The Virginia Nursery & Landscape Horticulture Research Foundation (VNLHRF)

Optimizing Horticultural Production: Blue Shade Materials to Improve Nursery Crop Management

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Study Highlights:

- 30% blue and 30% red shade netting had no significant effect on the growth of *Hydrangea macrophylla* compared to a commonly used 30% black shade netting.
- Increasing the percentage of blue shade did not result in more compact growth of hydrangea.
- The growth habit of hydrangea was influenced by the total amount of light they received, not the color of the light.
- Light management alone was insufficient to control the growth habit of a vigorous hydrangea cultivar.

1. Introduction:

Why use shade and why shade hydrangea? Elevated air temperatures and intense light levels from late spring to early fall can damage foliage and cause rapid leaf desiccation in nurseries and greenhouses. Damage is often most severe for transplants, seedlings, and species native to shaded environments. To mitigate these environmental stresses, horticulturists often shade nursery and greenhouse crops (Stamps 2009). Growers typically shade the economically important woody perennial plant *Hydrangea macrophylla* (hydrangea) to prevent damage to the leaves caused by high light levels and air temperatures. Damaged foliage is common in open-field nursery production because hydrangeas are native to shaded environments in East Asia and not adapted to full-sun (Yan et al. 2021).

How do we currently shade hydrangea? Traditionally, shading materials such as aluminized netting, black netting, and whitewash have been used for shading hydrangea and horticultural crops in general. These materials are commonly referred to as "neutral density," meaning they do not alter the color of light reaching the crops, only the total amount of light (e.g., 30%, 50%, 70% shade). Most shading materials used in horticulture are neutral density, and it is common to use shade factors ≥30% for hydrangea production in Virginia.

What is colored shade and how does it affect plants? Colored shade materials, also known as "photoselective", have the potential to not only protect horticultural crops in the same way neutral-density shade does, but also potentially alter crop quality and growth habits (Bastías et al. 2021; Díaz-Pérez et al. 2020; Nesi et al. 2011; Oren- Scarascia Mugnozza et al. 2011; Shamir et al. 2001; Runkle Heins 2002). In general, colored shade materials have been most used to influence plant growth rate. To generally promote growth, plastics reduce the amount of blue (400-500 nm) and green (500-600 nm) light reaching the plants, giving these materials themselves a yellow to red appearance. To generally restrict growth, pigments are used that remove red (600-700 nm) and far-red (700-800 nm) light, resulting in materials that appear blue to green. Although introduced over 30 years ago, the effect of colored shade is still not well understood for most horticultural crops (Stamps 2009). Only a limited number of studies have looked at the effect of color shade on a range of economically important species such as pittosporum, bell pepper, apple trees, annual bedding plants, and hydrangea. Despite some successful uses of colored shade netting, the adoption of colored shade in agriculture has been minimal, likely due to their higher initial costs and the unpredictable effects on crop timing, flowering, and growth habits. As a result, research is still needed to validate the use of spectrum-altering shade materials for a wider range of nursery and greenhouse crops.

Why use colored shade for hydrangea? Even with a well-tailored growing environment, vigorous hydrangea cultivars often grow too large for sale by the time they have a fully developed root system and flower buds. As a result, hydrangeas frequently require pruning before sale, which reduces the total number of flowers, or requires multiple applications of plant growth regulators (PGRs) during the growing period, both of which are undesirable. These practices increase production costs, so finding alternative management strategies would be economically advantageous for growers. Since shading materials are already in use, blue shade has the potential to provide similar crop protection from excessive amounts of light while also possibly enhancing plant compactness. In theory, blue shade could thus offer a passive means of controlling growth habits. However, only one published study exists describing the effects of colored shade netting on hydrangea growth (Nesi et al. 2011). Thus, our objective was to determine if colored shade materials can economically replace plant growth retardants and/or pruning to produce sufficiently compact containerized hydrangea plants. We hypothesized a blue shade net would produce more compact plants compared to a 30% black and 30% red shade net. Additionally, we wanted to determine whether increasing the dose of blue shade could progressively increase plant compactness, in case the efficacy of blue shade was not most effective at a common 30% shade factor.

2. Objectives:

- Objective 1: Compare *Hydrangea macrophylla* growth under a black, blue, grey, or red colored shade netting in a nursery setting.
- Objective 2: Determine how the percentage of blue shade affects hydrangea growth.

