding parameter values that were incorporated into the pass/fail model. While the topography and soil parameter surfaces had a resolution of 10 m, the climate surfaces had a resolution of 4 KM. Because climate varies little with distances on the scale of 4 km, resampling was not necessary.

5. Results

5.1. Climate results

The results for GDD revealed that a large portion of the state falls within the modified Winkler Region V. This includes all vineyards in and around the Haw River AVA, a small portion of the southeast corner of the Yadkin Valley AVA, and most of the vineyards not in an AVA (Fig. 4). Many of the vineyards in and around the Yadkin Valley and Swan Creek AVAs are in Region IV. The southwestern mountain region vineyards, including those of the Upper Hiwassee Highlands AVA, are mostly in Region III and IV. The few northeastern mountain vineyards, all of which are in the Appalachian High Country AVA, fall within Regions Ia, Ib, and II. This is significant since it means that North Carolina has wine regions spanning across the entire GDD index range.

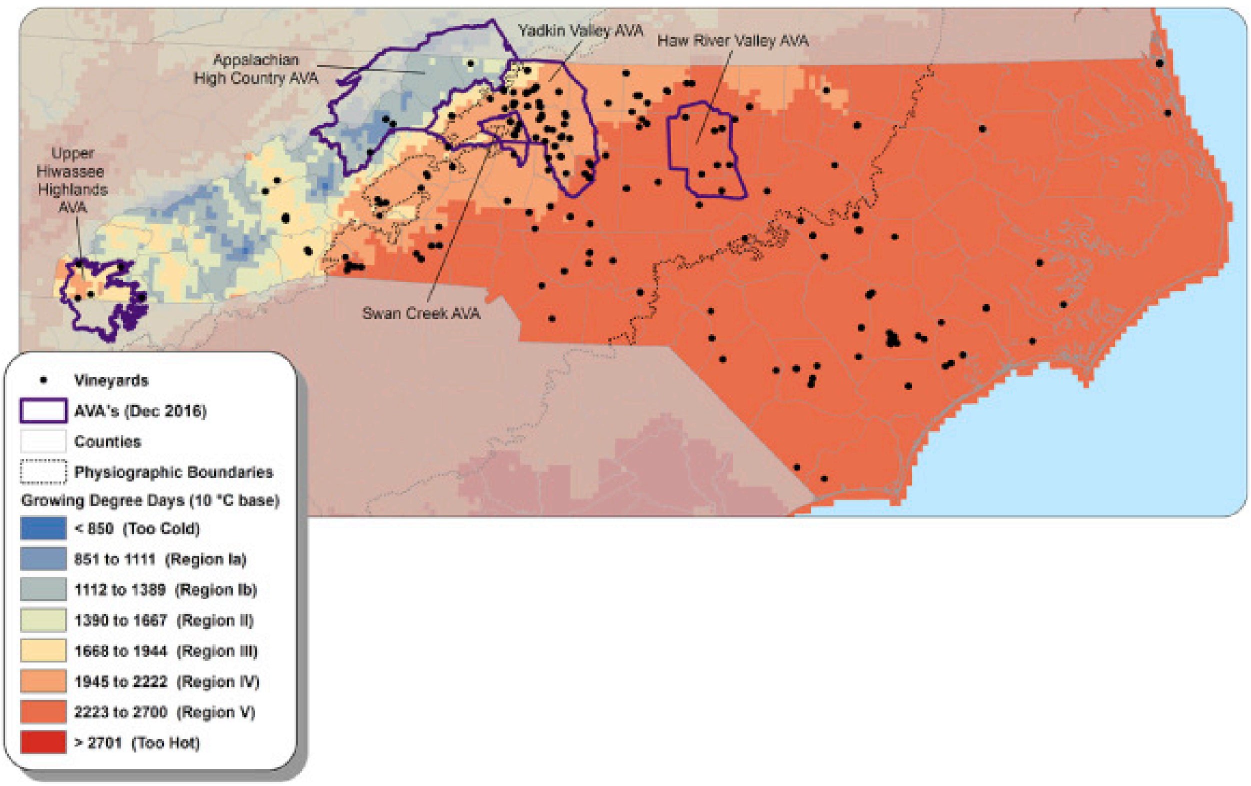

Figure 4. Mean growing degree-days in North Carolina (1981–2014) using Amerine and Winkler 1944

As for the MJT results, the pattern is very similar to that of GDD with a clear northwest to southeast pattern of increasing temperatures (Fig. 5). The extra classes in this modified Smart and Dry MJT index reveal the distribution of warm temperatures in the eastern portion of the state. The impact of humidity on MJT becomes apparent. North Carolina's relatively high humidity climate results in warmer night temperatures. This increases the mean diurnal temperatures far higher than in growing regions that have a dry summer climate with a higher diurnal temperature range.

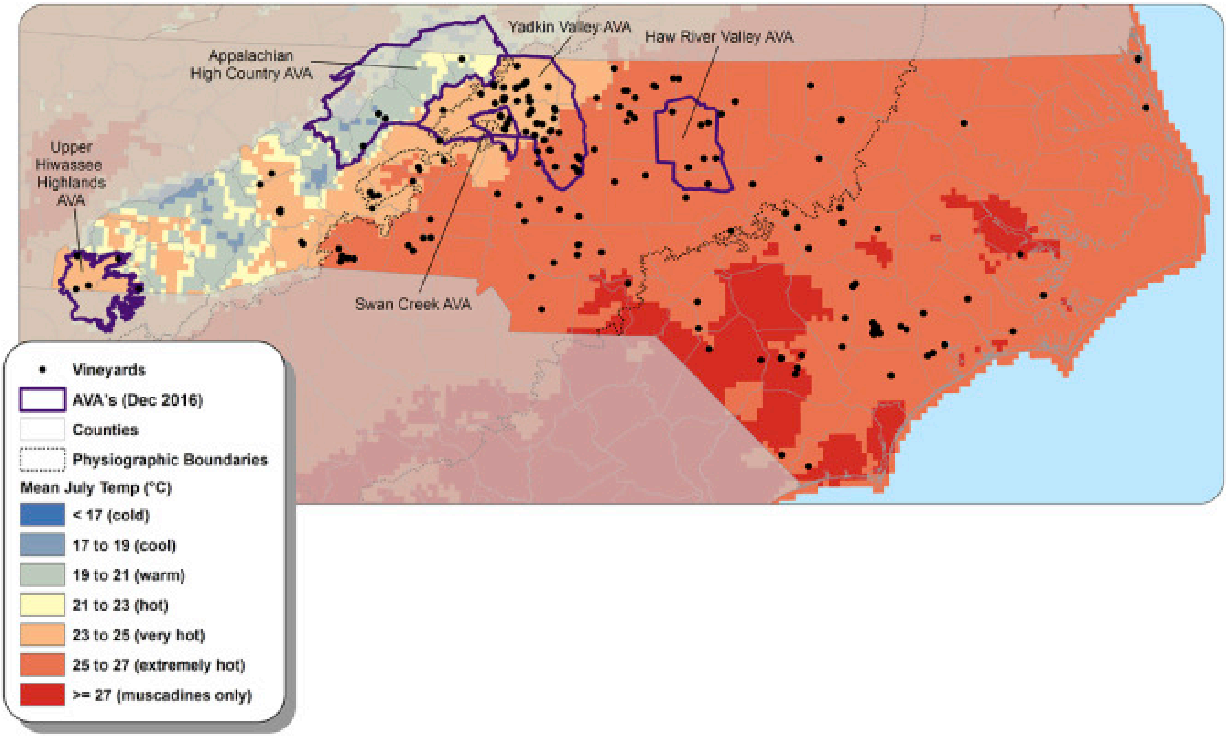

Figure 5. Mean July temperature in North Carolina (1981–2014), adaptation of Smart and Dry (1980).

The pattern of annual continuous frost-free days shows that there is a general northwest to southeast gradient, varying from below 165 days in the highest portions of the Appalachian Mountains to a nearly year-round growing season on the coastal barrier islands of the Outer Banks (Fig. 6). The only AVA with an FFP, which severely limits grape varietal, is the Appalachian High Country.

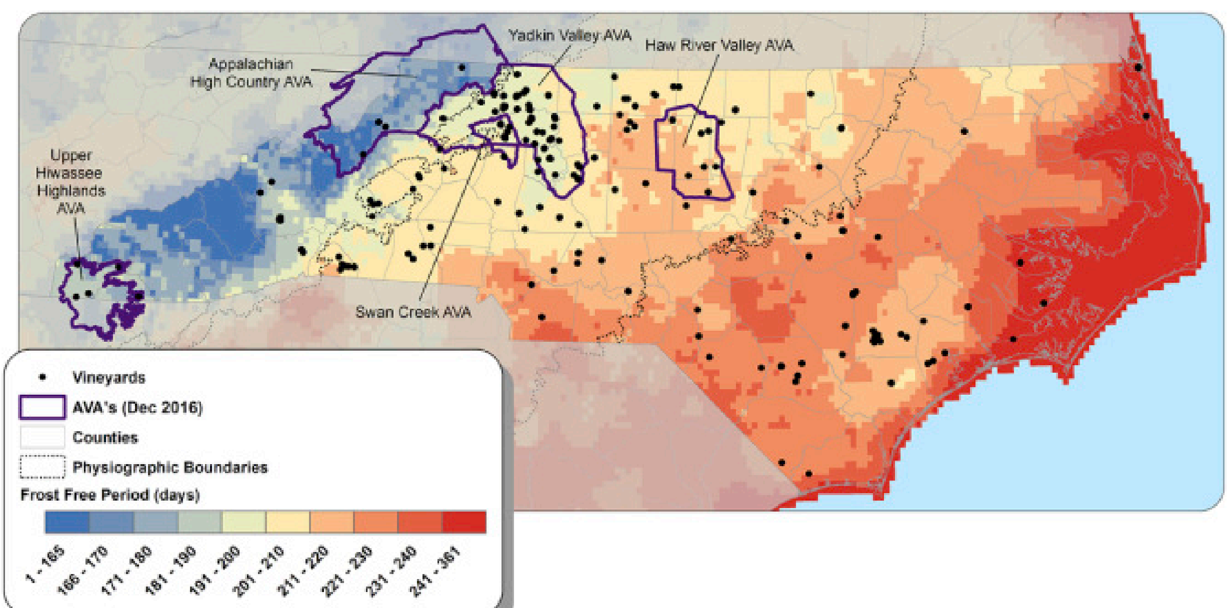

Figure 6. Mean frost free period in North Carolina (1981–2014).

The results of the mean number of ECR days reveals the very few areas of the state that experience significant multi-decadal risk. The vineyards of the Appalachian High Country AVA are the only exceptions. These vineyards are not suitable for *V. vinifera* grape varieties extreme cold areas can kill substantial portions of the vines (Fig. 7).

