Delineation of within-site terroir effects using soil and vine water measurement. Investigation of Cabernet Franc.

By

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Abstract. The influence of vine water status was studied in commercial vineyard blocks of *Vitis vinifera* L. cv. Cabernet Franc in Niagara Peninsula, Ontario from 2005 to 2007. Vine performance, fruit composition and vine size of non-irrigated grapevines were compared within ten vineyard blocks containing different soil and vine water status. Results showed that within each vineyard block water status zones could be identified on GIS-generated maps using leaf water potential and soil moisture measurements. Some yield and fruit composition variables correlated with the intensity of vine water status.

Chemical and descriptive sensory analysis was performed on nine (2005) and eight (2006) pairs of experimental wines to illustrate differences between wines made from high and low water status winegrapes at each vineyard block. Twelve trained judges evaluated six aroma and flavor (red fruit, black cherry, black current, black pepper, bell pepper, and green bean), three mouthfeel (astringency, bitterness and acidity) sensory attributes as well as color intensity. Each pair of high and low water status wine was compared using t-test. In 2005, low water status (LWS) wines from Buis, Harbour Estate, Henry of Pelham (HOP), and Vieni had higher color intensity; those form Château des Charmes (CDC) had high black cherry flavor; those at Rief Estates were high in red fruit flavor and at those from George site was high in red fruit aroma. In 2006, low water status (LWS) wines from George, Cave Spring and Morrison sites were high in color intensity. LWS wines from CDC, George and Morrison were more intense in black cherry aroma; LWS wines from Hernder site were high in red fruit aroma and flavor. No significant differences were found from one year to the next between the wines produced from the same vineyard, indicating that the attributes of these wines were maintained almost constant despite markedly different conditions in 2005 and 2006 vintages. Partial

Least Square (PLS) analysis showed that leaf Ψ was associated with red fruit aroma and flavor, berry and wine color intensity, total phenols, Brix and anthocyanins while soil moisture was explained with acidity, green bean aroma and flavor as well as bell pepper aroma and flavor.

In another study chemical and descriptive sensory analysis was conducted on nine (2005) and eight (2006) medium water status (MWS) experimental wines to illustrate differences that might support the sub-appellation system in Niagara. The judges evaluated the same aroma, flavor, and mouthfeel sensory attributes as well as color intensity. Data were analyzed using analysis of variance (ANOVA), principal component analysis (PCA) and discriminate analysis (DA). ANOVA of sensory data showed regional differences for all sensory attributes. In 2005, wines from CDC, HOP, and Hernder sites showed highest red fruit aroma and flavor. Lakeshore and Niagara River sites (Harbour, Reif, George, and Buis) wines showed higher bell pepper and green bean aroma and flavor due to proximity to the large bodies of water and less heat unit accumulation. In 2006, all sensory attributes except black pepper aroma were different. PCA revealed that wines from HOP and CDC sites were higher in red fruit, black currant and black cherry aroma and flavor as well as black pepper flavor, while wines from Hernder, Morrison and George sites were high in green bean aroma and flavor. ANOVA of chemical data in 2005 indicated that hue, color intensity, and titratable acidity (TA) were different across the sites, while in 2006, hue, color intensity and ethanol were different across the sites. These data indicate that there is the likelihood of substantial chemical and sensory differences between clusters of sub-appellations within the Niagara Peninsula

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Chapter 1

Introduction

In 1988, the Ontario Vintners Quality Alliance (VQA) was established to set standards for producing premium wines in Ontario. Initially VQA recognized three viticultural areas or appellations by considering soil, climate, and topographical features. The three appellations, Lake Erie North Shore, Pelee Island, and Niagara Peninsula, are believed to have the potential to produce different wine quality due to various soil and climatic condition. The concept of separating Appellations was initiated in countries with a longer history of vine growing such as France, Italy, Germany and Spain by considering soil characteristics as an essential factor in the determination of boundaries for each Appellation. In 2006, Prince Edward County became Ontario's most recent Designated Viticultural Area. The Niagara Peninsula, with its distinctive feature of a relatively mild winter climate, favors cultivation of a wide range of grape cultivars. The position of Niagara Peninsula between Lake Ontario and Lake Erie exposes the region to lake breezes that moderate high summer temperatures as well as cold winter temperatures (Shaw 2002).

Different climatic factors such as distance from the lake, slope, elevation, and airflow patterns, as well as soil type and parent material, create a wide range of mesoclimates with various potential for producing quality winegrapes. The soils in the region range from imperfectly drained silty clay to moderately well-drained sandy loam with slightly high water holding capacities. Consequently, the Niagara Peninsula has been further sub-divided into sub-appellations. Using infra-red and aerial photography, Wiebe and Anderson (1977) indicated that climatological differences existed between

“Lakeshore”, “Lake Plain”, and “Bench” regions of Niagara. Later Sayed (1992) showed regional differences with regard to geographical and geological data. Most recently, VQA Ontario established 10 sub-appellations in the Niagara Peninsula based on a combination of climate, elevation, and soil characteristics.

Previous sensory descriptive analysis on ice wines from Ontario and British Columbia illustrated that Ontario wines had the highest fruity and floral aromas and a golden copper color while wines from British Columbia have higher sweetness, body and intensity of aftertaste (Cliff *et al.* 2002). Sensory studies (Douglas *et al.* 2001, Schlosser *et al.* 2005) in Ontario showed differences between the ‘Lakeshore’, ‘Lakeshore Plain’ and the ‘Bench’ regions of the Niagara Peninsula using commercial Riesling and Chardonnay wines. A sensory study on Bordeaux-red wine cultivars (Kontkanen *et al.* 2005) in the Niagara Peninsula also showed regional differences based on red fruit, dried fruit, fresh vegetable, canned vegetable, spice, and oak sensory attributes among the three regions. One of the purposes of this study was to develop sensory and analytical methodologies for characterization of Cabernet Franc wines from typical vineyards within these 10 sub-appellations within the Niagara Peninsula to determine the degree and nature of any differences.

Literature Cited

Cliff, M.A., D. Yuksel, B. Girard, and M. King. 2002. Characterization of Canadian ice wines by sensory and compositional analysis. Amer. J. Enol. Vitic. 53:46-53.

Douglas, D., M.A. Cliff, and A.G. Reynolds. 2001. Canadian terroir: characterization of Riesling wines in the Niagara Peninsula. Food Res. Int. 34: 559-563.

Kontkanen, D., A.G. Reynolds, M. King and M.A. Cliff. 2005. Canadian terroir: characterization of Bordeaux-style red wines from the Niagara Peninsula. Food Res. Int. 38: 417-425.

Sayed, H. 1992. Vineyard Site Suitability in Ontario. Toronto: Agriculture Canada/Ontario Ministry of Food. Queen's Printer for Ontario.

Schlosser, J., A.G. Reynolds, M. King, and M.A. Cliff. 2005. Canadian terroir: sensory characterization of Chardonnay in the Niagara Peninsula. Food Res. Int. 38: 11-18.

Shaw, A.B. 2002. A climatic assessment of the Niagara Peninsula viticultural area of Ontario for the application of wind machines. J. Wine Research 13:143-164.

Wiebe, J. & E.T. Anderson. 1977. Site Selection for Grapes in the Niagara Peninsula, Canada. Horticultural Research Institute of Ontario, Vineland Station.

Chapter 2

Literature Review

Terroir. Terroir is a French word and its definition is somewhat ambiguous. Terroir derives from the Latin word 'territorium' for which there is no satisfactory word in other languages. It is defined in French dictionaries as territory, region, or a small area of land being considered for its qualities or agricultural properties (Rey et al. 1998). Seguin (1986) noted that terroir has often been used interchangeably with soil which refers to the subsurface environment. Common meanings given to terroir are origin, persistence, specificity and personality (Vaudour 2002).

During the last 30 years, terroir-related studies have mostly focused on the relationships between the quality of grapes and wines and some environmental factors around the vines or in particular areas. Terroir can be defined as an interactive ecosystem, in a given place, including climate, soil, and the vine (rootstock and cultivar) that has an important role in wine quality (Seguin 1988). Seguin (1988) believes that the role of terroir is important especially in temperate climates. Terroir has been defined as a "growing environment" (Johnson and Robinson 2001) or from a viticultural point of view as the "total elements of the vineyard"that contribute to the wine charateristics (Wilson 1998). Martin (2000) has expanded this definition as the conjunction of all attributes, historical, geographical, human, and environmental of a given region which contribute to the wines produced there. Vaudour (2002) suggested to study terroir in a larger scale such as nation, region or even in global scale rather than local point measurement, by using GIS technology, which is the goal of spatial analysis.

Asselin *et al.* (1983) designed a methodology to relate wine sensory attributes to soil type in order to describe differences in Cabernet Franc wines produced from different sites in the Loire Valley. They found that the wines with the greatest aroma and flavor intensity were produced in brown calcareous soils with appreciable chalk content. Vilanova *et al.* (2007) analyzed the volatile composition of the Albarino variety grown in the north and south of Galicia, Spain to determine the influence of terroir on wine volatiles. They reported that numerous differences for most of the aromatic compounds were found in relation to terroir. For instance they found the highest total concentration of volatiles from northern Galicia; among the terpenes, while geraniol was abundant in the north, nerol and linalool were most abundant in the south. Reynolds and De Savigny (2001) studied the impact upon flavor compounds and wine sensory attributes of Chardonnay and Riesling varieties in six Niagara Peninsula vineyards with heterogeneous soil types. They found few differences between sites in terms of sensory descriptive analysis of wines produced from individual soil by vine size interaction categories, but soil texture and vine size had independent effects.

Chemistry of the soil and terroir. Johnson and Robinson (2001) refer to the soils of wine regions as gravely, sandy or heavy clay in relation to the rock types on which the soils are formed. There are a few references to the chemistry of the soil. Many of the great vineyards of the world occur on calcareous soils formed on limestone or chalk or on transported materials derived from these rocks. Saxton (2002) stated that soil Ca created a favorable medium for root exploration, uptake of minerals and growing a healthy vine which is a very non-specific statement. Saxon also indicated that the higher growth of vigorous vines maximized Ca uptake and this would result in more pronounced expression of terroir. By contrast, Smart (2002) concluded that the best Bordeaux vineyards occurred on acidic gravelly soils deficient in most nutrients and the soil chemistry had no specific influence on wine quality. However, McKenzie and Christy (2005) showed for Riesling grapes produced in the northern Adelaide Hills, South Australia, had a grape sugar concentration and TA that were correlated with the presence of several available trace elements in the soil such as: Ca, strontium, barium, lead and silicon. This result confirms that correlation analysis can sometimes produce nonsensical results that do not explain mechanisms responsible for the characteristics of a wine. Moran (2001) suggested that the process by which elements of soil generate the flavor, color and or other qualities of wines remains unknown.

Physical properties of soil and terroir: Seguin (1986) and van Leeuwen *et al.* (2004) indicated that soil physical properties such as structure, particularly macroporosity, which affects drainage and ease of root growth and penetration as well as the amount of available water, were predominant in determining wine quality and character. Seguin (1986) indicated that the main influence of Ca on wine quality was due to its positive function on soil structure, particularly in clay soils. Good soil structure with sufficient macroporosity in the dry land vineyards of Sauternes and Graves regions of France enable roots to penetrate to 5 to 7 m deep (Seguin 1986). However, vines grown in hard limestone soils (upper slopes of McLaren Vale, South Australia) have a restricted rooting depth; similarly for vines grown on clay soils with poor drainage or with compacted B horizon in Australia and South Africa.

Vine water status and terroir: Vine water status depends on climate (rainfall and potential evapotranspiration), soil water holding capacity and training system. Vine water uptake conditions are important in understanding the effect of the terroir, including climate, soil, and grapevine, on grape quality potential. Seguin (1975) showed that grape quality was related to a regular but moderate water supply to the vines. In non-irrigated vineyards, berry size is decreased and total phenols are increased when vines face water deficits, which result in lower yield and higher grape quality potential for red wine-making (Duteau *et al.* 1981; van Leeuwen and Seguin 1994; van Leeuwen *et al.* 2004). These effects were confirmed in irrigation trials by Matthews and Anderson (1988) and Ojeda *et al.* (2002).

Many studies have assessed the effect of single parameter of terroir on grape quality such as: climate (Gladstones 1992), soil (Van Leeuwen and Seguin 1994), cultivar (Huglin and Schneider 1998), or rootstock (May 1997). The effects of vine water and nitrogen status, related to soil type, have been shown for winemaking in Cabernet Sauvignon and Merlot (Tregoat *et al.* 2002). Van Leeuwen *et al.* (2004) studied the three main components of terroir: climate, soil and cultivar simultaneously. They compared vine development and berry composition of Merlot, Cabernet Franc, and Cabernet Sauvignon cultivars on a gravelly soil, a soil with heavy clay subsoil and a sandy soil with a water table within the reach of roots. They also assessed the influence of climate as variations of maximum and minimum temperatures, degree days (base on 10 ˚C), sunshine hours, rainfall and water balance and found that the effects of climate, soil and cultivar were highly significant with regard to vine behavior and berry composition. They also found that many of the variables correlated with the intensity of vine water status.

Vineyard site selection. The initial site selection is very important in determining the potential yield and wine quality because the climatic and environmental factors are very difficult or impossible to change. Vineyard management and winemaking techniques will also affect the final wine quality. Therefore site selection is the most crucial decision in establishing a new vineyard (Gladstones 1992).

Climatic factors. Climatic suitability is perhaps the most important factor in site selection. Except low rainfall that can be offset by irrigation, most climatic factors such as temperature, incident sunshine, frost and humidity are not possible to control. Based on the stage of development of the grapevine, abnormal climatic events may affect winegrape yield and quality, with climate at veraison the most critical in grape quality determination (Jones and Davis 2000).

Temperature. Temperature has a large effect in the style of wine production, with the great wine regions characterized by low diurnal fluctuations in temperature around harvest (Gladstones 1992). Generally the lower the variation in temperature around the mean, the greater the grape flavor, aroma and pigmentation at a given maturity. For producing good table wines mean temperature in the month leading up to harvest needs to be around 15 and 21 °C (Johnson and Robinson 2001). However, Amerine and Winkler (1944) reported that although temperature regimes vary substantially in California, it has the capacity to produce high quality wines.

Although climate must be warm enough to allow grapes to mature, wine quality is generally inversely related to temperature during fruit maturation (Jackson and Lombard 1993). The titratable acidity and pH of the must are temperature-dependent and lower wine quality is often related to growth in warm climates that decrease titratable acidity

(Jackson and Lombard 1993). However, this is not always the case; Reynolds *et al.* (1996) found that warmer Gewurztraminer sites produced wines with the most intense fruity, muscat and cedar aromas and flavors together with a plesant aftertaste. Warm temperatures caused increased phenolic concentration of the must (Herrick and Nagel 1985), producing undesirable wines. Grapes ripening under cool temperatures (9 to 15 °C), especially whites, produce fresher wine with more acidity and a finer aroma (Jackson and Lombard 1993). For red wines, this situation is complicated considering that production of must/wine color is temperature-dependent with anthocyanin production optimized between 17 and 26 °C (Coombe 1970). Therefore, warmer average temperatures are preferred for good color development in red wine.

Solar radiation. Wine grapes need a photosynthetically-active radiation (PAR) > 700$\mu Em^{-2}s^{-1}$ for optimum photosynthesis. Below ~30$\mu Em^{-2}s^{-1}$ carbohydrate consumption is greater than production (Smart and Barrs 1973). Clear skies have a PAR of ~2500$\mu Em^{-2}s^{-1}$ and overcast skies between 300 and 1000$\mu Em^{-2}s^{-1}$ (Jackson and Lombard 1993). Generally speaking high levels of radiation, either intensity or duration, cause yield increases or enhanced sugar accumulation (Jackson and Lombard 1993). On the other hand, in cool climates, prolonged cloudy conditions reduce rates of photosynthesis (Kliewer 1970). Ebadi *et al.* (1996) found that as shading increased yield decreased, Shading also decreased sugar concentration and increased titratable acidity in berries (Smart *et al.* 1988).

Sun exposed berries have higher phenolic and anthocyanin concentrations but over-exposed berries can provide undesirable wine aroma (Carbonneau 1985). These undesirable aromas are due to an alteration in phenolic compounds within the grape, producing anthocyanins harmful for producing quality wines (Haselgrove *et al.* 2000). Therefore, growers have to properly manage the vine canopy to ensure that grapes are not over or under exposed to solar radiation.

Gladstones (1992) recommended certain minimum criteria for the amount of solar radiation required to grow quality grapes. For cultivars that ripen early at least 1200 sunshine hours are needed. Cool climate regions with < 1600 sunshine hours produce only table wines. In warm climates a minimum threshold of 1500 to1600 sunshine hours is required and < 1750 sunshine hours only table wines are produced. Hot climates with more than 2000 sunshine hours usually produce poor quality table or fortified wines. Halliday (1993) suggested that in warmer climates more sunshine hours are needed to reach optimum maturity, which is related to increased respiration consuming higher levels of assimilates at increased temperatures.

Irrigation and water stress. In the absence of good quality irrigation water, the shortage of rainfall could cause adverse affect on grape productivity. Johnson and Robinson (2001) suggest a minimum amount of 500 mm of rainfall/irrigation, and in regions with high evapotranspiration (ET) rates during growing season, this value may climb higher. Excess rainfall is also a problem and most quality wines are produced in regions where annual rainfall does not exceed 700 to 800 mm (Jackson and Schuster 1987). However, the timing of the excess rainfall is more important than its quantity (Johnson and Robinson 2001).

Water stress vs. vegetative growth and carbohydrate partitioning. Water availability has a clear effect on vegetative growth. Koundouras *et al.* (1999) determined water uptake of the rootstock cultivar Saint George in three non-irrigated vineyards. They found vegetative growth decreased early in the season in plot A (located at altitude of 350 m with high amount of gravel and stones between 0 and 50 cm depth) and late in plot N (located on a plain with altitude of 260 m, high amount of clay and loam and presence of a permanent water table within reach of the roots). Bravdo and Hepner (1986) found that vigor control by irrigation management in dry climates can provide a desirable rapid growth in spring followed by a slow growth from veraison to ripening. Water stress is also important in the fall when the grapevine prepares itself for winter by building up wood reserves. Carbohydrates produced by photosynthesizing leaves and nitrogen taken up by roots make these reserves, which will contribute to the success of the vine in the following season (Ludvigsen 1987). In northern climates with harsh and cold winters wood reserves play an important role in preventing winter damage due to cold temperatures (Wolf and Pool 1988). Water stress in grapevines on the other hand, is known to reduce photosynthetic ability through stomatal closure (Carbonneau *et al.* 1983, Schultz 1996). Water stress also reduces the amount of dry matter produced by the vine and subsequently reduces leaf area (Kliewer *et al.* 1983, Miller *et al.* 1996).

Esteban *et al.* (1999) observed increases in berry weight during stages II and III of berry growth in both irrigated and non-irrigated Tempranillo grapes. He reported a significant difference between irrigated and non-irrigated treatments while higher differences were seen when berries became larger due to the accumulation of solutes and water. Greater water availability in the irrigated treatment increased yield components such as cluster weight and clusters per vine. The increased vegetative growth due to irrigation resulted in higher pruning weights. Ollat and Gaudillere (1995) studied carbon imports into grape berries during their development in Cabernet Sauvignon grapevines.

They found that during the first growth period, carbon was equally partitioned between pericarp, seed development and respiration. At veraison carbon translocation towards berries increased three times while respiration rates did not change. Carbon was mainly stored as hexoses in the flesh. After veraison, flesh and skin were the main sinks for carbon. Bartolomé *et al.* (1995) compared non-irrigated Tempranillo vines to trickle irrigated ones which received water throughout the growing season in a semiarid climate. In both treatments, diurnal patterns of leaf Ψ, stomatal conductance and net photosynthesis decreased by the second date of measurements. A larger decrease in carbon assimilation was found in the stressed treatment due to water deficit plus leaf senescence. Stressed vines conserved water by reducing transpiration rates through stomatal closure. Water stress has many effects on plant productivity. One of the most important responses is decreased stomatal aperture, which enables the plant to reduce adverse conditions of water status. However, this leads to reduction in uptake of CO_2 and hence photosynthesis. According to Smart (1974), water-stress induced stomatal closure at -13 bars, though shoot growth rate was inhibited before negative tension became that large.

Water stress vs. floral initiation, berry growth, and yield components. During the differentiation of buds in late spring/early summer the vine is susceptible to water stress. Heavy spring rain can indirectly promote growth which suppresses bud differentiation and fruit setting by utilizing plant assimilates and over-shading (Johnson and Robinson 2001). Water stress over budburst has the potential to cause irregular budburst, short shoots, and fewer flowers (Mullins *et al.* 1992). Flowering and berry set are moisture sensitive and stress at this stage can strongly affect yield due to a decrease in vegetative growth (Christensen 1975, Ludvigsen 1987, Reynolds and Naylor 1994). Excess rain at flowering may also suppress yield. Vines can tolerate moisture stress from bud differentiation stage until a week or two before veraison, but severe stress a few weeks before and also after veraison has been shown to inhibit flavor development and lower berry size, berry weight and overall yield (Christensen 1975, Ludvigsen 1987, Reynolds and Naylor 1994). However, moderate stress at this stage seems to be favorable for color and flavor by limiting berry size, ceasing vegetative growth and redirecting assimilates to the clusters (Ludvigsen 1987, Matthews and Anderson 1988). Stress at this stage does not alter the ripening rate (Mathews and Anderson 1988).

Ollat and Gaudillere (1995), in a study on Cabernet Sauvignon showed that at the end of the first growing period, berries had reached 50% of their final fresh weight, 20% of their dry weight and 67% of their final volume. The yield of irrigated grapevines has been extensively studied. For instance, Kliewer *et al.* (1983) found a 25.6% increase in irrigated Carignane as well as increased berry weight and berry number per cluster compared to a non-irrigated treatment. Supplemental irrigation from bloom to veraison increased yield and vine size in Concord grapes (Morris and Cawthon 1982). Freeman *et al.* (1979) reported that irrigation increased yield in Shiraz vines at 80 and 160 nodes per vine due to increased berry weight; the maximum yield increase was shown to be 266% at the 160 node level. Christensen (1975) compared an early (early July) and a late (early August) irrigation cut-off through the maturation and harvest period in Thompson Seedless and found that total yield was not affected. The early cut-off treatment had a lower accumulation of total soluble solids per berry and lower raisin grades in addition to smaller berries in the last year of study.

Water stress vs. fruit composition and wine sensory attributes. Müller-Thurgau grown in pots and given dry conditions from veraison to harvest produced "fruity, fragrant and elegant wines". However, vines with adequate soil moisture during this period were "full-bodied and less elegant" (Becker and Zimmerman 1983). Preferred wines were from vines moist until veraison and then dry, least preferred wines were dry until veraison and then moist (Becker and Zimmerman 1983). Hardie and Martin (1989) proposed a strategy to improve table wine quality by maintaining minimal water stress until fruit set, and thereafter imposing sufficient water stress to control growth without seriously impairing photosynthesis and other physiological processes. Bartolomė *et al.* (1995) noticed that larger leaf area and higher photosynthesis in irrigated Tempranillo vines resulted in similar soluble solids as those of the non-irrigated vines while having a larger yield. Freeman and Kliewer (1983) on the other hand found reduced soluble solids in irrigated grapevines with increased pH and K concentration. They also noticed irrigation reduced the concentration of anthocyanins in berry skin and wine compared to non-irrigated vines. Freeman (1983), in an irrigation experiment on Shiraz grapevines, showed reduced wine color and increased pH in irrigated vs. non-irrigated vines. The reduction in wine color was correlated with an increase in berry size due to irrigation while water stress increased wine color. Koundouras *et al.* (1999) showed that in a non-irrigated gravely soil, berries were smaller, higher in sugar and anthocyanin concentration and lower in malic acid, while wine was rich in ethanol, anthocyanins and tannins. In another non-irrigated soil with high amount of clay and loam and presence of a permanent water table within reach of the roots, berries had a low sugar and anthocyanin concentration, and wine was low in ethanol and phenolics.

Because of the higher water content of the grapes, irrigation regimes have a major impact on grape juice composition, which results in dilution of some important components such as color and aroma factors. These factors are dependent to a large extent on the frequency and volume of water carried to the grapevines (Bravdo *et al.* 1985). Esteban *et al.* (1999) studied the impact of water availability on the yield and must composition of Tempranillo grapes. They found berry sugar content was higher in irrigated than non-irrigated treatments due to the higher photosynthetic activity or increased leaf area. According to Bravdo *et al.* (1985), sugar concentration was reduced in irrigated vines when the dilution caused by the berry growth was higher than that of sugar transport into the berry. Titratable acidity was higher and pH was lower under irrigation. Seguin (1983) emphasized the significance of water but concluded that insufficiency could be as bad as excess. Ludvigsen (1987) demonstrated that excessive irrigation would affect wine quality with significant changes in wine composition.

Identifying water stress in vineyards. Leaf Ψ measurement is a valuable tool in determining vine water status. It varies daily as well as seasonally and inversally related with solar radiation (Smart and Barrs 1973). Thus its value is lowest during midday due to increase in evaporative demands. Matthews *et al.* (1987) showed that weekly irrigating of vines had little effect on the early season decline in midday leaf Ψ. Liu *et al.* (1978) hypothesized that early season decline in vine water status may be due to the fact that transpiration exceeds the capacity of the root system to supply the water to the leaves, even under high soil water content.

Soil Factors of Site Selection. The importance of soil type on the quality of wine has long been understood. Gladstones (1992) reported that light wines from sandy soils are often lacking in strength and color but rich in aroma. Wines from limestone soils have high alcoholic content while clay soils produce acidic grapes, high in tannins that lead to rich red wines. He also stated that rocky, stony or chalky soils gave the best wines. Seguin (1986), on the other hand, reported that clay may have an influence on organoleptic character and the type of wine, but it was possible to produce high quality wines on stony soils with low pebble content. In all of these reports only the physical characteristics of soil were considered.

Chemical properties of soil as they relate to fruit composition and wine quality: The influence of soil chemical properties on must and wine quality has long been debated. Good soils for viticulture are often infertile; therefore it seems soil chemicals are not important for good grape production. The concentration of some specific ions is important for quality of must while the relationship between soil chemical concentration and must have not been well understood. Seguin (1986) stated that knowledge on the relationship is not enough otherwise it would be possible to produce excellent wines.

Potassium and nitrogen which are exceptions to the general lack of chemical knowledge, can affect wine quality. Although in recent years researchers have investigated the effect of other ions on grape production, the correlation of wine quality with soil chemistry is still considered circumstantial (Bohmirch 1996).

Potassium is a dominant element in determination of must quality and its concentration in the fruit is dependent on several climatic factors. Excess soil potassium is tolerable in cool climates since the climatic conditions are not suitable for its uptake by the vine. However, potassium deficiency can be a problem since it reduces vegetative growth and yield and increases the susceptibility of the vine to fungal and bacterial infections as well as uneven ripening of grapes (Van Huyssteen 1989). In hot climates excess K could raise a problem due to high accumulation in the vine, especially if there is a large flow of water through the plant (Rühl 1989).

Nitrogen is a major nutrient in production and fruit quality of grapevines. It has been observed that the fruit harvested from vines receiving adequate N provides less trouble in fermentation (Van Huyssteen 1989). Excess nitrogen availability is usually harmful since it promotes excessive vegetative growth, can cause groundwater pollution and delay ripening. As a result, it promotes disease by increasing shade and canopy humidity and may also cause deficiencies by increasing the vegetative demand for micro-nutrients (Gay Eynard *et al.* 1998).

The grapevine is very tolerant to soil pH. The main effect of soil pH is its impact on the availability of micro-nutrients (Gladstones 1992). However, Conradie (1983) reported that the vine does not perform well at pH values lower than 5.0, leading to stunted shoot and root growth. Conradie (1983) examined Chenin blanc grapevines grafted on 15 different rootstocks with respect to pH range. It was shwon that the average shoot mass production growing in pots at pH 5.0 and 6.0 were increased by 27% and 87% respectively compared to control plants growing at pH 4.1. Accordingly, root mass was increased by 11% and 32%.

Physical properties of soil as they relate to fruit composition and wine quality. Physical properties are traditionally the main factor being considered in a vineyard's soil selection. Water holding capacity and appropriate drainage are important for good grape production, especially in areas where irrigation is unavailable or not permitted. Shallow, poorly drained soils are prone to waterlogging and moisture deficiency (Gladstones 1992).

On the other hand, deep soils allow the development of an extensive root system which buffers the plant against fluctuations in soil moiture leading to a more consistent grape quality. In Mediterranean type environments the ability of soil to hold water is very important for grape production, especially in the areas that irrigation is prohibitted (Gladstones 1992).

Texture is the primary soil property managing its water holding capacity. The texture and depth of horizons in a soil profile should be considered in soil moisture estimation (Cass 1999). Stevens and Cole (1986) studied the effect of different amount of irrigation ranging from 740 to 1342 mm during the season on yield and must composition in vineyards in the Riverland region of South Australia. They found that increased water stress decreased yield and berry weight with no effect on must Brix, pH, TA, tartarate and potassium concentration. The quality of wine does not seem to have correlation with soil texture, since in wine producing regions, considerable variations can be seen in the gravel, pebble and clay content (Seguin 1986).

The need for good drainage is a key factor for vineyard selection whether water is supplied through rainfall or irrigation. For optimal production, roots need at least 15% air filled porosity (Cass 1998, 1999). According to Brown *et al.* (2001), in heavy clay soils excessive waterlogging can cause cane dieback and lead to poor vine growth for several years after the event. This can be improved by tilling and efficient drainage (Brown *et al.* 2001). Stony or rocky soil surface is a favorable characteristic for viticulture. These soils often have lower fertility and advantage of enhanced water infiltration due to their uneven surface which prevents water runoff. This also reduces the loss of topsoil due to erosion (Gladstones 1992).

Topographic factors of site selection. The topographic characteristics of a site are recognized to affect vine production by influencing the meso-climate of the site (Gladstones 1992). Gladstones (1977) reported that premium vineyards with topographic characteristic such as location on slopes which affect air drainage, facing the sun during part of the day, and proximity to large water bodies if located inland, show a lesser fluctuation in temperature.

Slope. The best sites are in general situated on slopes, while apart from some exceptions, plains or low lands are not very favorable for the production of quality wines. They have well structured, highly permeable, and well aerated soils (Seguin 1986). The location of the vine on a slope is more important since the degree of the slope will determine how the vine is affected by air drainage. During the night, cold and denser air settles down at the base of a slope. Directly above this cold layer, a thermal zone of warm air is established on the low to mid slope. This phenomenon is especially pronounced in isolated hills. Gladstones (1992) identified slope as the best approach to try to reduce diurnal temperature range. Another advantage of slope is proper water drainage and reduced risk of water logging (Bomrich 1996).

At higher latitudes, the angle of the slope becomes more important, since radiation interception becomes more limiting. Steeper slopes will receive more radiation per square meter due to a suitable aspect. However, slopes greater than 15% can create problems for operating machinery as well as increased potential for soil erosion (Wolf and Boyer 2003).

Aspect. In higher latitudes, where the sun's angle leads to weak radiation and limited light interception to growth, aspect is a critical factor in site selection. Sun-facing aspects are favorable even in lower latitudes (Gladstones 1992). In the northern hemisphere, east, west and south facing slopes and in the southern hemisphere east, west and north facing aspects are preferred (Wilson 1998). In both hemispheres, since westerly winds and storms may damage vines from early growth up to flowering, western aspects are less preferred (Gladstones 1992). At low and limited temperature, early morning radiation which heats up canopy and soil, easterly aspects are more appropriate (Wilson 1998). Conversely, during early-mid afternoon, westerly slopes are better exposed to solar radiation. Sun-facing aspects can also be problematic in regions where late frost is common. Increased warming during winter will promote early budbreak, hence, the risk of frost damage. In colder climates, heating during the day followed by sudden drop in temperature during the night may lead to bark splitting and cold damage (Wolf and Boyer 2003).

Water bodies. Water body can have a large impact on the local climate due to its temperature inertia compared to that of surrounding land (Magarey *et al.* 2000). Large inland water bodies such as lakes and rivers can influence the temperature of surrounding land in some distance. This provides protection against frost and high afternoon temperatures (Gladstones 1992). The Finger Lakes and Lake Erie Belt regions of New York State are good examples of regions where grape production is only possible due to the influence of the lakes (Magarey *et al.* 2000).

Precision viticulture. Site-specific management (SSM) also called precision agriculture is well adapted to high value crops such as many horticultural crops (Robert 2001). Precision viticulture (PV) is the use of a range of information technologies that enable grape growers and winemakers to better see and understand variability in their production systems. This knowledge may be utilized in matching the inputs optimally with desired or expected outputs (Bramley *et al.* 2003). In other words, PV depends on the existence of variability in product quantity and/or quality. The most convincing factor for the adoption of PV is the variability shown in vegetative, yield and quality in vineyards during the past few years (Bramley 2001, Hall *et al.* 2002). The key technologies involved in PV are global positioning systems (GPS), grape yield monitors, geographic information system (GIS) and remote sensing.

Pierce (2001) suggested that site-specific management is appropriate for wine grape production. Vineyard establishment can benefit from PV by reducing the net establishment costs. In fact the initial planting of vines in a vineyard is very important. If vines can initially be planted in zones of similar soil type or similar environment, it may reduce the need to differentially manage them later. In other words, by planting differentially, we can manage uniformly. This would be more economic than planting uniformly and managing differentially. For established vineyards, PV reduces the cost of producing high quality fruits either by increasing yield with the same quality, or reducing inputs.

Bramley (2001) showed that the yield varies with the amount and position of clay in the soil profile. Specifically, he found that the low yielding areas corresponded to areas where the clay subsoil occurred close to the surface, and that these areas were more prone to waterlogging in wet years. The pattern of yield variation in a vineyard in Coonawarra, Australia was shown to be temporally stable over a 3 year period. Different wine characteristics were produced in wines made from different zones (Bramley 2002).

GPS allows determination of location (latitude, longitude, altitude) by using specifically designed equipment to receive satellite signals and translate the information into a geographic location. Specifying a location with GPS is referred to as georeferencing. The accuracy of GPS equipment varies from a few centimeters to few meters with greater accuracy at greater cost. GPS is operated using software known as GIS to store data corresponding with specified location and its features. The analysis lead to a pictorial representation of georeferenced data that can be used to evaluate several attributes of a specific location (Davenport *et al* 2001).

Remote sensing is a potentially valuable tool for assessment of vineyard variability, and has particular application for mid-season monitoring (Hall *et al.* 2002). Recent studies have focused on centimeter-and meter-resolution multispectral remote sensing in the blue, green, red (R) and infra red (IR) bands of the electromagnetic spectrum. Collection of reflectance data at wavelengths corresponding to these parts of the spectrum allows calculation of a number of indices of canopy condition, of which the normalized difference vegetation index (NDVI; IR-R/IR+R) is the most commonly used (Hall *et al.* 2002).

Greenspan and O'Donnell (2001) investigated the spatial variability within two vineyard blocks to see if there were correlations between remotely sensed canopy density (NDVI) and some viticultural properties. They segregated a vineyard block into management zones and evaluated the ground-samples data to find if each property differed between zones. They noticed that dividing the blocks into management zones had different means of yield, Brix, and water status.

Bramley *et al.* (2003) collected imagery of a Cabernet Sauvignon block using airborne digital multispectral video (DMSV) at veraison in four separate wavebands corresponding with infra red, red, green and blue wavelengths. The variation in plant cell density index was considered as an indication of variation in vine vigor, and fruit from areas of low and high plant cell density were sampled and analyzed for maturity indices. On the basis of the imagery and subsequent analysis, they split the study area into a northern (high yielding) and southern (low yielding) areas. The fruit from the higher yielding area was considered suitable for classic dry red wine ($19/bottle), while, lower yielding area was assigned to the Cabernet Sauvignon varietal ($30/bottle). Had the block been harvested as a single unit, it would have all been assigned to the lower value wine.

Remote sensing of vine stress is difficult, especially when the goal is to determine the actual cause of the stress. For example, remotely sensed canopy density will identify stressed areas, but only reduced vegetative growth is revealed. Therefore remote sensing should be coupled with ground sampling as well (Greenspan and O'Donnell 2001).

Objectives

The general objective of this study was attempt to delineate water-status zones within commercial Cabernet Franc vineyards by GPS and GIS, using leaf Ψ and soil moisture measurements. The second objective was to verify if these within-site terroirs impact berry and wine composition and wine sensory response. The third objective was to find correlations between vine water status levels with total phenolics and or anthocyanins and finally this study tried to validate the VQA's sub-appellations in the Niagara Peninsula of Ontario.

Hypothesis

The first hypothesis was that soil type plays a minor role in the determination of grape and wine composition and sensory quality, and that vine water status plays a major role. The second hypothesis was that water status zones can be identified within vineyard blocks, and that this spatial variation will be consistent and stable temporally. The third hypothesis was that vine water status would cause differences in yield components and fruit composition and sensory attributes of wine.

Literature Cited

Amerine, M.A. and J.A. Winkler. 1944. Composition and quality of musts and wines of California grapes. Hilgardia 15:493-675.

Asselin, C., R. Morlat, H. Leon, J. Robichet, M. Remoue, and J. Salette. 1983. Methode d' analyse sensorielle adaptée a la caracterisation des vins rouges issus des terroirs differents. Sciences des Aliments 3: 245-263.

Bartolomė, M.C., V. Stoes, C. Ruiz, P. Bacza, and J.R. Lissarrague. 1995. Water management: A method to improve physiological activity in Tempranillo grapevines under field conditions in a semiarid climate. Poni, S Peterlunger, E. Iacono, F. Intrieri, C. (Eds.) First ISHS Workshop on Strategies to Optimize Wine Grape Quality. Italy.

Becker, N.J. and H. Zimmerman. 1983. Der Einfluss verschiedener Wasserversorgung auf Triebwachstum, Beerenentwickiung, Holzreife and Holzstrukter bei Topfreben. Wein-Wiss. 38:363-78.

Bohemrich, R. 1996. Terroir: Competing perspectives on the roles of soil, climate and people. J. Wine Research, 7:33-46.

Bramley, R.G.V. 2001. Progress in the development of precision viticulture-variation in yield, quality and soil properties in contrasting Australian vineyards. In Currie L.D. and Loganathan P. (Eds.) Precision tools for improving land management. Occasional report No 14. Massey University, New Zealand.

Bramley, R.G.V. 2002. Towards optimal resource management for grape and wine production. In: Blair, R.J. Williams, P.J. and Hsøj, P.B. (Eds.) Proceedings of the 11th Australian wine industry technical conference. Winetitles, Adelaide, pp. 274-275.

Bramley, R.G.V., B. Pearse, and P. Chamberlin. 2003. Being profitable precisely – a case study of precision viticulture from Margaret River. The Australian & New Zealand Grapegrower & Winemaker. Annual Technical Issue 84-87.

Bravdo, B., Y. Hepner, C. Loinger, S. Cohen, and H. Tabacman. 1985. Effect of irrigation and crop level on growth, yield and wine quality of Cabernet Sauvignon. Amer. J. Enol. Vitic. 36:132-139.

Bravdo, B., and Y. Hepner. 1986. Irrigation management and fertigation to optimize grape composition and vine performance. Acta Horticulture 206:49-67.

Brown, M.V., D.C. Ferree, D.C. Scurlock, and G. Siegel. 2001. Impact of drainage on growth, productivity, cane dieback, and fruit composition of Chambourcin and Pinot gris grapevines. HortTechnology 11:272.276.

Carbonneau, A., R.E. Smart, and C. de Loth. 1983. Measurement of gross photosynthesis under natural conditions by using a carbon dioxide fusion porometer. Photosynthetica 17:426-430.

Carbonneau, A. 1985.Trellising and canopy management for cool climate viticulture. In: Heatherbell, D.A. Lombard, P.B. Bodyfelt, F.W. and Price, S.F. (Eds) Proceedings of the International Symposium on Cool Climate Viticulture and Enology, Oregon, pp. 158-174.

Cass, A. 1998. Assessment of vineyard soils. In: Blair, R.J. Sas, A.N. Hayes, P.F. and Høj, P.B. (Eds.) Proceedings of the Tenth Australian Wine Industry Technical Conference. August 2-5, 1998, Sydney, New South Wales, pp. 78-82.

Cass, A. 1999. What soil factors really determine water availability to vines? The Australian Grapegrower and Winemaker Annual Technical Issue (426a):95-97.

Christensen, P. 1975. Response of Thompson Seedless grapevines to the timing of pre-harvest irrigation cut-off. Amer. J. Enol. Vitic. 26:188-194.

Conradie, W.J. 1983. Liming and choice of rootstocks as cultural techniques for vines in acid soils. S. Afr. J. Enol. Vitic. 4:39-44.

Coombe, B.G. 1970. Fruit set in grapevines: the mechanism of CCC effect. J. Hortic. Sci. 45: 415-424.

Davenport, J.R., L.J. Mills, J.M. Tarara, F.J. Pierce, and S. Lang. 2001. Application of GPS, GIS, yield monitors and °Brix monitors for effective vineyard management. In: A.G. Reynolds (Ed.) Space Age Winegrowing. Proceedings of a Symposium Held at White Oaks Conference Centre and Spa Niagara-on-the-Lake, Ontario. July 2001, pp. 50-55.

Duteau, J., M. Guilloux, and G. Seguin. 1981. Influence des facteurs naturels sur la maturation du raisin, en 1979, a Pomerol et Saint-Emilion. Connaissance de la Vigne et du Vin 15:1-27.

Ebadi, A., P. May, and B.G. Coombe. 1996. Effect of short-term temperature and shading on fruit-set, seed and berry development in model vines of *V. vinifera*, cvs. Chardonnay and Shiraz. Austral. J. Grape and Wine Research. 2:2-9.

Esteban, M.A., M.J. Villanueva, and J.R. Lissarrague. 1999. Effect of irrigation on changes in berry composition of Tempranillo during maturation, sugars, organic acids and mineral elements. Amer. J. Enol. Vitic. 50:418-434.

Freeman, B.M., H.L. Terence, and C.R. Turkingtone. 1979. Interaction of irrigation and pruning level on growth and yield of Shiraz vines. Amer. J. Enol. Vitic. 30:218-223.

Freeman, B.M. and W.M. Kliewer. 1983. Effect of irrigation, crop level and potassium fertilization on Carignane vines. II. Grape and wine quality. Amer. J. Enol. Vitic. 34:197-207.

Freeman, B.M. 1983. Effects of irrigation and pruning of Shiraz grapevines on subsequent red wine pigments. Amer. J. Enol. Vitic. 34:23-26.

Gay Eynard, G., M.A. Lovisolo, and M. Bovio. 1998. Nitrogen effects on yield and canopy of white Muscat grapevine. In: Possingham, J.V. and Neilsen, G.H (Eds.) Proceedings of the XXV International Horticultural Congress. Part 2, Mineral nutrition and grape and wine quality. Nutrition management to optimize fruit quality. 1998. Belgium.

Gladstones, J.S. 1977. Temperature and wine grape quality in European vineyards. In: Proceedings of the Third Australian Wine Industry Technical Conference, Albury, 7-11.

Gladstones, J.S. 1992. Viticulture and Environment. 310 pp. Winetitles, Adelaide.

Greenspan, M.D. and J.J. O'Donnell. 2001. Evaluating the utility of remotely sensed canopy density for the understanding of vineyard spatial variability. In: A.G. Reynolds (Ed.) Space Age Winegrowing. A Proceedings of a Symposium Held at White Oaks Conference Centre and Spa, Niagara-on-the-Lake, Ontario. July 2001, pp. 27-41.

Hall, A., D.W. Lamb, B. Holzapfel, and J. Louis. 2002. Optical remote sensing applications in viticulture-a review. Austral. J. Grape and Wine Research 8:36-47.

Halliday, J. 1993. Climate and soil in Australia. J. Wine Research 4:19-34.

Hardie, W.J. and Martin, S.R. 1989. A strategy for vine growth regulation by soil water management. Williams P.J. Davidson D.M. and Lee T.H. (Eds.) Proceedings of the seventh Australian wine industry technical conference, 1989 Australia.

Haselgrove, L., D. Botting, R. Van Heeswijck, P.B. Høj, P.R. Dry, C. Ford, and P.G. Iland. 2000. Canopy microclimate and berry composition: The effect of bunch exposure on the phenolic composition of *Vitis vinifera* L. cv. Shiraz grape berries. Austral. J. Grape and Wine Research 6:141-149.

Herrick, I.W. and Nagel, C.W. 1985. The caffeoyl tartrate content of white Riesling wines from California, Washington and Alsace. Am. J. Enol. Vitic. 36: 95-97.

Huglin, P. and Ch. Schneider. 1998. Biologie et ecologie de la vigne. Paris: Lavoisier Tec et Doc.

Jackson, D.I. and P.B. Lombard. 1993. Environmental and management practices affecting grape composition and wine quality-A review. Amer. J. Enol. Vitic. 44:409-430.

Jackson, D. and D. Schuster. 1987. Production of Grapes in Cool Climates. Butterworths. New Zealand.

Johnson, H. and J. Robinson. 2001. The World Atlas of Wine (5th edition). Mitchell Beasley, London.

Jones, G.V. and R.E. Davis. 2000. Using a synoptic climatological approach to understand climate-viticulture relationships. International J. Climatology, 20:813-837.

Kliewer, W.M. 1970. Effect of day temperature and light intensity on coloration of *Vitis vinifera* L. grapes. J. Amer. Soc. Hortic. Sci. 95:693-697.

Kliewer, W.M., B.M. Freeman, and C. Hossom. 1983. Effect of irrigation, crop level, and potassium fertilization on Carignane vines. I. Degree of water stress and effect on growth and yield. Amer. J. Enol. Vitic. 34:186-196.

Koundouras, S., C. Van Leeuwen, G. Seguin, and Y. Glories. 1999. Influence of water status on vine vegetative growth, berry ripening and wine characteristics in Mediterranean zone. J. Int. Sci. Vigne Vin. 33:149-160.

Liu, W.T., R. Pool, W. Wenkert, and P.E. Kriedemann. 1978. Changes in photosynthesis, stomatal resistance and abscisic acid of *Vitis labruscana* through drouth and irrigation cycles. Amer. J. Enol. Vitic. 29:239-246.

Ludvigsen, P.K. 1987. Wise use of irrigation could improve yield without harming wine quality. Australian Grapegrower and Winemaker (280):102-108.

Magarey, R., R. Seem, J. Zack, F. Wolf, and T. Martinson. 2000. A high resolution atmospheric model for prediction of winter injury and vineyard site selection. In: Proceedings of the Fifth International Symposium on Cool Climate Viticulture and Oenology, January, 2000, Melbourne, Australia.

Martin, D. 2000. The search for terroir- a question of management. In: Proceedings of the 5th International Symposium on Cool Climate Viticulture and Oenology, January 16-20, 2000, Melbourne, Australia.

Matthews, M.A., M.M. Anderson, and H.R. Schultz. 1987. Phenologic and growth responses to early and late season water deficits in Cabernet Franc. Vitis 26:147-160.

Matthews, M.A. and M.M. Anderson. 1988. Fruit ripening in *Vitis vinifera* L. Responses to seasonal water deficits. Amer. J. Enol. Vitic. 39:313-320.

May, P. 1997. Using Grapevine Rootstocks. The Australian Perspective. 62 pp. Winetitles, Adelaide.

McKenzie, D.E. and A.G. Christy. 2005. The role of soil chemistry in wine grape quality and sustainable soil management in vineyards. Water Science and Technology 51:27-37.

Miller, D.P., G.S. Howell, and J.A. Flore. 1996. Effect of shoot number on potted grapevines. Amer. J. Enol. Vitic. 47:244-256.

Moran, W. 2001. Terroir-the human factor. Australian and New Zealand Wine Industry Journal 16:32-51.

Morris, J.R. and D.L. Cawthon. 1982. The effect of irrigation, fruit load, and potassium fertilization on yield, quality, and petiole analysis of Concord (*Vitis labruscana* L.) grapes. Amer. J. Enol. Vitic. 33:145-148.

Mullins, M.G., A. Bouquet, and L.E. Williams. 1992. Biology of the Grapevine. Cambridge University Press, Cambridge, UK.

Ojeda, H., C. Andara, E. Kraeva, A. Carbonneau, and A. Deloire. 2002. Influence of pre- and postveraison water deficit on synthesis and concentration of skin phenolic compounds during berry growth of *Vitis vinifera* cv. Syrah. Amer. J. Enol. Vitic. 53:261-267.

Ollat, N. and P.J. Gaudillere. 1995. Investigation of assimilate import mechanisms in berries of *Vitis vinifera* var. Cabernet Sauvignon. Poni, S Peterlunger, E. Iacono, F. Intrieri, C. (Eds.) First ISHS Workshop on Strategies to Optimize Wine Grape Quality, Italy.

Pierce, F.J. 2001. Site-specific management for the 21st century. II. Application to perennial crops. In: Andrew G. Reynolds (Ed.) Space Age Winegrowing. A Proceedings of a Symposium Held at White Oaks Conference Centre and SPA Niagara-on-the-Lake, Ontario, July 2001, pp. 16-25

Rey, A., M. Tomi, T. Hore, and C. Tanet. 1998. Dictionnaire historique de la langue francaise, Paris: Dictionnaries Le Robert.

Reynolds, A.G. and A.P. Naylor. 1994. Pinot noir and Riesling grapevines respond to water stress duration and water-holding capacity. Hortscience 29:1505-1510.

Reynolds, A.G., D.A. Wardle, and M. Dever. 1996. Vine performance, fruit composition, and wine sensory attributes of Gewurztraminer in response to vineyard location and canopy manipulation. Amer. J. Enol. Vitic. 47:77-92.

Reynolds, A.G. and C. De Savigny. 2001. Use of GPS and GIS to determine the basis for terroir. In: Andrew. G. Reynolds (Ed.) Space Age Winegrowing. A Proceedings of a Symposium Held at White Oaks Conference Centre and SPA Niagara-On-The-Lake, Ontario, July 2001, pp. 79-102.

Robert, P. 2001. Precision agriculture for the 21st century. I. Status and research needs. In: Andrew G. Reynolds (Ed.) Space Age Winegrowing. Proceedings of a Symposium Held at White Oaks Conference Centre and SPA Niagara-on-the-Lake, Ontario, July 2001, pp. 7-15.

Rühl, E.H. 1989. Uptake and distribution of potassium by grapevine rootstocks and its implication for grape juice pH of scion varieties. Austral. J. Experimental Agric. 29:707-712.

Saxton, V. 2002. Calcium in viticulture-unraveling the mystique of French terroir. Australian and New Zealand Wine Industry Journal 17:28-33.

Schultz, H.R. 1996. Water relations and photosynthetic responses to two grapevine cultivars of different geographical origin during water stress. Acta Hortic. 427:251-266.

Seguin, G. 1975. Alimentation en eau de la vigne et composition chimique des mouts dans les Grands Crus du Medoc. Phenomenes de regulation. Conaissance de la Vigne et du Vin 9:23-34.

Seguin, G. 1983. Influence des terroirs viticoles. Bulletin de I'O.I.V. 56:3-18

Seguin, G. 1986. Terroirs and pedology of wine growing. Experimentia 42:861-872.

Seguin, G. 1988. Ecosystems of the great red wines produced in the maritime climate of Bordeaux, in: L. Fuller-Perrine (Ed.) *Proceedings of the Symposium on Maritime Climate Winegrowing*. Geneva, NY: Department of Horticultural Sciences, Cornell University.

Smart, R.E. and H.D. Barrs. 1973. The effect of environment and irrigation interval on leaf water potential of four horticultural species. Agric. Meteorol. 12:337-346.

Smart, R.E. 1974. Aspects of water relations of the grapevine (*Vitis vinifera*). Amer. J. Enol. Viticult. 25: 84-91.

Smart, R.E., and B.G. Coombe. 1983. Water relations of grapevines. *In* T.T. Kozlowski (Ed.): Water Deficits and Plant Growth. Academic Press, New York, pp.137-196.

Smart, R.E. Smith, S.M. and Winchester, R.V. 1988. Light quality and quantity effects on fruit ripening for Cabernet Sauvignon. Amer. J. Enol. Viticult. 39:250-258.

Smart, R. 2002. New World responses to Old World terroir. Australian and New Zealand Wine Industry Journal 17:65-67.

Stevens, R.M. and P. Cole. 1986. Grape must composition depends on irrigation management. In: Lee T. (Ed.) Proceedings of the Sixth Australian Wine Industry Technical Conference, Adelaide, pp 159-164.

Tregoat, O., J.P. Gaudillere, X. Chone, and C. van Leeuwen. 2002. Etude du regime hydrique et de la nutrition azotee de la vigne par des indicateurs physiologiques. Influence sur le comportement de la vigne et la maturation du raisin (Vitis vinifera L. cv Merlot, 2000, Bordeaux). Journal International des Sciences de la Vigne et du Vin 36:133-142.

Vaudour, E. 2002. The quality of grapes and wine in relation to geography: Notions of terroir at various scales. Journal of Wine Research 13:117-114.

Van Huyssteen, L. 1989. The effect of soil management and fertilization on grape composition and wine quality with special reference to South African condition. In:Williams, Patrick J. Davidson Dianne M. and Lee Terry H. (Eds) Proceedings of the seventh Australian wine industry technical conference. Adelaide, South Australia.

Van Leeuwen, C. and G. Seguin. 1994. Incidences de l'alimentation en eau de la vigne, appreciee par l'etat hydrique du feuillage, sur le development de l'appareil vagetatif et la maturation du raisin (*Vitis vinifera* variete Cabernet franc, Saint-Emilion, 1990). Journal International des Sciences de laVigne et du Vin 28:81-110.

Van Leeuwen, C., P. Friant, X. Chone, O. Tregoat, S. Koundouras, and D. Dubourdieu. 2004. Influence of climate, soil and cultivar on terroir. Amer.J. Enol. Vitic. 55:207-217.

Vilanova, M., S. Zamuz, F. Vilarino, and C. Sieiro. 2007. Effect of terroir on the volatiles of *Vitis vinifera* cv. Albarino. J. Sci. Food Agric. 87:1252-1256.

Wilson, J. E. 1998. Terroir – the role of geology, climate and culture in the making of French wines. Mitchell Beasley, London.

Wolf, T.K. and R.M. Pool. 1988. Nitrogen fertilization and rootstock effects on wood maturation and dormant bud cold hardiness of cv. Chardonnay grapevines. Amer. J. Enol. Vitic. 39: 308-312.

Wolf, T.K. and J.D. Boyer. 2003. Site selection for commercial vineyards. Virginia Cooperative Extension. Publication Number 463-020.

Chapter 3

Spatial Variability in Ten Cabernet Franc Vineyards in the Niagara Peninsula of Ontario. I. Soil Composition, Soil Texture, and Soil and Vine Water Status.

Abstract. The influence of vine water status was studied in commercial vineyard blocks of *Vitis vinifera* L. cv. Cabernet Franc in Niagara Peninsula, Ontario from 2005 to 2007. Soil texture, soil chemical composition, soil moisture and leaf water potential, as indicators of vine water status, were determined and compared within ten research vineyard blocks. In each vineyard block, water status zones were identified on GIS-generated maps using leaf water potential (Ψ) and soil moisture measurements. Spatial correlation analyses demontrated that soil moisture zones were consistent at one vineyard (Reif) in 2005 to 2006 while in 2006 to 2007 consistency was observed at six blocks including Buis, Cave Spring, Chateau des Charmes, Henry of Pelham, Morrison and Reif. Leaf Ψ zones were temporally consistent at Harbour Estate over three years from 2005 to 2007; at the Hernder site from 2005 to 2006; and at Reif site from 2006 to 2007. Spatial correlation analyses between soil texture and soil chemicals, including percent organic matter, cation exchange capacity, soil pH and base saturation, K, P, Ca and Mg demonstrated site-specific relationships.

Introduction

Vineyard variability has been the subject of recent studies where spatial variation has been demonstrated in terms of vegetative growth, yield and fruit composition (Bramley 2001, Hall *et al.* 2002). Precision viticulture (PV) is an appropriate means to study the vineyard variability. It is a range of information technologies that enables grape growers to better understand variability in their production systems. This knowledge may be utilized in matching the inputs with desired or expected outputs (Bramley *et al.* 2003). In other words, PV depends on the variability in product quantity and/or quality.

Bramley (2001) reported that yield varies with the percentage and position of clay in soil profile. Specifically, the low yielding areas corresponded with areas where the clay subsoil occurred close to the surface, and that these areas were more prone to waterlogging in wet years. The pattern of yield variation in a vineyard in Coonawarra, Australia, was shown to be temporally stable over a 3 year period. Different wine characteristics were produced in wines made from different zones (Bramley 2002).

In terms of sampling vines for the purpose of managing crop nutrition, petioles may be collected using geo-referenced sampling points by a GPS. In this case, the vineyard manager will be enabled to supply proper nutrients necessary for individual vines rather than uniform fertilization of entire vineyard (Bramley *et al.* 2003).

Remote sensing is a technology involved in PV, which could be a valuable mean in assessing vineyard variability. This has particular application for mid-season monitoring of vineyards (Hall et al. 2002) with a focus on elaboration of centimeter and meter-resolution multispectral remote sensing in wavelengths including blue, green, red (R) and infra-red (IR). Collection of reflectance data at these wavelengths enables calculating number of indices corresponding with canopy condition. The most commonly used index is the normalized difference vegetation index (NDVI; calculated from IR-R/IR+R) (Hall *et al.* 2002).

Greenspan and O'Donnell (2001) investigated the spatial variability within two vineyard blocks to see if there was any correlation between remotely sensed canopy density (NDVI) and viticultural properties. They split a vineyard block into management zones and evaluated the ground-samples data to find if each property differed between zones. They noticed that dividing the blocks into management zones provided different yield, Brix, and water status.

Johnson *et al.* (1996) used airborne digital sensors to collect visible and near-infrared images of phylloxera-infested (*Daktulosphaira vitifoliae*) vineyards in Napa County, California. Reduced vegetative growth was found as the most pronounced symptom of phylloxera-induced stress. Image values strongly corresponded with ground measurements of vine pruning weight and leaf area. The images were utilized for mapping patterns of leaf area and assessing year-to-year changes in canopy. The imagery was shown to be beneficial in planning for replacement of phylloxera-infested fields, managing for crop uniformity and segregating grapes with different quality during harvest.

Remote sensing of vine stress is challenging, especially when the goal is to determine the actual cause of the stress. For example, remotely sensed canopy density will be able to identify stressed areas, but only reduced vegetative growth is revealed; hence remote sensing should be combined with ground sampling as well (Greenspan and O'Donnell 2001).

The purpose of this study was to determine spatial variability with respect to soil composition, soil texture, soil and vine water status in ten Cabernet Franc vineyards in the Niagara Peninsula of Ontario.

Materials and Methods

Site and variety selection. Ten commercial vineyard blocks of Cabernet Franc variety were selected, one each in ten sub-appellations of the Niagara Peninsula including: Niagara Lakeshore, St. Davids's Bench, Creek Shores, Four Mile Creek, Niagara River, Lincoln Lakeshore, Beamsville Bench, Short Hills Bench, Vinemount Ridge, and Twenty Mile Bench for the project in Spring of 2005 (Table 1). General features of each vineyard including VQA sub appellation, area of vineyard, number of sentinel vines (72 at Vieni– 80 at CDC), soil series, parental material, soil drainage, clone, rootstock, year of planting, vine spacing, and floor management were recorded for each vineyard (Table 2).

Table 1- The origin of each Cabernet Franc site and its related sub-appellation, Niagara Peninsula, Ontario.

	Name of vineyard block	Abbreviation	Name of sub-appellation
1	Buis		Niagara Lakeshore
2	Château des Charmes	CDC	St. Davids's Bench
3	Hernder		Four Mile Creek
4	Reif		Niagara River
5	George		Lincoln Lakeshore
6	Harbour Estate	Harbour	Creek Shores
7	Cave Spring		Beamsville Bench
8	Henry Of Pelham	HOP	Short Hills Bench
9	Vieni		Vinemount Ridge
10	Morrison		Twenty Mile Bench

Table 2. General features of Niagara Peninsula Cabernet Franc vineyards used for elucidation of terroir study, 2005-07.

Variable	**Sites**				
	Chateau des Charmes	**Rief**	**Hernder**	**Buis**	**Henry of Pelham**
VQA Sub-appellation	St. David's Bench	Niagara River	Four Mile Creek (Lakeshore Plain)	NOTL Lakeshore	Short Hills Bench
Area of vineyard block (ha)	2.29 ha	0.61	2.63	0.71	2.17
Number of sentinel vines	80	84	70	77	80
Soil series	TLD7	CGU 7	CGU 1	CGU 19	BVY 1
Parent materials	Lacustrine silty clay	Washed reddish hued clay loam till, modified by lacustrine processes	Mainly clay loam till	Mainly reddish hued clay	Mainly lacustrine silty clay
Soil drainage	Imperfect to poor	Imperfect	Imperfect	Imperfect to poor	Imperfect
Rootstock	3309	3309	3309	So4 + 3309	So4
Vine age at initiation of trial (yr planted)	1992	1999	1998	1988	1999
Vine spacing (m; row X vine)	2.2m X 0.9m	3.0m X 1.3m	2.8m X 1.25m	2.9m X 1.3m	2.7m X 1.3m
Number of rows; vines per row	27 rows; 376 vines/ row	6 rows @ 284v/r	58 rows @ 137v/r	20 rows@ 118 v/r	29 rows @240v/r
Training system	Guyot	Pendlbogen	Vertical Shoot Positioning (VSP)	Scot Henry	VSP
Floor management	Clean	Alternate sod	Alternate sod	Clean	Alternate sod

Table 2. Contd.

Variable	**Sites**				
	Harbour Estates	**Morrison vineyard**	**Cave Spring**	**George Vineyard**	**Vieni Estate**
VQA Subappellation	Creek Shores	20 Mile Bench	Beamsville Bench	Lincoln Lakeshore	Vinemount Moraine
Area of vineyard block (ha)	1.67 ha	0.97	1.54	1.23	1.19
Number of sentinel vines	80	72	75	72	72
Soil series	VIT 16	CSH 3	CGU 14	CGU 24	CGU 1
Parent materials	40-100 cm reddish-hued sandy textures over lacustrine silt loam	40-100 cm lacustrine silty clay over clay loam till	15-40 cm loamy textures over clay loam till	Washed clay loam till, modified by lacustrine processes	Mainly clay loam till
Soil drainage	Imperfect	Moderately well	Imperfect	Imperfect-poor	Imperfect
Rootstock	Riparia	So4	101-14	So4	So4
Vine age at initiation of trial (yr planted)	1999	1999	1999	1995	1998
Vine spacing (m; row X vine)	2.7m X 1.5m	2.9m X 1.3m	2.7m X 1.44m	2.7m X 1.4m	2.0m X 1.25m
Number of rows; vines per row	37 rows @ 105 vines/ row	18 @ 155	23 rows @ 233	24 rows @ 137 v/r	30 rows @135 v/r
Training system	Scott Henry	Scott Henry	VSP	VSP	VSP
Floor management	Clean	Clean	Alternate sod	sod	Alternate sod

Site features. The project consisted of ten sites in which soil parent material ranged from lacustrin silty clay, reddish hued clay, and loamy texture to reddish hued sandy texture (Table 2). Soil drainage was imperfect to poor, imperfect or moderately well drained. Area of vineyard blocks varied from 0.6 ha (Rief) to 2.6 ha (Hernder). Vine spacing varied from 2.0 m X 1.25 m (vine X row) at Vieni Estate to 3.0 m X 1.3 m at Rief. Training system was pendelbogen, Scott Henry, VSP or Guyot . Floor management in some sites was clean and in the others was alternate sod. Rootstocks were 101-14, 3309 or SO4 and vine age varied from 7 to 18 years (Table 2).

GPS and GIS. Raven Invicta 115 GPS Receiver Raven Industries (Sioux Falls, SD) (with 1.0 to 1.4 meters accuracy) was used to delineate the shape of each vineyard block as well as to geo-locate each sentinel vine. Using GIS programs MapInfo and Vertical Mapper (Northwood GeoScience, Ottawa, ON) water status zones were mapped based on vine leaf Ψ values (Table 3). The inverse distance weighting (IDW) interpolation algorithm was used to construct the grid files. IDW interpolation algorithem was chosen vs. Kiriking due to uneven nature of vineyards. In this method, closer grid points have more influence on the calculation of unknown grid values compared to the points that are further away. In regard with power, exponential option was selected, which enables the user to define the exponential rate of decreasing the influence by neighbouring points that lie further from the point being calculated. The lowest value was chosen for exponential rate. The values on each zone of the constructed maps were the minimum value of the range for that zone. Spatial correlation analysis was performed in Vertical Mapper, which gives an r value. However, there is no p-value associated with r-values. Therefore, the higher r-values (higher than 0.6) assumed to be significant.

Each vineyard block was separated into three zones of high, medium, and low water status (HWS, MWS, LWS respectively). Grapes from each of these water status zones were harvested separately based on the leaf Ψ map at each vineyard block in both 2005 and 2006 and were used to make wine. Therefore, from each vineyard block three types of HWS, MWS and LWS wines were made with three replicates each in both years.

Soil sampling. Soil samples were collected from every fourth vine with an auger from within the row, 40 to 50 cm apart from the trunk. Soil was taken from a 0 to 45 cm depth and in total about 350 g of a homogenized sample was taken. Based on the area of each vineyard block, 15 to 20 soil samples were taken. Soil samples were analyzed for pH, organic matter, P, K, Mg, Ca, texture, CEC, and base saturation using standard procedures (CSSS 1993).

Soil water status. Soil moisture data were taken bi-weekly between late June and early September in 2005 growing season for a total of five sampling dates. These data were determined via a Theta Probe model ML2X (Delta-T Devices Ltd., Cambridge, UK). Probe readings (% water by volume) were taken at each experimental vine in each block. A total of 72 to 80 vines were measured between 0800h and 1800h. Measurements were taken in the row ca 10 cm from the base of each vine trunk over a 40 mm depth. In 2006 and 2007 growing seasons, soil moisture in percent water by volume was measured at each sentinel vine using a Fieldscout TDR-300 soil moisture probe (Spectrum Technologies Inc., East Plainfield IL) on five separate dates between late June and early September. Measurements were taken in the row ca 10 cm from the base of each vine trunk over a 12 cm depth. The mean soil moisture at each sentinel vine was calculated from the five separate readings. Both Theta Probe and TDR measure soil moisture were based on the principal of time domain reflectometry.

Vine water status. Midday leaf water potential (Ψ) was determined between 1100h and 1600h for fully exposed, mature leaves of similar physiological stage which showed no visible sign of damage and had been in full sunlight. Each leaf sample was covered in a plastic bag and sealed immediately after excision at the petiole to suppress transpiration. The leaf petiole was cut with a sharp razor blade and then inserted into a pressure chamber Model 3005 Plant Water Status Console (Soil Moisture Equipment Corp., Santa Barbara, CA) with the cut edge of the petiole facing the outside surface. After sealing the chamber, pressure was increased slowly by opening the compressed nitrogen gas valve. As soon as sap emerged at the cut end of the petiole, gas flow was stopped and the corresponding pressure was recorded from the gauge, which was in negative bar units (10 bars = 1 MPa) (Turner 1988). A total of 15 to 20 leaves per vineyard block were used to estimate leaf Ψ for each sample date. Overall, there were five sampling dates during the growing season; bi-weekly between late June and early September for each site.

Data analysis. Within each vineyard block, high and low water status zones were identified accordingly based on GIS- generated maps, and fruit were harvested separately from each zone. In each vineyard block all data were analyzed based on high and low water status treatments using SAS statistical package version 8 (SAS Institute; Cary, NC, USA). Correlation analysis was performed at each vineyard block as well as across the blocks for each year. Spatial correlation analysis was done by MapInfo and Vertical Mapper (Northwood GeoScience, Ottawa, ON) at each site and each year.

Results

Spatial variation at the research sites. Soil texture and composition. Parent material in research blocks ranged from lacustrine silty clay, reddish hued clay and loamy texture to reddish hued sandy texture. Sand varied from 26 to 52% across all sites with highest % sand at Harbour followed by Buis and Rief sites, while clay ranged from 10 to 23% with highest % clay at CDC and Buis sites (Fig. 1 & 2). Organic matter ranged between 1.0 and 6.0%, values lower than 3.0% is considered somewhat low, while cation exchange capacity (CEC) ranged between 6 to 53 (meq/100 g soil) (Fig. 3, 4). CEC values > 20 are considered optimal and lower values can be raised by addition of organic matter. Soil pH ranged between 5.5 and 8.0 (Fig. 5). Soil base saturation as Ca ranged between 32 to 94% (Fig. 6). Soil phosphorus (P) varied between 6 and 186 mg/kg and potassium (K) from 101 to 653 mg/kg (Fig. 7 & 8). Soil calcium (Ca) ranged between 514 and 9898 mg/kg and magnesium (Mg) ranged between 100 and 716 mg/kg (Fig. 9, 10).

Soil and vine water status 2005 to 2007. Soil moisture in 2005 ranged from 7 to 20%, in 2006 from 11 to 36% and from 4 to 28% in 2007 (Fig. 11 to 15) across all sites. The lowest and highest soil moisture was observed at Hernder and Buis in 2005, at Rief and Vieni in 2006 and at Harbour and Buis in 2007 respectively (Table 3). Leaf Ψ ranged from -8.0 to -16.0 bars in 2005, between -8.2 and -16.0 in 2006, and from -9.3 to -16.4 bars in 2007 (Fig. 16 to 20) across all sites. The highest and lowest leaf Ψ was observed at Harbour and CDC in 2005, at Vieni and Hernder in 2006 and at Harbour and CDC in 2007, respectively (Table 3). Leaf Ψ values were the basis for the water status treatments that were tested in terms of yield components, and berry composition, and those from which wines were made in 2005 and 2006.

Soil moisture was spatially consistent at Rief site across the 2005 to 2006 vintages (Fig. 12D,E), while it was consistent at six sites from the 2006 to 2007 vintages including Buis, Cave Spring, CDC, HOP, Morrison, and Rief (Fig. 11B,C,E,F, 14B,C,E,F, 15E,F). Leaf Ψ was spatially consistent at Harbour over the three years (Fig. 18A,B,C); at Hernder site it was consistent in 2005 to 2006 vintage (Fig. 17A, 17B) while at Rief it was consistent in 2006 to 2007 vintage (Fig. 17E, F).

Spatial correlation analysis. ***Soil texture and composition.*** Spatial correlation analysis indicated that at the Buis site in 2005, percent sand was highly spatially correlated with percent organic matter (OM) and was inversely correlated with percent clay, Ca, Mg, and soil pH (Fig. 1A, 2A, 3A, 5A, 9A, 10A). Percent clay showed positive spatial correlation with Ca, Mg, and soil pH but negatively correlated with K, P, and OM (Fig. 2A, 3A, 5A, 7A, 8A, 9A, 10A).

The 2005 spatial correlation analysis of the CDC site showed that % clay was negatively correlated with % sand (Fig. 1B, 2B) and % sand was inversely correlated with soil moisture (Fig. 1B, 11D). Ca was positively correlated with CEC, BS, and soil pH while inversely correlated with Mg (Fig. 4B, 5B, 6B, 9B, 10B). CEC positively correlated with BS and soil pH but had negative correlation with Mg (Fig. 4B, 5B, 6B, 10B); K positively correlated with OM (Fig. 3B, 8B); Mg positively correlated with leaf Ψ and P while inversely correlated with soil pH (Fig. 5B, 7B, 10B, 16A).

At the Hernder site spatial correlation analysis in 2005 indicated that Ca positively correlated with BS and soil pH (Fig. 5C, 6C, 9C). K positively correlated with P (Fig. 7C, 8C). Spatial correlation analysis in 2005 at Rief showed that % clay correlated positively with soil base saturation, Ca, CEC and soil pH, but negatively correlated with P, K and OM (Fig. 2D, 4D, 5D, 6D, 9D); OM positively correlated with Ca and CEC while inversely correlated with BS, K and Mg (Fig. 3D, 4D, 6D, 8D, 9D, 10D); Ca positively correlated with K and soil pH and negatively correlated with OM and Mg (Fig. 3D, 5D, 8D, 9D, 10D).

In 2005 spatial correlation analysis at the Harbour site showed that percent clay negatively correlated with percent sand (Fig. 1E, 2E). In 2005 spatial correlation analysis at George site indicated that percent clay was highly correlated with Ca, K, Mg, soil base saturation (BS), soil pH and leaf Ψ while negatively correlated with percent sand (Fig. 1F, 2F, 5F, 6F, 8F, 9F, 10F, 18D); percent sand negatively correlated with soil pH, BS, Mg, and Ca (Fig. 1F, 5F, 6F, 9F, 10F); Ca positively correlated with CEC, OM, BS, and soil pH (Fig. 3F, 4F, 5F, 6F, 9F,); K positively correlated with Mg and soil pH (Fig. 5F, 8F, 10F).

Spatial correlation analysis at Cave Spring in 2005 revealed that percent sand negatively correlated with soil pH, CEC, Ca, P, and BS while positively correlated with Mg (Fig. 1G, 5G, 6G, 7G, 9G); Ca positively correlated with CEC, P and soil pH while negatively correlated with Mg (Fig. 4G, 5G, 7G, 9G, 10G). At HOP spatial correlation analysis in 2005 indicated that percent clay positively correlated with soil pH, Ca, CEC, BS and negatively correlated with OM and percent sand (Fig. 1H, 2H, 3H, 4H, 5H, 6H, 9H) while percent sand negatively correlated with percent clay and soil pH (Fig. 1H, 2H, 5H).

Spatial correlation analysis at Vieni in 2005 revealed that percent clay negatively correlated with percent sand and leaf Ψ while positively correlated with BS, Ca, CEC, Mg and soil pH (Fig. 1I, 2I, 4I, 5I, 6I, 9I, 10I, 20A), while percent sand negatively correlated with percent clay and Mg (Fig. 1I, 2I, 10I). Spatial correlation analysis at Morrison site in 2005 illustrated that clay negatively correlated with sand and OM (Fig. 1J, 2J, 3J); Ca positively correlated with CEC and BS (Fig. 4J, 6J, 9J).

Correlation analysis. ***2005.*** Correlation analysis of soil factors for all sites in 2005 indicated that leaf Ψ was positively correlated with percent clay, organic matter (OM), soil pH, base saturation, Ca and Mg, and was negatively correlated with percent sand. Soil moisture had positive correlation with CEC, base saturation, and Ca, but was negatively correlated with K. Mg was positively correlated with percent clay, OM, CEC, soil pH, base saturation and Ca, but was negatively correlated with percent sand, P and K. Ca was positively correlated with percent clay, CEC, soil pH and base saturation, and was negatively correlated with percent sand; K was positively correlated with P and percent sand, and was negatively correlated with base saturation; P was negatively correlated with percent clay and base saturation but had positive correlation with percent sand. Base saturation had a positive correlation with percent clay, CEC and soil pH, and was negatively correlated with percent sand. Soil pH was positively correlated with CEC and percent clay and negatively with percent sand; OM and CEC both negatively correlated with percent sand and positively with percent clay; percent clay negatively correlated with percent sand (Table 4).

Discussion

Spatial variability

Soil moisture. Based on the range of soil moistures obtained at each site and in each year, it was possible to identify soil water status zones at each vineyard block; therefore this part of hypothesis was supported by the data in all three years. However, the hypothesis that the spatial variation would be stable temporally was only partially proven by the data. This hypothesis carried with it the assumption that soil water status zones as well as vine water status zones would be stable temporally. This stable water status zones would give opportunity for selective harvest of these different sections of the block. Since this variation is often reflected in yield and fruit quality, it is often to the winemaker's advantage for these zones to be individually harvested which would translate to different wine quality from the same vineyard block and with the opportunity of separating high quality grapes from low quality ones. Therefore, it would be possible to produce some high quality wine that would translate to higher income to the winery rather than blending all grapes to a lower quality wine.

The lowest and highest soil moistures at different sites during the growing season of 2005 to 2007 are presented at Table 3. Hernder had a loam soil texture with a shallow soil profile therefore; the ability of soil to retain water was low. Rief contained a loam soil texture with lot of gravels that facilitate faster soil drainage. Harbour, with 48% sand, had a sandy loam soil texture that provided less soil moisture retention. Buis site had deep loam soil with higher ability to hold water in the soil profile. Soil texture is an important factor that affects soil water retention. Goldberg *et al.* (1971) reported the range of available soil moisture from 30 mm/m of soil depth for sands and 160 mm/m for clays.

The capacity of soil to store water depends on root zone depth and soil water holding capacity. Infiltration rate also has significant effect on water supply (Smart and Coombe 1983).

Volumetric soil moisture values varied among vineyards as well as within vineyards in all three years. The lowest soil moisture values were observed at the Hernder, Reif and Harbour sites. At Hernder low soil moisture values were 7.3%, 15.1% and 6.1% in 2005, 2006 and 2007, respectively; whereas the high soil moisture values were 6.1%, 12.9% and 21.6% higher for the same periods of time. At Reif low soil moisture values were 7.6%, 11.3% and 8.8% in 2005, 2006 and 2007, while values were 6.0%, 14.3% and 12.5% higher in high soil moisture areas. Likewise, at Harbour site low soil moisture values were 9.9%, 11.7% and 3.5% in 2005, 2006 and 2007, while values were 3.5%, 7% and 5% higher in high soil moisture areas. The low soil moisture values at these sites can be attributed to shallow soil profile, sandy loam soil texture and higher content of gravels in the soil that do not allow for high water retention in the soil profile.

The highest soil moisture values in 2005 were at Buis site in a range of 14.0% to 20.4%; in 2006 the highest soil moisture values were observed at Vieni site with the range of 22.2% to 35.9% and in 2007 Buis site had the highest soil moisture with the range of 17.2% to 27.6%. Overall, soil moisture values were higher in 2006 at all sites in comparison with 2005 and 2007 due to higher precipitation in 2006 and also due to soil moisture measurement by TDR rather than Theta Probe which was able to measure soil moisture in higher depths (Table 4). High soil water availability reduced vine water stress by decreasing the absolute leaf Ψ values. The data indicated that midday leaf Ψ was a better indicator of vine water status than soil moisture content (Fig. 21).

Leaf water potential. The results demonstrated that leaf Ψ values varied within all vineyard blocks enabling vine separation into three groups, high, medium and low water status (HWS, MWS, LWS), at each vineyard block and in all three years, therefore this part of hypothesis was proven by data in all three years. The highest and lowest leaf Ψ values were observed at Harbour and CDC in 2005, at Vieni and Hernder in 2006 and at Harbour and CDC in 2007 respectively (Table 3). Water stress was always more intense at the CDC and Hernder sites. The lowest leaf Ψ values at CDC (2005, 2007) was possibly due to heavy clay loam soil texture at this site which, even with relatively high soil moisture in soil profile (14% and 17.2%) water may have been less available for the vines. The lowest leaf Ψ value at Hernder in 2006 was likely due to shallow soil and loam soil texture that had less moisture in the profile. The highest leaf Ψ values at Harbour (2005 and 2007) could be due to a sandy loam soil texture as well as a deep soil profile that permitted vigorous vine growth. Long and deep roots of these vines allowed them to absorb water from deeper soil layers; therefore vines at this site did not face water stress in any of three years. Williams and Araujo (2002) reported the Chardonnay vines that received irrigation water of 100% evapotranspiration (ET) had leaf Ψ values of – 10 bars, which suggest that vines at the Harbour site had adequate water availability, similar to that of irrigated vines. Smart and Coombe (1983) indicated that grapes growing in deep coarse sands or gravel, have been found with roots penetrating to depths of 6 m and more. The highest leaf Ψ value at Vieni in 2006 was due to high soil moisture in that year; in fact in 2006 Vieni site had the highest soil moisture among all ten sites (Table 3). Although leaf Ψ was different within each vineyard block as well as across vineyards, the range of leaf Ψ values remained almost consistent in most vineyard blocks in all years even with different weather conditions (Table 3). In terms of sample size, 15 to 20 leaf samples were measured at each sampling date. These measurements were repeated five times during the growing season. The little temporal variation within the season suggests that the data density was sufficient. In 2005 and 2007, which were dry and hot years, water stress appeared earlier and was more severe. The leaf Ψ values observed in different sites are in the range commonly reported for non-irrigated grapevines (Williams and Matthews 1990). Under the conditions of this study, the data indicate that midday leaf Ψ would be a better indicator of vine water status than soil moisture content. Therefore, the hypothesis of water-status zones can be identified within vineyard blocks was supported by data.

Temporal stability

Soil moisture. Soil moisture zones were temporally stable at Rief for 2005 and 2006. However, from 2006 to 2007 soil moisture zones were temporally stable at six sites including: Buis, Cave Spring, CDC, HOP, Morrison and Rief. This could be in part due to the use of Theta Probe rather than TDR in 2005. The Theta probe was able to measure soil moisture only in the top 4 cm, while TDR was able to measure soil moisture in the top 20 cm. The moisture variation in the top 5 cm of soil can be high, as a little rain will result in high soil moisture readings. That is especially true in heavy clay soils with low infiltration rates while, the lower layers might be drier. On the other hand, when the soil surface is dry (no rain) it shows low soil moisture while lower layers of soil may contain moisture. The majority of the rootsystem of grapevines is found in the top one meter of soil (Van Zyl and Weber 1981) (most of them in 30 to 50 cm) and studies have shown that a grapevine's rootsystem may grow up to 600 cm deep through the soil (Smart and Coombe 1983). The vineyard blocks in this study were all non-irrigated sites and were expected to have roots growing deeply in the soil profile. On the other hand, soil water table is relatively high in Niagara hence most of roots are in the top 30 cm. Therefore, measuring soil moisture with Theta probe in 2005 did not reflect the soil moisture in the root zone. However, in 2006 to 2007 years TDR was used to measure soil moisture and six sites were shown to have temporally stable soil moisture zones, which shows that soil moisture measurements by TDR was appropriate. In addition, three growers decided to irrigate their vineyards (once) in the hot and dry year of 2007 which were Buis, Rief and George. This was a uniform application over the blocks of interest and could be considered as a rainfall event. Overall, soil moisture zones showed more stability from 2006 to 2007, possibly due to measurement in deeper layers of soil compared to 2005. Therefore, the hypothesis that soil moisture zones will be consistent and stable temporally within vineyard blocks was only partially supported by the data from 2005 to 2006, but was proven by the 2006 to 2007 data.

Leaf water potential. Leaf Ψ zones were temporally stable at the Harbour from 2005 to 2006. From 2006 to 2007, leaf Ψ zones were also temporally stable Harbour and Rief. At Harbour leaf Ψ zones were stable over all three years. Considering that soil texture was stable at each site, water holding capacity of each soil was also consistent, the only difference was the amount of precipitation in each year. We assume that as the average volume of water in the soil profile changes between years so does vine water status change. There may, however, be factors other than soil texture and soil water holding capacity that affect vine water status. Reynolds *et al.* (2007), in a study on spatial variatiability in a Riesling vineyard, reported that specific areas of the vineyard that producing high yields and high concentrations of monoterpenes were transient and that their spatial distribution varied temporally. Our data suggest that there might be weakness in using leaf Ψ measurements as the basis for precision viticulture as spatial distribution for leaf Ψ may vary temporally, which makes selected harvest based on constant leaf Ψ values challenging. Therefore, the hypothesis of water-status zones will be consistent within vineyard blocks was only partially supported by the data.

For the results of this study to be useful, the patterns of variation within vineyard blocks would have to be constant from year to year. Bramley (2005) has indicated that although the absolute values of yield and berry composition for a vineyard may vary from vintage to vintage, the patterns of variation within block were stable. In this study, variation in soil composition, soil moisture, leaf Ψ, yield components and fruit composition has been demonstrated in all vineyard blocks either by statistical analysis such as ANOVA or using interpolation maps of data. The patterns of variation, however, were not temporally consistent from year to year for all variables at all sites. Precision Viticulture (PV) is dependent on the existence of variability in product quantity and or quality. If the variability does not exist then a uniform management system is cheaper and more effective. In dealing with variability, if vines can be planted in zones of similar terroir it may reduce the need to manage them differentially afterwards; therefore, by differentially planting we can uniformally manage them which is more economical than the reverse of uniformally planting and differentially managing (Bramley 2005). While the author has not come across comparable published studies on precision viticulture, data suggest that longer period of study would help to find these trends.

Literature Cited

Bramley, R.G.V. 2001. Progress in the development of precision viticulture-variation in yield, quality and soil properties in contrasting Australian vineyards. In Currie L.D. and Loganathan P. (Eds.) Precision tools for improving land management. Occasional report No 14. Massey University, New Zealand.

Bramley, R.G.V. 2002. Towards optimal resource management for grape and wine production. In: Blair, R.J. Williams, P.J. and Høj, P.B. (Eds.) Proceedings of the 11th Australian wine industry technical conference. Winetitles, Adelaide, 274-275.

Bramley, R.G.V., B. Pearse, and P. Chamberlin. 2003. Being profitable precisely – a case study of precision viticulture from Margaret River. The Australian & New Zealand Grapegrower & Winemaker. Annual Technical Issue 84-87.

Bramley R. 2005. Understanding variability in winegrape production systems. 2. Within vineyard variation in quality over several vintages. Austral. J. Grape and Wine Res. 11: 33-42.

CSSS (Canadian Society of Soil Science) 1993. Soil Sampling and Methods of Analysis. M.R. Carter (Ed.). Lewis Publishers, Raton, FL.

Goldberg S.D. Rinot M. and Karu N. 1971. Effects of trickle irrigation intervals on distribution and utilization of soil moisture in a vineyard. Soil Sci. Soc. Am. Proc. 35, 127-130.

Greenspan, M.D. and J.J. O'Donnell. 2001.Evaluating the utility of remotely sensed canopy density for the understanding of vineyard spatial variability. In: Andrew G. Reynolds (Ed.) Space Age Winegrowing. A Proceedings of a Symposium Held at White Oaks Conference Centre and SPA Niagara-On-The-Lake, Ontario. July 2001, St. Catharines, Canada. 27-41.

Hall, A., D.W. Lamb, B. Holzapfel, and J. Louis. 2002. Optical remote sensing applications in viticulture-a review. Australian J. Grape and Wine Research 8: 36-47.

Johnson, L., B. Lobitz, R. Armstrong, R. Baldy, E. Weber, J. De Bendictis, and D. Bosch. 1996. Airborne imaging aids vineyard canopy evaluation. California Agriculture. 50:14-18.

Reynolds, A. G., I.V. Senchuk, C. van der Reest, and C. de Savigny. 2007. Use of GPS and GIS for elucidation of the basis for terroir: Spatial variation in an Ontario Riesling vineyard. Amer. J. Enol. Vitic. 58:2, 145-162.

Smart, R.E., and B.G. Coombe. 1983. Water relations of grapevines. *In* T.T. Kozlowski (Ed.): Water Deficits and Plant Growth. Academic Press, New York, pp.137-196.

Turner, N.C. 1988. Measurement of plant water status by the pressure chamber technique. Irrig. Sci. 9: 289-308.

VanZyl J.L. and Weber H.W.1981. The effect of various supplementary irrigation treatments on plant and soil moisture relationships in a vineyard (Vitis vinifera var. Chenin blanc). S. Afr. J. Enol. Vitic. 2, 83-99.

Williams, L.E. and F.J. Araujo. 2002. Correlations among predawn leaf, midday leaf and midday stem water potential and their correlations with other measures of soil and plant water status in Vitis vinifera. Amer. J. Enol. Vitic.127:448-545.

Williams, L. E. and Matthews M.A. 1990. Grapevine. In: Irrigation of Agricultural Crops. Eds. B.A. Stewart and D.R. Nielson (American Society of Agronomy, Madison, WI) pp. 1019-1055.

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Table 3- Leaf water potential and soil moisture ranges in ten sites, Niagara Peninsula, ON, 2005-2007. Measurements were made bi-weekly between July to September.

Site	Leaf ψ (-bar)			Soil moisture (%)		
	2005	2006	2007	2005	2006	2007
Buis	10.0-13.5	11.1-13.5	11.4-14.5	14.0-20.4	17.6-32.0	17.2-27.6
Chateau des Charmes	12.0-16.0	12.5-15.0	15.2-16.4	10.9-16.2	19.4-33.5	9.3-24.8
Hernder	12.6-15.9	12.9-16.0	13.7-16.0	7.3-13.4	15.1-28.0	6.1-27.7
Reif	11.0-13.5	10.7-13.4	11.1-13.4	7.6-13.6	11.3-25.6	8.8-21.3
George	11.0-14.6	10.1-12.6	11.6-15.0	11.1-15.8	18.1-29.0	12.4-21.7
Henry of Pelham	11.0-14.5	11.4-13.7	13.1-15.0	12.0-15.6	18.1-29.7	14.0-25.9
Cave Spring	12.0-15.5	10.9-12.4	14.3-15.8	10.7-15.6	21.8-32.7	10.1-20.9
Harbour Estate	8.0-10.9	9.0-11.5	9.3-11.2	9.9-13.4	11.7-18.7	3.5-8.5
Vieni	12.0-14.5	8.2-11.0	13.8-15.9	9.1-15.7	22.2-35.9	10.7-25.2
Morrison	12.1-14.7	9.7-12.4	14.2-16.4	11.0-19.1	21.3-33.9	11.0-20.6

Table 4- Overall correlations of soil factors for all sites Niagara Peninsula, ON. 2005.

