INTERACTION OF CROP LEVEL AND FRUIT CLUSTER EXPOSURE ON 'SEYVAL BLANC' FRUIT COMPOSITION

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Additional index words. *Vitis*, French-hybrid, color development

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[1] Manuscript submitted for publication July 1996. Salaries and research support provided by state and federal funds appropriated to the Ohio Agricultural Research and Development Center, The Ohio State University, Journal Article No. 134-96. Hummell acknowledges additional support provided by the Lonz Foundation. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper must, therefore, be hereby marked *advertisement* solely to indicate this fact.

Abstract

'Seyval blanc' grapevines (*Vitis* spp.) were cluster thinned 7 days after full bloom to 20, 40, and 80 clusters/vine to create light, moderate, and heavy crop levels. Vines were also shoot positioned at veraison to create exposed, partially shaded, and densely shaded cluster microclimates to examine the interactions between crop level and light exposure on fruit composition during stage III of berry development. Clusters were harvested using one of two criteria: on the same date or at similar soluble solids concentrations. Cluster weight and berries per cluster decreased with increasing crop level regardless of harvesting criterion. When harvested on the same date, soluble solids concentration, pH and malic acid concentration of juice decreased with increasing crop level. When harvested at similar soluble solids concentrations, increasing crop level delayed harvest and reduced titratable acidity (TA), tartaric acid, and malic acid. As cluster light exposure increased, soluble solids and pH increased and TA and malic acid decreased when clusters were harvested on the same date. When harvested at similar soluble solids concentration, increasing light exposure advanced harvest date and pH, TA, tartaric acid and malic acid decreased. If clusters were harvested on the same date, significant interactions were found between crop level and light exposure for soluble solids concentration and the hue angle of berries. Significant interactions were found for berry weight, pH, TA and tartaric acid when clusters were harvested at similar soluble solids. When harvested on the same date in 1995, soluble solids concentration of densely shaded clusters declined as crop level increased, whereas the soluble solids of exposed and partially shaded clusters declined as cluster number increased from 20 to 40 clusters/vine but remained constant from 40 to 80 clusters. In 1995, the hue angles of exposed clusters decreased with increasing crop level, while those of partially shaded and densely shaded clusters increased. When harvested at similar soluble solids concentration, berry weights of exposed and partially shaded clusters were similar across crop levels, whereas berry weights of densely shaded clusters declined as crop levels increased. Based on contribution to treatment error, crop level influenced pH more, and TA less, than did light exposure if harvested at the same date. Conversely, crop level influenced TA more, and pH less, than did light exposure if harvest was done at similar soluble solids concentrations. Regardless of harvest criterion, crop level influenced yield components, and soluble solids concentration to a greater extent and hue angle to a lesser extent than did light exposure.

INTRODUCTION

Crop level and grapevine light microclimate can be manipulated to influence fruit and wine composition. For large clustered French/American hybrid cultivars, such as 'Seyval blanc', controlling crop through a combination of balanced pruning and cluster-thinning have often been suggested in order to maintain vine size and fruit composition (Cahoon et al., 1991; Reynolds et al., 1986). Reducing the node number per vine via increased pruning severity and/or reducing the cluster number per vine via cluster-thinning have increased soluble solids concentration (Bravdo et al., 1985; Edson et al., 1993; Howell et al., 1987; Reynolds et al., 1986) and anthocyanins (Gao, 1993; Kliewer and Weaver, 1971) in grape berries. The effect that crop control has on titratable acidity (TA) is inconclusive. Some studies have shown that TA decreased with reduced crop level (Reynolds and Wardle, 1989; Wolpert et al., 1983), whereas others have shown that it increased (Bravdo et al., 1985; Reynolds et al., 1986). Increasing fruit exposure to light penetration has been linked to enhanced accumulation of soluble solids (Morrison and Noble, 1990; Reynolds et al., 1986; Smart, 1987), reduced pH and potassium ion concentration (Morrison and Noble, 1990; Smart et al.,1985), decreased TA levels (Archer and Strauss, 1989; Reynolds et al.,1986), and elevated levels of anthocyanins and other phenolics in colored cultivars (Gao, 1993; Morrison and Noble, 1990).

