RESEARCH REPORT

DENDRO-VITICULTURAL APPLICATIONS

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ABSTRACT

Twenty cross-sectional grapevine (*Vitis vinifera* L.) samples were used to explore the utility of using dendrochronological techniques to verify and reliably estimate vine age, and to determine the level of annual growth variability among vines for potential viticultural adoption. The annual xylem-growth rings from the study-site samples were easily discernable, and cross-sectional growth patterns were significantly associated among the samples. Samples from the site also revealed distinct pointer years, indicating a homogeneous environmental growth response. The impetus for the adoption of dendrochronological-based vineyard measurements is to increase the understanding of the relationships between climate and environmental variability on vine growth, and the associated effects on crop yields, to ultimately improve vineyard management methods and yields, and therefore enhance profitability.

Keywords: viticulture, grapevine, dendro-viticultural, *Vitis*, dendroagronomy.

INTRODUCTION

The number of wineries, vineyards, and the quantity of wine consumed in the U.S. has seen a substantial increase in the last 10 years, with some states (e.g. North Carolina) reporting a 500% increase in number of new wineries and a doubling in the amount of land used to grow grapes (Hussam 2012). The adoption and promotion of agritourism-based businesses by governmental agencies and entrepreneurs has created a niche for the acquisition of “old” or abandoned vineyards, which are thought to harbor superior grapes and inherited vigor. However, primary research on aged vineyards (i.e. older vines) producing “better” wines is limited (e.g. Howell 2001; Reynolds *et al.* 2007). This perception is, nonetheless, generally accepted by enologists and wine connoisseurs and is propagated into the marketing plans of vineyards. Conversely, there is a wealth of literature that equates wine quality and wine’s distinguishable characteristics (e.g. color,

taste, and aroma) to vineyard micro-site conditions, known as *terrior* (Dougherty 2012).

Wine production accounts for ca. 80% of the world’s grape crop (Mullins *et al.* 2007), and grapes are the highest value fruit crop in the U.S. (National Agricultural Statistics Service 2011). The production of wine, table grapes, and raisins is based primarily on the traditional cultivars of *Vitis vinifera* L. (wine grape), which have been perpetuated for centuries by vegetative propagation. The grapevine is known for its remarkable ability to regrow after pruning, and tended grapevines can remain productive for centuries (Schweingruber and Poschlo 2005); however, in commercial viticulture, grapevines are seldom retained for >40 years (Mullins *et al.* 2007). Four examples of long-lived grapevines are the ca. 400-year-old Mother Vine in Manteo, North Carolina (Zucchini 2010); the Great Vine at Hampton Court Palace in London, which was planted in 1769 (Richardson 2000); the St. Georgen Vine, an estimated 500-year-old grapevine in Austria (Jahn 2011); and a >400-year-old grape vine in Maribor, Slovenia (Vrsic *et al.* 2011). Dendrochronological

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age verification has not been reported for these long-lived grapevines, and the assumed ages are based on extrapolation from historical records and paintings.

Grapevines are woody lianas that are perennial, polycarpic, and deciduous. The vegetative sections of grapevines are divided into two portions: roots; trunk and shoots. The aerial axis of the grapevine is composed of the shoots, arms, and trunk, and is botanically called the stem. The woody skeleton of a deciduous perennial is a storehouse for reserves and provides carbohydrates and mineral nutrients for growth during the early part of the season, post-bud break. Grapevine radial growth is influenced by endogenous (e.g. hormones) and exogenous (environmental) factors that regulate fruit yield (Keller 2010).

Disease and environmental variables that cause growth decline and death of grapevines are possible threats to the economic viability and productivity of vineyards. Viticulturists are called upon to determine the causes of poor vine growth, which can indicate the presence of disease in the form of latent viruses and fungal disease, complications related to root-stock graft incompatibility, and suboptimal growth factors (Santesteban *et al.* 2010). Although many diseased vines show foliar symptoms, the fungi inhabit the wood cells, and sampling wood for diagnosis of disease type can be destructive to the vine and preclude future observations. Increment boring, alternatively, provides a non-destructive method of sampling, and has previously been used to study wood decay (Vasiliauskas *et al.* 1996), the assessment of esca (black measles) symptoms (Bruno and Sparapano 2007), vine trunk disease (Manning and Mundy 2009), and *Eutypa* (fungal) dieback (Muramendiáraz and Legorburu 2009). Conversely, viticultural research has seldom taken trunk size and radial growth into account as a diagnostic metric, and patho-physiological and eco-physiological stresses are known to alter stem growth (Keller 2010). Additionally, the longevity of clonal plants (e.g. grapes) is poorly documented and is of considerable biological interest and a direct life-span measurement via growth-ring analysis is an ideal technique (de Witte and Stöcklin 2010).