	% Sand	% Clay	% OM	CEC (meq/100 g)	Soil pH	base saturation (% Ca)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	SM (%)	WP (-bars)
% Sand	1.0000	**-0.895** <.0001	**-0.2179** 0.0055	**-0.6409** <.0001	**-0.5256** <.0001	**-0.6147** <.0001	**0.2048** 0.0092	**0.1747** 0.0266	**-0.6130** <.0001	**-0.6234** <.0001	-0.1353 0.0871	**-0.5966** <.0001
% Clay		1.0000	**0.1555** 0.0489	**0.6294** <.0001	**0.5112** <.0001	**0.6099** <.0001	**-0.2796** 0.0003	-0.1012 0.2013	**0.5889** <.0001	**0.6470** <.0001	0.0129 0.8709	**0.7257** <.0001
% OM			1.0000	0.0869 0.2728	0.0366 0.6447	0.0488 0.5385	0.0916 0.2476	0.1354 0.0889	0.0387 0.6258	**0.4025** <.0001	-0.0131 0.8689	**0.2158** 0.0060
CEC (meq/100 g)				1.0000	**0.7678** <.0001	**0.7551** <.0001	-0.0297 0.7082	-0.1459 0.0648	**0.9888** <.0001	**0.3474** <.0001	**0.2676** 0.0006	**0.4294** <.0001
Soil pH					1.0000	**0.8908** <.0001	-0.0918 0.2465	-0.1489 0.0595	**0.8146** <.0001	**0.3407** <.0001	0.1390 0.0786	**0.3584** <.0001
Base saturation (% Ca)						1.0000	**-0.1685** 0.0326	**-0.1604** 0.0421	**0.8132** <.0001	**0.3469** <.0001	**0.1899** 0.0158	**0.5051** <.0001
P (ppm)							1.0000	**0.6086** <.0001	-0.0214 0.7872	**-0.4501** <.0001	0.0294 0.7114	-0.1304 0.0991
K (ppm)								1.0000	-0.154 0.0511	**-0.2546** 0.0011	**-0.183** 0.0199	0.0489 0.5375
Ca (ppm)									1.0000	**0.2922** 0.0002	**0.2691** 0.0006	**0.3919** <.0001
Mg (ppm)										1.0000	0.0384 0.6289	**0.4356** <.0001
SM (%)											1.0000	-0.095 0.2266
WP (-bars)												1.0000

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Figure 12. Spatial distribution of soil moisture (%), at two vineyard sites, Niagara Peninsula, ON; A to C: Hernder; 2005 (A); 2006 (B); 2007 (C). D to F: Reif; 2005 (D); 2006 (E); 2007 (F).

Figure 13. Spatial distribution of soil moisture (%), at two vineyard sites, Niagara Peninsula, ON; A to C: Harbour Estate; 2005 (A); 2006 (B); 2007 (C). D to F: George; 2005 (D); 2006 (E); 2007 (F).

Figure 14. Spatial distribution of soil moisture (%), at two vineyard sites, Niagara Peninsula, ON; A to C: Cave Spring 2005 (A); 2006 (B); 2007 (C). D to F: Henry of Pelham; 2005 (D); 2006 (E); 2007 (F).

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Figure 16. Spatial distribution of leaf water potential (-bars) at two vineyard sites, Niagara Peninsula, ON; A to C: Buis; 2005 (A); 2006 (B); 2007 (C). D to F: Chateau des Charmes; 2005 (D); 2006 (E); 2007 (F).

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Figure 21. Partial Least Squares analysis of field and sensory data for nine Cabernet Franc wines from Niagara Peninsula, ON, 2005. Aroma attributes are represented in lowercase and flavor attributes are represented in uppercase.

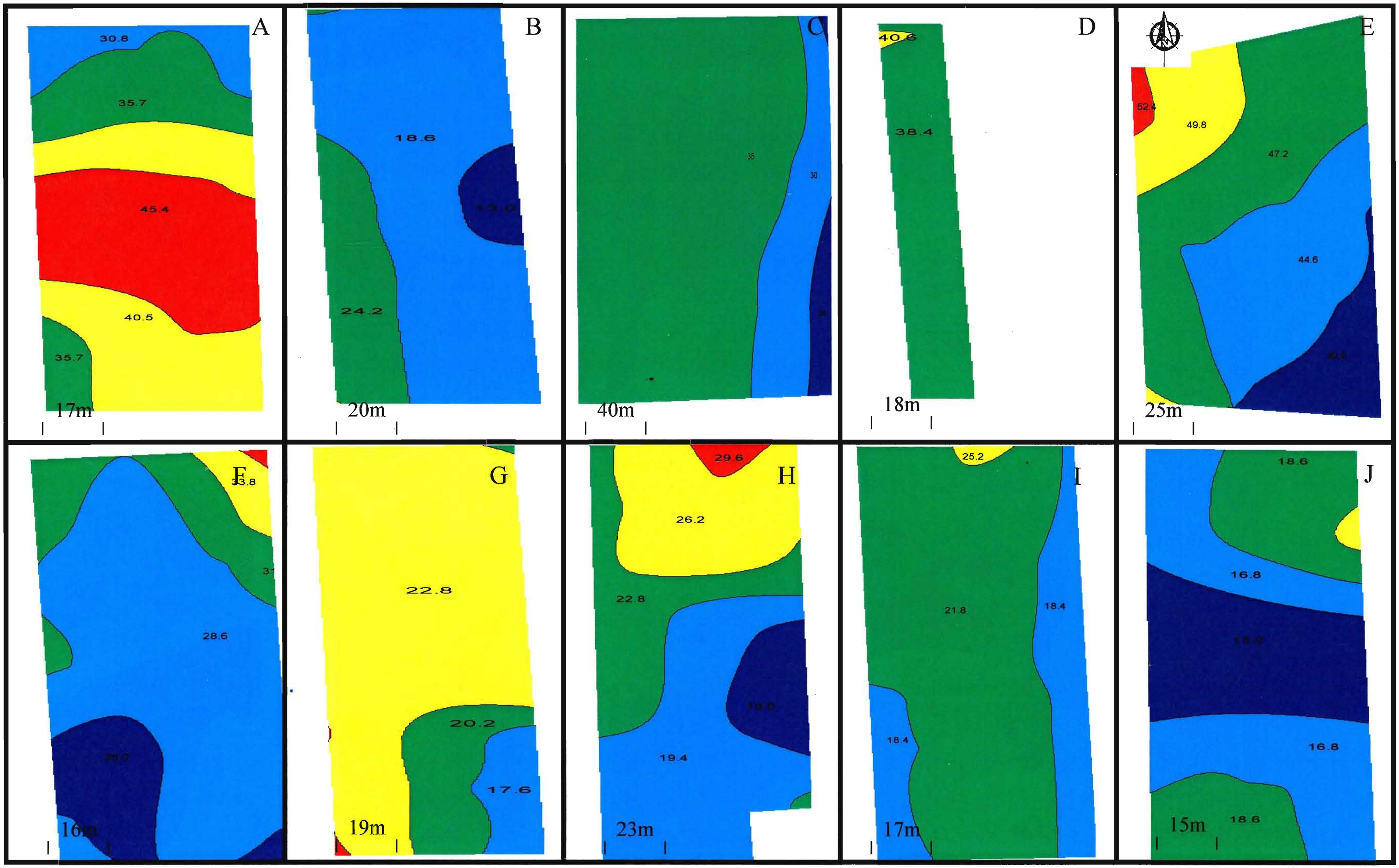


Figure 1- Spatial distribution of sand (%) at all vineyard blocks, Niagara Peninsula, ON; A: Buis; B: Chateau des Charmes; C: Hernder; D: Reif; E: Harbour Estate; F: George; G: Cave Spring; H: Henry of Pelham; I: Vieni; J: Morrison. In each map, the value of each zone represents the corresponding lower limit for that zone.

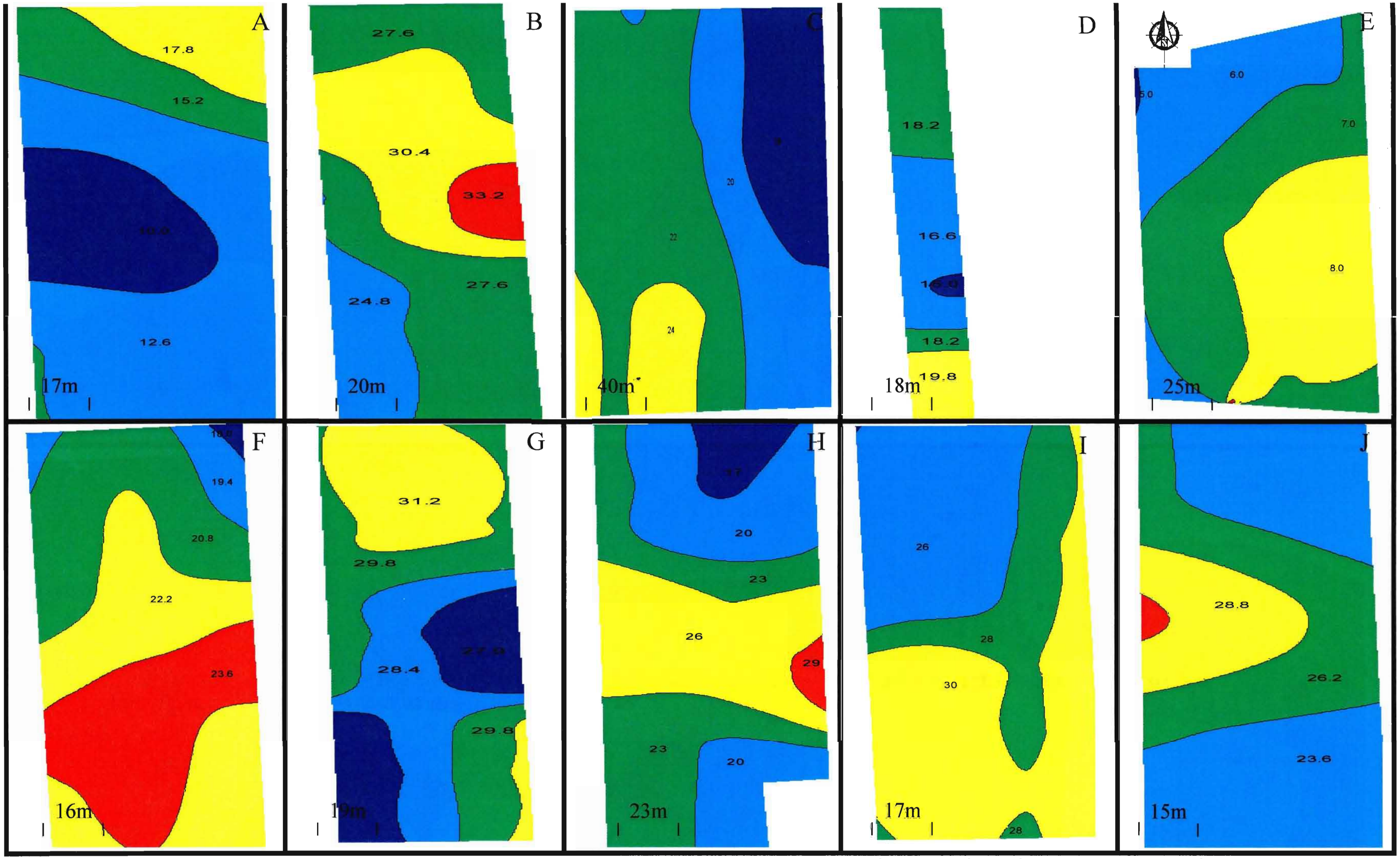
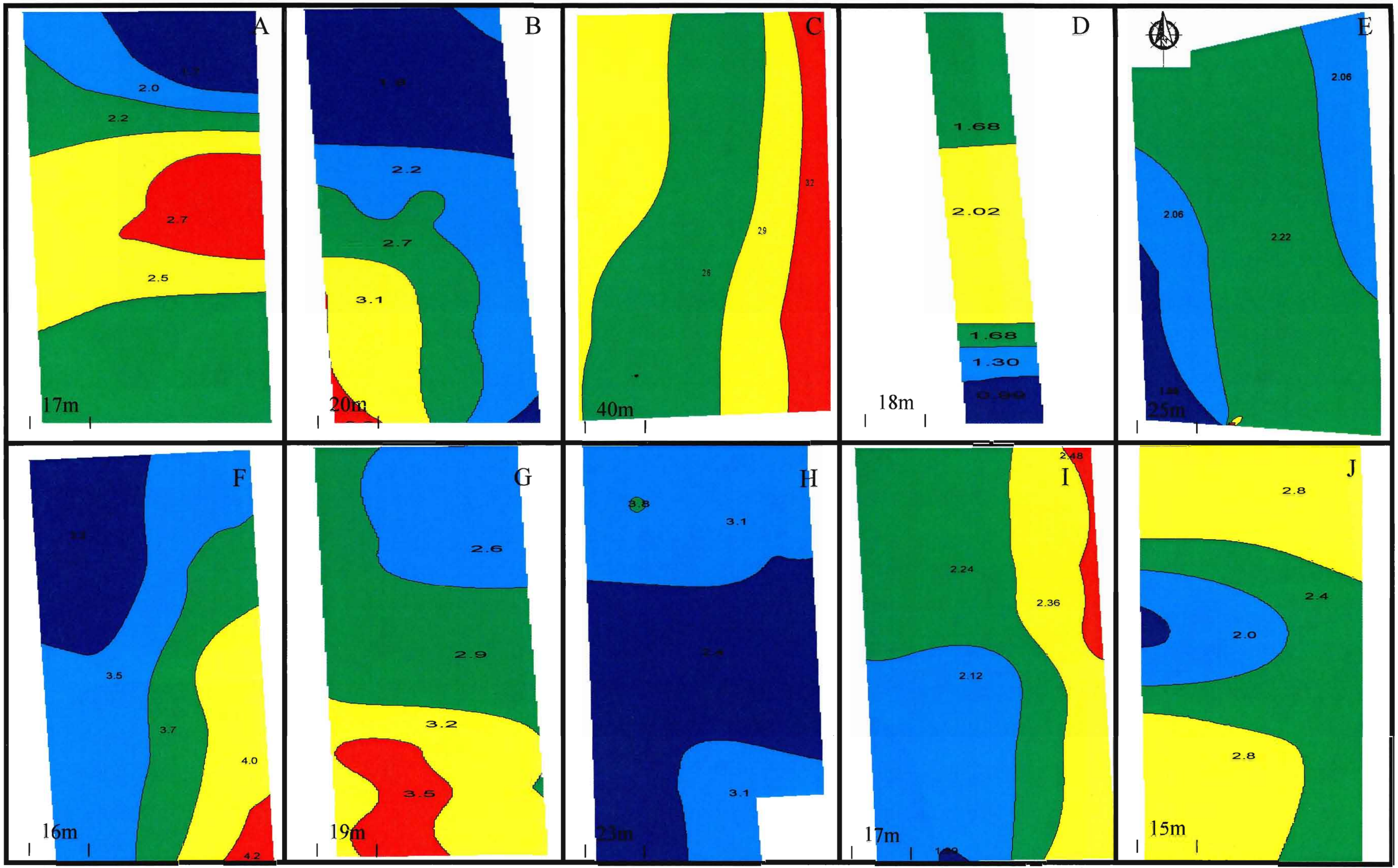


Figure 2- Spatial distribution of clay (%) at all vineyard blocks, Niagara Peninsula, ON; A: Buis; B: Chateau des Charmes; C: Hernder; D: Reif; E: Harbour Estate; F: George; G: Cave Spring; H: Henry of Pelham; I: Vieni; J: Morrison. In each map, the value of each zone represents the corresponding lower limit for that zone.



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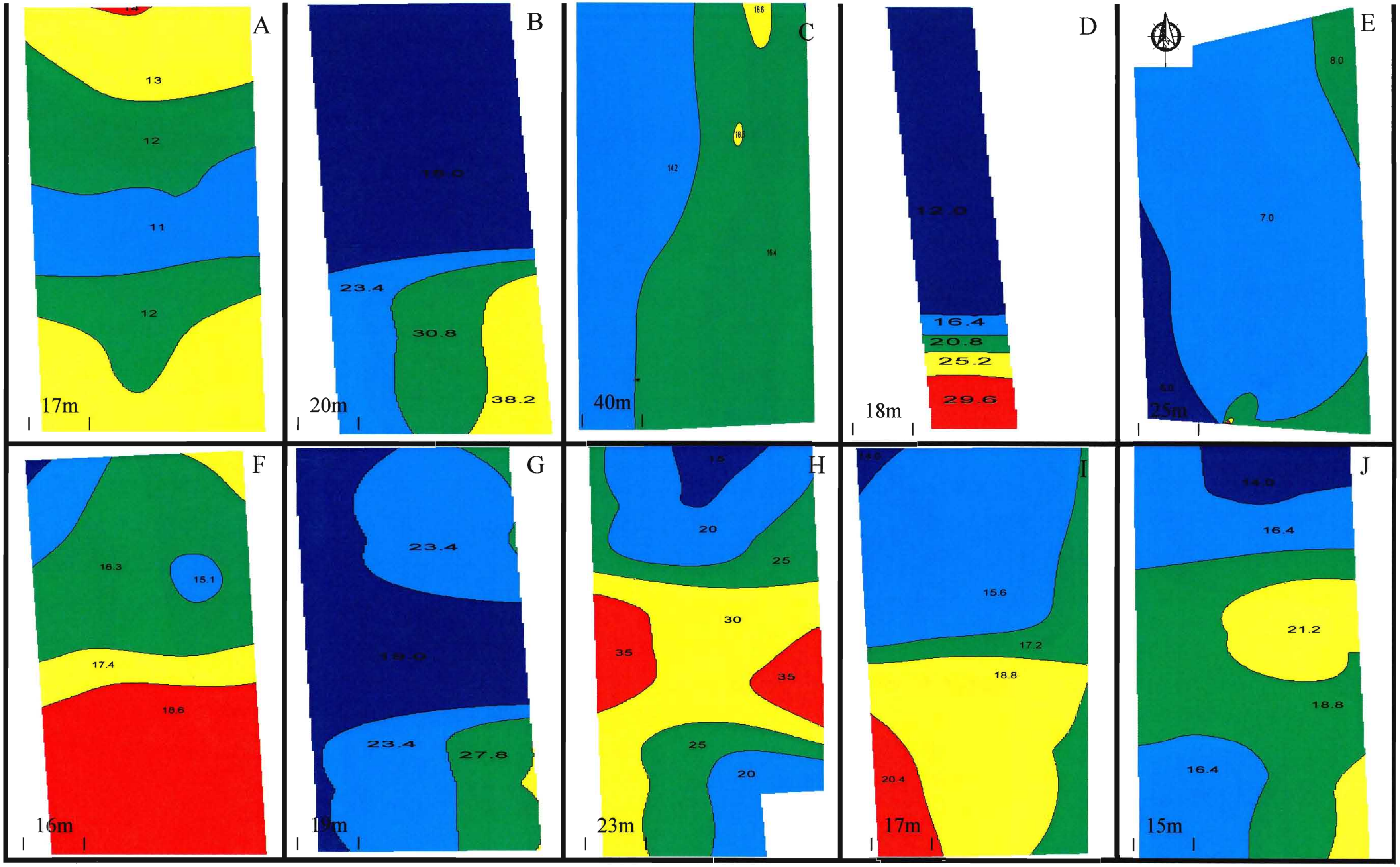

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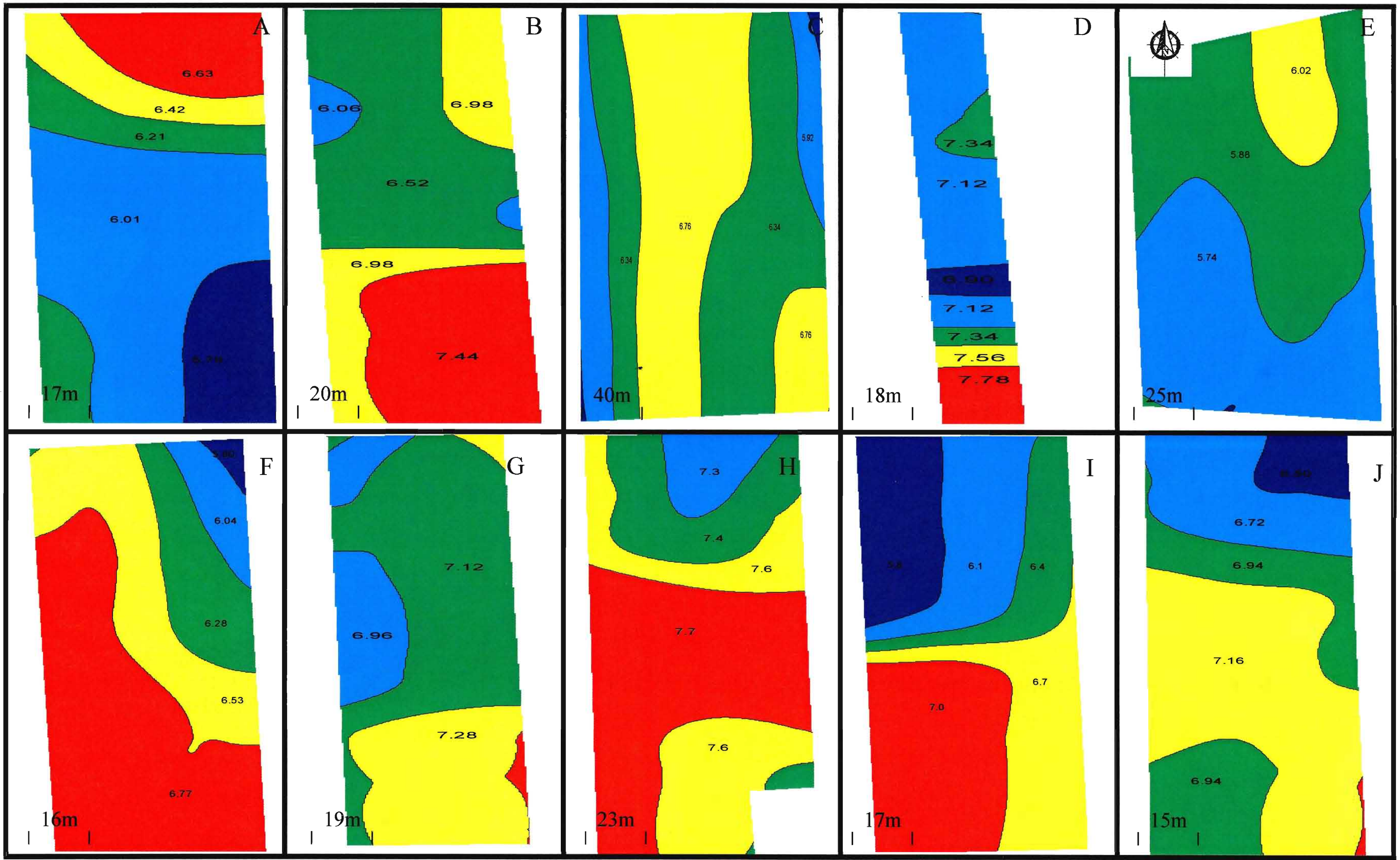

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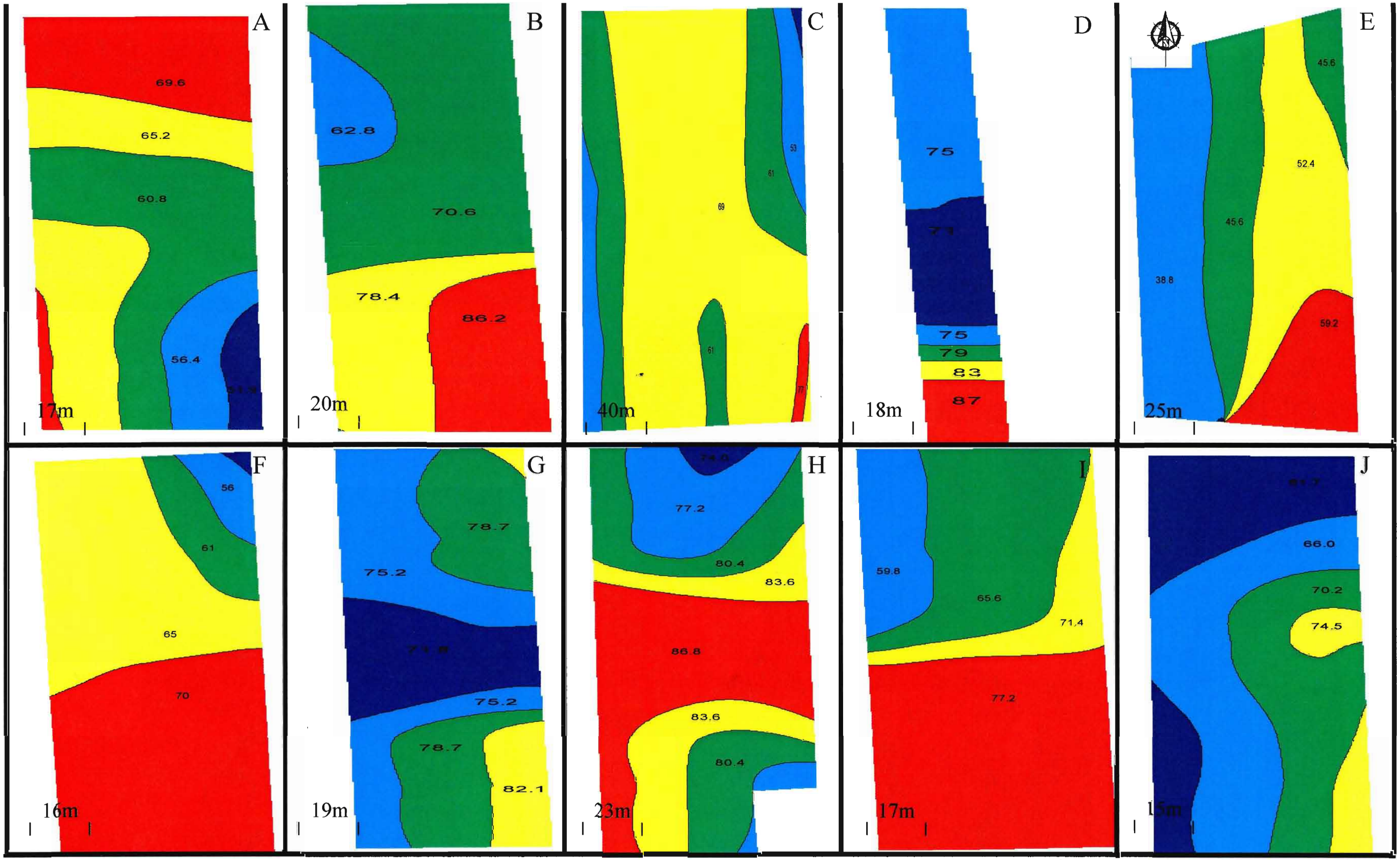
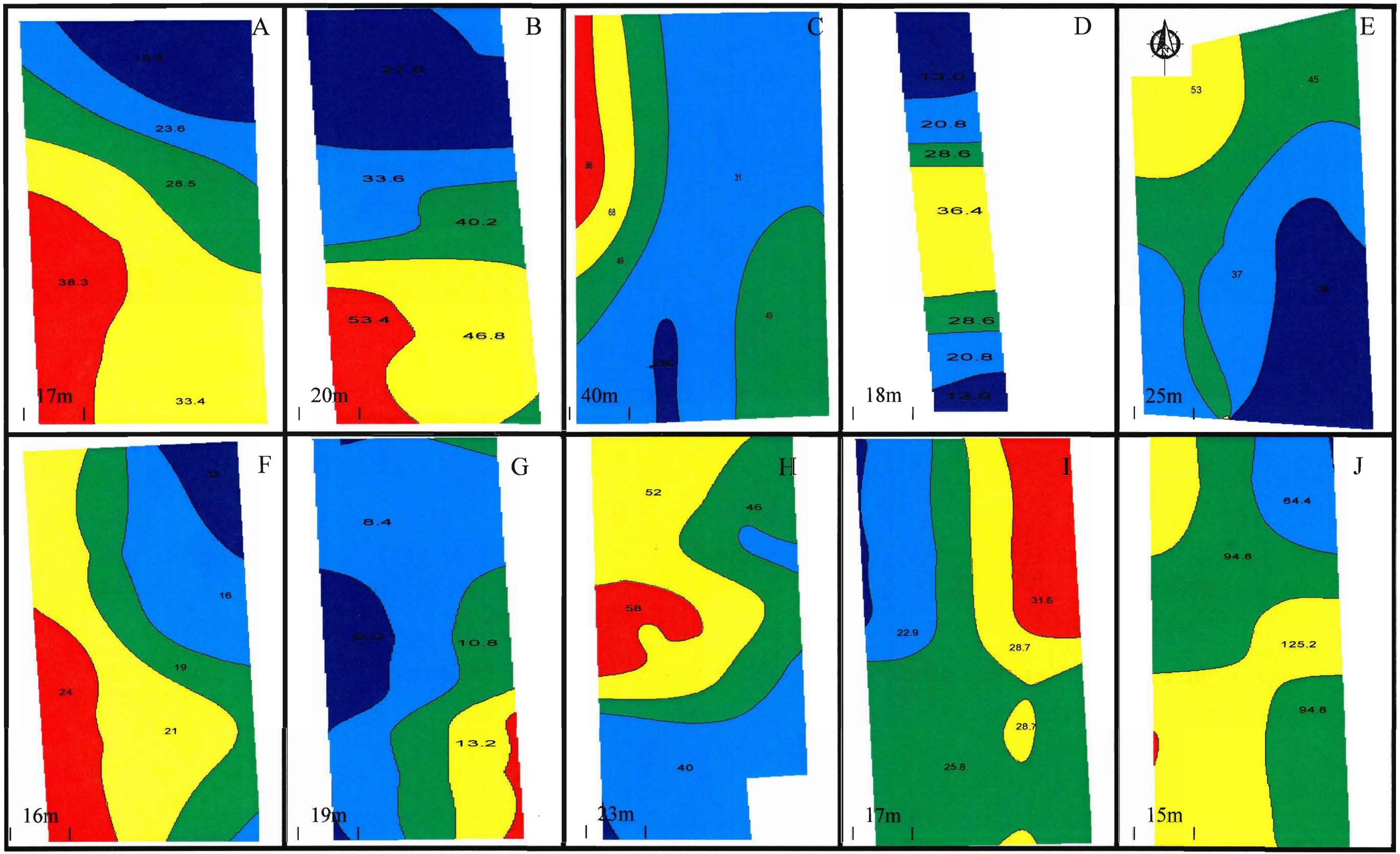


Figure 6- Spatial distribution of soil base saturation as Ca (%) in all vineyard blocks, Niagara Peninsula, ON; A: Buis; B: Chateau des Charmes; C: Hernder; D: Reif; E: Harbour Estate; F: George; G: Cave Spring; H: Henry of Pelham; I: Vieni; J: Morrison. In each map, the value of each zone represents the corresponding lower limit for that zone.



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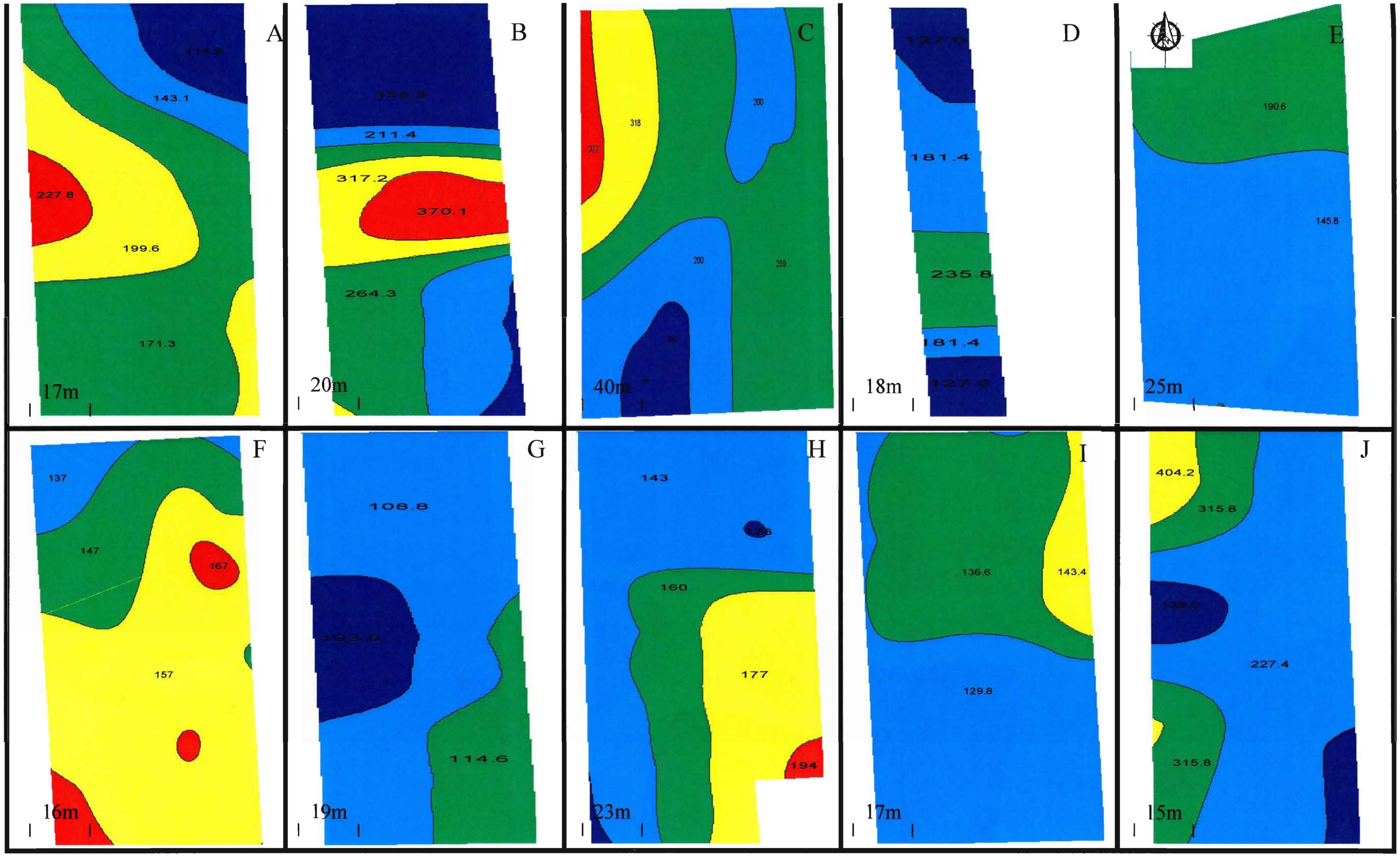


Figure 8- Spatial distribution of K (mg/kg soil), at all vineyard blocks, Niagara Peninsula, ON; A: Buis; B: Chateau des Charmes; C: Hernder; D: Reif; E: Harbour Estate; F: George; G: Cave Spring; H: Henry of Pelham; I: Vieni; J: Morrison. In each map, the value of each zone represents the corresponding lower limit for that zone.

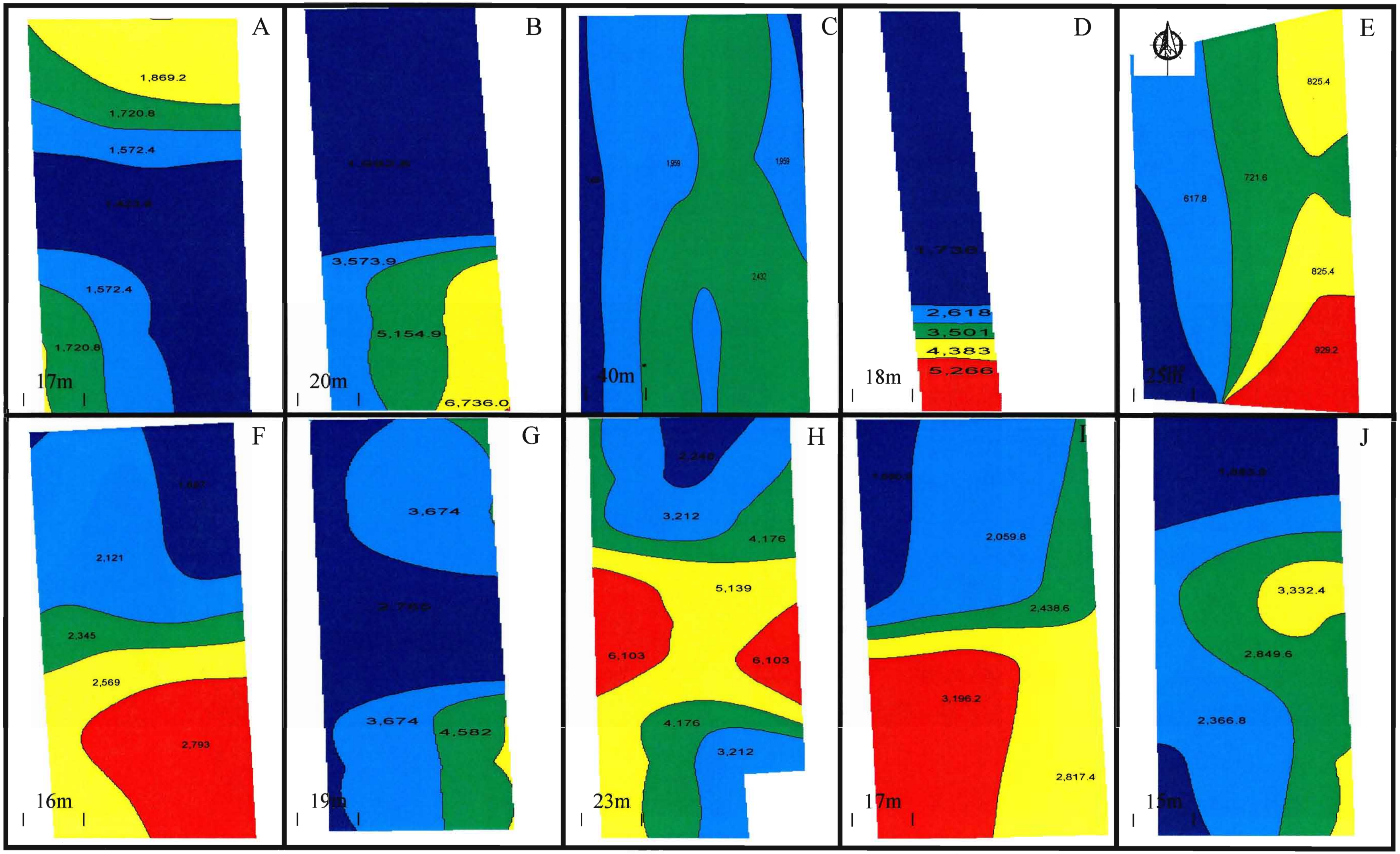


Figure 9- Spatial distribution of Ca (mg/kg soil), at all vineyard blocks, Niagara Peninsula, ON; A: Buis; B: Chateau des Charmes; C: Hernder; D: Reif; E: Harbour Estate; F: George; G: Cave Spring; H: Henry of Pelham; I: Vieni; J: Morrison. In each map, the value of each zone represents the corresponding lower limit for that zone.

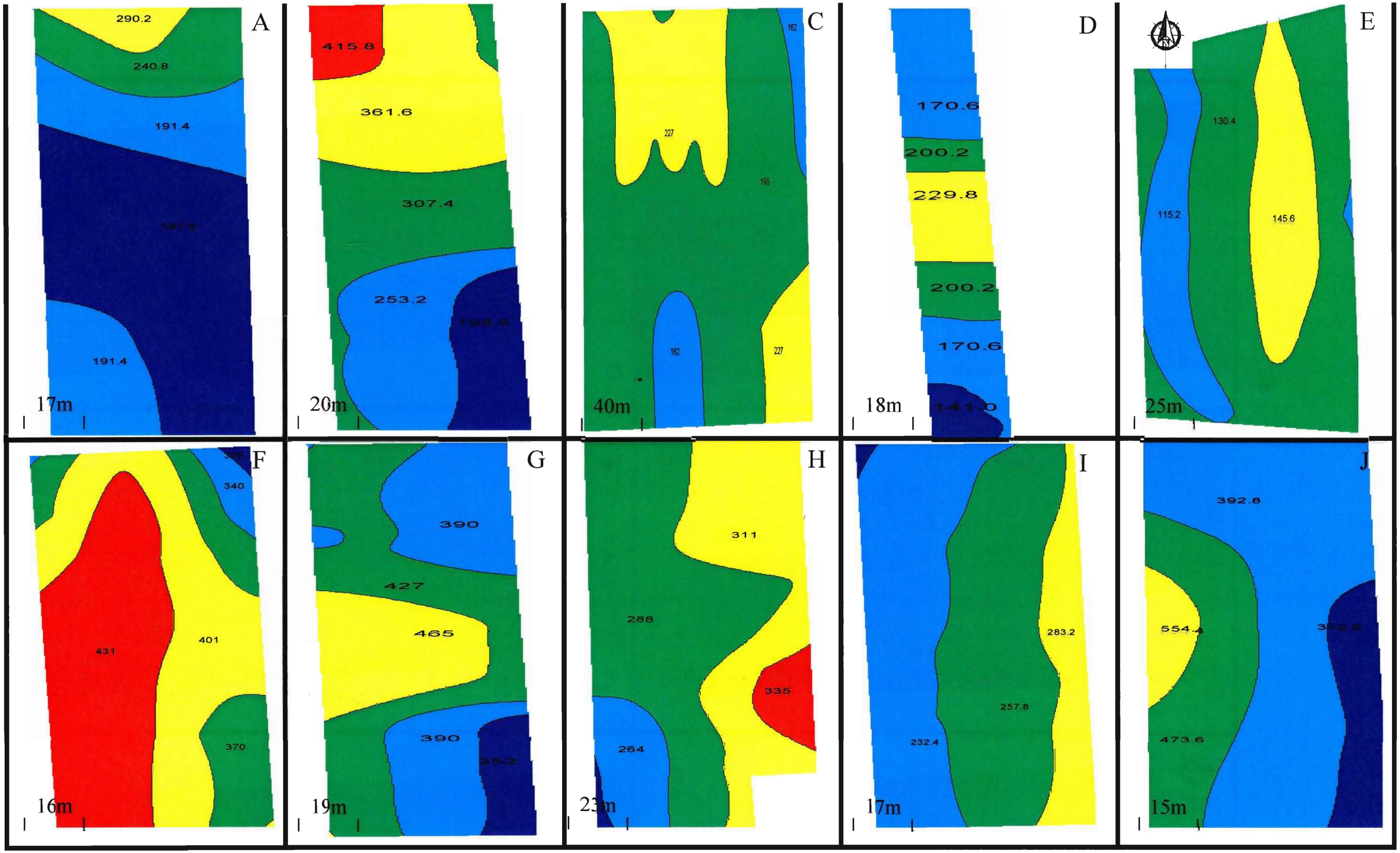


Figure 10- Spatial distribution of Mg (mg/kg soil), at all vineyard blocks, Niagara Peninsula, ON; A: Buis; B: Chateau des Charmes; C: Hernder; D: Reif; E: Harbour Estate; F: George; G: Cave Spring; H: Henry of Pelham; I: Vieni; J: Morrison. In each map, the value of each zone represents the corresponding lower limit for that zone.

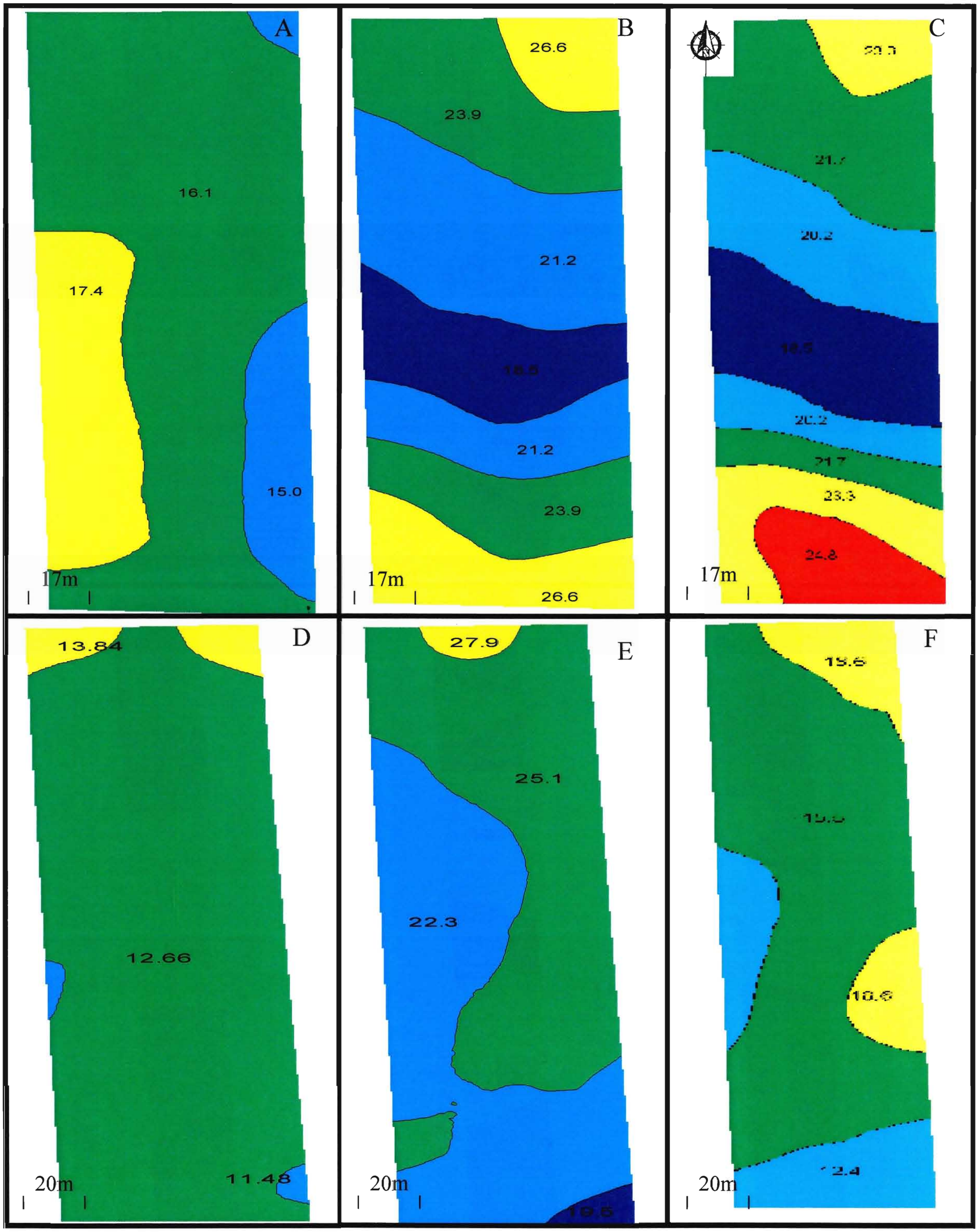
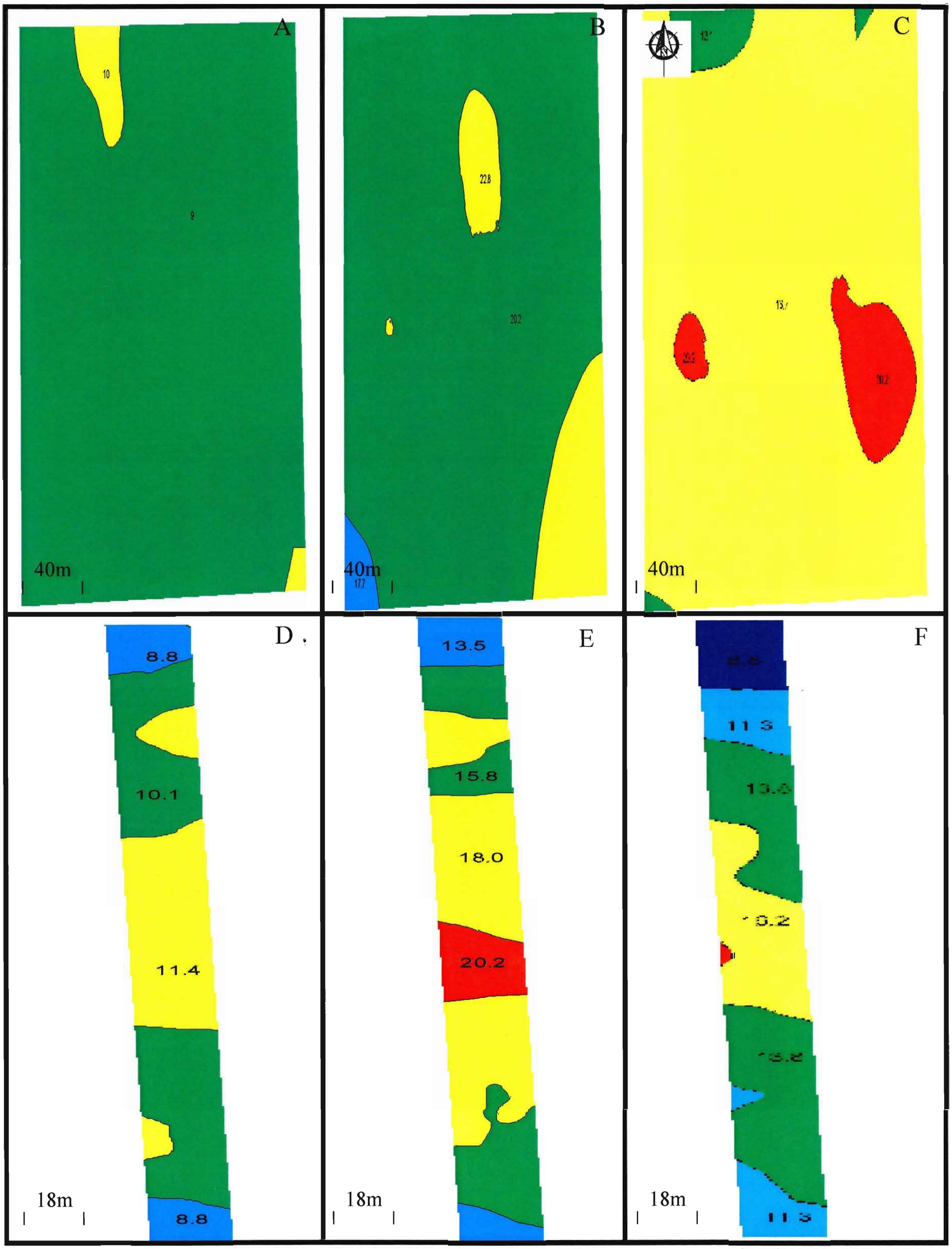


Figure 11. Spatial distribution of soil moisture (%), at two vineyard sites, Niagara Peninsula, ON; A to C: Buis; 2005 (A); 2006 (B); 2007 (C). D to F: Chateau des Charmes; 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.



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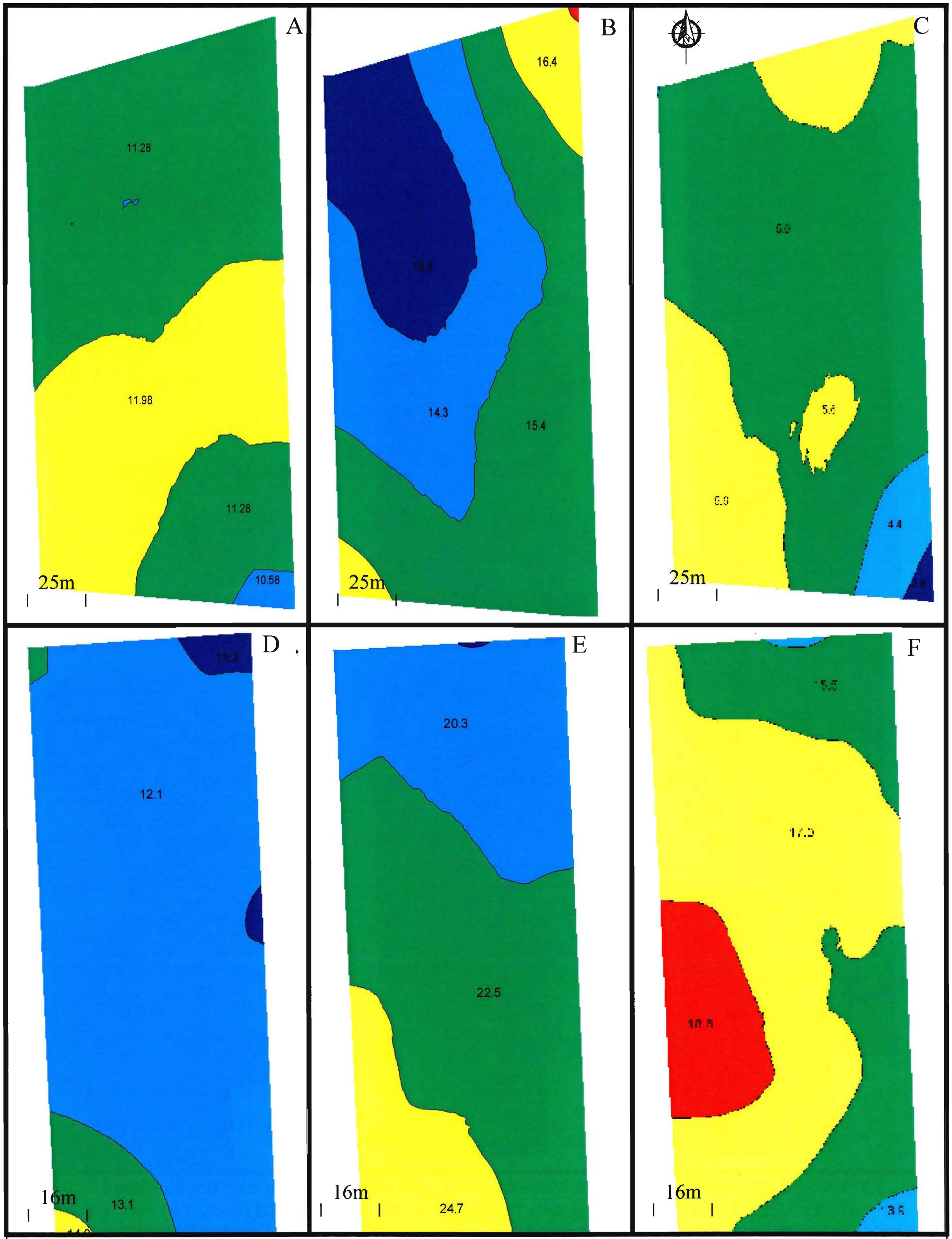

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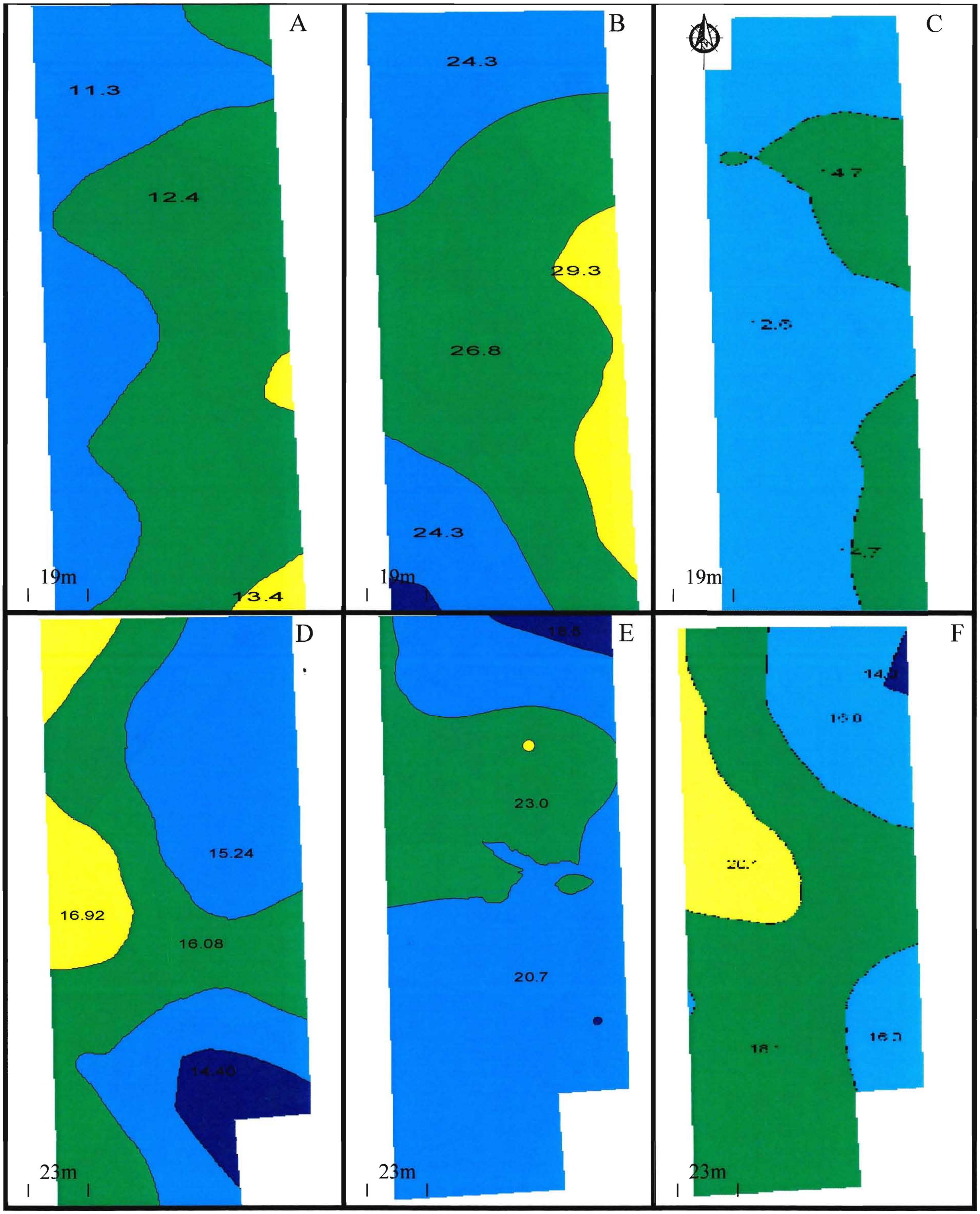

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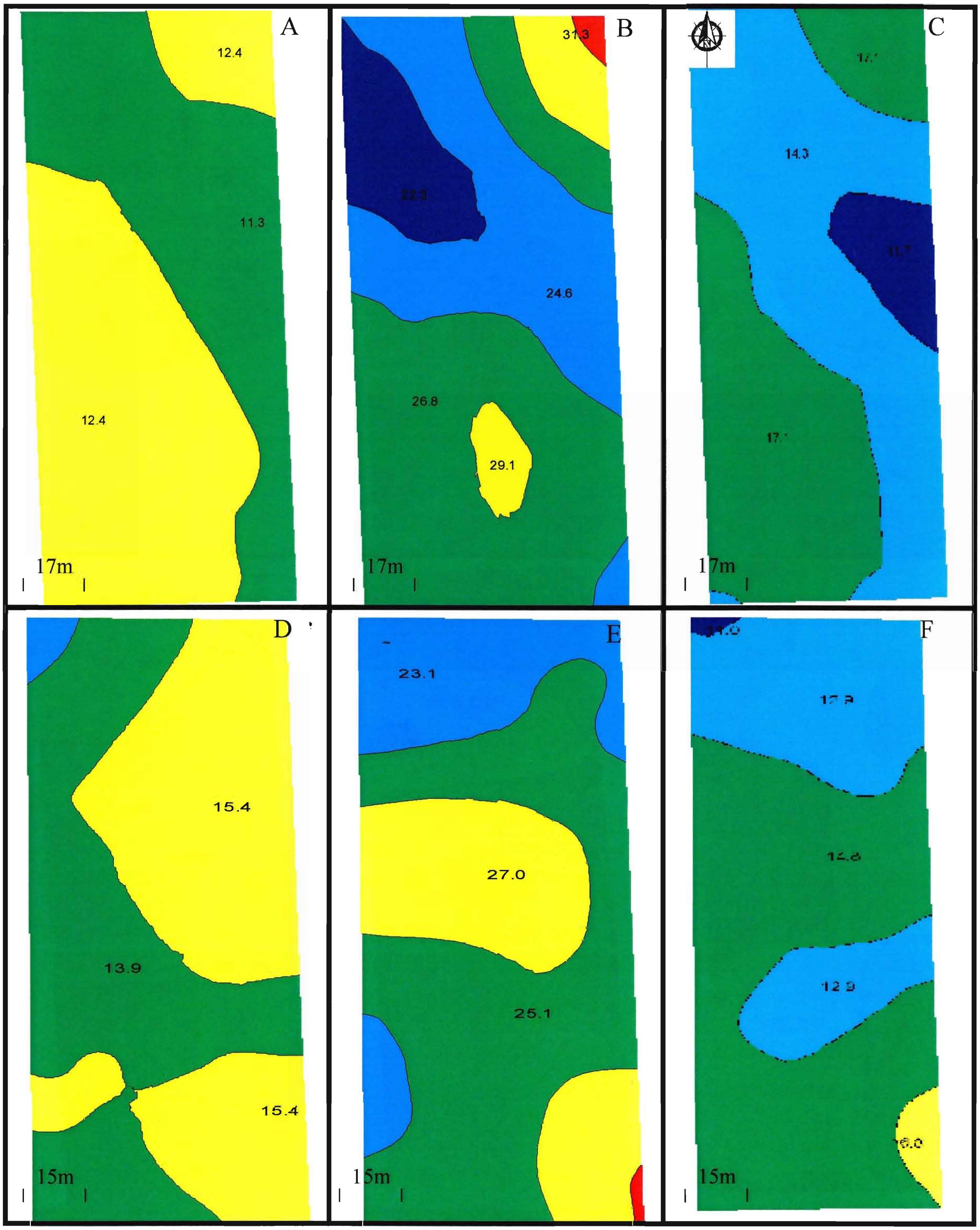

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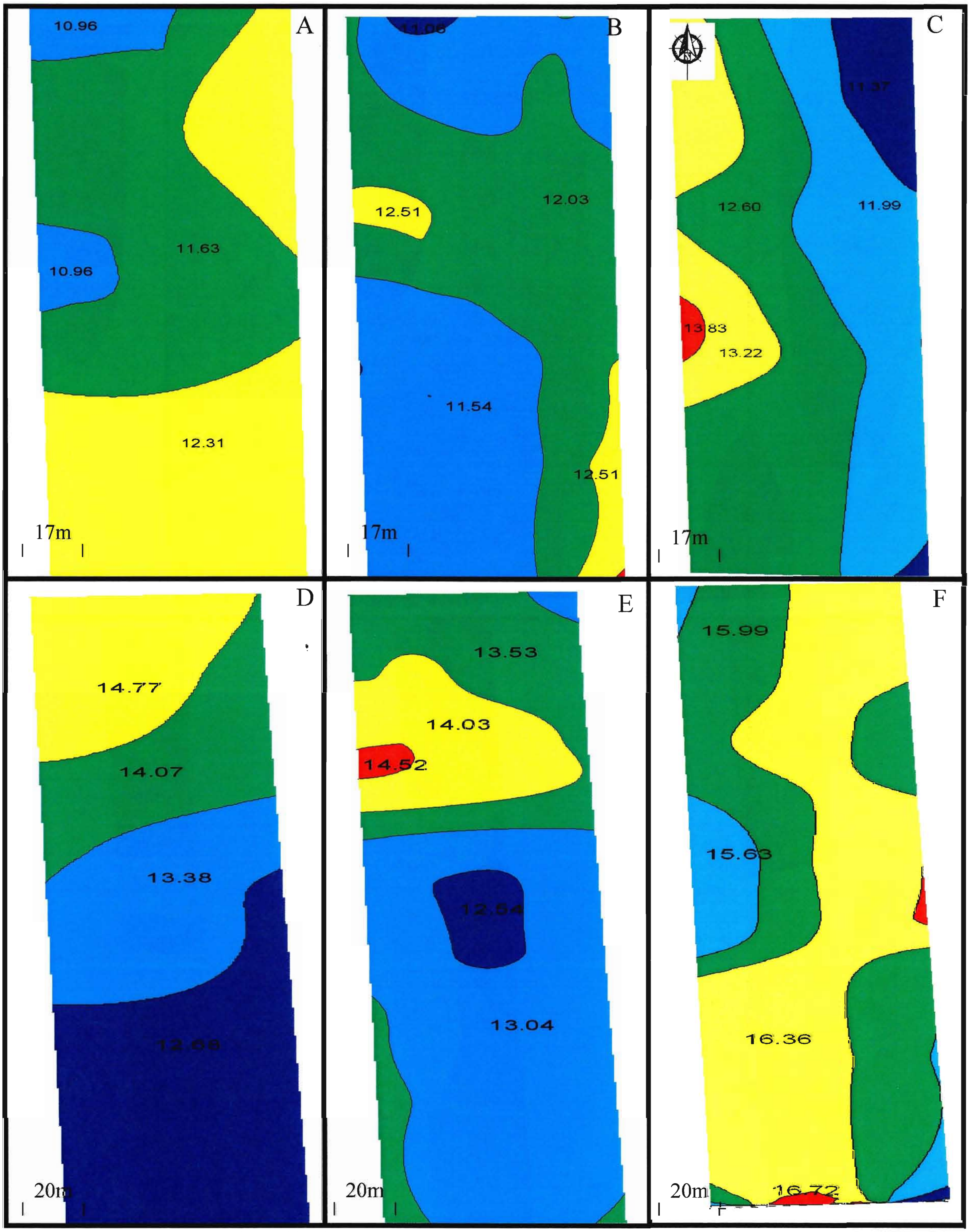

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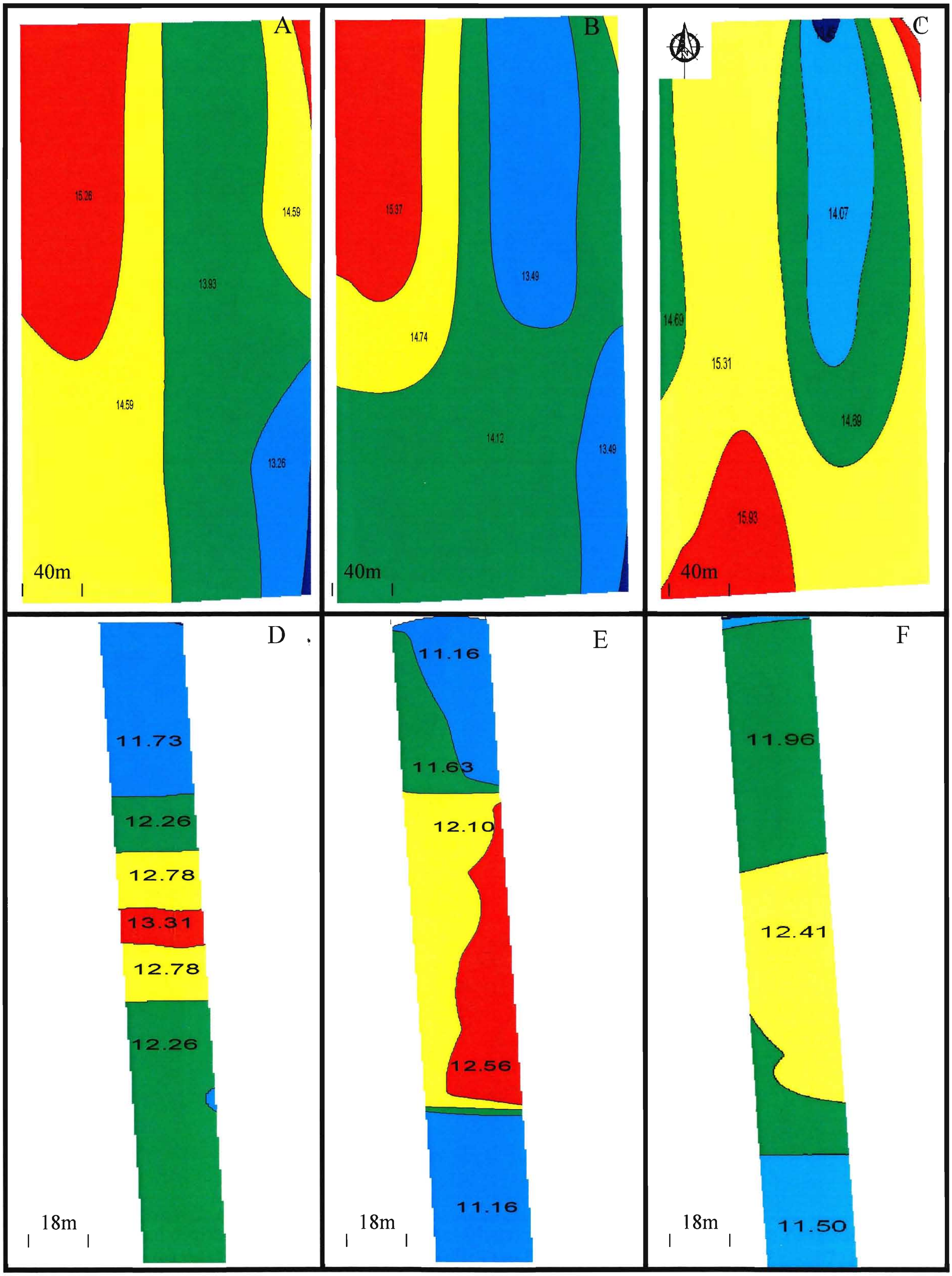

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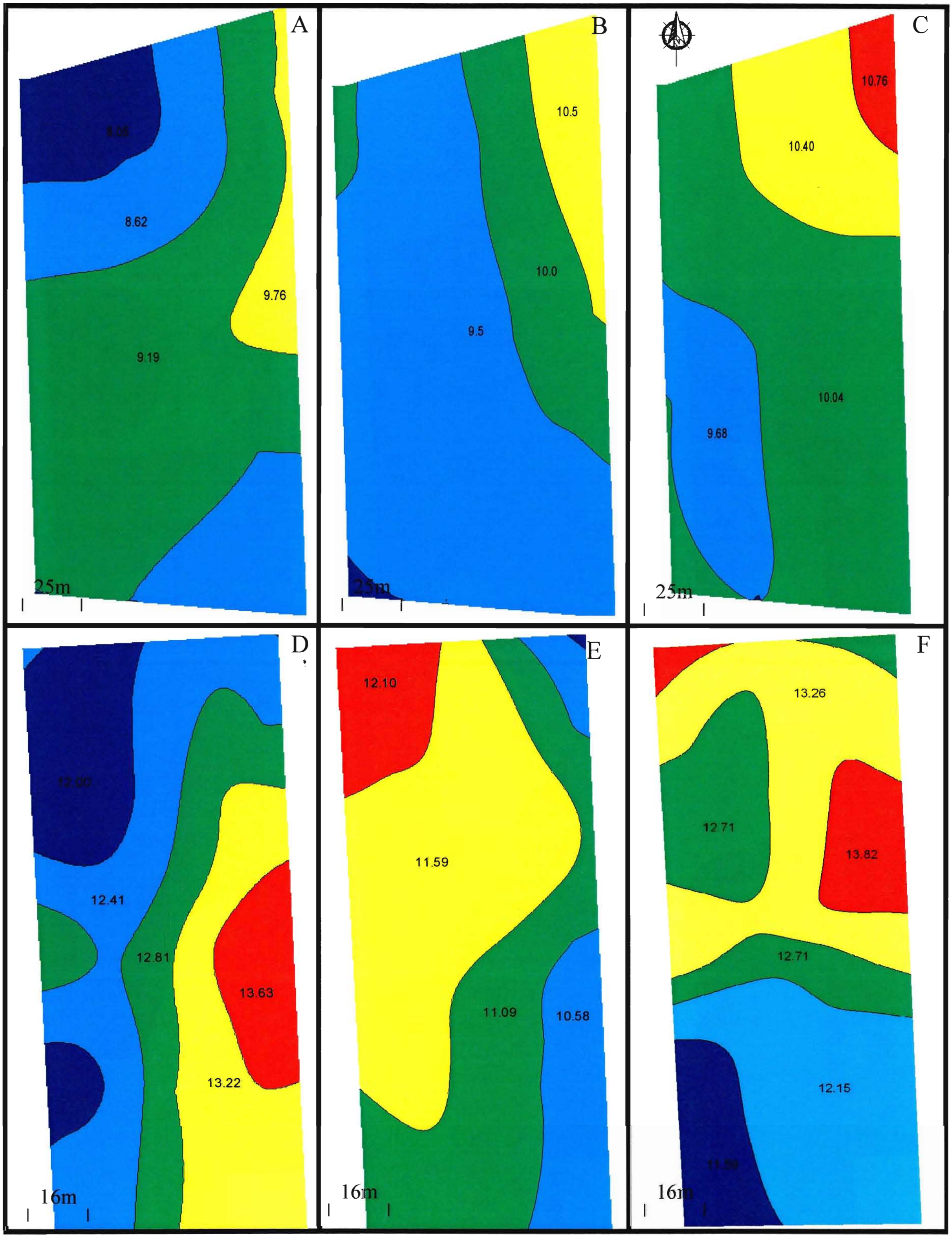

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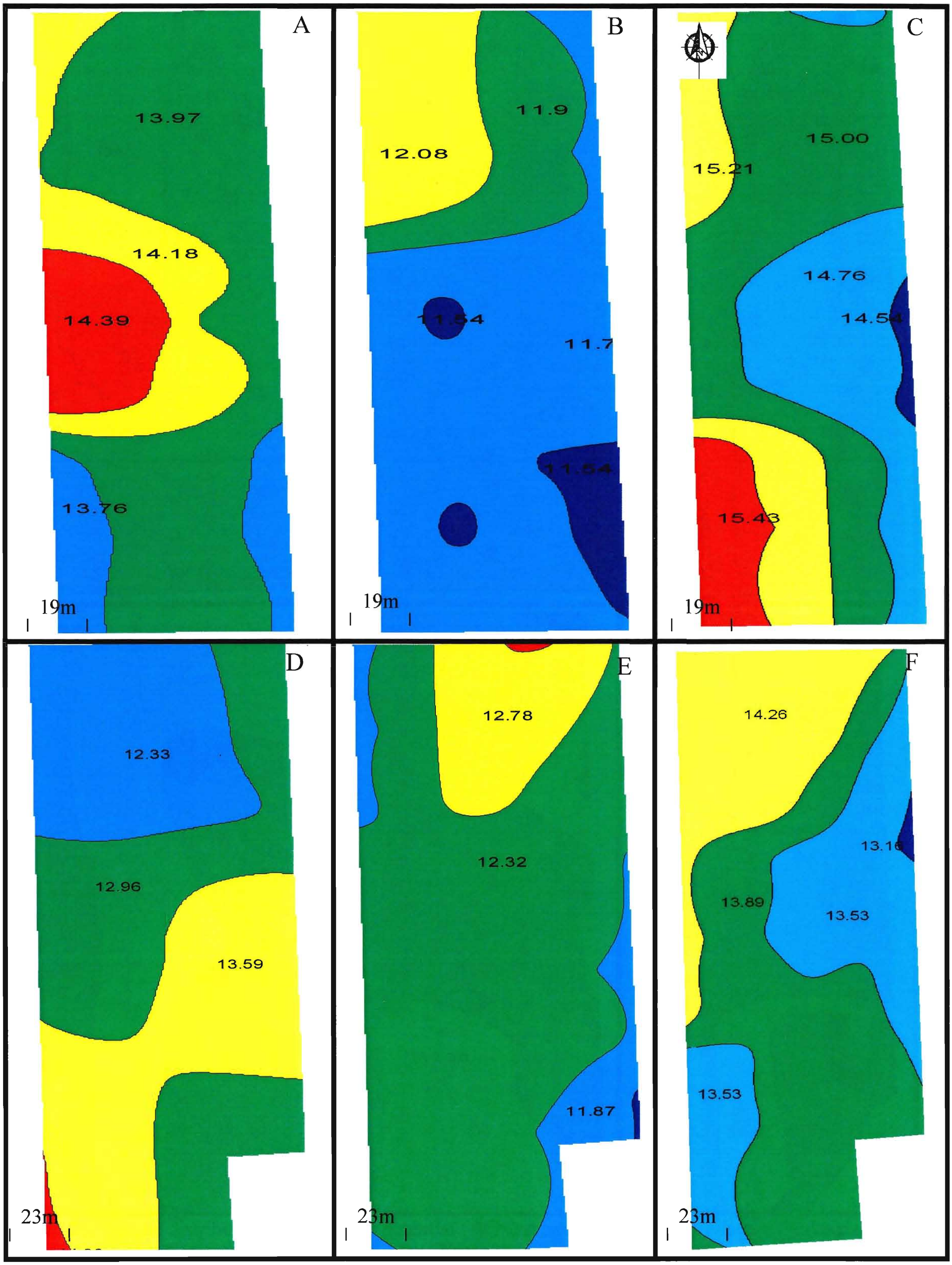

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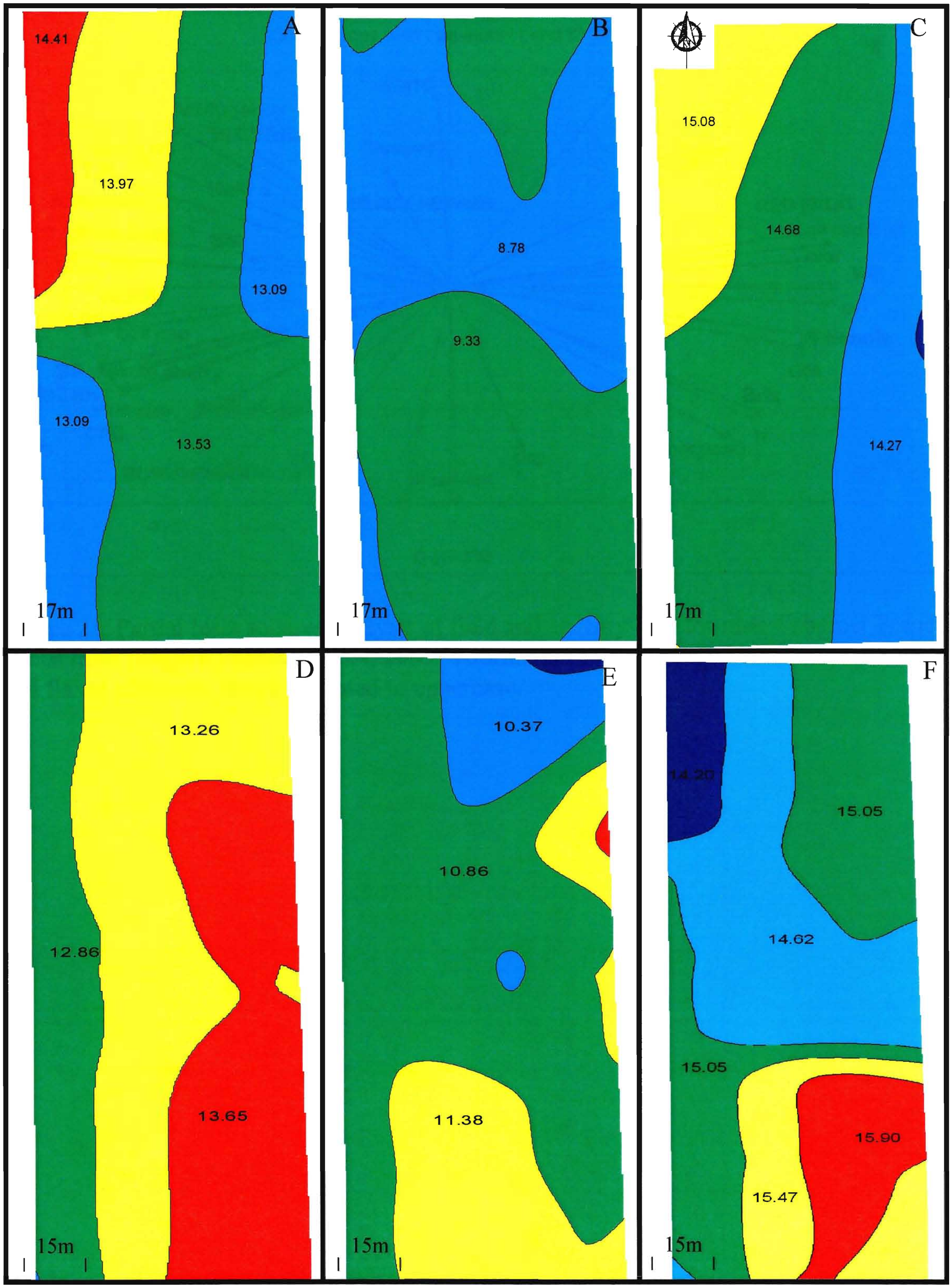

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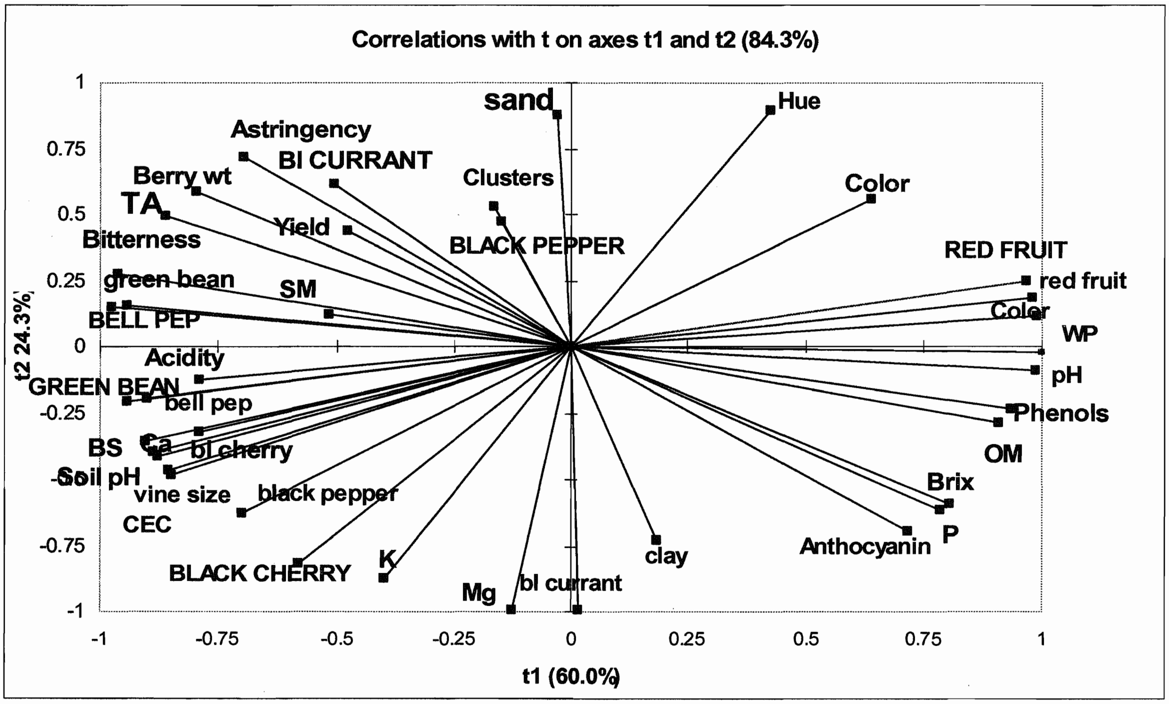

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Chapter 4

Spatial Variability in Ten Cabernet Franc Vineyards in the Niagara Peninsula of Ontario. II. Yield Components, Berry Composition and Their Relationships with Soil and Vine Water Status.

Abstract. The impact of vine water status was studied in ten commercial vineyard blocks of Cabernet Franc (*Vitis vinifera* L.) in the Niagara Peninsula, Ontario. Vine performance, fruit composition and vine size of non-irrigated grapevines were compared within vineyard blocks with different soil and vine water status. Differences in vine water status, led to differences in the yield components and fruit composition of Cabernet Franc winegrapes. Vine water status affected clusters per vine, berry weight, Brix, berry titratable acidity, color intensity, anthocyanin, and total phenol concentration in some sites in 2005 to 2007. Analyses of soil factors indicated that leaf water potential positively correlated with percentage of clay content and organic mater, while negatively correlated with sand percentage. Analyses of soil factors vs. yield components, fruit composition and vine size in 2005 revealed that leaf Ψ negatively correlated with yield, berry weight, vine size and TA but positively correlated with Brix, color intensity, anthocyanins and total phenols; in 2006, leaf Ψ positively correlated with berry weight and negatively with TA; in 2007, it was negatively correlated with yield, berry weight, vine size and TA. Spatial correlation analyses indicated that at most sites, berry anthocyanins were highly correlated with color intensity and phenols. Leaf Ψ negatively correlated with berry weight, vine size, and yield. Spatial correlation analyses were performed for each yield component and fruit composition attribute at each site. For instance, yield spatial distribution was consistent at Cave Spring and George sites for 2005 and 2006 vintages. Vintage altered clusters/vine at eight sites in all of which more

clusters/vine was observed in 2006. Yield was increased at eight sites in 2006. Higher berry weights were produced in 2006 at all sites except Buis and Harbour. Vintage influenced vine size at seven sites; at Hernder, George, Cave Spring and Morrison higher vine size was produced in 2006, while at HOP and Harbour vine size was higher in 2005. Vintage altered Brix levels at nine sites indicating lower Brix levels in 2006. Except for the Hernder site, that showed lower pH in 2006, all other Niagara-on-the-Lake sites were characterized with lower pH in 2005. Other than the George site that showed lower TA in 2005, all other sites showed lower TA in 2007. Color intensity was affected at six sites; other than George site that showed lower color in 2005, all other sites produced less color in 2006. Except Buis, all other sites had lower anthocyanins in 2006. Except Morrison; HOP and Cave Spring that produced higher concentration of phenols in 2006, all other sites showed lower total phenols in 2006.

Introduction

Precision viticulture (PV) is utilization of a series of information technologies that enable grape growers in better understanding variability in their production systems. This knowledge may be used in matching the inputs optimally with desired or expected outputs (Bramley *et al.* 2003). In other words, PV depends on the variability in product quantity and/or quality. Vineyard variability has been demonstrated in vegetative growth, yield and quality during the past few years (Bramley 2001, Hall *et al.* 2002).

According to Bramley (2001), yield varied with the percentage and position of clay in the soil profile. Specifically, he reported that the low yielding areas corresponded to areas where clay subsoil occurred near the surface which also were more prone to waterlogging in wet years. The pattern of yield variation in a vineyard in Coonawarra, Australia was shown to be temporally stable over a 3-year-period. Different wine characteristics were produced in wines made from different zones (Bramley 2002).

Bramley and Hamilton (2004a) reported 8 to 10-fold variation in yield within vineyards. However, low yielding areas did not necessarily imply high quality. They demonstrated that the patterns in yield within vineyard spatial variation were stable temporally. Hence a system of zonal vineyard management could be suggested in which individual blocks may be split in similar characteristics to be managed separately.

The water status of grapevine varies among vineyards and during the growth season. It is obvious that water status influences plant's functions (Bradford and Hsiao 1982). The importance of understanding physiological responses to water status is magnified in winegrapes, where the composition of fruit affects yield as productivity parameter.

Water stress in grapevines leads to low yields, poor shoot growth, and compromised fruit composition (Smart and Coombe 1983). A number of studies (Hepner et al. 1985; Van Zyl 1984) have indicated that irrigation of grapevines has a significant impact on grape yield and certain fruit composition factors such as Brix, pH, titratable acidity; hence on wine quality. Irrigation has a variable influence on sugar accumulation in the berries. In comparing irrigated and non-irrigated vineyards, an increase, a decrease, or no change in sugar concentration has been observed (Bartolomė et al. 1995, Freeman and Kliewer 1983). Both excess irrigation (Matthews and Anderson 1988) and severe water stress (Hardie and Considine 1976) may affect sugar accumulation significantly.

In potted experiments with Cabernet Sauvignon, low soil water status decreased bud fruitfulness but had no effect on the vegetative development of the bud (Buttrose 1974). These data suggest that the effect of water status on bud development was primarily on the initiation of reproductive growth, i.e. formation of the anlagen (Sirinivasan and Mullins 1981). The purpose of this study was to determine spatial variability in terms of yield components, berry composition and their relationships with soil and vine water status in ten Cabernet Franc vineyards in the Niagara Peninsula of Ontario.

Materials and Methods

Yield components and vine size. Measurements were made during 2005 to 2007 seasons on 72 to 80 sentinel vines at each vineyard block. Prior to the harvest of each block in September/October, 100-berry samples were collected from random clusters in each experimental vine and stored at -25°C until analysis. All berry samples and fruit were collected one day before the commercial harvest. These samples were used to determine berry weights, soluble solids (Brix), pH, titratable acidity (TA), color intensity (A_{420} + A_{520}), hue (A_{420}/A_{520}), anthocyanins, and total phenols. All sentinel vines were hand-harvested and yield and cluster numbers were determined for each vine as well. In December to March after the leaves had fallen, the vines were pruned based on the training system. Removed wood were collected separately from each vine and weighed using a digital scale (Rapala, China) to determine pruning weights (vine size) in kg.

Berry analysis for Brix, TA and pH. The frozen berry samples were thawed, weighed and placed in 250 mL beakers and then heated to 80°C in a water bath (Fisher Scientific Isotemp 228, USA) and held for one hour to dissolve any precipitated tartrates. Samples were cooled to the room temperature and juiced in an Omega 500 fruit juicer. The resulting juice was centrifuged at 4500 rpm for 10 minutes in an IEC Centra CL2 centrifuge (International Equipment Company, Needham Heights, MA) to remove solids.

The supernatant was retained for analysis of pH via an Accument pH meter (model 25; Denver Instrument Company, Denver, CO), TA with a PC-Titrate autotitrator (Man-Tech Associates, Guelph, ON) by titration with 0.1 *N* NaOH to an end point of pH 8.2, and Brix using an Abbé refractometer (model 10450; American Optical, Buffalo, NY). The remaining juice was centrifuged with Model B-20 centrifuge (International Equipment Co. Needham Heights, MA) at 12000 g for 10 minutes and stored at -25°C for further analysis for color intensity, anthocyanins and total phenolics. Wine and must samples were analyzed using the aforementioned method, except soluble solids which was not performed on wine samples.