The crop level and the light microclimate of the vine can also influence yield. Limiting crop level through post-set cluster-thinning has the potential to decrease yields by reducing berry number per vine. Vines moderately cluster-thinned shortly after fruit set however may compensate for reduced berry numbers by producing berries at greater weight (Looney, 1981). Increasing light exposure generally increases berry weights (Archer and Strauss, 1989; Smart et al., 1988). In some instances, however, berry weights and berry sizes have been reported to decrease when clusters are fully exposed, due to increases in cluster temperatures (Reynolds et al., 1986).

Crop level and light microclimate are not mutually exclusive variables and changes in one can directly affect the other. For example, Edson et al. (1993) found that 'Seyval blanc' vines with light crop levels produced more and larger leaves and greater overall leaf areas than those with heavy crop levels. The objectives of this study were to determine the relative influences and interactions between crop level and light exposure on fruit composition of 'Seyval blanc' grapevines when harvested on the same date or at similar soluble solid concentrations.

MATERIALS AND METHODS

Experimental design

Eleven-year-old, own rooted ›Seyval blanc: grapevines planted at a spacing of 2.4 m in row and 3.0 m between rows and located at the Ohio Agricultural Research and Development Center in Wooster, Ohio, were used in these studies. The vines were trained to a single curtain, bilateral cordon at 1.8 m height and pruned to five bud canes leaving the appropriate count buds/vine. In June 1994 and 1995, vines were cluster thinned one week after full bloom to one of three crop levels: 20, 40 or 80 clusters/vine to create vines with light, moderate or heavy crops, respectively. In anticipation that vines with 80 clusters/vine in 1994, would not have adequate growth to sustain this crop level a second year, an additional treatment cluster-thinned to 40 clusters/vine in 1994 and 80 clusters/vine in 1995 (referred to as heavy 1995) was established. To maintain these crop level treatments, summer laterals and shoots that emerged after adjustment were removed on a weekly basis throughout both growing seasons.

Nine clusters/vine were selected at veraison and three clusters were given each of the following light exposure treatments on each vine: exposed- clusters positioned so they received little natural shading; partially shaded- clusters positioned so that at least a portion of the clusters were shaded by 1-2 leaf layers; and densely shaded- clusters positioned so that the entire cluster was shaded by 2 or more leaf layers. Shading was achieved by moving shoots around the clusters and tying them into position to achieve the desired degree of shade.

Treatments were arranged as a split plot design with the four crop levels as the whole plots and the three light exposures on each vine as the split plot with 10 single-vine replications for a total of 40 vines. In 1994 all vines were harvested on the same date. In 1995, vines were split based upon harvesting criteria (same date harvest vs. similar soluble solids harvests), each with 5 single-vine replications for a total of 20 vines for each harvest criteria.

Monitoring light and temperature

To characterize cluster exposure levels under different natural light conditions, three photosynthetic photon flux (PPF) measurements were taken: one in the morning under sunny conditions, one in the afternoon under sunny conditions, and one under overcast conditions. All three data sets were collected by holding by hand a quantum sensor (LI-190SB, LI-COR, Lincoln, NE) attached to a Quantum/Radiometer/Photometer (Model LI-185, LI-COR, Lincoln, NE) at the top, middle, and bottom portions of the cluster on the south side of the cluster and comparing the resulting light readings to full sunlight. The three light exposure treatments were monitored on a 24 hr basis using quantum sensors, attached to Integrators (Model LI-510B, LI-COR, Lincoln, NE) in 1994 and a micrologger (Model 21X, Campbell Scientific, Logan, UT) in 1995. Quantum sensore were mounted at mid-cluster on the south side of two exposed, three partially shaded, and two densely shaded clusters on one representative vine between veraison and harvest. In addition, a remote cosine receptor (Model 1800-11 LI-COR, Lincoln NE) connected to a LI-COR portable spectroradiometer (Model LI-1800, LI-COR, Lincoln, NE) was placed mid-cluster at the surface of each treatment cluster to characterize the light spectra surrounding clusters under sunny and overcast sky conditions during September. These spot readings were taken from 10:00 a.m. to 2:00 p.m. The spectroradiometer was programmed to average the value of three scans at 10 nm intervals between 400 nm to 800 nm.

