Physiological response of *Vaccinium corymbosum* cv. Elliott to shading ~ets in Michigan

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bstract

ants of the highbush blueberry cv. Elliot (16-year-old, planted at 3 x 1 m) were :own in a sandy loam soil under colored shade nets (white, red, black and no net) of different density (25, 50 and 75% of shading) in Gobles, Michigan, USA, during 2006-07. Treatments were assigned randomly with 3 reps, and established as a continuum of 4 rows with 6 plants in each row. Nets (provided by Polysack Plastic Industries, Israel) were established horizontally from July to October at 3 m height. Leaf chlorophyll content increased and the ratio Chl a/Chl b decreased as shading intensity increased, with the black nets giving the largest changes. Also, leaf photosynthesis, measured at the actual light intensity under the nets, decreased as shading intensity increased, with the red and black 70% having the lowest values. Fluorescence (Fv/Fm), was significantly lower in plants without shading (control) compared with plants under 70% shading (white, black or red). Nets retarded fruit development; thus, on August 10th, the proportion of ripe fruit was 26.9 % without shading, while less than 10 % of the fruit were ripe under black 70 %, black 50 %, red 70 % and red 50%. On August 23, the separation between the controls and the most delayed fruit development (black 70 %) was over 30 %. In general, the various shading treatments increased fruit weight compared to the controls, but decreased fruit soluble solids, with the black 50 and 70 % having the greatest impact. Thus it is clear that colored shade nets alter blueberry physiology and could be a valuable tool to displace peak harvest season in blueberries.

INTRODUCTION

Blueberries grow naturally in the understory. When plants are subject to open field conditions, they might be stressed due to excess radiation, temperature and moisture deficit. Colored shading nets have been investigated in ornamentals and fruit crops (Oren-Shamir et al., 2001; Shahak et al., 2004); in these crops, depending upon the degree of shading and color used, they have changed light quantity and quality received by plants, which has altered branching, shoot extension, time of harvest, fruit set and fruit quality. In this context, the use of shading nets could alleviate environmental stresses faced by blueberries, increase yields and delay harvest.

MATERIALS AND METHODS

The trial was conducted in Gobles, Michigan using a commercial 16-year-old field of 'Elliott' planted in a sandy loam soil at 3 x 1 m. A completely randomized design was used with 3 replications of each treatment. The treatments were applied to 4 rows of 6 plants each and data were collected from the 12 plants in the middle two rows.

Combination of 3 colors of net (white, red and black) and 3 intensities (25, 50 and 75%) of shading nets (provided by Polysack Plastic Industries, Israel), plus control treatment (without net), generated 10 treatments (Figure 1). The trial was established horizontally at 3.5 m height after fruit set (July 7^{th}, 2006) and removed at the onset of leaf drop.

Maturity measurement. At the beginning of the study and peak harvest, fruit maturity was estimated using a hoop-count following the technique described by Hancock et al. (2000), by counting the number of mature fruit as a proportion of total fruit number.

Leaf gas exchange measurement. Single leaf gas-exchange parameters: (carbon dioxide assimilation rate (A), stomatal conductance (g_s), internal CO_2 concentration (C_i) and leaf temperature (T)) were measured with a CIRAS-2 portable open system gas analyzer (PP System, Hitchin Herts, UK), operated at 0.15 L min^{-1} flow rate and ambient CO_2 of about 34 Pa. Natural sunlight was used as light source at a photosynthetic photon flux density (PPFD) always higher than 1000 μmol m^2 s^{-1}. Photosynthesis was monitored on 4 selected branches for each bush, with a broad leaf cuvette that includes 2.5 cm^2 of leaf area, placed perpendicular to the sun. Measurements were conducted on sunny days between 12:00 - 13:00 pm.

Soluble solids. At harvest (25fruit per replication), total soluble solids (TSS) (°Brix) were determined using a temperature compensated digital refractometer (RFM 320, Bellingham & Stanley, Ltd., Tunbridge Wells, Kent, U.K.) at 20°C.