Berry analysis for color intensity, anthocyanins, and total phenols. After thawing to room temperature for several hours, color, anthocyanins and total phenols were determined in berry samples. Color intensity and hue were determined using a modified method provided by Mazza *et al.* (1999). Color intensity and hue were calculated from absorbance values measured at 420 nm and 520 nm on an Ultrospec 2100 pro UV/VIS spectrophotometer (Biochrom Ltd., Cambridge, UK). Undiluted juice, must and wine samples were measured in a 1 mm quartz cuvette and the values were multiplied by 10 to compensate for the 10 mm pathlength. The blank for juice and must samples was prepared using 120g/L fructose, 120g/L fructose and 10 g/L tartaric acid in distilled water as a zero absorbance. The blank for wine samples was a solution of 12% v/v ethanol and 10 g/L tartaric acid. Color intensity and hue were calculated using the following formulas:

$$\text{Color intensity} = A_{520} + A_{420}$$

$$\text{Hue} = A_{420}/A_{520}$$

Total anthocyanin concentrations in berries were determined using pH shift method provided by a modified version of the Fuleki and Francis (1968). pH 1.0 and pH 4.5 buffer solutions were prepared using 0.2M KCl with 0.2M HCl and 1M sodium acetate with 1M HCl in distilled water respectively and adjusted with HCl or NaOH when it was necessary. One mL of each sample was diluted by both buffers separately and held in dark for one hour. Subsequently absorbance was measured at 520 nm with a 10mm path length cuvette using a Biochrom Ultrospec 2100 pro UV/Vis spectrometer (Biochrom Ltd.) against zero reference of appropriate buffer solution. The total anthocyanin concentration was calculated with the following formula:

$$\text{Total anthocyanins (mg/L)} = A_{520}\ (\text{pH } 1.0 - \text{pH } 4.5) \times 255.75$$

Total phenolics were estimated by colorimetric measurement of blue color caused by the redox reaction between reductant phenols and oxidant Folin-Ciocalteu reagent (VWR, West Chester, PA) in an alkaline solution of sodium carbonate using method of Singleton and Rossi (1965). Berry juice, must and wine samples were diluted in ratio of 1:9 with distilled water and one mL of diluted sample (or gallic acid standard) was added to a 100 mL volumetric flack containing ca 60 mL of distilled water. Then 5 mL of Folin-Ciocalteu reagent was added to the flask and mixed with the contents; afterwards in less than 8 minutes 15 mL of a pre-filtered and saturated solution of 20% sodium carbonate was added and the volume of the flack was brought to 100 mL by adding distilled water. The reaction took two hours at room temperature to complete while changing the yellow color of Folin-Ciocalteu reagent to green and then blue. A stock solution of 5 g/L gallic acid was prepared by dissolving 0.5 g of anhydrous gallic acid in 100 mL distilled water and kept in a dark and cool area covered with aluminum foil. In order to prepare calibration standards 0, 1, 2, 3, 5 and 10 mL of stock solution was added to 100 mL volumetric flacks and diluted by distilled water to obtain 0, 50, 100, 150, 250, and 500 mg/L gallic acid standards. Absorbance at 765 nm was measured against a zero absorbance of the first standard (containing distilled water, 5 mL Folin-Ciocalteu reagent and 15 mL sodium carbonate) in 10 mm plastic cuvettes. A calibration curve of total phenolics (mg/L gallic acid) was created using standards of gallic acid. The calibration curve was used to calculate the total phenolics in juice, must and wine samples and expressed in mg/L gallic acid equivalents (GAE) and the values were adjusted by multiplying to 10 to compensate for the dilution.

Sodium carbonate solution was prepared by dissolving 200 g of anhydrous sodium carbonate in 700 mL of distilled water. The mixture was heated until the sodium carbonate was dissolved and the volume brought to 1 L by adding distilled water. After cooling to room temperature, 2 to 3 g of sodium carbonate was added to make a saturated solution then it left for 24 hours before being filtered through Whatman No. 2 filter paper.

GPS and GIS. Raven Invicta 115 GPS Receiver manufactured by Raven Industries, Sioux Falls, SD (with 1.0 to 1.4 meters accuracy) was used to delineate the shape of each vineyard block as well as to geo-locate each sentinel vine. Using GIS programs MapInfo and Vertical Mapper (Northwood GeoScience, Ottawa, ON) water status zones were mapped based on vine leaf Ψ values. The inverse distance weighting (IDW) interpolation algorithm was used to construct the grid files. IDW interpolation algorithem was chosen vs. Kiriking due to uneven nature of vineyards. In this method of interpolation, closer grid points have more influence on the calculation of unknown grid values compared to the points that are further away. In regard with power, exponential option was selected, which enables the user to define the exponential rate of decreasing the influence by neighbouring points that lie further from the point being calculated. The lowest value was chosen for exponential rate. The values on each zone of the constructed maps were the minimum value of the range for that zone. Each vineyard block was separated into three zones of high, medium, and low water status (HWS, MWS, LWS respectively). Grapes from each of these water status zones were harvested separately based on the leaf Ψ map at each vineyard block in both 2005 and 2006 and were used to make wine. Therefore, from each vineyard block three types of HWS, MWS and LWS wines were made in three replicates in both years.

Data analysis. Within each vineyard block, high and low water status zones were identified accordingly based on GIS- generated maps, and fruit were harvested separately from each zone. In each vineyard block all data were analyzed based on high and low water status treatments using SAS statistical package version 8 (SAS Institute; Cary, NC, USA). Correlation analysis was performed at each vineyard block as well as across the blocks for each year. Wines from each of high and low water status zone from each vineyard block were subjected to descriptive analysis. Using a t-test, chemical and sensory attributes were compared at each site by means of XLSTAT 2008 (Paris, France); also wines from medium water status were compared with each other.

A correlation matrix was created on the sensory attributes to illustrate the relationship among variables. Using GLM, analysis of variance was performed on chemical and sensory attributes. Three-way ANOVA (site, judge, replicate) was also performed on sensory attributes to find out the main effects as well as interactions. Duncan's multiple range test was used to separate the means for both sensory and chemical data. Principal component analysis (PCA) and partial least square analysis (PLS) were also performed using XLSTAT 2008 (Paris, France). Data analysis and statistics with Microsoft Excel (Paris, France) on the mean sensory scores for the aroma, flavor, and mouthfeel attributes. PCA was also done on field data in each year.

Results

Impact of vine water status on yield, vine size and fruit composition.

Vine water status vs. yield components. ***2005.*** In 2005, analysis of variance showed that vine water status had a significant effect on clusters/vine at HOP, specifically lower cluster numbers were observed in LWS treatment. Yield/vine was only affected at HOP where lower yield was produced in LWS treatment. Berry weight was affected at Vieni site in which lower berry weight was observed in HWS treatment. Vine size was affected in both Herrider and Reif sites with higher cane pruning weight in HWS treatment (Table 1).

2006. Analysis of variance in 2006 indicated that vine water status influenced clusters/vine and yield at the George and Cave Spring sites in which in LWS treatment less clusters and lower yield was produced at the George site while more clusters and higher yield was observed at Cave Spring. Berry weight was much lower in LWS treatment at Buis while in all other sites it was similar in both LWS and HWS treatments. Vine size was only affected at George site, where smaller vines were observed in LWS treatment (Table 4).

2007. In 2007 clusters/vine was similar in both high and low water status treatments. Vine water status affected yield/vine at four sites, higher yield was produced at HOP and Buis sites and lower yield was observed at George and Morrison in LWS treatment. Berry weight at the George and Cave Spring sites was lower in the LWS treatment. Weight of cane pruning was affected by vine water status at two sites, higher values were seen at Buis site and lower values were observed at George site in LWS treatment (Table 7).

Vine water status vs fruit composition. ***2005.*** Vine water status had a significant effect on Brix values at four sites. At Hernder, George and HOP higher Brix values were observed in LWS treatment, while at Reif, Brix was higher in HWS treatment. Niagara-On-The-Lake (NOTL) sites were characterized by higher TA in HWS treatment. Berry pH was affected at three sites; at CDC and HOP higher pH was observed in LWS and at Reif pH was higher in HWS treatment. Vine water status affected hue at CDC, George, and HOP sites with higher values in LWS treatment. Lower color intensity was observed at George in LWS treatment. Higher anthocyanins were produced in LWS at Buis and HOP. Total phenols were significantly higher in HWS treatment at Harbour and George and lower at HOP sites (Tables 2, 3).

2006. Higher Brix were observed in LWS treatment at the CDC and Harbour sites, while at Buis Brix was higher in HWS treatment. Vine water status had a significant effect on berry TA at Buis, Harbour and Cave Spring sites; TA was lower in LWS treatment at the Buis and Harbour sites and high at Cave Spring. pH was lower at Hernder and high at Buis in HWS treatment. Areas of low vine water status had higher hue values at Hernder and lower values at George. Color intensity was higher in HWS treatment at three sites (Hernder, Reif, Cave Spring) and lower at Harbour. Berry anthocyanin was only affected at Hernder in which low anthocyanins were observed in

LWS treatment. Total phenols were high at George and Morrison and low at Hernder in LWS treatment (Tables 5, 6).

2007. Vine water status significantly influenced Brix at Harbour and Morrison, both sites having higher Brix levels in the LWS treatments. TA was affected at four sites (CDC, Reif, Harbour and George) with lower TA in the LWS treatment. Berry pH was also affected at five sites. Morrison, Vieni, Cave Spring and Buis sites had higher pH values, whereas Hernder site had lower pH in LWS treatment. Hue was affected by vine water status at five sites (Buis, Reif, Harbour, HOP and Vieni) values were low at Buis and HOP sites in LWS treatment, Reif, Harbour and Vieni sites had higher values. Vine water status altered color intensity at all sites except CDC, Hernder and HOP; higher color intensity was observed in LWS treatment at Buis, Harbour, George, Cave Spring and Morrison, while Reif and Vieni sites showed lower values. Anthocyanins were also affected at seven sites; high anthocyanins were produced at Buis, Harbour, George, Cave Spring, and Morrison while lower values were observed at CDC and Reif in the LWS treatment. Total phenols were different at three sites; at Buis and Morrison higher values were seen in the LWS treatment while at HOP lower values were seen (Tables 8, 9).

Correlation analysis between soil factors vs. yield components, fruit composition and vine size for all sites in 2005 revealed that leaf Ψ was negatively correlated with yield, berry weight, vine size and TA, but was positively correlated with Brix, color intensity, anthocyanins and total phenols. Soil moisture was positively correlated with berry weight, TA and total phenols. Percent sand had a positive correlation with vine size and was negatively correlated with Brix, pH, color intensity, anthocyanins and total phenols. Percent clay was positively correlated with Brix, color intensity, anthocyanins and total phenols but was negatively correlated with vine size and TA. OM was positively correlated with berry weight and pH and was negatively correlated with color intensity and total phenols. CEC had positive correlation with Brix, pH, color intensity, anthocyanins and total phenols but negatively correlated with vine size. Base saturation was positively correlated with Brix, color intensity, anthocyanins and total phenols but was negatively correlated with yield and vine size. P was positively correlated with vine size, TA and total phenols and was negatively correlated with Brix. K was positively correlated with vine size and was negatively with yield, Brix, pH and color intensity. Ca had positive correlation with Brix, pH, color intensity, anthocyanin and total phenols and was negatively correlated with yield and vine size. Mg was positively correlated with Brix, pH, color intensity, anthocyanins and was negatively correlated with vine size and TA (Table 10).

2006. Overall correlation analysis of soil factors vs. yield components, fruit composition and vine size for all sites in 2006 showed that leaf Ψ was positively correlated with berry weight and negatively with TA. Soil moisture was positively correlated with berry weight, color intensity, anthocyanins and total phenols but was negatively correlated with yield and TA. Percent sand was positively correlated with yield and negatively with total phenols. Percent clay had positive correlation with Brix, anthocyanins and total phenols while was negatively correlated with yield and TA. OM was positively correlated with yield and negatively with Brix and berry pH; CEC had positive correlations with color, anthocyanins and total phenols while it was negatively correlated with yield and vine size; soil pH was positively correlated with anthocyanins and total phenols but was negatively correlated with yield and vine size; soil base saturation (BS) was positively correlated with berry weight, Brix, anthocyanins, and total phenols while it was negatively correlated with yield, vine size and TA. The P concentration had positive correlation with vine size, berry pH and TA, but was negatively correlated with berry weight, Brix, color intensity, anthocyanins and total phenols; The K concentration was positively correlated with vine size and berry pH and was negatively correlated with color intensity, anthocyanins and total phenols; the Ca concentration had positive correlation with color intensity, anthocyanins and total phenols while was negatively correlated with yield and vine size; the Mg concentration was positively correlated with color and total phenols but was negatively correlated with yield and berry weight (Table 11).

2007. In 2007 correlation analysis of soil factors vs. yield components, vine size and fruit composition revealed that leaf Ψ was negatively correlated with yield, berry weight, vine size and TA; soil moisture was negatively correlated with vine size and anthocyanins; percent sand was positively correlated with yield, berry weight, vine size and TA, but was negatively correlated with color intensity. Percent clay had negative correlations with yield, berry weight, vine size and TA but was positively correlated with color intensity; OM was negatively correlated with vine size (Table 12). CEC was positively correlated with color intensity but was negatively correlated with yield and vine size; both soil pH and base saturation were negatively correlated with yield and berry weight; P and K were positively correlated with berry pH while negatively correlated with TA, color intensity, anthocyanins and total phenols; Ca had positive correlation with color intensity but was negatively correlated with yield and vine size;

Mg was positively correlated with color intensity and anthocyanins but was negatively correlated with yield, berry weight, and vine size (Table 12).

Relationships among yield components, fruit composition, vine size and soil texture. ***2005.*** Relationships among yield components, fruit composition, vine size and soil texture in 2005 are illustrated in Fig. 1. Principal component analysis (PCA) explained 57.6% of the variability in the data in the first two dimensions. PC1 accounted for 36.1% of the variability and was most heavily loaded in the positive direction with Brix, color intensity, anthocyanins, total phenols and clay and was negatively loaded with vine size and sand. PC2 explained 21.5% of the variation in the data set, and was positively loaded with clusters/vine, yield, berry weight and pH (Fig. 1). The third PC explained another 16.3% of the variation (data not shown).

Some attributes such as color intensity, anthocyanins and total phenols were positively correlated and grouped together in the lower right of the plane. Clay, Brix and pH were positively correlated and grouped together in the upper right of the plane. Yield, clusters/vine, berry weight, vine size and hue were grouped together in the upper left of the plane and highly positively correlated. TA, sand and soil moisture also grouped together in the lower left of the plane and were positively correlated. Color intensity, anthocyanins and total phenols were negatively correlated with berry weight, vine size and hue (Fig. 1).

The distribution of high (H), medium (M) and low (L) water status treatments at each site on the PCA plot illustrated that Hernder (M, L), CDC (H, M), HOP (L) and Vieni (H) were located in the lower right of the plot indicating color intensity, anthocyanins and total phenols characters. CDC (L), Vieni (M), and Cave Spring (H, M,

L) were in the upper right of the plane and were associated with Brix and clay. HOP (H, M) and George were associated with yield, clusters/vine and pH. Harbour (H, M, L) was associated with berry weight, vine size, hue, and sand. Buis (H, M, L), Reif (H, M, L), and Herndner (H) were associated with sand and TA.

In general Harbour Estate (Creek Shores sub-appellation), Reif (Niagara River), George (Lincoln Lakeshore), and Buis (Niagara Lakeshore) sites were all on the left side of the plane and exhibited high yield, clusters/vine, berry weight, vine size, TA and hue. On the other hand, CDC (St. David's Bench sub-appellation), HOP (Short Hills Bench), Herndner (Four Mile Creek), Cave Spring (Beamsville Bench) and Vieni (Vinemount Ridge) were all on the right side of the plain and were associated with color intensity, anthocyanins, total phenols, Brix, pH and clay.

2006. Fig. 2 illustrates the relationships among yield components, fruit composition, vine size and soil texture in 2006. PCA explained 58.8% of the variability in the data set in the first two dimensions. PC1 explained 34.5% of the variability and was most heavily loaded in the positive direction with color intensity, anthocyanins, total phenols and clay while negatively loaded with vine size, TA, hue, and sand. PC2 accounted for 24.3% of variability and was positively loaded with Brix and pH and negatively loaded with clusters/vine, yield and berry weight.

Some attributes such as color intensity, anthocyanins, total phenols, clay and Brix were positively correlated and grouped together in the upper right of the plane. This group of attributes was negatively correlated with clusters/vine, yield, vine size and sand. Soil moisture and berry weight are positively correlated in the lower right of the plane. TA, pH and hue were positively correlated in the upper left of the plane. Berry weight and soil moisture were negatively correlated with TA and hue. Brix was strongly negatively correlated with clusters/vine and yield and vine size was negatively correlated with color intensity, anthocyanins, total phenols and clay (Fig. 2).

The distribution of high, medium and low water status treatments at each site on the PCA plot showed that Cave Spring (H, M, L) and CDC (H, M,L) were explained with high color intensity, anthocyanins, total phenols, clay and Brix. CDC (L) had higher Brix than CDC (M, H). Hernder (H, M, L) and Buis (M) were associated with high yield, clusters/vine, vine size and sand. Hernder (L) had more clusters/vine while Hernder (M, H) had fewer clusters/vine and. Harbour (H, M, L), Morrison (H, M, L), and Reif (H, M, L) were associated with hue, TA and pH; among these three sites Harbour was more intense in the above mentioned attributes as it was further away from the center of the plot. George (H, M, L) and HOP (H, M, L) had higher soil moisture and bigger berries (Fig. 2).

The third PC explained another 17.3% of the variability in the data set (data not shown). Morrison (H, M, L) and Harbour (H, M, L) both were explained better by this PC, such that Morrison (H, M, L) was associated with high vine size, clusters/vine and hue and Harbour (H, M, L) was associated with high yield and sand.

2007. The relationships among yield components, fruit composition, vine size and soil texture in 2007 are illustrated in Fig. 3. PCA explained 58.7% of the variability in the data set in the first two dimensions. PC1 accounted for 31.6% of the variance and was most heavily loaded in a positive direction with color intensity, anthocyanins, total phenols, TA and Brix while negatively loaded with clusters/vine and hue. PC2 explained

27.1% of the variability and was positively loaded with clusters/vine, yield, berry weight, TA and sand and negatively loaded with clay (Fig. 3).

Similar to 2005 and 2006 color intensity, anthocyanins, total phenols and Brix were strongly positively correlated in the lower right of the plane. Berry weight and TA were strongly positively correlated in the upper right of the plane. Clusters/vine, yield, berry weight and sand were positively correlated in the upper left; hue, soil moisture, pH and clay were positively correlated in lower left of the plane. Yield and clusters/vine were negatively correlated with color intensity, anthocyanins, total phenols and Brix. TA was negatively correlated with pH and hue. Clay was also negatively correlated with berry weight and yield. Vine size, pH, soil moisture and hue were, however, not explained well in the first two dimensions (Fig. 3).

The distribution of high, medium and low water status treatments at each site on the PCA plot showed that CDC (H, M, L), Cave Spring (H, M, L), Vieni (H) and George (M, L) were associated with high color intensity, anthocyanins, total phenols and Brix; among these sites CDC was more and George was less intense in these attributes. George (H) and Reif (M) were associated with lower TA. Harbour (H, M, L) was associated with sand, berry weight and vine size. Buis (H, M, L) had high sand, yield and vine size. HOP (H, M, L) and Reif (L) were high in yield, vine size and clusters/vine. HOP (L) had higher clusters/vine than HOP (H, M). Hernder (H, M, L), Morrison (H, M, L) and Vieni (L) were explained with high pH, soil moisture, hue and low TA.

PC 3 explained extra 16.3% of the variability in the data (data not shown). Variability for Morrison and Hernder sites was explained better by PC3. Morrison (L) was explained by high pH, Brix, and total phenols, Morrison (M) was associated with sand, hue, clusters/vine, and vine size while Morrison (H) was explained by berry weight and yield. Hernder (H, M, L) also associated with hue, clusters/vine as well as sand. Overall, in hot and dry years of 2005 and 2007, the relationships among the various attributes were explained much better compared to the wet season of 2006.

Spatial correlation analysis. ***Soil texture and composition.*** Spatial correlation analysis indicated that at the Buis site in 2005 berry anthocyanins were highly spatially correlated with Brix, color intensity and phenols (Fig. 19A, 29A, 34A, 39A); berry weight was highly positively correlated with soil moisture while was inversely correlated with total phenols (Fig. 11A[chapter 3], 14A, 39A). Brix had positive spatial correlations with color and phenols while was negatively correlated with TA (Fig. 19A, 24A, 29A, 39A). Color was highly positively correlated with phenols (Fig. 29A, 39A). In 2006 berry anthocyanins showed high spatial correlation with color intensity (Fig. 29B, 34B); berry weight was highly positively correlated with vine size (Fig. 4B, 14B); color intensity had high spatial correlations with total phenols and soil moisture (Fig. 11B[chapter 3], 29B, 39B) and total phenols were highly positively correlated with soil moisture (Fig. 11B[chapter 3], 39B). In 2007, as with the previous two years, color intensity was highly spatially correlated with anthocyanins and total phenols (Fig. 29C, 34C, 39C); Brix had positive spatial correlation with soil moisture and TA while was inversely correlated with yield (Fig. 9C, 11C[chapter 3], 19C, 24C) and yield had a positive correlation with vine size (Fig. 4C, 9C).

In 2005 spatial correlation analysis at the CDC site showed that berry anthocyanins were highly spatially correlated with color and total phenols (Fig. 29D, 34D, 39D); color also highly correlated with total phenols (Fig. 29D, 39D) and soil moisture had high spatial correlation with TA (Fig. 11D[chapter 3], 15A). In 2006 color intensity had high spatial correlation with anthocyanins and total phenols while inversely correlated with berry weight (Fig. 14E, 29E, 34E, 39E). In 2007 like the last two years color intensity highly positively correlated with anthocyanins (Fig. 29F, 34F) and berry weight spatially correlated with vine size (Fig. 4F, 14F).

At the Hernder site spatial correlation analysis in 2005 indicated that berry anthocyanins were positively correlated with Brix, color intensity and total phenols while inversely correlated with berry weight and TA (Fig. 15A, 20A, 25A, 30A, 35A, 40A). Total phenols were spatially correlated with color and were inversely correlated with berry weight (Fig. 15A, 30A, 40A); Brix correlated positively with color intensity and negatively with TA (Fig. 20A, 25A, 30A); leaf Ψ correlated positively with total phenols and negatively with TA (Fig. 17A[chapter 3], 25A, 40A). In 2006 only anthocyanins correlated with color intensity and total phenols (Fig. 30B, 35B, 40B). The 2007 vintage showed more significant spatial correlations. Berry anthocyanins spatially correlated with color and TA (Fig. 25C, 30C, 35C); while color intensity correlated positively with total phenols and TA, but negatively correlated with vine size (Fig. 5C, 25C, 40C); TA also negatively correlated with vine size (Fig. 5C, 25C).

Spatial correlation analysis in 2005 at Rief showed that berry anthocyanins were spatially correlated with Brix and color (Fig. 20D, 30D 35D). Color was correlated with total phenols (Fig. 30D, 40D); Brix was inversely correlated with TA (Fig. 20D, 25D) while TA positively correlated vine size (Fig. 5D, 25D). In 2006 there was high spatial correlation between color with anthocyanins and total phenols (Fig. 30E, 35E, 40E). In

2007 anthocyanin spatially correlated with color and total phenols (Fig. 30F, 35F, 40F) also color positively correlated with total phenols and TA (Fig. 25F, 30F, 40F).

In 2005 spatial correlation analysis at the Harbour site showed that anthocyanins were positively correlated with color and total phenols (Fig. 31A, 36A, 41A). In 2006 there was no yield data, but berry samples were analyzed. Anthocyanins positively correlated with Brix (Fig. 21B, 36B) and total phenols positively correlated with TA (Fig. 21B, 41B). In 2007 color positively correlated with anthocyanins (Fig. 31C, 36C).

In 2005 spatial correlation analysis at George site indicated that anthocyanins were positively correlated with color and total phenols while were negatively correlated with berry weight (Fig. 16D, 31D, 36D, 41D); Color was positively correlated with anthocyanins and total phenols while was inversely correlated with berry weight (Fig. 16D, 31D, 36D, 41D); soil moisture was spatially correlated with vine size and yield (Fig. 6D, 11D 13D[chapter 3]). Yield was positively correlated with vine size (Fig. 6D, 11D). In 2006 there were few significant correlations. There was a positive correlation between color and total phenols (Fig. 31E, 41E), vine size and Brix (Fig. 6E, 21E), and a negative correlation between total phenols and TA (Fig. 26E, 41E). In 2007 however, there were more significant spatial correlations. Anthocyanins were positively correlated with color and total phenols while were negatively correlated with yield and berry weight (Fig. 11F, 16F, 31F, 36F, 41F); leaf Ψ was negatively correlated with berry weight, vine size, and yield (Fig. 6F, 11F, 16F, 18F[chapter 3]). Vine size was positively correlated with berry weight and yield (Fig. 6F, 11F, 16F) and Brix was spatially correlated with color (Fig. 21F, 31F).

Spatial correlation analysis at Cave Spring in 2005 revealed that berry weight was positively correlated with soil moisture and vine size but was negatively correlated with color and total phenols (Fig. 7A, 14A[chapter 3], 17A, 32A, 42A); TA was negatively correlated with anthocyanins and Brix (Fig. 22A, 27A, 37A); total phenols were positively correlated with color but were inversely correlated with berry weight (Fig. 17A, 32A, 42A). Vine size was positively correlated with soil moisture (Fig. 7A, 14A[chapter 3]). In 2006 color was positively correlated with anthocyanins and Brix (Fig. 22B, 32B, 37B). In 2007 color was spatially correlated with anthocyanins (Fig. 32C, 37C); Brix was positively correlated with phenols (Fig. 22C, 42C) and leaf Ψ was negatively correlated with berry weight (Fig. 17C, 19C[chapter 3]).

At HOP spatial correlation analysis in 2005 indicated that anthocyanins had positive correlations with Brix, color and total phenols (Fig. 22D, 32D, 37D, 42D); color positively correlated with anthocyanins, Brix, and total phenols (Fig. 22D, 32D, 37D, 42D); total phenols correlated with Brix and yield (Fig. 12D, 22D, 42D). In 2006 color correlated with anthocyanin (Fig. 32E, 37E). In 2007 anthocyanin and color were positively correlated (Fig. 32F, 37F); vine size positively correlated with berry weight (Fig. 7F, 17F) and yield positively correlated with TA while had negative correlation with Brix (Fig. 12F, 22F, 27F).

Spatial correlation analysis at the Vieni in 2005 revealed that total phenols positively correlated with anthocyanins, Brix and color while negatively correlated with berry weight (Fig. 18A, 23A, 33A, 38A, 43A); Color had positive correlations with anthocyanins and Brix (Fig. 23A, 33A, 38A); Brix was positively correlated with anthocyanins but was negatively correlated with berry weight (Fig. 18A, 23A, 38A) and also there was positive correlation between berry weight and vine size (Fig. 8A, 18A). Due to severe disease problems there were no data in 2006. In 2007 color was positively correlated with anthocyanins and total phenols (Fig. 33B, 38B, 43B) also leaf Ψ was positively correlated with TA and vine size (Fig. 8B, 20C[chapter 3], 28B).

There were no yield data available at Morrison site in 2005 due to severe winter damage in the previous year. In 2006 Brix had a positive spatial correlation with color (Fig. 23C, 33C). In 2007 there were more significant correlations than in 2006. Anthocyanins were correlated positively with Brix, color, total phenols and correlated negatively with yield (Fig. 13D, 23D, 33D, 38D, 43D); berry weight correlated positively with vine size (Fig. 8D, 18D); yield correlated negatively with Brix (Fig. 13D, 23D) and color was correlated positively with total phenols (Fig. 33D, 43D).

Impact of vintage on yield components, vine size and fruit composition

Vintage effects. The influence of vintage was studied on yield components, vine size and fruit composition. Vintage ifluenced clusters/vine at eight sites, all of which had more clusters/vine in 2006. Yield was affected at all sites, with higher yield at eight sites in 2006. Only Harbour and Vieni had higher yield in 2007. Berry weight was significantly different in all sites except Reif. Higher berry weights were produced in 2006 at all other sites except Buis and Harbour which had higher Berry weight in 2007. Vintage influenced vine size at seven sites. Hernder, George, Cave Spring and Morrison had higher vine size in 2006. HOP and Harbour had higher vine size in 2005 (Table 13).

Vintage altered Brix levels at all sites except CDC. All other sites produced lower Brix levels in 2006 except Harbour which had lower Brix in 2005. The Hernder site had lower pH in 2006 and all other Niagara-on-the-Lake (NOTL) sites were characterized by lower pH in 2005. Results from West of St. Catharines were not consistent. Harbour, Vieni and Cave Spring had higher pH in 2005, while George and Morrison had higher values in 2007. Vintage affected TA at all sites, with all sites having lower TA in 2007 (except George site which had lower TA in 2005) (Table 14).

Vintage affected hue at Morrison and George, both of which had lower hue values in 2006. Color intensity was affected at six sites; excepting the George site which showed lower color in 2005, all other sites produced less color in 2006. All sites had different anthocyanin levels in which lower concentrations were produced in 2006, other than Cave Spring, which showed higher anthocyanin concentration in 2006. Vintage significantly influenced total phenols at all sites except Morrison; HOP and Cave Spring produced higher concentration of phenols in 2006 while all other sites showed lower total phenols in 2006 (Table 15).

Vintage x site relationships between yield components and fruit composition. The impact of vintage was also studied at each site. PCA was performed on yield components, fruit composition and vine size at Buis for the years 2005 to 2007 and shows the relationships between high, medium and low water status treatments. PCA explained 73.1% of the variability in the first two dimensions. PC1 accounted for 39.7% of the variability and was heavily loaded in the positive direction with clusters/vine, yield, berry weight, and soil moisture, but was negatively loaded with hue. PC2 explained 33.4% of the variability in the data and was positively loaded with Brix, pH, total phenols and negatively loaded with TA and color intensity (Fig. 44).

Vintage in 2005 was characterized by high TA and anthocyanins; the concentration of anthocyanins was higher in Buis L5 than Buis M5 and Buis H5. The 2006 vintage was characterized by high color intensity, vine size and high clusters/vine such that Buis L6 was higher in color intensity, Buis M6 was higher in vine size and Buis H6 was higher in clusters/vine. The 2007 vintage was associated with soil moisture, yield, berry weight, pH, Brix, and total phenols; Buis H7 was higher in total phenols and Brix, Buis L7 was high in pH and Buis M7 had bigger berries (Fig. 44).

PCA illustrated relationships between yield components, fruit composition and vine size at CDC in 2005 to 2007 and shows the relationship between high, medium and low water status treatments for these three vintages. PCA explained 84.18% of the variability in the first two dimensions. PC1 explained 53.4% of the variability and was heavily loaded in positive direction with color intensity, anthocyanins, total phenols, hue and Brix, while being negatively loaded with clusters/vine and TA. PC2 accounted for 30.8% of the variability in the data and was positively loaded with berry weight, yield, pH and soil moisture and was negatively loaded with vine size (Fig. 45).

In the 2005 vintage all three treatments were grouped together in lower left of the plane and were characterized by vine size as well as low pH and berry weight. In 2006 also, all treatments were grouped together in upper left of the plane and were characterized by yield, clusters and soil moisture. 2007 vintage was explained by color intensity, total phenols, Brix, pH and berry weight; such that CDC L7 was high in color intensity, total phenols and Brix while CDC M7 was explained by berry weight and pH (Fig. 20).

PCA indicated relationships between yield components, fruit composition and vine size at Hernder in 2005 to 2007 which shows the relationship between high, medium and low water status treatments in three vintages. PCA explained 94.91% of the variability in the data set. PC1 explained 53.5% of the variability and was heavily loaded in positive direction with clusters/vine, yield, berry weight, vine size, and soil moisture, but negatively loaded with color intensity, anthocyanins and total phenols. PC2 accounted for 41.4% of the variance in data and was positively loaded with Brix, pH, and hue and negatively loaded with TA (Fig. 46).

All treatments were grouped together in 2005 vintage in the lower left of the plane and were explained with color intensity, anthocyanin, TA and low hue. In 2006 all treatments were grouped together in the lower right of the plane and were associated with yield, berry weight and vine size. In the 2007 also all treatments were grouped together in the upper right of the plane and were characterized by Brix, hue pH and low TA (Fig. 21).

PCA indicated relationships between yield components, fruit composition and vine size at Reif in 2005 to 2007 which shows the relationship between high, medium and low water status treatments in three vintages. PCA accounted for 93.24% of the variability in the data set. PC1 explained 56.8% of the variability and was heavily loaded in positive direction with berry weight, vine size, Brix, pH, hue, and total phenols while negatively loaded with color intensity and TA. PC2 explained 36.5% of the variance in data and was positively loaded with clusters/vine, yield and soil moisture and negatively loaded with anthocyanins (Fig. 47).

In 2005 all treatments were grouped together in lower left of the plane and were explained by color intensity, anthocyanins and TA. All treatments were grouped in the

2006 in the upper left of the plane and were associated with soil moisture and yield. In the 2007 vintage all treatments were located in the right side of the plane and were characterized by Brix, hue, pH, vine size, berry weight, total phenols and clusters/vine; Reif M7 and Reif H7 were grouped in the lower right of the plane and were associated with vine size while Reif L7 was in the upper right of the plane and was explained with Brix, hue, pH, berry weight, total phenols and clusters/vine (Fig. 47).

PCA was performed on yield components, fruit composition and vine size at Harbour Estate in 2005 to 2007 and shows the relationship between high, medium and low water status treatments in all three vintages. PCA accounted for 79.7% of the variability in the first two dimensions. PC1 explained 46.5% of the variance and was heavily loaded in positive direction with color intensity, anthocyanins, total phenols, Brix, and yield and negatively loaded with hue and pH. PC2 explained 33.2% of the variability in the data and was positively loaded with berry weight and negatively with TA and soil moisture (Fig. 48).

In the 2005 vintage Harbour (H5 and M5) grouped together in lower left of the plane and explained by hue, vine size and soil moisture. Harbour L5 was in the upper left and was associated with high pH and low TA. All treatments were grouped together in the 2006 vintage in the lower right of the plane and were explained by low pH and high TA. In the 2007 vintage all treatments were also grouped together in the upper right of the plane and were explained by color intensity, anthocyanins, total phenols, Brix, yield and berry weight (Fig. 48).

Relationships between yield components, fruit composition and vine size is shown by PCA at George in 2005 to 2007 vintages. PCA explained 86.3% of the variability in the first two dimensions. PC1 accounted for 51.6% of the variability and was heavily loaded in positive direction with anthocyanins, Brix, pH, and hue while negatively loaded with vine size, clusters/vine and berry weight. PC2 explained 34.8% of the variability in the data and was positively loaded with color intensity, total phenols, TA, yield, and soil moisture (Fig. 49).

In the 2005 vintage all three treatments were grouped together in lower left of the plane and were explained by clusters/vine, as well as low color intensity and total phenols. In the 2006 vintage treatments grouped together in the upper left of the plane and were characterized by soil moisture, TA, yield and vine size. Treatments also grouped together in 2007 in the upper right and were associated with color intensity, total phenols and Berry weight (Fig. 49).

PCA was performed on yield components, fruit composition and vine size at Cave Spring in 2005 to 2007 and shows the relationship between high, medium and low water status treatments in all three vintages. PCA accounted for 83.3% of the variability in the first two dimensions. PC1 explained 44.3% of the variability and was heavily loaded in positive direction with clusters/vine, yield, color intensity, anthocyanins and total phenols while negatively loaded with hue. PC2 explained 39.1% of the variability in the data and was positively loaded with berry weight, vine size, TA, soil moisture and negatively loaded with Brix and pH (Fig. 50).

Vintage in 2005 was explained by high pH and hue as well as low Brix; Cave M5 was low in Brix while Cave L5 and Cave H5 were high in pH and hue. The 2006 vintage was characterized by high total phenols, anthocyanins, clusters/vine, vine size, soil moisture, TA, berry weight and yield. The 2007 vintage was associated with hue, pH, Brix, and color intensity such that Cave H7 was high in hue and pH, and Cave L7 was high in Brix and color intensity (Fig. 50).

PCA was performed on yield components, fruit composition and vine size at Henry of Pelham (HOP) in 2005 to 2007 and shows the relationship between high, medium and low water status treatments in all three vintages. PCA accounted for 77.4% of the variability in the first two dimensions. PC1 explained 40.2% of the variability in the data set and was positively loaded with anthocyanins, total phenols, TA and pH while negatively loaded with berry weight and yield. PC2 explained 37.2% of the variance in data and was positively loaded with Brix and color intensity, but negatively loaded with clusters/vine, yield and soil moisture (Fig. 51).

All treatments in 2005 were located in the upper right of the plane and were explained by pH and anthocyains; HOP L5 was more intense in these characters and was further away from the tow other treatments HOP (H5, M5). In the 2006 vintage all treatments were in the lower part of the plane and were explained with yield, berry weight, clusters/vine and soil moisture. In the 2007 vintage all treatments were in the upper left of the plane and were explained with color intensity and Brix (Fig. 51).

PCA was performed on yield components, fruit composition and vine size at Vieni in 2005 and 2007 which shows the relationship between high, medium and low water status treatments in all three vintages. PCA accounted for 83.32% of the variability in the first two dimensions. PC1 explained 61.3% of the variability and was heavily loaded in positive direction with color intensity, anthocyanins, total phenols and pH while negatively loaded with berry weight, vine size, yield, Brix and soil moisture. PC2 explained 22.0% of the variability in the data and was positively loaded with TA and hue (Fig. 52).

Vintage in 2005 was explained by high color intensity, anthocyanins, total phenols, pH and TA. The treatments were separated such that Vieni L5 was lower right of the plane and was explained by color intensity, anthocyanins and total phenols, while Vieni M5 and Vieni H5 were in the upper right and were characterized by pH and TA. The 2007 vintage was associated with hue, vine size, berry weight, soil moisture, yield and Brix. All treatments were on the left side of the plane and there was a good separation among them such that Vieni H7 was in upper left of the plane and was explained with hue and vine size while Vineni L7 was in lower left and was explained by color intensity (Fig. 52).

PCA illustrated relationships between yield components, fruit composition and vine size at Morrison site in 2005 to 2007 and shows the relationship between high, medium and low water status treatments in three vintages. PCA explained 95.67% of the variability in the first two dimensions. PC1 explained 81.8% of the variability and was heavily loaded in positive direction with color intensity, anthocyanins, hue, pH, berry weight and Brix while negatively loaded with clusters/vine, yield, vine size, TA and soil moisture. PC2 accounted for 13.9% of the variability in the data and was positively loaded with total phenols (Fig. 53).

There was no yield data to harvest in 2005 due to severe winter damage in the previous year. In 2006 all treatments were in the left side of the plane and were associated with soil moisture, vine size, clusters/vine and yield; Morrison H6 had higher yield that Morrison M6 and L6. In the 2007 vintage all treatments were on the right side of the plane and were explained by color intensity, anthocyanins, total phenols, hue, Brix, pH and berry weight. There was also a good separation of treatments such that Morrison L7 was in the upper right of the plane and was explained by color intensity, anthocyanins and total phenols while Morrison M7 and H7 were in the lower right of the plane and were associated with hue, Brix, pH and berry weight (Fig. 53).

Spatial variability in yield and fruit composition.

Yield spatial distribution was consistent at Cave Spring and George sites between the 2005 and 2006 vintages but not between 2006 to 2007 (Fig. 12A,B,C, 11D,E,F). Yield spatial distribution at CDC was consistent between 2006 and 2007 vintages, but not between 2005 and 2006 vintages (Fig. 9D,E,F). At all other sites yield spatial distribution varied over the three vintages. Berry weight was highly spatially consistent at Cave Spring between the 2005 and 2006 vintages as well as between the 2006 and 2007 vintages (Fig. 17A, B, C). Berry weight was also highly spatially correlated at CDC and Harbour sites (Fig. 14E, F, 16B,C) and was stable over the 2006 and 2007 vintages. At all other sites, however, berry weight was not consistent form year to year.

Brix was not spatially consistent at any site between the 2005 and 2006 vintages but between the 2006 and 2007 vintages was only consistent at Harbour site (Fig. 21B,C). Berry titratable acidity was spatially consistent only at Harbour site (Fig. 26A,B,C), while at all other sites spatial distribution was changed substantially over time. Vine size was highly spatially consistent at three sites between the 2005 and 2006 vintages including Buis, Cave Spring and George (Fig. 4A, B, 6D, E, 7A, B). Between 2006 and 2007 it was highly consistent at four sites including Buis, CDC, George, and Morrison (Fig. 4B, C, E, F, 6E, F, 8A, B).

Color intensity was temporally consistent only at Herndер between 2006 and 2007 (Fig. 30B, C), and not at any other site. Anthocyanins were spatially consistent over time at Cave Spring between 2005 and 2006 but not between 2006 and 2007 (Fig. 37A, B, C). Between 2006 and 2007 anthocyanins were spatially consistent at both Hernder and Morrisson sites (Fig. 35B, C, 38C, D). Total phenols were consistent at CDC over the three vintages (Fig. 39D,E,F). At HOP total phenols were consistent only between the 2005 and 2006 vintages (Fig. 42D, E), whereas at Harbour they were consistent only between 2006 and 2007 (Fig. 41B, C).

Impact of vine water status levels on must and wine composition.

Vine water status did not have a significant influence on must pH, Brix, hue, anthocyanins and total phenols in 2005, however, it affected TA at Hernder and Reif sites for which lower TA was observed in LWS vines at Hernder while, at Reif site TA was higher. Color intensity was affected at Harbour where high color intensity was observed for the HWS treatment (Tables 16, 17).

Vine water status did not alter must pH, TA, Brix, hue, anthocyanins and total phenols in 2006; however, it had an effect on color intensity at Reif site where higher color was observed for LWS vines (Tables 18, 19).

Wine composition analysis in 2005 vintage showed that vine water status did not alter pH and hue. TA was only affected at Harbour site where higher TA was observed for the HWS treatment; vine water status had a significant effect on ethanol concentration at Buis and CDC, both of which had higher ethanol for the LWS treatment; color intensity was affected at CDC and Veini where higher color intensity was observed in LWS vines. Anthocyanin concentration was different only at Harbour where higher anthocyanins were produced in LWS vines; total phenols were affected at Hernder site with higher phenol concentration in LWS treatment (Tables 20, 21).

In 2006 vine water status did not affect wine's TA, ethanol, hue, anthocyanin and total phenols; however, it had a significant effect on pH at George with higher pH in HWS and also affected color intensity at CDC where higher color was observed in the LWS treatment (Tables 22, 23).

Discussion

Impact of vine water status on yield components and fruit composition

Yield components and vine size. According to the PCA in 2005, the Harbour, George, Reif and Buis sites were associated with high yield, high cluster numbers, high berry weight and vine size (Fig. 1); all of these sites had higher leaf Ψ values, lighter soil texture and cooler temperatures due to close proximity to the lake or river. Therefore, higher vine water availability, lower temperatures and lighter soil textures promoted higher vegetative growth, higher vine size, higher yield, and higher berry weight. The remaining sites, including CDC, HOP, Hernder, Cave Spring and Vieni were all on the right side of the plane and were characterized by higher color intensity, anthocyanins, total phenols, Brix, pH and clay; these sites had lower leaf Ψ values, heavier soil texture and higher temperatures as they were further away from large water bodies. The data suggested that lower leaf Ψ values suppressed vegetative growth and caused smaller berry size due to less available water to the plant, smaller berry size leads to increased skin to juice ratio. Anthocyanins are known to be produced in the skins of red grapes in response to sunlight exposure and high temperatures. Coombe (1987) showed that temperature had a direct effect on anthocyanin and phenolic concentration; the concentration of anthocyanins and total phenols were highest in Cabernet Sauvignon berries at a temperature range of 21 to 26 ˚C and low at higher or lower temperatures.

More clusters were observed at Cave Spring (2006) in LWS vines, while HOP (2005) and George (2006) had fewer clusters (Tables 1, 4). Yield/vine was higher at Cave Spring (2006), Buis (2007) and HOP (2007) in LWS vines, while lower at HOP (2005), George (2006), George (2007) and Morrison (2007) (Tables 1, 4, 7). This can be explained by the fact that low leaf Ψ reduces vegetative growth and allows more sun exposure into the canopy which, in turn, stimulates more floral induction and increases fruitfulness; as a consequence more clusters are produced and higher yields are obtained. Fewer clusters at HOP (2005) and George (2006) could possibly ifluenced by high vegetative growth in the previous year that resulted in a shaded and crowded canopy that reduced floral induction.

Berry weight was lower at Vieni (2005), Buis (2006), George (2007) and Cave Spring (2007) in LWS vines (Tables 1, 4, 7). Low leaf Ψ reduces photosynthesis in leaves resulting in less water and photosynthate being translocated to berries (Carbonneau et al. 1983). This is in agreement with other studies that have shown increased water availability results in higher berry weights (Christensen 1975, Smart 1985, Williams and Matthews 1990).

Vine size was higher at Buis (2007) in LWS vines but lower at Hernder (2005), Reif (2005), George (2006), George (2007) sites (Tables 1, 4, 7). Smart and Coombe (1983) reported that pruning weight was increased by irrigation from 4 to 137% over the non-irrigated control vines. Low water availability decreases vine vegetative growth and size of canopy that allows for more efficient light exposure into canopy and clusters, ultimately resulting in a more manageable canopy. The hot and dry year of 2007 forced some growers to irrigate their vineyard, as was the case at Buis (2007), which resulted in large vine size. A benefit of lower vine size in low water status vines might be the reduction in pruning cost for the growers as well as the possibility of reduced canopy shade (Smart *et al.* 1985).

The weight of cane prunings (vine size) was higher at Hernder (2005), Reif (2005), and George (2006, 2007) in HWS vines, but lower vine size was observed at Buis (2007) in the HWS vines (Tables 1, 4, 7). Higher vine size in HWS vines could be due to higher vegetative growth as a result of higher water availability to the vines. This is in agreement with Smart and Coombe (1983) study in which they reported 4 to 137% increase in vine size of irrigated vs. non-irrigated vines. Lower vine size at Buis (2007) in HWS treatment contradicts literature. This could be due to the irrigation of the block due to very dry condition in 2007. High water content was measured in the soil surface while deeper roots of the vines may not have received enough water. With the exception of Buis (2007), the hypothesis of vine water status causing differences in yield components and vine size was supported by the data.

Impact of vine water status on fruit composition. Higher soluble solids (°Brix) were observed at Hernder (2005), George (2005), HOP (2005), Harbour (2006), CDC (2006), Morrison (2007) and Harbour (2007) in LWS vines, while Reif (2005), and Buis (2006) had lower °Brix (Tables 2, 5, 8). It is commonly assumed that larger berries will have lower sugar concentrations than smaller berries due to an increase in the water to soluble solids ratio, this has also been demonstreated here. Results from previous studies

(Ginestar *et al.* 1998), however, showed that this is not always the case. This might be explained by the fact that low leaf Ψ reduces photosynthesis, the source of sugar, by closing stomata to reduce transpiration. This reduction in photosynthesis lowers the soluble solids in water-stressed grapevines. As a consequence high water availability increases berry sugar by higher photosynthetic activity or increased leaf area which is consistent with Esteban *et al.* (1999) study comparing irrigated vs. non-irrigated vines. On the other hand, Hardie and Considine (1976) found that sugar concentration was increased by water stress. However, sugar content on a whole vine basis was actually reduced because gains in fruit ripening induced by water stress were associated with reductions in berry weight rather than increases in sugar production. Therefore, although total sugar production on a per vine basis may decrease, higher sugar in LWS vines was likely due to the concentrating effect of smaller berries.

TA values were high at Buis (2005, 2006), CDC (2005, 2007), Hernder (2005), Reif (2005, 2007), Harbour (2006, 2007), and George (2007) in HWS vines while Cave Spring (2006) had lower values (Tables 2, 5, 8). This could be attributed to low light levels within canopy as high water availability increases vegetative growth and shade inside the canopy. Seguin (1975) indicated that grape berry tartaric acid content does not change much from veraison to maturity. Malic acid, however, degrades from veraison to maturity, but the concentration increases with an increase in water availability. Further, canopy shading decreases the rate of malic acid degradation (Kliewer and Lider 1968). It is interesting to note, however, that the TA values in HWS vines were lower at Cave Spring (2006) which seems contradictory to the literature. A possible explanation could be higher precipitation overall in 2006 that might have increased vegetative growth at that site or water might have diluted some of the acids (Mullins et al. 1992).

Higher pH values were observed at CDC (2005), HOP (2005), Hernder (2006), Buis (2007), Cave Spring (2007), Vieni (2007) and Morrison (2007) in LWS vines, while lower values were observed at Reif (2005), Buis (2006) and Hernder (2007) sites (Tables 2, 5, 8). Low pH in LWS vines may be attributed to high temperature and high light levels in the canopy, lower canopy size and possibly faster malic acid degradation in the fruit. A study by Mullins *et al.* (1992) found that high cluster exposure in non-irrigated, low vigor vines may have reduced pH. Cool nights followed with warm days showed reduced pH and increased TA levels compared with warm days and warm nights (Kliewer 1973). Bergqvist and colleagues (2001) suggest that temperature may play a greater role in affecting pH than does sunlight exposure.

Smart and Coombe (1983), however, indicated that an imbalance between shoot and fruit growth, that can be caused by irrigation or severe pruning, may directly increase juice pH. Morrison (1988) reported that shading resulted in higher potassium concentration and as a result higher pH than control vines; therefore, potassium levels may also play a role in determining juice pH. This is in agreement with most of our results where higher pH was found in LWS vines. It is interesting to note that pH differences between HWS and LWS were most obvious in hot and dry years of 2005 and 2007.

Color intensity was higher at Harbour (2006, 2007), Buis (2007), George (2007), Cave Spring (2007), and Morrison (2007) in LWS vines. Lower color intensity was observed at the George (2005), Cave Spring (2006), Reif (2006, 2007), Hernder (2006) and Vieni (2007) sites (Tables 3, 6, 9). Lower color intensity in LWS vines at George (2005), Cave Spring (2006), Reif (2006, 2007), Hernder (2006) and Vieni (2007) sites could be due to increased temperature of sunlight-exposed fruit under field conditions that leads to reduced berry color. This is in agreement with Bergqvist *et al.* (2001) who found that high temperatures inhibited color formation. These findings also confirmed with the studies on Tempranillo, in which an increase in color intensity was found in irrigated vines (Esteban *et al.* 2001). High color intensity at Harbour (2006, 2007), Buis (2007), George (2007), Cave Spring (2007), and Morrison (2007) in LWS vines could be due to smaller berries as the result of less available water to vines. This is in agreement with findings of Mazza *et al.* (1999) that showed higher color intensity in vines with greater sun exposure in the fruiting zone from deficit irrigation.

Higher anthocyanins were observed at Buis (2005, 2007), HOP (2005), Harbour (2007), George (2007), Cave Spring (2007) and Morrison (2007) in LWS vines, while lower values were observed at the Hernder (2006), CDC (2007) and Reif (2007) sites (Tables 3, 6, 9). The impact of vine water status on color intensity paralleled those of anthocyanins in most sites. In both cases, the greatest differences were observed in 2007, which was a hot and dry year. Water stress may increase or decrease the development of anthocyanins in the grape skin (Hardie and Considine 1976) which is in agreement with the findings of this study. Similar results were also obtained with Sovereign Coronation table grapes (Ehtaiwesh 2006). Some studies indicated that anthocyanin concentration in the skins of berries from irrigated vines was lower than in the skins of berries from non-irrigated low-yielding vines (Esteban *et al.* 2001, Mullins *et al.* 1992). Williams and Matthews (1990) also reported that the positive effect of water stress on anthocyanin production was not simply due to a decrease in berry size since the effect is observed when anthocyanin concentration is expressed on a berry surface area basis. Bravdo *et al.* (1985) also reported that water increased anthocyanin development in red grape cultivars. Therefore, the high levels of anthocyanins in LWS vines can be attributed to concentration effect of smaller berries as a consequence of low available water to the plant and increased light exposure. This in turn leads to smaller canopy size as a result of less available water which stimulates anthocyanin accumulation in grape berries (Bergqvist *et al.* 2001) or, a direct effect of water stress on anthocyanin synthesis. We also found lower anthocyanin concentration in LWS vines at some sites. This could be due to higher temperatures at those specific sites that resulted in decreased total anthocyanin concentrations (Downey *et al.,* 2004). This is also in agreement with Spayd *et al. (*2002) who designed an experiment to separate the effects of light and temperature, and observed that sunlight increased anthocyanin concentration while high berry temperatures reduced anthocyanin concentration in afternoon sunlight exposed fruit. Sunlight exposed berries have been reported to have increased temperatures from 3 to 13°C (Dokoozlian and Kliewer 1996; Spayd *et al.* 2002) compared to non-exposed fruit due to incident radiation. A net loss of anthocyanins in Merlot was associated with the number of hours over 35 °C the fruit experienced (Spayd *et al* 2002).

Total phenols were higher at HOP (2005), George (2006), Buis (2007) and Morrison (2006, 2007) in LWS vines however, lower values were also observed at Harbour (2005), George (2005), Hernder (2006) and HOP (2007) (Tables 3, 6, 9). Higher total phenols in LWS vines can be attributed to small canopy size and more cluster exposure to sunlight, resulted from less vegetative growth due to less water availability to vines. Avenant (1994) and Smart *et al.* (1985) attributed lower phenol levels to canopy shading. Similar results were also obtained with Sovereign Coronation table grapes (Ehtaiwesh 2006). Smart *et al.* (1985) also found that overall shading (leaf and berry) reduced fruit soluble solids, tartaric acid, anthocyanins and phenols; and increased malic acid and the pH of the fruit. Coombe (1987) on the other hand, showed that temperature had a direct effect on anthocyanin and phenolic concentration. The optimum concentration of anthocyanins and total phenols in Cabernet Sauvignon berries was produced at the intermediate temperature of 26 ˚C day/21 ˚C night. Temperatures above or below 26/21 ˚C may partially explain lower total phenols in LWS vines. Therefore, the hypothesis that vine water status would cause differences on fruit composition was supported by data.

Correlations among variables. In the hot and dry year of 2005 leaf Ψ, as an indicator of vine water status, correlated (either in positive or negative direction) with many yield components, fruit composition and wine sensory characters while percent clay or percent sand were correlated with only four yield components, fruit composition or wine sensory characters (Table 10, Fig. 54). In the wet year of 2006, leaf Ψ was correlated with berry weight and TA; percent sand correlated with yield and total phenols; percent clay correlated with yield, Brix, TA, anthocyanins and total phenols (Table 11). In 2007, leaf Ψ correlated with yield, berry weight, vine size and TA while percent sand and percent clay correlated with yield, berry weight, vine size, TA and color (Table 12). PLS analysis of the entire data set for 2005 indicated that leaf Ψ correlated with numerous yield components, fruit composition and wine sensory characters, by contrast, percent sand and percent clay correlated with few attributes (Fig. 54). In 2006, PLS analysis showed the same correlations for leaf Ψ and percent sand and percent clay (Fig. 55). Vine water status influences almost every aspect of plant metabolism (Bradford and Hsiao 1982) and as a result it affects most aspects of fruit composition. Low vine water status may be associated with reduced vegetal characteristics and increased fruity aroma and flavor in red wines. Koundouras *et al.* (2006) found that limited water availability increased the main aromatic compounds of the grapes and the resultant wines were preferred in tasting trials. This is consistent with our 2005 results, which indicate that absolute value of leaf Ψ (low water status) was positively correlated with fruity characters and negatively correlated with vegetal characters (Fig. 54); however, it was not entirely consistent with 2006 results, perhaps due to excess precipitation that season (Fig. 55). Therefore, in general, the hypothesis that soil type plays a minor role in the determination of grape and wine composition and sensory quality, and that vine water status plays a major role was supported by the data.

Impact of vine water status on must and wine composition

Must composition. The effects of vine water status on fruit composition in the vineyard are reflected in the composition of must and wine. The impact on must composition of vine water status was more pronounced in the hot and dry year of 2005, but it was not significant in the wet year of 2006 in which only color intensity was affected at the Reif site.

In 2005 all attributes other than TA and color intensity were similar across LWS and HWS treatments. TA was lower in the LWS treatment at Hernder, while it was higher at Reif (Table 16); these trends were the same in berry samples. Higher color intensity was observed at Harbour (2005) in the HWS treatment (Table 17). Lower TA in

LWS at Hernder can be attributed to decreased vegetative growth in LWS vines; smaller canopy size, better light exposure and more malic acid degradation. Higher TA in HWS at Reif (2005) could be due to higher shade due to increased vegetative growth. High color in HWS vines at Harbour (2005) is in agreement with the Bravdo *et al.* (1985) finding that increasing water increased anthocyanin development in red grape cultivars.

In 2006, only color intensity at Reif was responsive to vine water status as higher color intensity was observed in the LWS treatment (Table 18). This can be explained by the concentration effect of smaller berries as a consequence of low available water to the plant as well as direct effect of water stress on anthocyanin synthesis.

Wine composition. Wine composition tended to be better responsive to vine water status compare to must composition. Lower pH was observed in LWS treatment at George (2006) (Table 20). Lower TA was found in LWS treatment at the Harbour (2005) site (Table 20). Ethanol was higher in LWS treatment at both Buis (2005) and CDC (2005) (Table 21). Hue was not different in both years. Higher color intensity was found in LWS treatment at CDC (2005, 2006) and Vieni (2005) sites (Table 21, 23). Anthocyanin concentration was higher in the LWS treatment at Harbour (2005) (Table 21). Higher total phenols were found in the LWS treatment at Hernder (2005) (Table 21).

Lower pH in LWS treatment at George (2006) could be explained by high temperature and high light levels in the canopy, and lower canopy size. This is in agreement with Smart's (1985) study in which he found shaded microclimate increased the pH and K content of the must. The lower TA of the LWS treatment at George (2006) can be explained by lower canopy size, better light exposure and higher rate of malic acid degradation. This is consistent with the finding of Coombe and Monk (1979) in which they showed lower water stress associated with higher acidity. Higher ethanol in the LWS treatment at Buis (2005) and CDC (2005) resulted from higher soluble solids in the LWS vines at both sites due to concentration effect of smaller berry size. Phenolic compounds including anthocyanins were higher in the LWS treatments at Harbour (2005) and Hernder (2005) as well as color intensity at CDC (2005, 2006) and Vieni (2005). All of these can be attributed to less shade and better light exposure due to smaller canopy size as a consequence of less water availability to vines.

Williams and Matthews (1990) indicated that wines had more color and total phenols when made from vines that exposed to water stress compared to irrigated vines. Hepner *et al.* (1985) reported the same results. This is in agreement with finding of this study in which higher color was observed in the LWS treatment at the CDC (2005, 2006) and Vieni (2005) sites (Tables 21, 23) as well as higher total phenols in the LWS treatment at Hernder (2005).

Impact of soil type on yield components and vine size. The assumption was made at the beginning that soil variables would not change drastically during the course of this study. Due to only few significant correlations between soil variables and yield components/fruit composition at each site, correlation analysis was performed on pooled data, therefore it doesn't show site specific relationships.

In terms of the relationships between soil texture and yield components, our results in pooled data showed that yield was positively correlated with sand and negatively with clay in two of three years (Tables 10, 11, 12). This could be due to more vegetative growth in sandy soils and as a result higher yields. In contrast, heavier soils may tend to suppress vegetative growth and yield. Yield was negatively correlated with soil pH, base saturation (BS) and calcium (Ca) in all three years (Tables 10, 11, 12). Clay provides less water availability resulting in higher water stress to grapevines, also, clay has more colloids that contribute to higher soil pH, BS and Ca.

Berry weight had no consistent relationships with soil texture or soil variables during the study. Vine size was positively correlated with sand and negatively with clay in two years (2005, 2007). Clay may limit root growth and penetration due to poor drainage and/or soil compaction, while sandy soils facilitate grapevine growth. In fact, the highest growth and vine size was at the Harbour site with a sandy loam soil and the lowest vine size was observed at CDC, Cave Spring and Vieni with clay loam soil texture. This is in agreement with the findings of Seguin (1986). Interestingly the impact of soil texture on vine size was not significant in 2006 which was a wet year with high water availability. Thus, there was no limiting root and canopy growth factor between sand and clay. Vine size was also positively correlated with phosphorus (P) and potassium (K) in two years (2005, 2006). Vine size was negatively correlated with cation exchange capacity (CEC) and Ca in all 3 years.

Impact of soil type on fruit composition. Brix did not have consistent relationships with soil texture during the study. There were positive correlations between % clay and Brix in 2 of 3 years and a negative correlation between % sand and Brix was observed only in 2005. In 2007 there was no relationship between Brix and soil texture. Although there was a positive correlation between Brix and most of the soil variables in 2005, there was only a single positive correlation between Brix and BS and a negative correlation with P in 2006, but no significant correlations in 2007, therefore the relationships between Brix and soil variables in the three vintages appeared to be inconsistent (Tables 10, 11, 12).

Berry pH was negatively correlated with percent sand only in 2005. There was a positive correlation between berry pH with P and K in two years, but other relationships with soil variables were inconsistent between years. TA was negatively correlated with percent clay in all three years, but positively correlated with percent sand only in 2007. TA showed some relationships with soil variables which were inconsistent between years (Tables 10, 11, 12).

Color intensity was positively correlated with percent clay and negatively with percent sand (2005, 2007). There was also positive correlation between color intensity with CEC, Ca and Mg and a negative correlation with K. There was positive correlation between anthocyanins with clay, CEC, soil pH, BS and Ca in 2 years (2005, 2006), anthocyanins inversely correlated with P and K in 2 years (2006, 2007). Total phenols were positively correlated with clay, CEC, soil pH, and BS (2005, 2006) and were negatively correlated with sand, P and K (2006 and 2007) (Tables 10, 11, 12). Color intensity, anthocyanins and total phenols were positively correlated with clay in 2 of 3 years. This might have been due to the fact that grapevines encountered higher water stress in clay soils. The water stress in turn reduced vine vegetative growth and berry weight and may have increased skin to juice ratio. The increase of this ratio increases color, anthocyanins and total phenols, which are produced mainly in berry skins and is proportional with clay content of the soils. This leads to a new hypothesis that heavy clay soils increase color intensity, anthocyanins and total phenols compared to sandy soils.

Impact of vintage. Factors other than those being studied apparently impacted grape and wine quality. Chemical and sensory analyses suggested that the effects from vintage parameters (macro and mesoclimate) such as rainfall, mean temperature, and sunshine could have played a more significant role than soil moisture or leaf Ψ. This was especially apparent in the principal component analysis of the field data at each individual site as well as all sites together, in which all treatment replicates clustered together by vintage, considering there were huge differences among vintages such that 2006 vintage was a wet year while 2005 and 2007 years were hot and dry years. The distribution of growing degree days, and precipitation varied considerably across the three years. So it is likely that variation in yield components, berry composition and wine sensory response were at least partially due to climatological factors. Similar conclusions were made with Riesling in the Rheingau, Germany (Fischer *et al.* 1999).

Sensory analysis of the wines is discussed in detail in Chapters 5 and 6. Nonetheless, it is relevant to make some preliminary comments about sensory aspects of the wines insofar as they relate to the soil, yield, and berry composition variables discussed in this chapter. For three vineyards (Harbour Estate, Vieni and Morrison) it was not possible to make wine in both years of 2005 and 2006 due to either severe disease pressure or winter damage in previous year. Therefore, it was not possible to compare pairs of 2005 and 2006 wines at each site. In the remaining seven vineyards, the impact of vintage was not as clear on wine sensory analysis as it was on field data. This is supported by radar diagram where it showed that LWS wine at Buis (2005) had higher color intensity and less green bean flavor while, Buis (2006) was low in acidity (Fig. 41, 53). LWS wines at CDC (2005, 2006) were high in black cherry aroma/flavor (Fig. 42, 54). At Reif, LWS wines had fruity character in both vintages; in 2005 LWS wine had higher red fruit flavor and in 2006 black pepper aroma and flavor was higher (Fig. 45, 56). Although there was no difference between LWS and HWS wines in 2005 at Hernder site, in 2006 LWS wines had higher red fruit aroma/flavor (Fig. 43, 55). Similar observations were made at Cave Spring, where 2005 HWS and LWS wines were not different while in 2006 LWS wines had higher color intensity, higher back currant aroma and less green bean aroma (Fig. 44, 58). Interestingly at HOP, LWS wines in 2005 were high in color intensity and low in black cherry aroma while no differences were observed in 2006 wines (Fig. 48, 52). At George LWS wines in 2005 were high in red fruit aroma and black pepper flavor and lower in black current aroma (Fig. 47) while LWS wines in 2006 were high in color and black cherry aroma and lower in black pepper aroma/flavor and bell pepper aroma (Fig. 57). Therefore, LWS wines in both years had higher color and fruity characters and less vegetal compare to HWS wines. This can be attributed to lower canopy size in LWS vines presumably due to lower water availablity to plants hence better light exposure into canopy. It would have been better to have had wines from all ten sites for both years, which suggests that the study should have done for a longer period of time.

There is considerable research that has suggested that cultural practices, such as trellis system (Reynolds *et al.* 1996a, b), leaf removal (Reynolds *et al.* 1996a), shoot density (Reynolds *et al.* 1994) and irrigation (Kliewer *et al.* 1983) play significant roles in flavor compound concentration, sensory perception of flavor and overall composition of wine grapes. Although cultural practices were different from one site to another at each site they were almost the same for three years of the study period. Cultural practices may have improved fruit microclimate by controlling vine vigor (Smart 1985). Cultural practices therefore may have played a role as well.

Spatial distribution of yield components, vine size, fruit composition, soil moisture and leaf Ψ. Spatial distribution of yield was temporally stable at Cave Spring and George (2005 to 2006) and at CDC (2006 to 2007). Vine size spatial distribution was relatively stable in 2005 to 2006 in which areas of the same vine size were observed at Buis, Cave Spring and George; in 2006 to 2007 the same trend was observed at Buis, CDC, George and Morrison. Therefore, vine size spatial distribution was stable at Buis and George sites in 2005 to 2007. Interestingly, spatial distribution of yield and vine size were highly correlated at Cave Spring (2005 and 2006), George (2005, 2006) and CDC (2006, 2007) that shows areas of higher yield had also higher vine size. Reynolds *et al.* (2007) found relatively stable spatial distribution in vine size which is consistent with our results. Also, yield has been positively correlated to vine vigor (Shaulis 1982). Berry weight spatial distribution was temporally stable at Cave Spring in 2005 to 2007, as well as at CDC and Harbour in 2006, 2007. It is noteworthy that at Cave Spring areas of high yield were also areas of high berry weight in 2005, 2006 but did not hold for 2006, 2007.

Harbour Estate had stable spatial distribution in soluble solids (2006, 2007) and TA (2005 to 2007). Anthocyanins spatial distribution was temporally stable at Cave Spring (2005, 2006), Hernder (2006, 2007) and Morrison (2006, 2007). At CDC, areas of the same total phenols were stable in 2005 to 2007, while at HOP it was in 2005 to 2006 and at Harbour in 2006 to 2007. Color intensity was only temporally stable at Hernder in 2006 to 2007. In 2006 to 2007 areas of higher anthocyanins were same as those with higher color intensity. Overall, spatial distributions were more stable in yield components than berry composition data.

Literature Cited

Avenant, J. H. 1994. The effect of hail netting on the performance of table grapes in the summer rainfall regions of South Africa. In: Rantz, J. M. (ed.) *Proc. Int. Symp. Table Grape Production*, June 28 and 29, 1994, Anaheim, CA, USA. pp. 227-229.

Bergqvist, J., N. Dokoozlian, and N. Ebisuda. 2001.Sunlight exposure and temperature effects on berry growth and composition of Cabernet Sauvignon and Grenache in the central San Joaquin Valley of California. Amer. J. Enol. Vitic. 52:1-7.

Bradford K.I. and T.C. Hsiao. 1982. Physiological responses to moderate water stress. Plants' effect on growth and metabolism, growth regulators response, stomatal behavior, photosynthesis, respiration, proline and betaine transport, nutrient uptake. Encyclopedia of Plant Physiology 128:263-324.

Bramley, R.G.V. 2001. Progress in the development of precision viticulture-variation in yield, quality and soil properties in contrasting Australian vineyards. In Currie L.D. and Loganathan P. (Eds.) Precision tools for improving land management. Occasional report No 14. Massey University, New Zealand.

Bramley, R.G.V. 2002. Towards optimal resource management for grape and wine production. In: Blair, R.J. Williams, P.J. and Høj, P.B. (Eds.) Proceedings of the 11th Australian wine industry technical conference. Winetitles, Adelaide, 274-275.

Bramley, R.G.V., B. Pearse, and P. Chamberlin. 2003. Being profitable precisely – a case study of precision viticulture from Margaret River. The Australian & New Zealand Grapegrower & Winemaker. Annual Technical Issue 84-87.

Bramley RGV, Hamilton RP. 2004. Understanding variability in winegrape production systems. 1. Within vineyard variation in yield over several vintages. Australian Journal of Grape and Wine Research. 10: 32-45.

Bravdo, B., Y. Hepner, C. Loinger, S. Cohen, and H. Tabacman. 1985. Effect of irrigation and crop level on growth, yield and wine quality of Cabernet Sauvignon. Amer. J. Enol. Vitic. 36:132-139.

Carbonneau, A., R.E. Smart, and C. de Loth. 1983. Measurement of gross photosynthesis under natural conditions by using a carbon dioxide fusion porometer. Photosynthetica 17: 426-430.

Christensen, P. 1975. Response of Thompson Seedless grapevines to the timing of pre-harvest irrigation cut-off. Amer. J. Enol. Vitic. 26: 188-194.

Coombe, B.G. and P.R.Monk. 1979. Proline and abscisic acid content of the juice of ripe Riesling grape berries: effect of irrigation during harvest. Amer. J. Enol. Vitic. 30, 64-67.

Coombe, B.G. 1987. Distribution of solutes within the developing grape berry in relation to morphology. Amer. J. Enol. Vitic. 38: 120-127.

Dokoozlian, N.K. and Kliewer, W.M. 1996. Influence of light on grape berry growth and composition varies during fruit development. J. Amer. Soc. Hort. Sci.121, 869-874.

Downey, M.O. Harvey, J.S. Robinson, S.P. 2004. The effect of bunch shading on berry development and flavonoid accumulation in Shiraz grapes. Austral. J. Grape Wine Res. 1, 55-73.

Ehtaiwesh, A. 2006. Irrigation Scheduling for Sovereign Coronation Grapevines Based Upon Evapotranspiration Calculations and Crop Coefficients. MSc. Thesis, Brock University. Pp 99.

Esteban, M.A., M.J. Villanueva, and J.R. Lissarrague. 1999. Effect of irrigation on changes in berry composition of Tempranillo during maturation, sugars, organic acids and mineral elements. Amer. J. Enol. Vitic. 50: 418-434.

Esteban M., J. Lissarrage, and M. Villanueva. 2001. Effect of irrigation on changes in the anthocyanin composition of the skin of cv. Tempranillo(*Vitis vinifera* L) grape berries during ripening. J. Sci. Food Agric. 81:409-420

Fischer, U., D. Rothb, and M. Christmann. 1999. The impact of geographic origin, vintage and wine estate on sensory properties of Vitis vinifera cv. Riesling wines. Food Quality and Preference. 10: 281-288.

Freeman, B.M. and Kliewer, W.M. 1983. Effect of irrigation, crop level and potassium fertilization on Carignane vines. II. Grapes and wine quality. Am. J. Enol. Vitic. 34: 197-207.

Fuleki, T. and F.J. Francis. 1968. Quantitative methods for anthocyanins. 2. determination of total anthocyanin and degradation index for Cranberry juice. J. Food Sci. 33: 78-83.

Ginestar, C., C. J. Eastham, S. Gray and P. Iland. 1998. Use of sap-flow sensors to schedule vineyard irrigation. I. Effects of post-veraison water deficits on water relations, vine growth, and yield of Shiraz grapevines. Amer. J. Enol. Vitic. 49, 413-420.

Hall, A., D.W. Lamb, B. Holzapfel, and J. Louis. 2002. Optical remote sensing applications in viticulture-a review. Australian J. Grape and Wine Research 8: 36-47.

Hardie, W.J., and J.A. Considine. 1976. Response of grapevines to water-deficit stress in particular stages of development. Amer. J. Enol. Vitic. 27:55-61.

Hepner,Y., B. Bravdo, C. Loinger, S. Cohen and H. Tabacman. 1985. Effect of drip irrigation schedules on growth, yield, must composition and wine quality of Cabernet Sauvignon. Amer. J. Enol. Vitic. 36: 77-85.

Kliewer, W.M. and L.A. Lider. 1968. Influence of cluster exposure to the sun on the composition of Thompson Seedless fruit. Amer. J. Enol. Vitic. 19, 175-184.

Kliewer, W. M. 1973. Berry composition of *Vitis vinifera* cultivars as influenced by photo-and nycto-temperatures during maturation. J. Am. Soc. Hortic. Sci. 98:153-9.

Kliewer, W.M., B.M. Freeman, and C. Hossom. 1983. Effect of irrigation, crop level, and potassium fertilization on Carignane vines. I. Degree of water stress and effect on growth and yield. Amer. J. Enol. Vitic. 34: 186-196.

Koundouras S., V. Marinos, A. Gkoulioti, Y. Kotseridis, and C. van Leeuwen. 2006. Influence of vineyard location and vine water status on fruit maturation of non-irrigated cv. Agiorgitiko. Effects on wine phenolic and aroma components. J. Agric. Food Chem. 54:5077-5086.

Matthews, M.A. and Anderson, M.M. 1988. Fruit ripening in *Vitis vinifera* L. Responses to seasonal water deficits. Am. J. Enol. Vitic. 39:313-320.

Mazza, G., L. Fukumoto, P. Delaquis, B. Girard, and B. Ewert. 1999. Anthocyanins, Phenolics, and Color of Cabernet Franc, Merlot, and Pinot Noir wines from British Columbia, *J. Agric. Food Chem.* 47, 4009-4017.

Morrison, J. C. 1988. The effects of shading on the composition of Cabernet Sauvignon grape berries. In: Smart, R. E. et al. (eds.) *Proc. Second Int. Symp. Cool Climate Vitic. Oenol.*, 11-15 January, 1988, Auckland, NZ. pp.144-146.

Mullins, M.G., A. Bouquet, and L.E. Williams. 1992. Biology of the Grapevine. Cambridge University Press, Cambridge, UK.

Reynolds, A.G., D.A. Wardle, and M. Dever. 1994. Shoot density on Riesling grapevines: Interactions with cordon age. Amer. J. Enol. Vitic. 45: 435-443.

Reynolds, A.G., D.A. Wardle, and A.P. Naylor. 1996a. Impact of training system, vine spacing and basal leaf removal on Riesling. Vine performance, berry composition, canopy microclimate, and vineyard labour requirements. Amer. J. Enol. Vitic. 47: 63-76.

Reynolds, A. G., D.A. Wardle, and M. Dever, 1996b. Vine performance, fruit composition and wine sensory attributes of Gewurztraminer in response to vineyard location and canopy manipulation. Amer. J. Enol. Vitic. 47:77-92.

Reynolds, A. G., I.V. Senchuk, C. van der Reest, and C. de Savigny. 2007. Use of GPS and GIS for Elucidation of the Basis for Terroir: Spatial Variation in an Ontario Riesling Vineyard. Amer. J. Enol. Vitic. 58:2, 145-162.

Seguin, G. 1975. Alimentation en eau de la vigne et composition chimique des mouts dans les Grands Crus du Medoc. Phenomenes de regulation. *Conaissance de la Vigne et du Vin,* 9, 23-34.

Seguin, G. 1986. Terroirs and pedology of wine growing. Experimentia, 42: 861-872.

Shaulis, N. 1982. Responses of grapevines and grapes to spacing of and within canopies. *In* Proceedings of the Symposium at University of California Davis, Grape and Wine Centennial 1980. D. A. Webb (Ed.), pp. 353-361.

Singleton, V.L., and J.A. Rossi, Jr. 1965. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. Amer. J. Enol. Vitic. 16: 144-158.

Srinivasan, C. and M. G. Mullins. 1981. Physiology of Flowering in the Grapevine - a Review. Am. J. Enol. Vitic. 32:1:47-63.

Smart, R.E., and B.G. Coombe. 1983. Water relations of grapevines. *In* T.T. Kozlowski (Ed.): Water Deficits and Plant Growth. Academic Press, New York, pp.137-196.

Smart, R.E. 1985. Principals of grapevine canopy microclimate manipulation with implications for yield and quality. A review. Amer. J. Enol.Vitic. 36:230-239.

Smart, R. E., J.B. Robinson, G.R. Due, and C. J. Brien. 1985. Canopy microclimate modification for the cultivar Shiraz. II. Effects on must and wine composition. *Vitis* 24:119-128.

Spayd, S. E., Tarara, J. M., Mee, D. L. and Ferguson, J. C. 2002. Separation of sunlight and temperature effects on the composition of *Vitis vinifera* cv. Merlot berries. Amer. J. Enol. Vitic. 53:171-182.

VanZyl J.L. and Weber H.W.1981. The effect of various supplementary irrigation treatments on plant and soil moisture relationships in a vineyard (Vitis vinifera var. Chenin blanc). S. Afr. J. Enol. Vitic. 2, 83-99.

Williams, L. E. and Matthews M.A. 1990. Grapevine. In: Irrigation of Agricultural Crops. Eds. B.A. Stewart and D.R. Nielson (American Society of Agronomy, Madison, WI) pp. 1019-1055.

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Table 1- Impact of vine water status on yield components and vine size of Cabernet Franc in Niagara Peninsula, ON. 2005. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**Clusters/vine**			**Yield/vine (kg)**			**Berry weight (g)**			**Wt of cane prunings (kg)**		
	LWS	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	27	22	23	1.7	1.5	1.6	1.23	1.20	1.27	0.75	0.78	0.89
Significance.[a]		ns			ns			ns			ns	
Ch des Charmes	32	27	31	2.2	1.5	1.8	1.27	1.19	1.21	0.48	0.46	0.47
Significance		ns			ns			ns			ns	
Hernder	29	20	15	2.2	1.5	1.2	1.12	1.14	1.18	0.44ab	0.33b	0.60a
Significance		ns			ns			ns			*	
Reif	22	30	22	1.3	1.9	1.3	1.08	1.13	1.12	0.86a	0.57b	0.97a
Significance		ns			ns			ns			*	
Harbour Estate	46	59	64	3.6	3.8	4.1	1.22	1.23	1.23	1.31	1.61	1.76
Significance		ns			ns			ns			ns	
George	44	46	47	4.7	5.1	4.1	1.33	1.30	1.26	0.46	0.65	0.43
Significance		ns			ns			ns			ns	
Cave Spring	41	39	41	2.9	2.9	2.8	1.12	1.19	1.21	0.46	0.50	0.51
Significance		ns			ns			ns			ns	
H. of Pelham	29b	39a	41a	2.0b	3.0a	3.2a	1.28	1.37	1.33	0.45	0.55	0.54
Significance		*			*			ns			ns	
Vieni Estate	40	43	40	2.9	3.5	3.1	1.08b	1.12a	1.2a	0.24	0.27	0.19
Significance		ns			ns			*			ns	
Morrison		---			---			---			---	
Significance												

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test.

Table 2- Impact of vine water status on fruit composition of Cabernet Franc in Niagara Peninsula, ON. 2005. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**Soluble solids (Brix)**			**Titratable acidity**			**pH**		
	LWS	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	21.2	20.9	20.7	8.1b	8.5b	8.9a	3.50	3.48	3.47
Significance[a]		ns			*			ns	
Ch des Charmes	23.3	23.1	22.9	7.8b	8.2b	8.6a	3.58a	3.60a	3.55b
Significance		ns			*			*	
Hernder	21.0a	21.0a	20.2b	6.8b	7.3ab	8.0a	3.52	3.52	3.56
Significance		*			*			ns	
Reif	21.0b	21.5ab	21.9a	9.9a	8.5b	9.4a	3.37b	3.46a	3.41ab
Significance		*			*			*	
Harbour Estate	20.5	20.6	20.8	8.1	9.2	9.3	3.64	3.61	3.61
Significance		ns			ns			ns	
George	21.6a	21.0b	21.1b	7.2	6.9	6.6	3.59	3.58	3.59
Significance		*			ns			ns	
Cave Spring	23.8	23.7	24.2	6.4	7.0	6.5	3.62	3.66	3.63
Significance		ns			ns			ns	
Henry of Pelham	22.2a	21.2b	21.0b	11.5	11.6	11.3	3.68a	3.66ab	3.63b
Significance		**			ns			*	
Vieni Estate	22.3	22.1	22.6	6.8	6.9	6.8	3.65	3.63	3.61
Significance		ns			ns			ns	
Morrison		---			---			---	
Significance									

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test.

Table 3- Impact of vine water status on fruit composition of Cabernet Franc in Niagara Peninsula, ON. 2005. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**Hue**			**Color intensity**			**Anthocyanins (mg/L)**			**Total phenols (mg/L)**		
	LWS	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	0.41	0.44	0.44	20	18	20	551a	478b	518ab	1625	1555	1548
Significance[a]		ns			ns			*			ns	
Ch des Charmes	0.46a	0.43b	0.41c	19	21	21	594	659	630	1615	1850	1720
Significance		*			ns			ns			ns	
Hernder	0.39	0.39	0.40	18	19	18	578	589	535	1567	1480	1454
Significance		ns			ns			ns			ns	
Reif	0.38	0.40	0.38	20	19	22	605	594	669	1337	1235	1269
Significance		ns			ns			ns			ns	
Harbour Estate	0.46	0.44	0.44	13	14	16	462	465	501	697b	961b	1014a
Significance		ns			ns			ns			*	
George	0.40a	0.39ab	0.38b	17b	19a	19a	527	554	572	673b	783a	859a
Significance		*			*			ns			*	
Cave Spring	0.38	0.38	0.39	21	19	19	587	563	603	1668	1791	1858
Significance		ns			ns			ns			ns	
H. of Pelham	0.42a	0.40b	0.39b	20	18	19	660a	611b	603b	2586a	1974b	1928b
Significance		*			ns			*			*	
Vieni Estate	0.41	0.40	0.40	22	23	25	663	661	693	2300	2315	2444
Significance		ns			ns			ns			ns	
Morrison		---			---			---			---	
Significance												

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test Ch des Charmes, and H of Pl are abbreviations for Château des Charmes, and Henry of Pelham sites, respectively.

Table 4 - Impact of vine water status on yield components and vine size of Cabernet Franc in Niagara Peninsula, ON. 2006. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**Clusters/vine**			**Yield/vine (kg)**			**Berry weight (g)**			**Wt of cane prunings (kg)**		
	LWS	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	67.3	68.8	64.3	5.9	6.0	6.1	1.49b	1.59ab	1.68a	0.91	0.94	0.94
Significance.[a]		ns			ns			*			ns	
Ch des Charmes	39.1	40.9	41.4	2.6	3.4	3.3	1.33	1.36	1.34	0.30	0.49	0.41
Significance		ns			ns			ns			ns	
Hernder	62.8	70.9	62.4	6.9	7.1	6.3	1.45	1.45	1.47	0.88	0.85	0.89
Significance		ns			ns			ns			ns	
Reif	45.1	40.8	43.2	5.1	4.5	4.6	1.25	1.26	1.23	0.53	0.44	0.51
Significance		ns			ns			ns			ns	
Harbour Estate		---			---		1.10	1.08	1.03	1.08	1.21	1.19
Significance								ns			ns	
George	43.3b	45.7ab	48.9a	6.7b	7.3ab	7.7a	1.33	1.31	1.35	0.35c	0.47b	0.59a
Significance		*			*			ns			**	
Cave Spring	55.7a	42.2b	50.7ab	5.3a	3.8b	4.5ab	1.32	1.37	1.34	0.70	0.76	0.67
Significance		*			*			ns			ns	
H. of Pelham	54.8	51.7	53.6	7.0	7.0	6.8	1.39	1.45	1.38	0.41	0.36	0.33
Significance		ns			ns			ns			ns	
Vieni Estate		....			....			....			....	
Significance												
Morrison	61.9	67.3	64.2	3.8	3.9	3.9	1.15	1.14	1.12	0.82	0.94	0.99
Significance		ns			ns			ns			ns	

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test.

Table 5- Impact of vine water status on fruit composition of Cabernet Franc in Niagara Peninsula, ON. 2006. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**Soluble solids (Brix)**			**Titratable acidity**			**pH**		
	LWS	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	20.7ab	20.2b	20.8a	8.0b	7.8b	8.5a	3.53ab	3.47b	3.55a
Significance[a]		*			*			*	
Ch des Charmes	23.0a	22.3b	22.5b	9.1	8.9	8.7	3.68	3.67	3.69
Significance		*			ns			ns	
Hernder	19.9	19.9	19.9	7.8	7.5	7.5	3.50a	3.47a	3.42b
Significance		ns			ns			*	
Reif	21.9	21.8	22.0	8.9	8.4	8.6	3.53	3.55	3.51
Significance		ns			ns			ns	
Harbour Estate	22.0a	22.0a	21.3b	11.0b	11.4a	11.6a	3.58	3.58	3.56
Significance		*			*			ns	
George	20.0	20.2	20.4	9.1	8.7	9.0	3.43	3.49	3.40
Significance		ns			ns			ns	
Cave Spring	22.9	23.4	24.0	8.7a	8.6ab	8.3b	3.47	3.51	3.46
Significance		ns			*			ns	
Henry of Pelham	20.4	20.2	20.0	10.4	10.0	9.9	3.49	3.48	3.47
Significance		ns			ns			ns	
Vieni Estate									
Significance									
Morrison	21.2	21.0	21.1	10.1	9.9	9.8	3.54	3.53	3.53
Significance		ns			ns			ns	

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test.

Table 6- Impact of vine water status on fruit composition of Cabernet Franc in Niagara Peninsula, ON. 2006. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**Hue**			**Color intensity**			**Anthocyanins (mg/L)**			**Total phenols (mg/L)**		
	LWS	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	0.39	0.39	0.40	22	19	21	506	474	472	1338	1288	1452
Significance[a]		ns			ns			ns			ns	
Ch des Charmes	0.39	0.40	0.40	20	18	19	569	513	546	1650	1526	1724
Significance		ns			ns			ns			ns	
Hernder	0.42a	0.40b	0.39b	13b	15a	16a	371b	436a	435a	1156b	1334a	1285a
Significance		*			**			**			*	
Reif	0.42	0.41	0.43	18b	17b	21a	473	488	545	1699	1717	1886
Significance		ns			*			ns			ns	
Harbour Estate	0.43	0.42	0.43	17ab	18a	15b	499	558	430	1171	1323	1273
Significance		ns			*			ns			ns	
George	0.36b	0.37ab	0.39a	22	23	21	426	440	433	1683a	1818a	1409b
Significance		*			ns			ns			*	
Cave Spring	0.37	0.37	0.37	25b	26b	30a	686	690	747	2644	2543	2524
Significance		ns			*			ns			ns	
H. of Pelham	0.41	0.40	0.41	18	17	16	540	506	519	1808	2024	1982
Significance		ns			ns			ns			ns	
Vieni Estate												
Significance												
Morrison	0.44	0.43	0.44	13.0		13.8	373	349	342	1477a	1382ab	1245b
Significance		ns			12.8 ns			ns			*	

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test.

Table 7- Impact of vine water status on yield components and vine size of Cabernet Franc in Niagara Peninsula, ON. 2007. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**Clusters/vine**			**Yield/vine (kg)**			**Berry weight (g)**			**Wt of cane prunings (kg)**		
	LWS	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	51.4	47.6	44.7	7.3a	7.1ab	5.7b	1.65	1.66	1.62	0.98a	0.96a	0.54b
Significance. [a]		ns			*			ns			*	
Ch des Charmes	25.9	29.3	25.3	2.6	2.8	2.5	1.37	1.41	1.23	0.42	0.40	0.35
Significance		ns			ns			ns			ns	
Hernder	52.7	52.6	51.0	4.6	4.2	5.1	1.25	1.23	1.31	0.53	0.45	0.59
Significance		ns			ns			ns			ns	
Reif	49.2	42.7	44.1	4.1	3.8	3.4	1.35	1.33	1.32	0.57	0.50	0.51
Significance		ns			ns			ns			ns	
Harbour Estate	52.7	52.4	50.1	5.0	5.8	5.0	1.43	1.51	1.47	1.12	1.32	1.29
Significance		ns			ns			ns			ns	
George	32.0	29.5	32.1	3.6b	4.0ab	4.5a	1.33c	1.42b	1.51a	0.28b	0.36b	0.48a
Significance		ns			*			**			*	
Cave Spring	44.7	41.4	40.2	3.7	3.7	3.8	1.05c	1.22b	1.41a	0.51	0.56	0.58
Significance		ns			ns			**			ns	
Henry of Pelham	46.5	41.0	38.8	7.1a	5.5b	5.8b	1.45	1.43	1.41	0.3 3	0.36	0.36
Significance		ns			*			ns			ns	
Vieni Estate	38.9	41.3	40.1	4.0	4.5	4.1	1.29	1.23	1.26	0.48	0.40	0.32
Significance		ns			ns			ns			ns	
Morrison	29.9	38.6	43.5	1.9b	2.9a	3.6a	1.30	1.25	1.27	0.73	0.64	0.69
Significance		ns			**			ns			ns	

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test.