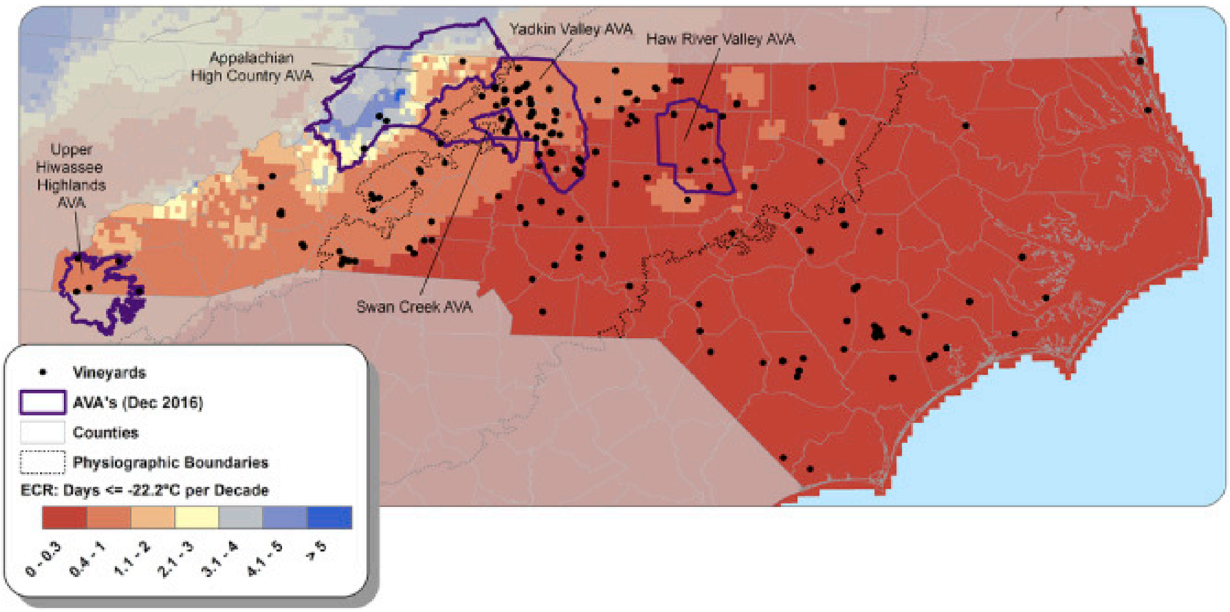

Figure 7. Mean Number of Extreme Cold Risk Days per Decade Below −22.2 °C. in North Carolina (1981–2014) based on Wolf & Boyer, 2003.

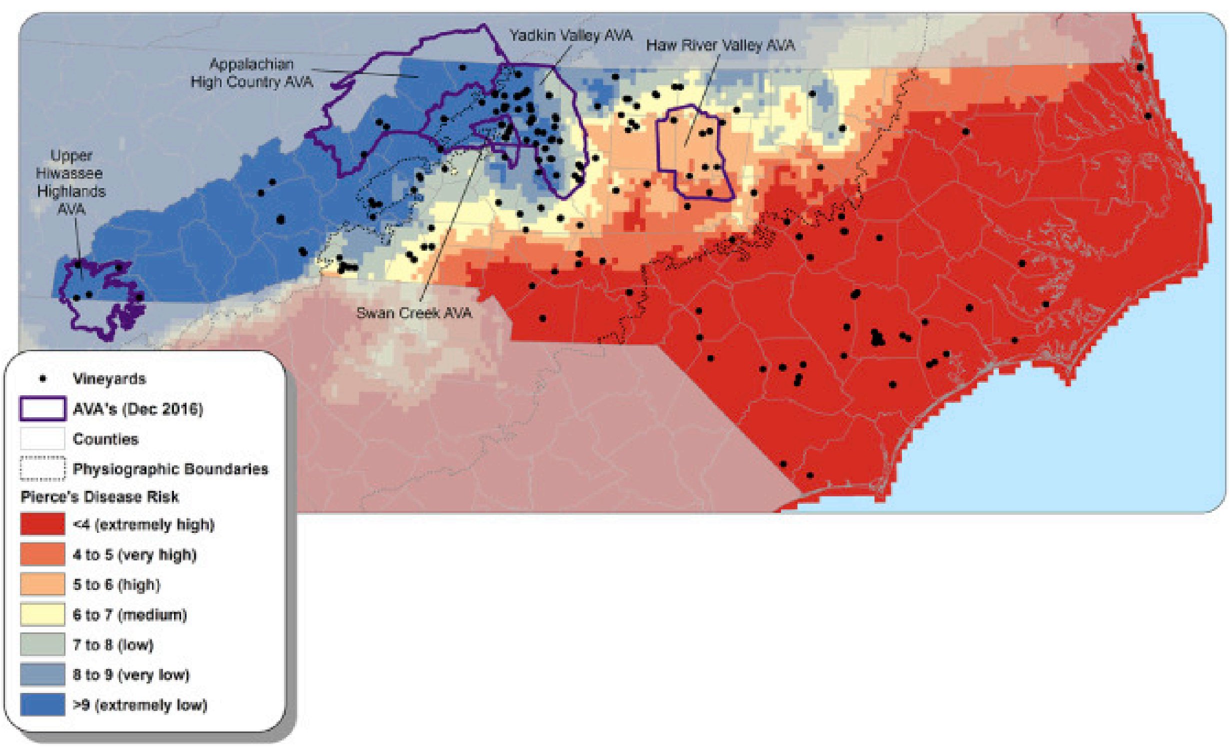

Figure 8. Mean Combined Pierce's Disease Risk Zones in North Carolina. (1981–2014) based on an adaptation of Sutton (2005).

PDR results reveal a familiar pattern with the northwest to southeast climate gradient. This surface layer summarizes and helps visualize the general risk more succinctly than the previous method of using two layers. In this layer, the areas with ≤ four days were failed. A major portion of the vineyards in Central North Carolina are likely to experience PD. All the vineyards in the central and southeastern portion of the state (pink and red areas) are at high risk for PD. This is significant since the vineyards within and around the Haw River Valley AVA are widely planted with *V. vinifera* vines (Fig. 8).

5.2. Topographic results

At the local scale, a discernible pattern begins to emerge. Since it was not practical to show all 160 vineyards on one map, the results are presented for five vineyard maps distributed across the three physiographic provinces of the state (Fig. 9, Fig. 10, Fig. 11). These vineyards represent 25.06% (14,471/57,747 cells) of the total area tested in the study (scale of 1:12000). These vineyards were selected because they are the largest commercial vineyards in their physiographic regions, and they provide great examples of topographic surfaces that vary spatially. The selected locations include Biltmore Vineyards in the mountains, the adjacent Piccione Vineyards and Raffaldini Vineyards, Shelton Vineyards, and Childress Vineyards in the Piedmont, and Cottle Farms on the Coastal Plain. More vineyards are included from the Piedmont because this physiographic region has the greatest density of vineyards. The TPI results show that large vineyards have portions of their boundaries failing in relatively low-lying areas. The core, or central area, of these vineyards are above the valley bottom in mid-slope and/or on relatively elevated yet flat portions of the local terrain (Fig. 9).

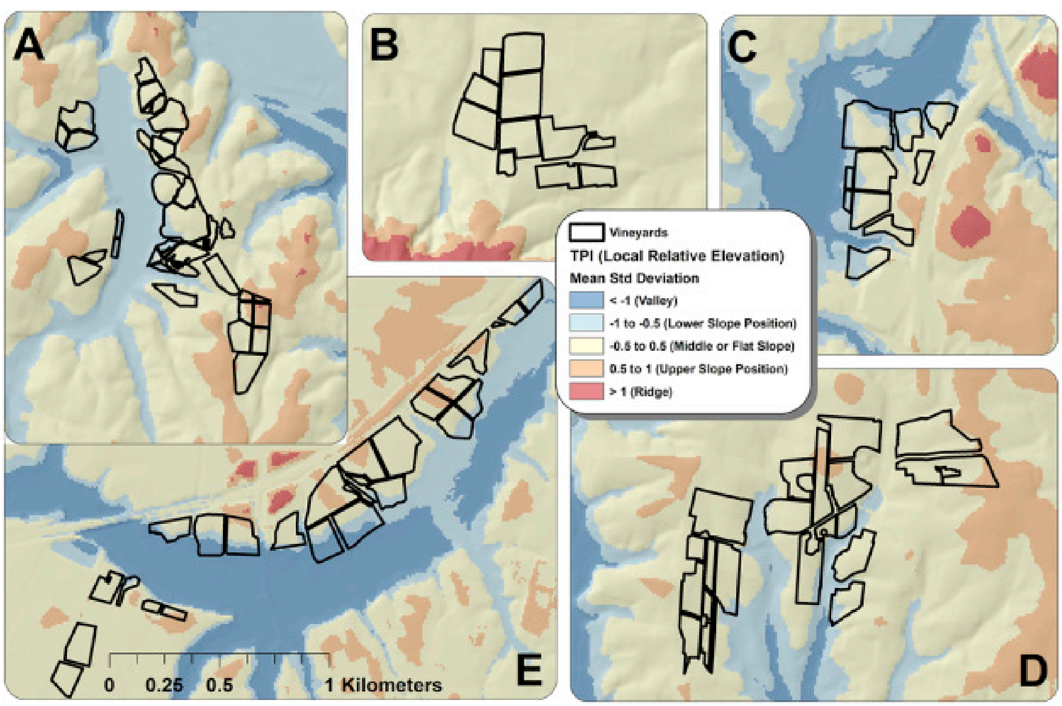

Figure 9. Topographic Position Index, for Cold Air Drainage, Examples of Large Vineyards from: The Mountains (Biltmore A), Upper Piedmont (Piccione and Raffaldini B; Childress C; Shelton D), and Coastal Plain (Cottle E), based on an adaptation of Weiss (2001).