3. Materials and Methods:

3.1. Lancaster Farms Pitchkettle Trial

Experimental setup. An on-site trial was conducted at Lancaster Farms Pitchkettle location to evaluate Objective 1. Figure 1 shows four 30×200 ft hoop houses covered with either a black, blue, red, or grey colored shade netting. We used a spectroradiometer to measure the light environments inside each hoop house on a sunny day. Figure 2 depicts the light environment inside each hoop house compared to direct sunlight outside the hoop houses. The common black shade netting typically used for horticultural crops was neutral density and evenly reduced all wavelengths of light inside the house by 30%. The grey shade material was also neutral density but provided a higher degree of shade (45%). The red shade netting (30% shade) prevented a portion of the green and blue light from entering the hoop house, creating an environment with a higher fraction of red light. The blue shade netting (30% shade) prevented a portion of the red and far-red light from entering the hoop house, creating an environment with a higher fraction of blue light. The shade nettings were used for the entire duration of the field trial, from 6/11/2024 to 7/30/2024 (49 days of growth). A weather station (Watchdog 2475, Spectrum Technologies inc., Aurora, IL, USA) was installed inside hoop houses covered with the black and blue shade netting to monitor the average air temperature, relative humidity (RH), vapor pressure deficit (VPD), and daily light integral (DLI).

Figure 1. The experimental setup at Lancaster Farms Pitchkettle location. A common black 30% shade netting is compared to a novel 30% blue, 30% red, and 45% grey shade netting.

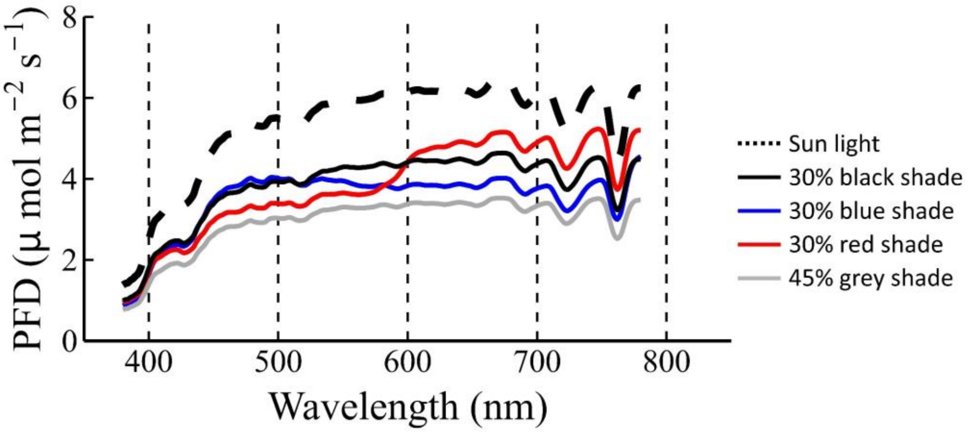

Figure 2. The photon flux density (PFD) at each nanometer between 380 and 780 nm under direct sunlight and black, blue, red, and grey shade netting. Measurements taken with a spectroradiometer at solar noon.

Plant material. Hydrangea macrophylla ‘Twist and Shout’ was selected for these experiments because of its vigorous growth rate that typically requires pruning or PGR applications. Plants were transplanted on 6/10/2024 by Lancaster Farms following their internal procedures. Each hydrangea was planted into a 3-gallon pot filled with pine bark soilless media and top dressed with 1 inch of rice hulls. Each treatment was on the same watering schedule and received no PGR applications.

Data collection. Data was collected on 25 plants in each treatment (n=25) on 6/11/2024, 7/2/2024, and 7/30/2024. Canopy height (pot media to tallest shoot meristem), canopy width (widest point), leaf chlorophyll concentration, leaf length (base of petiole to leaf tip), and projected canopy area (PCA) were measured at each data collection event. Canopy height, canopy width, and leaf length were measured with a ruler. The canopy volume was calculated by multiplying the width and height of each plant. Projected canopy area was measured using a digital images and ImageJ software. Leaf chlorophyll concentration was averaged for three representative leaves per plant with a portable chlorophyll meter (MC-100, Apogee Instruments, Logan, UT, USA).

Experimental design and data analysis. The experiment was organized as a completely randomized design. Each hoop house was an experimental unit randomly assigned a different shade netting. The data were analyzed using analysis of variance (ANOVA) and Tukey’s Honestly Significant test in R statistical software and an $\alpha=0.05$.