Table 8- Impact of vine water status on berry composition of Cabernet Franc in Niagara Peninsula, ON. 2007. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**Soluble solids (Brix)**			**Titratable acidity**			**pH**		
	LWS	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	22.6	23.0	23.1	7.6	7.4	7.5	3.69a	3.64b	3.62b
Significance[a]		ns			ns			**	
Ch des Charmes	26.2	30.2	26.7	6.9b	7.3ab	7.6a	3.70	3.70	3.70
Significance		ns			*			ns	
Hernder	22.6	22.5	21.9	4.8	4.9	4.7	3.66b	3.71a	3.74a
Significance		ns			ns			**	
Reif	24.0	23.9	24.5	7.0b	7.5a	7.3a	3.73	3.66	3.73
Significance		ns			*			ns	
Harbour Estate	24.7a	23.9b	23.9b	7.1b	7.5b	8.3a	3.58	3.59	3.58
Significance		*			*			ns	
George	24.7	24.9	24.3	7.6b	7.8ab	7.9a	3.65	3.67	3.67
Significance		ns			*			ns	
Cave Spring	24.8	24.3	24.1	6.6	6.5	6.3	3.64a	3.61b	3.59b
Significance		ns			ns			*	
Henry of Pelham	21.1	21.8	21.6	7.3	7.0	7.0	3.47	3.49	3.53
Significance		ns			ns			ns	
Vieni Estate	23.0	22.4	23.1	7.4	7.4	7.6	3.59a	3.54b	3.52b
Significance		ns			ns			*	
Morrison	25.0a	24.0b	23.4b	5.9	5.9	5.6	3.74a	3.69b	3.67b
Significance		**			ns			*	

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test.

Table 9- Impact of vine water status on berry composition of Cabernet Franc in Niagara Peninsula, ON. 2007. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**Hue**			**Color intensity**			**Anthocyanins (mg/L)**			**Total phenols (mg/L)**		
	LWS	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	0.42b	0.40b	0.43a	19a	19a	16b	466a	524a	450b	1921a	1892a	1597b
Significance[a]		**			*			*			**	
Ch des Charmes	0.48	0.48	0.47	29	27	32	668b	632b	774a	2336	2219	2535
Significance		ns			ns			*			ns	
Hernder	0.78	0.77	0.79	13	14	12	370	384	399	1419	1497	1437
Significance		ns			ns			ns			ns	
Reif	0.49a	0.46b	0.50a	15b	17a	16a	425b	477a	473a	1987	2097	2051
Significance		*			*			**			ns	
Harbour Estate	0.43a	0.42a	0.41b	23a	20b	21ab	575a	523b	543ab	1737	1766	1883
Significance		*			*			*			ns	
George	0.43	0.44	0.43	26a	23b	22b	637a	591b	459b	1873	1767	1766
Significance		ns			**			**			ns	
Cave Spring	0.39	0.38	0.39	27a	25ab	24b	633a	584ab	574b	2342	2109	2157
Significance		ns			*			*			ns	
Henry of Pelham	0.38b	0.40ab	0.42a	17	20	21	451	501	503	1184b	1512a	1419a
Significance		*			ns			ns			*	
Vieni Estate	0.43a	0.41b	0.40b	19b	22a	24a	506	530	582	1769	1879	2042
Significance		*			*			Ns			ns	
Morrison	0.47	0.49	0.50	15a	14ab	13b	468a	394b	376b	1511a	1397ab	1324b
Significance		ns			*			**			*	

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test.

Table 10- Overall correlations of soil factors vs. yield components, fruit composition and vine size for Cabernet Franc at all Niagara Peninsula sites in 2005.

	% Sand	% Clay	% OM	CEC (meq/100 g)	Soil pH	base saturation (% Ca)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	SM (%)	WP (-bars)
Yield (kg)	0.0195 0.8092	-0.1013 0.2083	0.1429 0.0750	-0.1364 0.0895	**-0.2139** 0.0073	**-0.288** 0.0003	0.008 0.9209	**-0.1808** 0.0239	**-0.1574** 0.0497	0.1224 0.1280	-0.1241 0.1227	**-0.2576** 0.0012
Berry wt (g)	0.0299 0.7066	-0.151 0.0570	**0.2571** 0.0010	0.0915 0.2497	0.0578 0.4677	0.0171 0.8305	-0.007 0.9258	-0.0580 0.4856	0.0833 0.2943	0.0569 0.4745	**0.2841** 0.0003	**-0.1713** 0.0303
Vine size (kg)	**0.5476** <.0001	**-0.5752** <.0001	-0.1613 0.0409	**-0.385** <.0001	**-0.2786** 0.0003	**-0.4384** <.0001	**0.1960** 0.0127	**0.2023** 0.0101	**-0.3622** <.0001	**-0.4364** <.0001	-0.0495 0.5330	**-0.6111** <.0001
Brix	**-0.469** <.0001	**0.5262** <.0001	-0.0278 0.7268	**0.3998** <.0001	**0.2546** 0.0012	**0.3441** <.0001	**-0.3069** <.0001	**-0.266** 0.0007	**0.3872** <.0001	**0.3812** <.0001	-0.0423 0.5953	**0.3554** <.0001
Berry pH	**-0.300** 0.0001	0.1402 0.0770	**0.2619** 0.0008	**0.1856** 0.0188	0.0768 0.3345	0.0718 0.3672	-0.0028 0.9717	**-0.1993** 0.0115	**0.1729** 0.0287	**0.2194** 0.0053	0.0372 0.6407	0.0831 0.2960
Titratable acidity (g/L)	0.0875 0.2715	**-0.236** 0.0027	-0.078 0.3266	0.1055 0.1844	**0.1942** 0.0139	0.0426 0.5925	**0.3811** <.0001	0.1187 0.1360	0.1295 0.1027	**-0.2168** 0.0059	**0.3347** <.0001	**-0.250** 0.0014
Color intensity	**-0.286** 0.0002	**0.3617** <.0001	**-0.1928** 0.0143	**0.1744** 0.0270	0.1183 0.1362	**0.1722** 0.0289	-0.0887 0.2630	**-0.156** 0.0475	**0.1636** 0.0381	**0.1594** 0.0435	0.0015 0.9850	**0.2381** 0.0024
Anthocyanins (mg/L)	**-0.403** <.0001	**0.4355** <.0001	-0.1140 0.1511	**0.2679** 0.0006	**0.2735** 0.0005	**0.3154** <.0001	-0.0262 0.7419	-0.1417 0.0739	**0.2673** 0.0006	**0.2030** 0.0100	-0.0903 0.2559	**0.2801** 0.0003
Phenols (mg/L)	**-0.303** 0.0001	**0.2963** 0.0001	**-0.2095** 0.0073	**0.2464** 0.0017	**0.2053** 0.0092	**0.2947** 0.0002	**0.2301** 0.0034	-0.0055 0.9450	**0.2563** 0.0011	-0.0734 0.3560	**0.2329** 0.0030	**0.2887** 0.0002

Table 11- Overall correlations of soil factors vs. yield components, fruit composition and vine size for Cabernet Franc at all Niagara Peninsula sites in 2006.

	% Sand	% Clay	% OM	CEC (meq/100 g)	Soil pH	base saturation (% Ca)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	SM (%)	WP (-bars)
Yield (kg)	**0.3784** <.0001	**-0.4008** <.0001	**0.2186** 0.0106	**-0.3004** 0.0004	**-0.2397** 0.0049	**-0.1713** 0.0462	-0.1139 0.1866	-0.0982 0.2551	**-0.2739** 0.0012	**-0.2135** 0.0128	**-0.2975** 0.0004	-0.0292 0.7361
Berry wt (g)	0.00658 0.9336	0.1164 0.1390	0.1144 0.1460	0.1452 0.0645	0.0631 0.4234	**0.2646** 0.0006	**-0.2141** 0.0061	-0.0214 0.7859	0.1531 0.0511	-0.1212 0.1232	**0.2379** 0.0022	**0.4501** <.0001
Vine size (kg)	0.0724 0.3630	-0.0989 0.2134	-0.0005 0.9947	**-0.3077** <.0001	**-0.298** 0.0001	**-0.3460** <.0001	**0.4925** <.0001	**0.4145** <.0001	**-0.3407** <.0001	-0.0581 0.4654	0.0011 0.9890	0.0374 0.6384
Brix	-0.099 0.2050	**0.1749** 0.0258	**-0.2167** 0.0055	0.1111 0.1579	0.0429 0.5858	**0.01834** 0.8162	**-0.1974** 0.0116	-0.1228 0.1182	0.1105 0.1603	0.0829 0.2931	0.1390 0.0768	-0.0901 0.2525
Berry pH	-0.0098 0.9011	-0.003 0.9678	**-0.2655** 0.0006	-0.0502 0.5260	-0.091 0.2515	-0.1002 0.2048	**0.1798** 0.0220	**0.3813** <.0001	-0.0448 0.5710	**-0.1732** 0.0275	-0.0713 0.3674	0.1334 0.0905
Titratable acidity (g/L)	0.0649 0.4102	**-0.3023** <.0001	-0.021 0.7870	-0.0969 0.2184	-0.077 0.3306	**-0.2569** 0.0009	**0.2045** 0.0088	-0.1238 0.1152	-0.0854 0.2785	-0.0449 0.5688	**-0.3216** <.0001	**-0.4542** <.0001
Color intensity	-0.0267 0.7350	0.1303 0.0974	0.0798 0.3112	**0.2092** 0.0074	0.0812 0.3027	0.1431 0.0685	**-0.4813** <.0001	**-0.4769** <.0001	**0.1992** 0.0108	**0.1684** 0.0316	**0.3288** <.0001	-0.0549 0.4859
Anthocyanins (mg/L)	-0.0484 0.5397	**0.1549** 0.0483	0.0319 0.6854	**0.2444** 0.0017	**0.1802** 0.0213	**0.2117** 0.0067	**-0.4698** <.0001	**-0.3840** <.0001	**0.2531** 0.0011	0.0553 0.4832	**0.1887** 0.0158	0.0089 0.9105
Phenols (mg/L)	**-0.3489** <.0001	**0.4150** <.0001	0.0775 0.3256	**0.4566** <.0001	**0.4394** <.0001	**0.4043** <.0001	**-0.2977** 0.0001	**-0.3385** <.0001	**0.4472** <.0001	**0.3416** <.0001	**0.3602** <.0001	0.0011 0.9885

Table 12- Overall correlations of soil factors vs. yield components, fruit composition and vine size for Cabernet Franc at all Niagara Peninsula sites in 2007.

	% Sand	% Clay	% OM	CEC (meq/100 g)	Soil pH	Base saturation (% Ca)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	SM (%)	WP (-bars)
Yield (kg)	**0.4643**	**-0.5150**	0.0467	**-0.286**	**-0.3272**	**-0.2577**	-0.1264	-0.1134	**-0.2549**	**-0.4098**	-0.0609	**-0.3898**
	<.0001	<.0001	0.5344	0.0001	<.0001	0.0005	0.0918	0.1306	0.0006	<.0001	0.4174	<.0001
Berry wt (g)	**0.3298**	**-0.3951**	-0.0037	-0.1238	**-0.1982**	**-0.1728**	-0.0453	0.0366	-0.1074	**-0.2881**	0.0784	**-0.4395**
	<.0001	<.0001	0.9606	0.0986	0.0078	0.0207	0.6379	0.6262	0.1523	<.0001	0.2909	<.0001
Vine size (kg)	**0.4050**	**-0.3769**	**-0.3463**	**-0.2189**	-0.0117	-0.0954	-0.0103	0.1076	**-0.1749**	**-0.3225**	**-0.2296**	**-0.4260**
	<.0001	<.0001	<.0001	0.0032	0.8766	0.2037	0.8913	0.1516	0.0192	<.0001	0.0020	<.0001
Brix	-0.044	0.1250	-0.0916	-0.0018	-0.1343	-0.0992	-0.0278	-0.0232	-0.0334	0.0483	-0.0753	0.0748
	0.5629	0.0954	0.2228	0.9807	0.0730	0.1885	0.7113	0.7582	0.6575	0.5206	0.3163	0.3199
Berry pH	0.0945	-0.0226	-0.0596	-0.0631	-0.0408	-0.0726	**0.1570**	**0.3754**	-0.0818	0.1051	0.0886	0.1056
	0.2082	0.7639	0.4275	0.4017	0.5876	0.3342	0.0358	<.0001	0.2769	0.1615	0.2382	0.1593
Titratable acidity (g/L)	**0.1843**	**-0.1836**	-0.0242	-0.0647	-0.0888	-0.1003	**-0.3123**	**-0.2679**	-0.0575	0.0135	-0.1301	**-0.5302**
	0.038	0.0142	0.7485	0.3909	0.2381	0.1830	<.0001	0.0003	0.4457	0.8583	0.0835	<.0001
Color intensity	**-0.1546**	**0.1995**	0.0613	**0.1702**	0.03808	0.1308	**-0.3784**	**-0.2996**	**0.1779**	**0.1932**	-0.1044	0.0185
	0.0387	0.0074	0.4148	0.0227	0.6128	0.0808	<.0001	<.0001	0.0172	0.0096	0.1642	0.8055
Anthocyanins (mg/L)	-0.0752	0.0791	0.0286	0.0986	-0.0268	0.0551	**-0.3399**	**-0.2639**	0.1051	**0.1652**	**-0.1691**	-0.092
	0.3171	0.2923	0.7041	0.1889	0.7216	0.4638	<.0001	0.0004	0.1614	0.0271	0.0237	0.2214
Phenols (mg/L)	0.0292	0.0433	-0.1453	-0.0185	-0.0016	0.0666	**-0.3635**	**-0.2038**	-0.0039	0.0604	-0.1335	-0.0891
	0.6981	0.5653	0.0553	0.8062	0.9827	0.3757	<.0001	0.0062	0.95810	0.4216	0.0748	0.2357

Table 13- Impact of vintage on yield components and vine size of Cabernet Franc in Niagara Peninsula, 2005-2007.

Vineyard location	**Clusters/vine**			**Yield (kg)**			**Berry wt (g)**			**Vine size (kg)**		
	2005	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
Buis	26c	72a	46b	1.7b	6.7a	7.0a	1.2c	1.6b	1.7a	0.89	0.96	1.10
Significance[a]		*			*			*			ns	
Ch des Charmes	31b	41a	27b	2.0b	3.1a	2.7a	1.2b	1.3a	1.3a	0.46	0.38	0.42
Significance		*			*			*			ns	
Hernder	29b	67a	52b	2.3c	6.8a	4.4b	1.2c	1.5a	1.3b	0.46b	0.80a	0.49b
Significance		*			*			*			*	
Reif	25b	43a	45a	1.5c	4.7a	3.8b	1.1c	1.3a	1.2b	0.71	0.82	0.72
Significance		*			*			ns			ns	
Harbour Estate	58	53	55	3.9c	4.5b	5.6a	1.2b	1.1c	1.5a	1.6a	1.2b	1.2b
Significance		ns			*			*			*	
George	46a	46a	31b	4.6b	7.3a	4.0c	1.3b	1.3b	1.4a	0.5a	0.5a	0.4b
Significance		*			*			*			*	
Cave Spring	41b	49a	43b	3.0c	4.3a	3.6b	1.2b	1.3a	1.2b	0.5b	0.7a	0.6b
Significance		*			*			*			*	
Henry of Pelham	37b	48a	46a	2.8b	6.0a	6.5a	1.3b	1.4a	1.5a	0.5a	0.3b	0.4b
Significance		*			*			*			*	
Vieni Estate	41	----	40	3.2b	----	4.3a	11b	-----	1.3a	0.3b	----	0.4a
Significance		ns			*			*			*	
Morrison	-	66a	38b	--	4.0a	2.8b	--	1.3a	1.1b	---	1.2a	0.7b
Significance		*			*			*			*	

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test

Table 14- Impact of vintage on fruit composition of Cabernet Franc in Niagara Peninsula, 2005-2007.

Vineyard location	**Brix**			**pH**			**Titratable acidity**		
	2005	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
Buis	21.0b	20.6c	22.7a	3.48c	3.52b	3.66a	8.5a	8.1b	7.6c
Significance[a]		*			*			*	
Ch des Charmes	23.7	23.1	26.3	3.59b	3.68a	3.71a	8.2b	8.9a	7.1c
Significance		ns			*			*	
Hernder	21.1b	20.2c	22.7a	3.54b	3.48c	3.71a	7.0b	7.5a	4.8c
Significance		*			*			*	
Reif	21.5b	21.8b	24.1a	3.42c	3.53b	3.70a	8.9b	9.3a	7.3c
Significance		*			*			*	
Harbour Estate	20.7c	22.0b	24.1a	3.61a	3.57b	3.58b	9.1b	11.4a	7.9c
Significance		*			*			*	
George	21.2b	20.3c	24.6a	3.58b	3.42c	3.66a	6.9c	9.1a	7.8b
Significance		*			*			*	
Cave Spring	23.9b	23.5b	24.6a	3.64a	3.50b	3.63a	6.9b	8.4a	6.3c
Significance		*			*			*	
Henry of Pelham	21.4a	20.2b	21.5a	3.67a	3.47b	3.48b	10.6a	10.2a	7.0b
Significance		*			*			*	
Vieni Estate	22.0b	----	22.6a	3.62a	----	3.54b	6.8a	----	6.5b
Significance		*			*			*	
Morrison	--	21.1b	24.1a	---	3.53b	3.69a	---	9.9a	5.7b
Significance		*			*			*	

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test.

Table 15- Impact of vintage on fruit composition of Cabernet Franc in Niagara Peninsula, 2005-2007.

Vineyard location	Hue			Color intensity			Anthocyanins (mg/L)			Total phenols (mg/L)		
	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
Buis	0.42	0.40	0.43	19	20	18	493	477	468	1553a	1354b	1757a
Significance[a]		ns			ns			ns			*	
Ch des Charmes	0.44	0.43	0.45	20b	19c	30a	625b	538c	689a	1750b	1688b	2343a
Significance		ns			*			*			*	
Hernder	0.42	0.41	0.43	19a	15b	15b	559a	434b	443b	1522a	1292b	1454a
		ns			*			*			*	
Reif	0.40	0.42	0.41	20a	16c	19b	623a	504b	509b	1780b	1758b	2027a
Significance		ns			*			*			*	
Harbour Estate	0.44	0.43	0.42	16b	17b	21a	478b	508b	535a	1260b	1259b	1705a
Significance		ns			*			*			*	
George	0.39b	0.37c	0.44a	18b	22a	23a	548b	435c	591a	756c	1627b	1792a
Significance		*			*			*			*	
Cave Spring	0.39	0.37	0.39	23	27	25	583b	721a	614b	2221b	2601a	2125b
Significance		ns			ns			*			*	
Henry of Pelham	0.40	0.41	0.39	19a	17b	20a	610a	512b	508b	2100a	1998a	1466b
Significance		ns			*			*			*	
Vieni Estate	0.41	-----	0.41	23	----	21	640a	----	521b	2306a	----	1833b
Significance		ns			ns			*			*	
Morrison	--	0.44b	0.48a	---	14	14	---	351b	404a	---	1374	1390
Significance		*			ns			*			ns	

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test

Table 16 - Impact of vine water status on Cabernet Franc must composition in Niagara Peninsula, 2005. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**pH**			**Titratable acidity**			**Brix**		
	LWS	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	3.34	3.31	3.32	8.3	10.9	9.9	22.1	22.1	21.8
Significance[a]		ns			ns			ns	
Ch des Charmes	3.34	3.36	3.36	5.4	5.7	6.2	23.6	23.7	23.3
Significance		ns			ns			ns	
Hernder	3.56	3.53	3.57	4.7b	5.2b	6.6a	20.5	20.5	20.9
Significance		ns			a			ns	
Reif	3.35	3.52	3.44	6.0a	5.4b	5.4b	20.8	21.3	21.3
Significance		ns			a			ns	
Harbour Estate	3.45	3.43	3.45	7.1	6.7	7.3	21.3	21.2	22.1
Significance		ns			ns			ns	
George	3.36	3.37	3.36	6.1	6.2	6.0	20.5	20.6	20.3
Significance		ns			ns			ns	
Cave Spring	3.43	3.41	3.41	4.5	4.6	4.6	22.7	23.1	22.6
Significance		ns			ns			ns	
Henry of Pelham	3.45	3.46	3.39	5.3	5.3	5.6	22.2	21.5	20.9
Significance		ns			ns			ns	
Vieni Estate	3.41	3.43	3.36	5.1	5.1	5.4	20.0	20.3	18.0
Significance		ns			ns			ns	
Morrison		....			...			....	
Significance									

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test.

Table 17 - Impact of vine water status on Cabernet Franc must composition in Niagara Peninsula, 2005. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**Hue**			**Color intensity**			**Anthocyanins (mg/L)**			**Total phenols(mg/L)**		
	LWS	**MWS**	**WS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	0.6	0.7	0.6	2.3	2.1	2.3	51.8	42.5	15.8	213	123	124
Significance[a]		ns			ns			ns			ns	
Ch des Charmes	0.7	0.6	0.7	1.0	1.9	2.0	89.5	87.3	67.6	531	436	306
Significance		ns			ns			ns			ns	
Hernder	0.9	0.6	0.7	2.6	2.3	2.3	90.2	92.4	92.6	223	216	266
Significance		ns			ns			ns			ns	
Reif	0.7	0.7	0.6	1.7	1.6	1.9	55	49	59	291	233	323
Significance		ns			ns			ns			ns	
Harbour Estate	1.4	1.2	0.8	0.4b	0.4b	0.9a	46.7	39.4	40.0	202	193	184
Significance		ns			a			ns			ns	
George	1.1	1.1	1.0	0.5	0.6	0.6	14.5	9.2	13.0	201	179	221
Significance		ns			ns			ns			ns	
Cave Spring	0.9	0.8	0.9	1.2	0.8	0.9	14.8	22.7	19.4	229	295	232
Significance		ns			ns			ns			ns	
H. of Pelham	1.1	1.2	1.4	0.7	0.6	0.6	14.3	12.4	9.0	219	342	401
Significance		ns			ns			ns			ns	
Vieni Estate	1.0	0.9	0.9	0.6	0.8	0.5	16.4	20.9	8.2	234	523	231
Significance		ns			ns			ns			ns	
Morrison		....			....			....			....	
Significance												

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test

Table 18- Impact of vine water status on Cabernet Franc must composition in Niagara Peninsula, 2006. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**pH**			**Titratable acidity**			**Brix**		
	LWS	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	3.13	3.18	3.11	5.9	5.2	6.8	14.7	14.4	15.5
Significance[a]		ns			ns			ns	
Ch des Charmes	3.15	3.15	3.20	5.0	5.8	5.7	15.4	16.3	17.3
Significance		ns			ns			ns	
Hernder	3.55	3.50	3.42	4.5	4.5	4.6	13.2	12.9	12.8
Significance		ns			ns			ns	
Reif	3.20	3.23	3.23	5.8	5.5	5.6	15.0	15.0	16.2
Significance		ns			ns			ns	
Harbour Estate		....			....			....	
Significance									
George	3.03c	3.07b	3.10a	6.7	6.9	7.4	14.5	15.0	15.9
Significance		a			ns			ns	
Cave Spring	3.28	3.30	3.23	5.4	5.0	5.5	19.4	17.1	18.6
Significance		ns			ns			ns	
Henry of Pelham	3.07	3.09	3.09	6.1	5.8	6.2	14.8	13..4	14.7
Significance		ns			ns			ns	
Vieni Estate		....			....			....	
Significance									
Morrison	3.25	3.26	3.27	6.8	7.5	7.4	14.1	15.8	15.1
Significance		ns			ns			ns	

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test.

Table 19- Impact of vine water status on Cabernet Franc must composition in Niagara Peninsula, 2006. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**Hue**			**Color intensity**			**Anthocyanins (mg/L)**			**Total phenols (mg/L)**		
	LWS	**MWS**	**WS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	1.4	1.4	1.2	0.3	0.4	0.4	15.0	14.6	15.8	314	233	214
Significance[a]		ns			ns			ns			ns	
Ch des Charmes	1.8	1.3	1.3	0.4	0.3	0.3	24	20	23	831	336	406
Significance		ns			ns			ns			ns	
Hernder	1.6	1.7	1.5	0.7	0.8	0.6	2.9	1.7	0.9	253	286	219
Significance		ns			ns			ns			ns	
Reif	2.1	1.8	1.9	0.7a	0.7a	0.4b	4.3	5.2	5.1	219	253	383
Significance		ns			[a]			ns			ns	
Harbour Estate		....			....			....			....	
Significance												
George	3.2	3.1	2.9	0.9	0.9	1.1	3.8	4.2	4.1	261	119	261
Significance		ns			ns			ns			ns	
Cave Spring	3.3	2.6	2.8	0.7	0.9	0.4	6.2	5.6	5.8	289	292	292
Significance		ns			ns			ns			ns	
H. of Pelham	3.3	5.8	0.8	0.6	3.0	1.5	9	17	18	239	542	481
Significance		ns			ns			ns			ns	
Vieni Estate		....			....			....			....	
Significance												
Morrison	1.8	2.2	2.1	0.3	0.4	0.4	24.3	17.6	25.4	439	553	439
Significance		ns			ns			ns			ns	

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test

Table 20- Impact of vine water status on Cabernet Franc wine composition in Niagara Peninsula, 2005. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**pH**			**Titratable acidity**			**Ethanol**		
	LWS	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	3.34	3.35	3.36	8.0	8.1	8.3	11.8a	11.7b	11.5c
Significance[a]		ns			ns			*	
Ch des Charmes	3.62	3.69	3.66	6.9	7.0	6.7	12.6a	12.5b	12.3c
Significance		ns			ns			*	
Hernder	3.59	3.59	3.50	5.9	5.8	5.9	11.2	11.0	11.1
Significance		ns			ns			ns	
Reif	3.65	3.63	3.59	5.9	5.8	5.9	11.3	11.2	11.1
Significance		ns			ns			ns	
Harbour Estate	3.85	3.77	3.79	5.5b	5.6b	5.8a	10.2	10.4	10.4
Significance		ns			*			ns	
George	3.48	3.49	3.47	5.7	5.7	5.9	10.9	10.8	11.2
Significance		ns			ns			ns	
Cave Spring	3.38	3.33	3.35	6.1	6.4	6.1	12.4	12.5	12.4
Significance		ns			ns			ns	
Henry of Pelham	3.67	3.67	3.52	5.3	5.7	5.8	11.7	10.8	10.7
Significance		ns			ns			ns	
Vieni Estate	3.57	3.51	3.57	5.5	5.6	5.5	10.7	10.4	10.4
Significance		ns			ns			ns	
Morrison		---			---			---	
Significance									

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test.

Table 21- Impact of vine water status on Cabernet Franc wine composition in Niagara Peninsula, 2005. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**Hue**			**Color intensity**			**Anthocyanins (mg/L)**			**Total phenols (mg/L)**		
	LWS	**MWS**	**WS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	0.6	0.6	0.7	7.4	7.5	6.3	242	195	232	2268	2050	2333
Significance[a]		ns			ns			ns			ns	
Ch des Charmes	0.7	0.7	0.7	7.7a	7.2b	7.1b	231	242	227	1783	1849	1653
Significance		ns			*			ns			ns	
Hernder	0.8	0.8	0.7	5.1	4.9	5.2	268	270	249	1358a	1333a	1259b
Significance		ns			ns			ns			*	
Reif	0.9	0.8	0.8	4.3	4.3	4.5	273	275	264	1450	1450	1346
Significance		ns			ns			ns			ns	
Harbour Estate	0.8	0.8	0.8	4.1	4.6	4.0	285a	274a	252b	914	913	819
Significance		ns			ns			*			ns	
George	0.6	0.6	0.6	5.5	5.6	6.3	281	265	315	1458	1422	1711
Significance		ns			ns			ns			ns	
Cave Spring	0.7	0.6	0.6	7.5	7.7	6.7	324	314	269	1469	1221	1451
Significance		ns			ns			ns			ns	
Henry of Pelham.	0.7	0.6	0.7	6.2	6.0	5.9	283	265	268	1467	771	925
Significance		ns			ns			ns			ns	
Vieni Estate	0.8	0.7	0.8	4.5a	4.2b	3.9c	277	257	245	1033	587	825
Significance		ns			*			ns			ns	
Morrison		---			---			---			---	
Significance												

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test

Table 22- Impact of vine water status on Cabernet Franc wine composition in Niagara Peninsula, 2006. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	**pH**			**Titratable acidity**			**Ethanol**		
	LWS	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**	**LWS**	**MWS**	**HWS**
Buis	3.50	3.44	3.48	6.1	6.4	6.4	10.1	9.9	9.9
Significance[a]		ns			ns			ns	
Ch des Charmes	3.65	3.67	3.73	6.0	6.0	5.9	11.1	11.0	11.2
Significance		ns			ns			ns	
Hernder	3.55	3.50	3.42	5.7	5.9	6.1	9.3	9.5	9.5
Significance		ns			ns			ns	
Reif	3.63	3.63	3.58	5.6	5.7	6.0	10.8	10.9	11.0
Significance		ns			ns			ns	
Harbour Estate		....			....			....	
Significance									
George	3.31b	3.32b	3.42a	7.9	6.7	6.3	9.8	9.8	9.6
Significance		*			ns			ns	
Cave Spring	3.22	3.30	3.26	7.1	7.1	6.8	12.1	11.9	11.4
Significance		ns			ns			ns	
Henry of Pelham	3.43	3.44	3.40	6.1	6.5	6.6	8.4	8.8	9.1
Significance		ns			ns			ns	
Vieni Estate		....			....			....	
Significance									
Morrison	3.81	3.75	3.80	5.2	5.3	5.3	9.2	9.4	9.7
Significance		ns			ns			ns	

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test.

Table 23- Impact of vine water status on Cabernet Franc wine composition in Niagara Peninsula, 2006. LWS, MWS, HWS: low, medium and high water status, respectively.

Vineyard location	Hue			Color intensity			Anthocyanins (mg/L)			Total phenols (mg/L)		
	LWS	MWS	HWS	LWS	MWS	HWS	LWS	MWS	HWS	LWS	MWS	HWS
Buis	0.6	0.5	0.5	5.4	5.8	5.9	155	164	165	836	825	853
Significance[a]		ns			ns			ns			ns	
Ch des Charmes	0.7	0.8	0.8	6.8a	6.0b	6.4b	136	134	143	1025	1014	1153
Significance		ns			*			ns			ns	
Hernder	0.6	0.5	0.5	5.3	5.8	5.9	168	163	155	1092	986	1231
Significance		ns			ns			ns			ns	
Reif	0.7	0.7	0.7	6.1	6.6	7.3	155	166	168	1017	997	1078
Significance		ns			ns			ns			ns	
Harbour Estate		....			....			....			....	
Significance												
George	0.4	0.4	0.5	8.8	7.9	6.2	257	245	216	1117	1069	1014
Significance		ns			ns			ns			ns	
Cave Spring	0.5	0.7	0.6	12.9	11.2	10.8	304	254	278	1344	1228	1089
Significance		ns			ns			ns			ns	
Henry of Pelham	0.6	0.6	0.7	4.8	5.5	5.8	186	174	186	1017	906	1028
Significance		ns			ns			ns			ns	
Vieni Estate		....			....			....			....	
Significance												
Morrison	1.0	1.0	1.1	4.8	4.6	4.6	81	96	105	1003b	1253b	1369b
Significance		ns			ns			ns			ns	

[a] *, ns: significant at $p \leq 0.05$ or not significant, respectively.

[b] Means in columns flowed by various letters are significant at $p \leq 0.05$, Duncan's multiple range test

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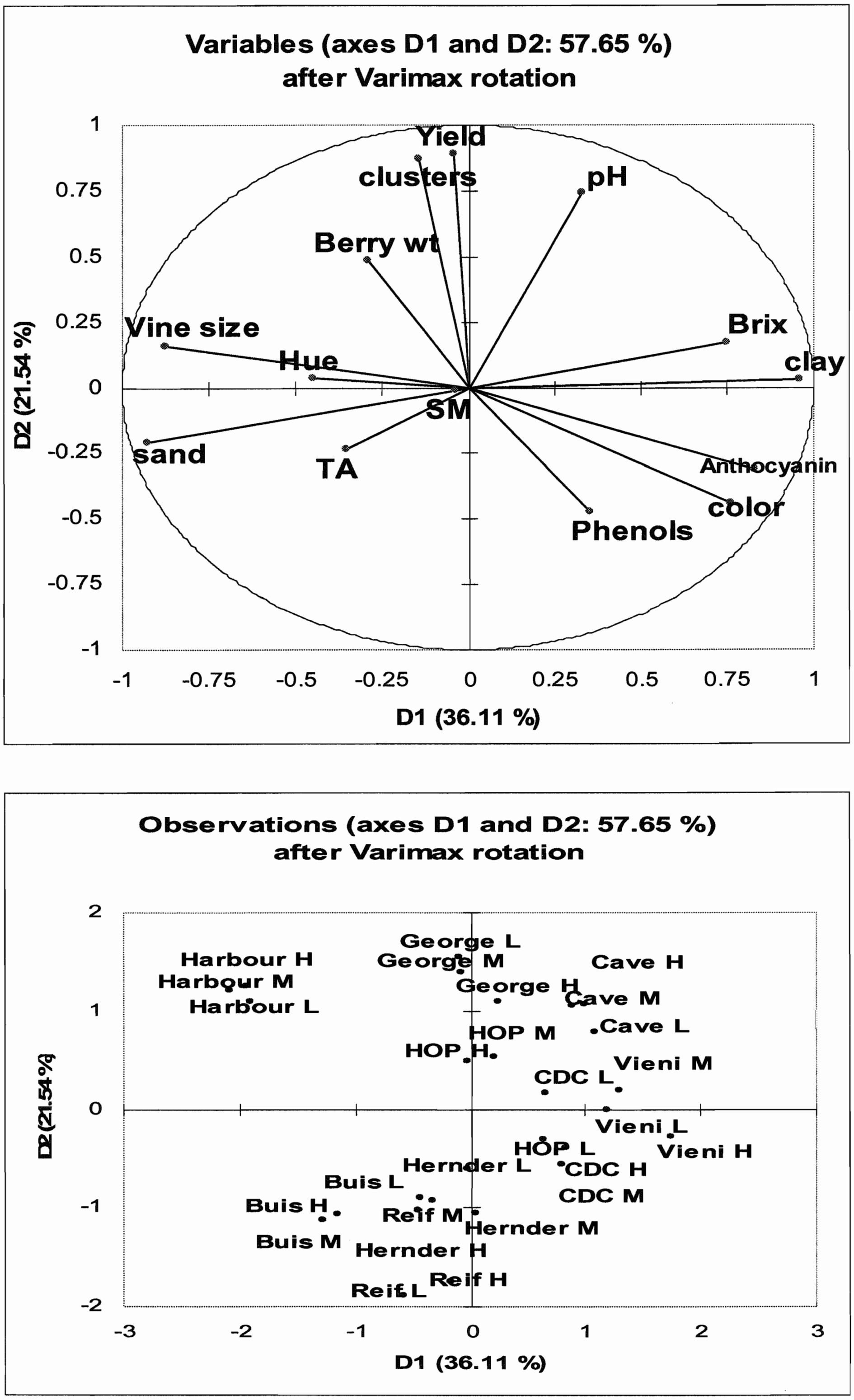

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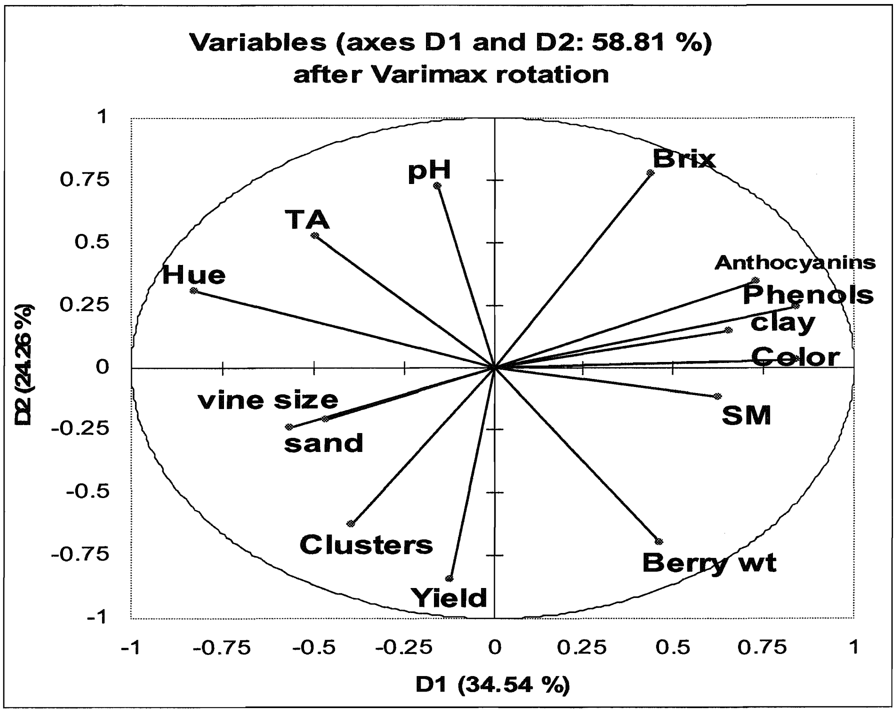

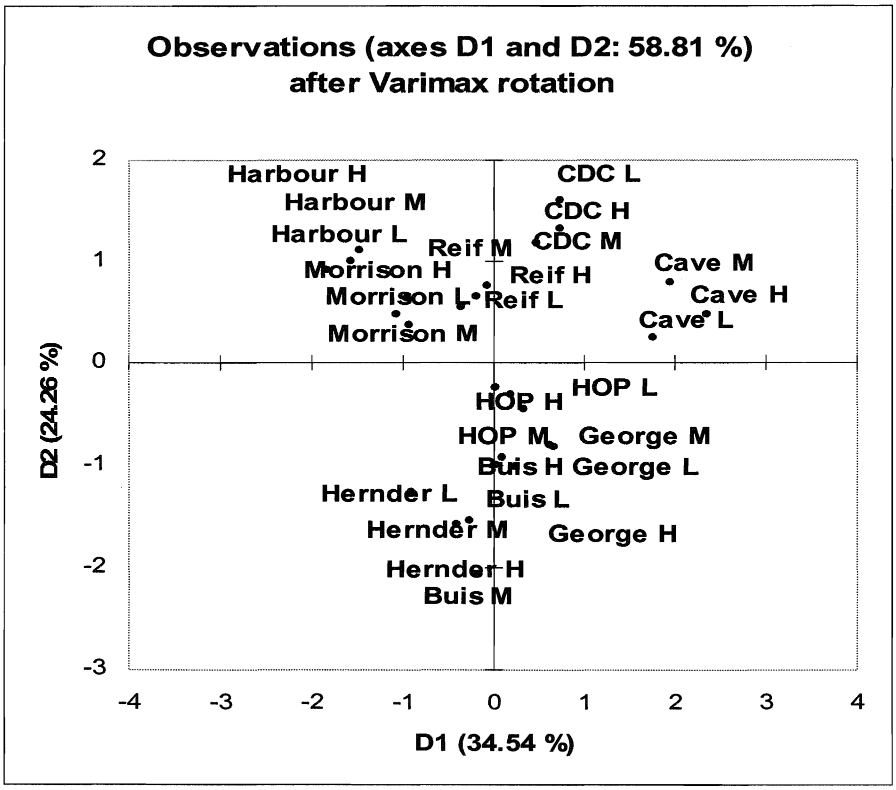

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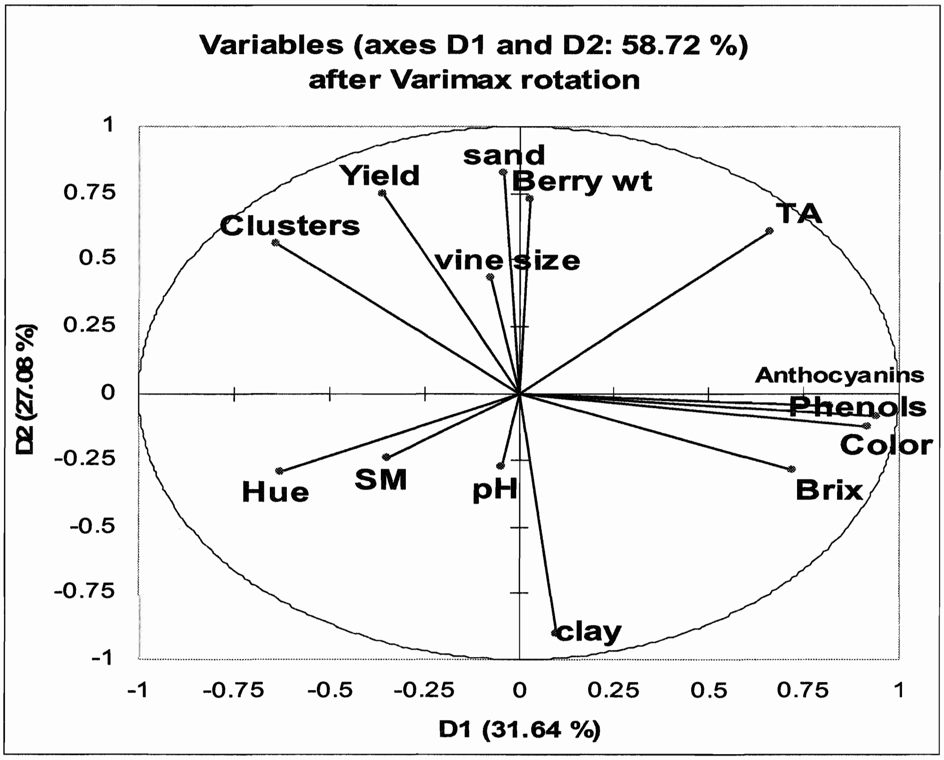

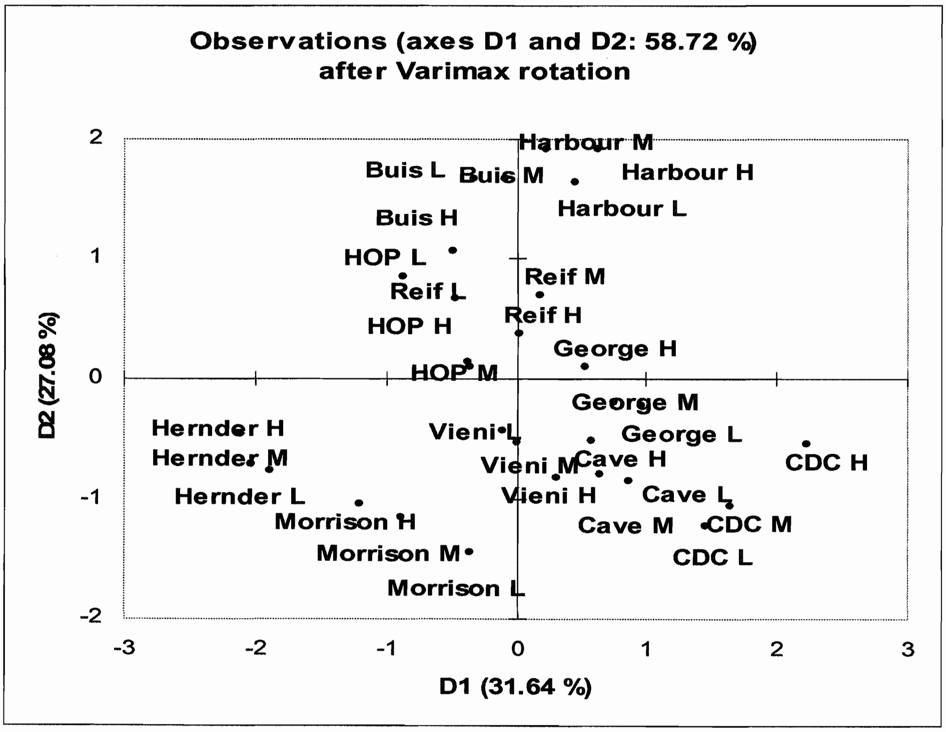

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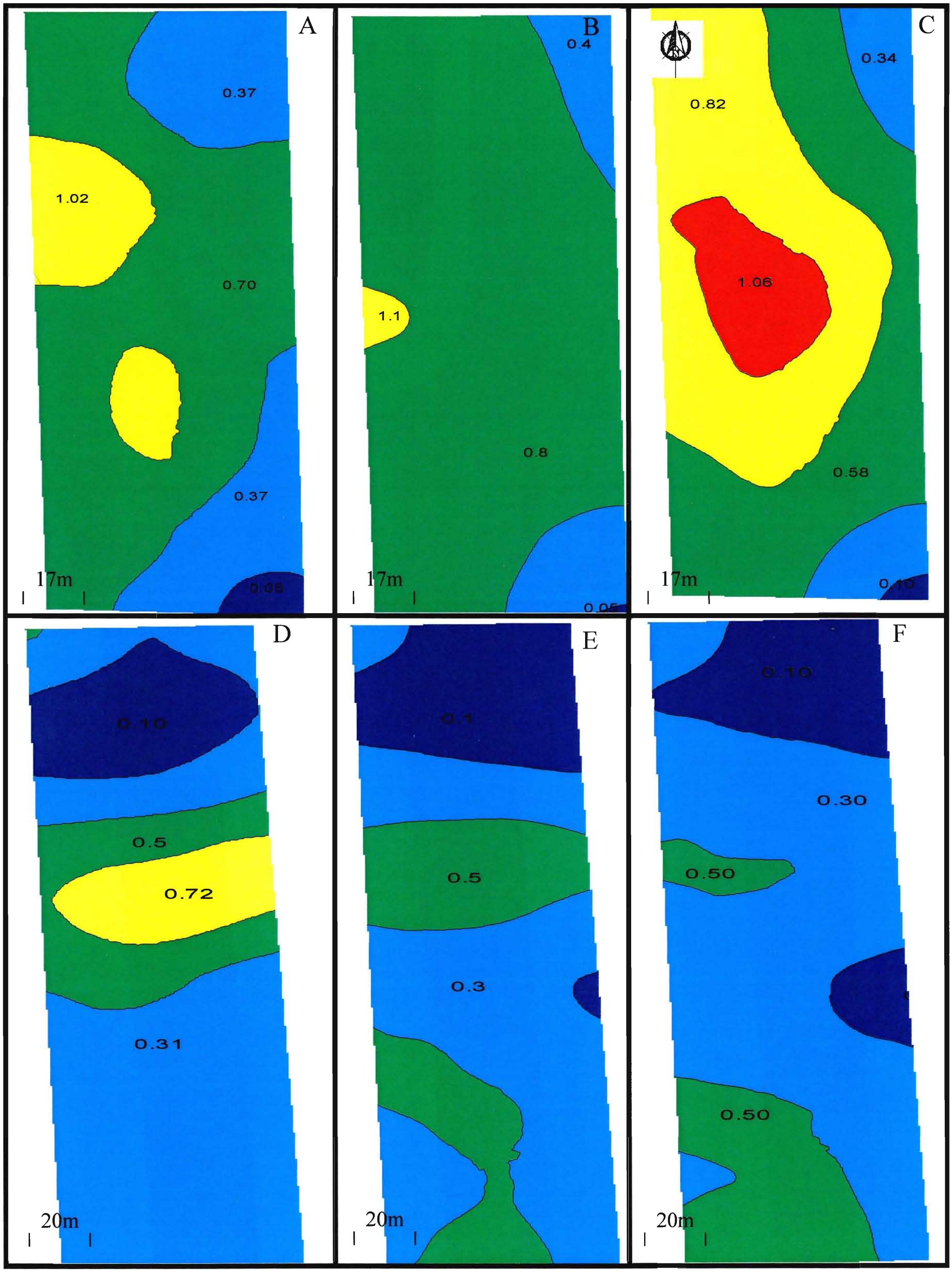

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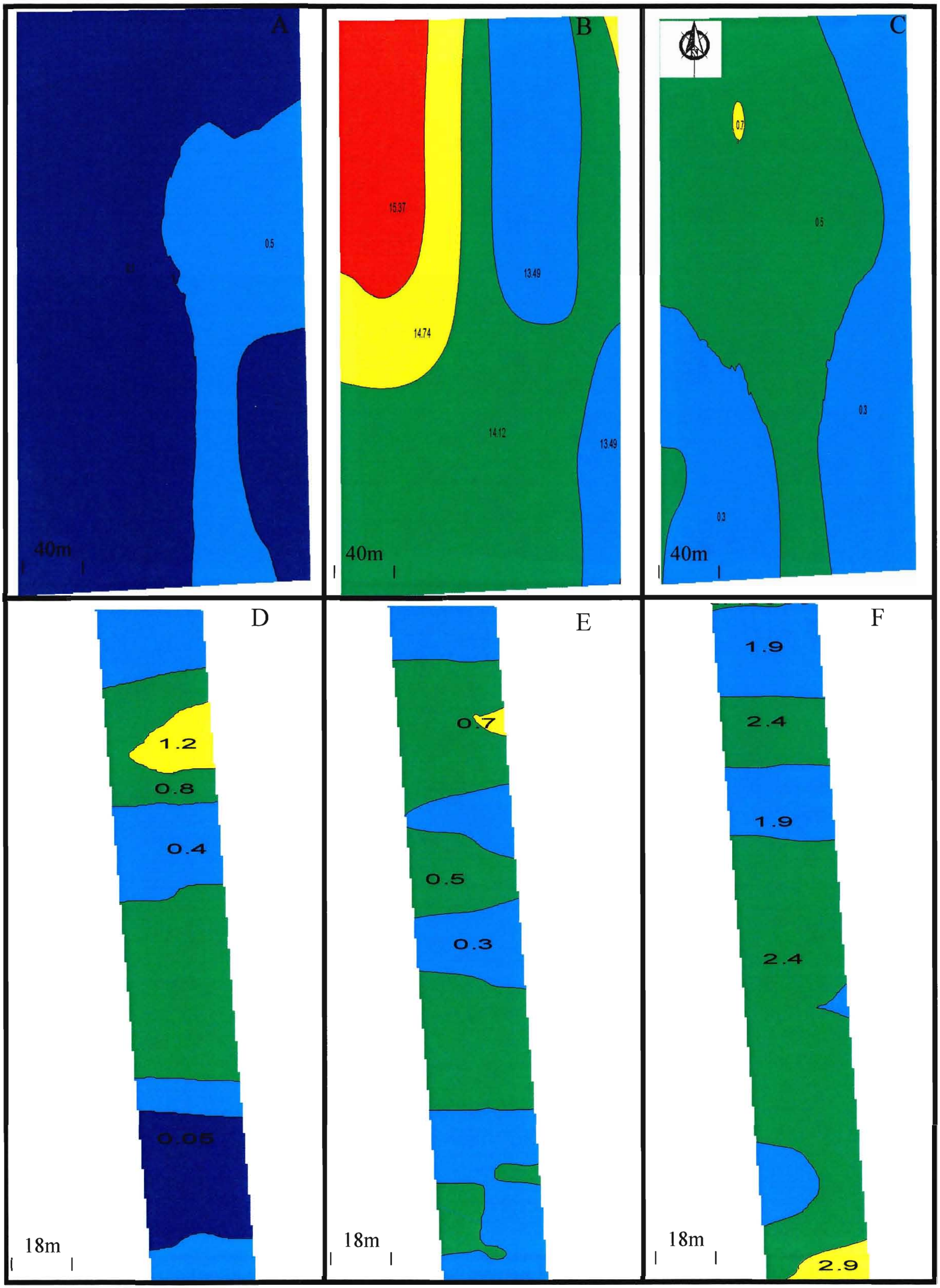

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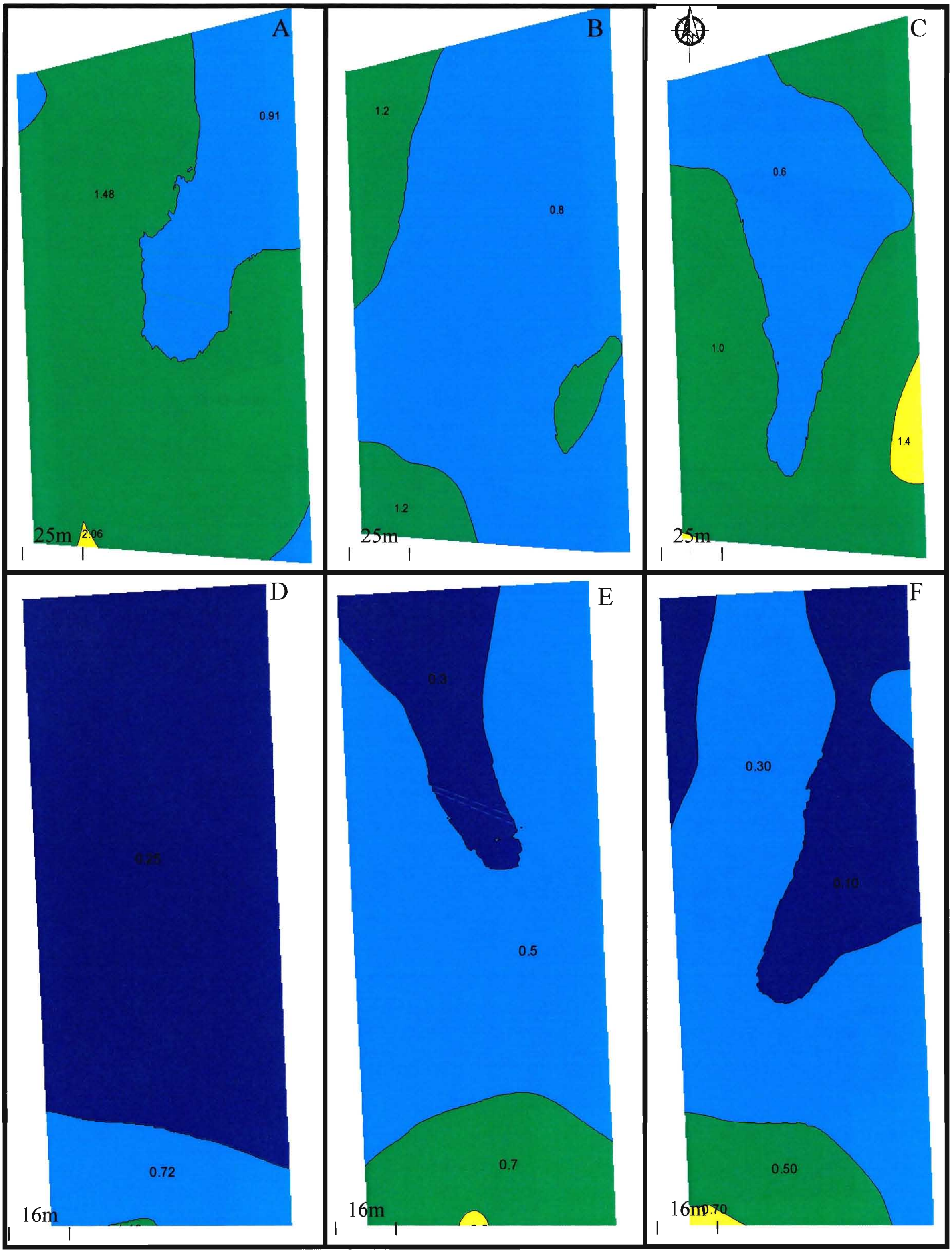

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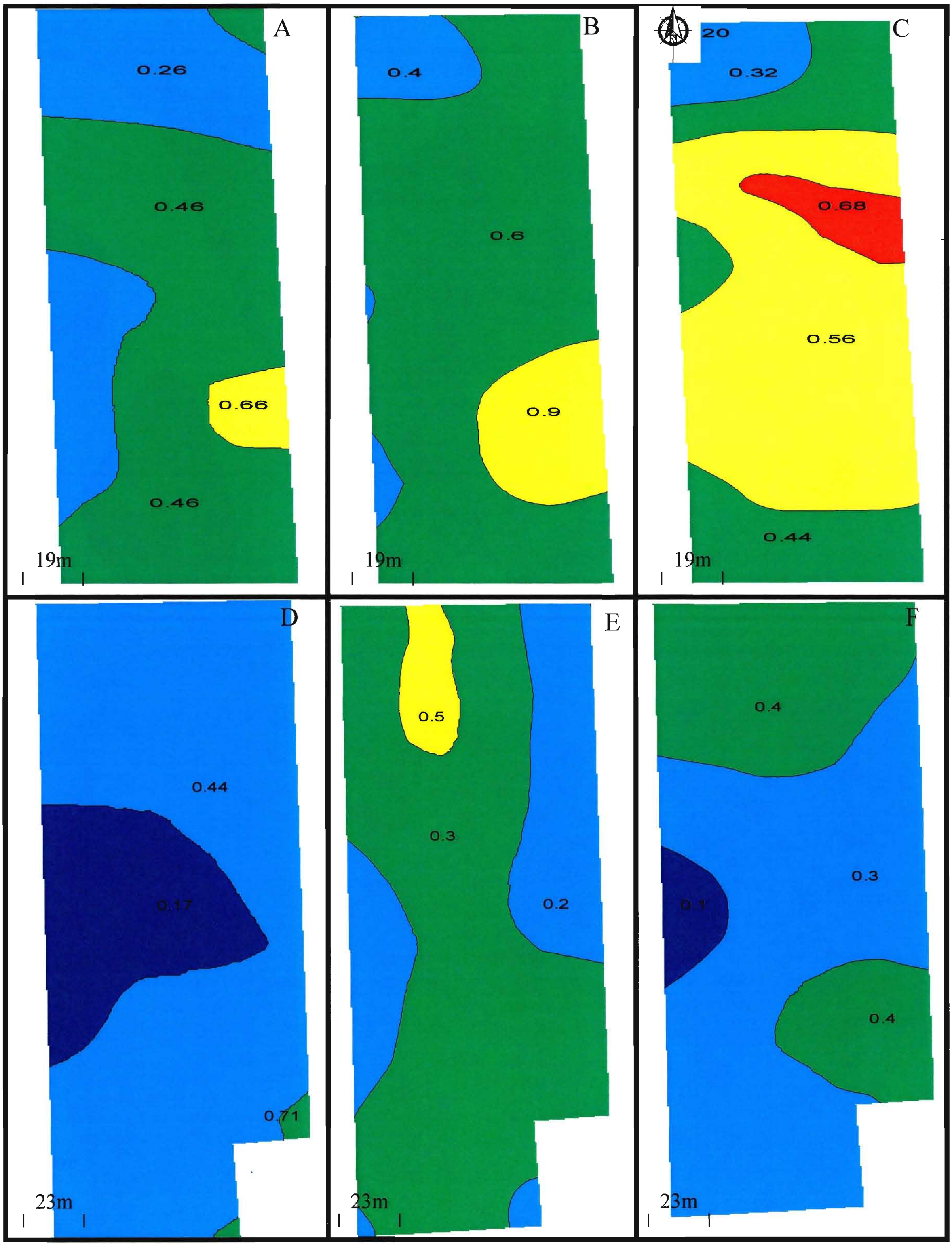

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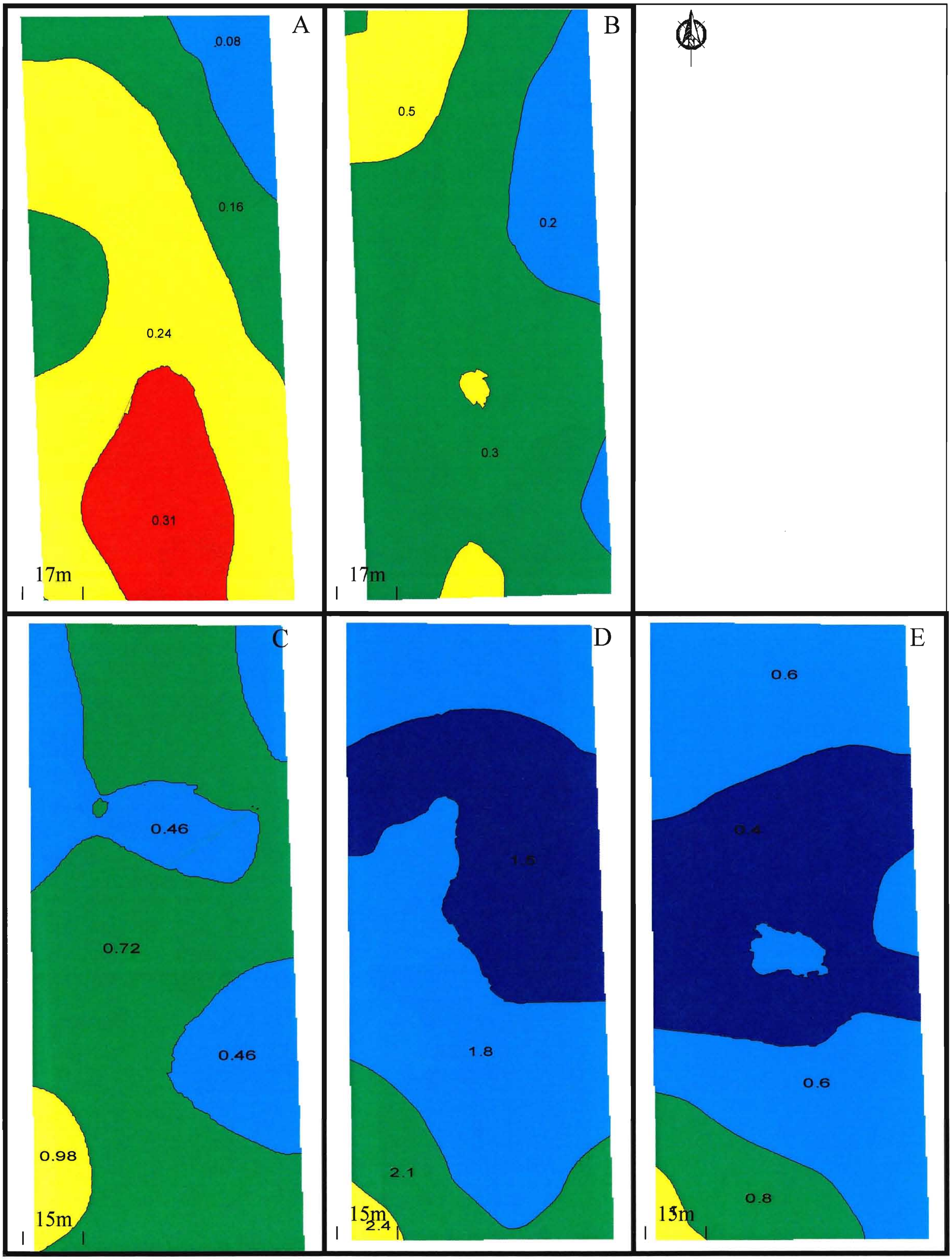

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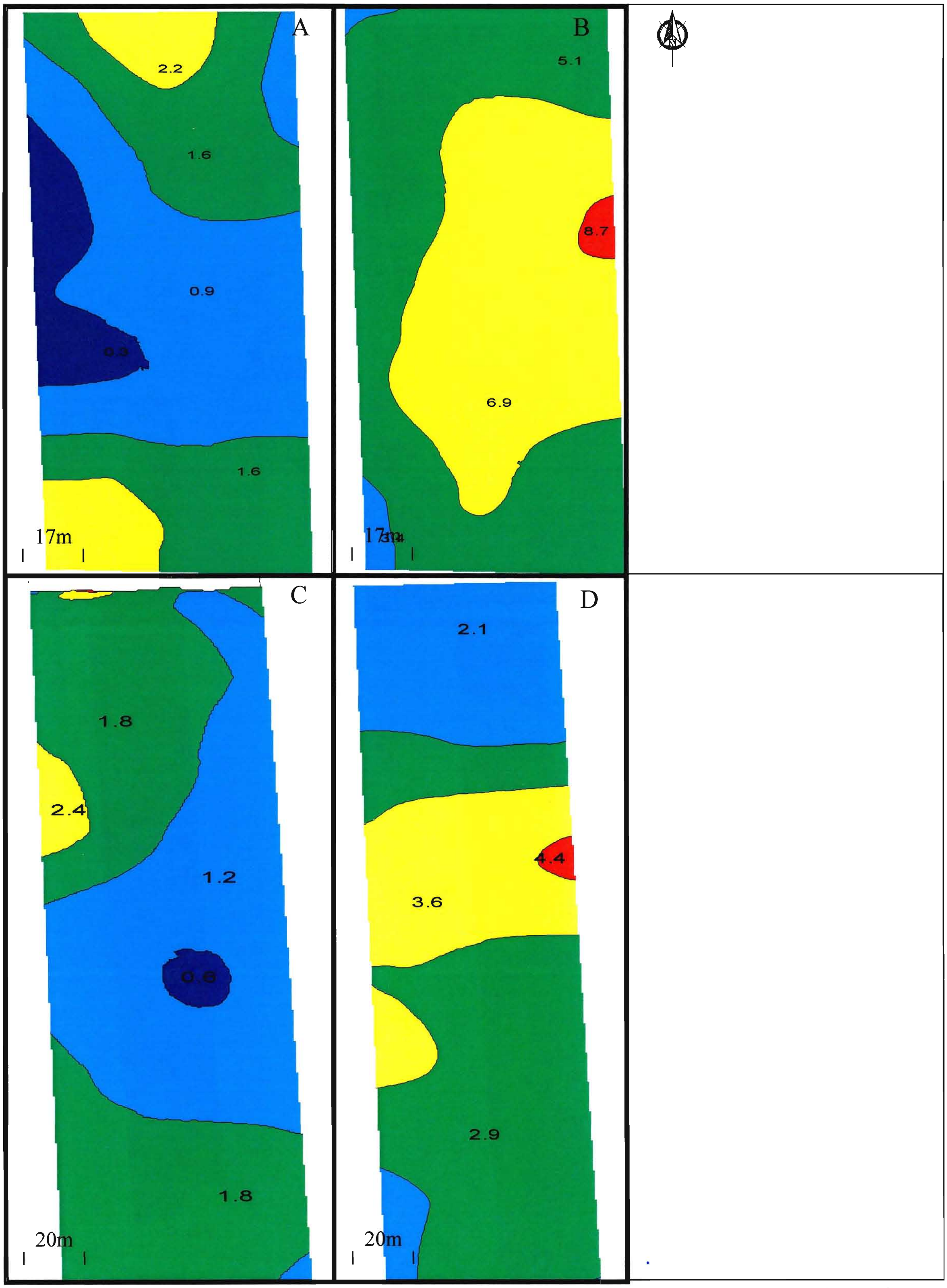

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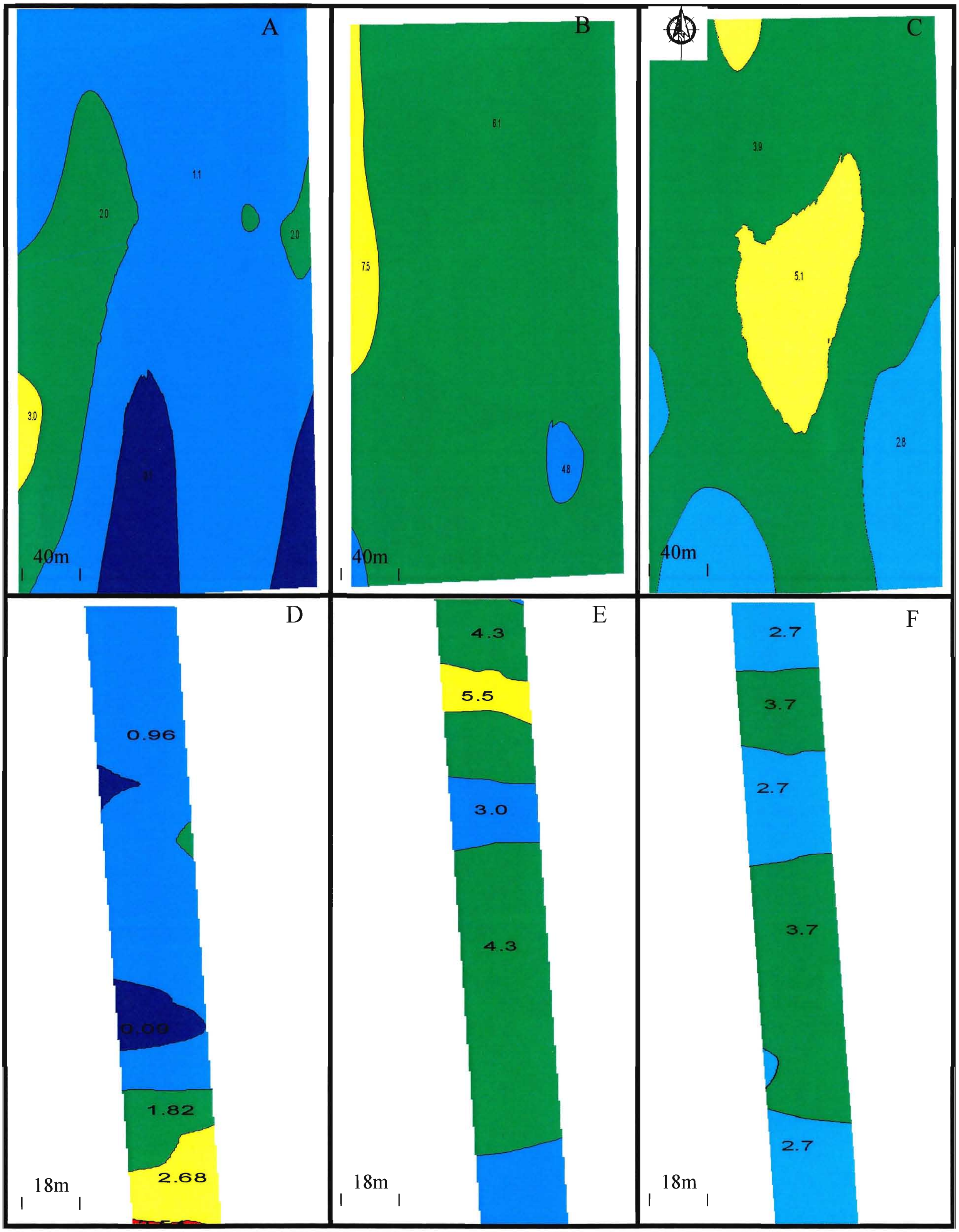

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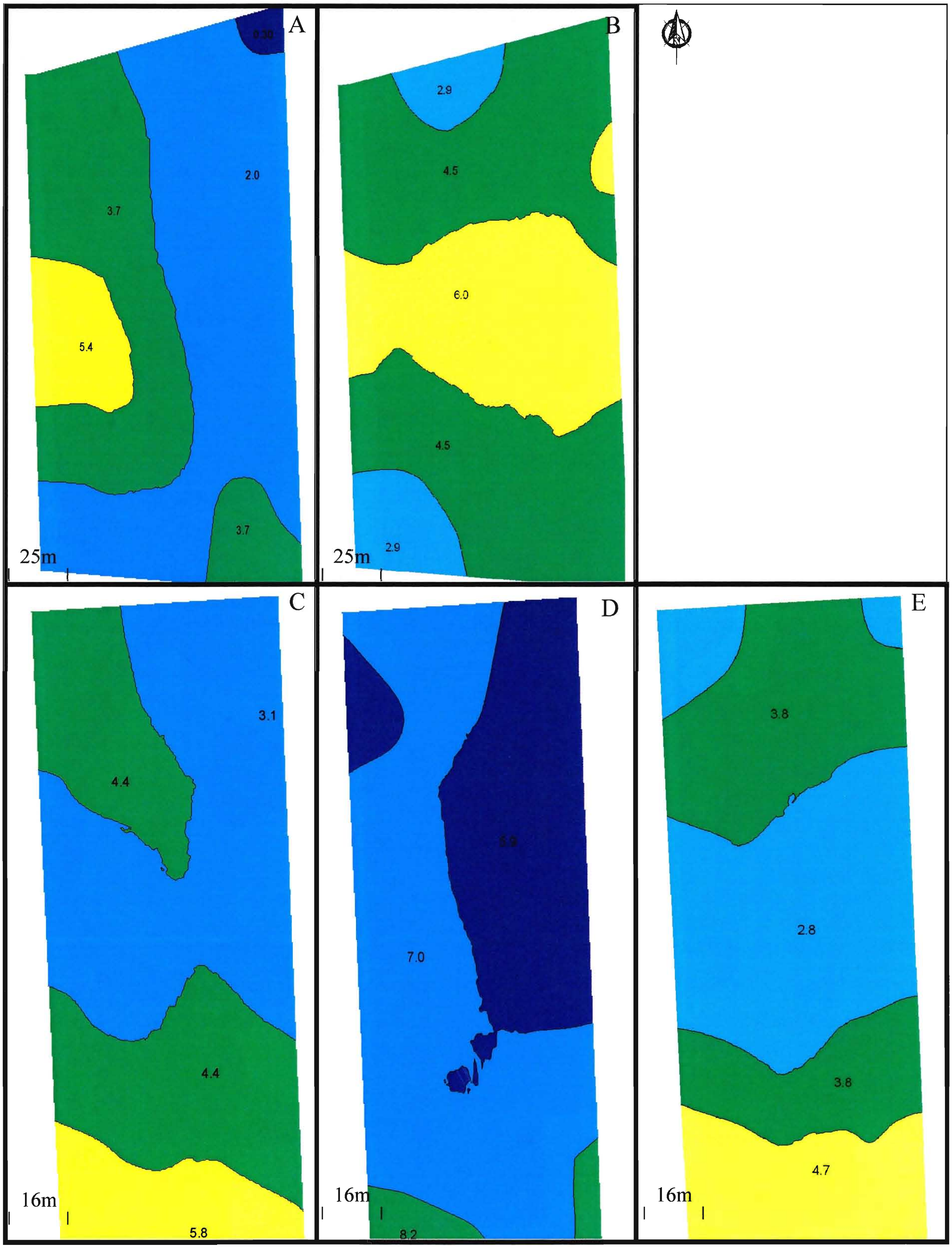

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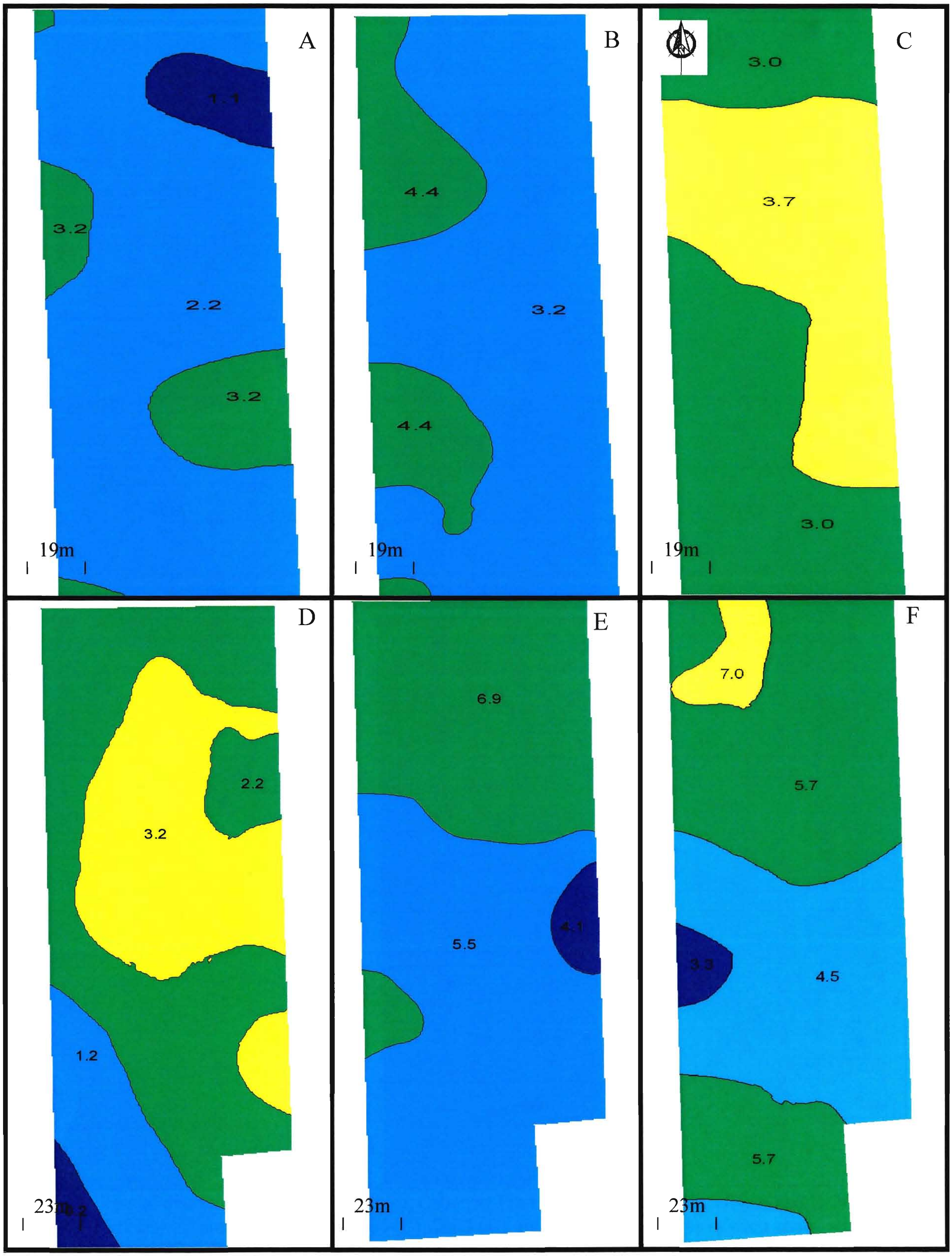

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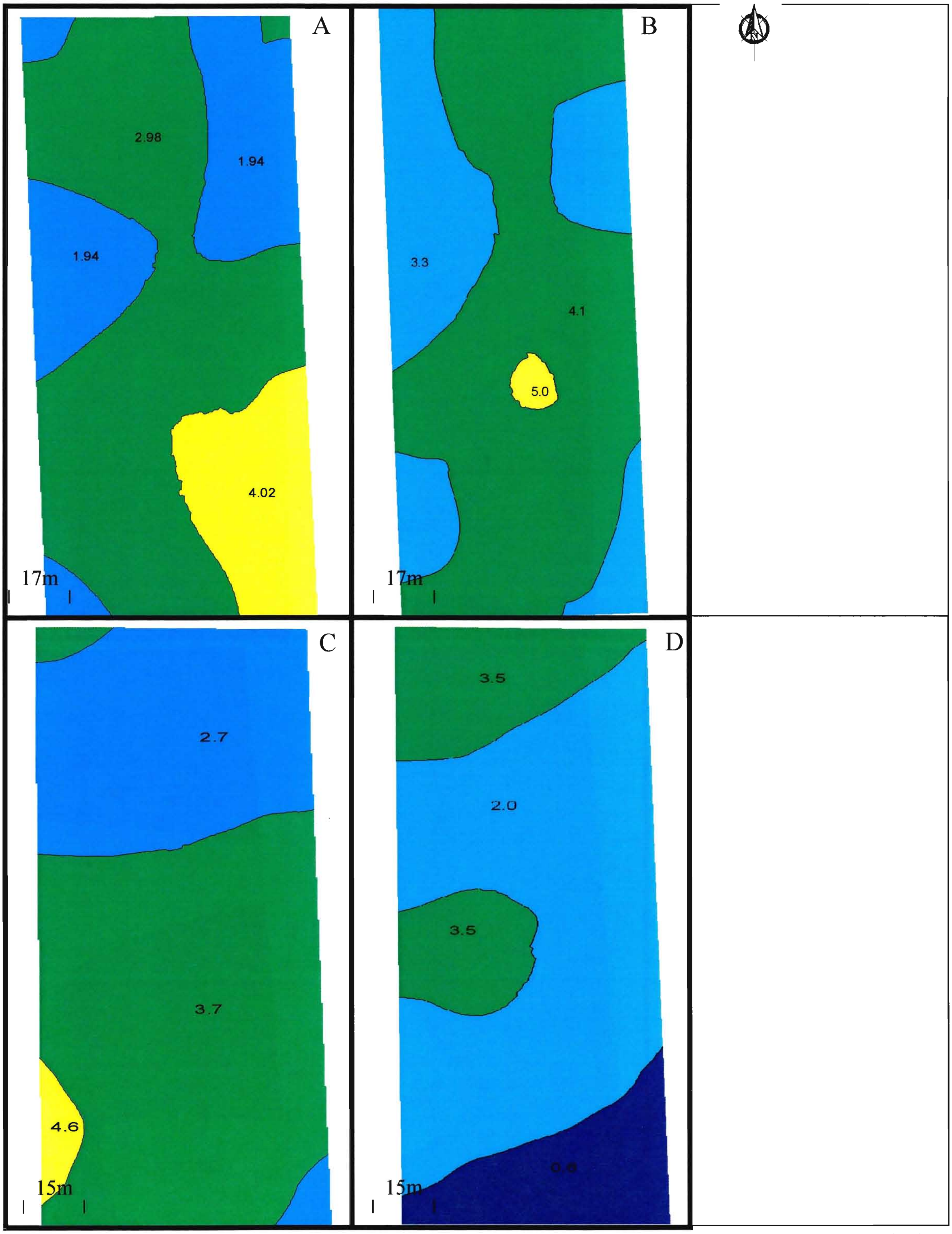

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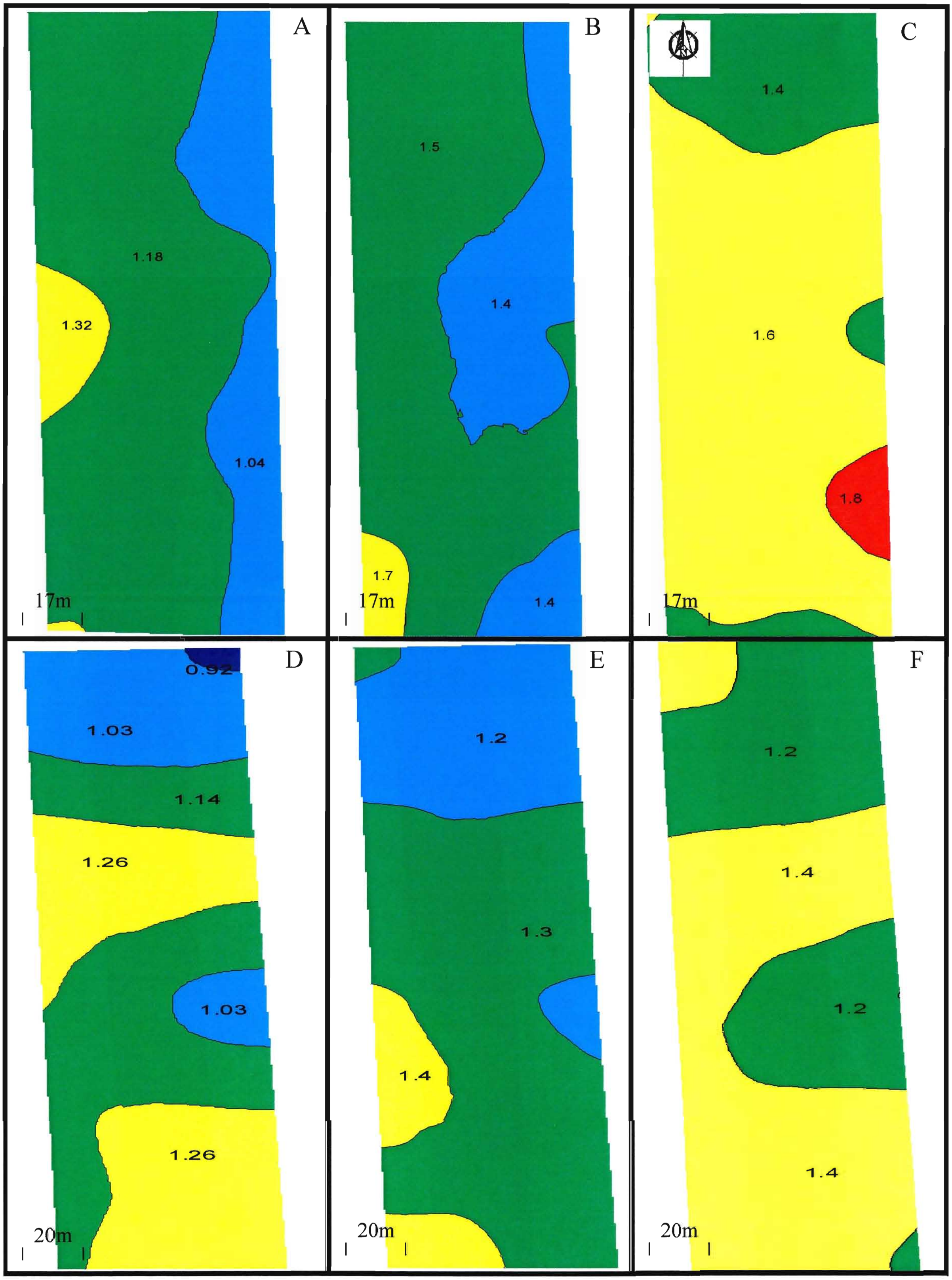

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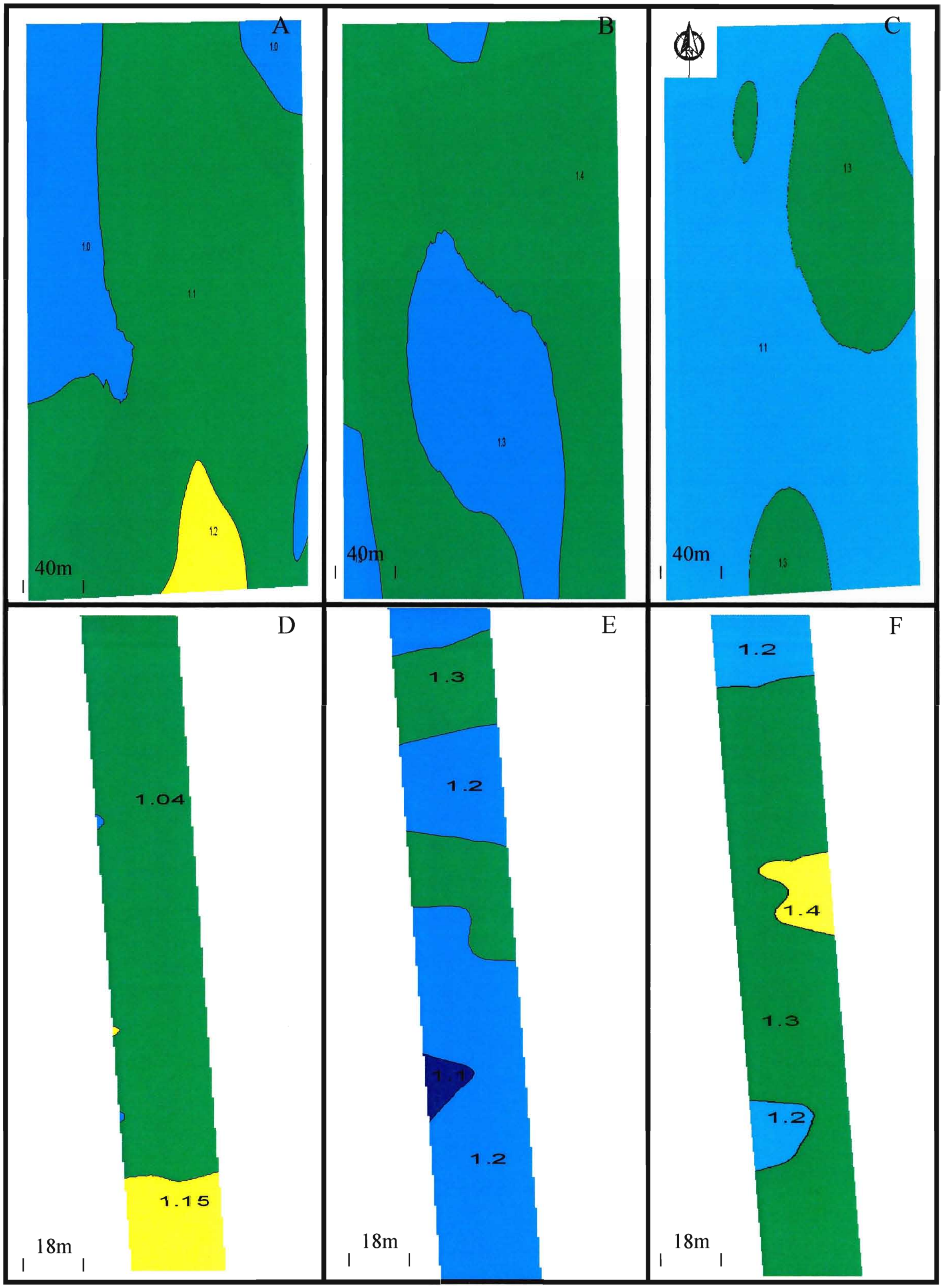