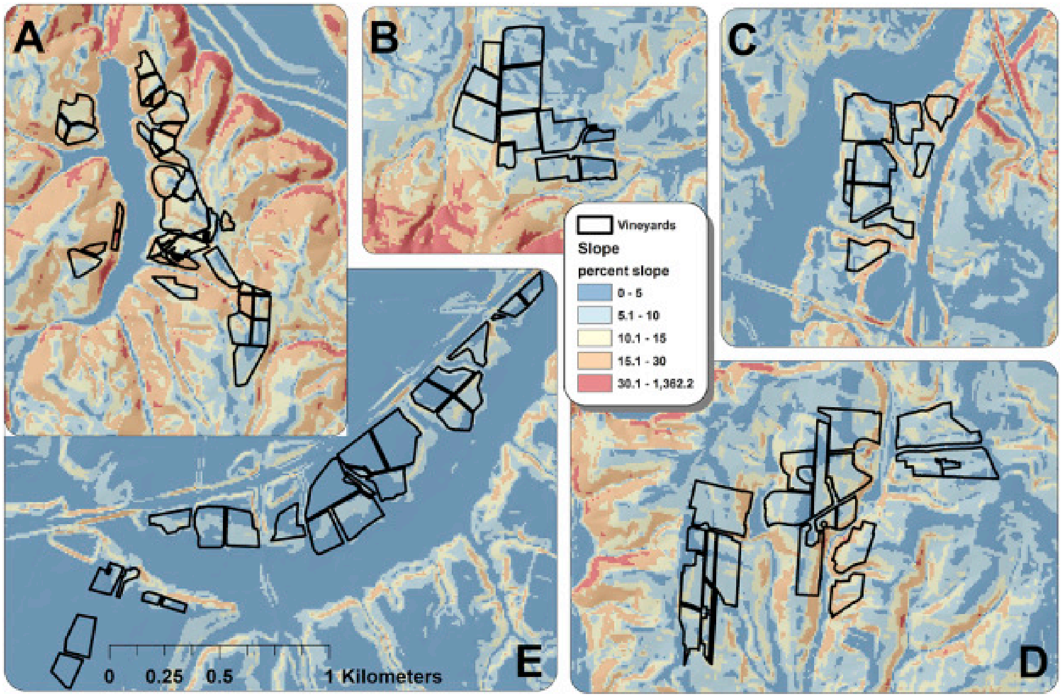

Figure 10. Slope, Examples of Large Vineyards from: The Mountains (Biltmore A), Upper Piedmont (Piccione and Raffaldini B; Childress C; Shelton D), and Coastal Plain (Cottle E).

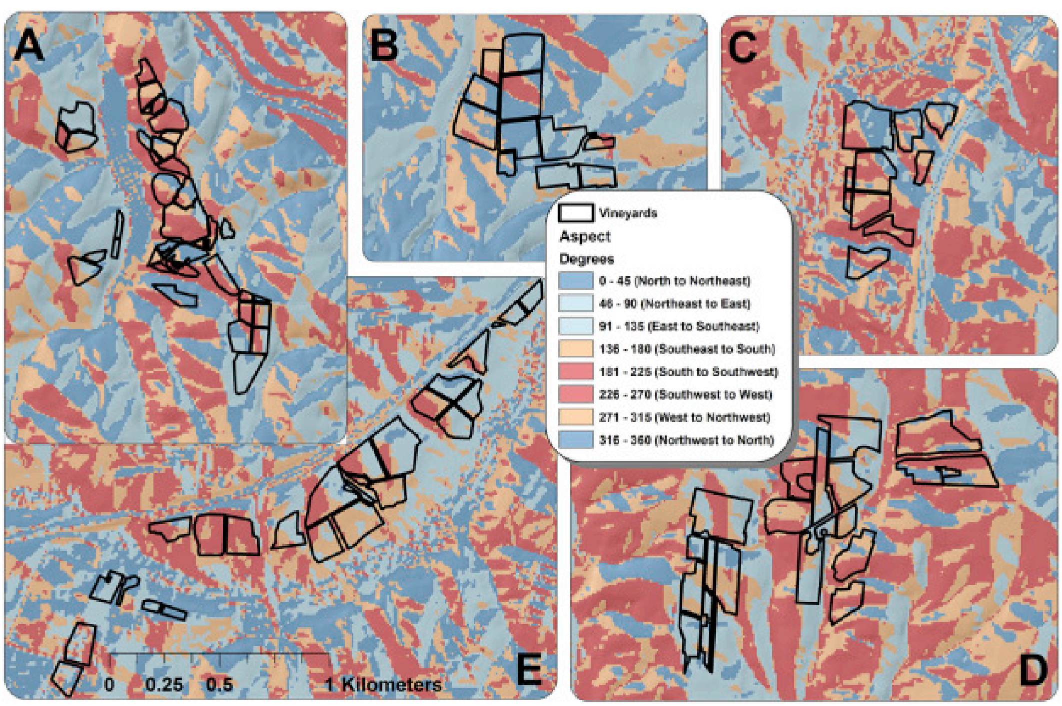

Figure 11. Aspect Classified by Primary Effect, Examples of Large Vineyards from: The Mountains (Biltmore A), Upper Piedmont (Piccione and Raffaldini B; Childress C; Shelton D), and Coastal Plain (Cottle E).

The pattern of slope resulting from the high relief area of the Western Mountains becomes evident when analyzing the Biltmore Vineyards map. There are slopes in this vineyard that surpass the 15% threshold, which likely means that special equipment and/or more manual operations are necessary to maintain the vineyard (Fig. 10).

There is very little discernible pattern to Aspect across the example vineyards. (Fig. 11). Many vineyards show dominant southeast to southwest aspects, however the undulating nature of the majority of the sites shown produce a wide range of aspects across their landscapes.

5.3. Soils results

The aggregation of gSSURGO soil survey data suggests that the depth to restrictive soil layer is deeper than 101 cm (Fig. 12). This is especially true on the Coastal Plain and the Piedmont. The Southern Piedmont, however, consist of large areas with more shallowly restricted root zones. This is visible as a large red splotch in the central portion of the southern border of the state (Fig. 12). This is also the case along the highest elevations and west portions of the Appalachian Escarpment where there are areas of shallow soil. No data was available for Caswell County, north of the Haw River Valley AVA.

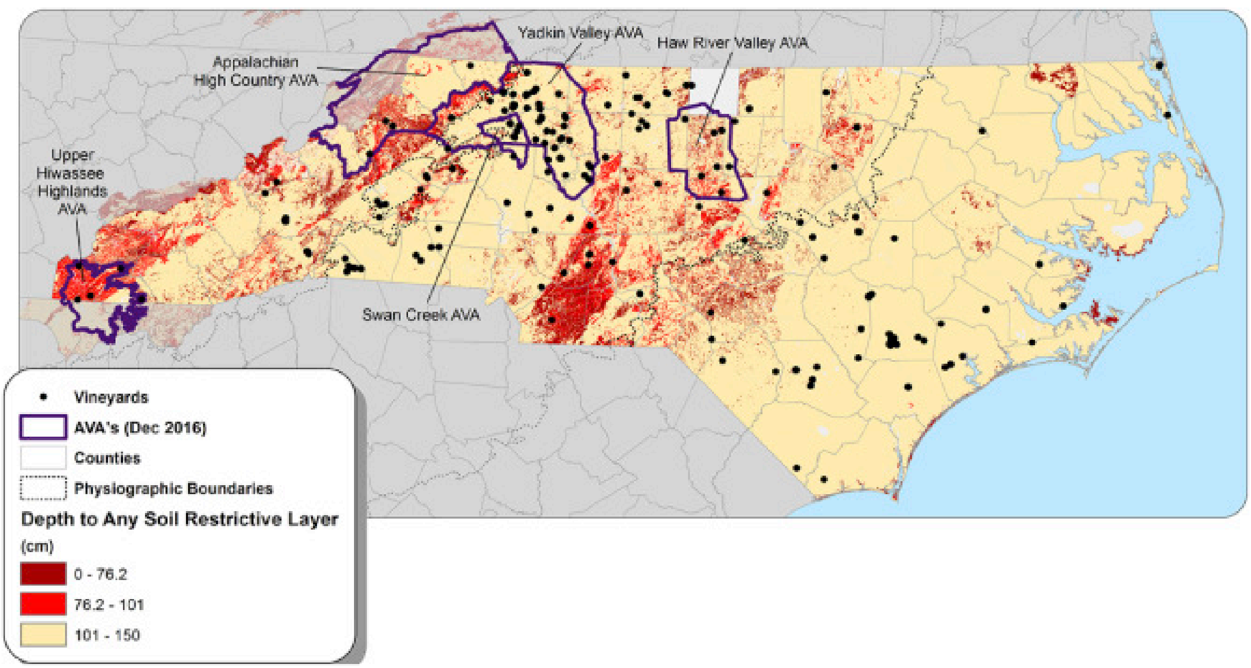

Figure 12. Soil Depth in North Carolina from gSSURGO (current in Dec 2016), Soils in the lower Coastal Plain approaching the Atlantic Ocean tend to suffer from poor drainage (Fig. 13). This zone is too water logged to be optimal for viticulture, while soils in the Piedmont and the Mountains are moderately drained to well drained.

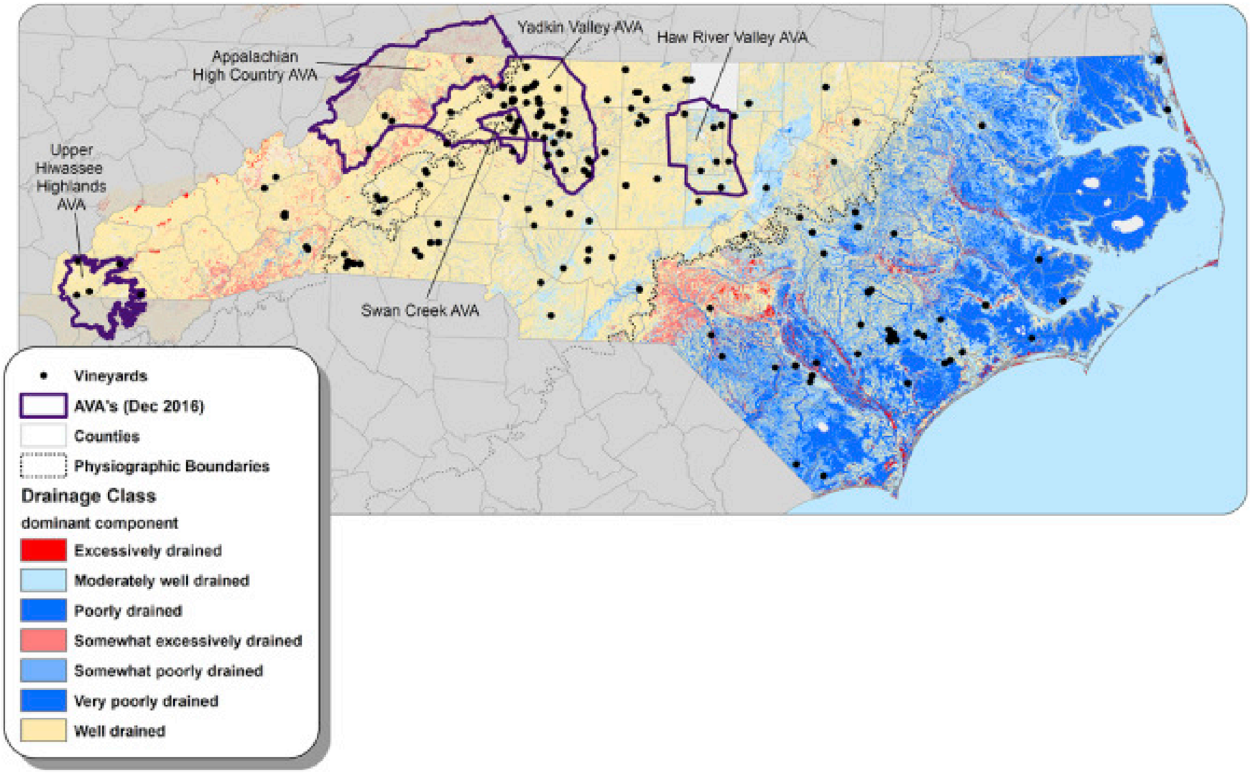

Figure 13. Soil Drainage Class in North Carolina from gSSURGO (current in Dec 2016), Map. Generally, North Carolina's soils are moderately low in silt (Fig. 14). This textual makeup suggests that they are moderately fertile. One contiguous zone of high silt soils extends northeast from the border of South Carolina immediately west of the Coastal Plain.

