Soil and Climate Interactions with Grapevines

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ABSTRACT
To test the hypothesis that soil type plays a minor role relative to that of vine vigor in the determination of yield, fruit composition and wine sensory attributes, 5 Chardonnay vineyards in the Niagara Peninsula of Ontario were chosen for study. These vineyards were located on sites with heterogeneous soil types to allow study of the impact upon yield, fruit composition and wine sensory attributes of: 1. Soil texture with mesoclimate kept constant; 2. The comparative magnitude of effects of soil texture, vine vigor, and crop size. Vineyard blocks were delineated using global positioning systems, and a series of 72-162 data vines per site were geo-located within a sampling grid imposed on each vineyard block. Data were collected on soil texture, soil composition, tissue elemental composition, vine performance (yield components and weight of cane prunings), and fruit composition. These variables were mapped using geographical information systems and relationships between them were elucidated. Soil texture and composition were frequently correlated to yield components and fruit composition but often relationships were site-specific. Spatial correlations were common between % sand, vine size, yield, berry weight, soluble solids (Brix), and titratable acidity (TA); however, these relationships were vineyard and vintage dependent. Several spatial relationships were apparent between vine size, yield, Brix, TA and many soil and petiole composition variables, including organic matter, soil pH, cation exchange capacity, and soil/petiole N, P, K, Ca, Mg, and B. Spatial relationships between yield, berry weight, berry composition, vine size, and several soil physical and composition variables suggests a likely soil basis to the so-called “terroir effect”.

Keywords: GPS, GIS, soil moisture, leaf water potential, vine size, soil texture.

1 INTRODUCTION

All plants, grapevines included, are characterized by complex interactions with their environment, which includes the soils in which they grow and the various levels of climate that they experience. Noteworthy soil factors include texture (sand and clay content), moisture, depth of solum, and factors impacting nutrition such as cation exchange capacity, organic matter, and pH (1). Most will ultimately influence vine vigor, which impacts cluster and leaf microclimate, fruit composition, and wine quality (2). Climatic factors, particularly microclimatic variables resulting from canopy management, also impact vine vigor and wine quality (2).

Terroir can be defined as the effects of vineyard location, including those of geology, soil, and climate, on wine composition and quality. In many terroir models, soil classification often plays a primary role, and consequently it has been a frequently-addressed factor (3-5). Soil’s influence on wine composition and quality, however, has been difficult to study objectively due to confounding influences of site climate, season, and within-vineyard variability (6,7). Nonetheless, many have demonstrated putative relationships between soil and wine sensory characteristics (8). The terroir concept has been re-defined to embrace soil and vine water status (3-5,9,10). Loire Valley soils leading to intense wine varietal character were free-draining sandstones that led to mild vine water stress during fruit maturation (11).

Wine quality is determined by vineyard factors such as site, soil, and canopy management (1). However, a question remains: is soil a primary determinant of wine quality, or simply a medium that impacts vine growth and vigor (and therefore does the skill by which vigor is accommodated determine wine quality)? This study addressed this controversy through use of geomatic tools such as global positioning systems (GPS) and GIS. It was hypothesized that soil texture would play a minor role in the determination of yield components, fruit composition, and wine sensory attributes, and vine vigor would play the major role. This hypothesis was simultaneously tested in a related study with Riesling (12). This study investigated direct soil effects by testing independent impacts of soil and vine vigor on yield components, berry composition, and wine sensory attributes of Chardonnay.

2 MATERIALS AND METHODS

2.1 Site selection

Five sites were selected in April 1998 throughout the Niagara Peninsula on the basis of their diverse soil types; 2 in the Lakeshore region of Niagara-on-the-Lake (Buis; Falk); 2 in the Lakeshore Plain region [Chateau des Charmes (CDC); Lambert], and one on the Niagara Escarpment near Vineland (Wismer). All blocks had heterogeneous soil types, particularly in terms of soil texture (13) and yield and vine size were variable. In each block, a grid-style sampling pattern was established with a “sentinel vine” (72-162 sentinel vines per site) at each grid intersection point. A GPS unit [GBX-12R (CSI-Wireless, Calgary, AB)] at < 1 m accuracy was used in May 1998 to delineate shape and size of the blocks and to geo-locate the sentinel vines.