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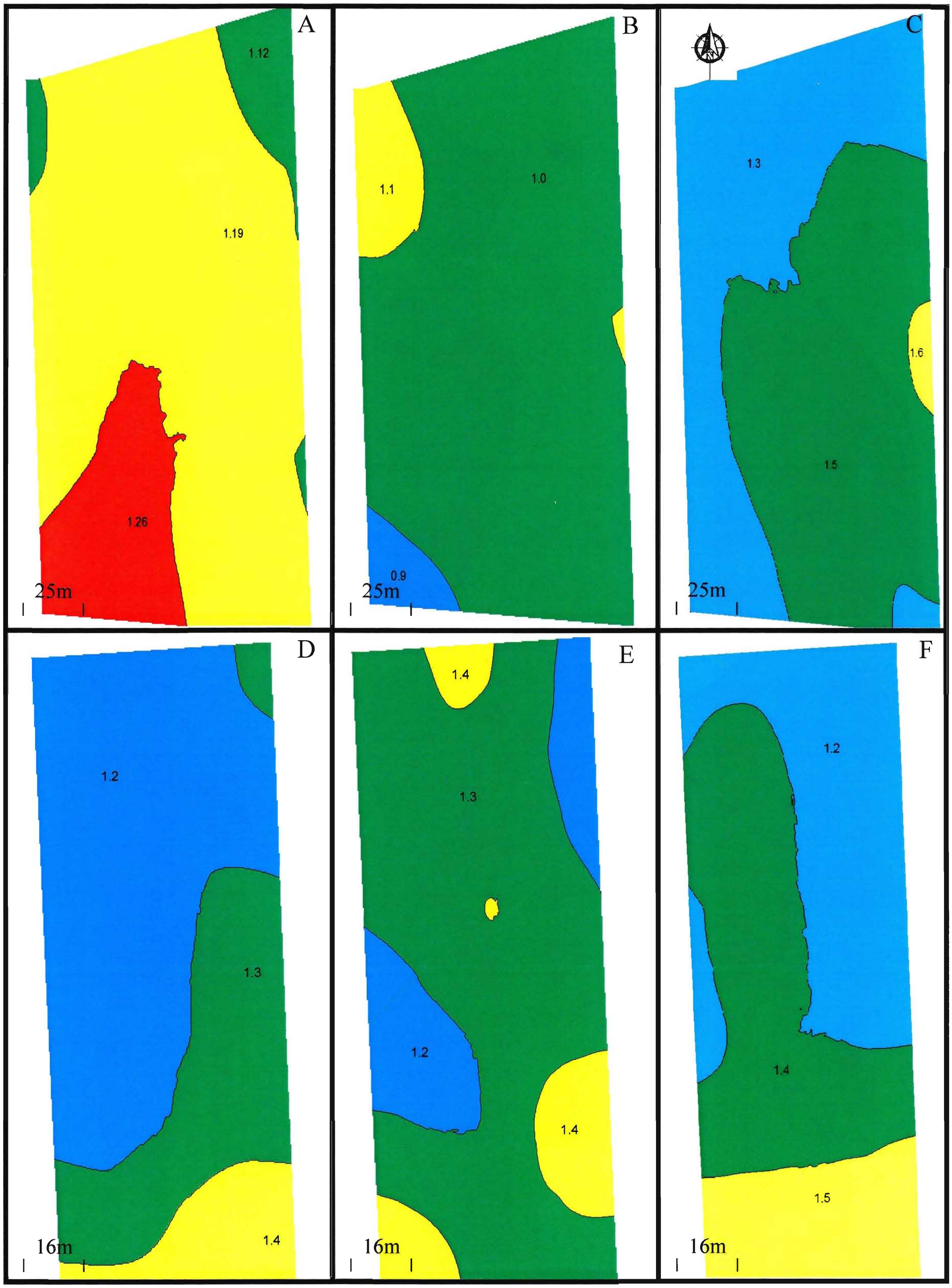

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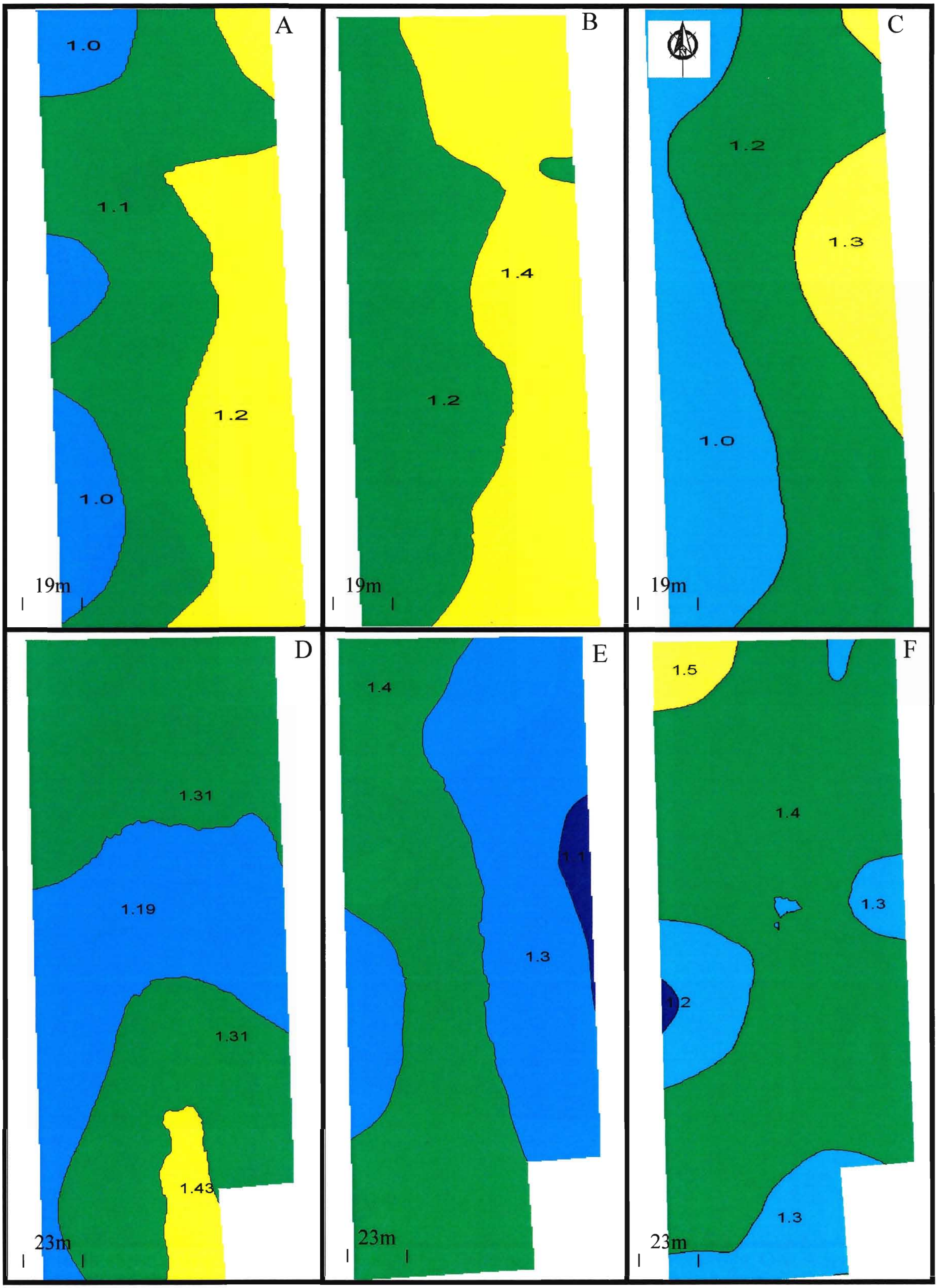

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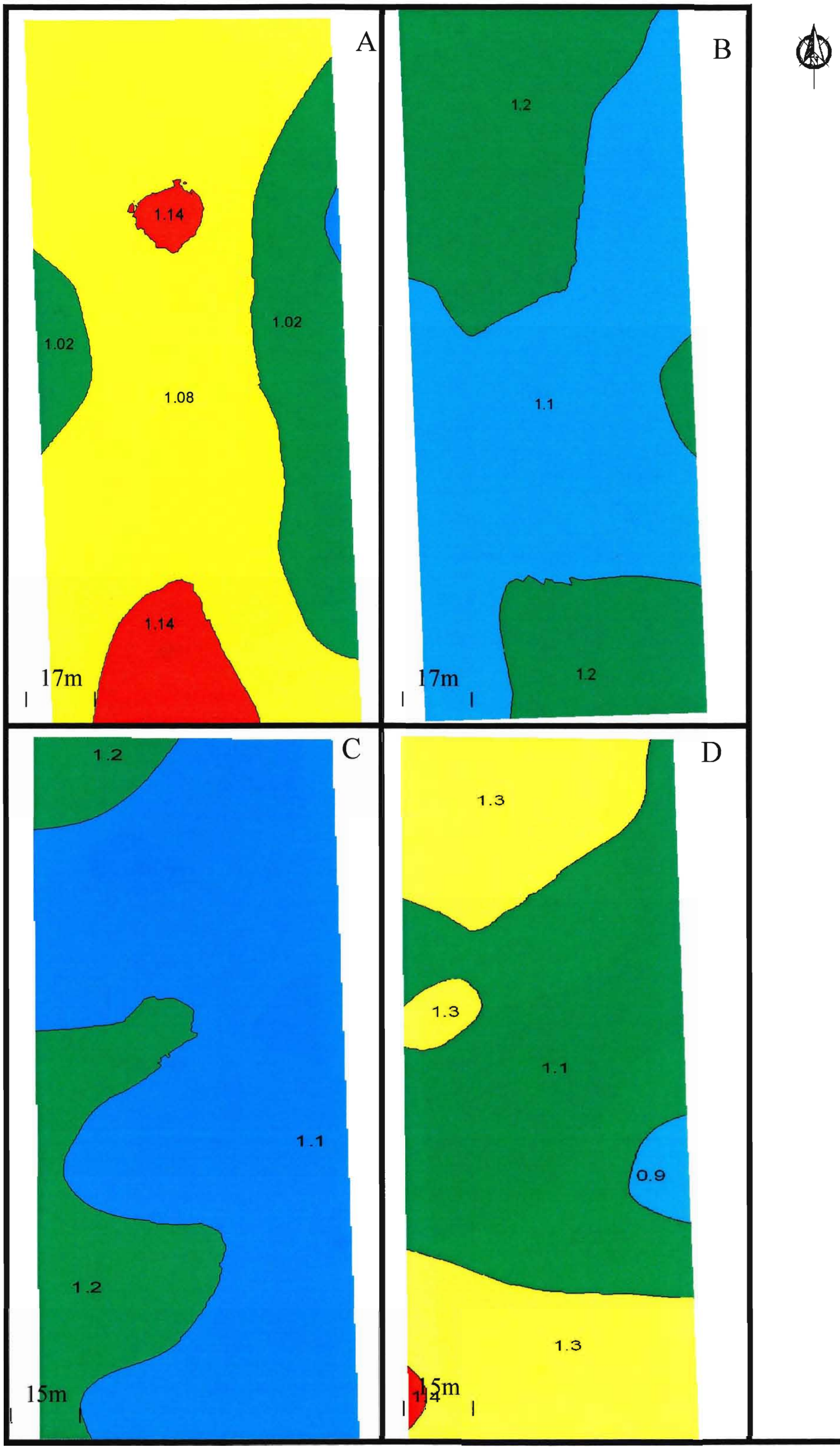

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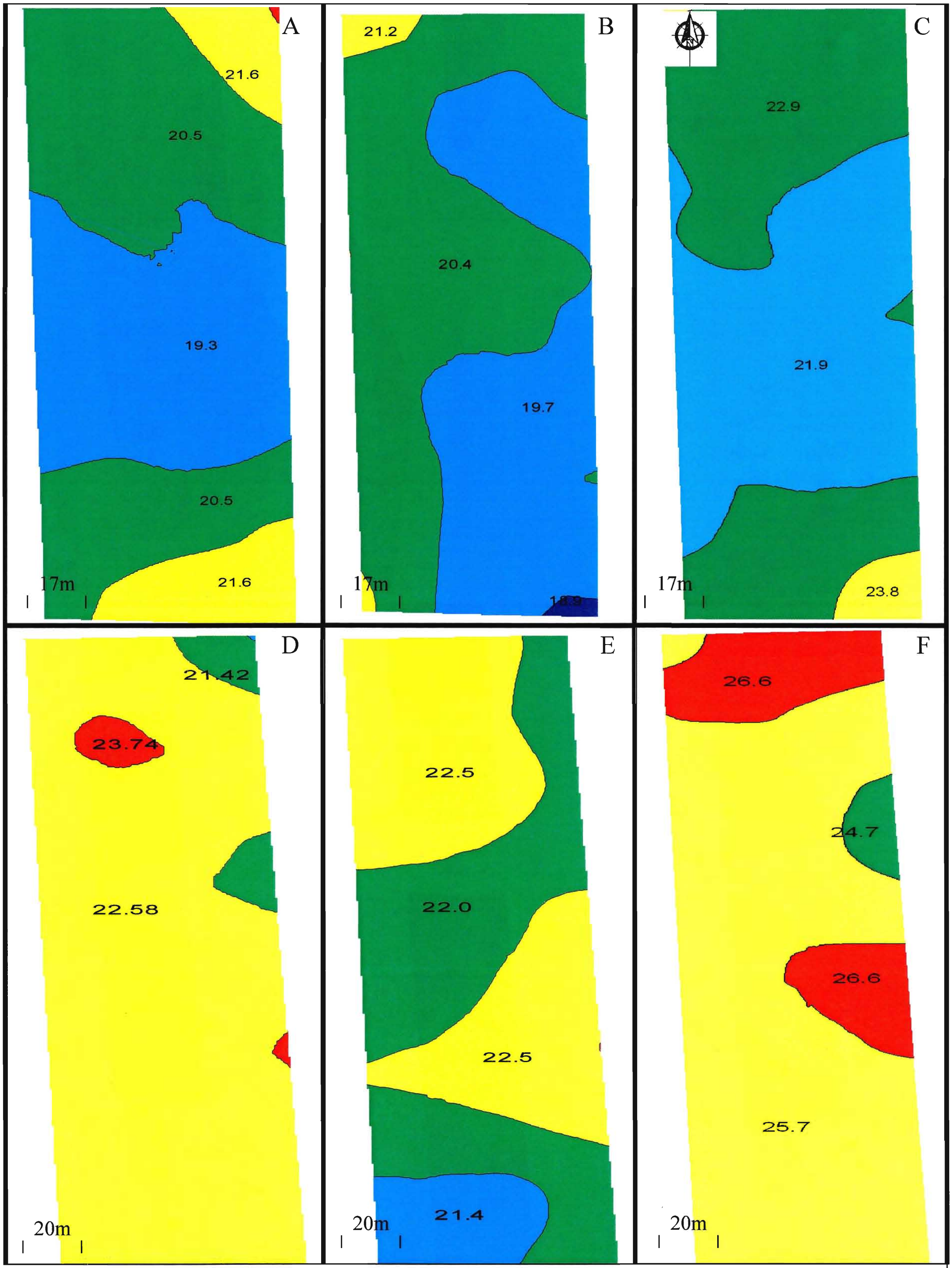

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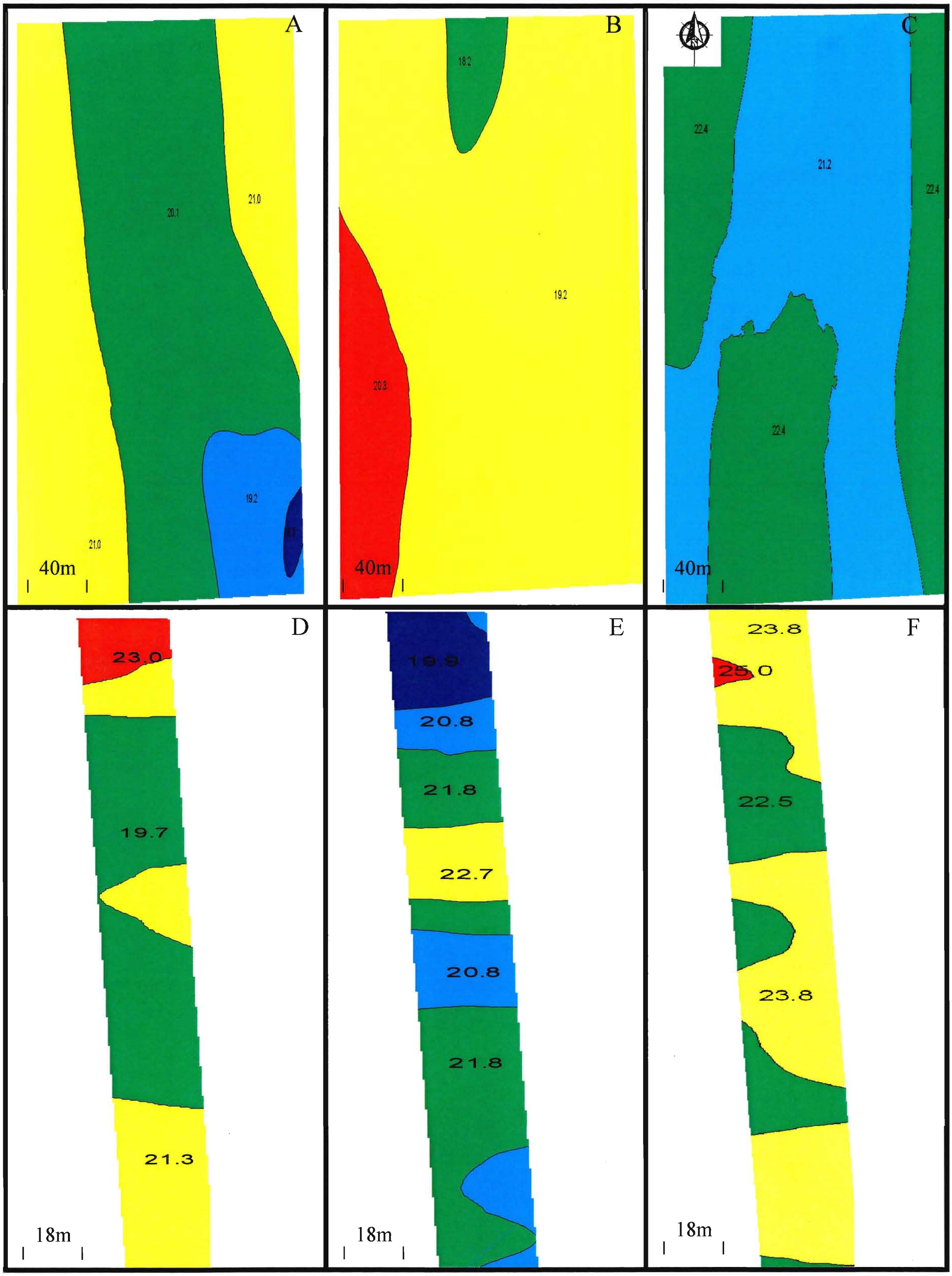

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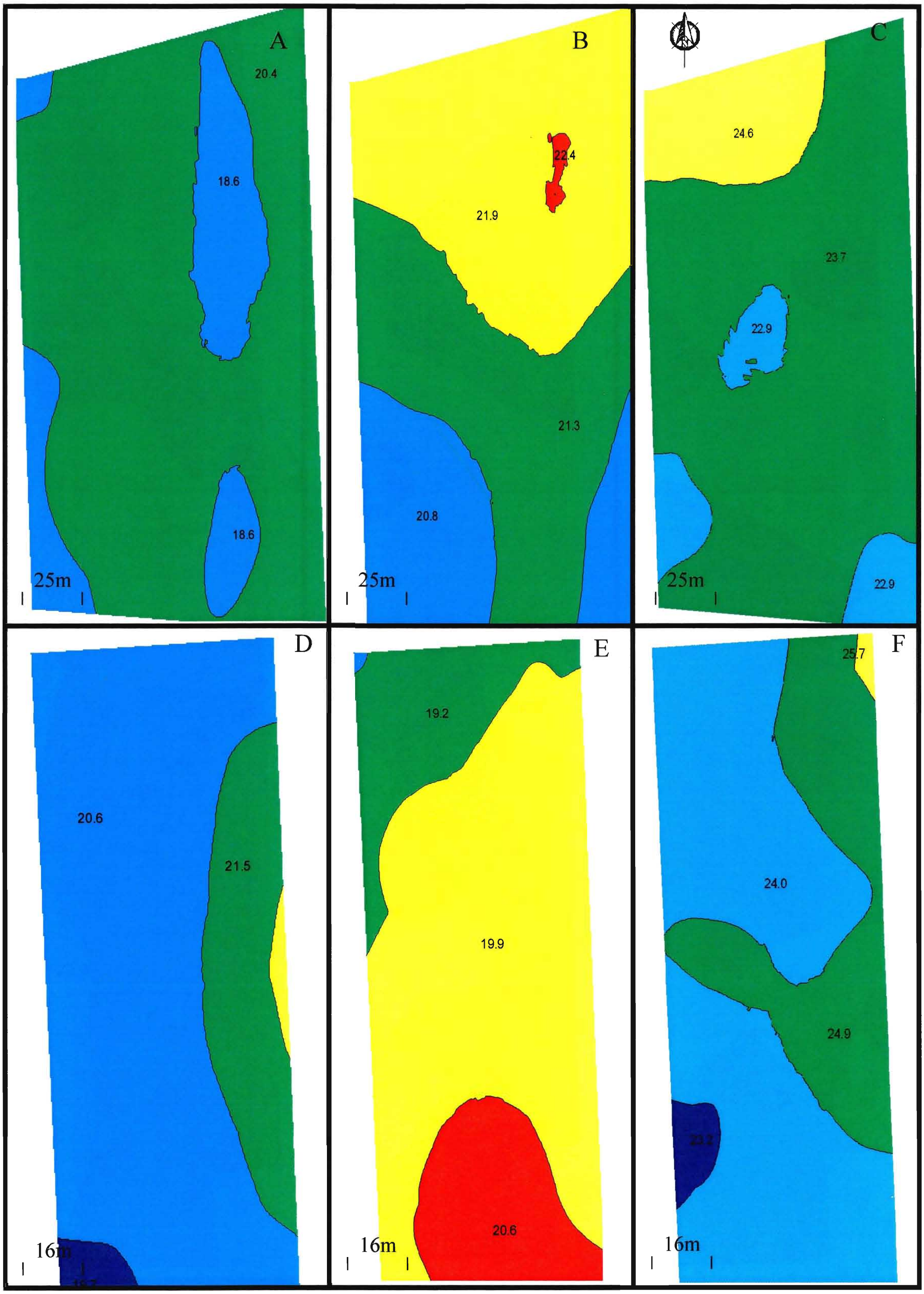

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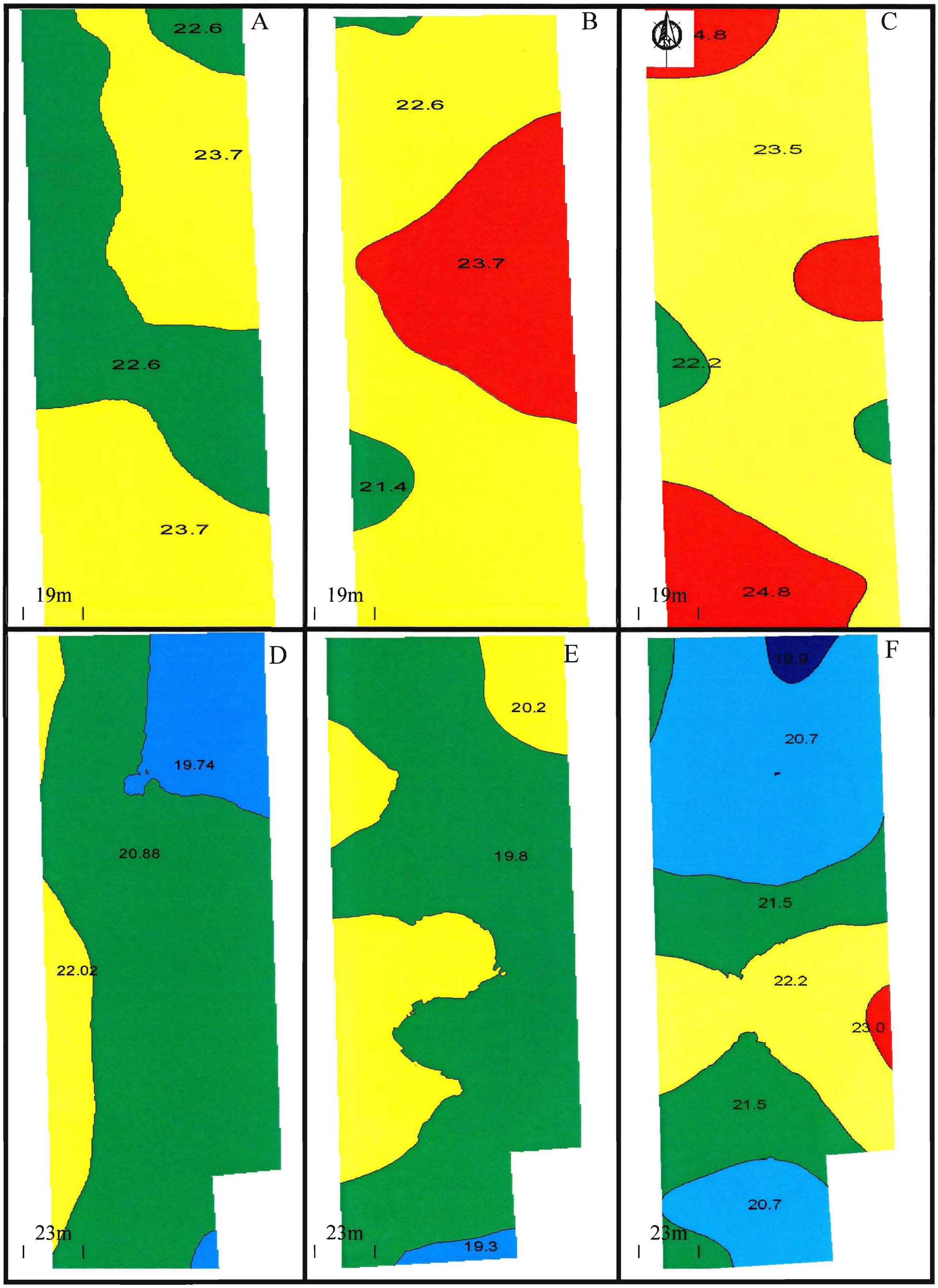


Figure 22. Spatial distribution of Brix, Cabernet Franc, Niagara Peninsula, ON; A to C: Cave Spring: 2005 (A); 2006 (B); 2007 (C). D to F: Henry of Pelham: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

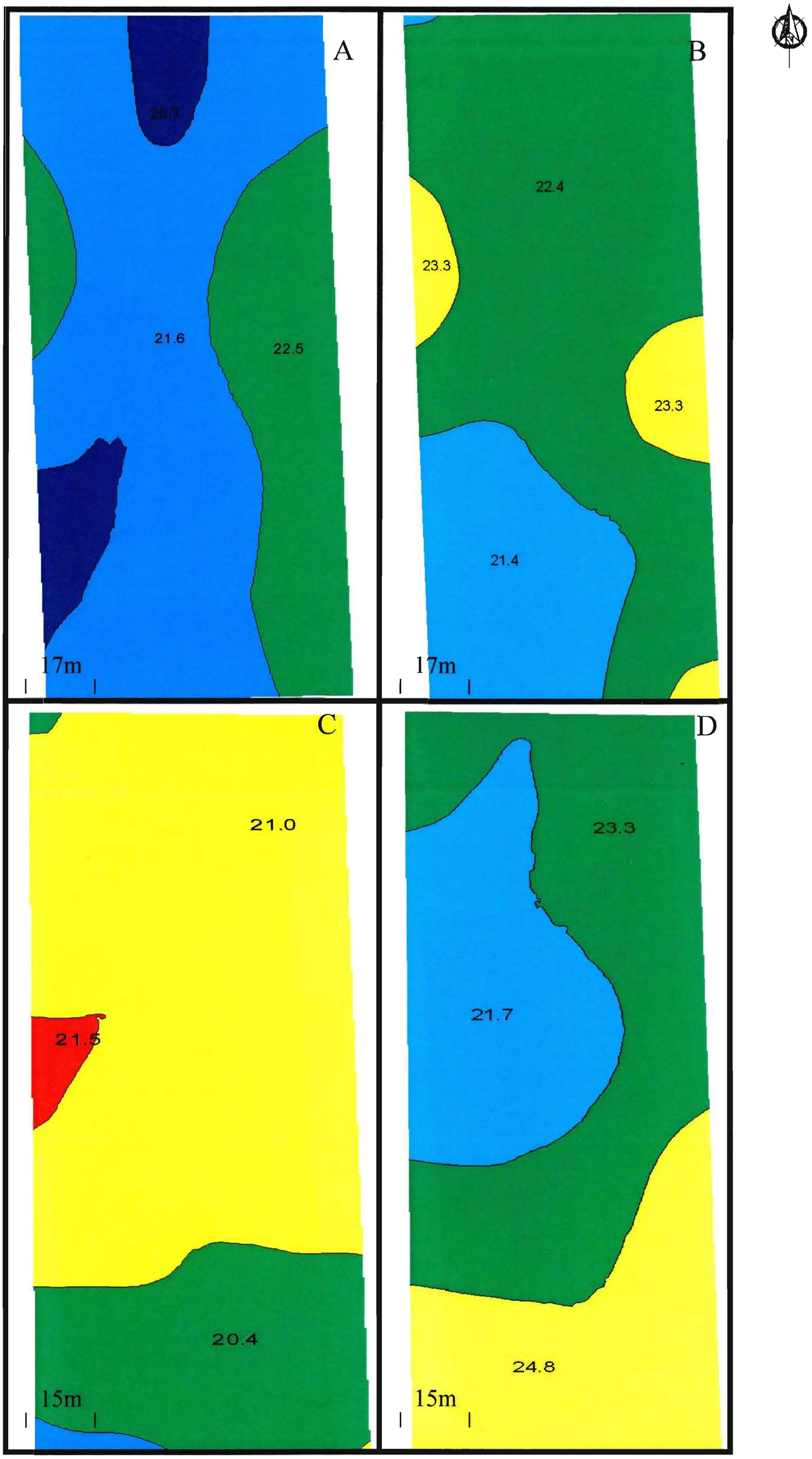


Figure 23. Spatial distribution of Brix, Cabernet Franc, Niagara Peninsula, ON; A and B: Vieni: 2005 (A); 2007 (B). C and D: Morrison: 2006 (C); 2007 (D). In each map, the value of each zone represents the corresponding lower limit for that zone.

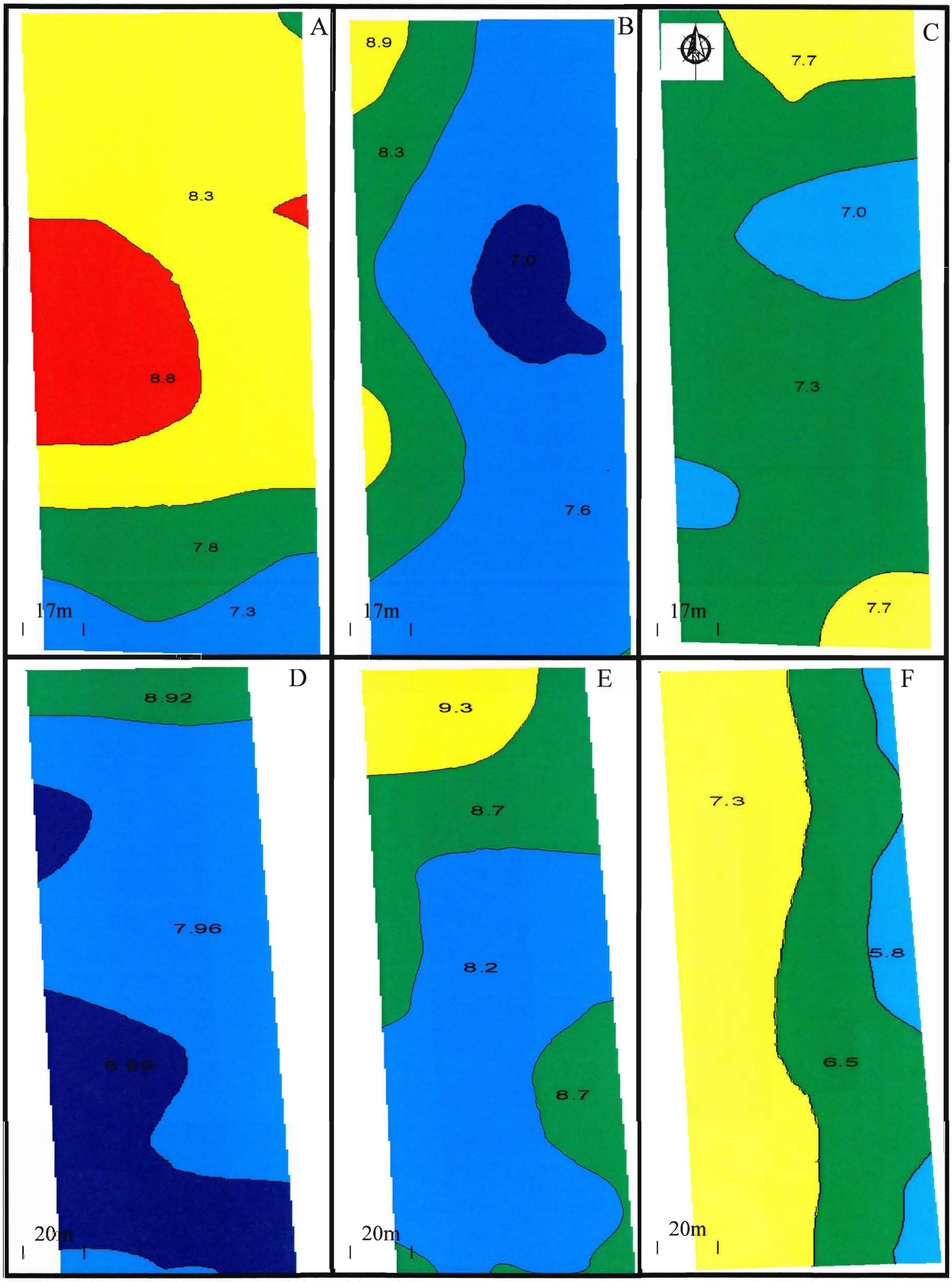


Figure 24. Spatial distribution of titratable acidity (g/L), Cabernet Franc, Niagara Peninsula, ON; A to C: Buis: 2005 (A); 2006 (B); 2007 (C). D to F: Chateau des Charmes: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

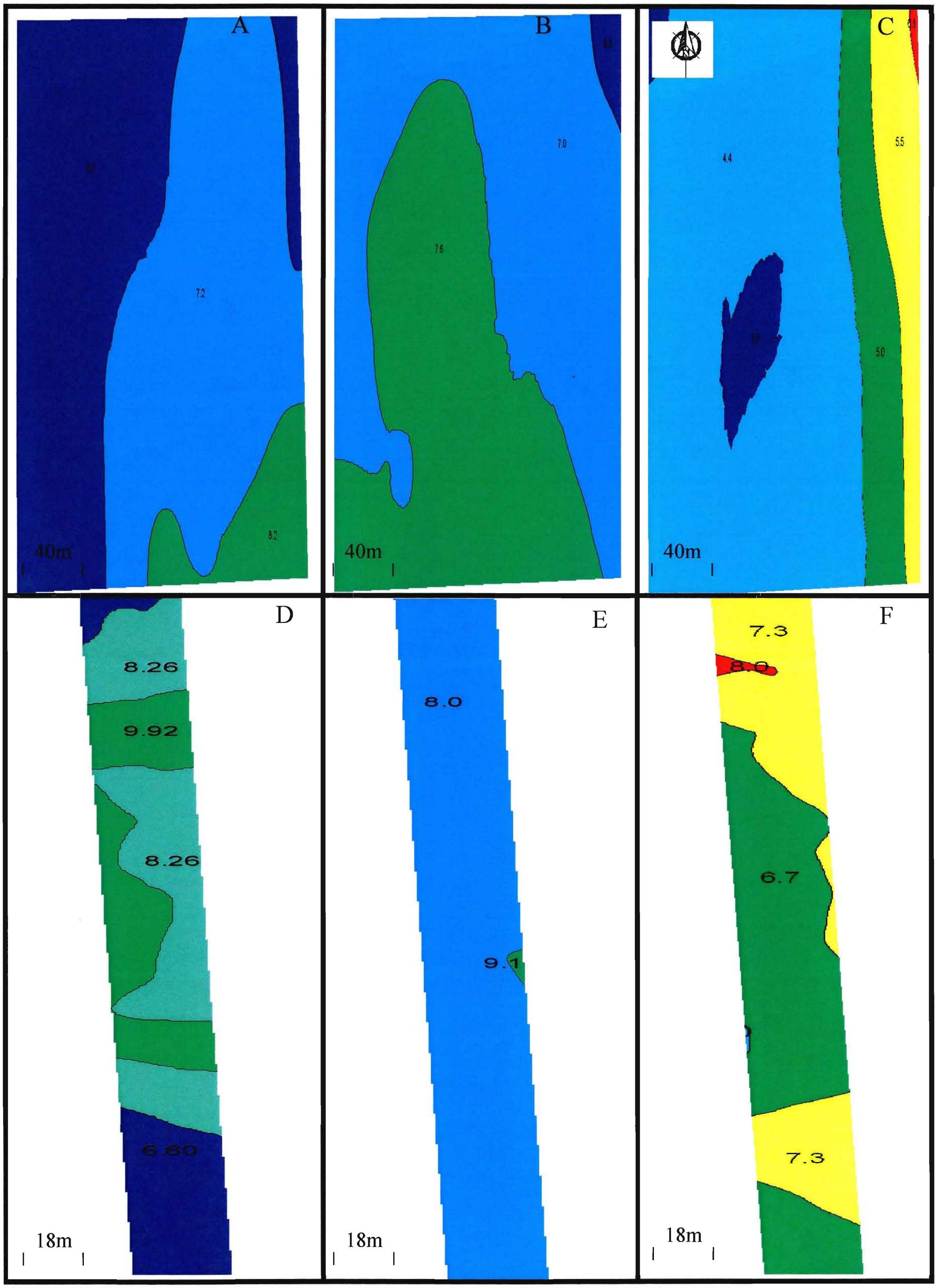


Figure 25. Spatial distribution of titratable acidity (g/L), Cabernet Franc, Niagara Peninsula, ON; A to C: Hernder: 2005 (A); 2006 (B); 2007 (C). D to F: Reif: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

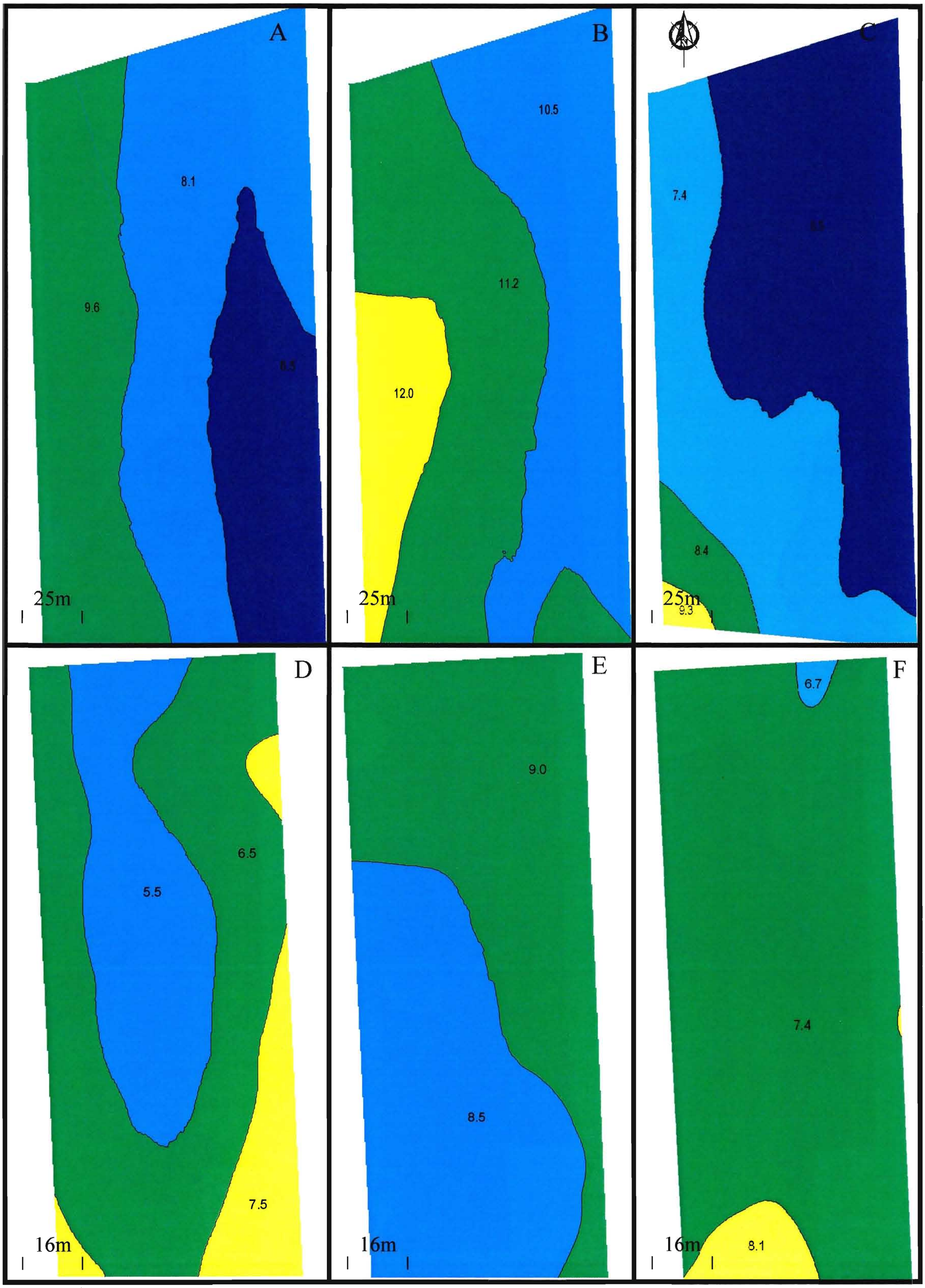


Figure 26. Spatial distribution of titratable acidity (g/L), Cabernet Franc, Niagara Peninsula, ON; A to C: Harbour Estate: 2005 (A); 2006 (B); 2007 (C). D to F: George: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

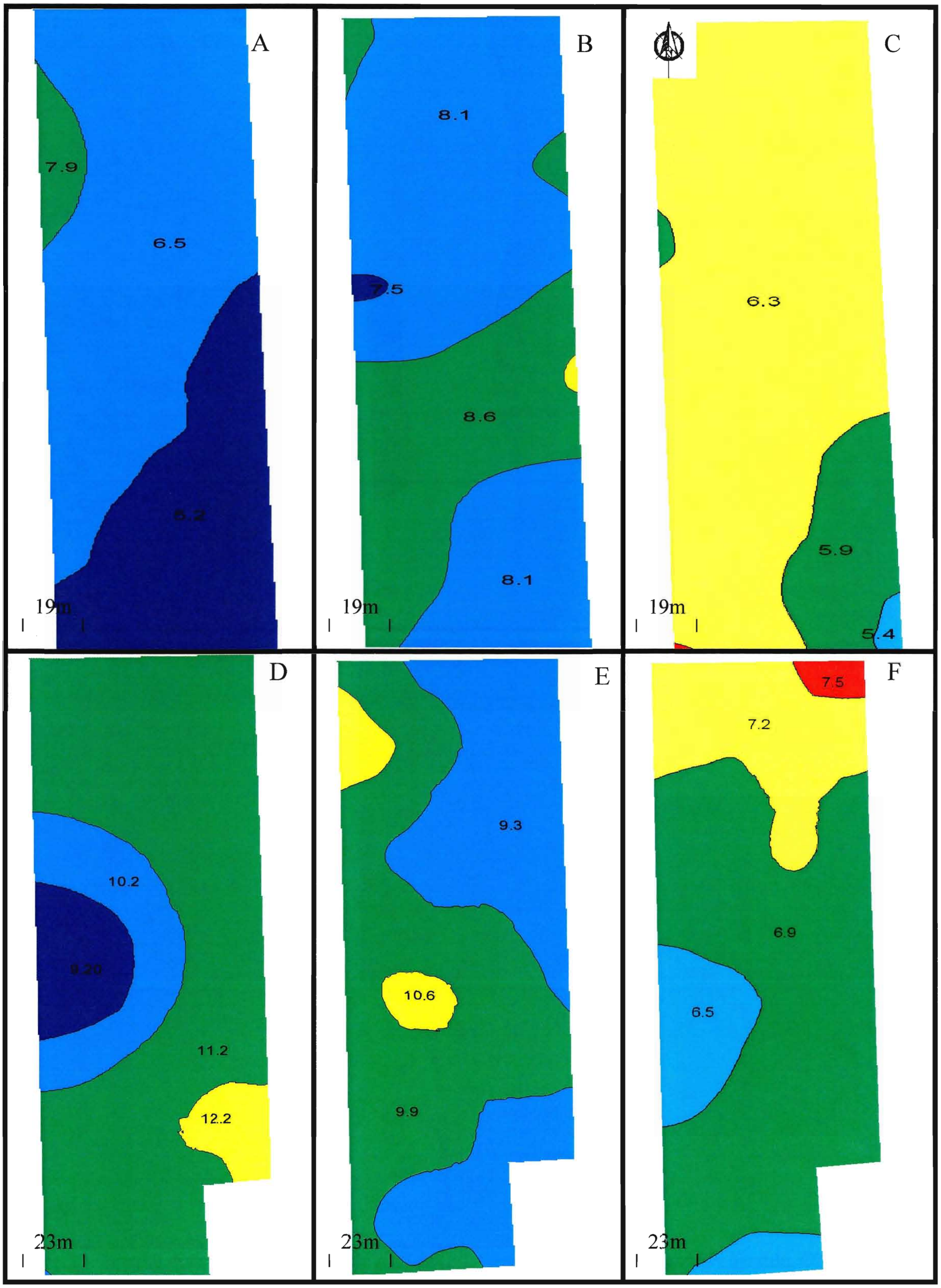


Figure 27. Spatial distribution of titratable acidity (g/L), Cabernet Franc, Niagara Peninsula, ON; A to C: Cave Spring: 2005 (A); 2006 (B); 2007 (C). D to F: Henry of Pelham: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

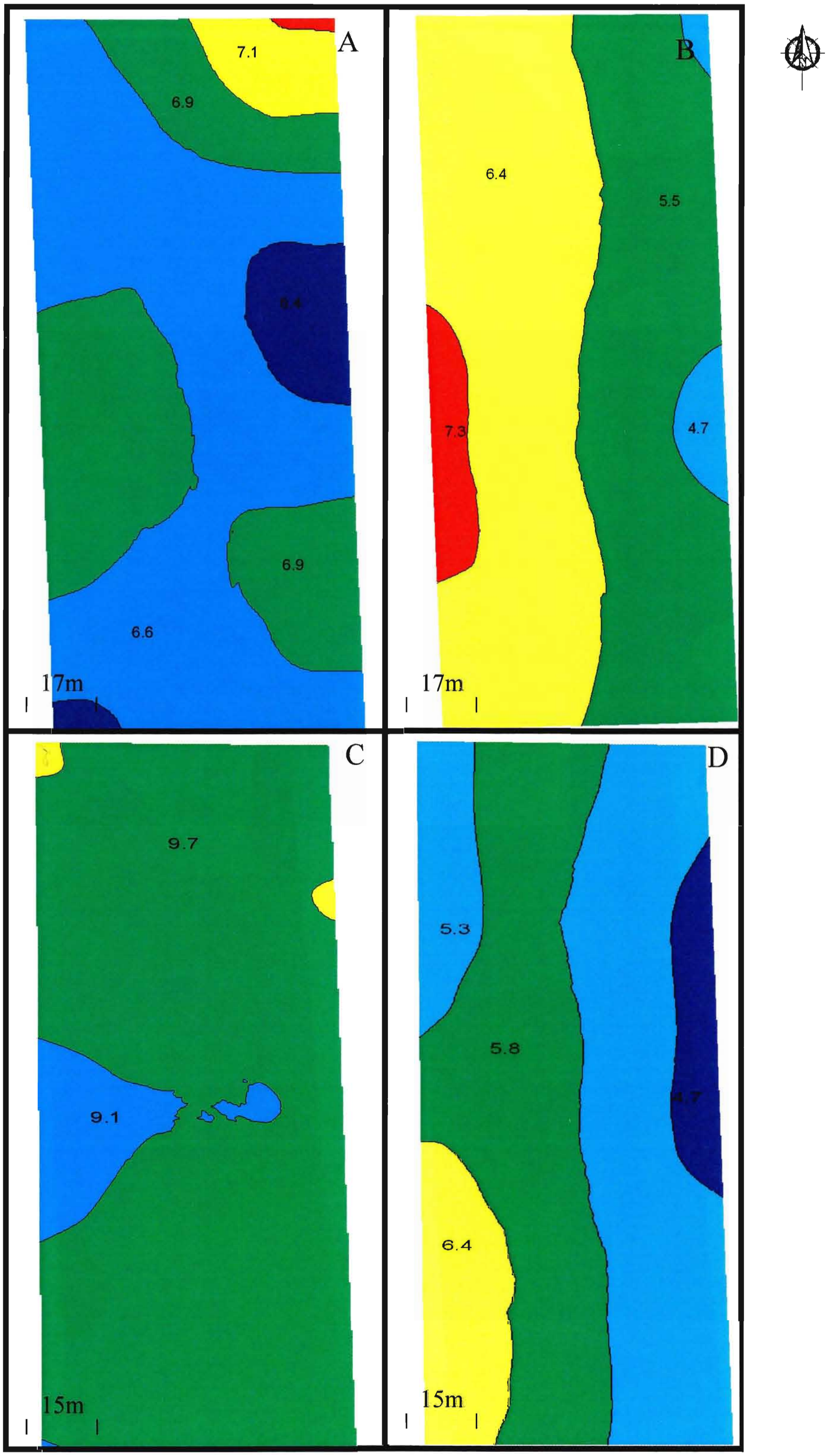


Figure 28. Spatial distribution of titratable acidity (g/L), Cabernet Franc, Niagara Peninsula, ON; A and B: Vieni: 2005 (A); 2007 (B). C and D: Morrison: 2006 (C); 2007 (D). In each map, the value of each zone represents the corresponding lower limit for that zone.

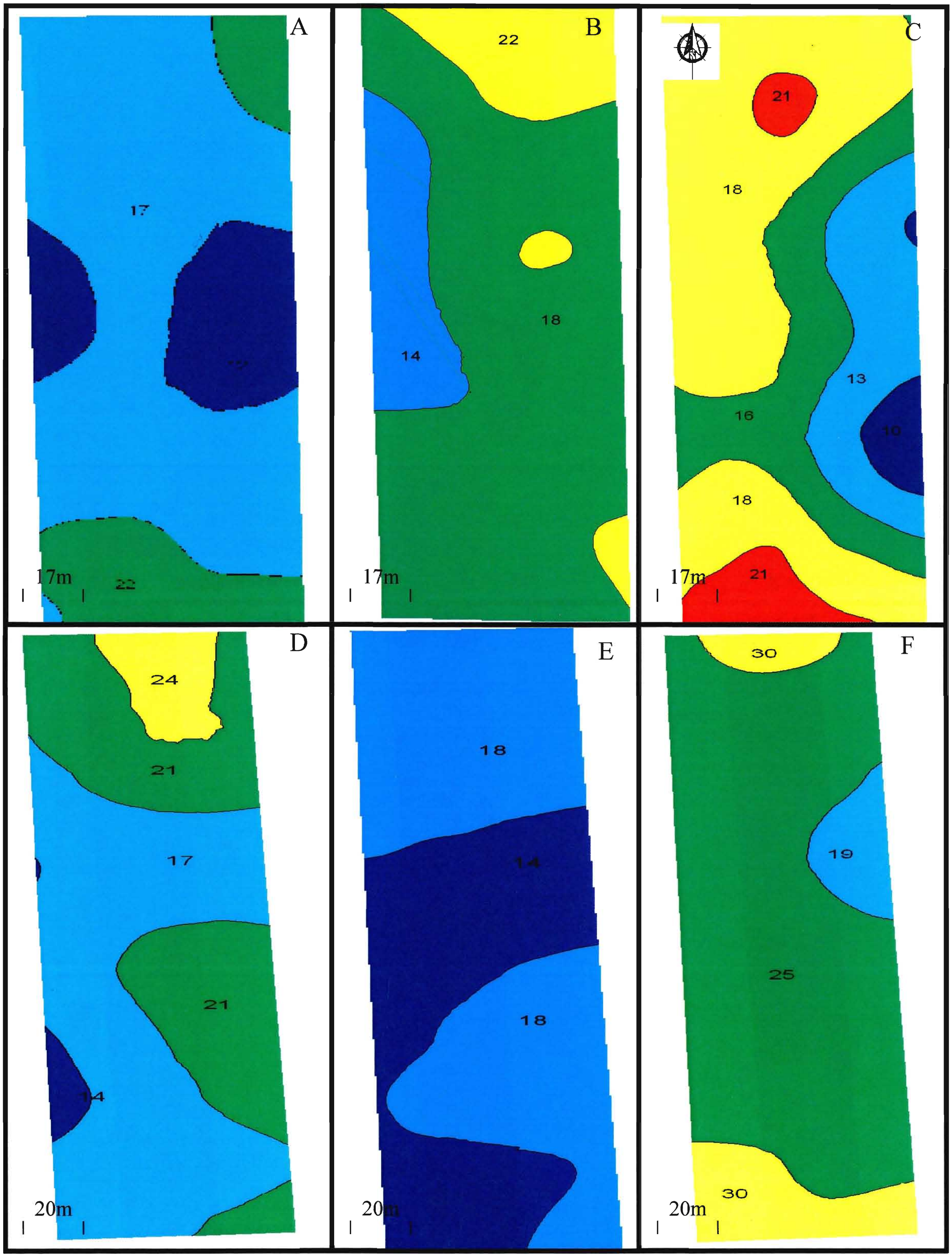


Figure 29. Spatial distribution of berry color intensity (absorbance units), Cabernet Franc, Niagara Peninsula, ON; A to C: Buis: 2005 (A); 2006 (B); 2007 (C). D to F: Chateau des Charmes: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

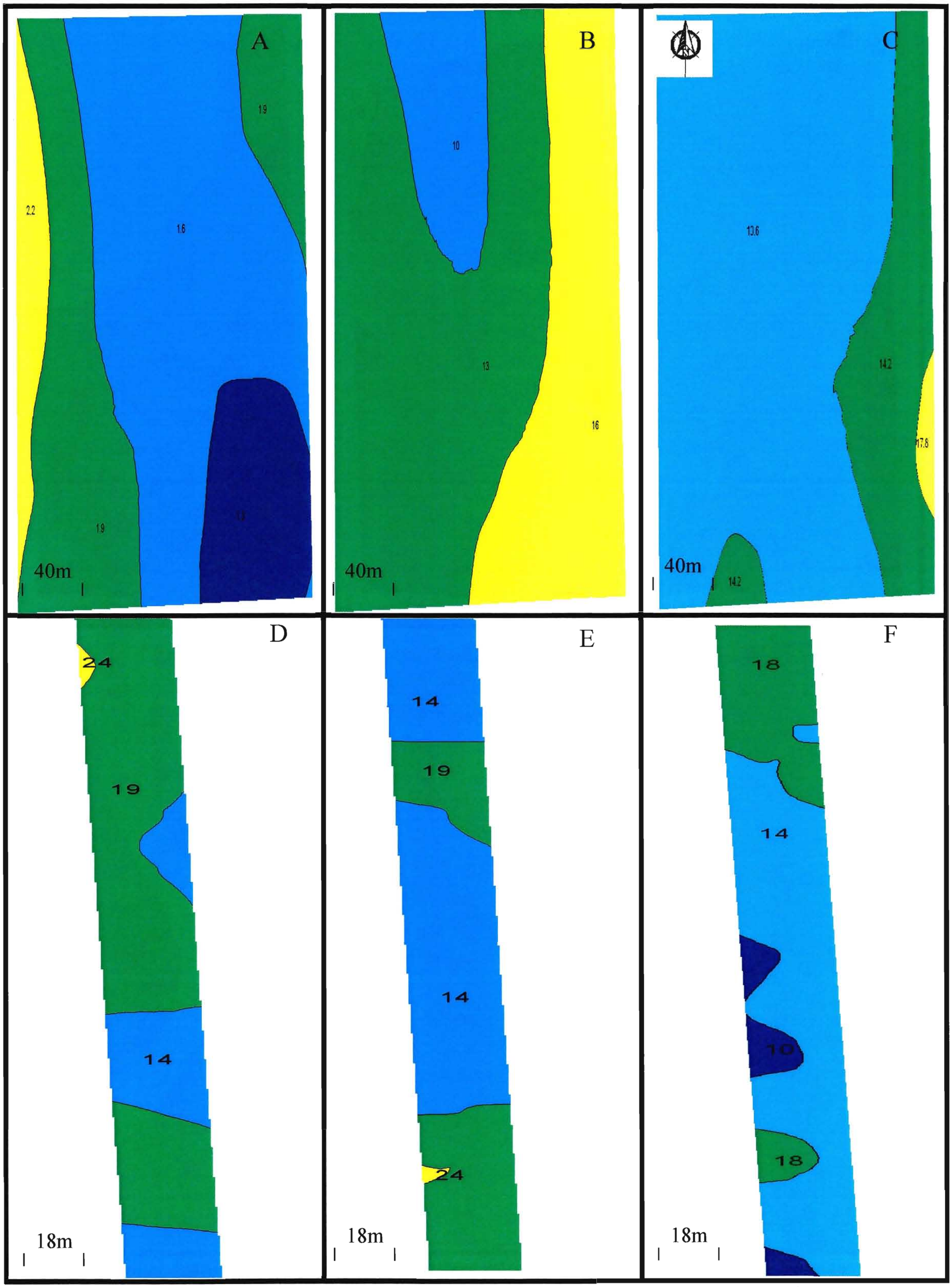


Figure 30. Spatial distribution of berry color intensity (absorbance units), Cabernet Franc, Niagara Peninsula, ON; A to C: Hernder: 2005 (A); 2006 (B); 2007 (C). D to F: Reif: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

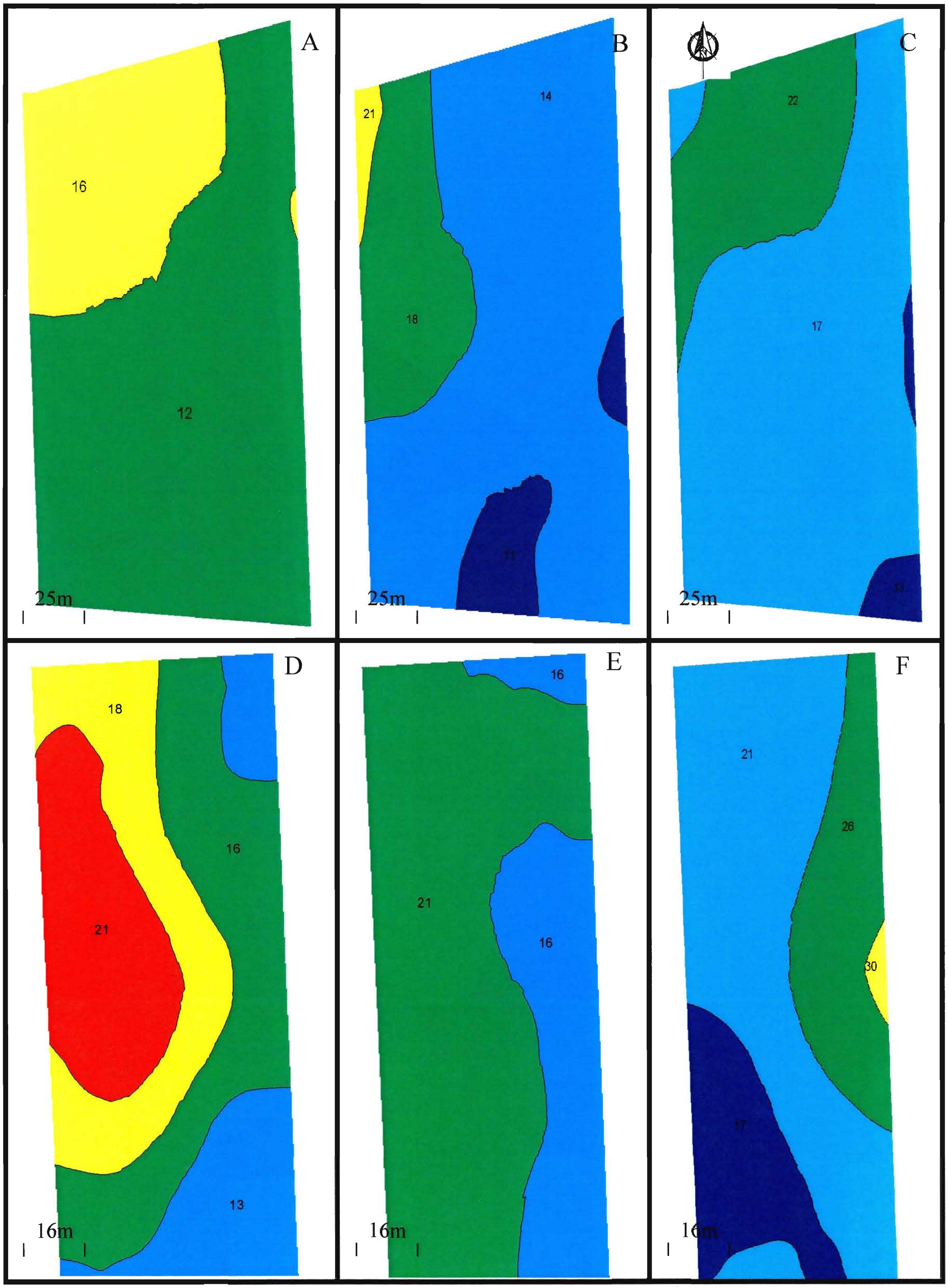


Figure 31. Spatial distribution of berry color intensity (absorbance units), Cabernet Franc, Niagara Peninsula, ON; A to C: Harbour Estate: 2005 (A); 2006 (B); 2007 (C). D to F: George: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

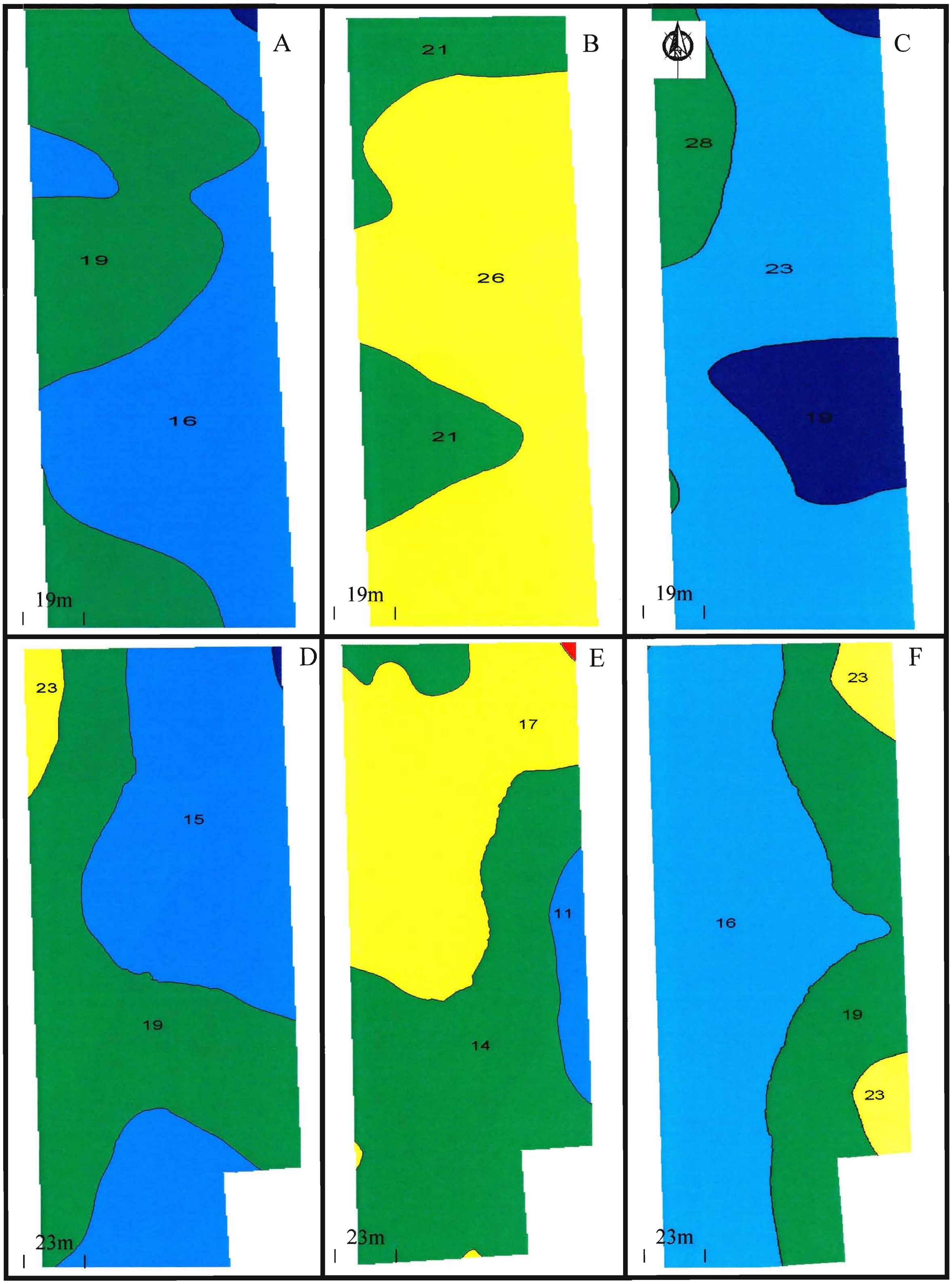


Figure 32. Spatial distribution of berry color intensity (absorbance units), Cabernet Franc, Niagara Peninsula, ON; A to C: Cave Spring: 2005 (A); 2006 (B); 2007 (C). D to F: Henry of Pelham: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

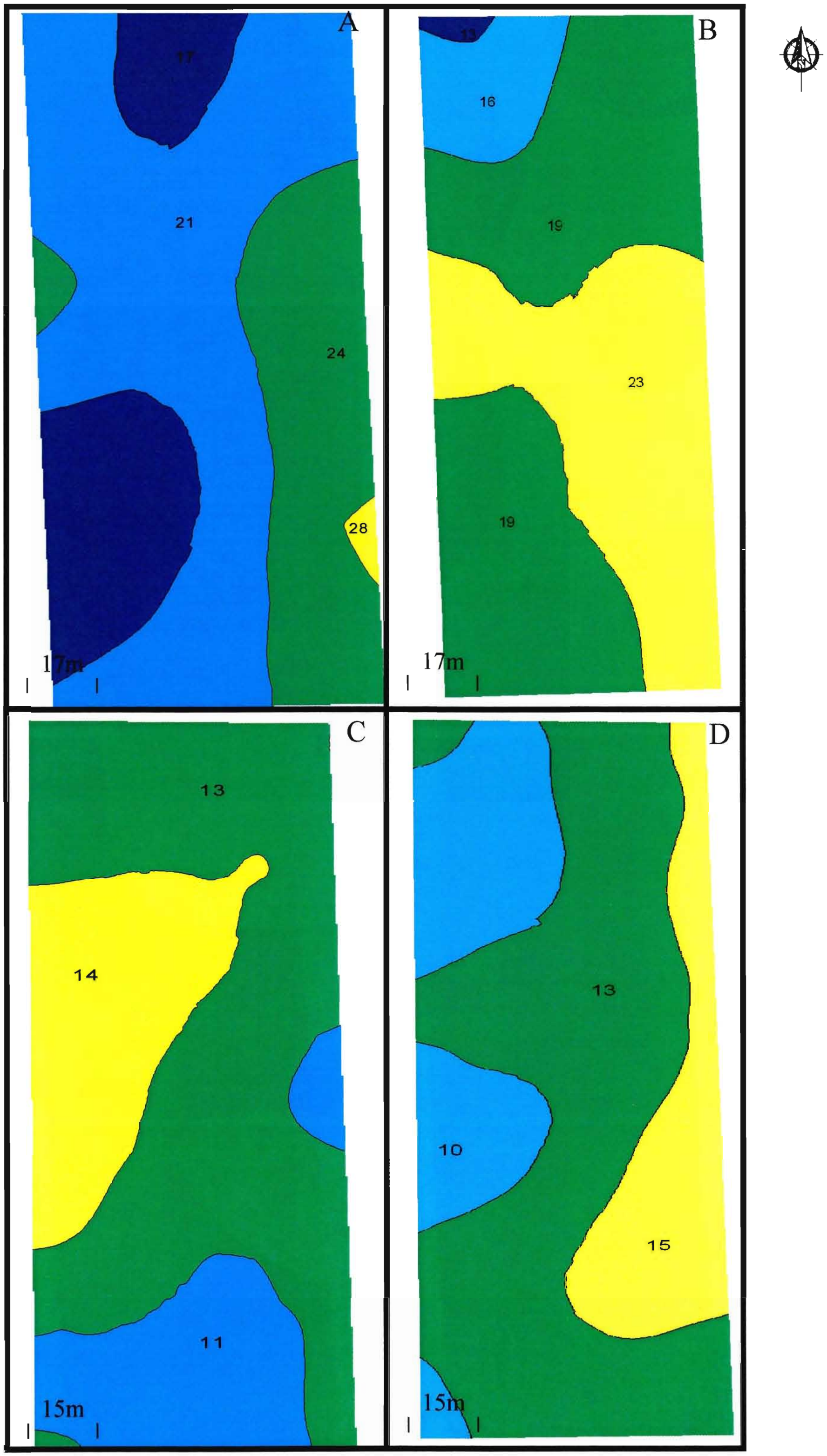


Figure 33. Spatial distribution of berry color intensity (absorbance units), Cabernet Franc, Niagara Peninsula, ON; A and B: Vieni: 2005 (A); 2007 (B). C and D: Morrison: 2006 (C); 2007 (D). In each map, the value of each zone represents the corresponding lower limit for that zone.

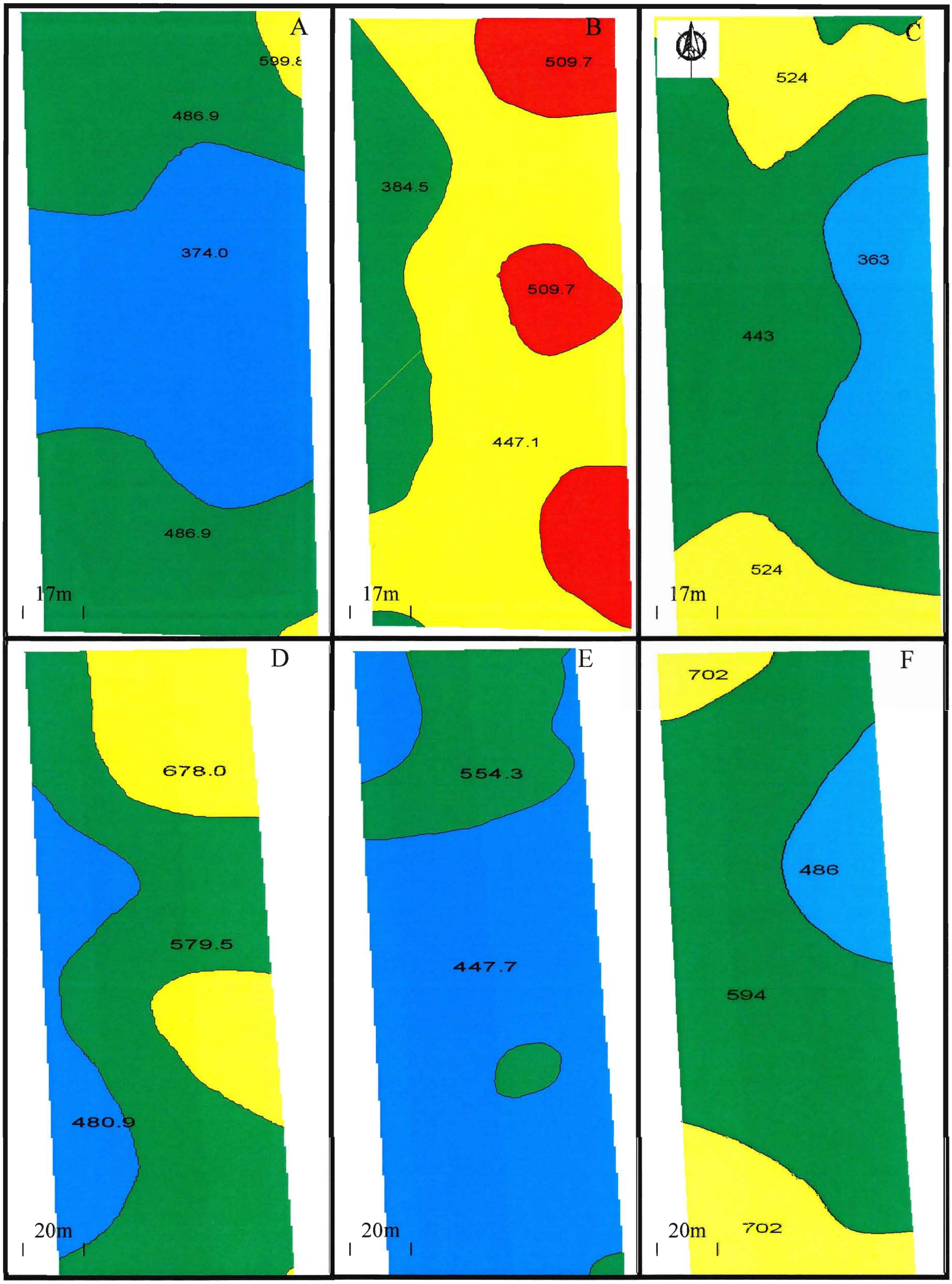


Figure 34. Spatial distribution of berry anthocyanins (mg/L), Cabernet Franc, Niagara Peninsula, ON; A to C: Buis: 2005 (A); 2006 (B); 2007 (C). D to F: Chateau des Charmes: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

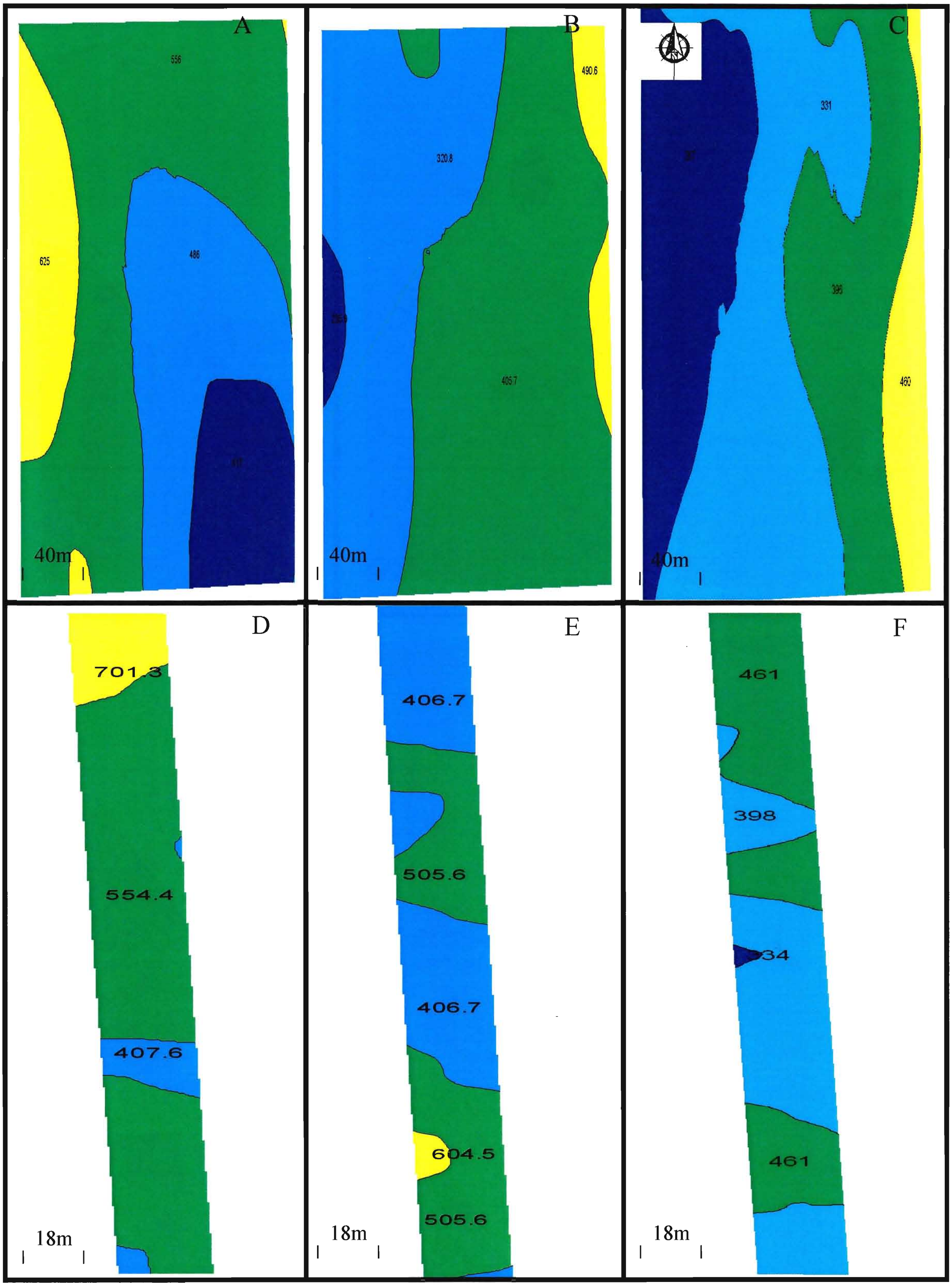


Figure 35. Spatial distribution of berry anthocyanins (mg/L), Cabernet Franc, Niagara Peninsula, ON; A to C: Hernder: 2005 (A); 2006 (B); 2007 (C). D to F: Reif: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

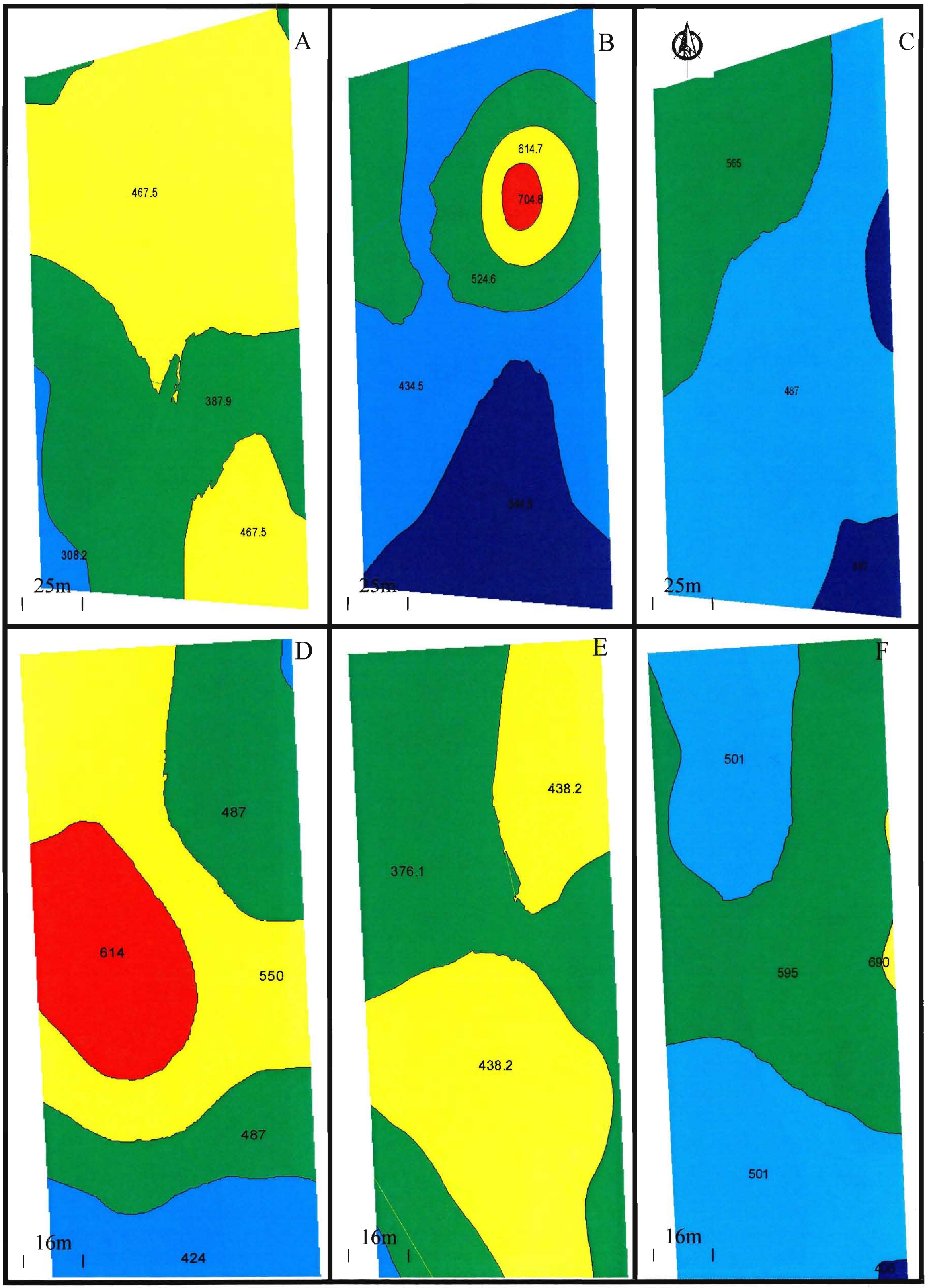


Figure 36. Spatial distribution of berry anthocyanins (mg/L), Cabernet Franc, Niagara Peninsula, ON; A to C: Harbour Estate: 2005 (A); 2006 (B); 2007 (C). D to F: George: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

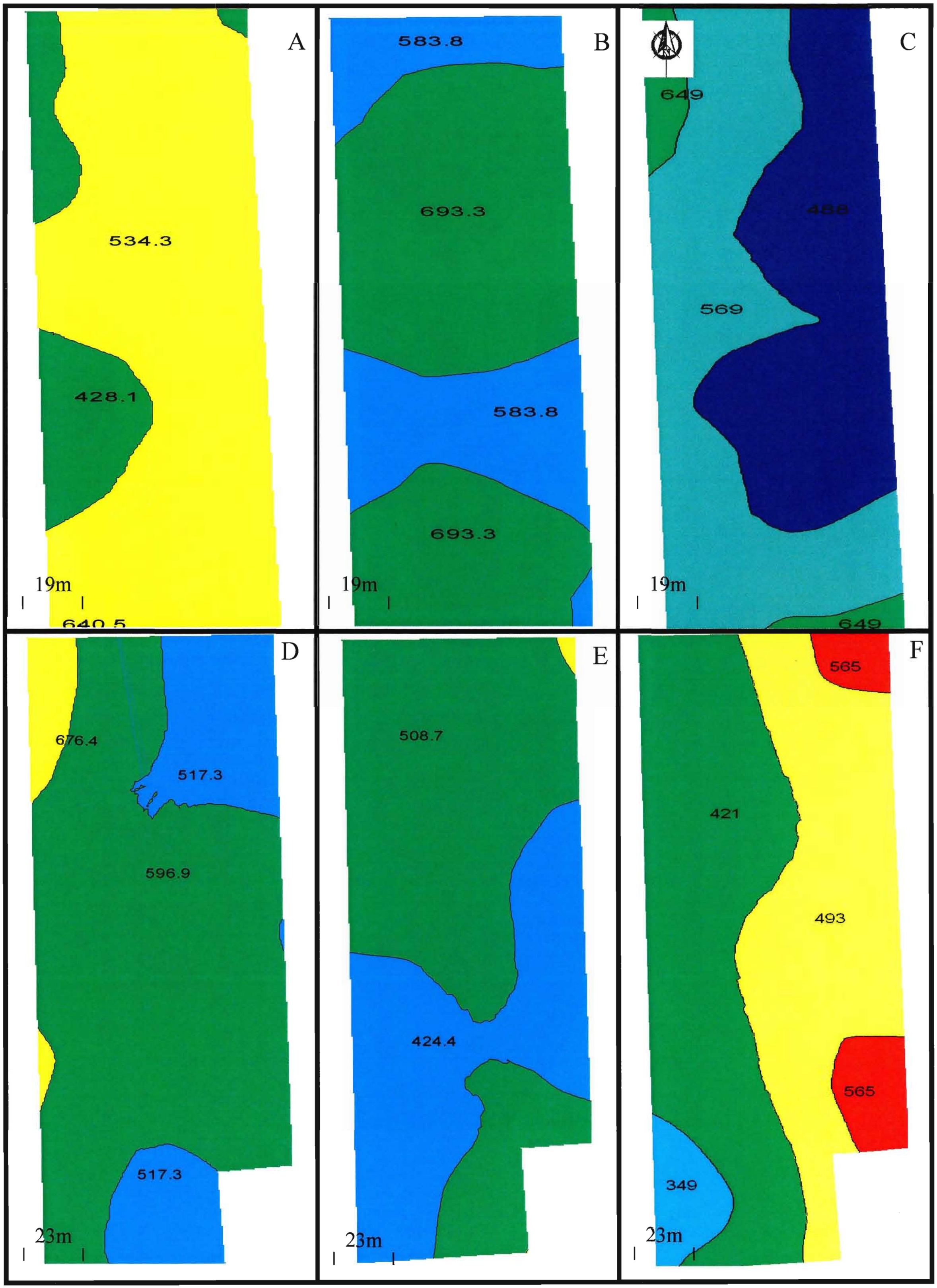


Figure 37. Spatial distribution of berry anthocyanins (mg/L), Cabernet Franc, Niagara Peninsula, ON; A to C: Cave Spring: 2005 (A); 2006 (B); 2007 (C). D to F: Henry of Pelham: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

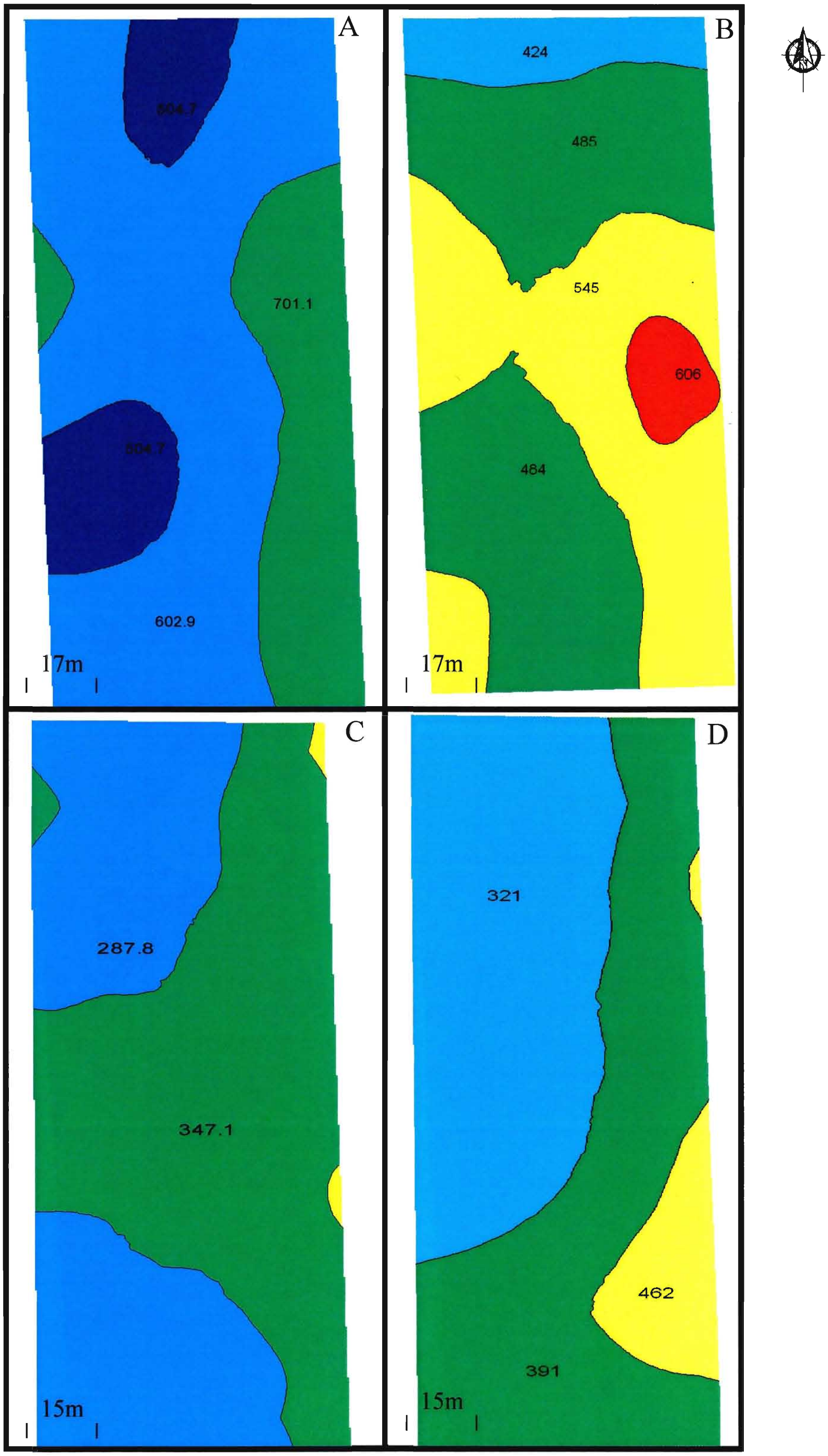


Figure 38. Spatial distribution of berry anthocyanins (mg/L), Cabernet Franc, Niagara Peninsula, ON; A and B: Vieni: 2005 (A); 2007 (B). C and D: Morrison: 2006 (C); 2007 (D). In each map, the value of each zone represents the corresponding lower limit for that zone.