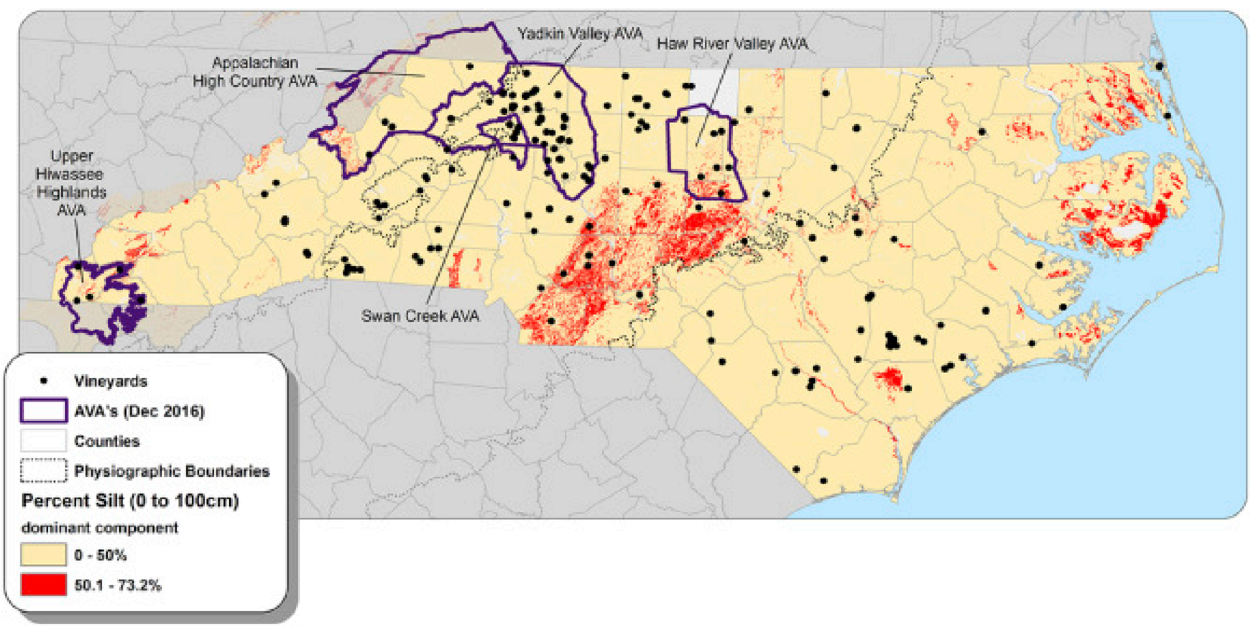

Figure 14. Soil Texture >50% Silt in North Carolina from gSSURGO. (current in Dec 2016).

5.4. Vineyard area results

Because North Carolina is a relatively new area for viticulture research, it was expected that the vineyard site selection failure rate would be high, maybe even above 33%. The resulting rate is much better than expected. In the final model, 82.68% of the area falling within North Carolina vineyards passed the tests across all factors in the final model. The percentage of overall cells failing by any factor was 16.78% (9691/57,747 cells).

While all failing cells are reported for all factors, it was determined that the PDR and aspect failures would not be used in the final capability model. The PDR failing zone was not used because there are PD resistant grape varieties that can be grown in the PDR failing area. Aspect was not used because there was no advice given in the NCWGG to assess the degree of aspect effect. This makes its failure somewhat ambiguous. While it is cited and reported in the NCWGG, it is not clear from the document where slope with respect to aspect begins to matter. Also, because there will be varieties that can prosper on the aspects in the failing range, this surface was ultimately deemed to be unnecessarily restrictive. For these reasons PDR and Aspect are colored gray in the summary results (Table 6). The summary results are reported as raw counts of failing cells and percentages of overall failing area by factor (Table 6).

Table 6. Results (out of 57,747 Cells within Vineyards); Counts and Percentages of Cells Failing by Factor (not used for final model in gray), including: Growing Degree Day (GDD), Mean July Temperature (MJT), Frost Free Period (FFP), Extreme Cold Risk (ECR), Pierces Disease Risk (PDR), Topographic Position Index (TPI), Slope, Aspect, Depth, Drainage, and % Silt.

Climate Factor	**GDD**	**MJT**	**FFP**	**ECR**	**PDR**
# Failing Cells	0	1955	0	153	19999
% Failing	0.00%	3.39%	0.00%	0.26%	34.63%

Topography Factor	**TPI**	**Slope**	**Aspect**
# Failing Cells	441	3608	17485
% Failing	0.76%	6.24%	30.28%

Soil Factor	**Depth**	**Drainage**	**% Silt**
# Failing Cells	616	2900	998
% Failing	1.07%	5.02%	1.73%

The number of failing factors by failing cells are reported by the number of cells failing by one, two, or three factors (Table 7). Since 90.94% (8813/9691) of cells failed by only one factor, it is likely that there is a single flaw being highlighted by most failing cells using this model.

Table 7. Number of failing cells within vineyards by count of failing factors.

Number of failing cells	**Number of failing factors**
8813	1
776	2
102	3
0	>3

The pattern of failure for large vineyards is shown in Fig. 15. These cells failed at least one of the pass/fail tests across all layers. Pass/fail statistics for all vineyards are reported in Appendix A. Additional supporting vineyard suitability information such as the dominant soil series, physical province, and the means of other metrics is reported in Appendix B.

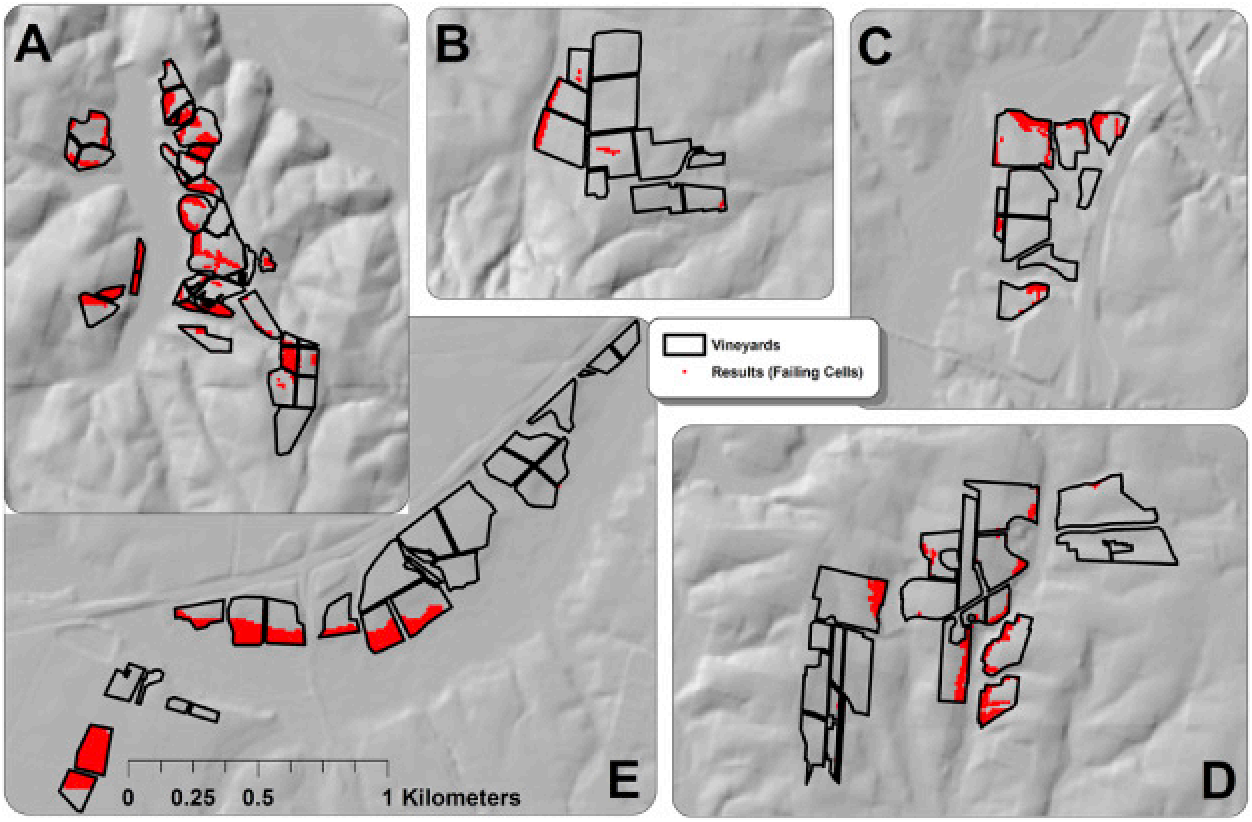

Figure 15. Failing Cells Examples of Large Vineyards from: The Mountains (Biltmore A), Upper Piedmont (Piccione and Raffaldini B; Childress C; Shelton D), and Coastal Plain (Cottle E).

6. Conclusions & discussion

The objective of this study was to determine if North Carolina vineyards had followed the advice given by the CES through the NCWGG. The results reveal that, for the most part, North Carolina's vineyard operators are following the guidelines offered by the NCWGG. More than 83% of the area in the state's vineyards passed all model tests. Furthermore, only about 1.5% of the area occupied by existing vineyards failed by more than one factor. Based on the Pierce's Disease risk pattern revealed in this research, North Carolina's northern border with Virginia and the western portions of Piedmont in the foothills of the mountains are areas where *V. vinifera* grape varieties are most suitable. These zones might be appropriate locations for establishing future AVA's. The Haw River Valley AVA, however, was determined to be a high-risk area for PD.

The methods used to classify risks associated with cold air drainage (TPI) and Pierce's Disease (PDR) surfaces make important contributions to vineyard site capability/suitability analyses. A vineyard's topographic position relative to its surrounding landscape is very important, especially since localized cold air drainage patterns significantly impact grape growing. No other research has incorporated this methodology into vineyard site suitability analysis. Moreover, Pierce's Disease, at least in the Southeast, is especially problematic to grape growers and represents an important factor when locating vineyards. No other study has incorporated the impacts of

Pierce's Disease risk into models. Climate change has undoubtedly influenced portions of the Southeastern U.S. where higher winter minimum temperatures have been observed over time. Since the PD risk zones are defined by winter minimum temperatures, it is expected that these risk zones will move both up-slope to higher elevations and poleward into higher latitudes. In addition, the method used to construct disease indexes from PRISM daily data opens up the opportunity for further explorations in other areas of research such as epidemiology.