3.2. Hampton Roads AREC Greenhouse Trial

Experimental setup. To accompany the onsite trial, a greenhouse trial was conducted simultaneously comparing a neutral-density black shade net with varying percentages of blue shade, ranging from 40% to 75%. Four chambers were constructed out of PVC pipe to hold shade materials above hydrangea. Each chamber was 7 ft long × 5 ft wide × 4 ft tall and placed on the same north-to-south oriented greenhouse bench. Opaque dividers were used to prevent light contamination between chambers. Each chamber contained a quantum sensor (SQ-500, Apogee Instruments) and combination RH, air temperature, and VPD sensor (HygroVue, Campbell Scientific, Logan, UT, USA) maintained at the top of the crop canopy. A 50% black shade was selected to create a light environment with an average DLI close to the 50% blue shade material. The blue shade materials were plastic films with differing concentrations of the same pigment (Lee Filters, Burbank, CA, USA). As such, the spectral distribution is very similar among the blue shade treatments.

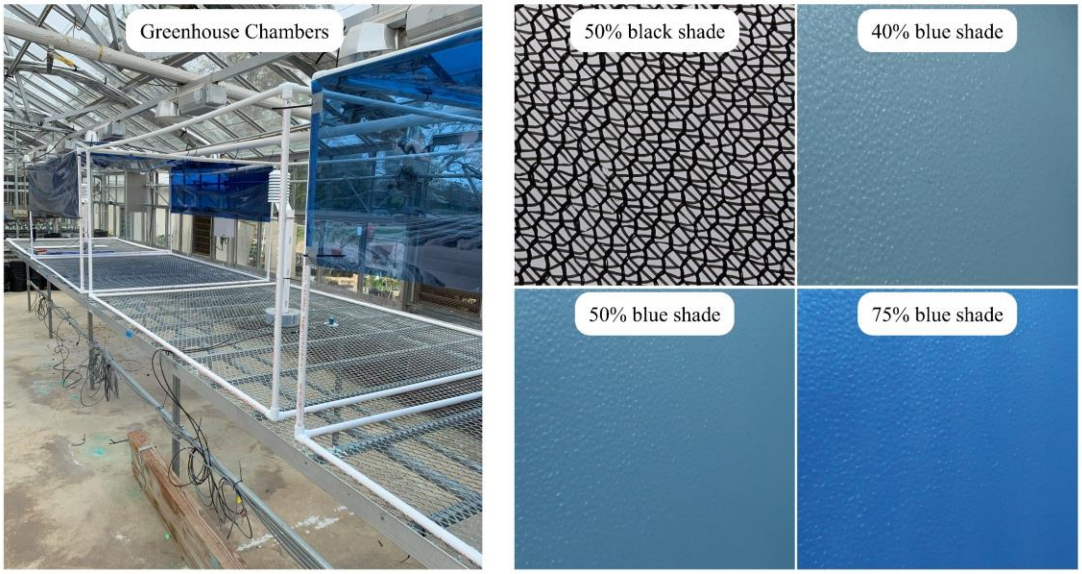

Figure 3. The experimental setup in the greenhouse of the Hampton Roads AREC. Small chambers made from PVC pipe held either a 50% black, 40% blue, 50% blue, or 75% blue shade.

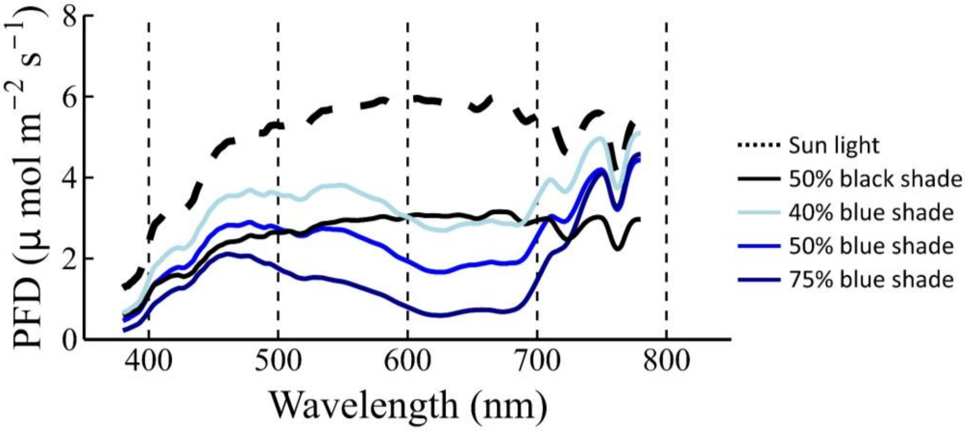

Figure 4. The photon flux density (PFD) at each nanometer between 380 and 780 nm under direct sunlight and 50% black, 40% blue, 50% blue, and 75% shade. Measurements taken with a spectroradiometer at solar noon.