The objective of this paper is threefold: 1) verify that *V. vinifera* L. vines can be dendrochro-

nologically dated and assessed for the presence of pointer years; 2) determine the statistical relationship between vine age and vine diameter and evaluate the level of ring-width variability agreement among samples; and 3) provide tree-ring scientists and viticulturists with a prospective alternative application of dendrochronological techniques. Dendroagronomy, defined here as the application of tree-ring analysis for the enhancement of understanding and predicting crop yields and cycles, has been used to predict and estimate agricultural productivity of maize (Therrell *et al.* 2006), the dynamics of grain crops (Kairiukstis *et al.* 1990), and maple syrup (Tyminski 2011). Similarly, grapevine annual rings have the potential to be used to measure a vineyard's productivity index (*i.e.* crop quality).

METHODS

Twenty *V. vinifera* L. vines (*i.e.* twenty cross-sections) from a wooded area in Greensboro, North Carolina, U.S.A. (30.066°N, 79.982°W) were sampled at base height (*ca.* 0.25 meters above ground level) with a standard handsaw. The cross-sections were prepared using standard dendrochronological surface-sanding techniques. The methodology described in Schweingruber and Poschlod (2005) was used for identifying the distinctiveness of growth rings and intra-annual growth characteristics, as determined by the size and distribution of vessel fibres and parenchyma cells. Alternatively, had preservation of the vine been required, a standard 4.3-mm increment borer or the LIMB mini-borer for smaller diameter vines (Hallman *et al.* 2006) could have been used.

Ages were assigned to each cross-section using the conventional ring-count and list method (Yamaguchi 1991); ring widths were measured using a Velmex measuring stage, and all series were standardized and detrended using a linear curve. To ensure accuracy in the crossdating, the *Gleichläufigkeit* sign test, an interval trend method for assessing the agreement of growth between two series, was used (Schweingruber 1988). The *Gleichläufigkeit* test statistic, *G*, was calculated for 153 unique cross-sectional comparisons. To determine significance, Huber's criterion of $p \leq 0.05$

Figure 1. A 24-year-old grapevine with distinctive ring boundaries.

when G for each cross-sectional comparison is equal to 50% plus two standard deviations of agreement was used (Schöne 2003).

To evaluate the presence of a significant association among all series, the critical limit for the total number of significant G s was determined using the binomial probability. Pointer years were identified using interval trend analysis (Schweingruber 1988), in which the percentage of the yearly intervals among all samples, trending positively or negatively year-to-year were $\geq 90\%$ (e.g. if ring x_t trended negatively compared to ring x_{t-1} in 18 of 20 samples, then define as pointer; see Schweingruber 1996). Because of the limitations in statistical analyses derived from short ring-width series, pointer years and correlation analysis were used jointly to determine if vine growth was associated with average summer (June–August) Palmer Z-index values (NOAA 2012; Palmer 1965). The Palmer Z-index measures short-term drought on a monthly scale and has been shown to be more desirable in agricultural applications (Karl 1986). Lastly, simple linear regression was used to assess the relationship between vine diameter and age.