2.2 GIS and soil mapping; petiole analysis

Soil mapping was carried out on each site. Soil samples (≈ 200 g) were collected with a 3-cm X 75-cm soil probe at every 3rd sentinel vine in September 1998. Soil analyses [elemental concentration, cation exchange capacity (CEC), base saturation (BS), pH, and organic matter (OM)] were performed (12,14). Proportions of sand, silt, and clay (by hydrometer) were determined, and soil texture and composition maps of each vineyard block were constructed from this information using GIS [MapInfo and Vertical Mapper (Northwood GeoScience, Ottawa, ON)]. Elemental analysis was performed by inductively-coupled plasma emission spectroscopy (Perkin-Elmer Optima 3000). Petiole sampling (≈30 g per vine) took place July-August 1998, and elemental composition was determined (12,14).

2.3 Viticultural data collection

Data were collected annually from each sentinel vine for weight of cane prunings ("vine size") as an estimate of vine vigor. Yield components were either measured directly (yield and clusters per vine) or calculated from measured variables (cluster weight, berries per cluster) during harvest each season. Samples (100 berries) were taken from each vine for determination of berry weight and fruit composition [soluble solids (Brix); titratable acidity (TA); pH]. Berry composition was determined as previously mentioned (12).

2.4 Winemaking and sensory analysis

Within each vineyard block, sentinel vines were sorted based upon vine size and identified accordingly on maps. Two vine size categories were established at 3 sites (Buis, CDC, Wismer) whereby vines $\pm$ 0.5 standard deviations above or below the mean vine size were designated as "large" or "small" size, respectively. Small and large vines within high-clay and high-sand regions in each vineyard were identified. Replicate wines were made with standard protocols (12) from all vine size X soil X site combinations. Sensory descriptive analyses were performed annually after 12 months of bottle storage (12).

2.5 Statistical analysis.

SAS (SAS Institute, Cary, NC) was used for all data analysis. MapInfo and Vertical Mapper were used to construct maps of soil texture, soil/petiole composition, yield components, vine size, and berry composition. These maps were used to examine annual spatial variation for all variables, temporal stability, and spatial relationships between correlated variables. Analysis of variance (PROC GLM) was used to analyze soil texture and vine vigor effects on berry weight, berry composition, and wine sensory attributes. Sensory and field data were also subjected to principal component analysis (PCA). Correlations were determined (PROC CORR) between all field and berry composition data.

3 RESULTS

3.1 Spatial distribution

3.1.1 Soil physical properties

The vineyards differed in terms of the magnitude of their variability in the many soil/petiole composition variables. There was also wide variability in soil texture (mean 18.3-61.1% sand). The CDC site ranged from 37-80% sand and contained a section with 60-80% sand. The Wismer site, in contrast, ranged from 4-36% sand.

3.1.2 Vine size and yield components

Spatial variability in vine size was apparent at all vineyard sites. Moreover, temporal stability in vine size was commonplace (1998-2002). Spatial variability and temporal stability in yield were observed at all sites. Spatial variability in yield (1998-2001) and berry weight (1999-2001) were temporally stable at the Buis site. The Lambert site showed temporal stability in yield (1998-99, 2002) and berry weight (1998-99, 2001). The Falk site had temporally stable yield (1998-2002), and berry weight was also temporally stable (1998-2000, 2002). The CDC site was unstable temporally for yield, although larger berries were produced annually in the sandier portion. The Wismer site displayed temporal stability in yield and berry weight (1998-2002).

3.1.3 Fruit composition

Both Brix and TA varied spatially each year at each site. Temporal stability in Brix at the Buis site was noticeable (1998-99, 2001). Spatial patterns in TA were also temporally stable. Temporal stability was noticeable for Brix and TA at the Lambert site (1998-99, 2001). Brix was temporally stable at the Falk site (1998-99, 2001-02), and TA was temporally stable (1999-2002). CDC did not display temporal stability in terms of Brix, but TA was temporally stable (1998-2001). The Wismer site showed temporal stability in Brix (1999, 2001-02); TA patterns were consistently stable (1998-2002).

3.2 Spatial correlations

High sand zones occasionally correlated spatially with high vine size (e.g. Falk, CDC) and high yields (CDC). Zones of high vine size also correlated spatially with high yields, berry weights, Brix, and TA. Spatial relationships were vineyard and vintage dependent. The Buis site displayed vine size vs. yield relationships (1998, 2001, 2002), and low vine size vs. high Brix relationships (1998, 2001). The Lambert site showed relationships between vine size and both yield and berry weight (2002 excepted), Brix (inversely) and TA. The Falk site had temporally stable vine size patterns but these were only spatially correlated with yield in 2000. Vine size and berry weight were spatially correlated (1998-2000), as were vine size and Brix (1998-99; 2001-02). The CDC site was the most anomalous of the sites; however, vine size was temporally stable (1998-2001), and berry weights were largest in the high vine size regions. Highest Brix was associated with highest yields and vine size in 2 years (1998, 2001), and high TA was consistently associated with high vine size. The Wismer site showed consistent temporal stability in vine size and spatial relationships with yield (1998-2002), berry weight (1998-2000), Brix (1999, 2001), and TA (1998-2002).