A limitation of this research relates to the polygons boundaries of the vineyards. The boundaries were created by using the best available sources of data for vineyards in North Carolina. It is quite possible that some vineyard blocks not adjacent to known locations of the commercial vineyards were omitted. Interviewing all operators of commercial vineyards to identify all tracts of land dedicated to vineyards could alleviate this shortcoming. Another limitation of this research is temporal. Vineyard sites that were established in the distant past and are still in operation will certainly pass at a higher rate than more newly established vineyards. Vineyards will most likely fail if they are located on poor sites. Over time, the pattern of failure and success of vineyards has the potential to cycle through a self-organizing process. This presents a challenge that is difficult to untangle with the methods used in this research. The industry in North Carolina is young with a number of new vineyards. The results of this research are thus limited to revealing problems with existing vineyards and making present and future choices about where to locate a vineyard.

The results of this research should be applicable to vineyards in other states but certainty about its transferability remains unknown. There is a dearth of research on topics related to guidance and practice, especially within the context of viticulture. The approach outlined in this research should provide impetus for future research that examines the important relationship between guidance and farming.

Appendix A. Vineyard site selection assessment, failing cells.

Vineyard	#Cells	PDR	Aspect	GDD	MJT	FFP	ECR	TPI	Slope	Depth	Drain.	Pct. Silt
A Secret Garden Winery	31	31	9	0	0	0	0	0	0	0	8	0
Adagio Vineyards	165	0	0	0	0	0	0	0	4	0	0	0
Adams Vineyards and Winery	363	363	147	0	0	0	0	0	0	0	13	0
Addison Farms Vineyard	128	0	32	0	0	0	0	0	71	0	0	0
Allison Oaks Vineyards	187	0	105	0	0	0	0	0	0	0	5	0
Autumn Creek Vineyards	206	0	107	0	0	0	0	0	9	0	0	0
Backroad Farm and Vineyard	46	0	0	0	0	0	0	0	0	0	0	0
Baker Buffalo Creek Vineyard & Winery	236	0	200	0	0	0	0	0	0	0	0	0
Banner Elk Winery	32	0	25	0	0	0	32	0	14	0	0	0
Bannerman Vineyard and Winery	577	577	110	0	0	0	0	1	0	0	117	0
Beaverdam Vineyards	120	0	89	0	0	0	0	0	33	0	0	0
Belle Nicho Winery	12	0	12	0	0	0	0	0	0	0	0	0
Belsogno Vineyard @ Fiore Farms	112	0	50	0	0	0	0	0	0	0	0	0
Benjamin Vineyards & Winery	180	0	30	0	0	0	0	0	0	0	0	0
Bennett Vineyards	1005	1005	358	0	0	0	0	1	0	0	554	0
Benny Parsons Rendezvous Ridge	166	0	117	0	0	0	0	0	161	0	0	0
Biltmore Winery and Vineyards	2718	0	998	0	0	0	0	0	737	0	0	0
Botticelli Vineyards	214	214	40	0	0	0	0	0	0	0	0	0
Boulder Vineyard	85	0	4	0	0	0	0	0	0	0	0	0
Brandon Hills Vineyard	125	0	23	0	0	0	0	0	1	0	0	0

Vineyard	#Cells	PDR	Aspect	GDD	MJT	FFP	ECR	TPI	Slope	Depth	Drain.	Pct. Silt
Burntshirt Vineyards	723	0	107	0	0	0	0	0	0	0	36	0
Calaboose Cellars	4	0	0	0	0	0	0	0	1	0	0	0
Cape Fear Vineyard and Winery	121	121	0	0	0	0	0	0	0	0	0	0
Carolina Heritage Vineyard & Winery	257	0	63	0	0	0	0	0	112	0	0	0
Cauble Creek Vineyard	275	0	263	0	0	0	0	0	0	0	0	0
Cellar 4201	172	0	58	0	0	0	0	0	16	0	0	0
Cerminaro Vineyard	149	0	73	0	0	0	0	0	50	0	0	0
Charts Hill V	160	0	8	0	0	0	0	0	24	0	0	0
Chateau Laurinda Vineyards	35	0	29	0	0	0	0	0	18	0	0	0
Chestnut Trail Vineyard	34	0	33	0	0	0	0	0	10	0	0	0
Childress Vineyards	1671	0	606	0	0	0	0	56	150	0	55	0
Chinqua Penn	107	0	65	0	0	0	0	0	0	0	0	0
Cloer Family Vineyards	52	0	8	0	0	0	0	0	0	0	2	0
Cottle Farms	3837	3837	962	0	0	0	0	340	0	0	526	0
Crooked Run Vineyards	604	604	0	0	0	0	0	0	0	0	0	0
CrossIn Back Vineyards	26	0	0	0	0	0	0	0	0	0	0	26
Cypress Bend Vineyards	310	310	73	0	0	0	0	0	0	0	0	0
Davesté Vineyards	141	0	19	0	0	0	0	0	1	0	0	0
DD Farms and Vineyard	11	11	11	0	0	0	0	0	0	0	0	0
Deerpath Farm	76	76	30	0	0	0	0	0	0	0	0	0
Demariano Vineyards	33	0	0	0	0	0	0	0	2	0	0	0
Dennis Vineyards & Winery	257	41	10	0	0	0	0	0	0	0	0	191
Divine Llama Vineyards	147	0	73	0	0	0	0	0	0	55	0	0
Dobbins Creek Vineyards	215	0	52	0	0	0	0	0	74	0	0	0
Douglas Vineyards	19	0	6	0	0	0	0	0	0	0	0	0
Eagle Fork Vineyards	36	0	10	0	0	0	0	0	0	0	5	0
Elkin Creek Vineyard	169	0	32	0	0	0	0	0	120	0	0	0
Enoch Winery & Vineyard	178	178	17	0	0	0	0	0	0	0	2	0
Fiddler's Vineyard	61	0	15	0	0	0	0	0	0	0	0	0
Flint Hill Vineyards	176	0	32	0	0	0	0	0	0	0	0	0
Foster Vineyards	1642	0	673	0	0	0	0	0	17	0	18	0
Fussy Gourmet Farms, LLC	4	4	4	0	0	0	0	0	0	0	0	0
Garden Gate Vineyards	21	0	10	0	0	0	0	0	0	0	0	0
Ginger Creek Vineyards	13	0	5	0	0	0	0	0	0	0	0	0
GlenMarie Vineyards & Winery	47	0	16	0	0	0	0	0	0	4	0	0
Golden Road Vineyards	191	0	53	0	0	0	0	0	59	0	0	0
Grandfather Vineyard & Winery	116	0	0	0	0	0	116	0	112	69	0	0
Grapefull Sisters Vineyard	75	75	8	0	0	0	0	0	0	0	24	0
Grassy Creek Vineyard & Winery	750	0	435	0	0	0	0	0	10	0	0	0
Green Creek Winery	277	0	137	0	0	0	0	0	0	0	0	0
Green River Vineyard	175	0	48	0	0	0	0	0	91	0	0	0
Gregory Vineyards	248	248	25	0	0	0	0	0	0	0	0	0
Grietje's Garden of Rocky Ridge Farm	77	0	0	0	0	0	0	0	0	0	0	0
Griffin Evergreens & Vineyard	55	55	10	0	0	0	0	0	0	0	0	0
Grove Winery & Vineyards	214	0	27	0	0	0	0	0	0	0	0	0
Hanover Park Vineyard	317	0	131	0	0	0	0	0	0	0	0	0
Herrera Vineyards	440	0	160	0	0	0	0	0	14	0	0	0
Hinnant Family Vineyards & Winery	2404	2404	740	0	0	0	0	23	0	65	148	0
Horizon Cellars	102	0	63	0	0	0	0	0	0	0	0	92
Huffman Vineyards Winery …	34	34	1	0	0	0	0	0	0	0	30	0
Hutton Vineyards	1299	0	446	0	0	0	0	0	2	0	0	0
Iron Gate Vineyards & Winery	281	0	33	0	0	0	0	0	0	0	0	0
Jewel of the Blue Ridge Vineyard	19	0	7	0	0	0	0	0	13	19	0	0
JOLO Winery & Vineyards	329	0	107	0	0	0	0	0	73	0	0	0
Jones Vineyards & Winery	1174	0	854	0	0	0	0	0	204	0	0	0