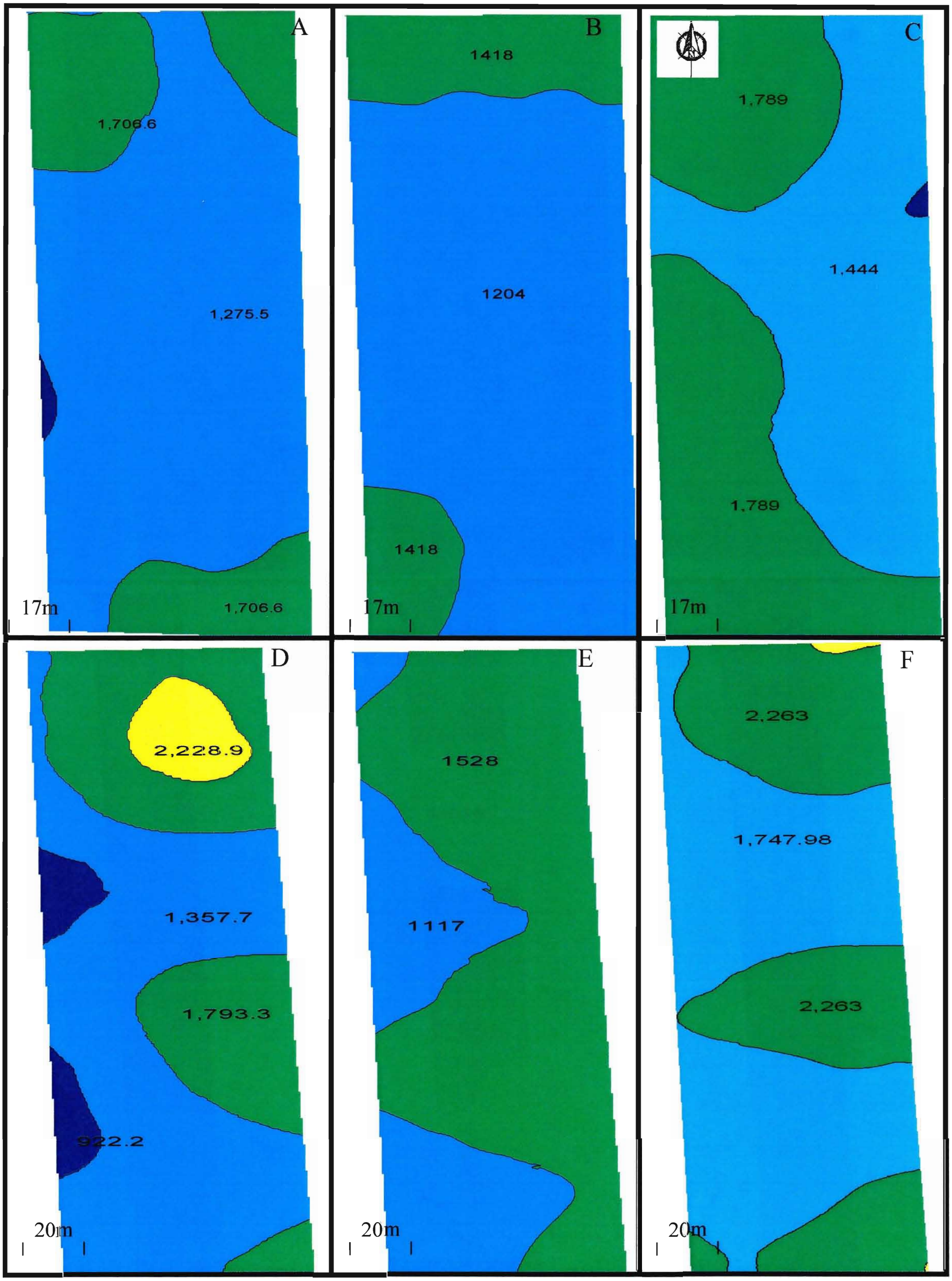


Figure 39. Spatial distribution of berry total phenols (mg/L), Cabernet Franc, Niagara Peninsula, ON; A to C: Buis: 2005 (A); 2006 (B); 2007 (C). D to F: Chateau des Charmes: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

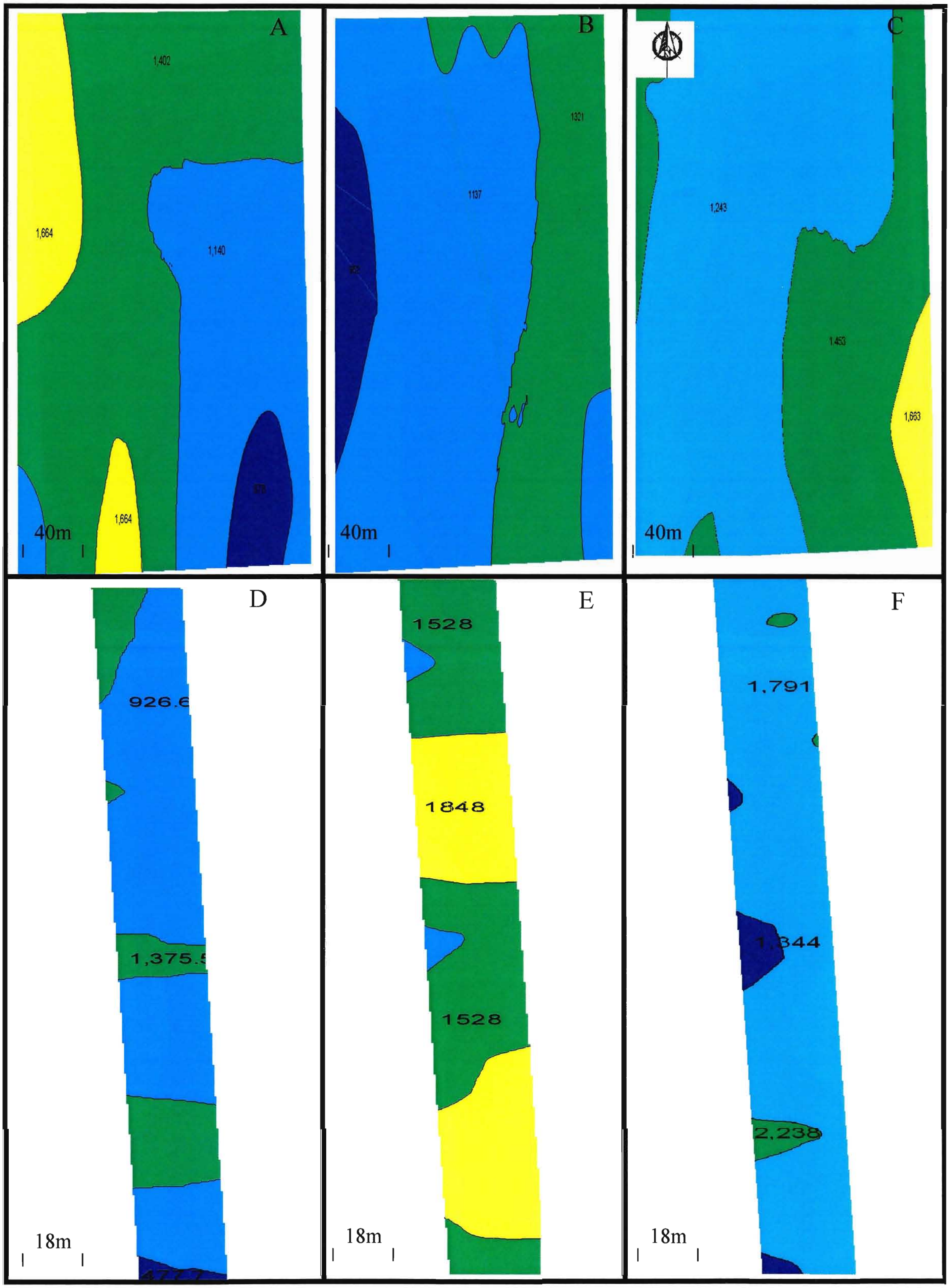


Figure 40. Spatial distribution of berry total phenols (mg/L), Cabernet Franc, Niagara Peninsula, ON; A to C: Hernder: 2005 (A); 2006 (B); 2007 (C). D to F: Reif: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

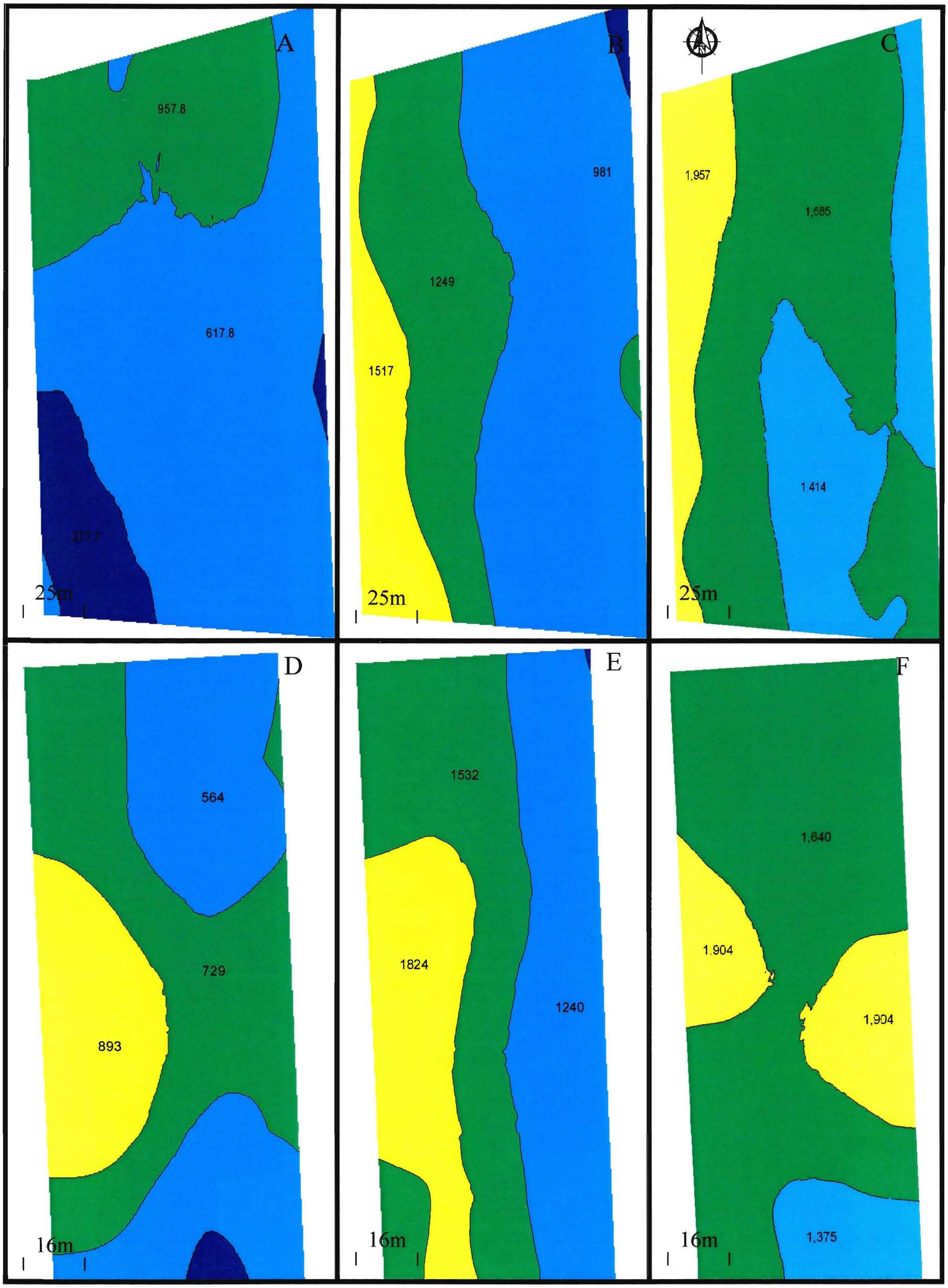


Figure 41. Spatial distribution of berry total phenols (mg/L), Cabernet Franc, Niagara Peninsula, ON; A to C: Harbour Estate: 2005 (A); 2006 (B); 2007 (C). D to F: George: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

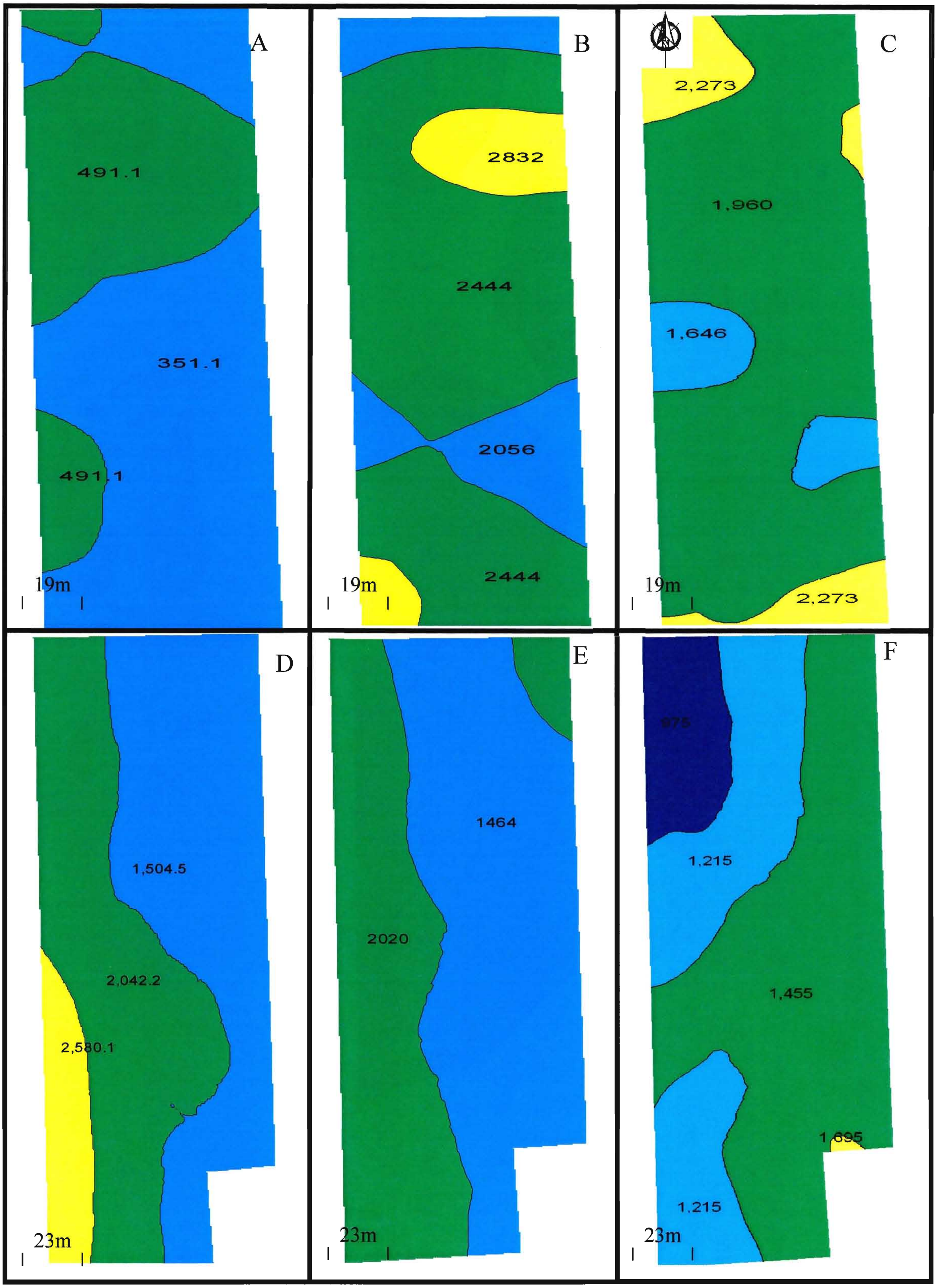


Figure 42. Spatial distribution of berry total phenols (mg/L), Cabernet Franc, Niagara Peninsula, ON; A to C: Cave Spring: 2005 (A); 2006 (B); 2007 (C). D to F: Henry of Pelham: 2005 (D); 2006 (E); 2007 (F). In each map, the value of each zone represents the corresponding lower limit for that zone.

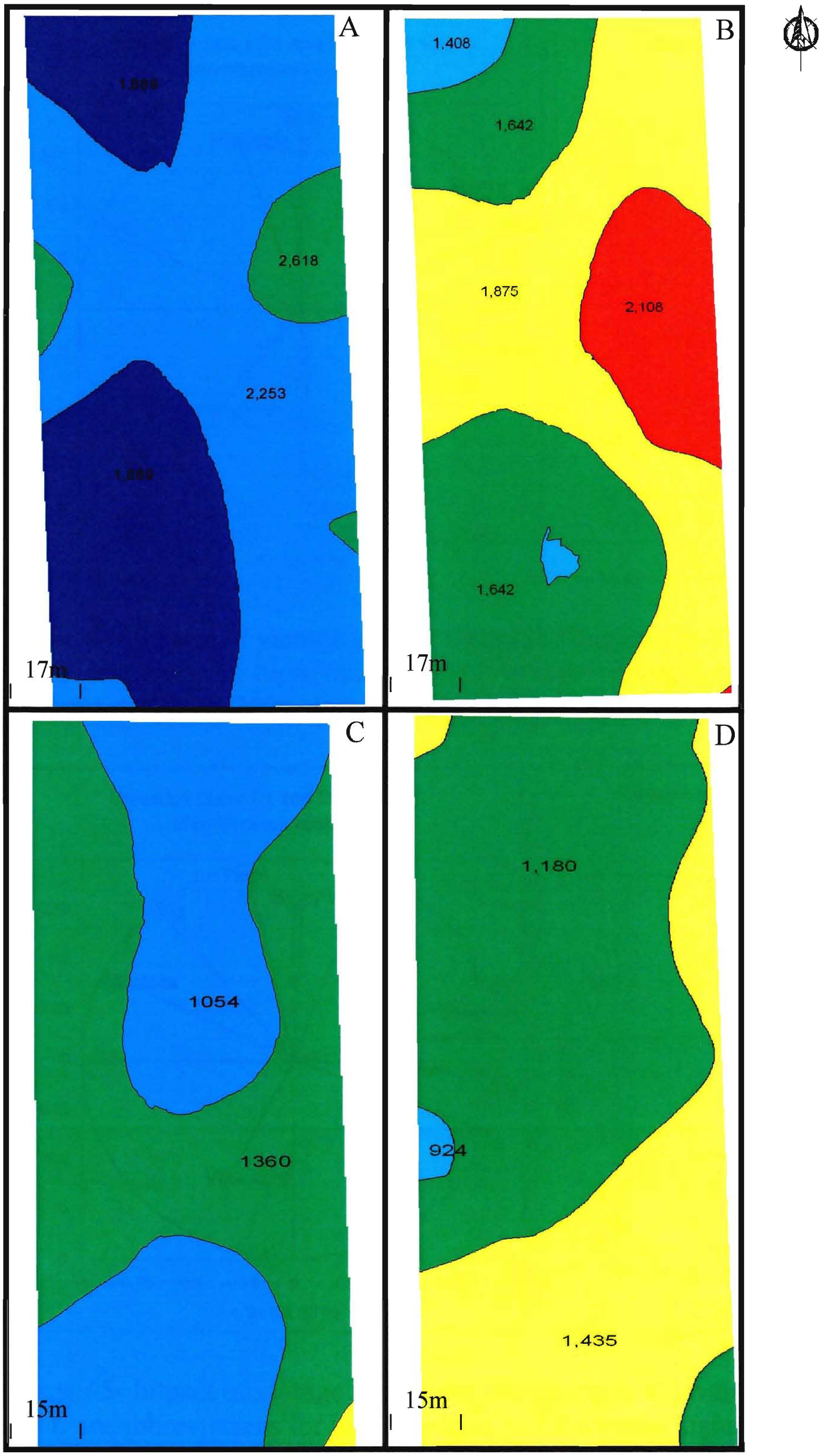
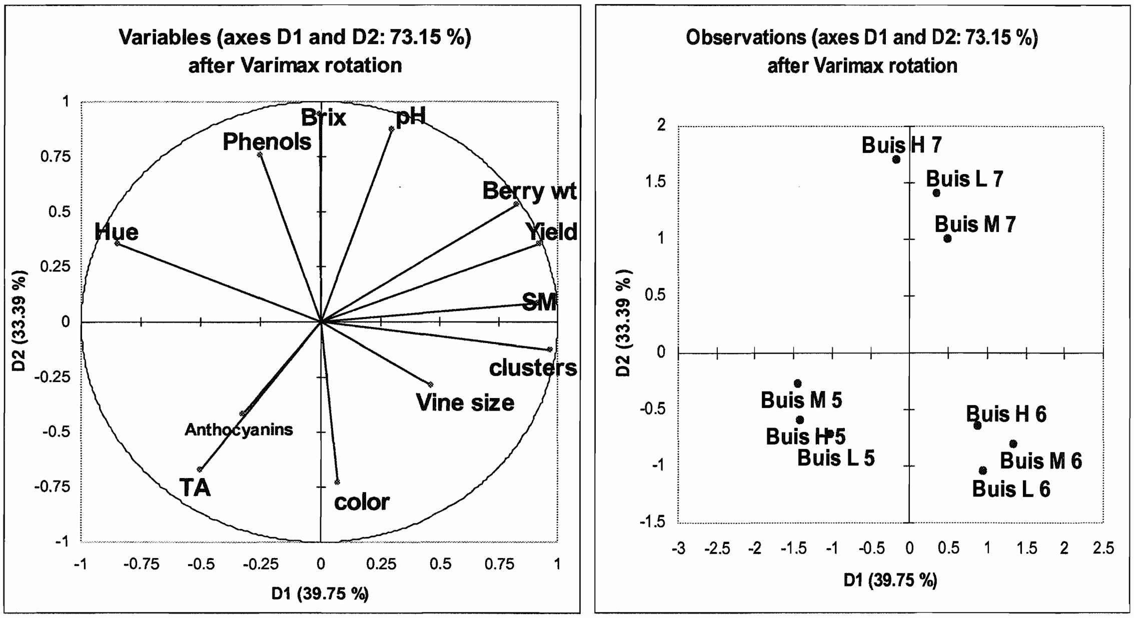
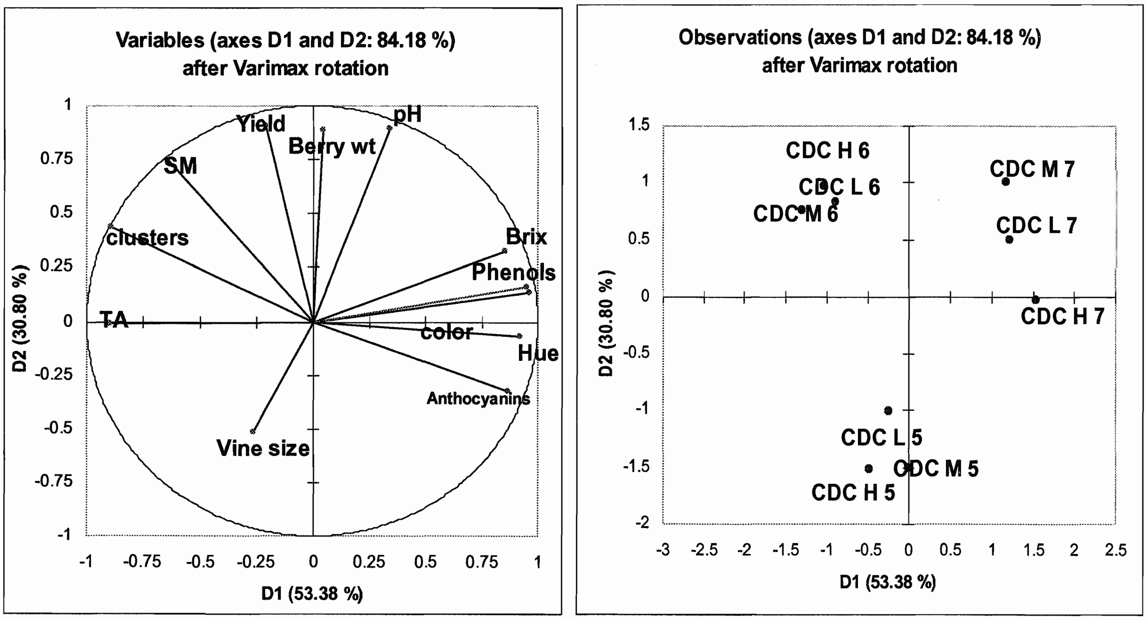


Figure 43. Spatial distribution of berry total phenols (mg/L), Cabernet Franc, Niagara Peninsula, ON; A and B: Vieni: 2005 (A); 2007 (B). C and D: Morrison: 2006 (C); 2007 (D). In each map, the value of each zone represents the corresponding lower limit for that zone.


Variables (axes D1 and D2: 73.15 %) after Varimax rotation

Observations (axes D1 and D2: 73.15 %) after Varimax rotation

Figure 44- Impact of vintage at Buis vineyard, Niagara-On-The-Lake, ON. (H, M, and L are abbreviations for high, medium and low water status; 5, 6 and 7 at the end of each label defines 2005, 2006, and 2007 years respectively).


Variables (axes D1 and D2: 84.18 %) after Varimax rotation

Observations (axes D1 and D2: 84.18 %) after Varimax rotation

Figure 45- Impact of vintage at Château des Charmes vineyard, St. Davis, ON. (H, M, and L are abbreviations for high, medium and low water status; 5, 6 and 7 at the end of each label defines 2005, 2006, and 2007 years respectively).

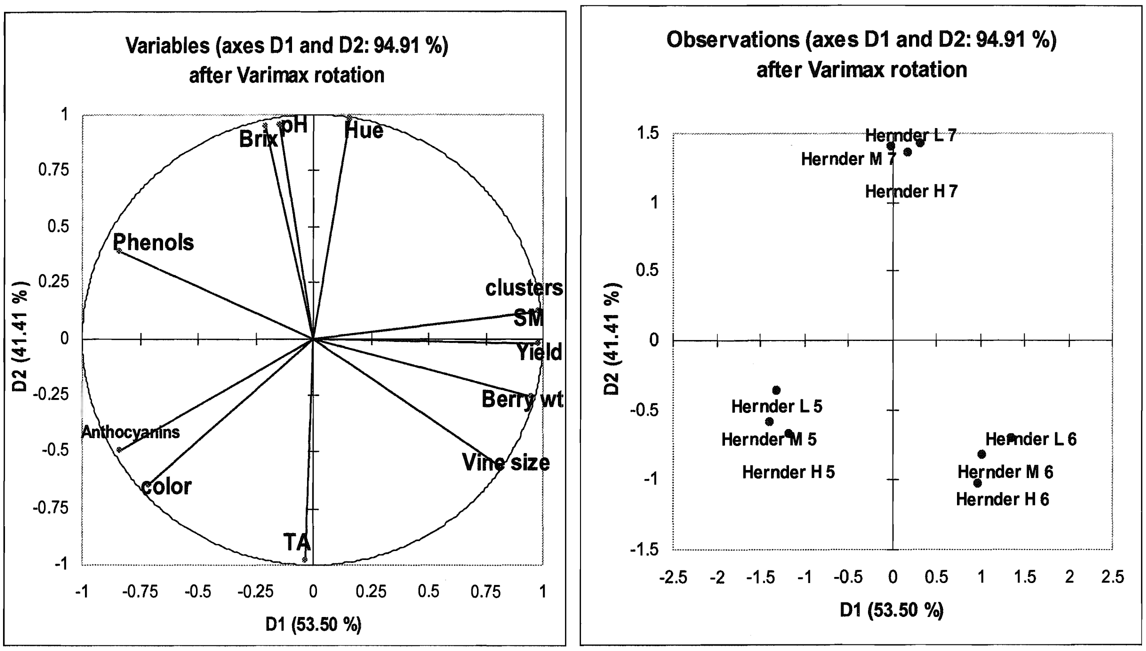


Figure 46- Impact of vintage at Hernder vineyard, Virgil, ON. (H, M, and L are abbreviations for high, medium and low water status; 5, 6 and 7 at the end of each label defines 2005, 2006, and 2007 years respectively).

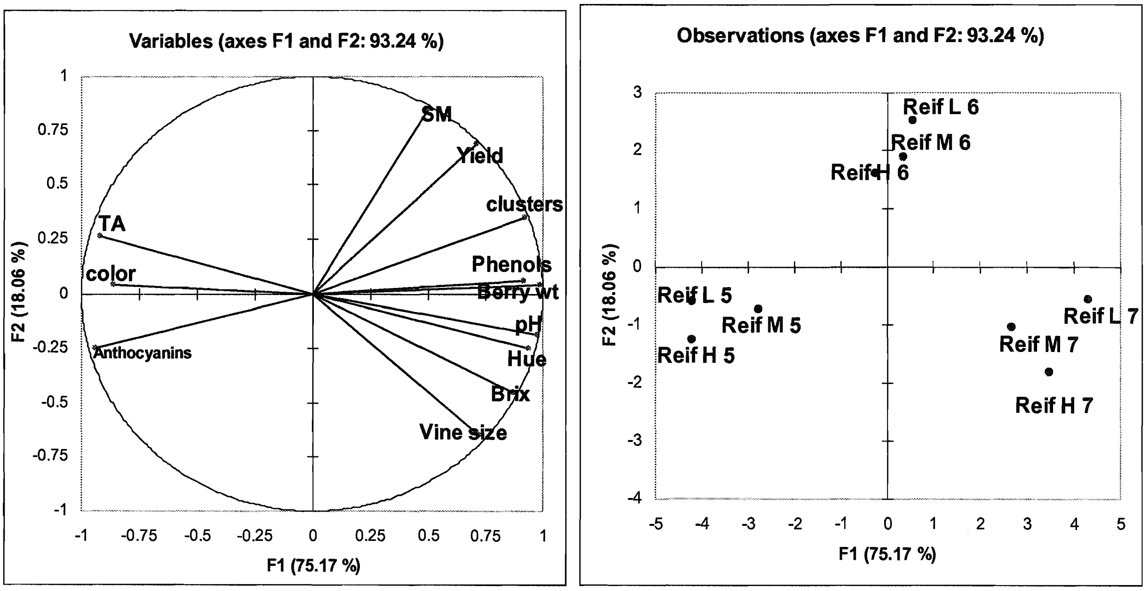


Figure 47- Impact of vintage at Reif vineyard, Niagara-On-The-Lake, ON. (H, M, and L are abbreviations for high, medium and low water status; 5, 6 and 7 at the end of each label defines 2005, 2006, and 2007 years respectively).

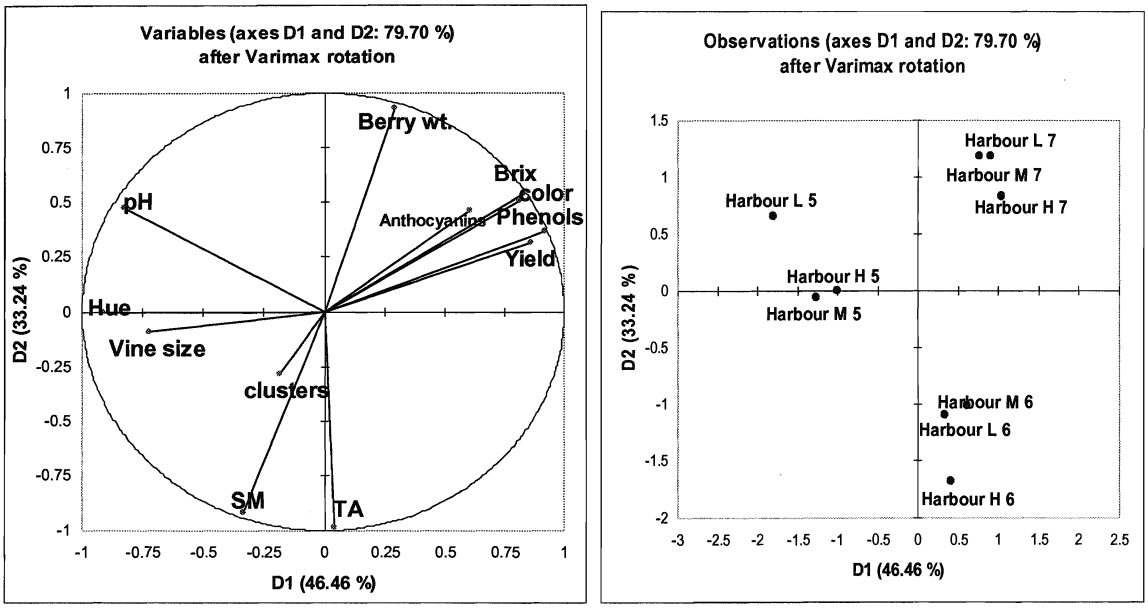


Figure 48- Impact of vintage at Harbour Estate vineyard, Jordan, ON. (H, M, and L are abbreviations for high, medium and low water status; 5, 6 and 7 at the end of each label defines 2005, 2006, and 2007 years respectively).

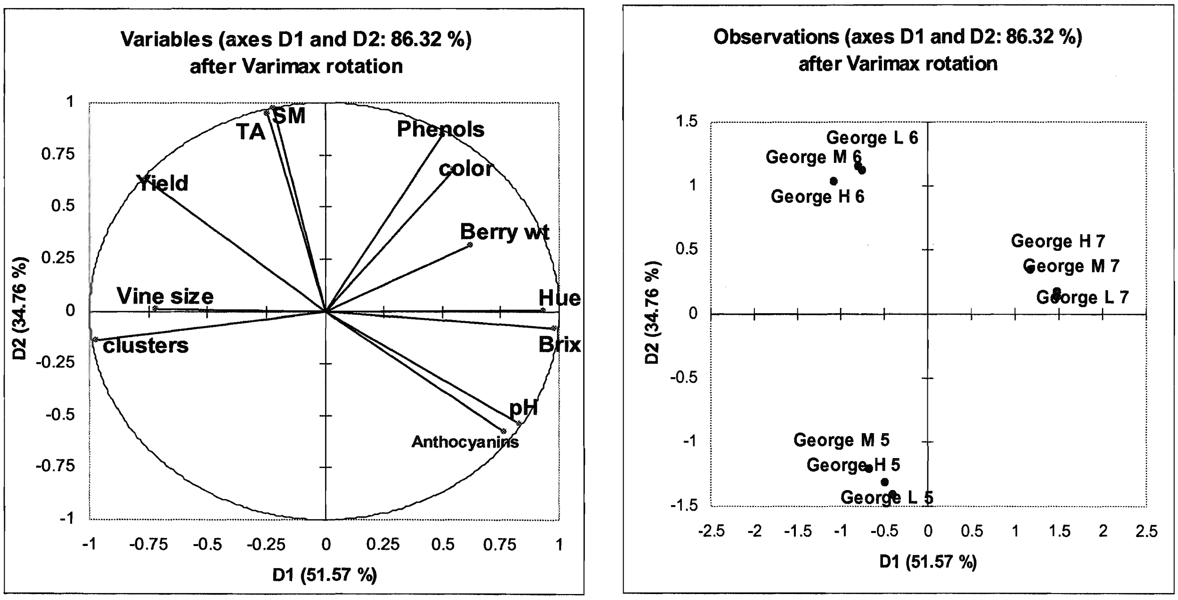


Figure 49- Impact of vintage at George vineyard, Vineland, ON. (H, M, and L are abbreviations for high, medium and low water status; 5, 6 and 7 at the end of each label defines 2005, 2006, and 2007 years respectively).

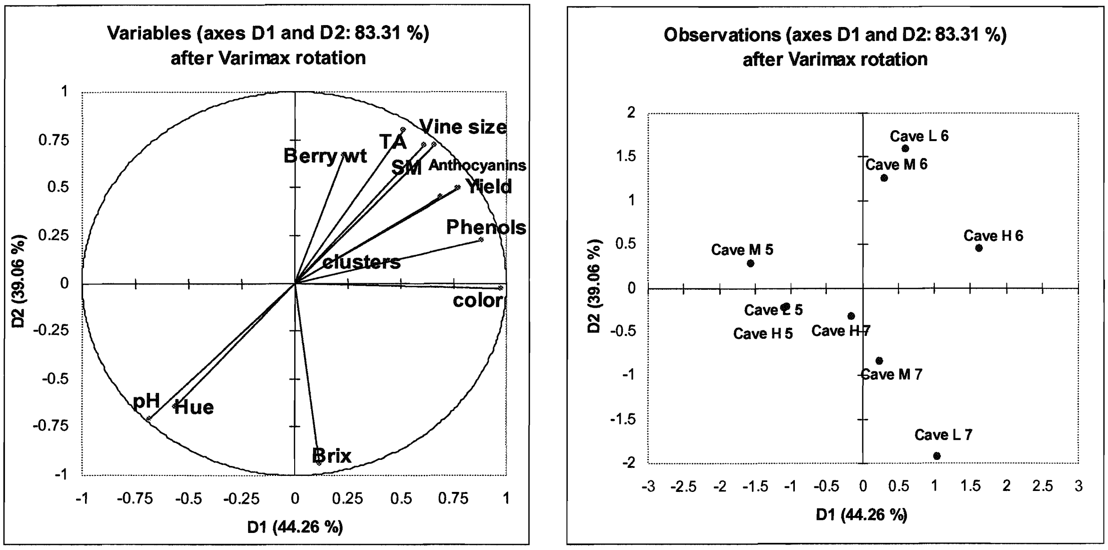


Figure 50- Impact of vintage at Cave Spring vineyard, Beamsville, ON. (H, M, and L are abbreviations for high, medium and low water status; 5, 6 and 7 at the end of each label defines 2005, 2006, and 2007 years respectively).

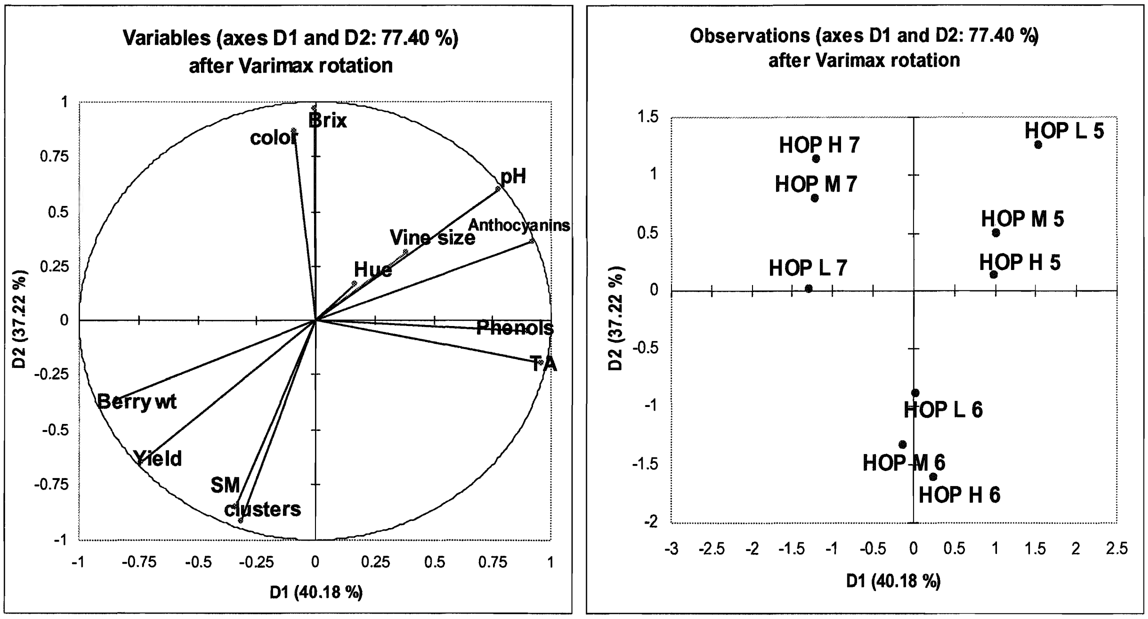


Figure 51- Impact of vintage at Henry of Pelham vineyard, West St. Catharines, ON. (H, M, and L are abbreviations for high, medium and low water status; 5, 6 and 7 at the end of each label defines 2005, 2006, and 2007 years respectively).

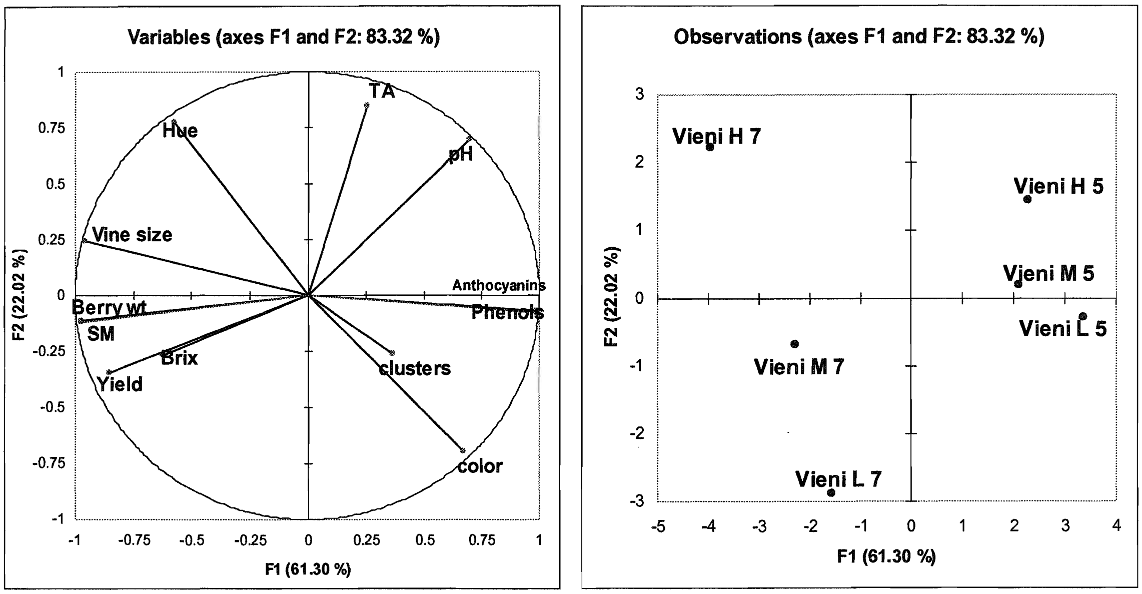


Figure 52- Impact of vintage at Vieni vineyard, Campden, ON. (H, M, and L are abbreviations for high, medium and low water status; 5 and 7 at the end of each label defines 2005 and 2007 years respectively).

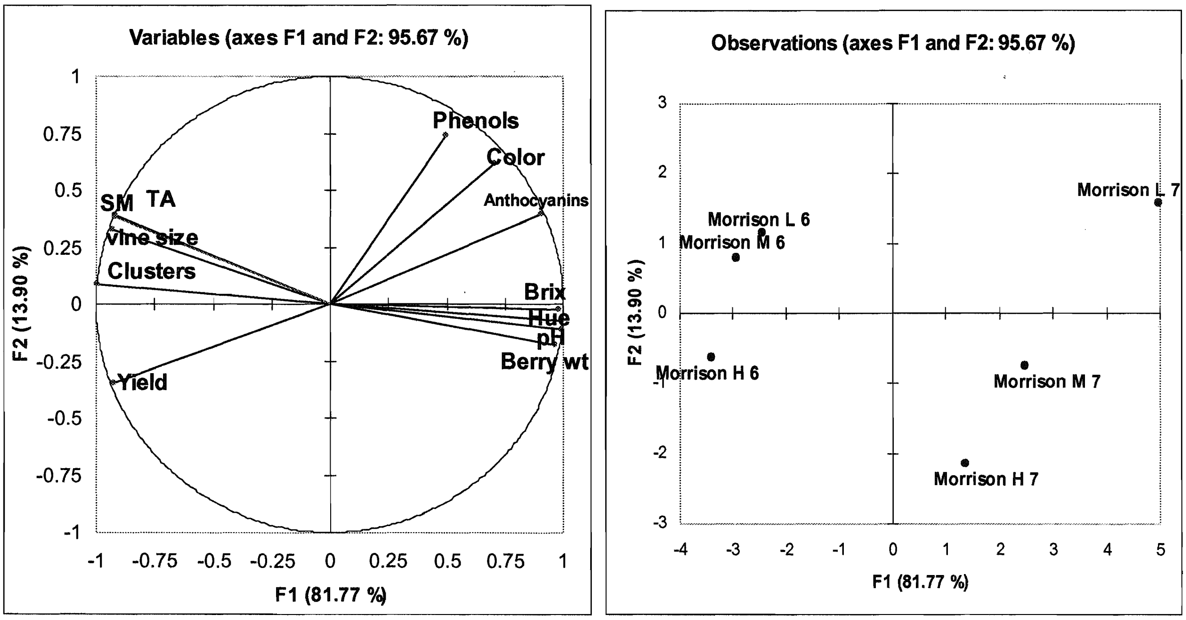


Figure 53- Impact of vintage at Morrison vineyard, Jordan, ON. (H, M, and L are abbreviations for high, medium and low water status; 6 and 7 at the end of each label defines 2006, and 2007 years respectively).

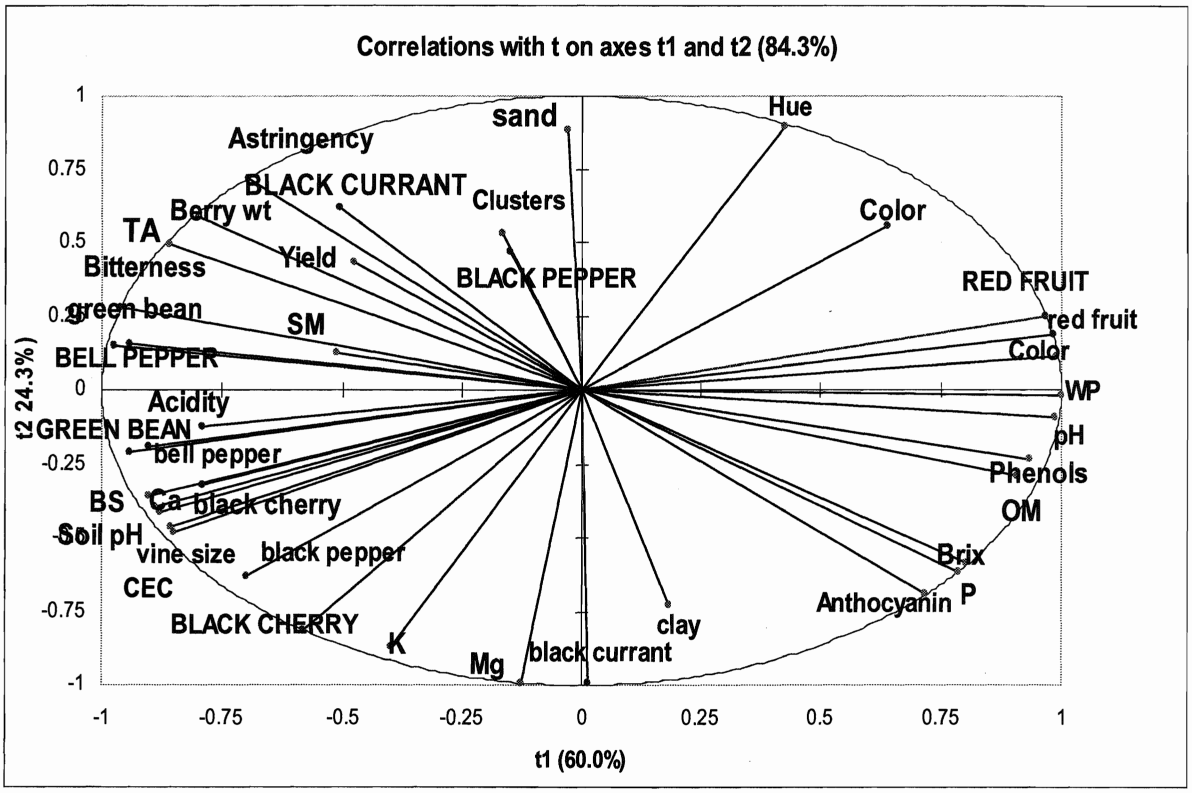


Figure 54- PLS analysis of field and sensory data for nine Cabernet Franc wines from Niagara Peninsula, ON, 2005. WP, SM, OM, and TA are abbreviations for leaf water potential, soil moisture, organic matter, and titratable acidity; in sensory characters upper case and lower case words are for aroma and flavor characteristics. Aroma attributes are represented in lowercase and flavor attributes are represented in uppercase.

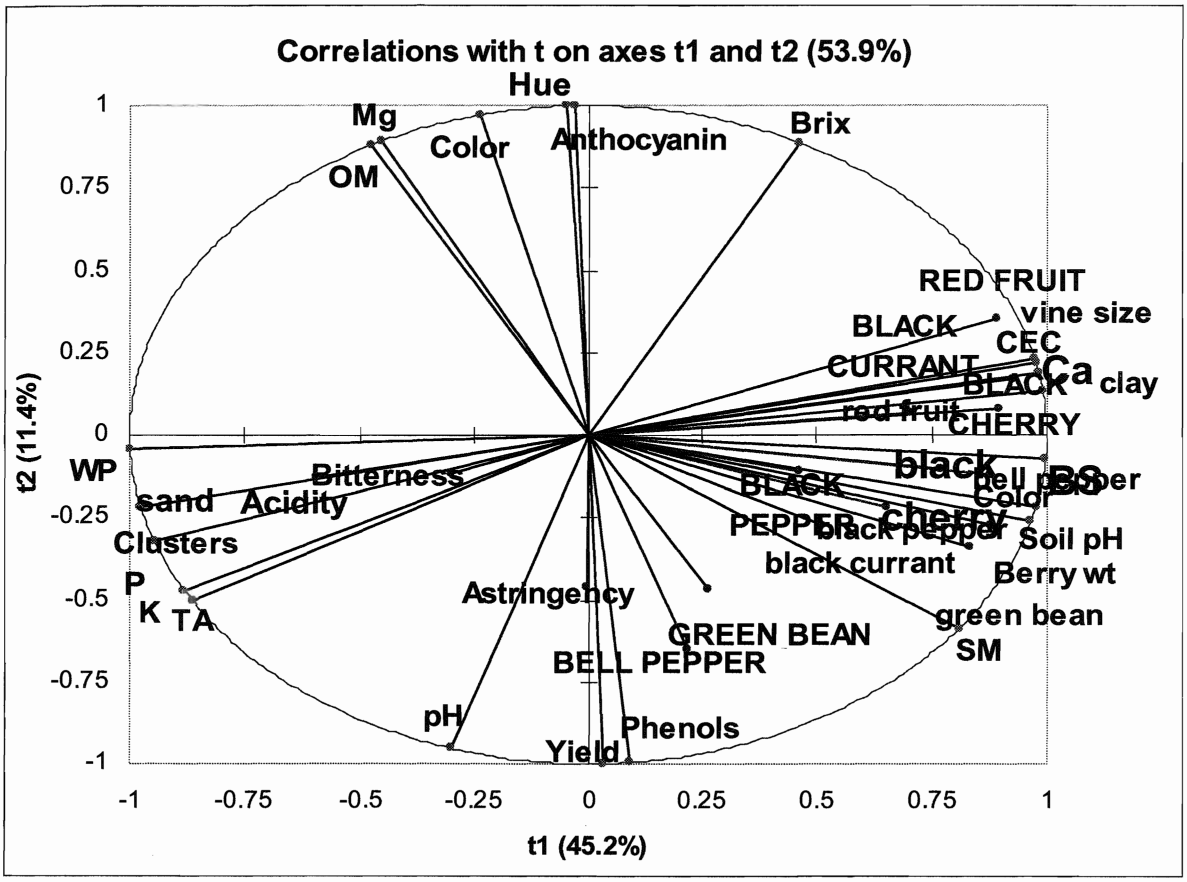


Figure 55- PLS analysis of field and sensory data for eight Cabernet Franc wines from Niagara Peninsula, ON, 2006. WP, SM, OM, and TA are abbreviations for leaf water potential, soil moisture, organic matter, and titratable acidity; in sensory characters upper case and lower case words are for aroma and flavor characteristics. Aroma attributes are represented in lowercase and flavor attributes are represented in uppercase.

Chapter 5

Characterization of Niagara Peninsula Cabernet Franc Wines by Sensory Analysis

Abstract. Chemical and descriptive sensory analysis was conducted on nine (2005) and eight (2006) experimental Niagara Peninsula Cabernet Franc wines to illustrate differences that might support the sub-appellation system in Niagara. Twelve trained judges evaluated six aroma and flavor (red fruit, black cherry, black current, black pepper, bell pepper, and green bean) and three mouthfeel (astringency, bitterness and acidity) sensory attributes plus color intensity. Data were analyzed using analysis of variance (ANOVA), principal component analysis (PCA) and discriminate analysis. ANOVA of sensory data showed regional differences for all sensory attributes. In 2005, wines from Château des Charmes (CDC), Henry of Pelham (HOP), and Hernder sites showed highest red fruit aroma and flavor. Lakeshore and Niagara River sites (Harbour, Reif, George, and Buis) wines showed higher bell pepper and green bean aroma and flavor due to proximity to the large bodies of water and less heat unit accumulation. In 2006, all sensory attributes except black pepper aroma were different. PCA revealed that wines from HOP and CDC sites were higher in red fruit, black currant and black cherry aroma and flavor as well as black pepper flavor, while wines from Hernder, Morrison and George sites were high in green bean aroma and flavor. Buis wines were high in bell pepper aroma and flavor and acidity due to cooler conditions within the proximity of Lake Ontario. ANOVA of chemical data in 2005 indicated that hue, color intensity, and titratable acidity were different across the sites, while, in 2006, hue, color intensity and ethanol were different. These data indicate that there is the likelihood of substantial chemical and sensory differences between clusters of sub-appellations within the Niagara Peninsula.

Introduction

The Ontario grape and wine industry has expanded rapidly in recent years. Total output from approximately 6870 ha of vineyards averaged about 53,000 tonnes per year during the 2004 to 2008 period. About 40% of the wine sales in Ontario between 2004 and 2008 originated chiefly from the Niagara region and smaller amounts from wine-producing regions of Pelee Island, Lake Erie North Shore and Prince Edward County (Grape Growers of Ontario 2009). In the 2008, vintage, Ontario growers produced a crop of 60,780 tonnes generating a farm gate value of $79.5 million (Grape Growers of Ontario, 2009).

The Ontario Vintners Quality Alliance (VQA) was established in 1988 to set standards for producing premium wines in Ontario. Initially VQA recognized three viticultural areas or appellations by considering soil, climate, and topographical features. These appellations, Lake Erie North Shore, Pelee Island, and Niagara Peninsula, are considered to have the potential to produce wines of different quality due to various soil and climatic conditions. Prince Edward County became Ontario's most recent Designated Viticultural Area in 2006. The Niagara Peninsula, with its distinctive feature of a relatively mild winter climate, favors cultivation of a wide range of grape cultivars. The position of Niagara Peninsula between Lake Ontario and Lake Erie exposes the region to lake breezes that moderate high summer temperatures as well as cold winter temperatures (Shaw 2002).

Different climatic factors such as distance from the lake, slope, elevation, and airflow patterns, as well as soil type and parent material, create a wide range of mesoclimates with various potential for producing quality winegrapes. The soils in the region range in texture from poorly drained heavy clays, clay loam tills, imperfectly drained silty clay, to moderately well-drained sandy loams, with a wide range of water holding capacities. Consequently, the Niagara Peninsula has been further divided into sub-appellations.

Initially, Wiebe and Anderson (1977) showed that climatological differences existed between 'Lakeshore', 'Lake Plain', and 'Bench' regions of Niagara, using infra-red and aerial photography. Sayed (1992) also illustrated regional differences with regard to geographical and geological data. Most recently, VQA Ontario established 10 sub-appellations in the Niagara Peninsula based on a combination of climate, elevation, and soil characteristics.

Previous sensory studies on commercial Riesling and Chardonnay wines in Ontario showed differences between the 'Lakeshore', 'Lakeshore Plain' and the 'Bench' regions of the Niagara Peninsula (Douglas *et al.* 2001, Schlosser *et al.* 2005). Sensory research on Bordeaux- red wine cultivars in the Niagara Peninsula also showed significant regional differences based on red fruit, dried fruit, fresh vegetable, canned vegetable, spice, and oak sensory attributes among the Lakeshore, Lakeshore Plain and Bench regions (Kontkanen *et al.* 2005). Sensory descriptive analysis on icewines from Ontario and British Columbia illustrated that Ontario wines had the highest fruity and floral aromas and a golden copper color while wines from British Columbia has higher sweetness, body and intensity of aftertaste (Cliff *et al.* 2002).

Thus far, the 10 sub-appellations established by the VQA have not been validated. The purpose of this study was to develop sensory and analytical methodologies for characterization of Cabernet Franc wines from typical vineyards within these 10 sub-appellations within the Niagara Peninsula to determine the degree and nature of any differences.

Materials and Methods

Site selection. Ten commercial vineyard blocks of Cabernet Franc were selected for this project in the spring of 2005. Each vineyard block was located in one of 10 sub-appellations of the Niagara Peninsula that were recently approved by Ontario's VQA. These included: Niagara Lakeshore, St. David's Bench, Creek Shores, Four Mile Creek, Niagara River, Lincoln Lakeshore, Beamsville Bench, Short Hills Bench, Vinemount Ridge, and Twenty Mile Bench (Fig. 1, Table 1). An 8 m X 8 m grid pattern of 75 to 80 sentinel vines was used in each vineyard block for all data collection. Sentinel vines were geolocated using a Raven Invicta 115 global positioning system (GPS Raven Industries, Sioux Falls, SD).

Vine water status. Midday leaf water potential (Ψ) was determined between 1100h and 1600h for fully exposed, mature leaves of similar physiological stage that showed no visible sign of damage and had been in full sunlight. Each leaf sample was covered in a plastic bag and sealed immediately after excision at the petiole to suppress transpiration. The leaf petiole was cut with a sharp razor blade and then inserted into a pressure chamber Model 3005 Plant Water Status Console (Soil Moisture Equipment Corp., Santa Barbara, CA) with the cut edge of the petiole facing the outside surface. After sealing the chamber, pressure was increased slowly by opening the compressed nitrogen valve. As soon as sap emerged at the cut end of the petiole, gas flow was stopped and the corresponding pressure was recorded from the gauge, which was in negative bar units (10 bars = 1 MPa). A total of 15 to 20 leaves per vineyard block were used to estimate leaf ψ for each sampling date. Overall, there were five sampling dates during the growing season, occurring bi-weekly between late June and early September for each site.

Soil water status. Soil moisture data were taken bi-weekly between late June and early September in the 2005 and 2006 growing seasons for a total of five sampling dates each season. These data were determined via a Theta Probe model ML2X (Delta-T Devices Ltd., Cambridge, UK) in 2005. Probe readings (% water by volume) were taken at each experimental vine at each block. In 2006, a Fieldscout TDR-300 soil moisture probe (Spectrum Technologies Inc., East Plainfield IL) was used for the measurements. Readings (% water by volume) were taken at each experimental vine at each block. A total of 72 to 80 vines per site were measured between 0800h and 1800h. Measurements were taken in the row ca. 10 cm from the base of each vine trunk over a 4 cm (2005) and 20 cm (2006) depth. The mean soil moisture at each sentinel vine was calculated from the five separate readings. Both Theta Probe and TDR measure soil moisture based on the principal of time domain reflectometry.

Soil sampling. Soil samples were collected from every fourth sentinel vine with an auger from within the row, 40 to 50 cm away from the trunk. Soil was taken from a 0 to 75 cm depth and in total about 350 g of a homogenized sample was taken. Based on the area of each vineyard block 15 to 20 soil samples were taken. Soil samples were analyzed for pH, organic matter, P, K, Mg, Ca, texture, cation exchange capacity, and base saturation using standard procedures (Canadian Society for Soil Science (CSSS) 1993). Soil samples were air-dried, pulverized and sieved to remove particles > 2 mm in diameter. Sub-samples were retained for elemental analysis (P, K, Ca, Mg) using a Perkin-Elmer Optima 3000 inductively-coupled plasma emission spectroscopy (ICP). Organic matter (OM) analysis was performed using standard colorimetric methods (CSSS 1993). Cation exchange capacity and base saturation were measured using standard methods (CSSS 1993). All soil analyses were carried out at Agri-Food Laboratories, Guelph, ON.

Yield components and vine size. Prior to the harvest of each block in September/October, 100-berry samples were collected from random clusters in each experimental vine and stored at -25 °C until analysis. All berry samples and fruit were collected one day before the commercial harvest. These samples were eventually used to determine berry weights, soluble solids (Brix), pH, titratable acidity, color intensity (A_{420} + A_{520}), hue (A_{420}/A_{520}), total anthocyanins, and total phenols. All sentinel vines were hand-harvested and yield and cluster numbers were determined for each vine as well. Vines were pruned during the dormant season in accordance to the corresponding training system, and weights of cane prunings were collected from each vine to determine pruning weights (vine size) in kg.

Berry and wine composition: The frozen berry samples were thawed, weighed and placed in 250-mL beakers and then heated to 80 °C in a water bath and held for one hour to dissolve any precipitated tartrates. Samples were cooled to the room temperature and juiced in an Omega 500 fruit juicer. The resulting juice was centrifuged at 4500 rpm for 10 minutes in an IEC Centra CL2 (International Equipment Company, Needham Heights, MA) centrifuge to remove debris. The supernatant was retained for analysis of pH via an Accumet pH meter (model 25; Denver Instrument Company, Denver, CO), titratable acidity (TA) with a PC-Titrate autotitrator (Man-Tech Associates, Guelph, ON) by titration with 0.1 *N* NaOH to an end point of pH 8.2, and Brix using an Abbé refractometer (model 10450; American Optical, Buffalo, NY). The remaining juice was centrifuged at 12000 g for 10 minutes and stored at -25°C for further analysis for phenolic analytes. Wine samples were analyzed for TA and pH using the aforementioned method.

Ethanol was determined using an Agilent 6890 series GC system gas chromatograph (Agilent, Wilmington, DE) equipped with an Omegawax 250 fused silica (30.0 m x 250.00 μm x 0.25 μm) column. Other conditions of operation included: carrier gas helium, split ratio of 100.183:1, oven initial temperature 60 °C, injection temperature 230 °C, and detector temperature 225 °C. Wine samples or standards were diluted 1:10 with 2% 1-butanol as an internal standard. A 1.0 μL wine sample or standard was injected by an automatic injector and the run time was 5.07 min.

After thawing to room temperature for several hours, color, anthocyanins and total phenols were determined on juice and wine samples. Total phenols were estimated using standard methods (Slinkard and Singleton 1977). Anthocyanin measurements were performed on wine samples using the pH shift method by measuring the differential absorbance at 520 nm between wines at pH 1.0 and pH 4.5 (Mazza *et al.* 1999). Color intensity was determined according to a modified method provided by Mazza *et al.* (1999). Color intensity and hue were calculated from absorbance values measured at 420nm and 520nm on an Ultrospec 2100 Pro UV/VIS spectrophotometer (Biochrom Ltd., Cambridge, UK).

Origin of wines: Four fermentation replicates each of nine (2005) and eight (2006) experimental Cabernet Franc wines from the Niagara Peninsula, Ontario were compared. Within each vineyard block, the four winemaking replicates were taken from one large homogeneous lot of grapes that was divided into four lots. In 2005, four wines were from east of St. Catharines, ON in the Niagara-on-the-Lake area, and the other five were from west of St. Catharines in the Jordan, Vineland, and Beamsville areas. In 2006, only four wines were from west of St. Catharines due to a severe powdery mildew problem in one of the subject vineyards. Each wine originated from zones of moderate water status ($\approx$ mean ψ for the season) within each vineyard block, based on maps created using MapInfo and VerticalMapper geographical information system software (Northwood GeoScience, Ottawa, ON). The inverse-distance algorithm was used for creation of the gridfiles and maps.

All wines were produced by one winemaker (the author) according to standard procedures from the 2005 and 2006 vintages at Brock University's winery facilities. Each of the 20-L fermentation replicates from each site was based upon a sub-section of the vineyard block. Grapes from each vineyard block were de-stemmed, crushed and treated with potassium metabisulfite at 25 mg/L, and then inoculated with Lalvin Selection ICV 254 (*Saccharomyces cerevisiae)* yeast (Lallemand Inc., Montreal, QB). The fermentation took place at 23°C in 30-L food grade plastic pails for 10 days until cap fall with three daily punch downs, during which the cap was also completely submerged. Afterwards, the wines were pressed in an Idropress "50" (Enoagricola Rossi s.r.l., Calzolaro, PG, Italy) bladder press to a pressure of 2.0 bar which was maintained for two minutes. The wines were kept in -2 °C for cold stabilization for 10 days; they were then racked and inoculated with malolactic bacteria (Lalvin VP41, St. Simon, France). Upon completion of malolactic fermentation, all wines were racked again, stored at -2 °C for 7 days, sulfited with an additional 50 mg/L, filtered through a 1-µ pad filter and 0.45-µ cartridge filter, and bottled under cork.

Sensory evaluation: The initial group of 20 judges composed of Brock University faculty, staff, and students were selected for the panel based on their availability and motivation. Six judges were experienced tasters and the others were students with limited wine tasting experience. Eight judges either withdrew or were dropped from the panel by the end of the training sessions. The final panel consisted of five females and seven males whose ages ranged from 22 to 54 years.

Nine (2005) and eight (2006) wines were evaluated by 12 judges (t=9/8, k=8, r=4, b=12), where t, k, r, and b are the number of treatments (wines), number of samples/session, number of replicates and sample sets in each session (or number of panelists), respectively. At the initial point of training, wine samples were presented to the panel to evaluate and identify relevant aroma, flavor, and mouthfeel attributes. The six experienced tasters individually evaluated these wines and wrote relevant attributes on evaluation sheets. Eight training sessions were thereafter held for all judges. Reference standards were available to define descriptors. In each training session, judges were asked to independently rate the intensity of the descriptive terms in the wine samples as well as standards themselves, and to add terms if necessary. There were also three mouthfeel standards including astringency, bitterness, and acidity used for evaluating sample wines (Table 2). In each training session, three sample wines were served with random codes to all judges to train them to be able to evaluate all wine samples as accurately and consistently as possible. After each training session, data were analyzed to evaluate the performance of each judge. Each attribute was also examined by analysis of variance to find out if that attribute varied across the wine samples and whether the judges were consistent and reproducible.

In each tasting session, each judge evaluated eight wines in two flights of four. Judges were given 30-mL wine samples to evaluate in the room temperature (~22°C), for the sensory (aroma, flavor, and mouthfeel) attributes. Samples were in 210-mL ISO approved wine glasses and covered with Petri dishes to prevent volatile loss. Glasses were labeled with three-digit random numbers and presented to judges in random order according to the design. All evaluations were conducted using Compusense Five (release 4.8, Compusense Inc., Guelph, ON) in isolated booths under red light to mask the color differences among wine samples. For color intensity evaluation, 10-mL wine samples were also presented in 5-cm diameter Petri dishes against a white background under natural light, with the same random numbers.

First, the judges evaluated aroma and flavor in the first four wines, and then while they took a short break, evaluated color intensity for the same wines and finished the session by evaluating the second flight of four wines. Evaluation of the magnitude of each attribute was done on a 15-cm unstructured line scale, where 0 and 15 were anchored with the labels 'absent' and 'high' respectively. Sensory scores were determined by measuring the judges scored mark from the origin in cm. Judges rinsed with water and pectin solution between flavor evaluations in order to prevent carry over effect. Evaluations were started in the morning at 1100h and continued until late afternoon to accommodate all judges' schedules. All evaluations were done at Brock University's sensory evaluation facility. All wine samples were poured from the same bottles (750 mL) to avoid bottle-to-bottle variation. Aroma standards (Table 2) developed during the training sessions were available to judges prior to each session as a reference.

Statistical analysis: Data were analyzed using SAS statistical package (SAS Institute; Cary, NC, USA). A correlation matrix was created on the sensory attributes to illustrate the relationship among variables. Using GLM, analysis of variance was performed on chemical and sensory attributes. Three-way ANOVA (site, judge, and replicate) was also performed on sensory attributes to ascertain main effects as well as interactions. Duncan's multiple range test was used to separate the means for both sensory and chemical data. Principal Components Analysis (PCA) and discriminate analysis were performed using XLSTAT 2008 (Paris, France) on the mean sensory scores for the aroma, flavor, and mouthfeel attributes. Partial Least Squares (PLS) was performed on the field, berry composition and sensory data to ascertain relationships between these data.

Results and Discussion

Sensory analysis. ***2005.*** Results from the ANOVA show the sources for variation for each of the sensory attributes for the main effects (wine (W), judge (J), replication (R) and interaction (WXJ), (JXR), (WXR) effects. Judges were a significant source of variation for all attributes. This was due to the use of different parts of line scale by judges (Poste *et al.* 1991). All attributes were significantly different; illustrating that the chosen terms were useful in characterizing differences among Cabernet Franc wines in Niagara region (Table 3). The reproducibility of the panel was shown by a non-significant effect of replication (data not shown). Likewise, the JXR and WXR (except one case) interactions were not significant, indicating similarity of wine bottles and good reproducibility of judges (data not shown). However, there were significant regional differences as indicated by comparing mean scores (Table 3). For instance, wines from Escarpment Bench or Lake Plain sites were higher in red fruit aroma and flavor, while

Lakeshore or Niagara River sites were lower, which shows that the sites closer to Lake Ontario or the Niagara River were generally low in red fruit character (for the location of each site please refer to Table 1 and Fig. 1). Wines from Cave Spring, Reif and Harbour sites were highest in black cherry aroma; while CDC, Cave Spring, Reif, HOP, and Hernder wines had highest black cherry flavor (Table 3).

Highest black currant aroma was detected at Cave Spring, Reif, and HOP, and there was also more black currant flavor at CDC, Cave Spring, Reif, and Hernder wines. Black pepper aroma was highest at CDC, Cave Spring, George, Reif, and Vieni while Buis, Cave Spring, George, Reif, and Hernder wines were most intense in black pepper flavor. Wines from Lakeshore and Niagara River sites had highest green bean aroma and flavor. More intense bell pepper aroma and flavor was detected in wines of Cave Spring, George, Reif, and Harbour sites. Wines from CDC, Buis, Cave Spring, and Hernder sites were more astringent, while bitterness was highest at CDC, Buis and George sites. Wines from Cave Spring and George were more acidic. High color intensity was observed at CDC, Cave Spring, George and Harbour sites (Table 3).

Relationships between aroma and flavor attributes are illustrated in Figure 2. PCA explained 52.1% of the variability in the data in the first two dimensions. PC1 accounted for 29.7% of the variability and was most heavily loaded in the positive direction with red fruit, black cherry, and black currant aroma and flavor as well as black pepper aroma and acidity. PC2 explained 22.4% of the variation in the data set, and was positively loaded with green bean and bell pepper aroma and flavor as well as black pepper flavor. The third PC explained another 13.5% of the variation (data not shown), however, there was a substantial amount of unexplained variability in the data that could not be attributed to the first three vectors.

The distribution of wines on the PCA plot illustrates that CDC wines were located in the right and lower part of the plot, dominated by red fruit aroma and flavor as well as black pepper aroma. HOP and Hernder wines were grouped in the lower right quadrant and were explained by red fruit aroma and flavor; HOP was more intense in the aforementioned characters because it was further away from the center. Astringency and bitterness appeared to explain a very small percentage of variability because of the shorter vector length. The Cave Spring wines were located in the upper right of the plane and were characterized with high black cherry aroma and flavor, black currant flavor and high color and acidity. The relatively short length of the color intensity eigenvector showed that the wines evaluated were not high in color intensity. Harbour Estate, George, and Reif wines (all either from adjacent to Lake Ontario or the Niagara River) were grouped in the upper left of the plane, lacking in fruity characters but associated with green bean aroma and flavor, bell pepper aroma and flavor and black pepper flavor (Fig. 2). Replicate 1 of Buis wines (also from adjacent to Lake Ontario) was also explained with green bean aroma and flavor while Buis replicates 2 and 3 and Vieni wines (from south of the Niagara Escarpment) were grouped in the lower left of the plane and didn't explain well in this PCA; however, they were low in black pepper flavor and acidity. Buis wines were grouped in the upper left of the plane in PC2 and were explained with green bean aroma and flavor. Vieni wines were grouped in the lower left of the plane and were characterized with low color intensity, astringency and bitterness (Fig. 2).

Discriminate analysis of sensory data (F1 and F2 = 81% of the variability) showed that Harbour Estate and George sites (both situated on the Lake Ontario shoreline) were clearly grouped and separated from other sites, characterized with bell pepper aroma and flavor, black pepper and green bean flavor as well as acidity. CDC and Buis also clearly separated from other groups, characterized by astringency and bitterness. The Vieni and Hernder sites were grouped together and separated from the other sites, with high red fruit aroma/flavor and black pepper aroma. Cave Spring, Reif and HOP were also grouped together and clearly separated from other groups, characterized by black cherry and black currant aroma and flavor (Fig. 3).

Proximity to large bodies of water plays a significant role in climatic patterns worldwide. Heymann and Noble (1989) illustrated that Cabernet Sauvignon wines from cool areas south of San Francisco Bay were characterized by intense vegetative notes. The cool air of the sea breeze in the Western Cape in South Africa, for instance, prevents high day temperatures (Bonnardot *et al.* 2002). They reported that the cooling effect of the breeze decreases rapidly with distance from the sea, resulting higher temperature variability in the inland sites. Consequently, Conradie *et al.* (2002) reported higher tropical fruit aroma character in Sauvignon blanc wines from warmer inland locations. In our situation in 2005, wines from Lakeshore or Niagara River sites (Harbour Estate, Reif, George and Buis) exhibited green bean aroma and flavor characters and lack of fruity aroma and flavor. These sites were all located in close proximity of either Lake Ontario or the Niagara River, and were characterized by lower temperatures and less heat unit accumulation (growing degree-days; GDD). Wines from CDC (St. Davids's Bench sub-appellation), HOP (Short Hills Bench), Hernder (Four Mile Creek) and Cave Spring

(Beamsville Bench) were located far from large water bodies, and showed highest fruity character and less green bean aroma and flavor. These sites received a greater number of GDD than the sites close to the lake or river early in the season (OGGMB 2009). The faster GDD accumulation typically results in early budburst and bloom as well as earlier harvest, compared to the sites where temperatures are moderated by Lake Ontario or are south of the Niagara escarpment (in Vieni's case).

2006. Analysis of variance showed significant differences among sites in all attributes except black pepper aroma (Table 3). There was no significant replication effect, which showed that judges were consistent from one session to the next (data not shown). In spite of eight training sessions for judges to score attributes of different intensities in a similar manner, significant judge effects for all attributes were observed (data not shown). The highly significant differences due to judge showed that the judges used different parts of the intensity scale, and as a result there were significant differences among the means for each judge. This difference among judges is normal and it is common in many studies. Except for one case, JXR interactions were not significant (data not shown). WXR interactions were also not significant except in four cases (data not shown).

Red fruit aroma was highest at Buis, HOP, CDC, Reif, Morrison and Cave Spring, while red fruit flavor was most intense at HOP, CDC, Reif and Cave Spring sites. Highest black cherry aroma was observed at HOP, CDC and Reif sites; Buis, HOP, CDC, Reif and Cave Spring sites had most intense black cherry flavor. Black currant aroma was highest at Buis, HOP, and CDC sites, while HOP, CDC, and Morrison sites were high in black currant flavor. Only CDC and Reif sites showed highest black pepper flavor. Green bean aroma and flavor was most intense at George and Hernder sites. Except Morrison, which was high in bell pepper flavor, Buis, HOP, George, CDC and Hernder sites were high in bell pepper aroma and flavor. Wines from Buis, George, Hernder and Cave Spring were more astringent. CDC wines were highest in bitterness and Buis and George wines were most acidic. Highest color intensity was observed at the George, CDC, Hernder and Cave Spring sites (Table 3).

The first two factors of PCA mean sensory scores explained 52.5% of the variability in the data set (Fig. 4). The PC3 explained another 11.9% of the variability in the data set (data not shown), so there was a substantial amount of unexplained variability in the data that could not be attributed to the first three factors. CDC and HOP wines were located in the upper left of the plane and were associated with red fruit aroma and flavor, black cherry aroma and flavor, black currant aroma and flavor and black pepper flavor. All Cave Spring and Reif wines were in lower left quadrant and were not explained well; however, they were low in bell pepper aroma and flavor, green bean aroma and flavor, astringency and acidity. Hernder, George, and Morrison wines were in both the upper and lower right of the plane and were explained by green bean aroma and flavor and color intensity; however, Morrison's wines were closer to the center and were lower in the intensities of the aforementioned attributes. Buis wines were in the upper right quadrant and were associated with bell pepper aroma and flavor, black pepper aroma, acidity and astringency (Fig. 4).

Discriminate analysis on 2006 sensory data (F1 and F2 explained 62% of the variability) showed that the Buis, George and Hernder sites were grouped together and separated from other sites. These sites were characterized by acidity, astringency, green bean aroma and flavor as well as bell pepper aroma. Two of these sites were located adjacent to Lake Ontario (Buis, George) while the third was likely overcropped. Morrison was separated from other sites, characterized with bell pepper flavor and black pepper aroma. Cave Spring was separated from the other sites, and characterized as high in color, bitterness and black pepper flavor. HOP, CDC and Reif grouped together and were characterized with red fruit, black cherry and black currant aroma and flavor (Fig. 5).

In cool climates, particularly in less than optimal vintages such as 2006 in Niagara, warm mesoclimates have a positive effect on grape and wine quality. This relationship between accumulated heat units and wine characteristics is well known worldwide. Becker (1985) experimented with Pinot Gris grown in containers in warm and cool sites, and suggested that some of the quality differences were due to aroma and flavor compounds. Comparing cool and warm vineyard sites in South Australia, Ewart (1987) found that volatile terpenes increased more slowly in cool sites but finally attained higher concentrations. Wine scores were also higher from grapes grown on the cool sites. Nonetheless, some compounds such as methoxypyrazines that give green bean and bell pepper aromas and flavors to cultivars such as Cabernet Franc may be at high concentrations in cooler climates, in particular under shaded situations (Lacey *et al.* 1991). In our study, high bell pepper and green bean aromas and flavors at Harbour Estate, George, Reif and Buis sites in 2005 and at George and Buis sites in 2006 were attributable to proximity of these sites to Lake Ontario and the Niagara River, which resulted in less GDD accumulation, and consequently unripe fruit, characterized by vegetal aroma and flavor. The HOP and CDC sites both had more heat units, which enabled them to ripen their fruit by the end of growing season; hence, the most intense fruity aroma and flavor were found in these wines.

The 2006 growing season in Niagara was characterized by several substantial precipitation events, including many during the harvest period. Excess rainfall or irrigation may result in delayed fruit ripening, and as a consequence may prevent grapes reaching full maturity, therefore reducing wine quality. Rain, especially before harvest, plus humidity also increases the chance of Botrytis and other fungal diseases which decrease the quality of grapes and wine. Rain or the threat of rainfall may sometimes force growers to harvest unripe fruit with high vegetal character. Jackson and Cherry (1987), using climatic indices for predicting site suitability for viticulture, found that areas with high rainfall had lower ripening capacity. In our situation, Buis, George, Morrison and Hernder wines in 2006 were high in bell pepper and green bean aroma and flavor. Higher available water and less heat unit accumulation may both explain the high vegetal character in Buis and George wines; at Hernder and Morrison sites, high vegetal character could have possibly been due to early harvest and unripe fruit.

Chemical analysis. ***2005.*** ANOVA for chemical attributes showed that except hue, color intensity, and TA, all other attributes were not different across the sites (Table 4). Reif, Hernder and Harbour sites were highest in hue while CDC, Cave Spring and Buis sites were highest in color intensity. Highest TA was observed at the Cave Spring, Buis and CDC sites while all other sites were low in TA (Table 4).

PCA on the chemical variables explained 77.18% of the variance in the data in the first two dimensions (Fig. 6). The first PCA explained 52.5% of the variance among the wines while PC2 accounted for 18.7% with additional 15.3% explained by PC3 (data not shown). Color, anthocyanins, TA, and ethanol had positive loadings on PC1, while it was highly negatively loaded with hue and pH. Color and TA were negatively correlated with pH. Color was positively correlated with TA, anthocyanins, and ethanol. CDC and Cave Spring wines were in upper right quadrant and associated with high color intensity, anthocyanins, phenols and ethanol. Buis wines were located in the lower right quadrant and were explained with high TA. Reif and Harbour wines were in the lower left quadrant and were associated with high hue, high pH and low ethanol and anthocyanins. Vieni, Hernder, George and HOP wines were located in the upper left of the plane and were associated with high pH and low color intensity and TA (Fig. 6).

Discriminate analysis on the chemical data in 2005 (F1 and F2 explained 62% of the variability) showed that the Cave Spring and Hernder sites were separated from other groups and explained by low color, anthocyanins, phenols, TA and ethanol. George and Reif (both adjacent to Lake Ontario or the Niagara River) were also separated as one group associated with high hue and pH. CDC, Vieni and HOP grouped together and explained with low hue and pH. Buis and Harbour (both adjacent to Lake Ontario) also were grouped together and characterized with high TA, anthocyanins and color (Fig. 7).

2006. Analysis of variance for chemical attributes revealed that except hue, color intensity, and ethanol, all other attributes were not different between the sites (Table 4). The Morrison site had the lowest color intensity and the highest hue. Color intensity was highest at the Cave Spring, George, and Reif sites. Highest ethanol was observed at the Cave Spring, Reif, and CDC sites (Table 4).

The PCA plot of chemical variables indicated that PC1 and PC2 accounted for 61.3% and 22.3% of the variability in the data set, respectively (Fig. 8) with an additional 10.0%

explained by PC3 (data not shown). Color intensity, anthocyanins and TA were highly positively loaded on PC1, while highly negatively loaded with hue and pH. Total phenols and ethanol both were highly positively loaded on PC2. Again, George and Buis wines were together in the lower right quadrant and associated with high TA as well as low hue and pH. The Cave Spring wines were associated with high color intensity, anthocyanins and ethanol. The Morrison, CDC, and Reif sites were in the upper left quadrant; CDC and Reif wines were explained with high phenols and Morrison wines were explained with high hue and pH. The Hernder and HOP sites were not readily explained, however, these sites were lower in ethanol, color intensity and phenols (Fig. 8).

Discriminate analysis of chemical data in 2006 (F1 and F2 explained 89% of the variability) indicated that Morrison, CDC and Reif were grouped together and characterized with high hue, phenol and anthocyanins. Cave Spring separated as a single group and was explained with high TA, color and anthocyanins. Buis, Hernder, George and HOP were grouped together and attributed with low phenols and ethanol (Fig. 9).

In many grape-growing areas the choice of grape cultivar is such that the maturity of the berries occurs just before the mean monthly temperatures drops to 10 °C (Jackson 1991). In cool climates, warm seasons and warm mesoclimates are an advantage. Generally it can be said that cool climates encourage low sugar levels and higher TA in grapes, while hot climates have opposite effects (Alleweldt et al. 1984). Berry maturation is typically associated with a rise in juice pH and lowering of TA, with the rate of malic acid decline normally related to temperatures in growth stage III (Alleweldt et al. 1984). Rankine *et al.* (1971) reported higher pH levels in wines made from warmer viticultural regions compared to wines made in cooler regions of Australia. Likewise, Reynolds *et al.* (1995) showed that pH and total volatile esters in Okanagan Riesling wines were higher in those from a warmer site. Herrick and Nagel (1985) found that the mean phenol concentration of Riesling wines from Alsace was very low (13 mg/L), while that from eastern Washington State and California was 123 mg/L. These patterns are consistent with our results, which showed high TA at a cooler site (Buis 2005 and 2006) and low TA [HOP (2005), Vieni (2005), and Hernder (2005)], high ethanol [Cave Spring (2005 and 2006)], and high pH (Morrison 2006) at warmer sites. This may have been due to the warmer temperatures leading to metabolism of malic acid. Also, there were higher anthocyanins and phenols at Vieni, HOP and Hernder (2005) as well as Cave Spring and CDC (2006), perhaps due to greater heat unit accumulations in these warmer mesoclimates.

Partial least squares analysis (PLS). PLS was performed on the entire 2005 and 2006 data sets to look for relationships among yield components, berry composition, vine size, soil attributes, and sensory data. PLS explained 84.3% of the variability in the 2005 data sets (Fig. 10). It illustrated that the absolute value of leaf ψ was positively correlated with red fruit aroma/flavor, berry pH, berry color intensity, wine color intensity, total phenols and Brix, while negatively correlated with soil moisture, green bean aroma/flavor as well as bell pepper aroma/flavor. This suggests that sites with lower vine water status were also those with the most intense color and ripe fruit characteristics. Vine size was positively correlated with bell pepper flavor, green been aroma and acidity. Soil moisture was positively correlated with acidity, bitterness, vine size, bell pepper aroma/flavor, green bean aroma/flavor and black cherry aroma and flavor. Clay was positively correlated with black currant and black pepper flavor (Fig. 10). PLS analysis in 2006 explained 53.9% of the variation in the data sets and indicated that soil moisture was positively correlated with green bean aroma/flavor, bell pepper aroma, yield and total phenols. Clay also was positively correlated with red fruit aroma and flavor, black currant aroma and black cherry flavor (Fig. 11).

The chemical and sensory differences in the wines were believed to be due to climatic conditions, which in turn are related to the topography of the region. East and south facing slopes in cool climate wine regions of the northern hemisphere receive more sunlight due to their early exposure during the growing season; as a consequence north facing slopes of the Niagara Escarpment receive less sunlight late in the summer (Shaw 2005). On the other hand, in sub-appellations located closer to Lake Ontario [Niagara Lakeshore (Buis), Lincoln Lakeshore (George) and Creek Shores (Harbour)], or the Niagara River (Reif), temperatures remain cool in April, budburst begins late in the season, and GDD are sometimes not sufficient to ripen Cabernet Franc. In sub-appellations that are far from the lake, these areas experience early warming in the spring, and therefore GDD are sufficient for ripening Cabernet Franc (Table 1) (Shaw 2005). However, although climate appears to be the most important driving force affecting grape and wine quality, the role of other factors such as vine water status (leaf ψ), vine size and soil texture cannot be discounted, as suggested by Chapman *et al.* (2005).

Vine water status influences almost every aspect of plant metabolism (Bradford and Hsiao 1982) and as a result it affects most aspects of fruit composition. Low vine water status may be associated with reduced vegetal characteristics and increased fruity aroma and flavor in red wines. Koundouras *et al.* (2006) found that limited water availability increased the main aromatic compounds of the grapes and the resultant wines were preferred in tasting trials. This is consistent with our 2005 results, which indicate that absolute value of leaf Ψ (low water status) was positively correlated with fruity characters and negatively correlated with vegetal characters (Fig. 10); however, it was not entirely consistent with 2006 results, perhaps due to excess precipitation that season (Fig. 11).

High vine size due to high vegetative growth is frequently correlated with vegetal characteristics of wines induced by methoxypyrazines. Hashizume and Samuta (1997), among others, indicated that methoxypyrazines were present at high concentrations in grape berries and these compounds might contribute to the vegetal flavor of wines. Hashizume and Samuta (1999) also proved the effect of photodecomposition on methoxypyrazines in several grape cultivars including Cabernet Sauvignon, Merlot, Pinot noir, Muscat Bailey, Semillon, Sauvignon blanc, Chardonnay, and Riesling. Our results in 2005 showed that high vine size was correlated with bell pepper flavor and green bean aroma as well as black cherry and black pepper flavor (Fig. 10). High vine size (hence high vegetative growth) creates more within-canopy shade that often leads to excessive vegetal characteristics in wines. In 2006, vine size correlated with bell pepper aroma and flavor and green bean flavor as well as some fruity characteristics (Fig. 11). Vegetative growth is stimulated by high soil water availability in the post-veraison period, which can delay sugar accumulation in grapes (Smart and Coombe 1983). In addition, excessive vegetative growth can create canopy shading, which has negative effects on the quality of red wines (Smart 1982).

The importance of soil type on the quality of wine has long been a subject of speculation. Gladstones (1992) suggested that wines from sandy soils often lack strength and color but are rich in aroma. Wines from limestone soils allegedly have high alcoholic strength while clay soils produce acidic grapes, high in tannins that lead to rich red wines. He also stated that rocky, stony or chalky soils gave the best wines. Seguin (1986), on the other hand, reported that clay may have an influence on organoleptic character and the type of wine, but it is also possible to produce high quality wines on stony soils with low pebble content. Likewise, Wahl's (1988) study in the Franken region of Germany, in which he investigated the impact of soil type on wine composition and sensory quality of Silvaner by moving seven different soil types to the same vineyard site in lysimeters, found no significant impact of soil type on wine flavor. This is consistent with our results in 2005, as it shows clay was only correlated with black currant flavor and sand was only correlated with black pepper aroma (Fig. 10); however, these relationships were somewhat different in 2006 due to higher precipitation and lower temperatures, whereby sand was correlated with acidity and bitterness while clay was correlated with some red and black fruit aroma and flavor descriptors (Fig. 11).

This may lead to a hypothesis that vineyards are a rather stable terroir and each wine estate has developed a method of grape growing which yields wines of similar and consistent sensory profiles across vintages, assuming the same winemaker and vinification processes. Thus, for consumers who seek specific sensory properties from a wine, vineyard designation is a meaningful label for the wines.

Conclusions

This study examined the sensory and fruit composition of Cabernet Franc wines from the Niagara Peninsula, Ontario. The sensory and chemical methodologies that were developed for this study separated clusters of sub-appellations for Niagara Peninsula Cabernet Franc wines. The PCA and discriminate analysis plots of sensory and chemical analysis showed that the attributes were useful in describing differences among the wines. In 2005, CDC, HOP, Cave Spring and Hernder sites (Escarpment Bench and Lake Plain sub-appellations) were associated with red fruit aroma and flavor. All these sites were warm with low water status. Harbour, George, Reif and Buis sites (Lakeshore or Niagara River sub-appellations) were associated with green bean and bell pepper aroma and flavor; this may indicate that there was insufficient heat to ripen the fruit. Harbour Estate and all Niagara-on-the-Lake sites showed highest pH, TA, phenols, and hue while sites west of St. Catharines were associated with high color, anthocyanins and ethanol. Despite two different vintages including a hot and dry year (2005) and a cool and wet year (2006), similar trends were observed. Except black pepper aroma, all other attributes were substantially different among the sites in 2006. Most notably, wines from Buis (Niagara Lakeshore sub-appellation), Morrison (Twenty Mile Bench), Hernder (Four Mile Creek) and George (Lincoln Lakeshore) were high in bell pepper and green bean aroma and flavor, astringency and acidity. Similarly, CDC (St. Davis Bench) and HOP (Short Hills Bench) sites were associated with red fruit aroma and flavor, black currant aroma and flavor, black cherry aroma and flavor, black pepper flavor and bitterness.