3.3 Sensory effects

Apple, fruity, color, sweetness, body, and finish of the 1999 wines were correlated and were located to the right of PC2, and inversely related to vegetal, cedar, earthy, and astringency. Wines from the Falk site and CDC wines from sandy textures were to the right of PC2, while 3 Buis wines plus CDC wines from clay textures were located to the left (Fig. 1A). In 2000, apple, citrus, vegetal, earthy, astringency, and body were closely related and located to the right of PC2, while floral, melon, and finish were inversely correlated and on the left. Seven of 8 Buis wines and Falk wines from sand were to the right of PC2, while all CDC and 6 of 8 Wismer wines were on the left (Fig. 1B). In 2001, citrus, vegetal, earthy, astringency, and finish were correlated and right of PC2, while apple, floral, melon were inversely correlated and the left. Among the wines associated with those descriptors right of PC2 were 9 from clay including: Buis (5 of 8 wines), CDC (3 of 4 wines; both clay wines), Falk (all wines), Lambert (both clay wines). All wines from the Wismer site, plus Lambert wines from sand were left of PC2 (Fig. 1C).

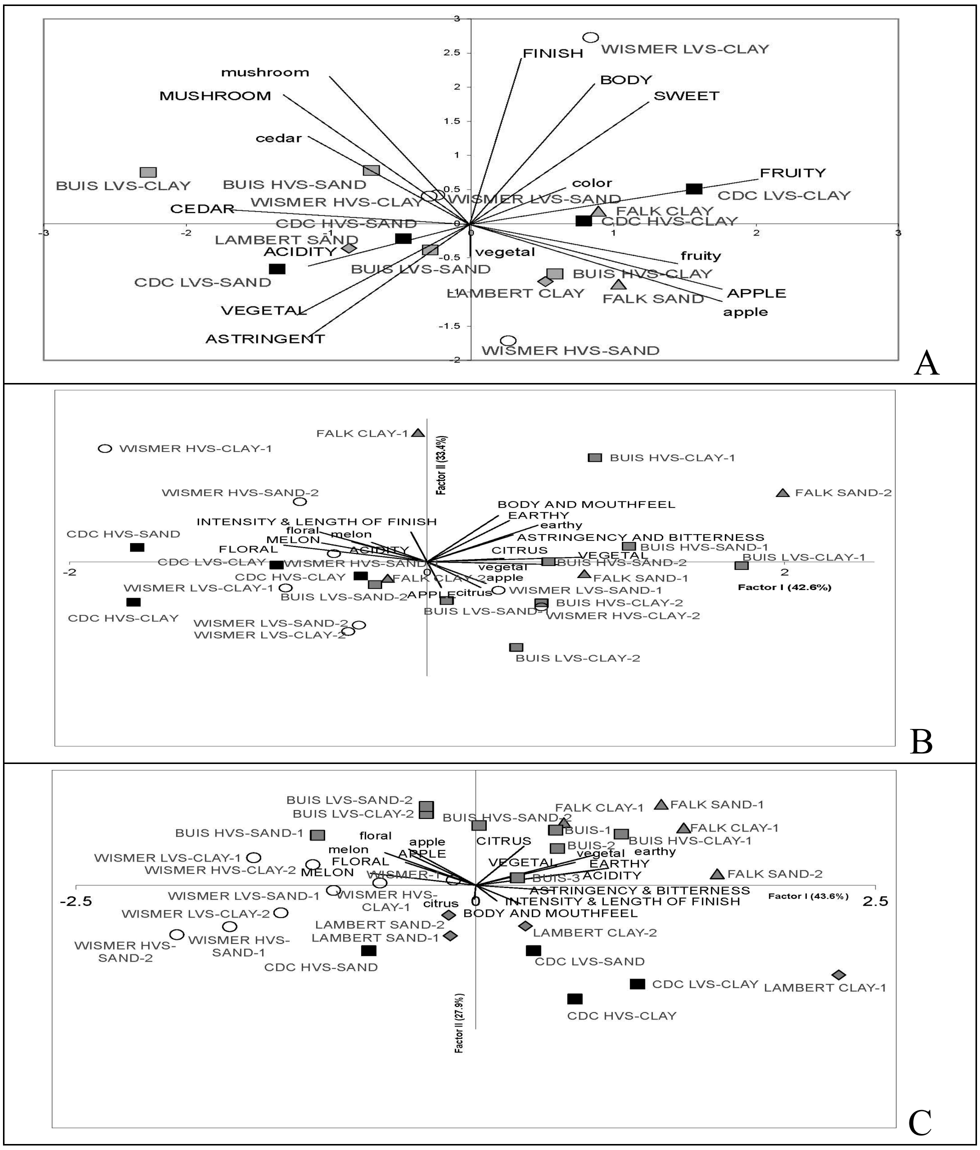

Figure 1. PCA diagram of aroma (lowercase) and flavor attributes (uppercase) of Chardonnay wines produced from grapes grown on two soil textures (sand, clay) and two vine sizes [low vine size (LVS); high vine size (HVS) at five sites in the Niagara Peninsula, ON. A: 1999; B: 2000; C: 2001. For Fig. 1C: Wine sample abbreviations: Buis 1: Buis LVS-clay-1; Buis 2: LVS-sand-1; Buis 3: HVS-clay-2; Wismer 1: Wismer LVS-sand-2.

4 DISCUSSION

At the time of its inception, this study sought applications for geomatic technologies to test two major hypotheses: 1. That soil texture would play a minor role in the determination of yield components, fruit composition, and wine sensory attributes (i.e. the terroir effect), and 2. That vine size, crop size and associated fruit environment would play the major roles. This study was possible by the use of vineyard blocks with heterogeneous soil textures, and, use of geomatic technologies to locate and accurately map vines of various size and yield categories.

4.1 Soil texture and composition

Sand and clay were correlated to several variables mathematically/spatially at some sites. PCA showed that % sand was related to petiole N, K, and B, while % clay was associated with 7 petiole elements. Other variables linked to % clay included OM, soil pH, CEC, and BS-Ca. Spatial relationships between soil textural variables and other soil physical properties (e.g. OM, CEC, pH) have been documented (9,12). Relationships between non-textural soil variables have likewise been demonstrated (9,12), although temporal stability in these relationships (e.g. between soil pH, N, P, K) is often low (15). Inverse correlations between soil/petiole K vs. Ca and Mg reflect nutrient antagonism (16). Other inverse relationships found in this study (e.g. petiole N vs. soil/petiole Ca and Mg) have also been documented (16).