Vineyard	#Cells	PDR	Aspect	GDD	MJT	FFP	ECR	TPI	Slope	Depth	Drain.	Pct. Silt
Jones von Drehle Vineyards & Winery	1	0	1	0	0	0	0	0	0	0	0	0
Junius Lindsay Vineyard	387	0	136	0	0	0	0	0	1	0	0	0
Lake Road Winery	4	4	0	0	0	0	0	0	0	0	3	0
Laurel Gray Vineyards & Winery	406	0	255	0	0	0	0	0	0	0	0	0
Lazy Elm Vineyard and Winery	219	0	20	0	0	0	0	0	0	0	0	0
Linville Falls Winery	71	0	46	0	0	0	0	0	62	0	0	0
Little River Vineyards and Winery	790	782	249	0	0	0	0	0	1	0	0	0
Locklear Vineyard & Winery	191	191	6	0	191	0	0	0	0	0	1	0
Lu Mil Vineyard	1557	1557	533	0	1402	0	0	0	0	0	130	0
Martin Vineyard & Orchard	219	219	88	0	0	0	0	0	0	0	10	0
Maxwell Creek Vineyard	549	549	324	0	0	0	0	0	0	0	53	0
McDuffie Family Farm	350	350	57	0	350	0	0	0	0	0	2	0
McRitchie Winery	98	0	59	0	0	0	0	0	59	0	0	0
Medaloni Cellars	38	0	24	0	0	0	0	0	24	28	0	0
MenaRick Vineyard & Winery	303	0	0	0	0	0	0	0	27	0	0	0
Mill Branch Vineyards	135	135	83	0	0	0	0	0	0	0	0	0
Misty Creek Vineyards	552	0	294	0	0	0	0	0	28	0	0	0
Moonrise Bay Vineyard	392	392	63	0	0	0	0	0	0	0	0	0
Morgan Ridge Vineyards	266	0	0	0	0	0	0	0	1	0	0	0
Mountain Brook Vineyards	277	0	66	0	0	0	0	0	28	0	0	0
Myrick Vineyards, LLC	180	180	13	0	0	0	0	0	0	0	0	63
Native Son Vineyard and Farm	115	0	0	0	0	0	0	0	3	0	0	0
Native Vines Winery	22	0	4	0	0	0	0	0	0	0	0	0
Neuse River Winery	117	117	32	0	0	0	0	0	0	0	110	0
Nottely River Valley Vineyards	193	0	47	0	0	0	0	0	0	0	0	0
Old Stone Winery	352	0	44	0	0	0	0	0	0	0	0	0
Overmountain Vineyards	253	0	96	0	0	0	0	0	45	0	0	0
Owl's Eye Vineyard & Winery	406	0	153	0	0	0	0	0	33	0	0	0
Parker-Binns Vineyard	150	0	87	0	0	0	0	0	14	0	0	0
Patria Properties	48	0	13	0	0	0	0	0	7	0	0	0
Pennini Vineyards	92	0	9	0	0	0	0	0	2	18	0	0
Piccione Vineyards	589	0	57	0	0	0	0	0	7	0	64	0
Plott Hound Vineyard	8	0	8	0	0	0	0	0	0	0	0	0
Raffaldini Vineyards & Winery	1666	0	162	0	0	0	0	0	17	0	0	0
RagApple Lassie Vineyards	1014	0	190	0	0	0	0	0	12	0	0	0
RayLen Vineyards & Winery	1512	0	640	0	0	0	0	0	25	0	0	0
Rinaldi Estate Vineyard	240	0	15	0	0	0	0	0	46	0	0	0
Riverbirch Vineyard	162	0	36	0	0	0	0	0	0	0	0	0
Roaring River Vineyards	76	0	33	0	0	0	0	0	69	0	0	0
Rock of Ages Winery & Vineyard	1011	0	85	0	0	0	0	0	0	0	0	0
Rockhouse Vineyards	314	0	84	0	0	0	0	0	4	0	0	0
Rocky River Vineyards	266	266	111	0	0	0	0	0	6	244	0	266
Round Peak Vineyards	529	0	144	0	0	0	0	0	78	0	0	0
Saint Paul Mountain Vineyards	114	0	66	0	0	0	0	0	0	0	0	0
Sanctuary Vineyards	136	136	11	0	0	0	0	0	0	0	51	0
Sanders Ridge Vineyard & Winery	559	0	301	0	0	0	0	0	10	0	0	0
Shadow Springs Vineyard	417	0	15	0	0	0	0	0	0	0	4	0
Shelton Vineyards	4579	0	1358	0	0	0	0	0	380	0	0	0
SilkHope Winery	58	0	0	0	0	0	0	0	0	0	0	0
Silver Coast Winery	11	11	0	0	0	0	0	0	0	0	0	0
Silver Fork Vineyard & Winery	116	0	3	0	0	0	0	0	63	0	0	0
Six Waterpots Vineyard & Winery	32	0	0	0	0	0	0	0	0	0	0	0
South Creek Vineyards & Winery	50	0	0	0	0	0	0	0	21	0	26	0
Stephens Vineyard & Winery	7	7	2	0	7	0	0	0	0	0	7	0
Stonefield Cellars Winery	61	0	0	0	0	0	0	0	0	0	0	0

Vineyard	#Cells	PDR	Aspect	GDD	MJT	FFP	ECR	TPI	Slope	Depth	Drain.	Pct. Silt
Stony Knoll Vineyards	205	0	108	0	0	0	0	0	7	0	0	0
Stony Mountain Vineyards	112	0	0	0	0	0	0	0	110	0	0	0
Storr's Vineyard	109	0	31	0	0	0	0	0	0	109	0	0
Surry County Community College Vineyard & Winery	290	0	151	0	0	0	0	0	0	0	0	0
Sweet Home Carolina Vineyard & Winery	11	0	0	0	0	0	0	0	10	0	0	0
The Tipsy Bee	35	35	1	0	0	0	0	0	0	0	31	0
Treehouse Vineyards	132	132	68	0	0	0	0	0	1	1	0	131
Triple B Vineyard	75	0	41	0	0	0	0	0	0	0	0	0
Twisted Vine Winery	10	0	10	0	0	0	0	0	0	0	0	0
Unknown Maple Hill Vineyard	259	259	65	0	0	0	0	0	0	0	232	0
Unknown Rose Hill Vineyard	2967	2967	843	0	0	0	0	0	0	0	611	0
Unknown Vineyard	229	63	69	0	5	0	5	2	41	4	8	5
Unknown Vineyard close to Lake Brandt	19	0	0	0	0	0	0	0	0	0	0	0
Unknown Vineyard off Pleasant Ridge Rd	26	0	0	0	0	0	0	0	0	0	0	0
Upper Piedmont Research Station	72	0	55	0	0	0	0	0	0	0	0	0
Uwharrie Vineyards	516	0	8	0	0	0	0	0	0	0	0	67
Valley River Vineyards	67	0	1	0	0	0	0	0	0	0	7	0
Ventosa Plantation Vineyard & Winery	659	659	352	0	0	0	0	0	0	0	0	0
Waldensian Heritage Wines	9	0	8	0	0	0	0	0	0	0	0	0
Warren Farms Vineyard	700	700	79	0	0	0	0	0	0	0	7	0
Weathervane Winery	71	0	46	0	0	0	0	0	0	0	0	0
Westbend Vineyards	715	0	181	0	0	0	0	0	40	0	0	0
White Rock Vineyard	3	0	1	0	0	0	0	0	0	0	0	0
Willis Dixon Vineyard	100	100	30	0	0	0	0	0	0	0	0	0
Windsor Run Cellars	265	0	24	0	0	0	0	0	0	0	0	0
Wolfe Wines	20	0	5	0	0	0	0	0	0	0	0	20
WoodMill Winery	346	0	0	0	0	0	0	0	0	0	0	0
Younts Wine Farm	211	0	81	0	0	0	0	0	24	0	0	0
Zimmerman Vineyards	186	0	0	0	0	0	0	18	99	0	0	137
Grand Total	**57747**	**19999**	**17485**	**0**	**1955**	**0**	**153**	**441**	**3608**	**616**	**2900**	**998**

Vineyard Name: boundaries were created by the author from geolocating public lists of NC commercial vineyards and creating polygons using aerial imagery from publicly available sources (NC Wine, 2017).
10m cells falling in each area: generated using ESRI ArcMap 10.4.1.
[Topographic] Aspect, TPI, Slope: generated ESRI ArcMap 10.4.1, & the most recently available NED DEM (10 m) in July 2015.
[Soil] Depth, Drainage, %Silt: generated for each area using ESRI ArcMap 10.4.1 & gSSURGO (10 m).
GDD, PDR, MJT, FFP, ECR: generated for each area using ESRI ArcMap 10.4.1, & derived from PRISIM maximum & minimum temperature (originally 4 km sampled at 10 m), daily data between 1981 and 2014.

Appendix B. Mean terroir analysis results by appellation and Vineyard.

No.	Appellation		Area (sq. km)	elev (m)	Phys Prov	ECR	PDR	PPT	FFP	GDD	GST	HI	BEDD
1	Yadkin Valley		5788.03	353.2	Pied.	0.28	10.1	1184	198	2037	19.5	2540	1461
2	Haw River		2478.80	187.6	Pied.	0.01	5.4	1145	213	2305	20.8	2785	1586
3	Swan Creek		593.29	294.3	Pied.	0.33	8.5	1166	202	2118	19.9	2596	1464
4	Upper Hiwassee Highlands		1786.96	602.6	Mts.	0.53	14.4	1468	181	1816	18.5	2342	1382
5	Buncombe		1708.71	818.0	Mts.	1.05	17.1	1132	181	1591	17.4	2122	1274
6	Yadkin		874.09	290.4	Pied.	0.33	9.2	1162	199	2078	19.7	2601	1469
7	Duplin		2122.42	28.9	Cst.	0.00	2.3	1281	219	2523	21.8	2938	1718
	Vineyard Name	**Soil Series-Txt-Dominant %**	**Area (ha)**										
8	A Secret Garden Winery	Norfolk loamy sand 71.9%	0.31	39.8	Cst.	0.00	2.3	1190	226	2521	21.8	2946	1714
9	Adagio Vineyards	Fairview sandy clay loam 92.6%	1.65	370.4	Pied.	0.33	10.9	1204	196	2018	19.4	2534	1424