Chlorophyll content. The chlorophyll content was determined taking ten leaf discs (3.08 mm^2 each one) which were removed from ten different leaves on each plant using a paper punch. The pigment was extracted by immediately placing the leaf discs in 5 ml N,N-dimethylformamide for 36 hours in the dark at 5°C. Absorbance of the extracts was measured at wavelength of 664.5 and 647.0 nm using the simultaneous equations necessary for quantifying the chlorophyll content as described by Inskeep and Bloom (1985). Chlorophyll was also measured indirectly with a color meter (Minolta SPAD 502); twenty measurements were taken per replication.

Leaf fluorescence. Chlorophyll fluorescence was measured in leaf samples (6 per replication) taken from the outside of the bush (Model FMS-1, Hansatech, Kings Lynn, UK) at 4:00 pm. Before measurements, leaves were dark-adapted for 20 min in special leaf clips; the following parameters were assessed: Fo, Fm, Fv, and Fv/Fm.

Fruit and leaf weight. Leaves grown after the treatment were applied, were collected at harvest time and dried for 70 hours at 70°C and weighted. Fruit were collected at the peak of the harvest and their fresh and dry weights were measured. The relation between these two was expressed as percentage fruit water content.

Statistical analysis. Analysis of the variance (ANOVA) and regression analysis were performed using SAS programs (SAS Institute Inc., Cary, N.C., USA) and Sigma Plot (SPSS, Chicago, Ill., USA). The significance of the differences was determined by Tukey's test ($P< 0.05$). To build the tendency line and the R^2, correlations did not include the control treatment.

RESULTS AND DISCUSSION

No matter what color shading, leaf chlorophyll content significantly increased (Fig. 2-A) as degree of shading intensity increased, with the black nets having the largest changes. The same tendency but with higher R^2 was observed in the SPAD measurements (Fig. 2-B). Plant stress measured as leaf fluorescence (Fv/Fm) also increased linearly with the percentage of shading (Fig. 2-C), being significantly lower in plants without shading (control) compared with plants under 70% shading (white, black or red). Nevertheless, no treatment (even the control) was under 0.8, which is considered to be normal for non stressed plants (Groninger et al., 1996).

Leaf photosynthesis, measured at the actual light intensity under the nets, decreased linearly as shading intensity increased (Fig. 2-D). The red and black at 70% shading had the lowest values. This is in contrast with the effect of shading on *Ugni molinae* reported by Pastenes et al. (2003), a Chilean forest under storey shrub were such negative effect was not observe. The stomatal conductance (Fig. 3-A) was not significantly affected by the colored shading nets, although there were large amounts of variability observed among the controls. Significant correlations were also observed with C_i and T (Fig. 3-B and 3-C respectively). TSS decreased linearly with degree of shading (Fig. 3-D), but black and red nets had much greater effects on this component than white ones at the same level of shade. Leaf dry weight under the various nets was negatively correlated with the percentage of shade (Fig. 3-E). Fruit water content was positively correlated with the amount of shade the plants received (Fig. 3-F).

The nets significantly retarded fruit development (Table 1). On August 10th, the proportion of ripe fruit was 26.9 % without shading, while less than 10 % of the fruit were ripe under black 70 %, black 50 %, red 70 % and red 50%. On August 23, the separation between the controls and the most delayed fruit development (black 70 %) was over 30 %. In general, the various shading treatments significantly increased fruit weight compared to the controls, but significantly decreased fruit soluble solids, with the black 50 and 70 % having the greatest impact. Both black and white hail nets, which reduced light intensity to 45 and 63% of no-net controls respectively, also delayed fruit development in apples (Guerrero et al., 2002)

CONCLUSIONS

Rates of fruit color development were delayed by many of the shading treatments, but the most severe shading treatments, black 50 and 70%, also significantly reduced soluble solids. If nets are going to be used in Michigan to delay harvest, a shading treatment will need to be selected that significantly delays harvest but does not impact too greatly on fruit quality and future yields. Among the nets analyzed, the white 70% and red 50% appeared to be the most promising, but more studies will need to be conducted to determine their effects on future yields (return bloom probably affected by 70%). It will also be necessary to determine with greater precision, the time for installment and removal of the nets, since it could affect fruit maturity and flower induction for the coming season. The increases in price received for late maturing fruit will have to be balanced by the extra cost of installing nets.