Plant material. The same plant material used in the onsite trial was used for the greenhouse trial. Each plant was watered as needed and received no PGR application.

Data collection. Data collection occurred the same weeks that data was collected at the Pitchkettle field trial. Each treatment had 13 hydrangeas (n=13). The same repeated measurements taken in the on-the trial were taken on the greenhouse plants.

Experimental design and data analysis. The experiment was organized as a completely randomized design. Each chamber was an experimental unit randomly assigned a different shade material. The data were analyzed using analysis of variance (ANOVA) and Tukey's Honestly Significant test in R statistical software and an $\alpha=0.05$.

4. Results:

4.1. Lancaster Farms Pitchkettle Trial

Environmental conditions. The environmental conditions inside the 30% black and 30% blue shade treatments were very similar (Table 1). The DLI, air temperature, RH, and air VPD were all less than 2% different from one another. Environmental data was not collected inside the 30% red and 45% grey treatments due to equipment limitations. Based on data generated from spectroradiometer measurements and weather stations, it can be estimated the average DLI inside the 30% red and 45% grey shade treatments were close to 31 and 25 mol m^{-2} d^{-1}, respectively. The air temperature, RH, and air VPD in the 30% red and 45% grey reatments cannot be estimated based on the current data.

Table 1. The average environmental conditions inside the 30% black and 30% blue shade covered hoop houses at Lancaster Farms Pitchkettle location.

Environmental parameter	30% black shade net	30% blue shade net
Daily light integral (mol m^{-2} d^{-1})	30.9	31.3
Air temp (°F)	78.7	78.7
Relative humidity (%)	78.9	78.8
Air vapor pressure deficient (kPa)	0.70	0.70

Plant growth. Hydrangea shoot growth (i.e., stems and leaves) was statistically similar among the 30% black, 30% blue, and 30% red treatments after 49 days (Fig. 5A-F). There was no statical difference between the plant width, height, PCA, canopy volume, leaf length, or leaf chlorophyll content among the 30% shade treatments. However, hydrangea grown under the 45% shade treatment had greater plant height, PCA, and volume compared to the 30% shade treatments (Fig. 5B, C, D). PCA and volume were 28% and 22% greater under the 45% shade treatment compared to hydrangea in the 30% shade treatments. Despite smaller canopy volumes under the various 30% shade colors, all the hydrangeas still required pruning before sale. Pruning occurred on 8/21/2024, 71 days after transplant. Each hydrangea was pruned to roughly a canopy height of 11 in and width of 16 in (volume = 176 in^2). This final target size was equivalent to hydrangea size around week four of the trial.