10	Adams Vineyards & Winery	Norfolk loamy sand 95.9%	3.69	103.1	Cst.	0.00	3.8	1179	218	2402	21.2	2855	1620
11	Addison Farms Vineyard	Clifton clay loam 100%	1.29	683.8	Mts.	1.00	16.5	1010	176	1689	17.9	2282	1282
12	Allison Oaks Vineyards	Clifford sandy clay loam 96.9%	1.87	274.4	Pied.	0.33	10.1	1141	197	2083	19.7	2600	1477
13	Autumn Creek Vineyards	Poplar Forest sandy clay loam 95.8%	2.11	291.0	Pied.	0.33	8.5	1172	200	2113	19.9	2638	1482
14	Backroad Farm & Vineyard	Cecil sandy clay loam 100%	0.46	145.3	Pied.	0.00	8.0	1118	202	2215	20.4	2730	1521
15	Baker Buffalo Creek Vineyard & Winery	Pacolet sandy clay loam 70.6%	2.40	272.9	Pied.	0.00	6.7	1192	205	2262	20.6	2746	1554
16	Banner Elk Winery	Porters gravelly loam 54.8%	0.32	1234.7	Mts.	4.33	34.5	1409	169	1045	14.6	1504	500
17	Bannerman Vineyard & Winery	Onslow loamy fine sand 79.4%	5.87	6.0	Cst.	0.00	2.4	1379	215	2570	22.0	2972	1762
18	Beaverdam Vineyards	Thurmont-Dillard complex 53.2%	1.20	540.6	Mts.	0.67	16.2	1728	179	1824	18.5	2404	1373
19	Belle Nicho Winery	Hayesville clay loam 100%	0.12	363.6	Pied.	0.33	10.4	1262	198	2092	19.8	2638	1497
20	Benjamin Vineyards & Winery	Appling coarse sandy loam 76.6%	1.82	155.8	Pied.	0.00	5.4	1134	213	2318	20.8	2797	1576
21	Bennett Vineyards	Lynchburg fine sandy loam 41.7%	10.25	9.2	Cst.	0.00	1.1	1307	248	2660	22.4	2966	1998
22	Biltmore Winewery & Vineyards	Evard-Cowee complex 73.8%	27.84	636.2	Mts.	0.67	13.7	1068	183	1761	18.2	2302	1331
23	Botticelli Vineyards	Goldsboro-Urban land complex 82.0%	2.18	5.1	Cst.	0.00	1.8	1411	228	2581	22.1	2924	1865
24	Brandon Hills Vineyard	Nathalie fine sandy loam 47.3%	1.27	271.6	Pied.	0.33	9.1	1149	199	2095	19.8	2620	1481
25	Burntshirt Vineyards	Bradson gravelly loam 43.3%	7.36	672.5	Mts.	0.67	11.1	1396	195	1810	18.5	2325	1401
26	Calaboose Cellars	Lonon-Northcove-Urban land complex 100%	0.04	557.1	Mts.	0.67	15.3	1619	181	1840	18.6	2174	1397
27	Cape Fear Vineyard & Winery	Wakulla sand 95.9%	1.22	35.9	Cst.	0.00	1.6	1231	225	2613	22.2	3012	1784
28	Carolina Heritage Vineyard & Winery	Fairview sandy clay loam 100%	2.60	295.1	Pied.	0.33	9.6	1182	196	2045	19.6	2610	1464
29	Cauble Creek Vineyard	Lloyd clay loam 97.2%	2.80	242.1	Pied.	0.00	7.3	1079	200	2212	20.3	2700	1561
30	Cellar 4201	Tomlin sandy clay loam 65.9%	1.70	283.4	Pied.	0.33	8.5	1136	200	2124	19.9	2629	1482
31	Charts Hill V	Poindexter-Wynott complex 70.9%	1.61	254.2	Pied.	0.00	6.6	1114	206	2225	20.4	2699	1583
32	Chestnut Trail Vineyard	Pacolet sandy clay loam 100%	0.33	238.9	Pied.	0.00	9.4	1109	194	2193	20.2	2726	1549
33	Childress Vineyards	Pacolet sandy loam 53.1%	17.13	220.5	Pied.	0.00	6.7	1105	204	2279	20.6	2748	1540
34	Cloer Family Vineyards	White Store sandy loam 79.2%	0.50	97.2	Pied.	0.00	5.3	1160	217	2351	21.0	2815	1613
35	Cottle Farms	Norfolk loamy sand 39.4%	39.18	43.6	Cst.	0.00	2.1	1222	222	2523	21.8	2939	1691
36	Crooked Run Vineyards	Autryville loamy sand 100%	6.14	33.4	Cst.	0.00	1.9	1230	222	2559	22.0	2963	1715
37	CrossIn Back Vineyards	Herndon silt loam 100%	0.27	166.3	Pied.	0.00	5.4	1142	210	2311	20.8	2784	1581
38	Cypress Bend Vineyards	Kenansville loamy sand 100%	3.15	64.2	Cst.	0.00	2.4	1164	224	2594	22.1	3019	1752
39	Davesté Vineyards	Lloyd clay loam 53%	1.50	269.8	Pied.	0.33	7.2	1128	204	2175	20.2	2649	1549
40	DD Farms & Vineyard	Cecil sandy clay loam 100%	0.12	218.9	Pied.	0.00	2.9	1137	230	2459	21.5	2854	1837
41	Deerpath Farm	Blanton sand 98.7%	0.76	37.0	Cst.	0.00	1.9	1266	221	2568	22.0	2986	1764
42	Demariano Vineyards	Hayesville clay loam 100%	0.33	394.3	Pied.	0.33	9.7	1285	197	2070	19.7	2555	1452
43	Dennis Vineyards & Winery	Badin channery silt loam 71.6%	2.61	150.2	Pied.	0.00	3.9	1191	211	2407	21.2	2910	1649
44	Divine Llama Vineyards	Tomlin sandy clay loam 50.3%	1.48	294.8	Pied.	0.33	8.5	1139	200	2128	19.9	2629	1482
45	Dobbins Creek Vineyards	Poplar Forest gravelly fine sandy loam 100%	2.18	407.7	Pied.	0.33	8.6	1204	202	2035	19.5	2545	1453
46	Douglas Vineyards	Saw-Pacolet complex 100%	0.20	251.6	Pied.	0.00	5.8	1121	205	2265	20.6	2798	1601
47	Eagle Fork Vineyards	Reddies loam 66.7%	0.39	653.2	Mts.	0.33	15.5	1628	186	1618	17.6	2086	1539
48	Elkin Creek Vineyard	Fairview sandy loam 97.6%	1.66	319.9	Pied.	0.33	10.7	1204	196	2018	19.4	2570	1451
49	Fiddler's Vineyard	Cecil sandy clay loam 91%	0.58	305.0	Pied.	0.00	6.5	1187	205	2255	20.5	2752	1587
50	Flint Hill Vineyards	Tomlin sandy clay loam 100%	1.81	284.3	Pied.	0.33	8.2	1139	200	2125	19.9	2595	1488
51	Foster Vineyards	Vance sandy loam 63.0%	16.67	113.0	Pied.	0.33	7.1	1146	205	2249	20.5	2779	1561
52	Fussy Gourmet Farms, LLC	Autryville loamy sand 100%	0.04	112.9	Cst.	0.00	3.1	1169	221	2533	21.8	2977	1697
53	Garden Gate Vineyards	Mecklenburg clay loam 72.7%	0.21	244.3	Pied.	0.00	9.3	1120	197	2175	20.2	2693	1507
54	Ginger Creek Vineyards	Fairview sandy clay loam 100%	0.15	365.7	Pied.	0.33	7.7	1217	209	2138	20.0	2571	1593

55	Golden Road Vineyards	Woolwine-Fairview-Westfield complex 99.5%	1.94	378.3	Pied.	0.33	11.9	1227	193	1952	19.1	2515	1407
56	Grandfather Vineyard & Winery	Ashe-Chestnut complex 57.7%	1.22	968.7	Mts.	3.67	29.4	1409	171	1197	15.4	1680	1207
57	Granny Pearls Farm	Appling sandy loam 100%	0.01	112.7	Pied.	0.00	4.3	1156	219	2347	21.0	2783	1595
58	Grapefull Sisters Vineyard	Goldsboro fine sandy loam 64.0%	0.74	14.0	Cst.	0.00	1.3	1307	227	2625	22.3	2983	1750
59	Grassy Creek Vineyard & Winery	Fairview sandy clay loam 100%	7.65	363.4	Pied.	0.33	10.0	1204	196	2018	19.4	2568	1449
60	Green Creek Winery	Cecil sandy clay loam 100%	2.82	311.8	Pied.	0.33	5.8	1331	209	2246	20.5	2777	1597
61	Green River Vineyard	Pacolet-Bethlehem complex 96.5%	1.78	272.8	Pied.	0.33	7.1	1260	206	2259	20.6	2785	1582
62	Gregory Vineyards	Gilead sandy loam 100%	2.53	63.5	Cst.	0.00	3.9	1152	218	2420	21.3	2905	1633
63	Grietje's Garden of Rocky Ridge Farm	Woolwine-Fairview-Westfield complex 96.2%	0.76	289.8	Pied.	0.33	8.8	1155	203	2126	19.9	2631	1469
64	Griffin Evergreens & Vineyard	Dothan loamy sand 67.2%	0.57	132.1	Cst.	0.00	4.3	1154	221	2431	21.4	2867	1682
65	Grove Winery & Vineyards	Enon fine sandy loam 53.0%	2.17	214.0	Pied.	0.00	5.8	1151	210	2284	20.7	2759	1592
66	Hanover Park Vineyard	Clover fine sandy loam 100%	3.21	273.0	Pied.	0.33	8.9	1132	199	2117	19.9	2633	1489
67	Herrera Vineyards	Fairview sandy clay loam 57.6%	4.44	335.8	Pied.	0.33	9.4	1192	194	1985	19.3	2533	1424
68	Hinnant Family Vineyards & Winery	Dorian fine sandy loam 37.0%	24.54	49.5	Cst.	0.00	3.2	1189	220	2448	21.4	2901	1641
69	Huffman Vineyards & Winery	Stallings loamy fine sand 88.2%	0.32	20.9	Cst.	0.00	2.6	1297	215	2487	21.6	2905	1694
70	Hutton Vineyards	Fairview sandy clay loam 100%	13.05	318.6	Pied.	0.33	9.4	1165	197	2037	19.5	2578	1449
71	Iron Gate Vineyards & Winery	Helena coarse sandy loam 53.6%	2.91	191.7	Pied.	0.00	5.8	1149	209	2300	20.7	2800	1545
72	Jewel of the Blue Ridge Vineyard	Walnut-Oteen-Mars hill complex 100%	0.16	640.4	Mts.	1.00	16.5	992	176	1790	18.4	2389	1379
73	JOLO Winery & Vineyards	Woolwine-Fairview-Westfield complex 82.3%	3.36	308.2	Pied.	0.33	7.9	1148	201	2100	19.8	2618	1464
74	Jones von Drehle Vineyards & Winery	Fairview sandy loam 56.3%	11.94	446.1	Pied.	0.33	11.8	1246	193	1863	18.7	2405	1382
75	Junius Lindsay Vineyard	Pacolet sandy loam 100%	3.97	252.3	Pied.	0.00	6.8	1102	204	2242	20.5	2720	1545
76	Lake Road Winery	Lynchburg fine sandy loam 100%	0.02	7.4	Cst.	0.00	0.9	1437	250	2624	22.3	2866	1958
77	Laurel Gray Vineyards & Winery	Nathalie fine sandy loam 52.1%	4.12	336.5	Pied.	0.33	8.7	1186	200	2068	19.7	2549	1446
78	Lazy Elm Vineyard & Winery	Clifford sandy clay loam 100%	2.26	248.8	Pied.	0.00	8.2	1114	197	2172	20.2	2671	1492
79	Linville Falls Winery	Edneytown-Pigeonroost complex 82.2%	0.73	1045.7	Mts.	2.33	28.8	1357	166	1220	15.6	1705	1273
80	Little River Vineyards & Winery	Mayodan sandy clay loam 85.1%	8.04	73.1	Pied.	0.02	3.4	1197	219	2542	21.9	2992	1720
81	Locklear Vineyard & Winery	Norfolk loamy sand 88.4%	1.97	56.6	Cst.	0.00	2.3	1167	227	2601	22.2	3016	1740
82	Lu Mil Vineyard	Norfolk loamy fine sand 46.7%	14.39	35.3	Cst.	0.00	1.5	1175	227	2630	22.3	3012	1771
83	Martin Vineyard & Orchard	Conetoe loamy sand 95.9%	2.24	3.1	Cst.	0.00	0.9	1193	257	2440	21.4	2656	1428
84	Maxwell Creek Vineyard	Autryville loamy fine sand 73.4%	5.63	24.8	Cst.	0.00	2.2	1299	218	2521	21.8	2937	1720
85	McDuffie Family Farm	Norfolk loamy fine sand 57.6%	3.59	33.1	Cst.	0.00	1.4	1220	227	2639	22.3	3013	1780
86	McRitchie Winery & Ciderworks	Fairview sandy clay loam 82.9%	1.06	422.0	Pied.	0.33	11.8	1246	193	1863	18.7	2405	1382
87	Medaloni Cellars	Siloam sandy loam 78.4%	0.39	246.6	Pied.	0.33	9.5	1131	198	2133	20.0	2649	1495
88	MenaRick Vineyard & Winery	Fairview sandy clay loam 84.1%	3.14	371.2	Pied.	0.33	10.5	1200	199	2067	19.7	2540	1423
89	Mill Branch Vineyards	Noboco loamy fine sand 60.9%	1.38	22.3	Cst.	0.00	2.4	1297	215	2504	21.7	2936	1742
90	Misty Creek Vineyards	Oak Level clay loam 31.9%	5.61	245.3	Pied.	0.33	8.8	1119	200	2145	20.0	2654	1490
91	Morgan Ridge Vineyards	Uwharrie silty clay loam 93.5%	2.72	221.1	Pied.	0.00	6.0	1125	204	2314	20.8	2794	1572
92	Mountain Brook Vineyards	Madison sandy clay loam 81.7%	2.77	275.4	Pied.	0.33	7.1	1269	206	2261	20.6	2782	1596
93	Myrick Vineyards, LLC	Norfolk loamy sand 66.1%	1.86	55.3	Cst.	0.00	3.2	1186	224	2439	21.4	2883	1643
94	Native Son Vineyard & Farm	Badin-Tarrus complex 100%	1.21	272.2	Pied.	0.00	5.0	1135	219	2303	20.8	2743	1667
95	Native Vines Winery	Appling sandy loam 87.0%	0.23	245.1	Pied.	0.00	7.1	1086	203	2246	20.5	2750	1524
96	Neuse River Winery	Yonges loamy fine sand 94.1%	1.18	2.2	Cst.	0.00	0.9	1387	256	2631	22.3	2898	1993