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Tables

Table 1. Effect of shading (degree and color) on fruit maturity of 'Elliott' blueberries at Gobles, Michigan in 2006.

	% Mature fruit	
Treatment	August 10	August 23
Control	26.9 f[z]	76.6 b
White 25 %	25.7 ef	74.0 b
White 50 %	17.9 cde	66.4 b
White 70 %	13.8 bcd	49.8 a
Red 25 %	19.1 def	69.8 b
Red 50 %	9.3 abc	50.2 a
Red 70 %	9.23 abc	45.4 a
Black 25 %	21.3 def	71.4 b
Black 50 %	5.7 ab	44.0 a
Black 70 %	4.7 a	42.8 a

[z]Means within a column followed by different letters are significantly different at $p \leq 0.05$ using Tukey's multiple range test.

Figures

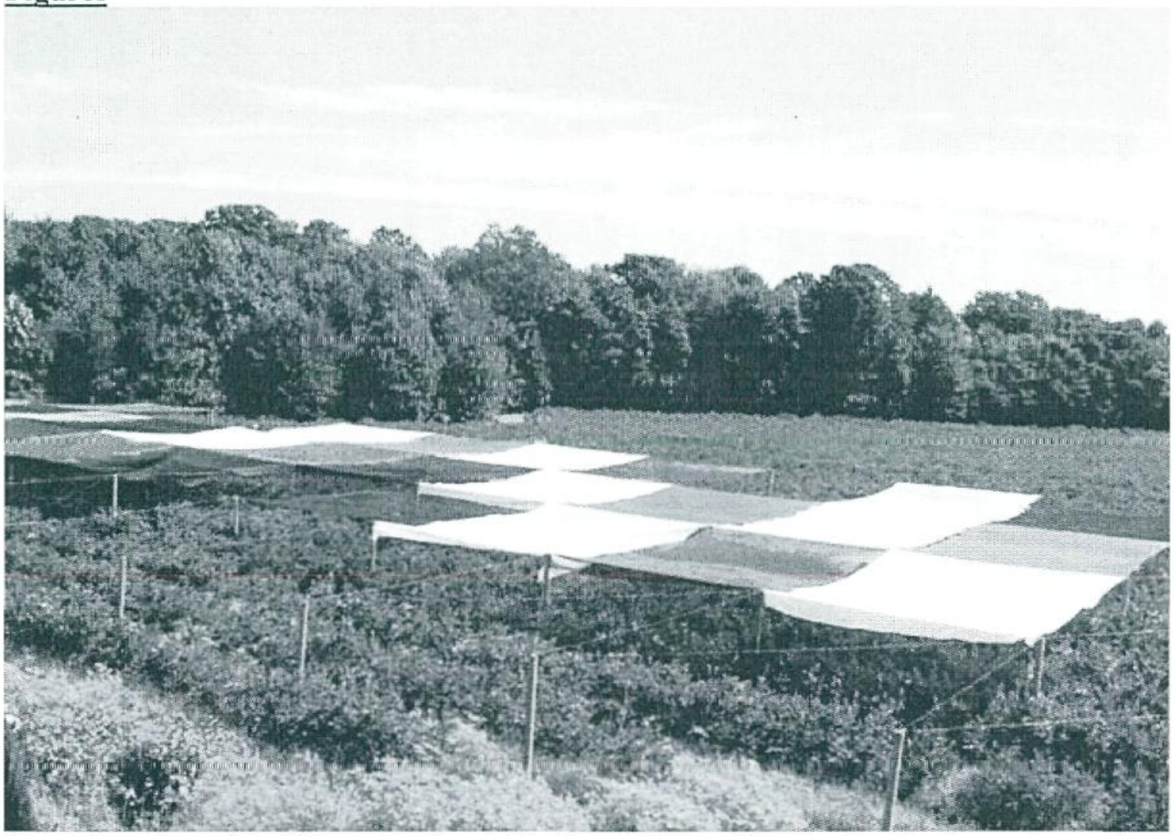

Fig. 1. Overview of the Elliott plot (Brookside Farm, Gobles, MI.) showing the three colors and shade percentages (Polysack Plastic Industries, Israel), plus control treatment.

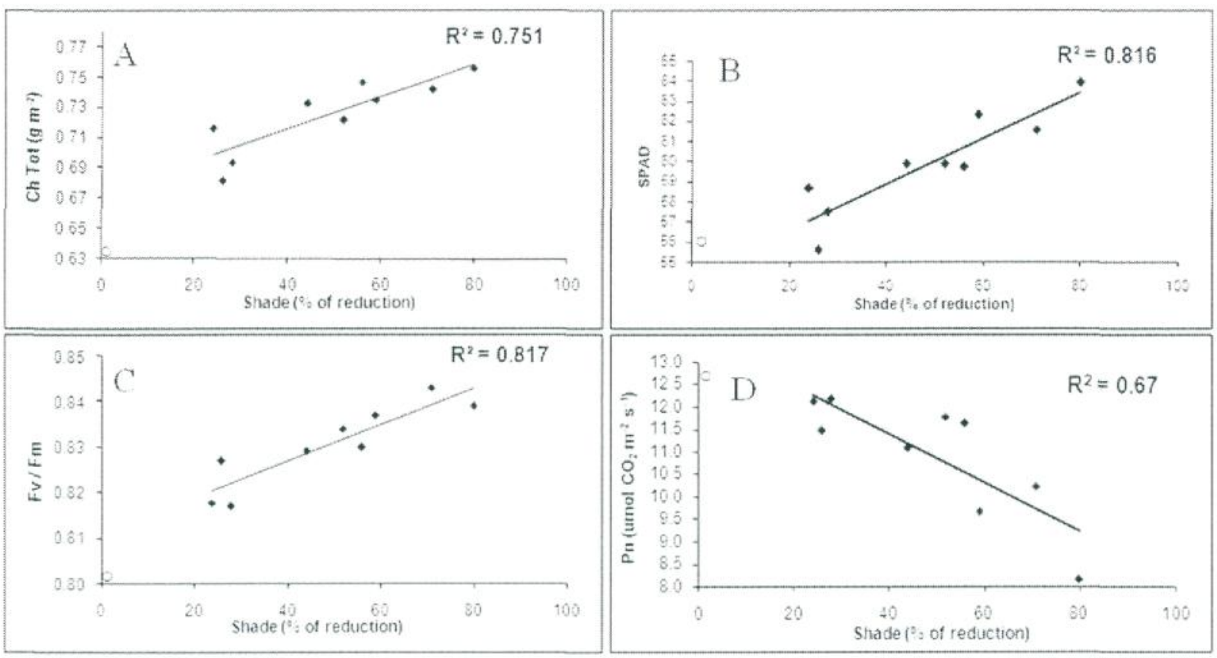

Fig. 2. Value of control (o) and correlations of degree of shading by nets (•) and : A) Total chlorophyll content B) SPAD readings, C) Fv/Fm level, D) Assimilation rate.