4.2 Soil/petiole composition vs. berry composition

Both pH and TA were mutually correlated and related to yield components, and petiole N, K, and B. This relationship between yield components, TA and pH, and elevated petiole K has been demonstrated and ascribed to canopy shading (2). The strong relationship of soil/petiole K vs. berry pH observed in 5 instances over the course of 3 years has also been previously demonstrated (16). Many have found that excessive soil K increases pH and lowers TA (16). Relationships might exist between soil/petiole elemental composition and berry aroma compounds, although direct connections have been difficult to determine. There is possibility for establishing temporally-stable zones of different flavor potential (9,10,12). Cysteine precursors of odor-active thiols were closely linked to N status in Sauvignon blanc, thus zones within vineyards with high N supply can potentially increase varietal typicity (4). In Cabernet franc, gravel soils were associated with lower 2-methoxy-3-isobutylpyrazine (17).

4.3 Sensory evaluation

There was no clear link to vine size across the 3 years. However, the relationships between the sensory vectors were relatively stable. Moreover, it was apparent that certain sites (e.g. Buis and Falk), were associated with citrus, vegetal, and earthy descriptors, perhaps because they were located in the Lakeshore zone and both had relatively high vine size. There was a tendency for clay zones to produce wines higher in vegetal, earthy, and citrus aromas, whereas sandy zones tended to produce wines with floral and melon aromas/ flavors.

5 CONCLUSIONS

The main hypothesis was that soil and vine size might have a direct impact upon fruit composition and hence wine varietal typicity. This study creates as many questions as answers. There were many consistent wine sensory effects that could be linked to both soil and site, and very few with vine size. Soil texture and composition had many consistent relationships with fruit composition and yield. Important questions are partly unanswered: (a) What factors exert the greatest control over the terroir effect?; (b) Do winemakers exert more influence over wines than site characteristics?; (c) Do viticultural and/or enological practices exert the greatest influence over wine varietal typicity?

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