Cluster temperature was monitored on one representative vine between veraison and harvest. Thermocouples were placed on the surface of two clusters at each light exposure level. Readings were taken every minute and averaged at 15-minute intervals using a micrologger (Model 21X, Campbell Scientific, Inc., Logan, UT).

Fruit Composition and Yield

Color change was measured weekly from veraison to harvest by placing the sensor of a Chromometer (Minolta Model CR-100, Ramsey, NJ) upon a middle berry on the south side of a treatment cluster. All readings were recorded in the L*a*b* mode and converted to Hunter Lab values of L (100 = bright, 0 = dark), a (CIE values; positive = red, negative = green), and b (positive = yellow, negative = blue). The values were converted to hue angle and saturation index using the following equations: hue angle= $(\tan^{-1} b/a)$ and saturation index= $(a^2 + b^2)^{1/2}$. Several studies with apple and peach have shown these values were related to sensory panel evaluations (Baugher et al., 1995; Singha et al., 1991).

In 1994, all treatment clusters were harvested on the same date. To follow the progression of berry maturity prior to harvest, 100 berries were randomly sampled from partially shaded, clusters established on vines outside the experimental group at the moderate crop level. When the target of approximtaely 20% soluble solids concentration was reached (actual values 2.87 pH, 9.7 $g.l^{-1}$ TA, and 19.7% soluble solids concentration) all clusters were harvested. In 1995, five replicates were harvested when fruit reached 20% soluble solids concentration as in 1994. The other five replicates were harvested when each treatment reached 20% soluble solids concentration. To determine when each crop level-light exposure combination reached similar soluble solids, 100 berry samples were randomly taken from nontreatment vines which had been adjusted in 1995 to 20, 40, and 80 clusters and had three clusters of each light exposure treatment as previously described. When each corresponding 100 berry sample reached 20% soluble solids concentration, the treatment combination was harvested.

At harvest, each cluster that received a light treatment was removed, weighed, scanned for color, and disassembled to determine berries per cluster and berry weights. Berries from the same vine and light exposure treatment were consolidated into one sample, pressed through a fruit strainer, centrifuged for 10 minutes, and the juice placed in individual sample bottles.

Soluble solids, pH, and TA readings were recorded on fresh samples. Soluble solids were measured using a refractometer (Model 10480 S/N, Abbe AO Scientific Instruments, Kenne, NH) with temperature correction. Measurements of pH were taken using a calibrated digital ionalyzer (Orion Research Model 701A). TA was determined by diluting 5 ml of juice into 100 ml of double distilled water and titrating with a standardized NaOH solution until solution reached a pH of 8.2.

Malic and tartaric acid concentrations were determined using reverse phase high performance liquid chromatography (HPLC) using a modification of the method of Martineau et al. 1995. The method modification was to eliminate the Hypersil ODE column because comparison showed little interference of sugar at the dilution used and good separation of malic acid, tartaric acid, glucose and fructose. Juice samples taken from clusters harvested at similar soluble solids were prepared fresh, while juice samples taken from clusters harvested on the same date were frozen and thawed prior to sample preparation. Frozen juice samples were thawed by placing them in a 75°C water bath for 1 hr during which time they were shaken by hand a minimum of three times.

The remaining clusters from all treatment vines were harvested to determine yield per vine, cluster weight, and final crop level. In March 1994 and 1995, vines were pruned to 12 five node canes and pruning weights recorded. These data were analyzed with crop level treatments arranged as a randomized complete block.

Statistical Analysis

All data were analyzed by analysis of variance (ANOVA). Treatment effects were compared using mean separation by LSD and polynomial contrasts. All analyses were performed using the PROC GLM function of SAS (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Experimental conditions

The climate of the growing season differed between the 1994 and 1995 growing seasons. Even though veraison as determined by berry softening occurred around 7 Aug. in both seasons, the harvest date of vines harvested on the same date was delayed in the second year from 7 Sept. to 27 Sept. This delay was partially due to the differences in weather conditions during this stage of development and may have also been influenced by the heavy crop in 1994. Specifically, maximum daily air temperatures ranged from 19.6°C to 30.5°C and from 23.3°C to 36.0°C during the month of August in 1994 and 1995, respectively. The elevation in temperatures during 1995 probably contributed to the delay in maturation observed. Studies have previously shown that the photosynthetic capabilities of grapevine leaves are inhibited when leaf temperatures exceed 30°C (Kriedemann and Smart, 1971). In the current study, cluster temperatures (Fig. 1) were shown to exceed air temperatures by as much as 10°C if directly exposed to sunlight, which was below the critical cluster temperature of 37ºC shown to inhibit accumulation of sugars in grape berries (Kliewer, 1977). Even though the temperature regimes were quite different between the two seasons, the overall amounts of solar radiation received were similar: 92% and 99% of the long term average in 1994 and 1995, respectively.