RESULTS AND DISCUSSION

Annual growth increments were easily identifiable (Figure 1), and vine age ranged from 3 to 24

years old (median = 9 yr; interquartile range = 11 yr), covering the period 1988–2011. There was a significant positive linear relationship between vine diameter and age ($R^2 = 67.3\%$, $p < 0.01$; R^2 -predicted = 61.3%; Figure 2); the robust age–diameter relationship found in these samples illustrates the potential feasibility to statistically predict age and determine the age–growth relationships at active and abandoned vineyards. Similarly, if the principal adaptive forces acting on grape species are their physical environment and the totality of competitive interactions within a vineyard, then different sites and species have the potential to exhibit useful site-specific age–diameter relationships (O’Brien *et al.* 1995; Dietz and von Arx 2005). Of the 153 G statistics calculated, 100 were identified as significant, indicating that the degree of associations among all cores (*i.e.* site chronology), was significant ($p < 0.01$). Correlation between the ring-width series and average summer Palmer Z-index was not significant ($r = 0.301$, $p = 0.106$; Figure 3). However, trend analysis revealed one wide and three narrow and pointer years–1995; 1993, 1998, and 2002, respectively (Figure 3)—that were significantly associated (Fisher’s exact test, $p < 0.04$) with years whose summer Palmer Z-index values were significantly different from the average (*i.e.* Palmer Z-values $\geq |2.0|$), demonstrating a synchronized environmental response to monthly moisture conditions.

Assessing the width of grapevine trunks in a vineyard can be used to estimate the trunk cross-sectional area (TCSA; Santesteban *et al.* 2010). TCSA allows for an integration of vineyard carbohydrate balance and when measured in a single vineyard, TCSA is correlated to factors limiting vine photosynthetic activity (*e.g.* soil conductivity); and when several vineyards of a single variety are compared, trunk average annual growth (cm^2/year) is also significantly correlated to average yield and sugar production per vine (Santesteban *et al.* 2010), key business-specific metrics viticulturists monitor to forecast wine production and related sales. Trunk growth rates have been shown to be a valid indicator of productivity and quality of vineyards (see Santesteban *et al.* 2010) and are positively associated with berry weight and sugar concentration at

Figure 2. Regression of vine diameter (centimeters) on vine age (years) with associated 95% confidence and prediction intervals.

Figure 3. Time series of the standardized, average ring-width series and the Palmer Z-index values. Pointer years are indicated with an open circle.

harvest. TCSA measurement should be included in experimental protocols attempting to understand vine behavior, because of its simplicity and physiological significance. Additionally, TCSA related to vineyard absolute age ($TCSA/age_{yr}$) may be used to calculate a vineyard's Vineyard Potentiality Index (VPI). Factors that can also affect trunk growth include phenological stage and crop load, because of their effect on carbon partitioning (Keller 2010). Therefore, dendro-based sampling provides a way to evaluate the changes in VPI and TCSA over the tenure of the vineyard/crop; this can then provide viticulturists with historical vineyard performance metrics and data that may be useful to prophylactic management strategies.

Temperature and precipitation during the growing season, wind direction and intensity, solar radiation, and other climate variables influence the phenological growth stages of crops. The precise onset and duration of growth stages in turn influence yields, qualities, and prices. Ultimately, climate affects the revenues and profits of farmers, and consumer prices of agricultural products. To predict future values of these variables requires accurate and reliable models of the relationship between climate and agriculture. The wine and viticulture sectors are particularly sensitive to climate fluctuations, which have strong influence on wine prices (e.g. Ashenfelter 2008). Thus, this research will help to promote the effectiveness of using dendrochronology to predict agricultural yields (i.e. dendroagronomics), which will ultimately provide farmers and viticulturists additional information about crop yield cycles and viticultural management effectiveness.

CONCLUSION

This study demonstrates the potential utility of integrating dendrochronological sampling as a tool for measuring and classifying vineyard ages, productivity, and health. Although more detailed and extensive studies are warranted to fully understand the value of utilizing dendrochronological methods in the viticultural industry, the utility is advantageous. This application could ultimately provide an understanding of changes

and trends in vine radial growth, which could serve as a proxy for changes occurring in grape harvest and quality (e.g. sugar concentration) and provide vineyard operators additional information about crop-yield cycles that could be used to help determine appropriate management methods for vineyards during less-favorable climatological conditions. Furthermore, the possible financial benefits that could be derived from this application include: 1) improved estimates of vineyard net present value; 2) increased market attraction for vineyards with statistically verified grapevine ages; and 3) enhanced estimates of vineyard productivity and wine quality—which influence wine prices.

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