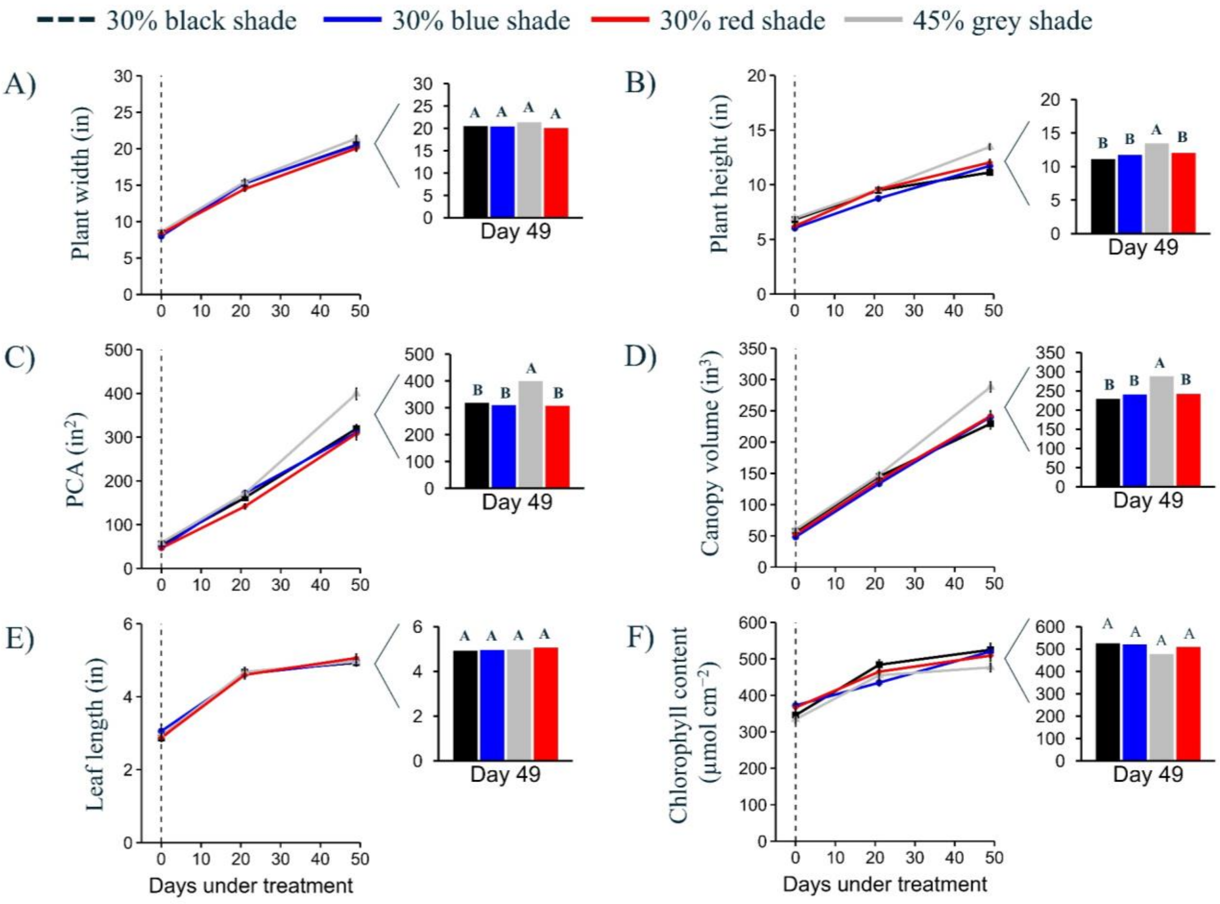

Figure 5. Growth results of Hydrangea macrophylla 'Twist and Shout' under a 30% black, 30% blue, 30% red, and 45% grey shade. Projected canopy area (PCA) measure with photographs. Canopy volume was calculated for each plant by multiplying the canopy height by its width. Means represent averages of 25 plants (n=25) ± SE. Analysis of variance (ANOVA) was conducted for the ninth week of growth. Letters above bars indicate significant differences according and Tukey's Honestly Significant test at α=0.05.

4.2. Hampton Roads AREC Greenhouse Trial

Greenhouse environmental conditions. Table 1 depicts the average environmental conditions inside the greenhouse chambers for the duration of the experiment. Similar to the Pitchkettle trial, the variance among treatment air temperature, RH, and air VPD was low and within 5% of each other. Unlike the Pitchkettle trial the average DLI inside experimental chambers ranged from 3.39 mol m^{-2} d^{-1} in the 75% blue to 8.43 mol m^{-2} d^{-1} in the 40% blue treament. Due to the location in the greenhouse, internal shading, and higher percentage shade being used, the average light levels were considerably lower than in the field trial where the average DLI was closer to 30 mol m^{-2} d^{-1}. On averagre, the greenhouse air temperature was ~5 °F higher than the Pitchkettle trial.

Table 1. The average environmental conditions inside

Greenhouse Trial Environmental Conditions in Each Chamber				
Parameter	50% black shade	40% blue shade	50% blue shade	75% blue shade
Daily light integral (mol m^{-2} d^{-1})	7.23	8.43	6.20	3.39
Air temp (°F)	81.9	82.8	82.0	82.8
Relative humidity (%)	77.3	74.8	77.5	75.5
Air vapor pressure deficient (kPa)	0.96	1.07	0.94	1.07

Plant growth. In general, hydrangea shoots (leaves and stems) were similar among all the treatments despite the differences in average DLI and varying shade color (Fig. 6). Hydrangea plant width was greater in the 50% blue than 75% blue shade (Fig. 6A). The average plant height, PCA, canopy volume, and leaf length were statistically similar after nine weeks of growth (Fig. B-E). Hydrangea leaf chlorophyll content was greater in the 40% blue shade than the 50% and 75% blue shade treatments (Fig. 6F).

5. Discussion

Daily light integral effect of shoot growth. Between the two studies, there were few differences in hydrangea growth resulting from the use of colored shade. The main factor determining hydrangea growth habit was the shade percentage, and as a result the average DLI. Figure 7 shows the Pitchkettle and greenhouse trial hydrangea after nine weeks of growth as a function of the average DLI. As DLI increased (i.e., less shade), plant height increased and plant width decreased (Fig. 7A, B). This caused the overall canopy volume to be relatively constant as a function of DLI, but the plant architecture to change considerably (Fig. 7C). This is consistent with the other observations that plants alter their growth to have longer stems when grown in shaded environments to increase the amount of light they can intercept. Longer stems can increase light interception by reducing internal leaf shading among leaves, improves competition among neighboring plants, and increases the ground surface area they cover. Although advantageous for the plant, stem elongation is ultimately unwanted for ornamental hydrangea cultivation because it reduces overall aesthetic quality, makes plants more prone to damage, and more difficult to move. Based on the field and greenhouse experiments, shade factors >30% would undesirably reduce plant compaction, regardless of shade color.