Yield

Yield increased linearly with cluster number creating light, moderate, and heavy crop levels for vines harvested on the same date (Table 1). When harvested at similar soluble solids, light, moderate, and heavy crop level vines produced similar yields per vine. The heavy (1995) vines produced higher yields per vine. The small size of three vines probably resulted from winter injury suffered in January 1994 (-32.1ºC) which killed some buds and reduced growth. Miller et al. (1993) reported that small vines with less than 1 kg prunings per vine declined more rapidly than did large vines when subjected to heavy cropping.

Cluster Microclimate

The three natural shade treatments created different cluster light environments. Under both overcast and clear sky conditions, the PPF at the cluster surface declined with reduced exposure (Fig. 1A & B). In 1994 exposed clusters averaged 86%, 88%, and 68% ambient light; partially shaded clusters averaged 26%, 26%, and 18% ambient light; and densely shaded clusters averaged 3%, 3%, and 3% ambient light under clear morning, clear afternoon, and overcast sky conditions, respectively. In 1995, exposed clusters received approximately 88%, 91%, and 76% ambient light; partially shaded clusters received approximately 32%, 34%, and 21% ambient light; and densely shaded clusters received approximately 2%, 1% and 4% ambient light, under clear morning, clear afternoon, and overcast sky conditions, respectively. Integrator and micrologger data showed similar distributions of light among light exposure treatments between veraison and harvest in 1994 and 1995, respectively. For example, in 1994, integrator measurements indicated that exposed, partially shaded, and densely shaded clusters received 88%, 26%, and 2% ambient light, respectively, between veraison and harvest.

In both years, fully exposed cluster temperature exceeded that of ambient air and of partially and densely shaded clusters during the afternoon (Fig. 1C & D). For example, in 1994, at 1500 HR., fully exposed berry temperatures averaged 31.6°C, while temperatures of partially shaded and densely shaded berries averaged 25.3°C and 24.2°C, respectively, while an ambient air at 23.6°C. On the hottest day between veraison and harvest, exposed clusters exceeded air temperatures by as much as 10°C, while partially shaded and densely shaded clusters deviated from air temperatures by only ±2°C.

Cluster characteristics

Average cluster weights decreased linearly with increasing crop level (Table 2). In 1994, differences in cluster weights were most closely linked to berries/cluster, which decreased with increased crop levels. In 1995, berry weights and berries per cluster declined linearly as crop level increased, regardless of harvesting criteria. Cluster weights and berries per cluster decreased linearly with increased light exposure, regardless of growing season or harvesting criteria. The increased yield per vine and lower average cluster weights, berry weights and berries per cluster with increasing crop levels were consistent with previous studies (Bravdo et al., 1984; Looney, 1981; Reynolds et al., 1986). However, results showing a decline in cluster weights, berry weights, and berries per cluster with increased light exposure conflicted with earlier studies (Archer and Strauss, 1989; Smart et al., 1988). These deviations can be partially explained by the selection of treatment clusters in the current study. When exposure treatments were chosen at veraison, berry numbers had already been established. Achieving proper cluster exposure treatments with minimal manipulation of the canopy was the primary factor governing cluster selection, whereas maintaining cluster uniformity was a secondary consideration. Shoots with exposed clusters tended to be from the first two nodes of five-node canes, while shoots with densely shaded clusters tended to come from the fourth or fifth nodes. Since nodes four and five are usually more fruitful, this may explain the increased cluster weights and berries per cluster among the densely shaded clusters. A detailed analysis of light and cluster location in the canopy fruiting zone (data not presented) indicated that all exposed clusters were located in the top third of the fruiting zone , while partially shaded clusters were usually between the top and the middle thirds of the fruiting zone, and densely shaded clusters between the middle and the bottom thirds of the fruiting zone. While the majority of foliage supporting exposed clusters on sunny days was exposed to light levels well above the saturation index for grapevines of 700 μmol $m^{-2}s^{-1}$ (Smart, 1985), portions of the foliage supporting densely shaded clusters were well below the light saturation index, and often below the light compensation point of grapevines estimated at 15 to 30 μmol $m^{-2}s^{-1}$ (Smart, 1987). Although this was a small part of the overall canopy, the effect of shading these leaves and shading the cluster is confounded during the time the clusters were shaded (veraison through harvest).