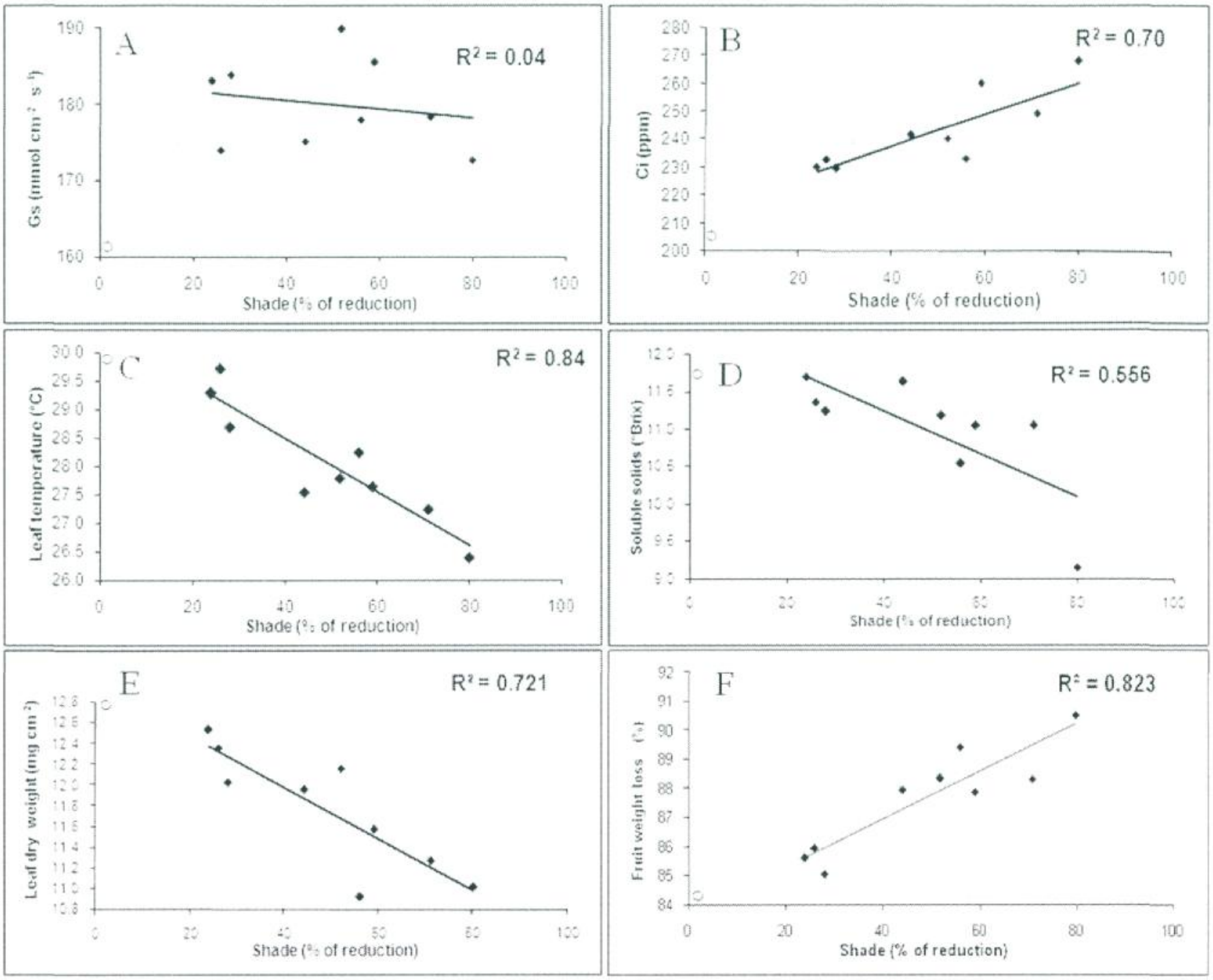

Fig. 3. Value of control (o) and correlations of degree of shading by nets (•) and : A) Stomatal conductance (G_s), B) Internal CO_2 concentration (C_i), C) Leaf temperature, D) Fruit total soluble solids, E) Leaf dry weight, and F) Fruit weight loss.