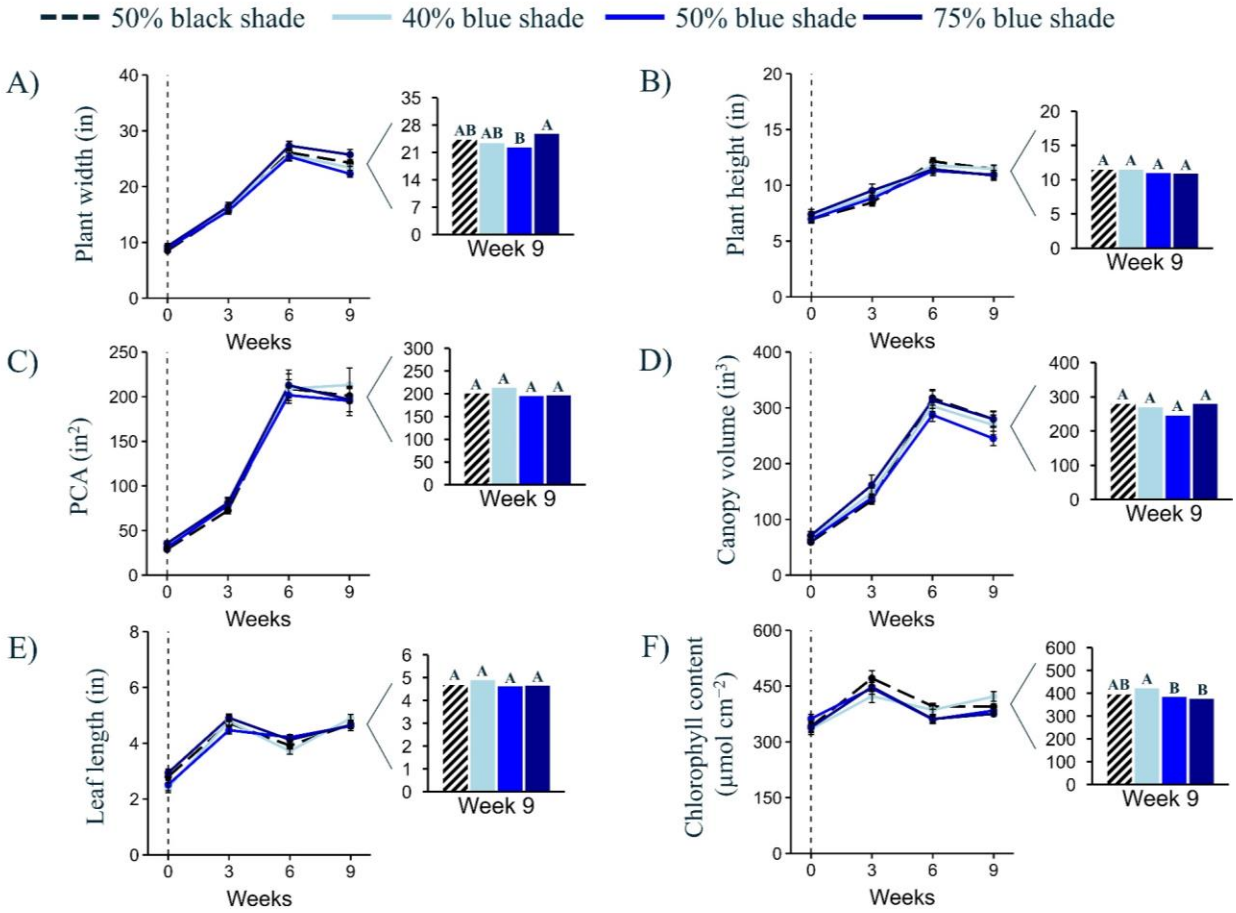

Figure 6. Growth results of *Hydrangea macrophylla* 'Twist and Shout' under a 50% black, 40% blue, 50% blue, and 75% blue shade in the Hampton Roads AREC research greenhouse. Projected canopy area (PCA) measure with photographs. Canopy volume was calculated for each plant by multiplying the canopy height by its width. Means represent averages of 13 plants (n=13) ± SE. Analysis of variance (ANOVA) was conducted on the ninth week of hydrangea growth. Letters above bars indicate significant differences according and Tukey's Honestly Significant test at α=0.05.