The location of wines on the PCA plots provided a graphic indication of their sensory and chemical profiles and allowed regional differences to be identified. Although it was not possible to assign each site into a unique sub-appellation that produces a specific lexicon of wine characteristics, it was possible to separate them in terms of clusters of sub-appellations based upon dominant sensory attributes. Also, this study provided evidence for proper site selection for Cabernet Franc in the Niagara region, since certain areas produced wines that were clearly dominant in herbaceous notes. This study was ideal for assessing chemical and sensory differences among sub-appellations in Niagara by producing Cabernet Franc wines with minimal enological intervention, a single winemaker, and single vintage comparisons. However, more investigation is required to further determine the basis of terroir effects in Niagara for other important winegrape cultivars.

Literature Cited

Alleweldt, G., H. During, and K.H. Jung. 1984. Zum Einfluss des Klimas auf Beerrentwicklung, Ertrag, und Qualiti bei Reben: Ergebnisse einer siebenjharigen Faktorenanalyse. Vitis 23:127-142.

Becker, N.J. 1985. Site selection for viticulture in cooler climates using local climatic information. In: Heatherbell, D.A., P.B. Lombard, F.W. Bodyfelt, and S.F. Price (Eds.). Proceedings of the First International Symposium on Cool Climate Viticulture and Enology. Pp 20-34. Eugene, OR. Oregon State University Experiment Station Technical Publication No. 7628.

Bonnardot, V., O. Planchon, V.A. Carey, and S. Cautenet. 2002. Diurnal wind, relative humidity and temperature variation in the Stellenbosch-Groot Drakenstein wine-growing area. S. Afr. J. Enol. Vitic. 23:62-71.

Bradford K.I. and T.C. Hsiao. 1982. Physiological responses to moderate water stress. Plants' effect on growth and metabolism, growth regulators response, stomatal behavior, photosynthesis, respiration, proline and betaine transport, nutrient uptake. Encyclopedia of Plant Physiology 128:263-324.

Canadian Society of Soil Science. 1993. Soil Sampling and Methods of Analysis. M.R. Carter (Ed.). Lewis Publishers, Boca Raton, FL.

Chapman, D.M., G. Roby, S.E. Ebeler, J.X. Guinard, and M. Matthews. 2005. Sensory attributes of Cabernet Sauvignon wines made from vines with different water status. Austral. J. Grape and Wine Research 11:339-347.

Cliff, M.A., D. Yuksel, B. Girard, and M. King. 2002. Characterization of Canadian ice wines by sensory and compositional analysis. Amer. J. Enol. Vitic. 53:46-53.

Conradie, W.J., V.A. Carey, V. Bonnardot, D. Saayman, and L.H. van Schoor. 2002. Effect of different environmental factors on the performance of Sauvignon blanc grapevines in the Stellenbosch/ Durbanville districts of South Africa. I. Geology, soil, climate, phenology and grape composition. S. Afr. J. Enol. Vitic. 23:78-91.

Douglas, D., M.A. Cliff, and A.G. Reynolds. 2001. Canadian terroir: characterization of Riesling wines in the Niagara Peninsula. Food Res. Int. 34:559-563.

Ewart, A.J. 1987. Influence of vineyard site and grape maturity on juice and wine quality of *Vitis vinifera*, cv. Riesling. In: Lee, T.H. (Ed.). Proceedings of the Sixth Australian Wine Industry Conference, Adelaide. Pp 71-74. The Australian Wine Research Institute, Urrbrae, SA.

Gladstones, J.S. 1992. Viticulture and Environment. 310 pp. Winetitles, Adelaide.

Grape Growers of Ontario. 2009. 61st Annual Report and Financial Statements for the Year Ending 2008.

Hashizume, K. and T. Samuta. 1997. Green odorants of grape cluster stem and their ability to cause a wine stemmy flavor. J. Agric. Food Chem. 45:1333-1337.

Hashizume, K. and T. Samuta. 1999. Grape maturity and light exposure affect berry methoxypyrazine concentration. Amer. J. Enol. Vitic. 50:194-198.

Herrick, I.W., and C.W. Nagel. 1985. The caffeoyl tartrate content of white Riesling wines from California, Washington and Alsace. Amer. J. Enol. Vitic. 36:95-97.

Heymann, H. and A.C. Noble. 1989. Comparison of canonical variate and principal component analysis of wine descriptive analysis data. J. Food Sci. 54:1355-1358.

Jackson, D.I. 1991. Environmental and hormonal effects on development of early bunch-stem necrosis. Amer. J. Enol. Vitic. 42: 290-294.

Jackson, D.I. and N.J. Cherry. 1987. Predication of a district's grape ripening capacity using a latitude-temperature index (LTI). Amer. J. Enol. Vitic. 39:19-28.

Koundouras S., V. Marinos, A. Gkoulioti, Y. Kotseridis, and C. van Leeuwen. 2006. Influence of vineyard location and vine water status on fruit maturation of non-irrigated cv. Agiorgitiko. Effects on wine phenolic and aroma components. J. Agric. Food Chem. 54:5077-5086.

Kontkanen, D., A.G. Reynolds, M. King and M.A. Cliff. 2005. Canadian terroir: characterization of Bordeaux-style red wines from the Niagara Peninsula. Food Res. Int. 38:417-425.

Lacey, M., M.S. Allen, R.L.N. Harris, and W.V. Brown. 1991. Methoxypyrazines in Sauvignon blanc grapes and wines. Amer. J. Enol. Vitic. 42:103-108.

Mazza, G., L. Fukumoto, P. Delaquis, B. Girard, and B. Ewart. 1999. Anthocyanins, phenolics, and color of Cabernet Franc, Merlot, and Pinot noir wines from British Columbia. J. Agric. Food Chem. 47:4009-4017.

Poste, L.M., D.A. Mackie, G. Butler, and E. Larmond. 1991. Laboratory Methods for Sensory Analysis of Food. Publication 1864/E. Research Branch, Agriculture Canada.

Rankine, B.C., J.C.M. Fornachon, E.W. Boehm, and M. Cellier. 1971. Influence of grape variety, climate and soil on grape composition and on the composition and quality of table wines. Vitis 10:33-50.

Reynolds, A.G., D.A. Wardle, J.W. Hall, and M. Dever. 1995. Fruit maturation of 'Okanagan Riesling' grapes: Effect of site, year, and basal leaf removal. Fruit Varieties J. 49(4):213-224.

Sayed, H. 1992. Vineyard Site Suitability in Ontario. Toronto: Agriculture Canada/Ontario Ministry of Food. Queen's Printer for Ontario.

Schlosser, J., A.G. Reynolds, M. King, and M.A. Cliff. 2005. Canadian terroir: sensory characterization of Chardonnay in the Niagara Peninsula. Food Res. Int. 38:11-18.

Seguin, G. 1986. Terroirs and pedology of wine growing. Experimentia 42:861-872.

Shaw, A.B. 2002. A climatic assessment of the Niagara Peninsula viticultural area of Ontario for the application of wind machines. J. Wine Research 13:143-164.

Shaw, A.B. 2005. The Niagara Peninsula viticultural area: A climatic analysis of Canada's largest wine region. J. Wine Research 16:1-19.

Slinkard, K. and V. Singleton. 1977. Total phenol analysis: Automation and comparison with manual methods. Amer. J. Enol. Vitic. 28:49-55.

Smart, R.E. 1982. Vine manipulation to improve wine grape quality. In: A.D. Webb (Ed). Proceedings of the UC Davis Grape and Wine Centennial Symposium, June 1980. Pp 362-375. American Society of Enology and Viticulture, Davis, CA.

Smart, R.E. and B.G. Coombe. 1983. Water relations of grapevines. *In* T.T. Kozlowski (Ed.): Water Deficits and Plant Growth. Pp. 137-196. Academic Press, New York.

Wahl, K. 1988. Climate and soil effects on grapevine and wine: Franconia. In: R.E. Smart, R. Thornton, S.B. Rodriquez, and J. Young, Proceedings of 2nd International Symposium of Cool Climate Viticulture and Oenology, Auckland, New Zealand. Pp. 1-5. New Zealand Society for Viticulture and Oenology, Auckland.

Wiebe, J. & E.T. Anderson. 1977. Site Selection for Grapes in the Niagara Peninsula, Canada. Horticultural Research Institute of Ontario, Vineland Station.

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Table 4. Comparison of mean chemical attributes among sites in the Niagara Peninsula of Ontario, 2005-2006. CDC, and HOP are abbreviations for Château des Charmes, and Henry of Pelham sites, respectively.

Table 1. The origin of each Cabernet Franc wine and its related sub-appellation, Niagara Peninsula, Ontario, 2005 and 2006.

Name of vineyard block	**Name of sub-appellation**	**Growing Degree Days (GDD) ****			**Precipitation (mm) May - October**		
		2005	**2006**	**2007**	**2005**	**2006**	**2007**
Buis	Niagara Lakeshore	1490	1417	1579	NA	NA	NA
Château des Charmes	St. Davids's Bench	1583	1466	1646	NA	461.9	219.8
Harbour Estate*	Creek Shores	1672	1457	1606	436.3	534.2	221.4
Hernder	Four Mile Creek	1505	1471	1572	457.1	NA	181.6
Reif	Niagara River	1604	1449	1539	NA	NA	163.8
George	Lincoln Lakeshore	1559	1401	1420	NA	NA	NA
Cave Spring	Beamsville Bench	1620	1415	1679	410.2	NA	197.8
Henry of Pelham	Short Hills Bench	1552	1412	1591	466.8	NA	172.2
Vieni Estate*	Vinemount Ridge	1565	1354	1594	409.7	526.5	NA
Morrison*	Twenty Mile Bench	1667	1457	1606	438.4	534.2	221.4

s*No wine was produced from Morrison (2005), Vieni Estate and Harbour Estate (2006) blocks due to lack of fruit caused by the previous year's winter injury (2005) and severe powdery mildew infection (2006), respectively.

** GDDs in ˚C (base 10) at each site were calculated from budburst until harvest time at each specific site.

Table 2. Standards used for sensory evaluation of Ontario Cabernet Franc wine evaluation, 2005 and 2006.

Product	**Brand**	**Method of preparation (added to 50 mL base wine)**
Strawberry	E.D. Smith strawberry jam	18.6 g jam
Raspberry	Fresh raspberry juice (President's Choice juice box)	4 mL juice
Red fruit	Mixture of E.D. Smith strawberry jam plus fresh raspberry juice (juice box)	10 mL strawberry std + 10 mL raspberry std
Black cherry	Stewart's black cherry juice	75 mL juice
Black current	Ribena concentrate (Chateau Thierry)	25 mL concentrate
Black pepper	Black pepper	0.5 mL stock
Bell pepper	Fresh green pepper	1 mL puree
Green bean	Del Monte cut whole green beans	20 mL puree
Acidity	Tartaric acid	1.5 g tartaric acid/L water
Astringency	Aluminum sulfate (Sigma)	0.9 g aluminum sulfate in 450 mL water
Bitterness	Quinine sulfate	0.1 g quinine sulfate/L water
Pectin (for rinsing)	Pectin from apple (Sigma)	1.25g pectin in 250 mL water

Table 3. Comparison of mean sensory scores (scale 0-15) among sites in the Niagara Peninsula of Ontario, 2005-2006. CDC and HOP are abbreviations for Château des Charmes and Henry of Pelham sites, respectively.

Variable	**CDC***	**Buis**	**Cave Spring**	**George**	**Reif**	**Vieni**	**Hernder**	**HOP**	**Harbour Estate**	**Pr > F**
Aroma					**2005**					
Red fruit	6.0a	5.5bc	6.1a	5.2c	5.0c	6.0ab	5.8ab	6.2a	5.1c	0.0001
Black cherry	5.1b	4.8bc	6.3a	4.6c	5.8a	5.1b	5.1b	5.1b	5.2b	0.0001
Black currant	5.6bc	5.3c	6.1a	5.4c	6.0a	5.1c	5.6bc	5.9ab	5.3c	0.0001
Black pepper	4.2a	3.6cd	4.3a	3.9ab	4.1a	3.9ab	3.7bc	3.7bc	3.3d	0.0001
Green bean	3.6c	4.3a	3.4c	4.1b	3.8bc	2.8d	3.7bc	3.3c	4.6a	0.0001
Bell pepper	2.6f	2.9ef	3.7a	3.6a	3.9a	3.3bc	3.3bc	3.1de	3.5ab	0.0001
Flavor/mouthfeel										
Red fruit	5.7a	5.1c	5.9a	5.1c	5.1c	5.3bc	5.5ab	5.7a	4.1d	0.0001
Black cherry	4.9b	4.3d	5.5a	4.3d	5.3a	3.9e	4.9b	5.0b	4.7cd	0.0001
Black currant	5.4bc	5.1cd	6.0a	5.0de	5.7a	4.9e	5.4bc	4.9e	5.2cd	0.0001
Black pepper	3.3cd	3.5c	4.1b	4.2b	4.7a	3.4c	3.4c	3.2d	3.5c	0.0001
Green bean	3.1e	4.1b	3.5cd	4.1b	3.9b	3.3de	3.8bc	3.4d	4.4a	0.0001
Bell pepper	2.6f	3.0e	4.0b	3.6bc	4.3a	3.2d	3.4cd	3.1de	3.7b	0.0001
Astringency	6.7a	6.9a	6.3b	5.9c	4.7e	4.3f	6.3b	5.0e	5.4d	0.0001
Bitterness	2.9a	2.9a	2.5bc	2.7a	2.3c	1.9d	2.5b	1.8d	1.8d	0.0001
Acidity	5.7b	5.8b	6.5a	6.3a	5.9b	5.7b	5.7b	5.8b	5.8b	0.0001
Color	10.8a	5.2e	8.5c	9.8b	6.4d	5.2e	5.8de	6.1d	8.9c	0.0001

2006

Variable	**CDC**	**Buis**	**Cave Spring**	**George**	**Reif**	**Hernder**	**HOP**	**Morrison**	**Pr > F**
Aroma									
Red fruit	6.3a	5.8a	6.3a	5.0b	6.1a	4.7b	6.2a	5.7a	0.0001
Black cherry	5.6ab	5.3bc	5.3b	4.5d	5.5ab	4.2d	6.0a	4.7cd	0.0001
Black currant	6.1ab	6.2ab	5.8b	5.6b	5.7b	4.9c	6.5a	5.7b	0.0001
Black pepper	4.0a	4.2a	3.8a	4.1a	4.1a	4.2a	3.7a	4.4a	0.546
Green bean	3.4d	4.2b	4.0bc	5.4a	3.4d	5.2a	3.6cd	4.1bc	0.0001
Bell pepper	3.9b	4.5a	3.0c	3.9ab	2.9c	4.1ab	3.9ab	3.7b	0.0001
Flavor/mouthfeel									
Red fruit	6.0a	5.1bc	5.7a	5.0cd	5.5ab	4.8d	5.6a	5.3b	0.001
Black cherry	5.5a	5.1ab	5.1ab	4.3c	5.3a	4.5c	5.3a	4.7bc	0.0001
Black currant	5.8ab	5.4bc	5.1de	5.2cde	5.4bc	4.9e	6.2a	5.7b	0.0001
Black pepper	4.5a	3.9b	3.8bc	3.9b	4.1ab	3.6c	3.8bc	3.6c	0.013
Green bean	3.4de	4.0bc	3.6cd	4.7a	3.1e	4.5a	3.4de	3.7cd	0.0001
Bell pepper	4.0a	4.0a	3.2b	3.8a	3.0b	4.0a	4.1a	3.9a	0.0001
Astringency	5.5cd	6.7a	6.4ab	6.6a	6.0cd	6.3ab	6.0bc	5.4d	0.0001
Bitterness	5.1a	4.3b	4.4b	4.4b	4.0b	3.9b	4.1b	4.3b	0.0001
Acidity	6.1bc	7.5a	6.4b	7.3a	5.7cd	6.1bc	6.4b	5.6d	0.0001
Color	7.3bc	6.6d	9.3a	7.9b	7.1cd	9.2a	7.3bc	4.2e	0.0001

[a] Means within rows with different letters are significantly different, Duncan's multiple range test.

Table 4. Comparison of mean chemical attributes among sites in the Niagara Peninsula of Ontario, 2005-2006. CDC, and HOP are abbreviations for Château des Charmes, and Henry of Pelham sites, respectively.

2005

Variable	CDC	Buis	Cave Spring	George	Reif	Vieni	HOP	Hernder	Harbour Estate	Pr > F
Hue	0.74b	0.63d	0.60d	0.62d	0.85a	0.73bc	0.65cd	0.77a	0.78a	0.047
Color intensity	7.4a	7.5a	7.7a	6.1bc	4.3e	4.3e	6.1bc	4.9de	5.1cd	0.045
Anthocyanins (mg/L)	229a	195a	314a	265a	291a	255a	264a	286a	278a	0.116
Phenols (mg/L)	1931a	2050a	1221a	1422a	1478a	1217a	1447a	1416a	1296a	0.344
pH	3.68a	3.35a	2.33a	3.49a	3.63a	3.52a	3.57a	3.57a	3.73a	0.106
TA (g/L)	7.2a	8.1a	6.4bc	5.7d	5.9cd	5.7d	5.8cd	5.9cd	5.7d	0.045
Ethanol (% v/v)	12.5a	11.5a	12.5a	10.8a	11.2a	10.3a	10.8a	11.0a	10.4a	0.55

2006

Variable	CDC	Buis	Cave Spring	George	Reif	HOP	Hernder	Morrison	Pr > F
Hue	0.77b	0.55cd	0.54de	0.43e	0.73b	0.67bc	0.54de	0.98a	0.037
Color intensity	6.0c	5.8cd	11.2a	7.9b	6.6b	5.5d	5.8cd	4.6d	0.045
Anthocyanins (mg/L)	134a	164a	254a	245a	166a	174a	163a	96a	0.437
Phenols (mg/L)	1014a	825a	1228a	1078a	997a	905a	986a	1253a	0.71
pH	3.67a	3.44a	3.30a	3.32a	3.63a	3.44a	3.50a	3.75a	0.109
TA (g/L)	6.0a	6.4a	7.1a	6.7a	5.7a	6.5a	5.9a	5.3a	0.204
Ethanol (% v/v)	10.9a	9.9b	11.9a	9.8bc	11.0a	8.8d	9.5c	9.4c	0.025

* Means within rows with different letters are significantly different, Duncan's multiple range test.

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Figure 10. Partial Least Squares analysis of field and sensory data for nine Cabernet Franc wines from Niagara Peninsula, ON, 2005. Aroma attributes are represented in lowercase and flavor attributes are represented in uppercase.

Figure 11. Partial Least Squares analysis of field and sensory data for eight Cabernet Franc wines from Niagara Peninsula, ON, 2006. Aroma attributes are represented in lowercase and flavor attributes are represented in uppercase.

Figure 1- Niagara Sub-appellations Map (courtesy VQA Ontario). Ten vineyard sites and their corresponding sub-appellations were: 1- Buis (Niagara Lakeshore), 2- Château des Charmes (St. Davids's Bench), 3- Harbour Estate (Creek Shores), 4- Hernder (Four Mile Creek), 5- Reif (Niagara River), 6- George (Lincoln Lakeshore), 7- Cave Spring (Beamsville Bench), 8- Henry of Pelham (Short Hills Bench), 9- Vieni Estate (Vinemount Ridge), 10- Morrison (Twenty Mile Bench).

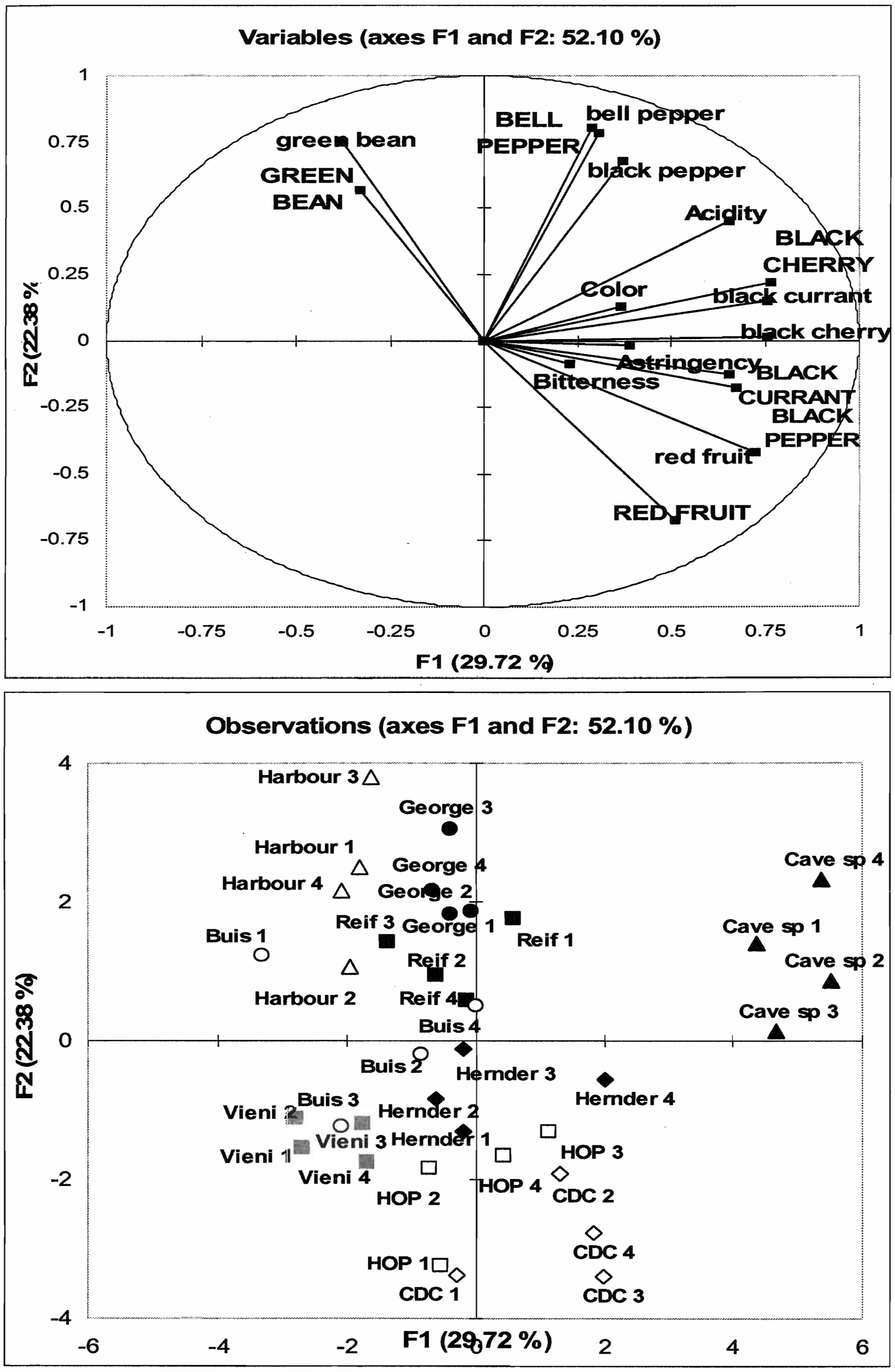


Figure 2. Principal component analysis (F1 & F2) of mean sensory data for nine Cabernet Franc wines from Niagara Peninsula, ON, 2005. CDC, HOP, Cave and Harbour are abbreviations for Château des Charmes, Henry of Pelham, Cave Spring and Harbour Estate sites, respectively. Aroma attributes are represented in lowercase and flavor attributes are represented in uppercase.

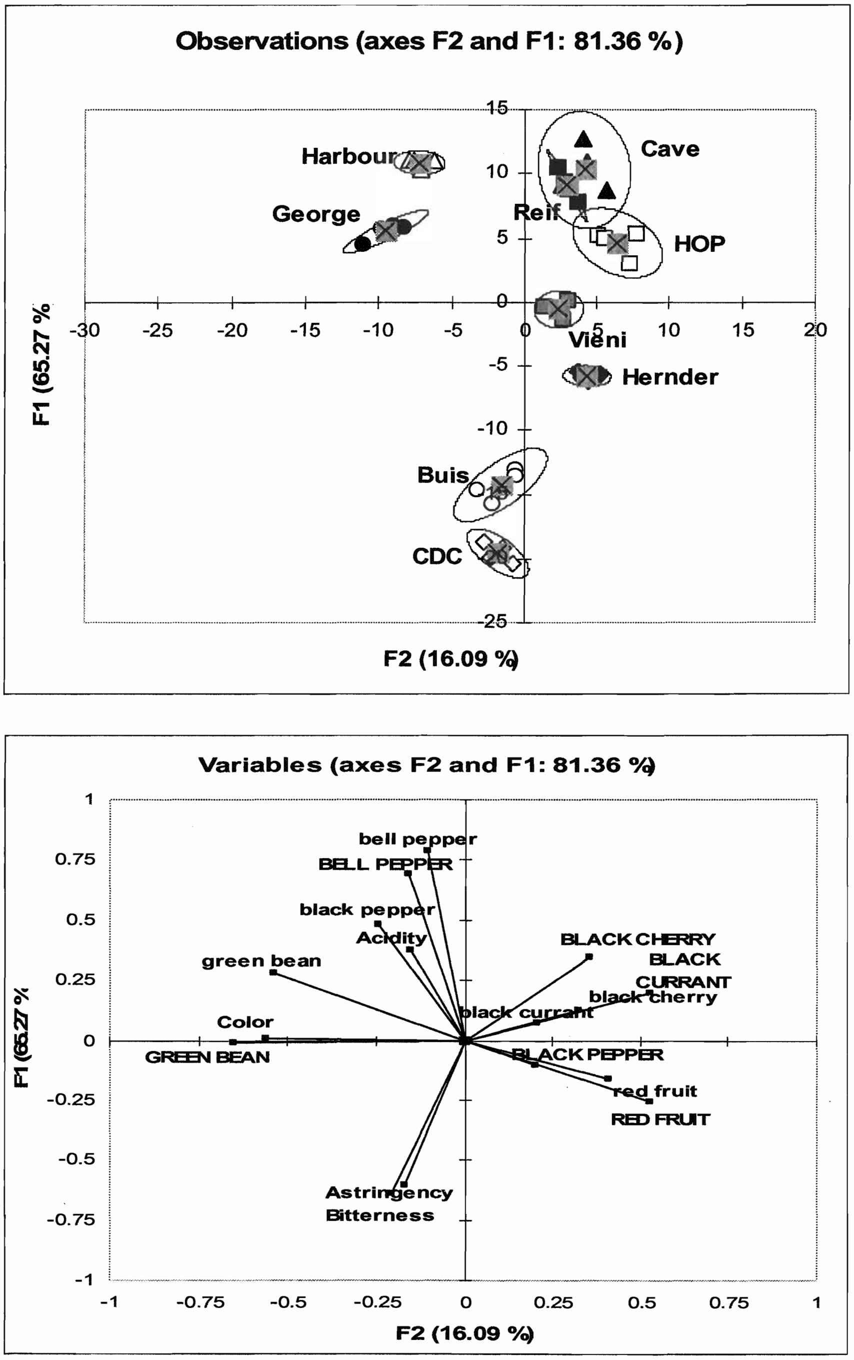


Figure 3. Discriminate analysis (F1 & F2) of mean sensory data for nine Cabernet Franc wines from Niagara Peninsula, ON, 2005. CDC, HOP, Cave and Harbour are abbreviations for Château des Charmes, Henry of Pelham, Cave Spring and Harbour Estate sites, respectively. Aroma attributes are represented in lowercase and flavor attributes are represented in uppercase.

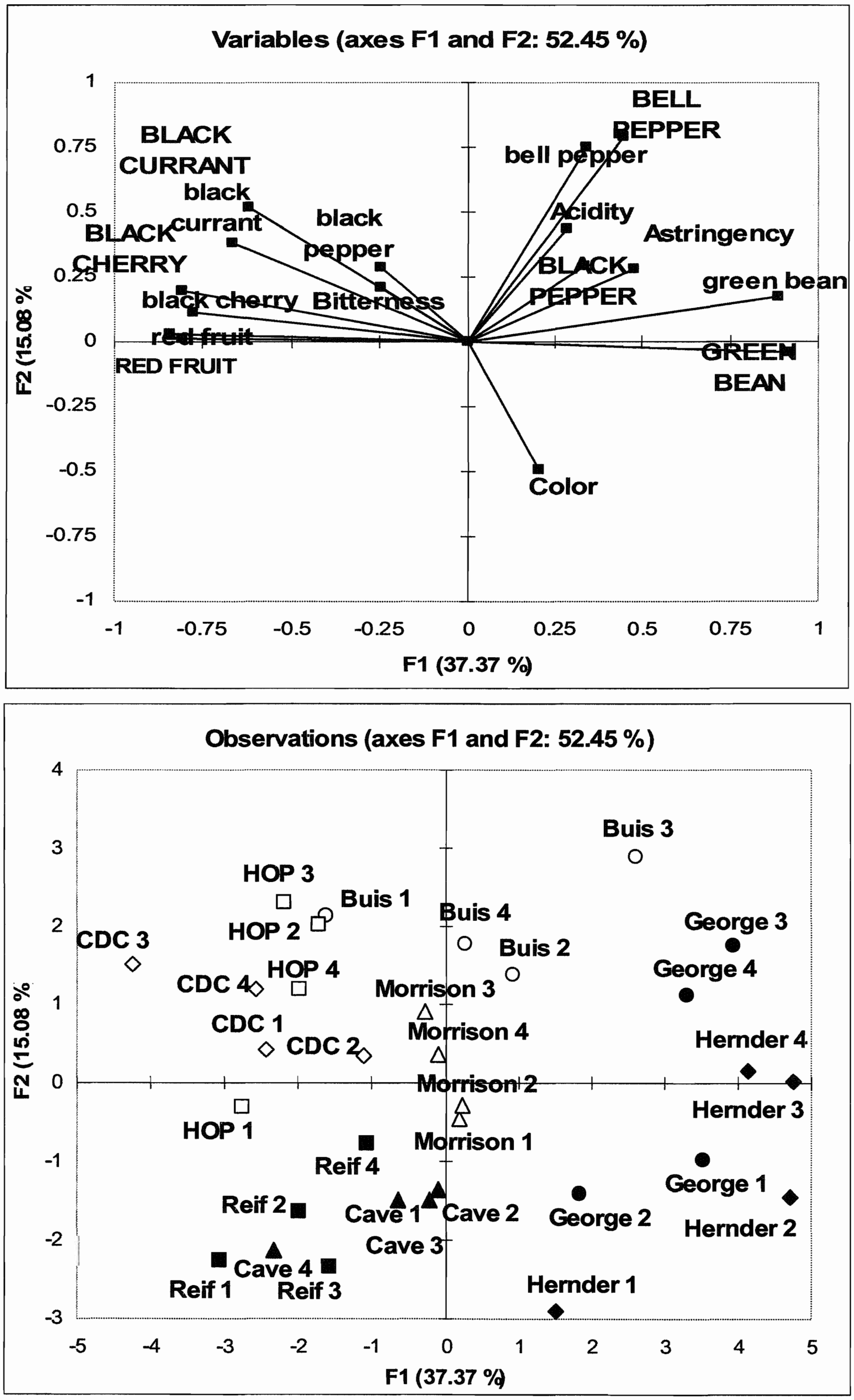


Figure 4. Principal component analysis (F1 & F2) of mean sensory data for eight Cabernet Franc wines from Niagara peninsula, ON, 2006. CDC, HOP, Cave and Harbour are abbreviations for Château des Charmes, Henry of Pelham, Cave Spring and Harbour Estate sites, respectively. Aroma attributes are represented in lowercase and flavor attributes are represented in uppercase.

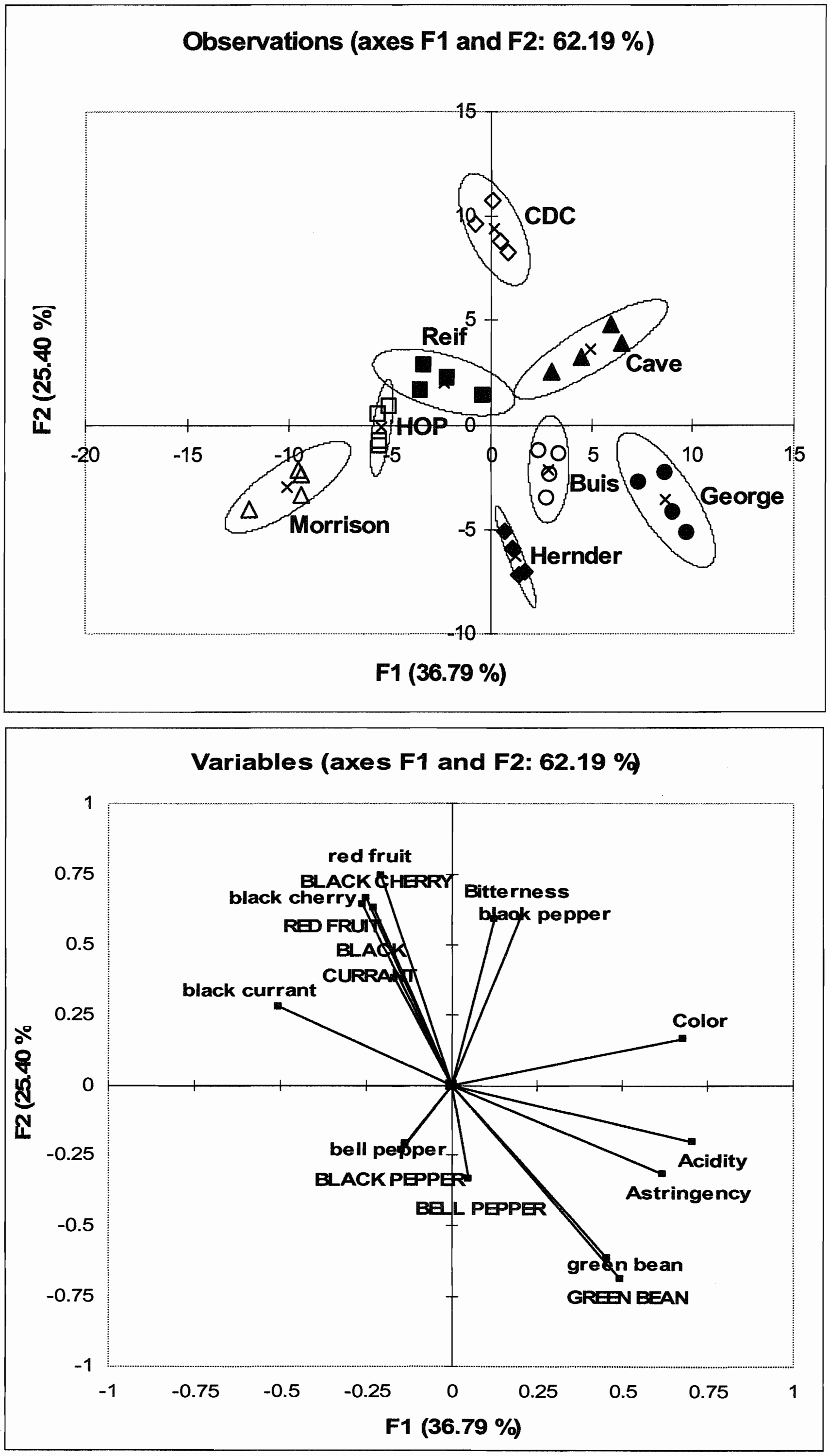


Figure 5. Discriminate analysis (F1 & F2) of mean sensory data for eight Cabernet Franc wines from Niagara Peninsula, ON, 2006. CDC, HOP, Cave and Harbour are abbreviations for Château des Charmes, Henry of Pelham, Cave Spring and Harbour Estate sites, respectively. Aroma attributes are represented in lowercase and flavor attributes are represented in uppercase.

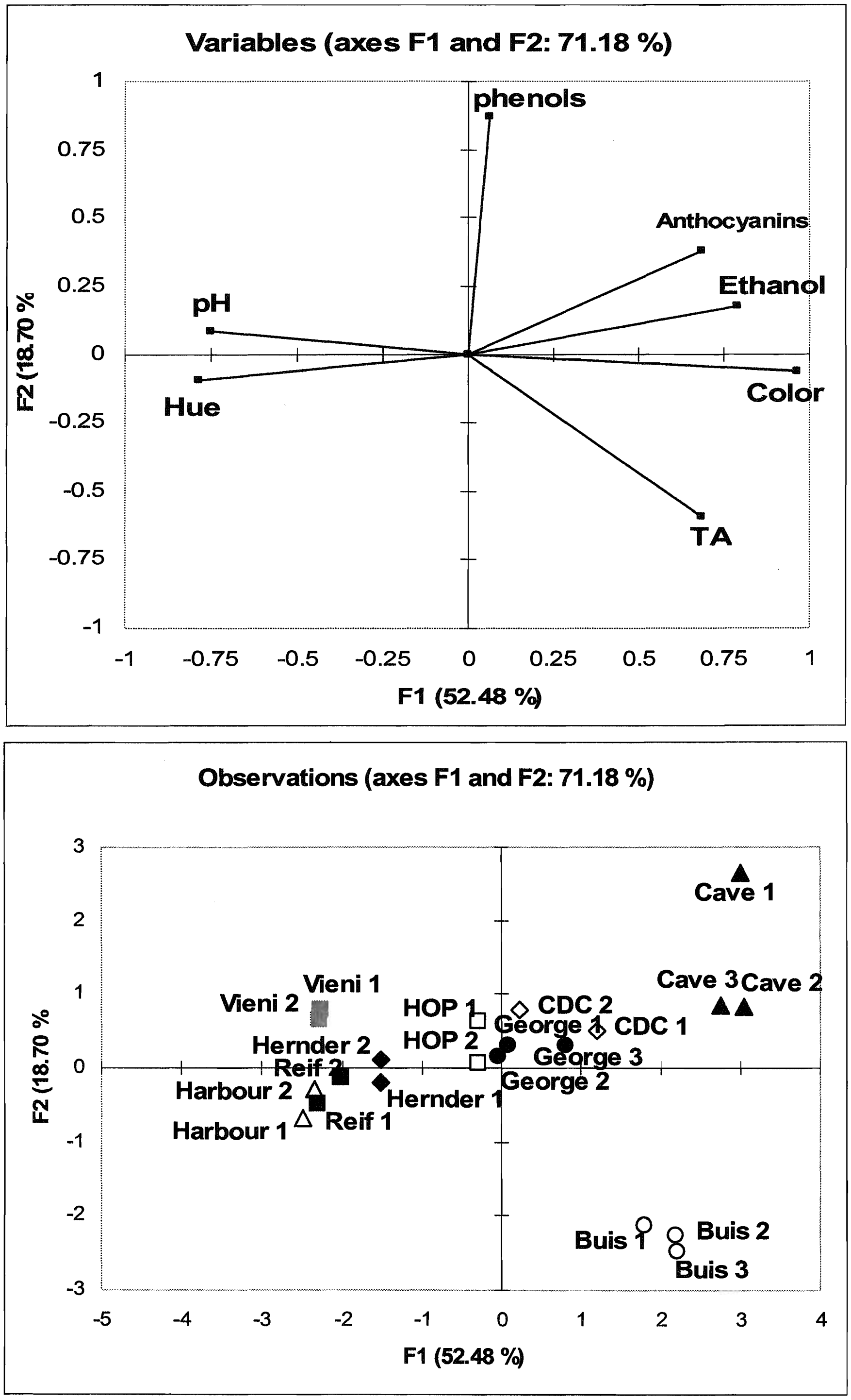


Figure 6. Principal component analysis of mean chemical data for nine Cabernet Franc wines from Niagara Peninsula, ON, 2005. CDC, HOP, Cave and Harbour are abbreviations for Château des Charmes, Henry of Pelham, Cave Spring and Harbour Estate sites, respectively.

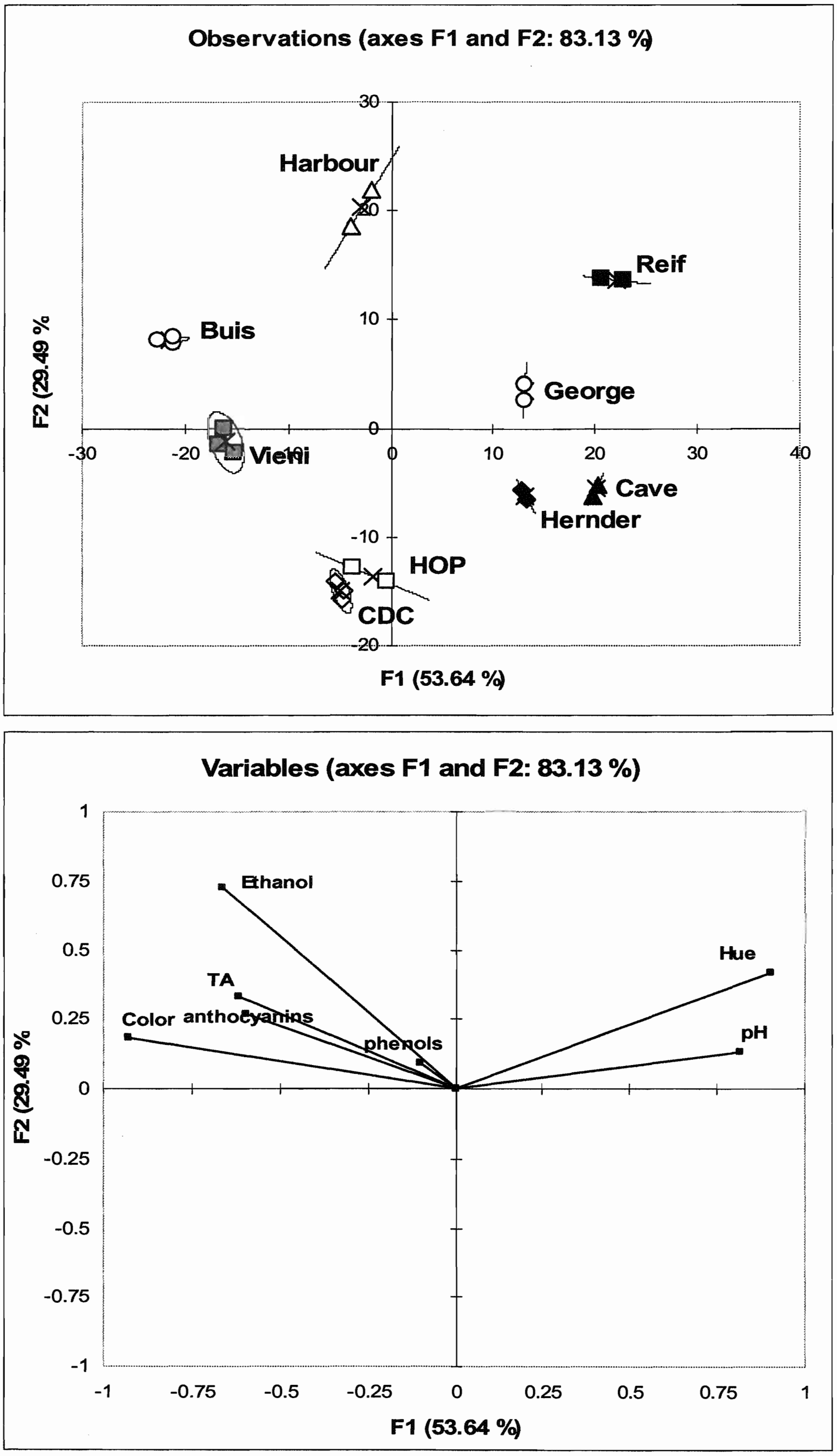


Figure 7. Discriminate analysis (F1 & F2) of mean chemical data for nine Cabernet Franc wines from Niagara Peninsula, ON, 2005. CDC, HOP, Cave and Harbour are abbreviations for Château des Charmes, Henry of Pelham, Cave Spring and Harbour Estate sites, respectively.

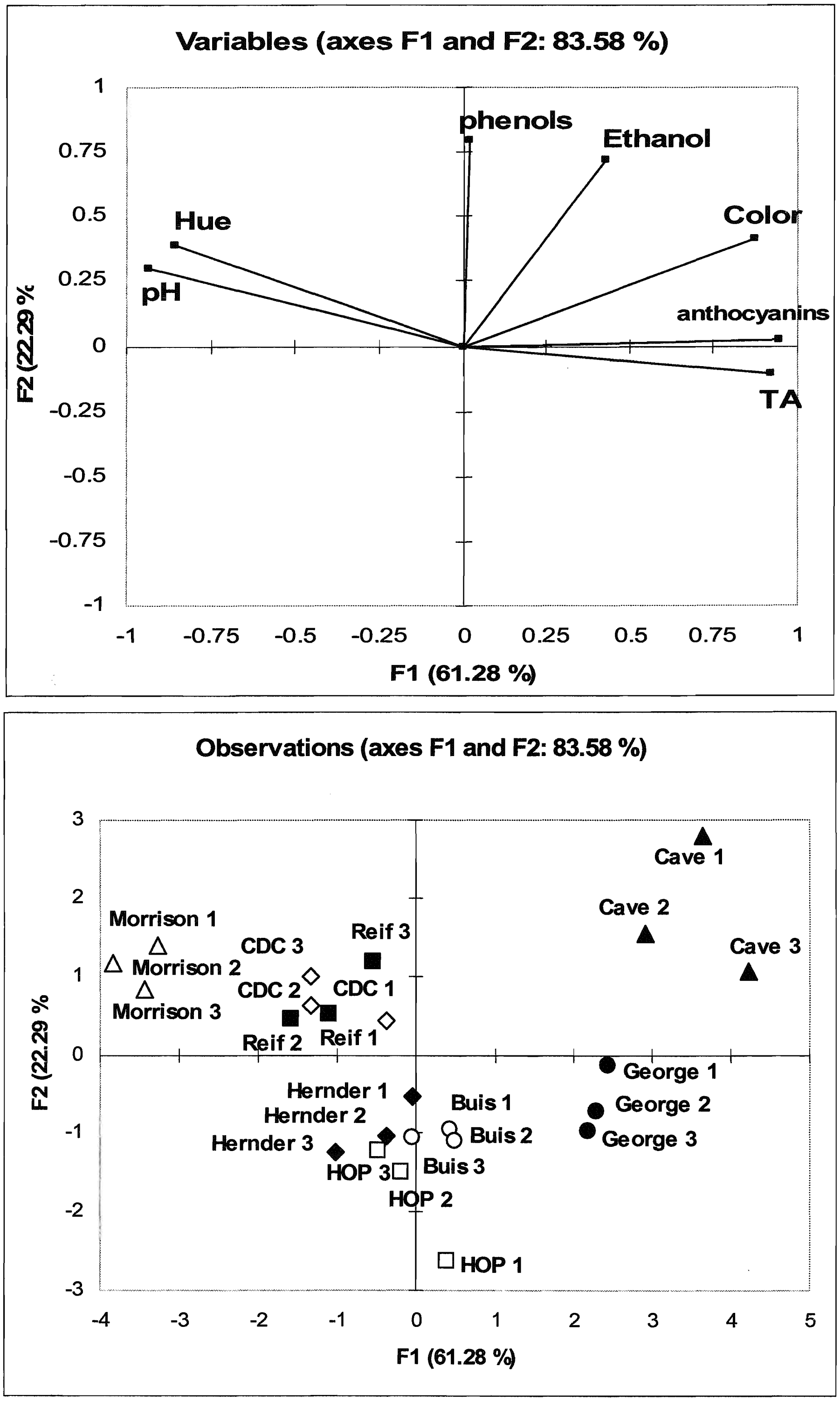
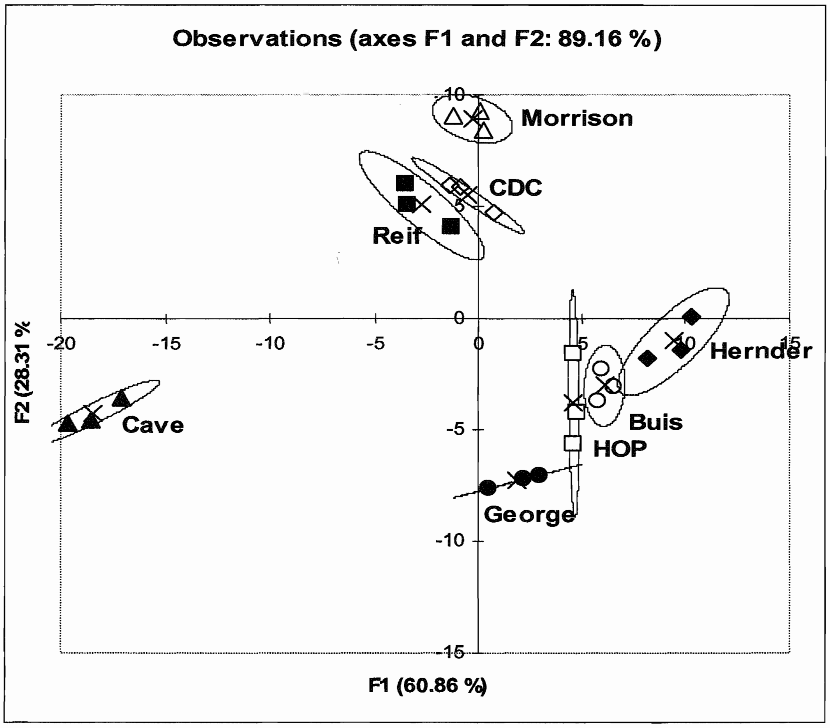


Figure 8. Principal component analysis of mean chemical data for eight Cabernet Franc wines from Niagara Peninsula, ON, 2006. CDC, HOP, Cave and Harbour are abbreviations for Château des Charmes, Henry of Pelham, Cave Spring and Harbour Estate sites, respectively.



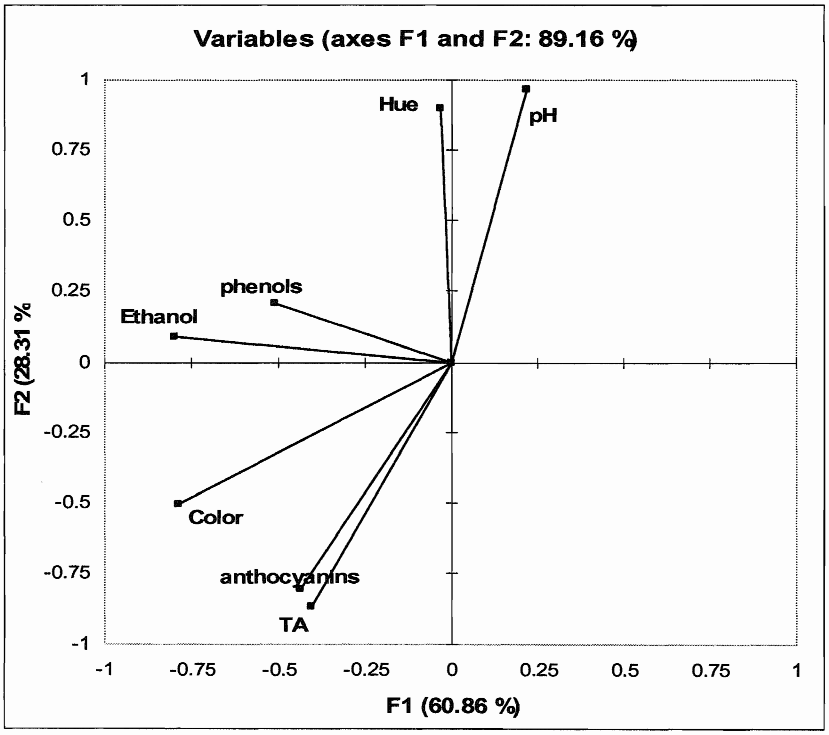


Figure 9. Discriminate analysis (F1 & F2) of mean chemical data for eight Cabernet Franc wines from Niagara Peninsula, ON, 2005. CDC, HOP, Cave and Harbour are abbreviations for Château des Charmes, Henry of Pelham, Cave Spring and Harbour Estate sites, respectively.

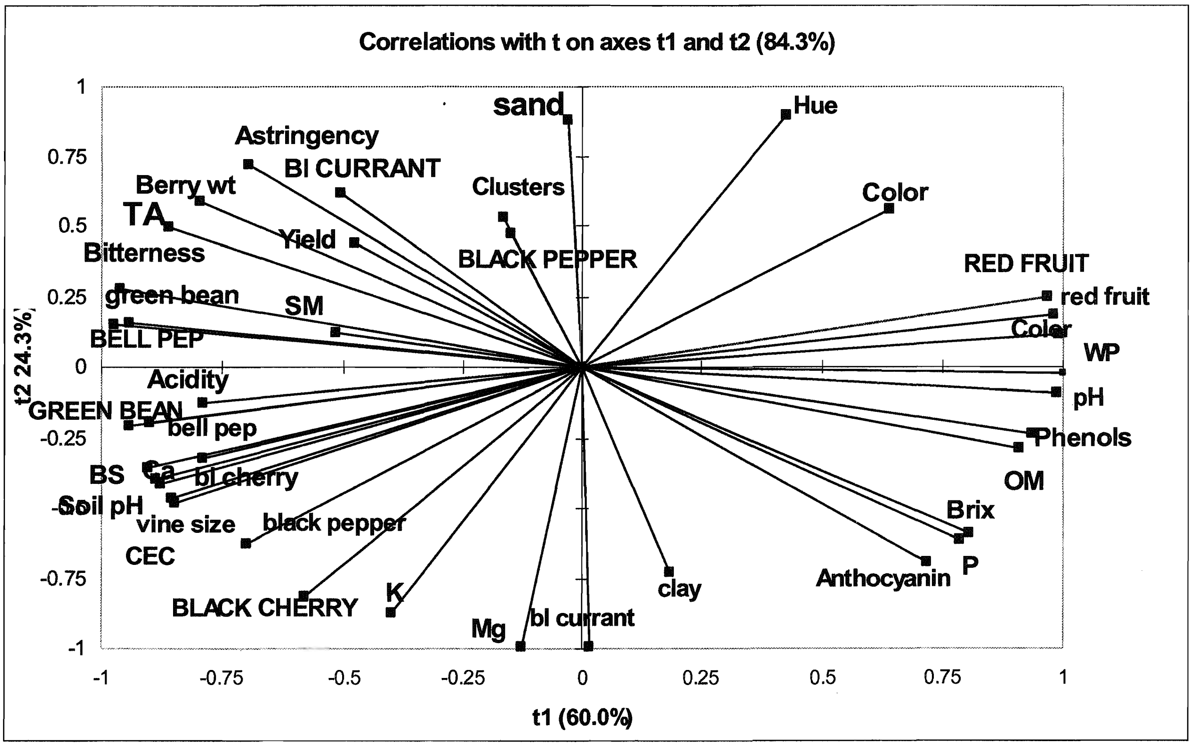


Figure 10. Partial Least Squares analysis of field and sensory data for nine Cabernet Franc wines from Niagara Peninsula, ON, 2005. Aroma attributes are represented in lowercase and flavor attributes are represented in uppercase.

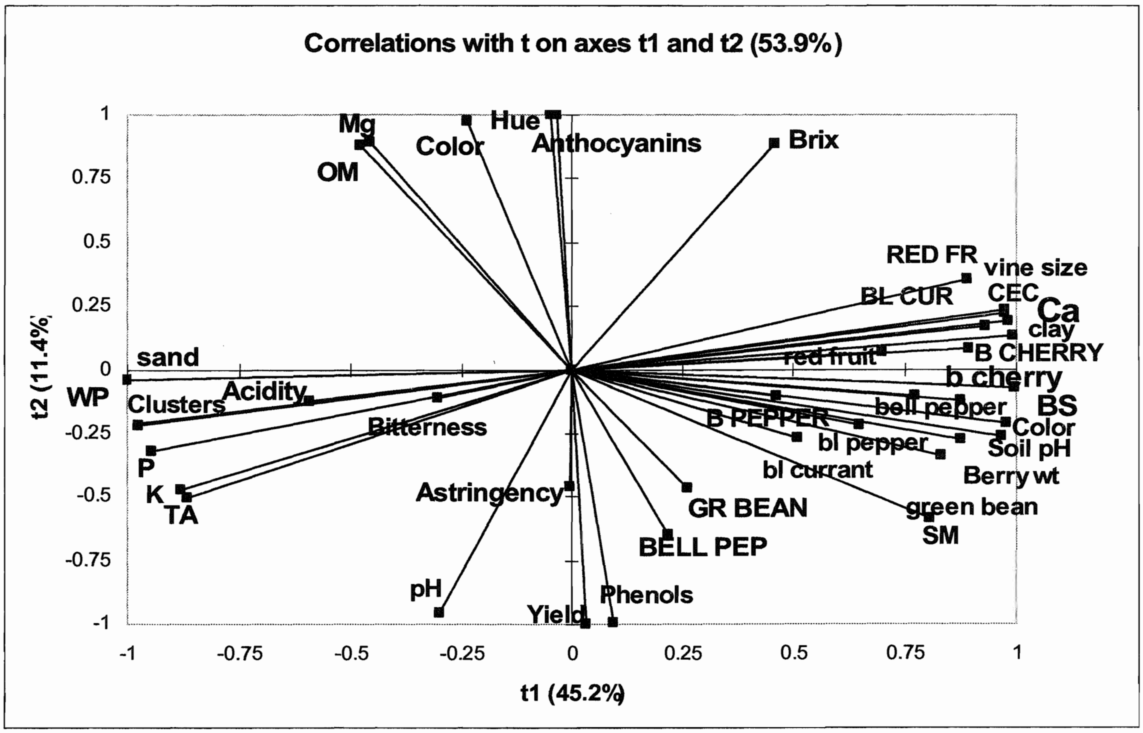


Figure 11. Partial Least Squares analysis of field and sensory data for eight Cabernet Franc wines from Niagara Peninsula, ON, 2006. Aroma attributes are represented in lowercase and flavor attributes are represented in uppercase.

Chapter 6

Impact of Vine Water Status on Sensory Evaluation of Cabernet Franc Wines in the Niagara Peninsula of Ontario

Abstract. The dependence of wine sensory response on vine water status was studied in *Vitis vinifera* L cv. Cabernet Franc in Niagara Peninsula, ON, in the 2005 and 2006 vintages. Vine water status was monitored in ten vineyard blocks using midday leaf water potential (Ψ) values. Leaf Ψ varied within and between vineyards in both years. Chemical and descriptive sensory analysis were performed on nine (2005) and eight (2006) pairs of experimental wines to illustrate differences between wines from high and low water status (HWS, LWS) zones in each vineyard. Twelve trained judges evaluated six aroma and six flavor (red fruit, black cherry, black current, black pepper, bell pepper, and green bean), three mouthfeel (astringency, bitterness and acidity) sensory attributes as well as color intensity. Each pair of HWS and LWS wine was compared using a t-test. In 2005, LWS wines from Buis, Harbour Estate, Henry of Pelham (HOP), and Vieni had higher color intensity; LWS wine from Château des Charmes (CDC) was high in black cherry flavor; at Rief was high in red fruit flavor and at George site was high in red fruit aroma. Similar trends were observed in 2006 vintage. No differences were found from one year to the next between the wines produced from the same vineyard, indicating that the attributes of these wines were consistent despite markedly different conditions in 2005 and 2006 vintages. Partial Least Squares analysis showed that leaf Ψ was associated with red fruit aroma and flavor, berry and wine color intensity, total phenols, Brix and anthocyanins while soil moisture was correlated with acidity, green bean aroma and flavor as well as bell pepper aroma and flavor.

Introduction

Wine water status has long recognized as an important factor determining winegrape quality and as a consequence affecting wine sensory attributes. Many papers have reported the impact of vine water status on the accumulation of various grape metabolites. Very few papers investigated the impact of vine water status in non-irrigated situations (van Leeuwen and Seguin 1994, Chone *et al.* 2001). For red winegrapes some extent of water deficit during the growing season has been considered as beneficial for quality (Bravdo *et al.* 1985, Williams and Matthews 1990). Sensory evaluation on wines made from four irrigation treatments showed significant differences in appearance, flavor, taste and aroma (Matthews *et al.* 1990). Chapman *et al.* (2005) studied the dependence of wine sensory attributes on vine water status in *Vitis vinifera* L. cv. Cabernet Sauvignon and showed that wines made from the minimal irrigation treatment were significantly higher in red/black cherry aroma, jam/cooked berry aroma, dried fruit/raisin aroma than the wines from the irrigated treatments. Koundouras *et al.* (2006) investigated the influence of site on grape and wine composition in three non-irrigated plots in *Vitis vinifera* L. cv. Agiorgitiko, in southern Greece and indicated that wines produced from grapes of stressed vineyards were preferred in tasting trails. However, they didn't perform sensory evaluation on the produced wines.

Secondary metabolites produced by grapes, are the main sources of wine color, aroma and flavor. Many studies have been conducted regarding the phenolic compounds of the skin as they play an important role in the quality of red grapes, providing much of the color and structural properties of wines. A Cabernet Franc study in California has shown that the concentration of organic acids (especially malate), anthocyanins and total phenolics in harvested grapes was altered by small changes of vine water status at different stages of vine development (Matthews and Anderson 1988). Esteban *et al.* (2001) found that vine water status affects the rate of accumulation of phenolic compounds in grapes. Most of these studies show a clear positive effect of water deficit on berry phenolic composition. Few data exist regarding the effect of vine water status

(Matthews *et al.* 1990, Escalona *et al.* 1999) on the volatile components of grapes and wines. The goal of this research was to examine the impact of vine water status on sensory and chemical characteristics of Cabernet Franc wines in Niagara Peninsula, Ontario to find out if these differences could be detected consistently.

Materials and Methods

Vine water status. Midday leaf water potential (Ψ) was determined between 1100h and 1600h for fully exposed, mature leaves of similar physiological stage which showed no visible sign of damage and had been in full sunlight. Each leaf sample was covered in a plastic bag and sealed immediately after excision at the petiole to suppress transpiration. The leaf petiole was cut with a sharp razor blade and then inserted into a pressure chamber Model 3005 Plant Water Status Console (Soil Moisture Equipment Corp., Santa Barbara, CA) with the cut edge of the petiole facing the outside surface. After sealing the chamber, pressure was increased slowly by opening the compressed nitrogen valve. As soon as sap emerged at the cut end of the petiole, gas flow was stopped and the corresponding pressure was recorded from the gauge, which was in negative bar units (10 bars = 1MPa). A total of 15 to 20 leaves per vineyard block were used to estimate leaf Ψ for each sample date. Overall, there were five sampling dates during the growing season, bi-weekly between late June and early September for each site.

Soil water status: Soil moisture data were taken bi-weekly between late June and early September in the 2005 to 2006 growing seasons for a total of five sampling dates. These data were determined using a Fieldscout TDR-300 soil moisture probe (Spectrum Technologies Inc., East Plainfield IL). Readings (% water by volume) were taken at each of the experimental vines in each block. In total, 72 to 80 vines per site were measured between 0800h and 1800h. Measurements were taken in the row ca 10 cm from the base of each vine trunk over a 20 cm depth. The mean soil moisture at each sentinel vine was calculated from the five separate readings.

The experimental vines were selected based on a grid pattern, all of which were geo-located by Raven Invicta 115 GPS Receiver Raven Industries (Sioux Falls, SD) with 1.0-1.4 meters accuracy. Using GIS programs MapInfo and Vertical Mapper (Northwood GeoScience, Ottawa, ON) water status zones were mapped based on vine leaf Ψ values. Each vineyard block was separated into three zones of high, medium, and low water status (HWS, MWS, LWS respectively). Grapes from each of these water status zones were harvested separately based on the leaf Ψ map for each vineyard block in both 2005 and 2006, and these were used to make wine. Therefore, from each vineyard block, three water status designations- HWS, MWS and LWS- were used to make wines in both years.

Chemical analysis: Each wine sample was analyzed for pH via an Accumet pH meter (model 25; Denver Instrument Company, Denver, CO), and titratable acidity (TA) with a PC-Titrate autotitrator (Man-Tech Associates, Guelph, ON) by titration with 0.1 *N* NaOH to an end point of pH 8.2. Ethanol was determined using an Agilent 6890 series GC system gas chromatograph (Wilmington, DE) equipped with an Omegawax 250 fused silica (30.0 m x 250.00 μm x 0.25 μm) column. Other conditions of operation included: carrier gas helium, split ratio of 100.183:1, oven initial temperature 60°C, injection temperature 230°C, and detector temperature 225°C. Wine samples or standards were diluted 1:10 with 2% 1-butanol as internal standard. A 1.0 μL wine sample or standard was injected by an automatic injector and the run time was 5.07 min.

Total phenols, anthocyanins, and color intensity were also determined in wine samples. Total phenols were estimated using standard methods (Slinkard and Singleton 1977). Anthocyanin measurements were performed on wine samples using the pH shift method by measuring the differential absorbance at 520 nm between wines at pH 1.0 and pH 4.5 (Mazza *et al.* 1999). Color intensity was determined according to a modified method provided by Mazza *et al.* (1999) while a 12% ethanol solution was used as a blank. Color intensity and hue were calculated from absorbance values measured at 420 nm and 520 nm on an Ultrospec 2100 Pro UV/VIS spectrophotometer (Biochrom Ltd., Cambridge, UK).

Origin of wines: Within each vineyard block, high and low water status zones were identified accordingly on GIS-generated maps. At harvest fruit from each water status zones were hand harvested separately and were brought to the Cool Climate Oenology and Viticulture Institute (CCOVI). From each water status zone, approximately 70 to 80 kg fruit were used and overall 950 liters of wine was produced each year (2005 and 2006). Grapes from each water status zone from each vineyard block were de-stemmed, crushed and sulfited with potassium metabisulfite (KMS) at 25 mg/L and then inoculated with LALVIN (Selection ICV) 254 *Saccharomyces cerevisiae* yeast (Lallemand Inc., Montreal, QC). All fermentations were done in 20-L plastic buckets each covered with a lid and air lock. Fermentation was carried out on the skins at 23 °C in an isolated room; with three daily punch downs of the caps for 7 days until dryness. Maceration was allowed to proceed until the caps had fallen for additional 2 days. A bladder press was used to press off the skins to a maximum pressure of 2 bars, and the young wines were transferred into 18-L glass carboys. Wines were kept in -2°C for cold stabilization for 10 days, and afterwards they were racked, sulfited at 25 mg/L and inoculated with *Oenococcus oeni* LALVIN VP41 (Lallemand Inc.) to induce malolactic fermentation, which completed in approximately 4 weeks. Wines were thereafter racked and kept in -2°C for cold stabilization for a week to precipitate potassium bitartrate from the wine. Following cold stabilization, wines were allowed to warm up to room temperature to prevent excess oxygen pick up by the cold wine and afterwards 50 mg/L KMS was added to all wine treatments, filtered through 1 μ pad filter and 0.45 μ cartridge filter, and then bottled.

Sensory methodology for Cabernet Franc wines: The initial group of 20 judges composed of Brock University faculty, staff, and students were selected for the panel based on their availability and motivation. Six judges were experienced tasters and the others were students with limited wine tasting experience. Eight judges either withdrew or were dropped from the panel by the end of the training sessions. The final panel consisted of five females and seven males whose ages ranged from 22 to 54 years.

Nine (2005) and eight (2006) pairs of HWS/LWS wines were evaluated by 12 judges (t=18/16, k=8, r=4, b=12), where t, k, r, and b are the number of treatments (wines), number of samples/session, number of replicates and sample sets in each session (or number of panelists), respectively. At the initial point of training, wine samples were presented to the panel to evaluate and identify relevant aroma, flavor, and mouthfeel attributes. The six experienced tasters individually evaluated these wines and wrote relevant attributes on evaluation sheets. Eight training sessions were thereafter held for all judges. Reference standards were available to define descriptors. In each training session, judges were asked to independently rate the intensity of the descriptive terms in the wine samples as well as standards themselves, and to add terms if necessary. There were also three mouthfeel standards including astringency, bitterness, and acidity to be used for evaluating sample wines (Table 1).

In each training session, three sample wines were served with random codes to all judges to train them to be able to evaluate all wine samples as accurately and consistently as possible. After each training session, data were analyzed to evaluate the performance of each judge. Each attribute was also examined by analysis of variance to find out if that attribute varied across the wine samples and that if the judges were consistent and reproducible.

In each session, each judge evaluated eight wines in two flights of four. Judges were given 30-mL wine samples to evaluate in the room temperature (~22°C), for the sensory (aroma, flavor, and mouthfeel) attributes. Samples were in 210-mL ISO approved wine glasses and covered with Petri dishes to prevent volatile loss. Glasses were labeled with three-digit random numbers and presented to judges in random order according to the design. All evaluations were conducted using Compusense Five, (release 4.8, Compusense Inc., Guelph, ON, Canada) in isolated booths under red light to mask the color differences among wine samples. For color intensity evaluation, 10-mL wine samples were also presented in 5-cm diameter Petri dishes against a white background under natural light, with the same random numbers.

First, the judges evaluated aroma and flavor in the first four wines, and then while they took a short break, evaluated color intensity for the same wines and finished the session by evaluating the second flight of four wines. Evaluation of the magnitude of each attribute was done on a 15-cm unstructured line scale, where 0 and 15 were anchored with the labels 'absent' and 'high' respectively. Sensory scores were determined by measuring the judges scored mark from the origin in cm. Judges rinsed with water and pectin solution between flavor evaluations in order to prevent carry over effect. Evaluations were started in the morning at 1100h and continued until late afternoon to accommodate all judges' schedules. All evaluations were done at Brock University's sensory evaluation room. All wine samples were poured from the same single bottles (750 mL) for duplicates. Aroma standards (Table 1) developed during the training sessions were available to judges prior to each session as reference.

Data analysis. Wines from each of high and low water status zone from each vineyard block were subjected to descriptive analysis. A correlation matrix was created on the sensory attributes to illustrate the relationship among variables. Using a t-test, chemical and sensory attributes were compared at each site by means of XLSTAT 2008 (Paris, France). Principal Components Analysis (PCA) was performed using XLSTAT 2008 on the mean sensory scores for the aroma, flavor, and mouthfeel attributes. Partial Least Squares (PLS) was performed using XLSTAT (Paris, France) on the field, berry composition and sensory data to ascertain relationships between these data.

Results and Discussion

Grapevine water status. The results showed that vine water status varied within all vineyard blocks enabling to separate vines to three groups of high, medium and low water status (HWS, MWS, LWS) at each vineyard block. Leaf Ψ tended to decrease during the growing season as the soil water content decreased and average temperature increased in both 2005 and 2006 years and minimum values were usually observed by the end of August. Leaf Ψ was different within each vineyard block as well as across vineyards. However, the range of leaf Ψ values remained almost consistent in most vineyard blocks in both years even with different weather conditions (Fig. 1A). The lowest leaf Ψ values were observed at CDC and Hernder sites in both 2005 and 2006 years. At CDC leaf Ψ values in HWS treatments were -12.0 and -12.5 bars in 2005 and 2006 and about 4 and 2.5 bars less in LWS treatments, respectively. Similarly, at the Hernder site, leaf Ψ values in HWS treatment were -12.6 and -12.9 bars in 2005 and 2006 and about 3.3 and 3.1 bars less in LWS treatments. The highest leaf Ψ values were observed at Harbour site in both years such that leaf Ψ values in HWS treatments were -8.0 and -9.0 bars in 2005 and 2006 while values of LWS treatments were 2.9 and 2.5 bars less than HWS, respectively. Water stress was always more intense at the CDC and Hernder sites, mainly due to shallow vine rooting and high clay content. Vines at the Harbour site did not face water stress because of deep rooting system and sandy soil. Williams and Araujo (2002) reported the Chardonnay vines that received quantities of ~100% evapotranspiration (ET) had leaf Ψ values of – 10 bars, which suggests that vines at the Harbour site were in a high water availability condition similar to that of irrigated vines. The range of leaf Ψ values at George, Cave Spring, Vieni and Morrison sites were higher in 2006 compared to 2005 due to higher precipitation in 2006. In 2005, which was a dry and hot year, water stress appeared earlier and was more severe. The leaf Ψ values observed in the different sites are in the range commonly reported for non-irrigated grapevines (Williams and Matthews 1990).

Soil moisture. Soil moisture values also varied among vineyards as well as within vineyards in both the 2005 and 2006 years (Fig. 1B). The lowest soil moisture values were observed at Hernder and Rief sites such that at the Hernder site, lowest soil moisture values were 7.3% and 15.1% in 2005 and 2006, while values were 6.1% and 12.9% higher in high soil moisture areas. Likewise, at the Rief site, low soil moisture values were 7.6% and 11.3% in 2005 and 2006 years, while values were 6.0% and 14.3% higher in high soil moisture areas. The highest soil moisture values in 2005 were at the Buis site with a range of 14.0% to 20.4%; in 2006 the highest soil moisture values were observed at the Vieni site with range of 22.2% to 35.9%. Overall, soil moisture values were higher in 2006 at all sites in comparison with 2005 due to higher precipitation in 2006 (Fig. 1B). High soil water availability reduced vine water stress by increasing leaf Ψ values. The data indicated that midday leaf Ψ was a better indicator of vine water status than soil moisture content (Fig. 1B).

Site differences. Sensory evaluation of Cabernet Franc wines from LWS and HWS vines showed that differences in vine water status resulted in wines with different composition, appearance, aroma and flavor. At almost at all sites in 2005, LWS wines were associated with more fruity, less vegetal character and higher color intensity; however, at each site, specific attributes were significantly different between LWS and HWS wines. Comparing high and low water status wines in the 2006 vintage indicated that there were differences between wines at all sites except HOP (Fig. 6B). For instance, at the Buis site in 2005, LWS wines showed less green bean flavor and higher color intensity compared with HWS wines (Fig. 2A), while in 2006, LWS wines had lower acidity (Fig. 2B). Higher red fruit flavor was detected in LWS wine at Reif in 2005 (Fig. 3A) but LWS wines in 2006 were high in bell pepper aroma and flavor (Fig. 3B). At CDC, black cherry flavor was higher in LWS wines in 2005 (Fig. 4A), similarly in 2006, LWS wines characterized with high black cherry aroma, low bell pepper aroma and more bitterness (Fig. 4B). At the Hernder site, there were no differences between LWS and HWS wines in 2005 (Fig. 5A), but in 2006, higher red fruit aroma and flavor was detected in LWS wines (Fig. 5B). At the HOP site, less black cherry and higher color intensity were observed in LWS wine in 2005 (Fig. 6A), while no differences were observed in 2006 (Fig. 6B). At the Harbour site in 2005, there was less bell pepper aroma and flavor in LWS wines as well as lower acidity and higher color intensity (Fig. 7). At the Morrison site in 2006, higher black cherry aroma, higher bell pepper flavor, lower acidity and higher color were detected in LWS wines (Fig. 8). There was higher red fruit and black currant aroma and higher black pepper flavor in LWS wines at the George site in 2005 (Fig. 9A), while in 2006, LWS wines had higher black cherry, lower black pepper and lower bell pepper aroma, as well as lower black pepper flavor and high color intensity (Fig. 9B). At the Vieni site in 2005, higher color intensity and higher green bean flavor were detected in LWS wines (Fig. 10). At Cave Spring site there were no differences between LWS and HWS wines in 2005 (Fig. 11A), but LWS wines in 2006 had higher black currant and low green bean aromas with higher color intensity (Fig. 11B).

Low vine water status overall produced significant sensory aromas and flavor differences in the resultant wine, including reduced vegetal character (bell pepper aroma and flavor, green bean aroma and flavor) and increased red and black fruit aroma and flavor. This is consistent with the result of Koundouras *et al.* (2006) study in which they found that limited water availability increased the main aromatic compounds of the grapes and the resultant wines were preferred in tasting trials. These differences in wine sensory attributes due to vine water status provides a basis for managing vine water status in winegrape production to produce high quality wine profile.

Principal components analysis. PCA was performed on sensory data in 2005, which shows the relationship between aroma and flavor attributes in nine pairs of high and low water status wines (Fig. 12). After rotation, PCA explained 55.3% of the variability in the data in the first two dimensions. PC1 accounted for 28.0% of the variability and most heavily loaded in positive direction with red fruit, black cherry, and black currant aroma and flavor. PC2 explained 27.3% of the variation in the data set, and positively loaded with green bean, bell pepper and black pepper aroma and flavor. The third PC explained another 16.6% of variation (Fig. 13).

Some attributes such as red fruit and black currant aroma and flavor were grouped in the lower right of the plane (Fig. 12). Black cherry and black pepper aroma and flavor were grouped in the upper right quadrant. Bell pepper and green bean aroma and flavor were grouped with color intensity, astringency and bitterness in the upper left of the plane. Interestingly, aroma of each attribute was highly positively correlated with its flavor. Red fruit and black currant aroma and flavor were negatively correlated with bell pepper and green bean aroma and flavor. Overall, all fruity attributes were highly positively loaded on PC1 and negatively on PC2. Vieni (H, L), Hernder (H, L), Cave Spring (H, L), Rief (H, L) and CDC (L) were all on the right hand side of the plane and were explained with red and black fruit aroma and flavor. George (H, L), Buis (H, L), Harbour (L) and CDC (H) were on upper left side of the plane and explained with bell pepper and green bean aroma and flavor as well as bitterness. Most of the LWS wines were located on the right hand side of the plane and explained with red and black fruit aroma/flavor. There was also a good separation of HWS and LWS wines at each site (Fig. 12).

Descriptive analysis of Cabernet Franc wines produced a contrast between fruity and vegetal descriptors. This is in agreement with Chapman *et al.* (2005) study where they found the same trend on Cabernet Sauvignon in which wines made from minimal irrigation treatments were characterized with higher red and black fruity aroma and flavor than wines from the irrigated treatments. In the current study, most of the variability in wine sensory perception was explained by differences in vegetal and fruity characters. On almost all sites, LWS wines had the lower rating for bell pepper aroma and flavor as well as for green bean aroma and flavor and had the higher rating for red fruit aroma and flavor as well as black fruit aroma and flavor. Our findings are consistent with those from Matthews *et al.* (1990) in which they compared early and late water deficit vines with continually irrigated ones and reported that continually irrigated wine differed from early and late season water deficit wine, and early season water deficit wine differed from late season water deficit wine in appearance, flavor, taste and aroma. However, they didn't perform sensory evaluation on the resultant wines. Our results are also consistent with those from Noble *et al.* (1995) in which fruity wines were associated with soils with low water holding capacities, and wines with vegetal characters were associated with soils with high water holding capacities. However, water status of the vines was not measured in that study, so it is not clear whether the differences in soil texture had any influence on vine water status.

The relationship between aroma and flavor attributes in eight pairs of high and low water status Cabernet Franc wines in 2006 are likewise illustrated by PCA (Fig. 14).

After rotation PCA explained 68.9% of the variability in the data set in the first two dimensions. PC1 explained 47.5% of the variability and most heavily loaded in positive direction with red fruit, black cherry, and black currant, black pepper aroma and flavor as well as bell pepper flavor and acidity. PC2 explained 21.4% of the variation in the data set, and positively loaded with green bean aroma and flavor as well as bell pepper aroma and bitterness (Fig. 14). The third PC explained another 10.8% of variation (Fig. 15).

Red fruit aroma and flavor were positively correlated in the lower right hand side of the plane. Some attributes such as black pepper aroma and flavor, black cherry aroma and flavor, black currant aroma and flavor, bell pepper flavor and astringency were positively correlated and grouped together in the upper right of the plane. Green bean aroma and flavor, bell pepper aroma and bitterness were also positively correlated and grouped together (Fig. 14). Again, in most cases, aroma of each attribute was highly positively correlated with its flavor. Overall, all fruity attributes were highly positively loaded on PC1 and negatively on PC2. CDC (L, H), Cave Spring (L), and George (L) were explained with red fruit aroma and flavor. HOP (L, H) and Morrison (L) were associated with black cherry, black currant and black pepper aroma and flavor. Morrison (H), George (H) and Hernder (L, H) were explained with green bean aroma and flavor and bell pepper flavor. Rief (L, H) as well as Buis (L) were explained with green bean flavor (Fig. 14). Most of the LWS wines were located on the right hand side of the plane and explained with red and black fruit aroma/flavor. There was a good separation of HWS and LWS wines at each site (Fig. 14).

Vine water status influences almost every aspect of plant metabolism (Bradford and Hsiao 1982, Niel and Burnett 1999) and as a result it affects most aspects of fruit composition as well. Water supply as irrigation is essential for grape production in some environments; therefore vine water status can be a regulation key to manipulate fruit composition and as a result wine sensory attributes. Although it is crucial to carry out vineyard trails over to sensory analysis of wines if the goal is to manipulate wine sensory response through vineyard management however, most irrigation/water relation studies illustrate the relationships among vine water status and fruit composition, yield components and only a few of these studies has been carried through to a sensory evaluation of resultant wines.

Chemical analysis. Chemical analysis of HWS and LWS wines from 2005 vintage showed that there was no differences between high and low water status wines at the Buis, CDC and Reif sites; however, at all other sites some differences were observed (Table 2). For example, at the Hernder site, higher pH was detected in LWS wine while at the Harbour site, LWS wine was characterized with high anthocyanins, high total phenols and low TA. Contrary to our results Freeman and Kliewer (1983) reported increased wine pH in Carignane from non-irrigated to irrigated treatments. However, Matthews *et al.* (1990) found no consistent irrigation treatment differences on wine pH across years.

Higher color intensity was observed in both Cave Spring and Vieni sites in LWS wine. At the George site, LWS wine was associated with lower color intensity, anthocyanins and total phenols, while at HOP, LWS wines had high total phenols, pH and ethanol (Table 2). This is consistent with the study performed by Matthews *et al.* (1990) in which they found higher color intensity and higher concentration of anthocyanins and total phenols in water deficit treatments than in continually irrigated vines. Koundouras *et al.* (2006) also reported that early water deficit during the growth period had beneficial effect on the concentration of anthocyanins and total phenols in the produced wines.

Chemical analysis of high and low water status wines in the 2006 vintage illustrated higher pH and low TA in LWS wines in both Hernder and Reif sites (Table 2). At George site LWS wine was characterized with low hue, high color intensity and high anthocyanins. Higher color intensity was found in LWS wine at Cave Spring, while LWS wine at HOP had lower ethanol. There were no differences between high and low water status wines at Buis, CDC, and Morrison sites (Table 2). Similar to our results, Salon *et al.* (2005) showed that the concentration of anthocyanins and total phenolics in rose wines as well as red wine anthocyanins, total phenols and color intensity significantly decreased with increasing water availability. They also showed that anthocyanins and total phenols were positively correlated with vine water status such that the more negative the leaf Ψ the higher the anthocyanins and total phenols concentration.

Partial least squares analysis. PLS was performed on the whole data set in 2005, which showed relationships among yield components, fruit composition, vine size, soil attributes and water relations with sensory data. PLS explained 84.3% of the variability in the data set (Fig. 16). It illustrated that leaf Ψ was positively correlated with red fruit aroma/flavor, berry pH, berry color intensity, wine color intensity, total phenols and Brix, while negatively correlated with soil moisture, green bean aroma/flavor as well as bell pepper aroma/flavor. Vine size was positively correlated with bell pepper flavor, green been aroma and acidity. Soil moisture positively correlated with acidity, bitterness, vine size, bell pepper aroma/flavor, green bean aroma/flavor and black cherry aroma and flavor. Clay was positively correlated with black currant flavor (Fig. 16). PLS analysis in

2006 explained 53.9% of the variation in data set and indicated that soil moisture was positively correlated with green bean aroma/flavor, bell pepper aroma, yield and total phenols. Clay also was positively correlated with red fruit aroma and flavor, black currant aroma and black cherry flavor (Fig. 17).

Conclusions

Measurement of midday leaf Ψ in this study was successful in detecting differences among vine water status levels throughout the growing season. The range of leaf Ψ values were almost consistent at most sites in both 2005 and 2006 years. Differences in vine water status resulted in wines with different composition, aroma, flavor, and color intensity. Almost at all sites LWS wines were associated with high red fruit aroma and flavor, black fruit aroma and flavor, berry and wine color intensity, total phenols, anthocyanins and berry pH.

Despite two different vintages of hot and dry (2005) and wet (2006) seasons, similar trends were observed in high and low water status wines. PLS illustrated that leaf Ψ was positively correlated with red fruit aroma/flavor, berry color intensity, wine color intensity, total phenols and Brix, while negatively correlated with soil moisture, green bean aroma/flavor as well as bell pepper aroma/flavor.

Under the conditions of this study, the data indicate that midday leaf Ψ would be a better indicator of vine water status than soil moisture content. Therefore, vine water status offers a means by which wine sensory characteristics can be manipulated.

Literature Cited

Bradford K.I. and T.C. Hsiao. 1982. Physiological responses to moderate water stress. Plants' effect on growth and metabolism, growth regulators response, stomatal behavior, photosynthesis, respiration, proline and betaine transport, nutrient uptake. Encyclopedia of plant physiology, Vol. 128, Springer. Pp. 263-324.

Bravdo B., Y. Hepner, C. Loinger, S. Cohen, and H. Tabacman. 1985. Effect of irrigation and crop level on growth, yield and wine quality of Cabernet Sauvignon. Amer. J. Enol. Viticult. 36:132-139.

Chapman D., G. Roby, S.E. Ebeler, J.X. Guinard, and M.A. Matthews. 2005. Sensory attributes of Cabernet Sauvignon wines made from vines with different water status. Austral. J. Grape and Wine Research 11:339-347.

Chone, X., C. van Leeuwen, P. Chery, and P. Ribereau-Gayon. 2001. Terroir influence on water status and nitrogen status of nonirrigated Cabernet Sauvignon (Vitis vinifera): vegetative development, must and wine composition. S. Afr. J. Enol. Vitic. 22:8-15.

Escalona J.M., J. Flexas, H.R. Schultz, and H. Medrano. 1999. Effect of moderate irrigation on aromas potential and other markers of grape quality. Acta Hortic. 493: 261-267.

Esteban M.A., M.J. Villanueva, and J.R. Lissarrague. 2001. Effect of irrigation on changes in the anthocyanin composition of the skin of cv. Temperanillo (*Vitis vinifera* L.) grape berries during ripening. J. Sci. Food Agric. 81:409-420.

Freeman, B.M. and W.M. Kliewer. 1983. Effect of irrigation, crop level and potassium fertilization on Carignane vines. II. Grapes and wine quality. Amer. J. Enol. Vitic. 34:197-207.

Koundouras S., V. Marinos, A. Gkoulioti, Y. Kotseridis, and C. van Leeuwen. 2006. Influence of vineyard location and vine water status on fruit maturation of non-irrigated cv. Agiorgitiko. Effects on wine phenolic and aroma components. J. Agric. Food Chem. 54:5077-5086.

Matthews, M.A. and M.M. Anderson. 1988. Fruit ripening in *Vitis vinifera* L. Responses to seasonal water deficits. Amer. J. Enol. Vitic. 39:313-320.

Matthews M.A., R. Ishii, M.M. Anderson, and M. O'Mahony. 1990. Dependence of wine sensory attributes on vine water status. J. Sci. Food Agricult. 51:321-335.

Mazza, G., L. Fukumoto, P. Delaquis, B. Girard, and B. Ewert. 1999. Anthocyanins, phenolics, and color of Cabernet Franc, Merlot, and Pinot noir wines from British Columbia. J. Agric. Food Chem. 47:4009-4017.

Neil S.J. and E.C. Burnett. 1999. Regulation of gene expression during water deficit stress. Plant Growth Regulation 29: 23-33.

Noble A.C. Elliot-Fisk D.I. and Allen M.S. 1995. Vegetative flavor and methoxypyrazines in Cabernet Sauvignon. In: Fruit Flavors: Biogenesis, Characterization and Authentication. Rousoff R.I. and Leahy M.M. (Eds.). ASC Symposium Series 596 (American Chemical Society; Washington DC). Pp. 226-234.

Salon J.L., C. Chirivella, and J.R. Castel. 2005. Response of cv. Bobal to timing of deficit irrigation in Requena, Spain: Water relations, yield and wine quality. Amer. J. Enol. Vitic. 56: 1-8.

Slinkard, K. and V. Singleton. 1977. Total phenol analysis: Automation and comparison with manual methods. Amer. J. Enol. Vitic. 28:49-55.

van Leeuwen C. and G. Seguin. 1994. Incidences de l'alimentation en eau de la vigne, appreciée par l'etat hydrique du feuillage, sur le development de l'appareil vegetatif et la maturation du raisin (Vitis vinifera varieté Cabernet franc, Saint-Emilion, 1990). J. Int. Sci. Vigne Vin 28: 81-110.

Williams, L E and M.A. Matthews. 1990. Grapevine. In: Irrigation of Agricultural Crops. B.A. Stewart and D.R. Nielson (Eds.). American Society of Agronomy, Madison, WI. Pp. 1019-1055.

Williams, L.E. and F.J. Araujo. 2002. Correlations among predawn leaf, midday leaf and midday stem water potential and their correlations with other measures of soil and plant water status in Vitis vinifera. Amer. J. Enol. Vitic.127:448-454.

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Table 1- Aroma, flavor and mouthfeel standards for sensory evaluation of Cabernet Franc wine treatments.

Product	**Brand**	**Method of preparation (added to 50 mL of Kressmann red wine)**
Strawberry	ED Smith strawberry jam	18.6 g jam
Raspberry	Fresh raspberry juice (President's Choice juice box)	4 mL juice
Red fruit	Mixture of E.D. Smith strawberry jam plus fresh raspberry juice	10 mL strawberry std + 10 mL raspberry std
Black cherry	Stewart's Black cherry juice	75 mL juice
Black current	Ribena concentrate	25 mL concentrate
Black pepper	Black pepper	0.5 mL stock
Green bean	Del Monte cut whole green beans	20 mL puree
Bell pepper	Fresh green pepper	1 mL puree
Astringency	Aluminum sulfate (SIGMA)	0.9 g aluminum sulfate in 450 mL water
Bitterness	Quinine sulfate	0.1 g quinine sulfate/L water
Acidity	Tartaric acid	1.5 g tartaric acid/L water
Pectin (for rinsing)	Pectin from apple (SIGMA)	1.25g pectin in 250 mL water

Table 2- Chemical analysis (p-values) of high vs. low water status wines, Niagara Peninsula, ON, 2005 and 2006.