97	Nottely River Valley Vineyards	Braddock gravelly loam 91.4%	1.98	514.6	Mts.	0.67	13.3	1396	186	1980	19.3	2496	1434
98	Old Stone Winery	Appling sandy loam 99.7%	3.54	238.4	Pied.	0.00	6.6	1100	203	2253	20.5	2697	1542
99	Overmountain Vineyards	Pacolet-Bethlehem complex 85.5%	2.55	298.3	Pied.	0.33	6.5	1269	206	2261	20.6	2747	1571
100	Owl's Eye Vineyard & Winery	Cecil sandy clay loam 70.1%	4.12	266.6	Pied.	0.33	6.6	1202	204	2272	20.6	2766	1572
101	Parker-Binns Vineyard	Pacolet sandy clay loam 100%	1.53	303.4	Pied.	0.33	7.3	1368	203	2213	20.3	2747	1561
102	Patria Properties	Fairview fine sandy loam 100%	0.49	253.0	Pied.	0.33	8.5	1122	203	2173	20.2	2671	1485
103	Pennini Vineayrds	Rhodhiss sandy loam 82.6%	0.92	188.2	Pied.	0.00	6.6	1145	205	2254	20.5	2732	1518
104	Piccione Vineyards	Fairview sandy clay loam 88.3%	5.99	343.6	Pied.	0.33	9.0	1206	200	2032	19.5	2655	1486
105	Raffaldini Vineyards & Winery	Fairview sandy clay loam 99.1%	16.96	353.2	Pied.	0.33	9.0	1206	200	2032	19.5	2655	1486
106	RagApple Lassie Vineyards	Clifford sandy clay loam 79.4%	10.21	318.7	Pied.	0.33	9.7	1163	197	2041	19.5	2596	1471
107	RayLen Vineyards & Winery	Oak Level clay loam 48.0%	15.35	238.2	Pied.	0.00	8.5	1121	197	2186	20.2	2705	1526
108	Rinaldi Estate Vineyard	Pacolet sandy clay loam 86.9%	2.43	254.7	Pied.	0.00	7.0	1102	203	2224	20.4	2720	1561
109	Roaring River Vineyards	Rhodhiss-Bannertown complex 62.2%	0.78	360.2	Pied.	0.33	11.1	1178	196	2011	19.4	2497	1401
110	Rock of Ages Winery & Vineyard	Enon fine sandy loam 61.5%	10.25	189.7	Pied.	0.00	6.6	1153	206	2258	20.5	2756	1537
111	Rocky River Vineyards	Goldston very channery silt loam 90.7%	2.71	159.8	Pied.	0.00	4.0	1144	218	2452	21.5	2915	1637
112	Round Peak Vineyards	Woolwine-Fairview-Westfield complex 98.1%	5.34	392.2	Pied.	0.33	11.9	1221	193	1907	18.9	2453	1401
113	Saint Paul Mountain Vineyards	Hayesville loam 96.6%	1.18	660.4	Mts.	0.67	11.1	1331	190	1784	18.3	2325	1401
114	Sanctuary Vineyards	Bojac loamy sand 42.1%	1.42	3.5	Cst.	0.00	0.5	1246	268	2440	21.4	2566	1231
115	Sanders Ridge Vineyard & Winery	Clifford fine sandy loam 93.9%	5.69	293.1	Pied.	0.33	9.5	1163	197	2041	19.5	2591	1456
116	Shadow Springs Vineyard	Nathalie fine sandy loam 40.1%	4.25	331.4	Pied.	0.33	8.8	1180	200	2073	19.7	2589	1445
117	Shelton Vineyards	Fairview sandy clay loam 92.9%	46.74	371.8	Pied.	0.33	10.7	1204	194	1955	19.1	2496	1410
118	SilkHope Winery	Georgeville-Badin complex 100%	0.65	198.3	Pied.	0.00	4.7	1162	218	2299	20.7	2780	1606
119	Silver Coast Winery	Foreston loamy fine sand 100%	0.18	15.5	Cst.	0.00	1.4	1346	227	2615	22.2	2948	1854
120	Silver Fork Vineyard & Winery	Fairview sandy clay loam 100%	1.21	371.0	Pied.	0.33	9.8	1246	199	2111	19.9	2649	1499
121	Six Waterpots Vineyard & Winery	Woolwine-Fairview-Urban land complex 100%	0.32	387.9	Pied.	0.33	8.5	1208	204	2118	19.9	2592	1478
122	South Creek Vineyards & Winery	Hayesville-Evard complex 47.2%	0.54	351.9	Pied.	0.33	10.4	1262	198	2092	19.8	2669	1516
123	Stephens Vineyard & Winery	Pantego fine sandy loam 100%	0.07	43.4	Cst.	0.00	1.7	1161	227	2605	22.2	3002	1738
124	Stonefield Cellars Winery	Clifford sandy loam 100%	0.62	288.2	Pied.	0.00	5.8	1124	212	2223	20.4	2669	1733
125	Stony Knoll Vineyards	Clifford sandy clay loam 64.4%	2.02	331.3	Pied.	0.33	9.3	1165	197	2037	19.5	2567	1441
126	Stony Mountain Vineyards	Enon very cobbly loam 100%	1.14	183.4	Pied.	0.00	4.3	1196	212	2495	21.7	2975	1711
127	Sweet Home Carolina Vineyard & Winery	Clifford sandy clay loam 100%	0.12	266.8	Pied.	0.33	10.4	1137	197	2089	19.8	2601	1475
128	The Tipsy Bee	Rains fine sandy loam 91.4%	0.35	20.9	Cst.	0.00	2.5	1306	215	2516	21.8	2930	1730
129	Treehouse Vineyards	Badin-Urban land complex 100%	1.40	178.6	Pied.	0.00	2.5	1164	227	2489	21.6	2886	1709
130	Triple B Vineyard	Cecil sandy clay loam 94.7%	0.77	267.9	Pied.	0.33	6.8	1186	207	2267	20.6	2766	1580
131	Twisted Vine Winery	Fairview sandy clay loam 100%	0.10	387.4	Pied.	0.33	8.9	1217	204	2093	19.8	2610	1486
132	Uwharrie Vineyards	Tarrus channery silt loam 86.8%	5.33	180.4	Pied.	0.00	4.5	1191	209	2360	21.0	2823	1623
133	Valley River Vineyards	Statler loam 72.6%	0.71	505.9	Mts.	0.67	13.6	1392	183	1920	19.0	2321	1321
134	Waldensian Heritage Wines	Meadowfield-Rhodhiss complex 50.0%	0.10	349.9	Pied.	0.33	8.4	1216	204	2147	20.0	2661	1484
135	Warren Farms Vineyard	Goldsboro loamy sand 83.3%	7.13	7.2	Cst.	0.00	1.5	1335	230	2563	22.0	2926	1767
136	Weathervane Winery	Pacolet sandy loam 100%	0.78	247.3	Pied.	0.00	6.8	1102	204	2242	20.5	2735	1546
137	White Rock Vineyard	Helena sandy loam 100%	0.03	224.1	Pied.	0.00	5.7	1161	210	2295	20.7	2789	1573
138	Willis Dixon Vineyard	Norfolk loamy fine sand 100%	1.01	15.1	Cst.	0.00	1.9	1384	227	2553	21.9	2914	1808
139	Windsor Run Cellars	Clifford sandy clay loam 62.4%	2.69	338.5	Pied.	0.33	8.9	1188	200	2068	19.7	2589	1445

140Wolfe Wines	Orange silt loam 100%	0.20	183.8	Pied.	0.00	5.1	1134	216	2301	20.8	2768	1600
141WoodMill Winery	Cecil sandy clay loam 71.9%	3.48	318.0	Pied.	0.33	6.9	1194	205	2223	20.4	2711	1555
142Younts Wine Farm	Clover fine sandy loam 100%	2.17	211.2	Pied.	0.33	8.9	1132	198	2105	19.8	2619	1472
143Zimmerman Vineyards	Badin-Tarrus complex 100%	1.93	162.3	Pied.	0.00	6.8	1130	205	2308	20.8	2781	1591

Appellation Boundaries: created from the textual descriptions given in C.F.R. Title 27 § Part 9.174, 9.211, 9.214, 9.234, and 9.260. These boundaries were generated manually by following the text and creating the polygons using the referenced USGS base maps and their features; this was performed in ESRI ArcMap 10.3.1.
County Boundaries: generated using data supplied by ArcGIS for Desktop Data and Maps, 2015 (\usa\census\dtl_cnty.gdb).
Vineyard Boundaries: boundaries were created from geolocating public lists of NC commercial vineyards {NCWine.org, northcarolinamuscadinegrapeassociation.org … }, and creating polygons using aerial imagery from publicly available sources (ArcGIS Online: world imagery and NAIP layers along with Google Maps imagery).
Soil Series-Txt-Dominant %: generated using ESRI ArcMap 10.3.1. & gSSURGO.
Area: generated using ESRI ArcMap 10.3.1.
[Absolute] Elevation: generated using ESRI ArcMap 10.3.1 and the most recently available NED DEM (10 m) in July 2015.
[Physiographic Province] Phys Prov: Mts. = Mountains, Pied. = Piedmont, and Cst. = Coastal Plain; generated using ESRI ArcMap 10.3.1.U.S. EPA Eco Regions Level IV.
[Precipitation] PPT: generated using ESRI ArcMap 10.3.1.; derived from PRISIM monthly precipitation between 1981 and 2014.
ECR, PDR, FFP, GDD, GST, HI, and BEDD: generated using ESRI ArcMap 10.3.1, & derived from PRISIM maximum & minimum temperature, daily data between 1981 and 2.

Appendix C. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apgeog.2019.03.003.

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