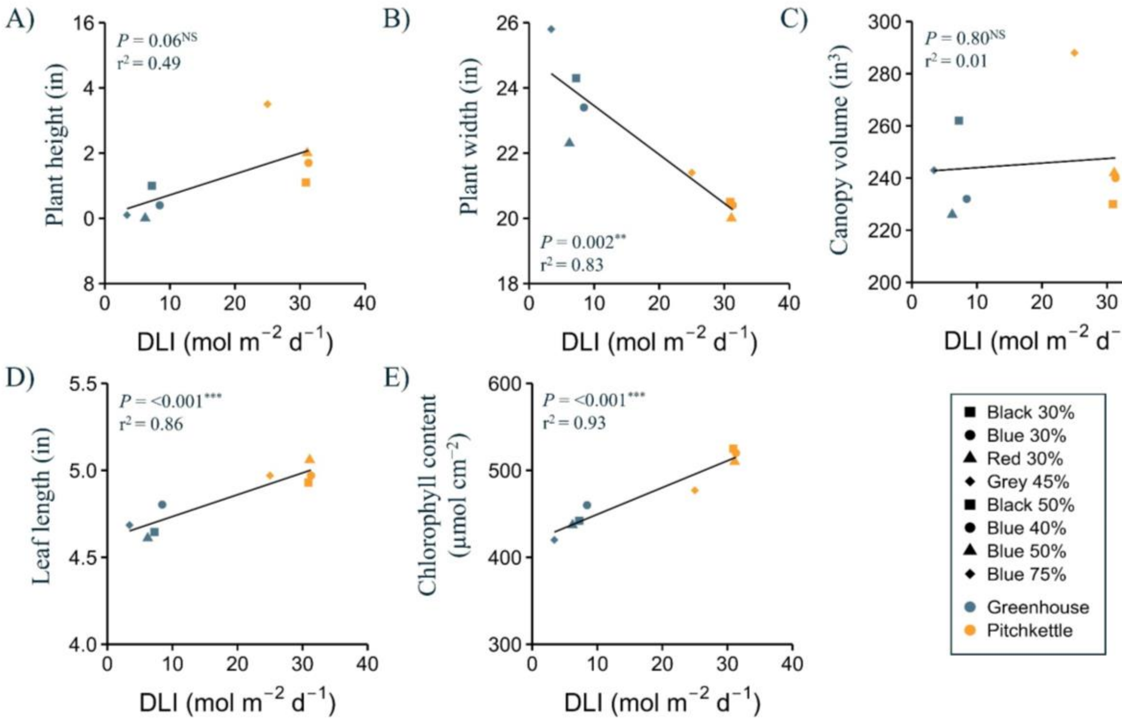

Figure 7. The average hydrangea growth metrics for both Pitchkettle and greenhouse trials as a function of the average daily light integral (DLI).

Daily light integral effect on hydrangea leaves. Similar to the stem elongation, DLI affected hydrangea leaves. As DLI increased both leaf length and chlorophyll concentration increased (Fig. 7D, E). With few data points falling far from the fit linear regression line, hydrangea leaves were not influenced by the color of shade netting, only the percentage shade. Our data is consistent with observations that plants develop darker green leaves at higher DLIs (Kelly et al. 2020). However, leaf length typically decreases or is unaffected as DLI increased, which is contrary to our findings (Kelly et al. 2020). Ultimately, the change in hydrangea leaf shape and color would be largely inconsequential to cultivation relative to the negative effect on stem elongation and should be considered a secondary concern.

Shade color implications for hydrangea production. While colored shade materials can influence other crops, we did not observe any meaningful effect of shade color on the shoot growth of hydrangea. In agreement with our results, Nesi et al. 2011 also reported that six different *Hydrangea macrophylla* cultivars were all nearly identical when grown under 70% blue, 70% black and 70% red shade nets. Although commercial blue shade materials may claim to restrict crop growth, and other anecdotal sources make similar claims, our results and another past study strongly suggest colored shade has no effect on *Hydrangea macrophylla*. Similarly, although the commercial red shade materials claim to promote shoot growth, we also did not observe this to occur for hydrangea in our field trial. Taken together, blue and red shade netting were no different than traditional black shade netting and did not prevent the need for time consuming pruning before sale, and therefore other considerations such as the availability, installation, and price of shade materials are more relevant concerns for determining what shade materials to use for hydrangea production.