Site	**Hue**	**Color intensity**[a]	**Anthocyanins (mg/L)**	**Phenols (mg/L)**	**pH**	**TA (g/L)**	**Ethanol (% v/v)**
2005							
Buis	0.11	0.18	0.97	0.70	0.74	0.21	0.41
CDC	0.12	0.06	0.86	0.27	0.43	0.06	0.27
Hernder	0.59	0.92	0.22	0.38	0.04*	1.00	0.11
Reif	0.24	0.74	0.34	0.50	0.11	0.43	0.21
Harbour	0.59	0.89	0.04*	0.02*	0.27	0.02*	0.54
George	0.17	0.03*	0.04*	0.03*	0.65	0.57	0.06
Cave Spring	0.21	0.05*	0.06	0.73	0.83	0.85	0.87
HOP	0.45	0.81	0.41	0.02*	0.01*	0.31	0.01*
Morrison	0.51	0.04*	0.06	0.68	0.81	0.76	0.26
2006							
Site	**Hue**	**Color intensity**	**Anthocyanins (mg/L)**	**Phenols (mg/L)**	**pH**	**TA (g/L)**	**Ethanol (% v/v)**
Buis	0.06	0.22	0.30	0.89	0.26	0.18	0.41
CDC	0.79	0.13	0.75	0.12	0.07	0.08	0.75
Hernder	0.42	0.25	0.39	0.32	0.01*	0.05*	0.58
Reif	0.28	0.06	0.46	0.58	0.01*	0.03*	0.51
George	0.01*	0.04*	0.01*	0.46	0.06	0.07	0.19
Cave Spring	0.17	0.01*	0.37	0.07	0.09	0.26	0.13
HOP	0.79	0.10	1.00	0.91	0.48	0.83	0.02*
Morrison	0.06	0.77	0.08	0.17	0.38	0.90	0.70

[a] * Represent significant p-values, t-test.

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2006 (B). (Aroma and flavor attributes are specified by higher and lower case letters respectively).

Figure 12- Principal component analysis (F1 & F2) of mean sensory data for nine pairs of low water status (LWS) and high water status (HWS) Cabernet Franc wines from the Niagara Peninsula, ON, 2005. CDC, HOP, Cave, Hrndr and Harbr are abbreviations for Château des Charmes, Henry of Pelham, Cave Spring, Hernder and Harbour Estate sites, respectively.

Figure 13- Principal component analysis (F1 & F3) of mean sensory data for nine pairs of low water status (LWS) and high water status (HWS) Cabernet Franc wines from the Niagara Peninsula, ON, 2005. CDC, HOP, Cave, Hrndr and Harbr are abbreviations for Château des Charmes, Henry of Pelham, Cave Spring, Hernder and Harbour Estate sites, respectively.

Figure 14- Principal component analysis (D1 & D2) of mean sensory data for eight pairs of low water status (LWS) and high water status (HWS) Cabernet Franc wines from Niagara Peninsula, ON, 2006. CDC, HOP, Cave, Gorg, Hrndr and Mor are abbreviations for Château des Charmes, Henry of Pelham, Cave Spring, George, Hernder and Morrison sites, respectively.

Figure 15- Principal component analysis (F1 & F3) of mean sensory data for eight pairs of LWS and HWS Cabernet Franc wines from Niagara Peninsula, ON, 2006. CDC, HOP, Cave, Gorg, Hrndr and Mor are abbreviations for Château des Charmes, Henry of Pelham, Cave Spring, George, Hernder and Morrison sites, respectively.

Figure 16- PLS analysis comparing field and sensory data of Cabernet Franc, Niagara Peninsula, ON, 2005.

Figure 17- PLS analysis comparing field and sensory data of Cabernet Franc, Niagara Peninsula, ON, 2006.

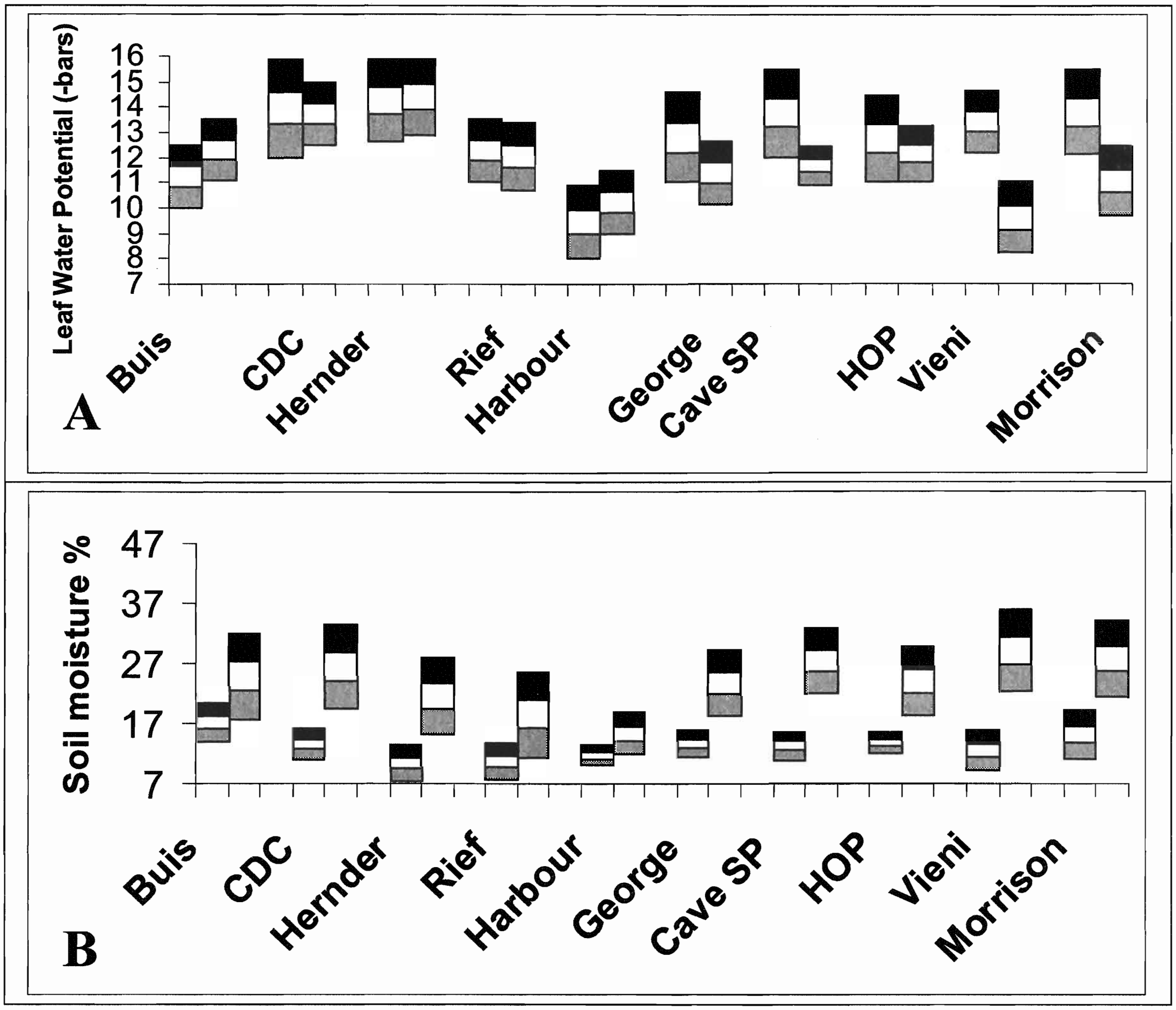


Figure 1- A-Midday leaf Ψ within each of ten vineyard sites (in negative bars), 2005-2006, Niagara Peninsula, ON. B- Soil moisture values (%) within each of ten vineyard sites, 2005-2006, Niagara Peninsula, ON. Black, white and gray colors represent low, medium and high water status (A) and high, medium and low soil moisture (B) at each site. CDC, HOP, Cave Springand Harbour are abbreviations for Château des Charmes, Henry of Pelham, Cave Spring and Harbour Estate sites, respectively.

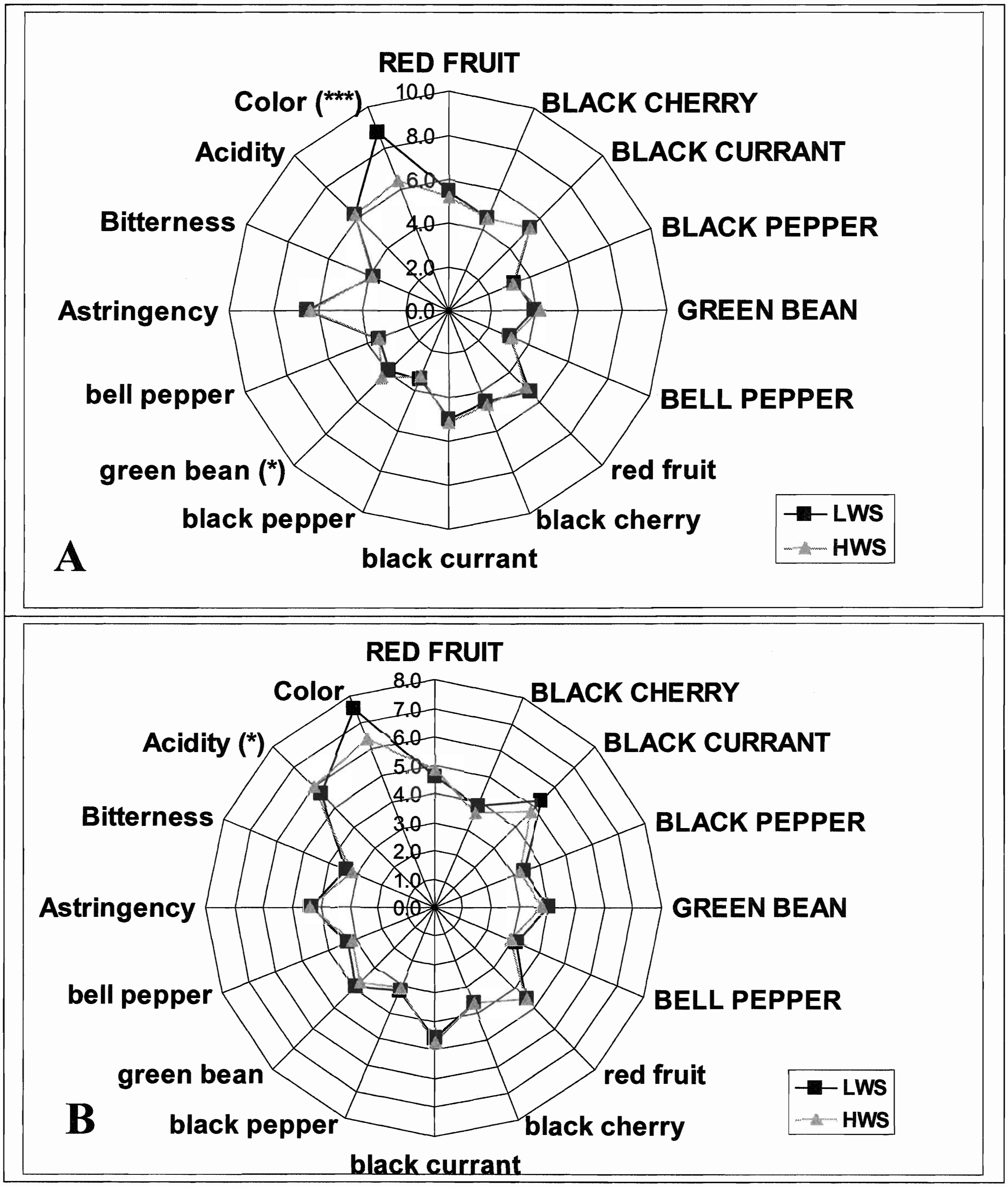


Figure 2- Radar diagram of low water status (LWS) and high water status (HWS) Cabernet Franc wines from Buis vineyard, Niagara-on-the-Lake, ON, 2005 (A) and 2006 (B). (Aroma and flavor attributes are specified by higher and lower case letters respectively).

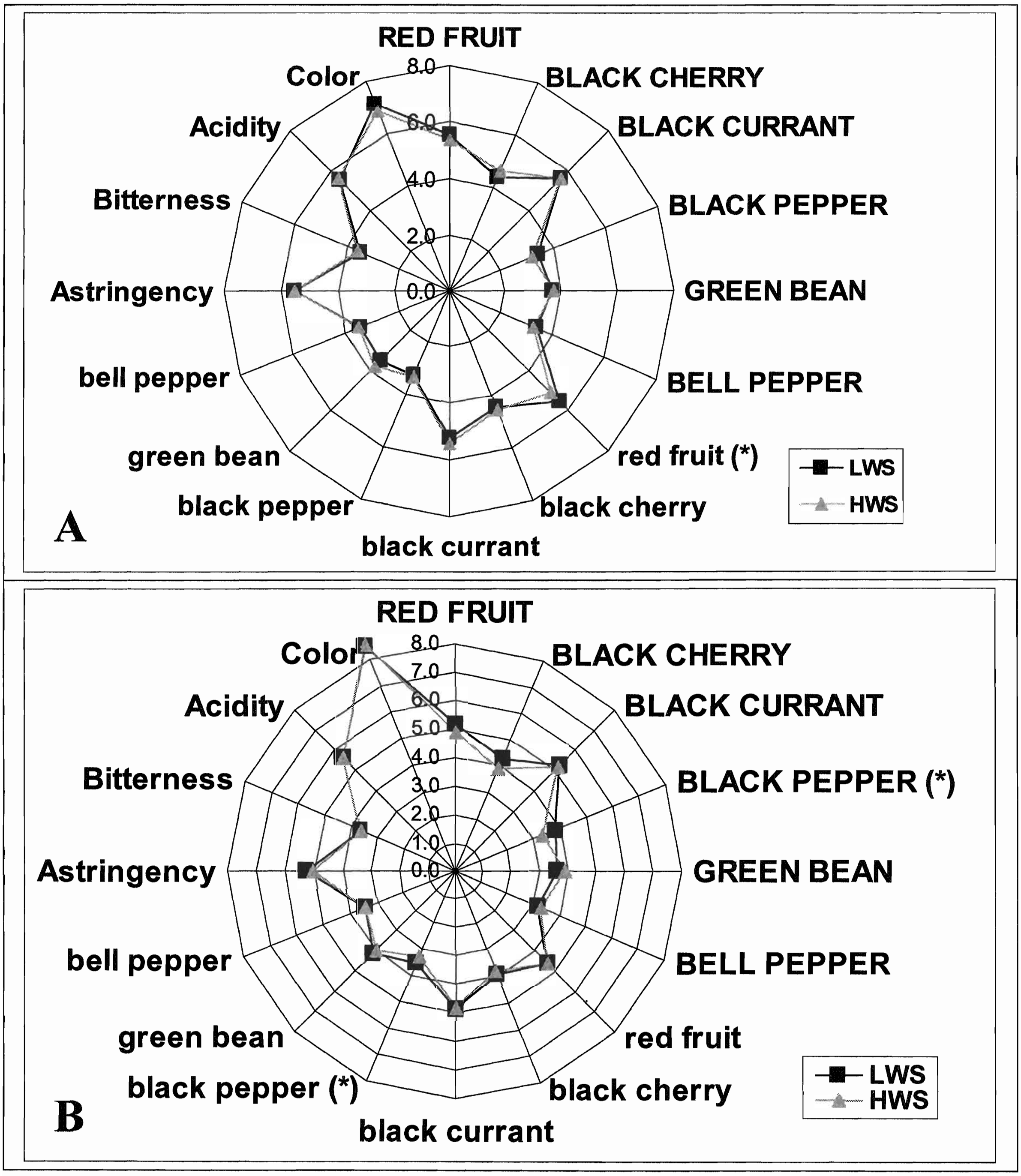


Figure 3- Radar diagram of low water status (LWS) and high water status (HWS) Cabernet Franc wines from Reif vineyard, Niagara-on-the-Lake, ON, 2005 (A) and 2006 (B). (Aroma and flavor attributes are specified by higher and lower case letters respectively).

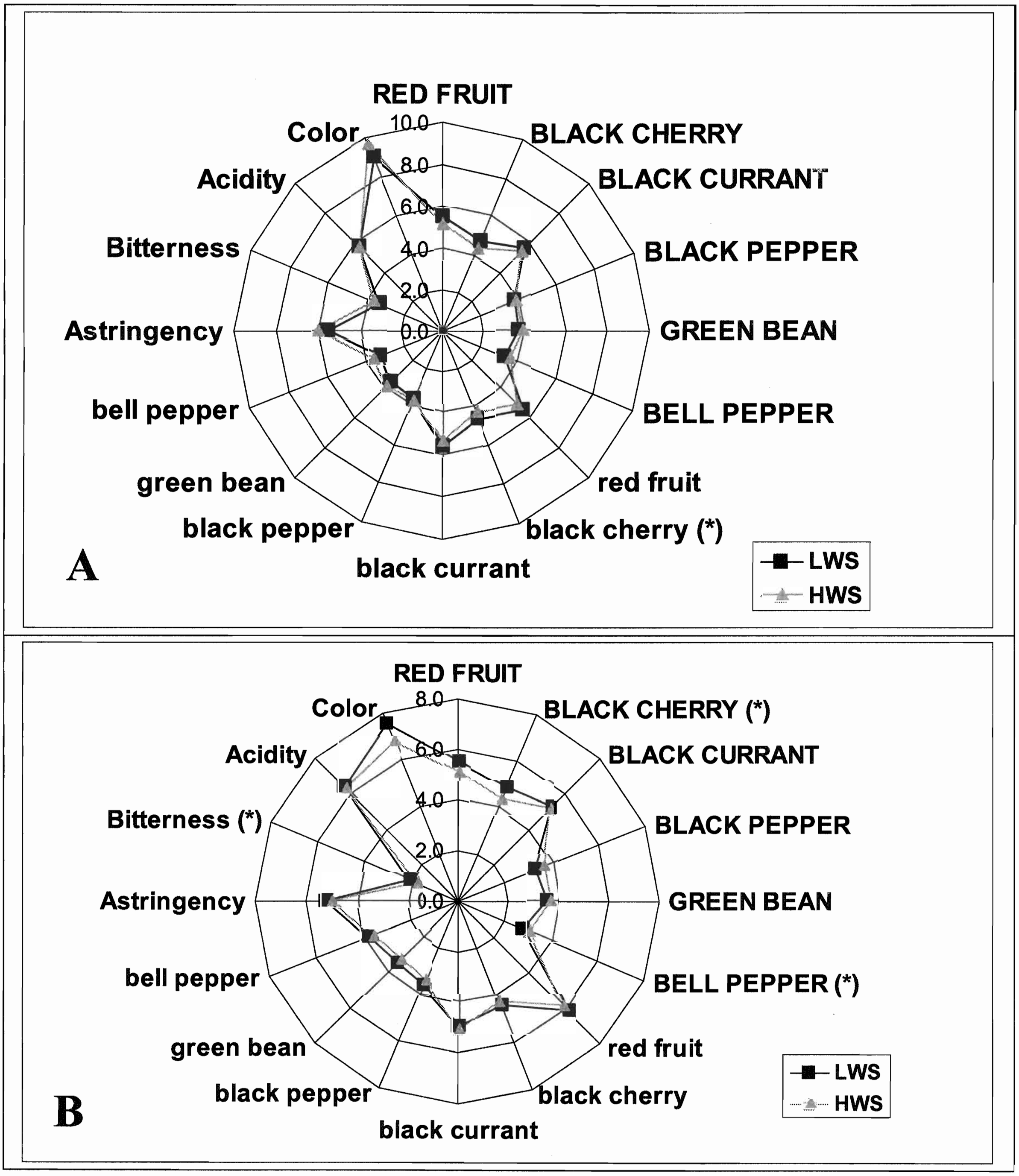


Figure 4- Radar diagram of low water status (LWS) and high water status (HWS) Cabernet Franc wines from Château des Charmes vineyard, St. Davids, ON, 2005 (A) and 2006 (B). (Aroma and flavor attributes are specified by higher and lower case letters respectively).

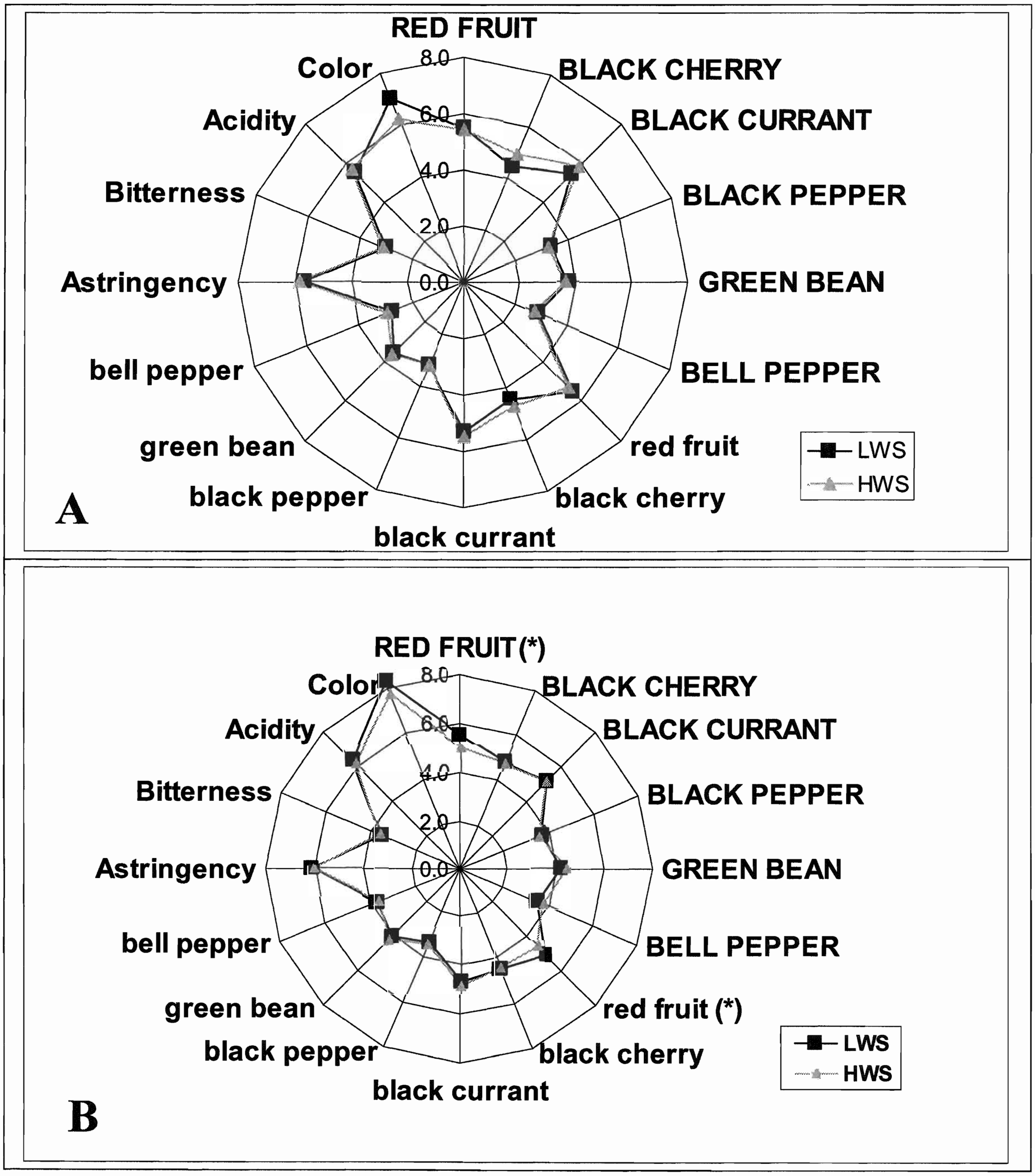


Figure 5- Radar diagram of low water status (LWS) and high water status (HWS) Cabernet Franc wines from Hernder vineyard, Virgil, ON, 2005 (A) and 2006 (B).(Aroma and flavor attributes are specified by higher and lower case letters respectively).

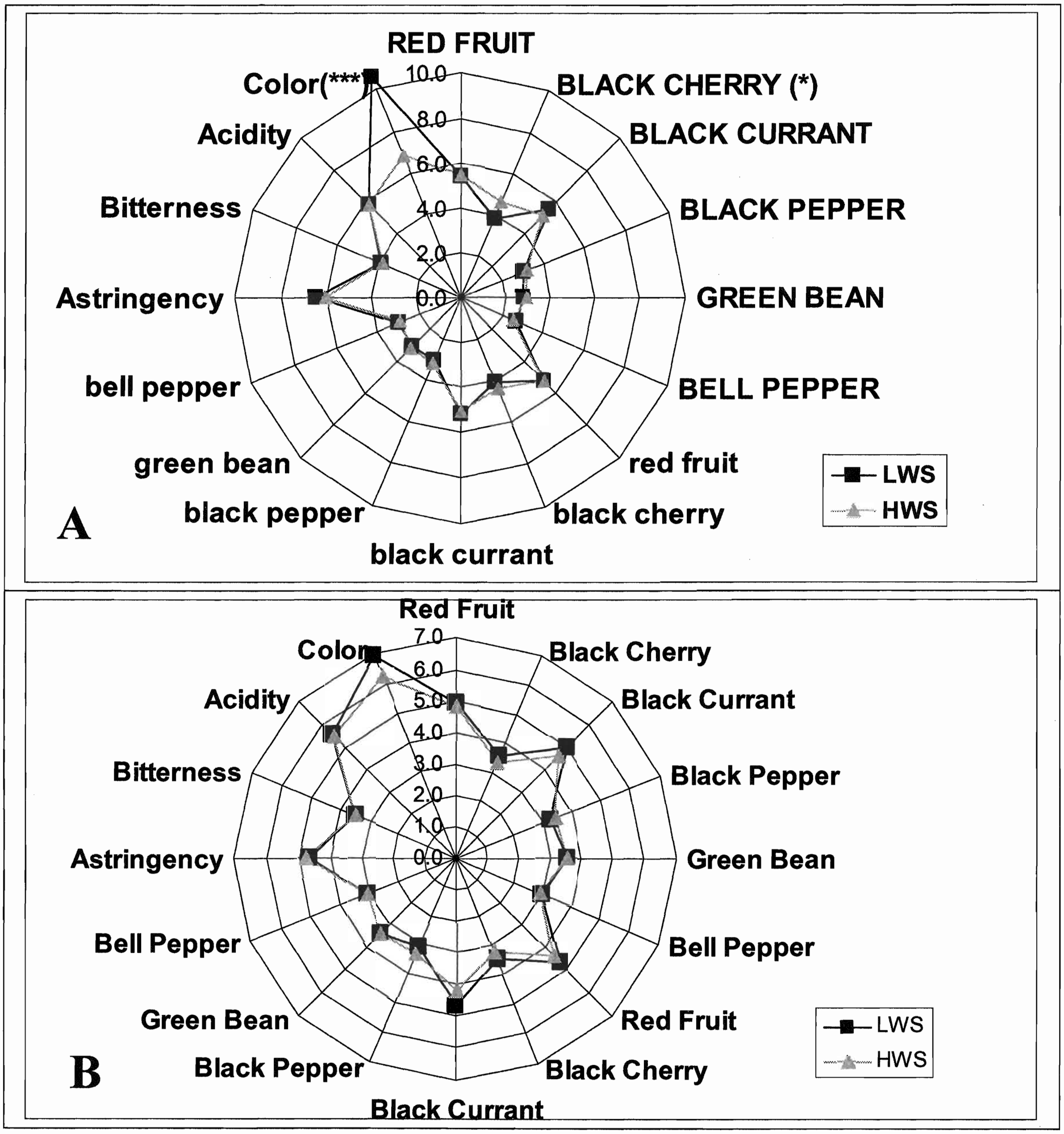


Figure 6- Radar diagram of low water status (LWS) and high water status (HWS) Cabernet Franc wines from Henry of Pelham vineyard, West St. Catharines, ON, 2005 (A) and 2006 (B). (Aroma and flavor attributes are specified by higher and lower case letters respectively).

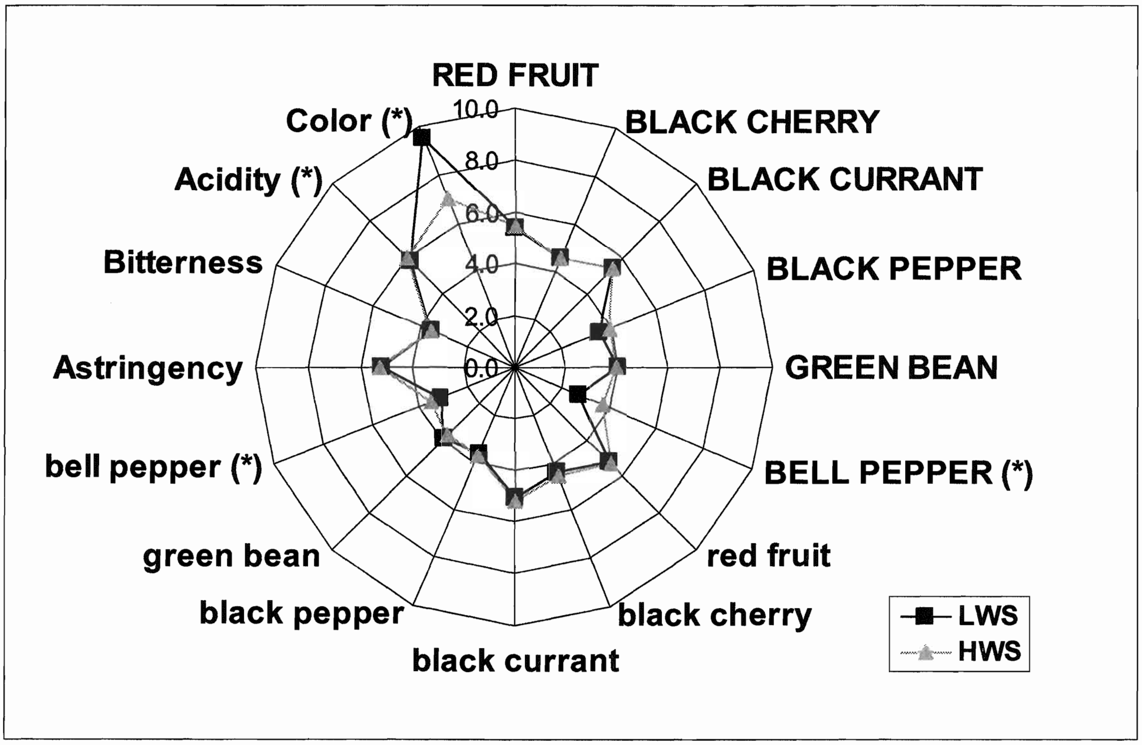


Figure 7- Radar diagram of low water status (LWS) and high water status (HWS) Cabernet Franc wines from Harbour Estate vineyard, Jordan, ON, 2005. (Aroma and flavor attributes are specified by higher and lower case letters respectively).

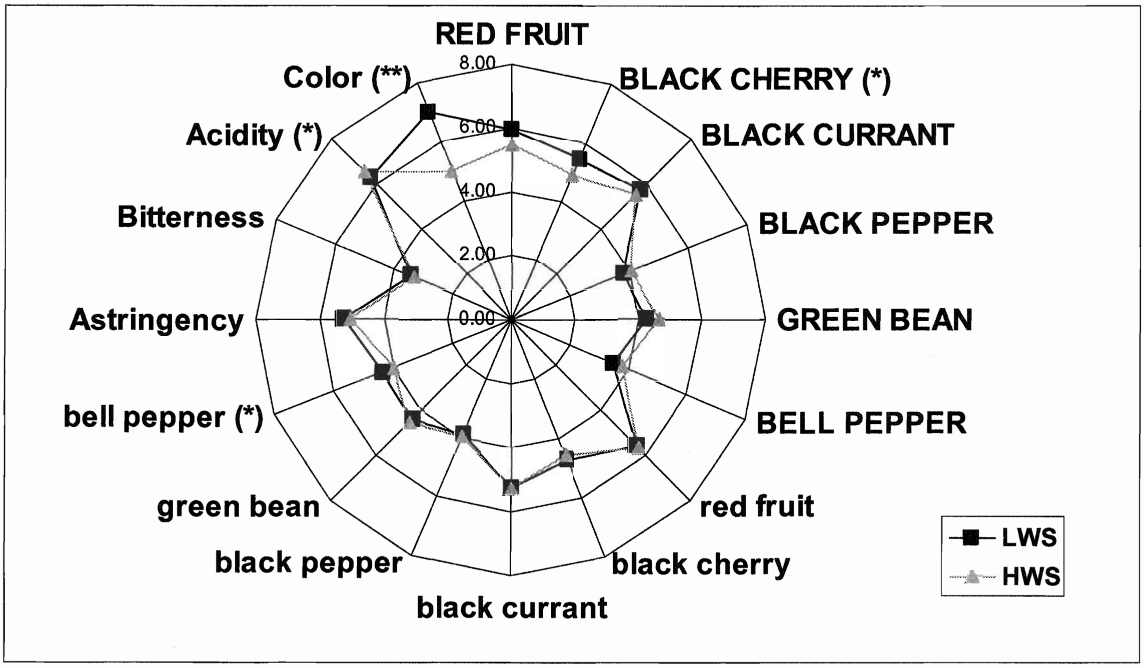


Figure 8- Radar diagram of low water status (LWS) and high water status (HWS) Cabernet Franc wines from Morrison vineyard, Jordan, ON, 2006. (Aroma and flavor attributes are specified by higher and lower case letters respectively).

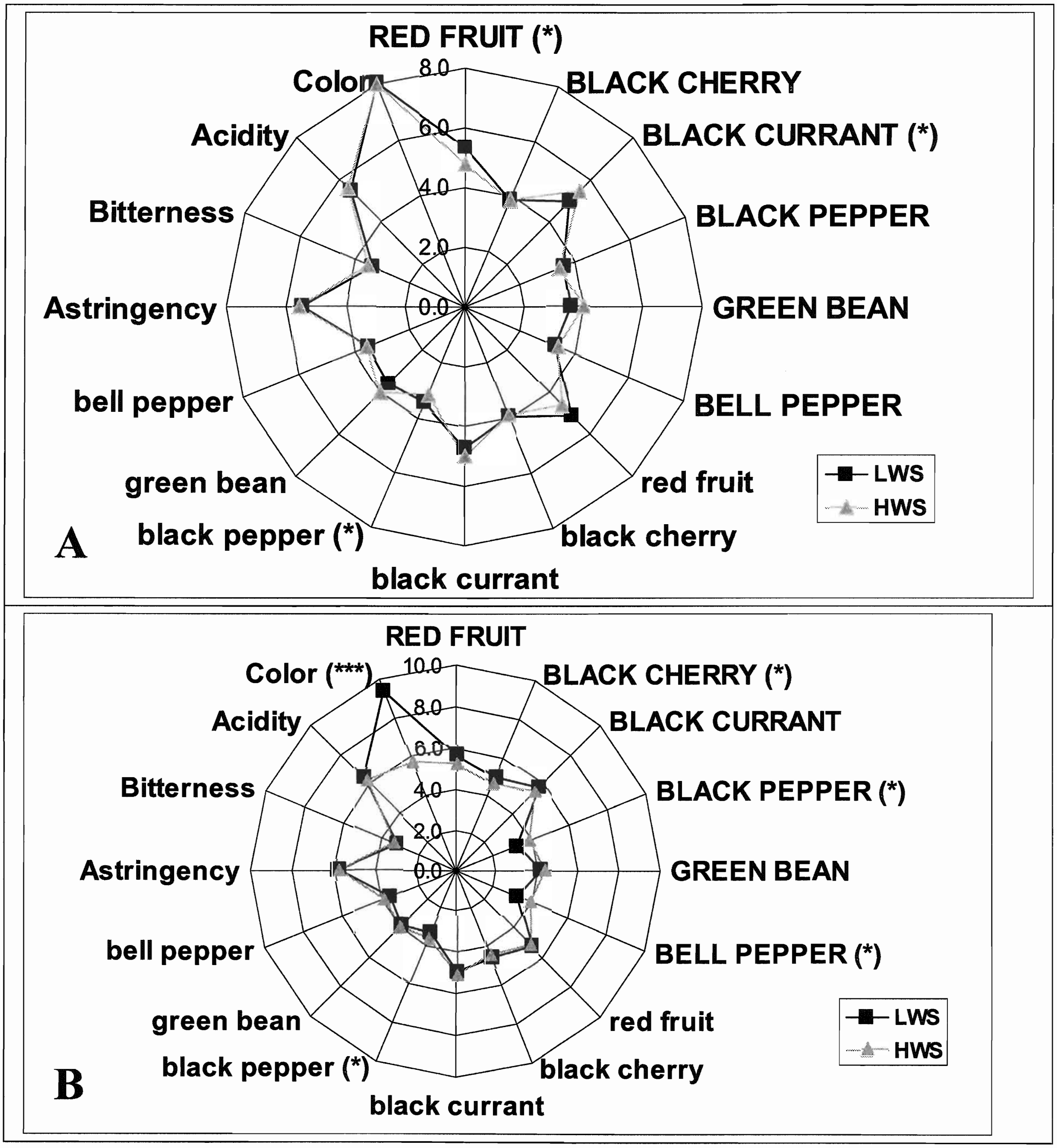


Figure 9- Radar diagram of low water status (LWS) and high water status (HWS) Cabernet Franc wines from George vineyard, Vineland, ON, 2005 (A) and 2006 (B). (Aroma and flavor attributes are specified by higher and lower case letters respectively).

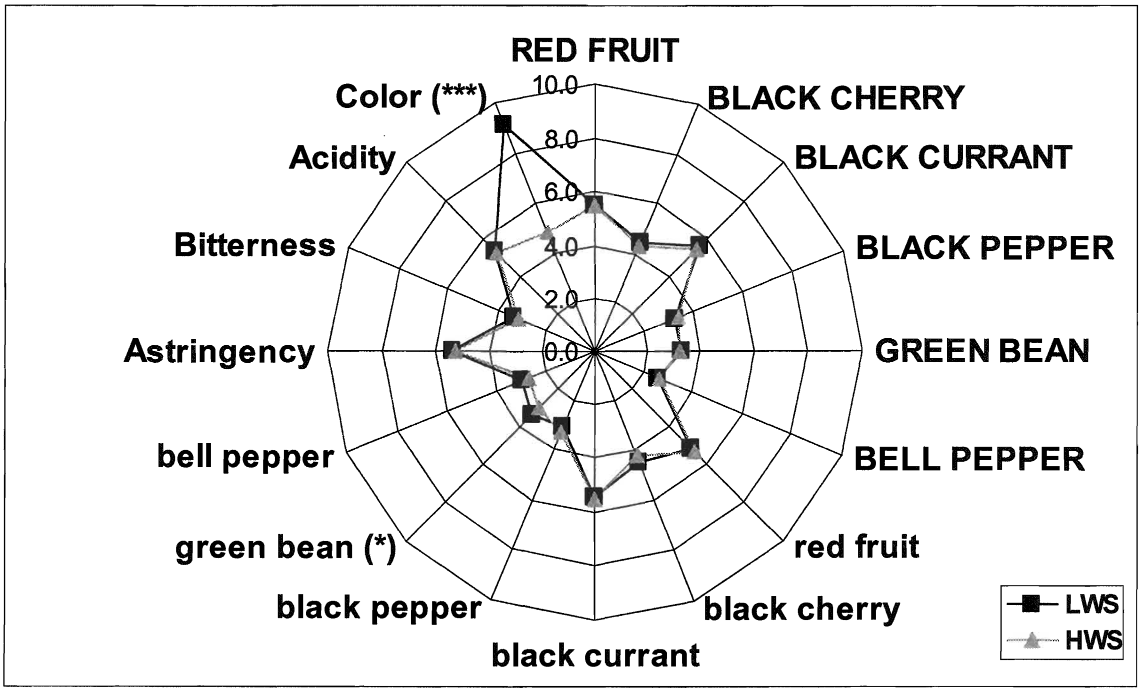


Figure 10- Radar diagram of low water status (LWS) and high water status (HWS) Cabernet Franc wines from Vieni vineyard, Campden, ON, 2005. (Aroma and flavor attributes are specified by higher and lower case letters respectively).

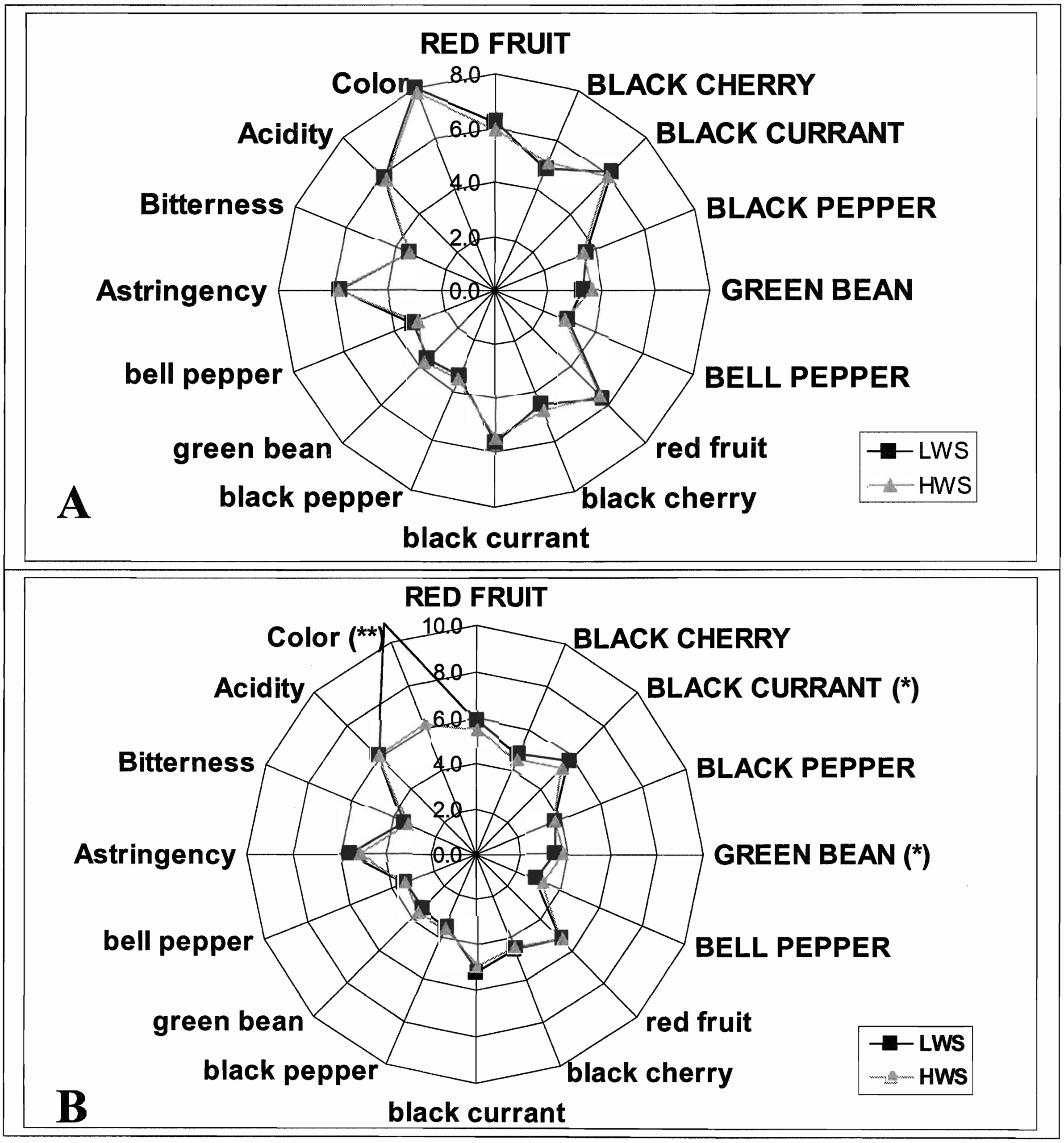
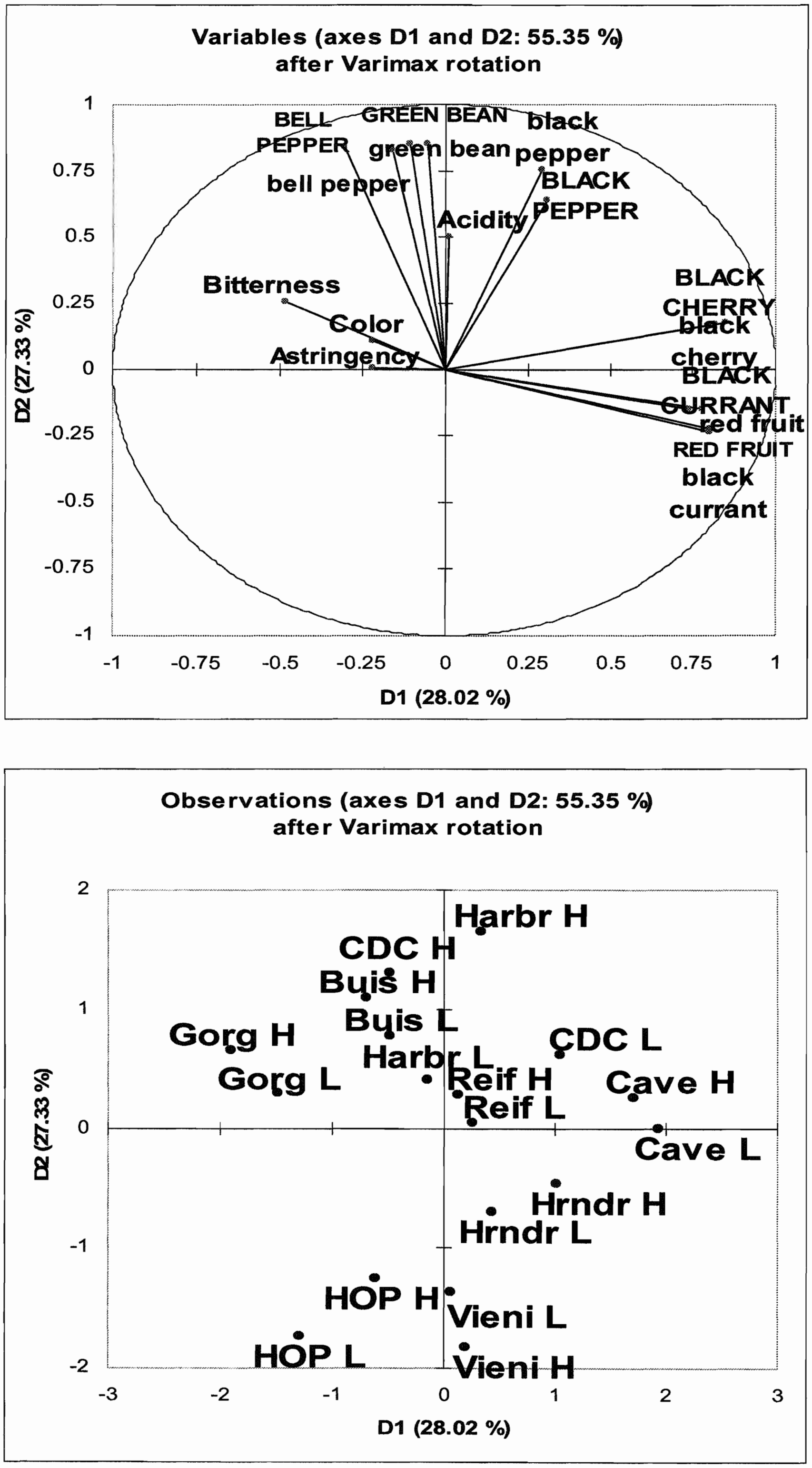


Figure 11- Radar diagram of low water status (LWS) and high water status (HWS) Cabernet Franc wines from Cave Spring vineyard, Beamsville, ON, 2005 (A) and 2006 (B). (Aroma and flavor attributes are specified by higher and lower case letters respectively).



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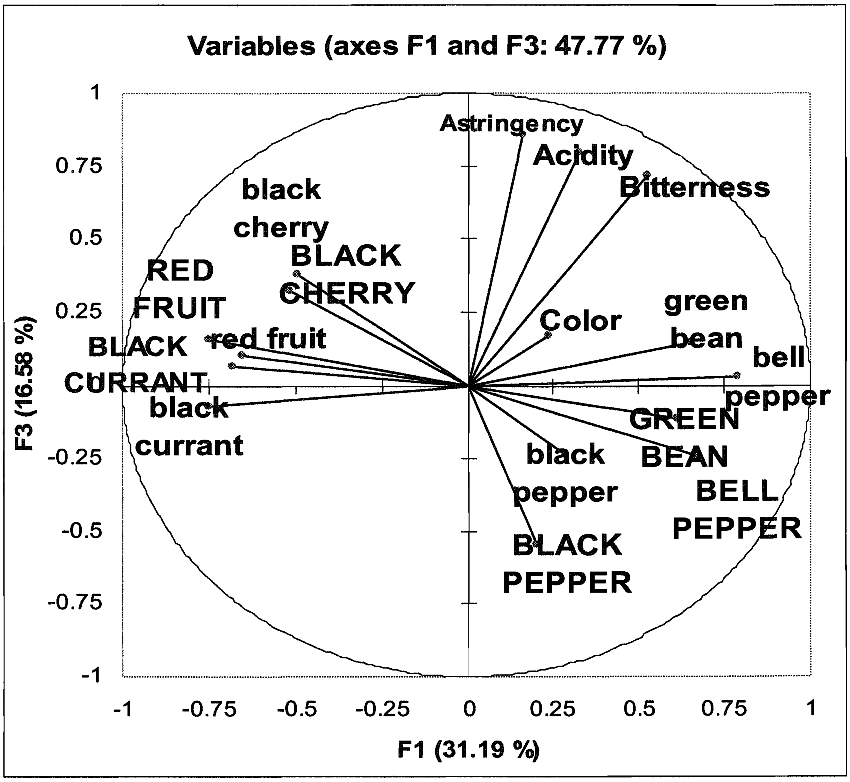

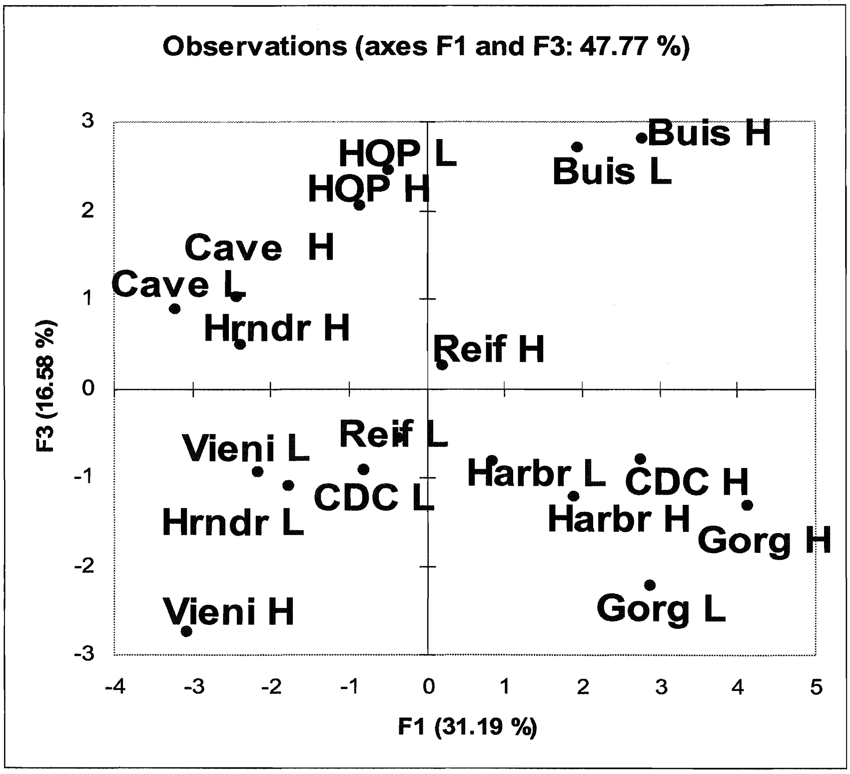

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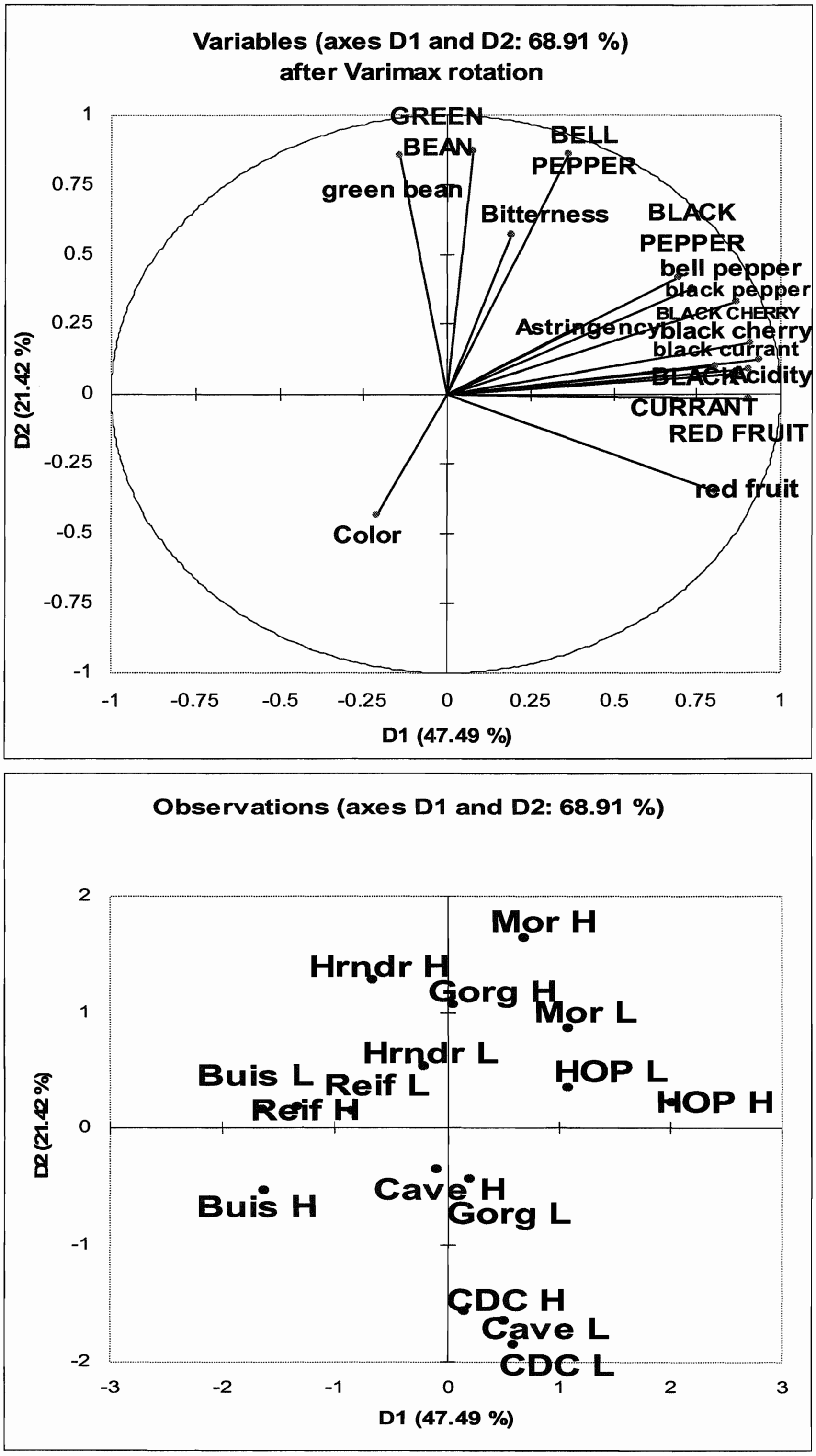

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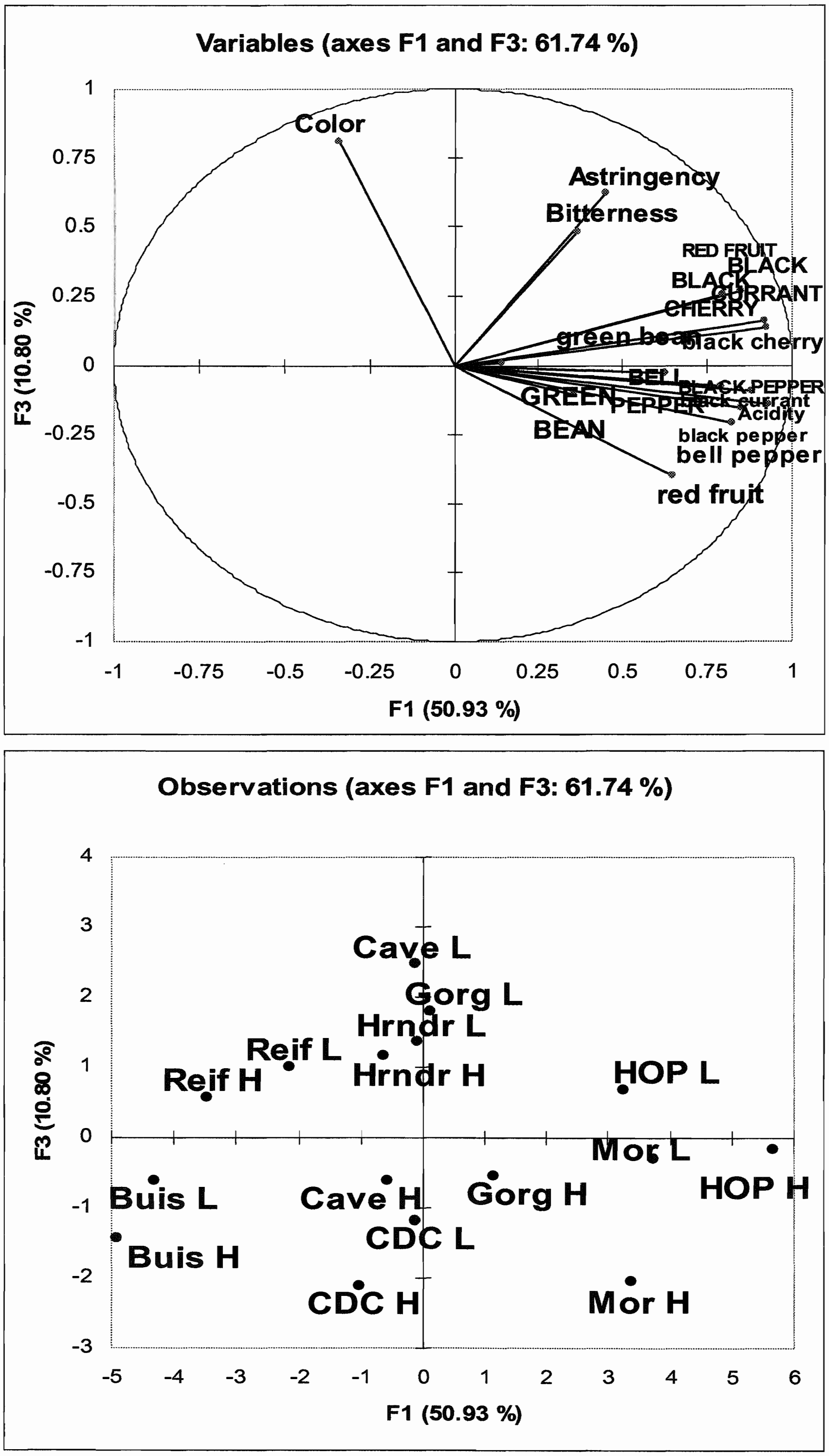

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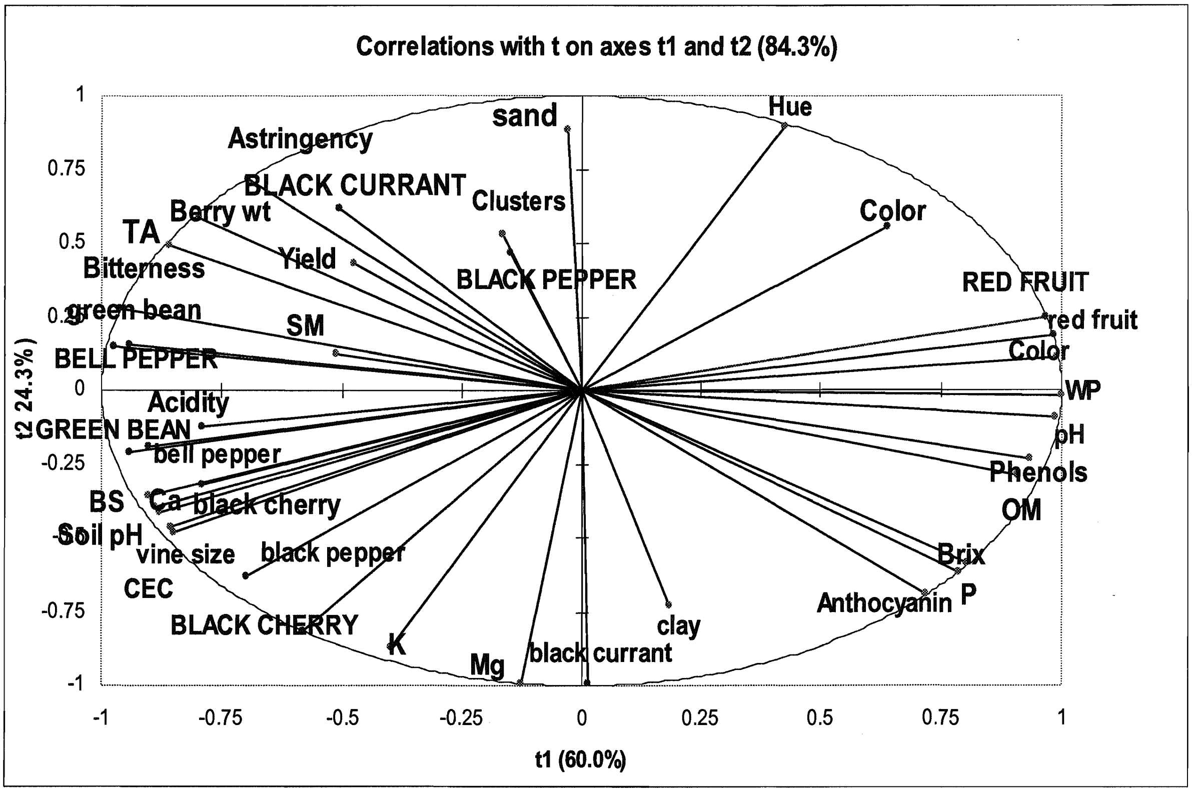
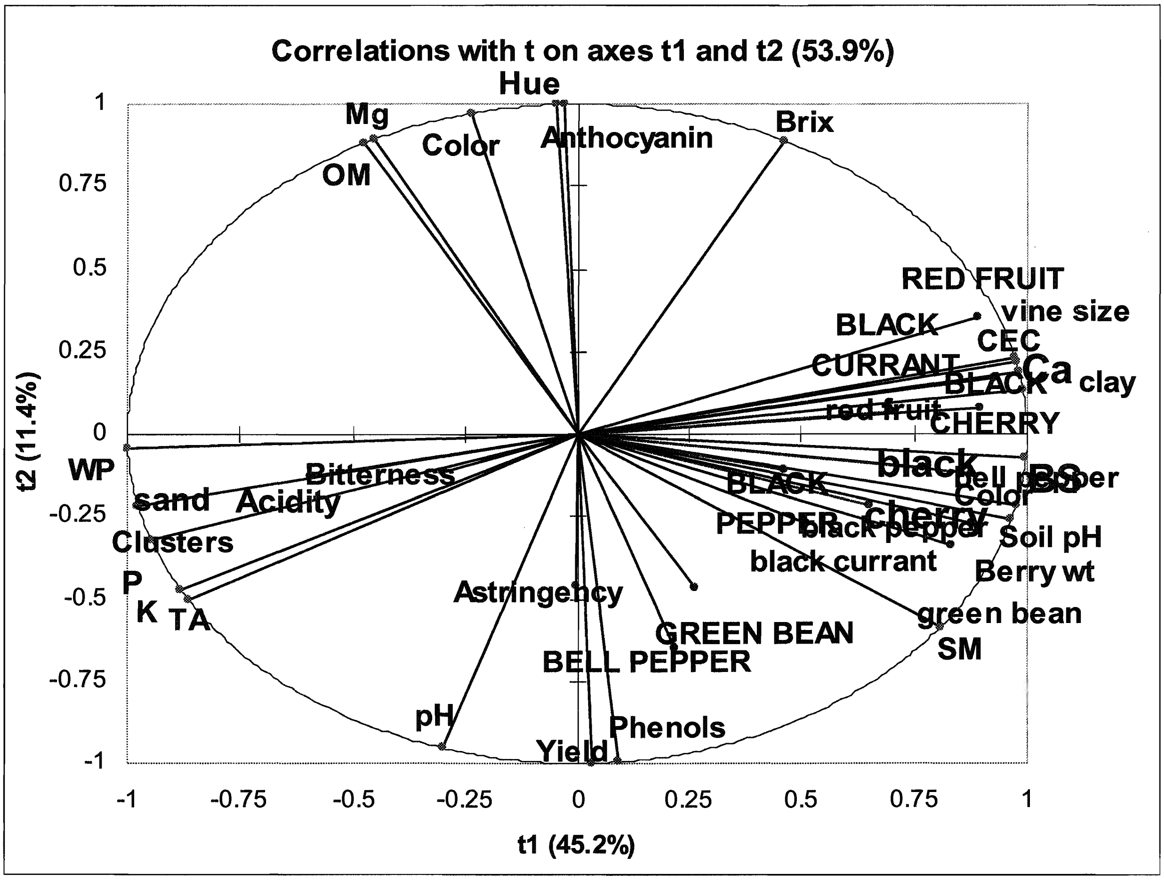


Figure 16- PLS analysis of field and sensory data for nine Cabernet Franc wines from Niagara Peninsula, ON, 2005. WP, SM, OM, and TA are abbreviations for leaf water potential, soil moisture, organic matter, and titratable acidity; in sensory characters upper case and lower case words are for aroma and flavor characteristics. Aroma attributes are represented in lowercase and flavor attributes are represented in uppercase.



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Chapter 7

General Discussion and Conclusions

At the initiation of this study three hypotheses were made. First, it was hypothesized that soil type plays a minor role in the determination of wine sensory attributes and that vine water status plays a major role. Second, it was hypothesized that water-status zones could be identified within vineyard blocks, and that this spatial variation would be consistent and stable temporally. Third, it was hypothesized that vine water status would cause differences in yield components and fruit composition and sensory attributes of wine.

Hypothesis 1: Impact of soil type on wine sensory attributes. In terms of the relationship between soil texture and wine quality, our results showed that sand was positively correlated with black pepper aroma and clay had positive correlation with black currant flavor. Therefore, soil did not play an important role compared to leaf Ψ as it correlated with black pepper aroma and black pepper flavor while leaf Ψ correlated with many yield components, fruit composition and wine sensory factors. This is consistent with Wahl's (1988) study in Germany in which he investigated the impact of soil type on wine composition and sensory quality of the Silvaner cultivar by moving seven different soil types to the same vineyard site in lysimeters and reported no significant impact on wine flavor of the investigated soil types.

There is much ambiguity about the role of soil as a component of terroir even though it is used on many wine labels and in many wine articles. There are some references to the chemistry of the soil that claim great vineyards of the world occur on calcareous soils formed on limestone or chalk or on transported materials derived from these rocks. Saxton (2002a) for instance, in a very vague statement claimed that soil Ca created a favorable medium for root exploration, uptake of minerals and growing a healthy vine. Saxton also indicated that the higher growth of vigorous vines maximized Ca uptake and this would result in more pronounced expression of terroir. By contrast, Smart (2002) reported that the best Bordeaux vineyards occurred on acidic gravelly soils which were deficient in most nutrients and concluded that the soil chemistry had no specific influence on wine quality. Therefore, it seems soil chemicals are not important for good grape production as good soils for viticulture are often infertile soils.

Further, some statistical relationships between soil chemicals with yield components/fruit composition might be misleading. McKenzie and Christy (2005) showed that Riesling grapes produced in the northern Adelaide Hills of South Australia had sugar concentrations and TA's that were correlated with several plant elements in the soil such as Ca, St, Ba, Pb and Si which suggests that correlation analysis can produce nonsensical results which do not explain mechanisms. Moran (2001) in his paper on terroir, stated that nobody has yet been able to show the process by which elements of soil are transferred to the flavors, color and or other qualities of wines.

Due to some overlap between hypothesis 1 and 3 the impact of soil and vine water status on yield components, fruit composition and wine sensory character will be discussed in more detail later. PLS analysis (2005) showed that leaf Ψ was positively correlated with red fruit aroma and flavor while negatively correlated with bell pepper aroma and flavor, green bean aroma and flavor, black cherry and black pepper flavor as well as acidity. Percent clay and percent sand correlated with either black currant flavor or black pepper aroma that indicates vine water status plays a major role in the determination of fruit and wine composition and wine sensory characters and soil type plays a minor role. Therefore, the hypothesis that soil type plays a minor role in the determination of fruit and wine composition and that vine water status plays a major role was supported by the data. This hypothesis was only partially supported with the 2006 data. Further studies are suggested to investigate the impact of soil chemicals on yield components, fruit composition and wine sensory response.

Hypothesis 2: Water-status zones could be identified within vineyard blocks, and that this spatial variation will be consistent and stable temporally. Leaf Ψ zones were temporally stable at the Harbour Estate and Hernder sites from 2005 to 2006. From 2006 to 2007, leaf Ψ zones were also temporally stable at Harbour Estate and Reif. At Harbour Estate leaf Ψ zones were stable over all three years. Considering that soil texture was stable at each site, water holding capacity of each soil was also consistent, the only difference was the amount of precipitation in each year. We assume that as the average volume of water in the soil profile changes between years so does vine water status. There may, however, be factors other than soil texture and soil water holding capacity that affect vine water status. Reynolds *et al.* (2007) in a study on spatial variation in a Riesling vineyard reported that specific areas of the vineyard that produce high yields and high concentrations of monoterpenes were transient and that their spatial distribution varied temporally. Our data suggest that there might be weakness in using leaf Ψ measurements as the basis for precision viticulture as spatial distribution for leaf Ψ may vary temporally. Therefore, the hypothesis of water-status zones will be consistent and stable temporally within vineyard blocks was only partially proven by the data.

Wines were made based on vine water status zones at each site in 2005 and 2006 vintages. Vine water status zones were temporally stable at Hernder and Harbour Estate in 2005 to 2006 vintages. However, due to severe disease pressure in 2006 at Harbour Estate, no wine was made. Wines made from Hernder in 2005 and 2006 were used to compare the aroma, flavor and color intensity. The higher vegetal character of Hernder wines in 2006 was possibly due to higher precipitation causing higher vegetative growth and canopy shade.

For the results of this study to be useful, the patterns of variation within vineyard blocks would have to be constant from year to year. Bramley (2005) has indicated that although the absolute values of yield and berry composition for a vineyard may vary from vintage to vintage, the patterns of variation within block were stable. In this study variation in soil moisture, leaf Ψ, yield components and fruit composition has been demonstrated in all vineyard blocks either by statistical analysis such as ANOVA or using interpolation maps of data. The patterns of variation, however, were not temporally consistent from year to year for all variables at all sites. Precision Viticulture is dependent on the existence of variability in product quantity and or quality. If the variability does not exist then a uniform management system is cheaper and more effective. In dealing with variability, if vines can be planted in zones of similar terroir it may reduce the need to manage them differentially afterwards; therefore, by differentially planting we can uniformally manage them which is more economical than the reverse of uniformally planting and differentially managing (Bramley 2005). While the author has not come across comparable published studies on precision viticulture, data suggest that longer period of study would help to find these trends.

Hypothesis 3: Vine water status would cause differences in yield components, fruit composition and sensory attributes of wine. This hypothesis carried with it the assumption that low vine water status would increase color intensity, anthocyanins, and total phenols. Presumably increases in the above mentioned variables would be due to increases in the skin to juice ratio which, in turn is the result of smaller berries due to lower water availability. Also, we assumed that low vine water status would decrease yield every year. This yield decrease would be due to smaller berry weights and to fewer clusters per vine as less water would be available to the plants. TA would theoretically have decreased and pH increased in low water status vines due to the fact that low water would decrease vine vegetative growth and would provide better light exposure into canopy which would help in degradation of malic acid.

Impact of vine water status on wine sensory attributes. Leaf Ψ was positively correlated to berry color intensity, anthocyanins, total phenols, berry pH and Brix as well as wine color intensity and red fruit aroma and flavor while negatively correlated with TA, yield, berry weight, vine size, soil moisture, wine bell pepper aroma and flavor and green bean aroma and flavor. In Cabernet Franc, vegetal character is largely due to bell pepper and green bean aromas. These are due to high methoxypyrazine concentration and are enhanced as a result of high water availability to grapevines. Hashizume and Samuta (1997) confirmed that methoxypyrazines were present at high levels in grape clusters and these compounds might contribute to the vegetal flavor of wine. Hashizume and Samuta (1999) also demonstrated photodecomposition of methoxypyrazines in several grape cultivars including Cabernet Sauvignon, Merlot, Pinot noir, Muscat Bailey, Semillon, Sauvignon blanc, Chardonnay, and Riesling.

Sensory evaluation of Cabernet Franc wines from the LWS and HWS vines showed that differences in vine water status resulted in wines with different composition, appearance, aroma and flavor. Low vine water status overall produced sensory aroma and flavor differences in the resultant wine, including reduced vegetal character (bell pepper aroma and flavor, green bean aroma and flavor) and increased red and black fruit aroma and flavor. This could be attributed to increased bound volatile components in wines due to low water uptake and or higher cluster exposure due to reduced vine vigor of LWS vines. This is consistent with the Koundouras *et al.* (2006) study on the Agiorgitiko cultivar, in which they found that limited water availability increased the main aromatic compounds of the grapes and the resultant wines were preferred in tasting trials. Comparing irrigated vs. non-irrigated grapevines, Freeman *et al.* (1980) found the same results. Considering two different vintages of hot and dry (2005) and cool and wet (2006) almost at all sites in both 2005 and 2006, LWS wines were associated with more fruity, less vegetal character and higher color intensity; however, at each site, specific attributes were significantly different between LWS and HWS wines. This is in agreement with Prado *et al.* (2007) study in which they found same attributes to describe the wines despite two different vintages.

Peyrot des Gachons *et al.* (2005) found that severe water stress limits aroma potential in Sauvignon blanc grapes while, mild water deficit might enhance it. Under mild water deficits vegetative growth is no longer in competition with reproductive development as a sink of photosynthesis resources since the fruit is the primary sink. This can partly explain the richer fruit and wine composition obtained from vines having undergone mild water stress. In a dry season such as 2005 high wine quality is strongly linked to mild water stress which is in agreement with Van Leeuwen and Seguin (1994) study. In cool and humid regions such as Niagara, negative effects of excess water on wine quality might be anticipated. Vegetative growth is stimulated by high soil water availability in the post-veraison period, which can delay sugar accumulation in grapes (Smart and Coombe 1983). In addition, excessive vegetative growth can create canopy shading, which has negative effects on quality of red wine (Smart 1982).

The results of this two year terroir study clearly demonstrated that vine water status linked to high enological potential for the red grape variety Cabernet Franc in Niagara region. Low vine water status induced higher sugar in the must and higher berry phenolics. Under the conditions of our research, low water availability was found to improve the aroma and flavor of Cabernet Franc wines, especially during the drier vintage of 2005. Finally, it remains to be elucidated in the future whether the effects of soil and climate on fruit composition and wine quality are mostly mediated through their influence on vine water status or if certain site parameters such as temperature, heat summation and light exposure hav an independent influence on berry and wine composition. Therefore, the hypothesis that vine water status would cause differences on wine sensory attributes was supported by data.

Validation of VQA's sub-appellations in Niagara Peninsula. In general, wines from Harbour Estate (2005; Creek Shores sub-appellation), Reif (2005, Niagara River), George (2005, 2006; Lincoln Lakeshore), Buis (2005, 2006; Niagara Lakeshore), Morrison (2006, Twenty Mile Bench) and Hernder (2006, Four Mile Creek) sites exhibited green bean aroma and flavor characters and a lack of fruity aroma and flavor. These sites are all located in a close proximity of either Lake Ontario or the Niagara

River, which are characterized with lower temperature and less heat unit accumulation. This is consistent with the Heymann and Noble (1989) study on Cabernet Sauvignon which illustrated the wines from cool areas of southern Sonoma where characterized by intense vegetative notes. Proximity to large bodies of water plays a significant role in climatic patterns which prevents high daytime temperatures. High vegetal character at Morrison (2006) and Hernder (2006) can be explained by high precipitation in 2006 which lead to higher vegetative growth, crowded and shaded canopy as well as higher yield.

Wines from CDC (2005, 2006; St. David's Bench sub-appellation), HOP (2005, 2006; Short Hills Bench), Hernder (2005, Four Mile Creek), and Cave Spring (2005, 2006; Beamsville Bench) are located far from large water bodies, and showed highest fruity character and less green bean aroma and flavor. These sites received a greater number of growing degree days (GDD) than the sites close to the lake or river early in the season (GGO 2005). The faster GDD accumulation results in early budburst and bloom as well as earlier harvest compared to the sites where temperatures are moderated by Lake Ontario or by the aspect and slope of the Niagara escarpment (in Vieni's case). This is in agreement with findings of Bonnardot *et al.* (2000) who reported higher tropical fruit aroma character in South African Sauvignon blanc wines from warmer locations. Bonnardot *et al.* (2001) also reported that the cooling effect of the sea breeze in the Western Cape decreases rapidly with distance from the sea, resulting in higher temperature variability in the inland sites. In cool climates, warm mesoclimates have a positive effect on grape and wine quality, as is the case farther away from large water bodies. Becker's (1985) study with Pinot gris and Lacey *et al.* (1991) with Sauvignon blanc were confirmed our results. Although climate plays a major role in separating sub-appellations, other factors such as vine water status, vine size, canopy microclimate and soil texture may play a role as it is shown in PLS analysis.

This may lead to a hypothesis that vineyards are a rather stable terroir and each wine estate have developed a method of grape growing which yields wines of similar sensory profiles across vintages provided that same winemaker and vinification processis used. Thus, for consumers who seek specific sensory properties from a wine, vineyard designation is a meaningful orientation for the wines. Due to the fact that no consumer studies have been done with these wines, it is not possible to make any concluding statements regarding overall quality. The results of the descriptive analysis clearly showed the degree of sensory variation, but it remains unclear how the intensity ratings translate into perceived quality and which of the recorded flavor attributes are the most important to define overall quality.

Conclusions

Measurement of midday leaf Ψ, determined by means of a pressure chamber, is a useful biological indicator in detecting differences among vine water status levels throughout the growing season and independent of region. The range of leaf Ψ values was consistent at most sites in 2005 to 2007 years. The initial hypothesis that vine water status would cause differences on yield components, fruit composition and wine sensory attributes was shown to be true, as vine water status influences almost every aspect of plant metabolism (Bradford and Hsiao 1982, Neill and Burnett 1999). However, the effect of vine water status was more sever in the hot and dry year of 2007.

All parameters considered here show that the environment plays an important role as vintage in Cabernet Franc vine performance. The vintage effect was more obvious on yield components and fruit composition mainly due to higher precipitation and cooler temperatures in 2006 which lead to higher yield, berry weight and more clusters per vine. Vine size was also higher in 2006; in terms of fruit composition Brix was lower and TA was higher in 2006. Color intensity, anthocyanins and total phenols were generally lower in 2006 mainly due to more available water and more vegetative growth.

Numerous correlations and spatial relationships between berry composition and soil texture/soil composition and water status were also observed and suggested that factors other than the experimental variables may have influenced fruit composition especially anthocyanins and total phenols. In most vineyards areas of low and high color intensity were highly positively correlated with low and high areas of anthocyanins and total phenols, but these spatial correlations were not consistent from year to year. Soil moisture spatial correlation was temporally consistent at six sites from 2006 to 2007, mostly due to deeper soil moisture measurements which wasn't the case from 2005 to 2006. Vine water status areas (indicated as leaf Ψ) were consistent at two sites from 2005 to 2006 and at another two sites from 2006 to 2007. However, specific areas of the vineyard with high and low water status appeared to be transient and their spatial distribution varied temporally except Harbour Estate that showed consistent water status zones from 2005 to 2007.

Under the condition of this study, the data indicate that midday leaf Ψ is a better indicator of vine water status than soil moisture content. PLS analysis demonstrated that leaf Ψ was positively correlated with red fruit aroma/flavor, berry color intensity, wine color intensity, total phenols and Brix, while negatively correlated with soil moisture, green bean aroma/flavor as well as bell pepper aroma/flavor. Soil moisture positively correlated with acidity, bitterness, vine size, bell pepper aroma/flavor, green bean aroma/flavor and black cherry aroma and flavor. Clay was positively correlated with black currant and black pepper flavor, while sand was correlated with clusters/vine and black pepper aroma. Therefore, the initial hypothesis of 'soil plays a minor role in the determination of fruit and wine composition and vine water status plays a major role' was shown to be true.

This study characterized the sensory and compositional properties of Cabernet Franc wines from the Niagara Peninsula, Ontario. The sensory and chemical methodologies that were developed for this study successfully separated clusters of sub-appellations for Niagara Peninsula Cabernet Franc wines. The PCA plots of sensory and chemical analysis showed that the attributes were useful in describing differences among the wines. In 2005, CDC, HOP, and Hernder (Escarpment Bench and Lake Plain sub-appellations) were associated with red fruit aroma and flavor. All these sites were warm with low water status. Harbour, George, Reif and Buis (Lakeshore or Niagara River sub-appellations) were associated with green bean and bell pepper aroma and flavor; this indicates that there was not enough heat to ripen the fruit. Harbour Estate and all Niagara-on-the-Lake sites showed highest pH, TA, phenols, and hue while sites from west of St. Catharines were associated with high color, anthocyanins and ethanol. Despite the two very different vintages of hot and dry (2005) and cool and wet (2006) seasons, similar trends were observed in 2006. Except black pepper aroma, all other attributes were significantly different among the sites in 2006. Most notably, wines from Buis (Niagara

Lakeshore sub-appellation), Morrison (Twenty Mile Bench) and George (Lincoln Lakeshore) were high in bell pepper and green bean aroma and flavor, astringency and acidity. Similarly, CDC (St. Davis Bench) and HOP (Short Hills Bench) sites were associated with red fruit aroma and flavor, black currant aroma and flavor, black cherry aroma and flavor, black pepper flavor and bitterness.

Considering that there were only minor sensory variations between the two vintages of 2005 and 2006 leads to the conclusion that some vineyard sites seem to be more stable regarding seasonal climatic variation and the impact of human factors during grape production and winemaking than other vineyard sites. Analysis of wines demonstrated that their quality was geographically controlled since they frequently illustrated the same attributes at each geographic origin.

The location of wines on the PCA plots provided a graphic indication of their sensory and chemical profile and allowed regional differences to be identified. Although it was not possible to assign each site to a unique sub-appellation that produces a specific lexicon of wine characteristics, it was possible to separate them in terms of clusters of sub-appellations based upon dominant sensory attributes. Also, this study provided evidence for proper site selection for Cabernet Franc in the Niagara region, since certain areas produced wines that were clearly dominant in herbaceous notes. This study was ideal for assessing chemical and sensory differences among sub-appellations in Niagara by producing Cabernet Franc wines with minimal enological intervention, a single winemaker, and single vintage comparisons. Based on the wines produced from different sites, a classification system based on vineyard designation would be appropriate for consumers. However, more investigation is required to further determine the basis of terroir effects in Niagara as it was not possible to make wines for two years at all sites, a longer period of study would provide enough data to compare the sites in different vintages.

Differences in vine water status resulted in wines with different composition, aroma, flavor and color intensity. At almost all sites LWS wines were associated with one or more characters such as high red fruit aroma and flavor, black fruit aroma and flavor, berry and wine color intensity, total phenols, and anthocyanins. In most cases, aroma of each attribute was highly positively correlated with its flavor. Most of the LWS wines were explained with red and black fruit aroma/flavor. There was a good separation of HWS and LWS wines at each site. Under the conditions of our experiment, limited water availability was found to improve the aroma and flavor of Cabernet Franc wines, especially during the driest vintage. It is possible that the higher levels observed under limited water supply are related to higher cluster exposure due to reduced vine vigor. These differences in wine sensory attributes due to vine water status provides a basis for managing vine water status in winegrape production to produce high quality wine profiles. Therefore, vine water status offers a means by which wine sensory characteristics can be manipulated.

Literature Cited

Becker, N.J. 1985. Site selection for viticulture in cooler climates using local climatic information. In: Proceedings of the First International Symposium on Cool Climate Viticulture and Enology. D.A. Heatherbell, P.B. Lombard, F.W. Bodyfelt, and S.F. Price (Eds.) pp 20-34. Eugene, OR. Oregon State University Experiment Station Technical Publication No. 7628.

Bonnardot, V., V. Carey, O. Planchon, and A. Schmidt. 2000. The effect of vintage and location on Sauvignon blanc wines aroma in the Stellenbosch-Klein Drakenstein winegrowing area (Vintages 1996-1999). Wynboer (10):114-118.

Bonnardot, V., V. Carey, O. Planchon, and S. Cautenet. 2001. Sea breeze mechanism and observations of its effects in the Stellenbosch wine producing area. Wynboer (147):10-14.

Bradford, K.J. and T.C. Hsiao. 1982. Physiological responses to moderate water stress. Plants, effect on growth and metabolism, growth regulators response, stomatal behavior, photosynthesis respiration, proline and betaine transport, nutrient uptake. Encyclopedia of Plant Physiology, Vol. 12B. Springer. Pp. 263-324.

Bramley R. 2005. Understanding variability in winegrape production systems. 2. Within vineyard variation in quality over several vintages. Austral. J. Grape and Wine Res. 11: 33-42.

Freeman, B.M., H.L. Trence, and C.R. Turkington. 1980. Interaction of irrigation and pruning level on grape and wine quality of Shiraz vines. Amer. J. Enol. Vitic. 31:124-135.

Grape Growers of Ontario. 2006. 56th Annual Report and Financial Statements for the Year Ending 2005.

Hashizume K. and Samuta T. 1997. Green odorants of grape cluster stem and their ability to cause a wine stemmy flavor. J. Agric. Food Chem. 45:1333-1337.

Hashizume K. and Samuta T.1999. Grape maturity and light exposure affect berry methoxypyrazine concentration. Amer. J. Enol. Vitic. Vol. 50, No. 2, 194-198.

Heymann, H. and A.C. Noble. 1989. Comparison of canonical variate and principal component analysis of wine descriptive analysis data. J. Food Sci. 54:1355-1358.

Koundouras S., V. Marinos, A. Gkoulioti, Y. Kotseridis, and C. van Leeuwen. 2006. Influence of vineyard location and vine water status on fruit maturation of non-irrigated cv. Agiorgitiko. Effects on wine phenolic and aroma components. J. Agric. Food Chem. 54:5077-5086.

Lacey, M., M.S. Allen, R.L.N. Harris, and W.V. Brown. 1991. Methoxypyrazines in Sauvignon blanc grapes and wines. Amer. J. Enol. Vitic. 42:103-108.

McKenzie, D.E. and A.G. Christy. 2005. The role of soil chemistry in wine grape quality and sustainable soil management in vineyards. Water Science and Technology 51:27-37.

Moran, W. 2001. Terroir-the human factor. Australian and New Zealand Wine Industry Journal 16:32-51.

Neill, S.J. and E.C. Burnett. 1999. Regulation of gene expression during water deficit stress. Plant Growth Regulation 29:23-33.

Peyrot des Gachons, D.C., C. Van Leeuwen, T. Tominaga, J.P. Soyer, L.P. Gaudillere and D. Dubourdieu. 2005. Influence of water and nitrogen deficit on fruit ripening and aroma potential of Vitis vinifera L cv Sauvignon blanc in field conditions. J. Sci. Food Agric. 85:73-85.

Prado, R.A., M. Yuste-Rojas, X. Sort, C. Andres-Lacueva, M. Torres, and R. M. Lamuela-Raventos. 2007. Effect of soil type on wines produced from Vitis vinifera L. cv. Grenache in commercial vineyards. J. Agric. Food Chem. 55, 779-786.

Reynolds, A. G., I.V. Senchuk, C. van der Reest, and C. de Savigny. 2007. Use of GPS and GIS for elucidation of the basis for terroir: Spatial variation in an Ontario Riesling vineyard. Amer. J. Enol. Vitic. 58:2, 145-162.

Saxton, V. 2002a. Calcium in viticulture-unraveling the mystique of French terroir. Australian and New Zealand Wine Industry Journal 17:28-33.

Smart, R.E. 1982. Vine manipulation to improve wine grape quality. Proc. Symp. Grape and Wine Cent. June 1980 A.D. Webb (Ed) Univ. of Calif., Davis pp 362-375.

Smart, R.E., and B.G. Coombe. 1983. Water relations of grapevines. *In* T.T. Kozlowski (Ed.): Water Deficits and Plant Growth. Academic Press, New York, pp.137-196.

Smart, R. 2002. New World responses to Old World terroir. Australian and New Zealand Wine Industry Journal 17:65-67.

Van Leeuwen, C. and G. Seguin. 1994. Incidences de l'alimentation en eau de la vigne, appreciee par l'etat hydrique du feuillage, sur le development de l'appareil vagetatif et la maturation du raisin (*Vitis vinifera* variete Cabernet franc, Saint-Emilion, 1990). J. International des Sciences de laVigne et du Vin 28:81-110.

Wahl, K. 1988. Climate and soil effects on grapevine and wine: Franconia. In R.E. Smart, R. Thronton, S.B. Rodriquez, V& J, Young, Proceedings of 2nd International Symposium of Cool Climate Viticulture and Oenology , 1-5. Auckland, New Zealand: New Zealand Soc.for Vitic .and Oenol.