Crop level and light exposure interacted to influence the berry weights of clusters harvested at similar soluble solid concentrations in 1995. Berry weights of exposed and partially shaded clusters were consistent across crop levels, while berry weights of densely shaded clusters declined as crop levels increased.

Color development

The interaction between crop level and cluster exposure was significant for hue angle in 1995 (Fig. 2A). At harvest, hue angle of partially shaded and densely shaded berries was within the green to yellow range (180^{o} > X 90^{o}), while exposed berries were within the red to yellow range (90^{o} > x 70^{o}). Hue angles of partially shaded and densely shaded clusters increased with increasing crop level. The hue angles of exposed clusters decreased with increasing crop level. Thus, increasing the crop level tended to delay the shift from the green axis probably indicating a delay in chlorophyll degradation and the shift toward the red axis was speeded if clusters were subjected to conditions encouraging sunburn; ie. full exposure.

In white grape cultivars, berry coloration depends predominantly on flavonoids and one of the key enzymes (phenylalanine ammonia-lyase) involved is their biosynthesis is mediated by phytochrome activity (Goodwin and Merced, 1985). This enzyme is promoted by increased light exposure in grapevines (Smart, 1987; Roubelakis-Argelakis and Kliewer, 1986). Moreover, Smart et al. (1988) reported that ›Cabernet Sauvignon∶ vines exposed to higher R/FR ratios reached veraison earlier and colored quicker, suggesting that phytochrome may play a role in color development. In the current study R/FR ratios adjacent to densely shaded clusters were 0.1 and 0.2, while adjacent to exposed cluster R/FR was 0.9 to 1.0. These values were similar to those found at the interior and exterior of grape canopies (Dokoozlian and Kliewer, 1995; Smart, 1987).

Fruit Composition

Previous reports indicate that lightly cropped vines have higher soluble solid concentrations and earlier harvest dates than vines with heavy crops (Bravdo et al., 1984; Edson et al., 1995). Our experiments support these findings (Table 3), but indicate that the magnitude of differences between light and heavy crop levels depends on the fruit microclimate. Within all crop levels, exposed and partially shaded treatments attained desirable soluble solids earlier than densely shaded treatments. These results agree with previous work examining the influence of canopy microclimate on berry composition (Morrison and Noble, 1990; Reynolds et al., 1986; Rojas-Lara and Morrison, 1989; Smart et al., 1988; Smart, 1987). The crop level and cluster light exposure interaction was significant for soluble solids when harvested on the same date in 1995. Overall, soluble solids of densely shaded clusters declined linearly as crop level increased, while the soluble solids of exposed and partially shaded clusters leveled off between the moderate and heavy crop levels. Thus, exposure had the greatest influence within the heavy crop level. Since the yield of moderately and heavily cropped vines were similar, these data suggest that the response of densely shaded clusters is related to the number of clusters per vine and higher crop loads. These results support previous work on 'Vidal blanc' which showed that fruit from cluster thinned vines contained soluble solids up to 2.5 °Brix higher than fruit from vines with similar yields that had not been cluster thinned (Howell *et al.,* 1987). Overall, crop level contributed 92% and 64% of the treatment error of the soluble solid concentration of berries in 1994 and 1995, respectively. Crop level also had a bigger influence on the timing of harvest dates when treatments were harvested at similar soluble solids.

The pH decreased with increased crop levels when harvested on the same date, regardless of season. In contrast, when harvested at similar soluble solids, pH showed no response to crop level. As light exposure increased, the pH values increased quadratically, increased linearly, and decreased linearly when harvested on the same date in 1994, on the same date in 1995, and at similar soluble solids in 1995, respectively. When harvested at similar soluble solids, exposed clusters showed increasing pH values as crop level increased (Fi.g3A). The pH of partially shaded clusters decreased between the light and moderate crop levels, but increased between moderate and heavy crop levels. In densely shaded clusters pH increased between the light and moderate crop levels, but declined slightly between the moderate and heavy crop levels. Within the moderate crop level, densely shaded clusters possessed higher pH than exposed and partially shaded clusters.