Implication for shade percentage. Comparing hydrangea growth to the average DLI, one might assume that reducing the level of shade, or not shading at all, could keep hydrangea plants smaller and potentially reduce the need for pruning. While potentially true, this is likely not a possible solution to improve plant compaction because at higher average DLI hydrangea leaves can become damaged and reduce their overall aesthetic quality. As such, 30% shade is still recommended for hydrangea production, but the color of that shade is less important.

Future prospectives. Changing the shading practices of hydrangea production is likely not an effective management practice because neither the color of shade nor the degree of shade was effective at reducing plant vigor. Additionally, removing the shade entirely is also not a feasible option. Our results suggest that light management is not the best management tool growers can choose to manage the growth of vigorous hydrangea cultivars. While a passive means to control plant growth is enticing, active management practices are likely needed to grow more compact hydrangeas. Active management would likely require 1) the application of PGRs and/or 2) the management practices such as water restriction (Morel 1999). PGRs such as Daminozide, Ancymidol, Paclobutrazol, Flurprimidol, and Chlormequat Chloride could be used for this purpose, and many suggestions exist for the application of PGRs for hydrangea. However, PGR applications will require on site trials, consultation, and/or research partnerships to determine the best management practices because PGR effectiveness depends on plant vigor, air temperature, fertility, light levels, and irrigation. The other active management practice available to growers involves providing less irrigation to plants. Water restriction has been shown to reduce plant vigor, but this management practice does come at the risk of damaging crops and may not be feasible without the purchase of water content sensors/probes or additional labor manually weighing pots to determine water content. As such, PGR applications would likely be the most practical method to control vigorous hydrangea growth.

6. Conclusions:

1. Blue shade netting is not effective for reducing shoot growth of hydrangea compared to the common black shade netting.
2. The percent shade had a more pronounced effect on hydrangea shoot size than the color of the shade.
3. All treatments were effective in reducing the need for manual pruning of hydrangea before sale.
4. Alternative crop management strategies are required for vigorous hydrangea cultivars.
5. Future research should investigate the potential of plant growth regulators to control vigorous hydrangea cultivars or the selection of cultivars that are less vigorous or have smaller growth habits.

7. Acknowledgements:

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8. References:

Bastías RM, Losciale P, Chieco C, Corelli-Grappadelli L. 2021. Red and blue netting alters leaf morphological and physiological characteristics in apple trees. Plants. 10(1):127.

Díaz-Pérez JC, John KS, Kabir MY, Alvarado-Chávez JA, Cutino-Jiménez AM, Bautista J, Gunawan G, Nambeesan SU. 2020. Bell pepper (Capsicum annum L.) Under colored shade nets: fruit yield, postharvest transpiration, color, and chemical composition. Hortscience. 55(2):181-187.

Morel P., 1999, August. Growth control of Hydrangea macrophylla through water restriction. In International Symposium on Growing Media and Hydroponics 548:51-58.

Nesi B, Lazzereschi S, Pecchioli S, Grassotti A, Salazar-Orozco G. 2011, November. Effects of colored shade netting on the vegetative development and on the photosynthetic activity in several Hydrangea genotypes. In VII International Symposium on New Floricultural Crops. 1000:345-352.

Oren-Shamir M, Gussakovsky E, Eugene E, Nissim-Levi A, Ratner K, Ovadia R, Giller Y, Shahak Y. 2001. Coloured shade nets can improve the yield and quality of green decorative branches of Pittosporum variegatum. The Journal of Horticultural Science and Biotechnology. 76(3):353-361.

Runkle ES, Heins RD. 2002. Stem extension and subsequent flowering of seedlings grown under a film creating a far-red deficient environment. Scientia Horticulturae. 96:257-265.

Scarascia Mugnozza G, Vox G, Schettini E. 2011. Radiometric properties of coloured nets for peach tree protected cultivation. In Atti del Convegno di Medio Termine dell'associazione Italiana di Ingegneria Agraria. 1-6.

Stamps RH. 2009. Use of colored shade netting in horticulture. Hortscience, 44(2):239-241.

Yan X, Wang S, Duan Y, Han J, Huang D, Zhou J. 2021. Current and future distribution of the deciduous shrub Hydrangea macrophylla in China estimated by maxent. Ecology and Evolution. 11(22):16099-16112.

Kelly N, Choe D, Meng Q, Runkle ES. 2020. Promotion of lettuce growth under an increasing daily light integral depends on the combination of the photosynthetic photon flux density and photoperiod. Scientia Horticulturae. 272:109565.