These converse responses to crop level and light exposure between the two harvesting criteria were related to maturation time following veraison. Exposed clusters were harvested between two to three weeks earlier than their densely shaded counterparts, depending on crop level.

Crop level did not influence the TA or tartaric acid concentration when harvested on the same date in either year (Table 3). When harvested at similar soluble solids in 1995, the TA and tartaric acid concentration declined linearly except for the densely shaded clusters, with increased crop levels (Fig. 3B & C). Malic acid (Table 3) declined with increased crop level regardless of season or harvesting criteria. As light exposure increased at heavy crop levels, the TA and malic acid decreased, regardless of season or harvesting criteria. Tartaric acid concentration showed no response to light exposure when harvested on the same date in either year. When harvested at similar soluble solids, densely shaded clusters had similar concentrations of tartaric acid over all crop levels, but it declined as crop level increased with a greater light exposure (Fig. 30).

Our results support previous studies examining the influence of light exposure on berry composition (Archer and Strauss, 1989; Reynolds *et al.*, 1986), and also reflect the effects of light-induced temperature changes. Clusters grown at 20°C have been shown to possess 2 to 3 times the amount of malic acid in their berries as compared to clusters grown at 30°C (Kliewer and Lider, 1970). The surface temperatures of exposed clusters often exceeded 30°C, especially during the 1994 season. In contrast, the surface temperatures of partially shaded and densely shaded clusters averaged around 20°C to 25°C. Previous studies found high TA in musts from severely thinned vines when thinned and unthinned vines were harvested at similar soluble solids (Bravdo et al., 1985; Bravdo et al., 1984). Exposed clusters from heavy crop levels were harvested almost a month after exposed clusters from light crop levels. Both tartaric acid (Crippen and Morrison, 1986) and malic acid (Morrison and Noble, 1990) have been shown to decrease with time following veraison due to a combination of dilution and degradation, respectively.

Comparisons between the total treatment errors of crop level, light exposure, and their interaction suggested that the relative influence of these factors upon pH and TA depended upon the harvesting criteria. For example, crop level contributed 77% and 88% of the treatment error of pH when all treatments were harvested on the same date in 1994 and 1995, respectively. In contrast, when harvested at similar soluble solids, the importance of the crop level factor declined to 10% of the treatment error and the importance of the light exposure and the crop level x light exposure interaction increased to 43% and 47% of the treatment error, respectively. Conversely, light exposure had a greater influence on TA if vines were harvested on the same date, while crop level had a greater influence on TA if harvested at similar soluble solids. These results may indicate that the relative response of acids to crop level and light exposure was sensitive to the ripeness of the berries.

In summary, regardless of harvesting criteria crop level influenced cluster weights, berry weights, berries per cluster, and soluble solids accumulation to a greater extent than did light exposure. Crop level contributed 92% and 64% of the treatment error of the soluble solid concentrations of clusters when harvested on the same date in 1994 and 1995, respectively. Crop level also had the greatest influence on the timing of harvest dates when treatments were harvested at similar soluble solids. Cluster light exposure contributed 68%, 96%, and 88% of the treatment error of the hue angle of berries when harvested on the same date in 1994, on the same date in 1995, and at similar soluble solids in 1995, respectively. Information developed in this study will help grape producers to know whether to focus their efforts on crop adjustment or training or both to improve cluster exposure depending on which must composition factor needs adjustment to improve wine quality.

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FIGURES

Figure 1. Light environments of fully exposed, partially shaded, and densely shaded ‘Seyval blanc’ clusters under overcast (A) and clear (B) sky conditions and the corresponding average daily surface temperatures of berries between veraison and harvest in the 1994 (C) and 1995 (D) growing seasons in relation to ambient air temperatures.

Figure 2. Influence of crop level and cluster light exposure on hue angle (A) and soluble solids (B) of ›Seyval blanc꞉ in 1995. Bar represents LSD (P=0.05).