Colored Shade Cloth Affects the Growth of Basil, Cilantro, and Parsley

by

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Abstract

A preliminary experiment evaluated the effect of plant growth regulators (PGRs) or mechanical stimulation (brushing) on branching of sweet basil (*Ocimum basilicum* L.), cilantro (*Coriandrum sativium* L.), and parsley (*Petroselinum crispum* (Mill.) Nyman ex A.W. Hill). Dikegulac sodium increased branching in sweet basil up to 400 ppm and thereafter branching decreased compared to control plants. Ethephon increased branching in sweet basil as rate increased up to 500 mg/L compared to control plants. Mechanical stimulation resulted in a significant decrease in plant height, plant width, number of branches, and number of leaders for all species compared to control plants. Benzyladenine and metaconazole had no effect on these species. In the main experiment the effect of colored shade cloth and PGRs or brushing were assessed on sweet basil, Thai basil (*Ocimum basilicum* 'Siam Queen' L.), Genovese basil (*Ocimum basilicum* 'Genovese' L.), cilantro, and parsley. All crops were grown under conventional black, blue ChromatiNet®, or red ChromatiNet® shade cloth. Subplot treatments included: dikegulac sodium at 400 ppm; benzyladenine at 300 ppm; ethephon at 350 ppm; brushing at 10 strokes applied twice daily. We assessed volatile compunds on all crops and conducted a sensory panel on sweet basil. Red shade cloth increased the number of branches and shoot fresh weight in sweet basil, Thai basil, and Genovese basil. Number of leaf stalks and shoot fresh weight also increased in cilantro plants grown under red shade cloth. Red shade cloth increased fresh weight of parsley plants. Sensory panel results showed a preference for the appearance of sweet basil grown under red shade cloth. Red shade cloth can be used to grow

sweet basil, Thai basil, Genovese basil, cilantro, and parsley plants that have more branches and higher fresh weights.

Dedication

I would like to dedicate this thesis to my family, without them I would not be working in the field that I truly love and enjoy. I would also like to thank Dr. Paul Thomas and Ms. Pamela Lewis. Both of you helped me gain insight into the world of horticulture and I learned many life lessons from the both of you during my undergraduate career.

I would also like to thank Dr. Joyce Latimer for all her guidance and encouragement during the past two years. I would like to thank my committee members Dr. Holly Scoggins and Dr. Sean O'Keefe for their guidance and help along the way. Mr. John Freeborn helped me set up my experiment and gave me advice about so many topics; I truly thank you for all of your help. Last but not least I would like to thank Mr. Jeff Burr, Dr. Susan Duncan, Mara Grossman, Kevin Harris, Carly Reynolds, J.B. Snelson, Brianna Swanson, Kim Waterman, and Harriet Williams.

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Chapter 1

Literature Review and Introduction

Why Grow Herbs?

Greenhouse herb production is becoming an increasingly important aspect of commercial greenhouse production in the United States. Data from the USDA 2009 Census of Horticultural Specialties reported that 323 operations were specializing in growing herbs (USDA, 2010). The value of herb production along with other food crops grown under cover represent the fastest growing market in horticulture with a 148 percent increase in value from $223 million in 1998 to $553 million in 2009 (USDA, 2010). Herb production presents several advantages to commercial greenhouse operations. Herb production can be easily added to bedding plant production operations because herbs have similar cultural requirements and they can be grown in a range of growing media (Gibson et al., 2000). Herb seed is relatively cheap and they have quick production times of about four to six weeks depending on species. Herbs also have few insect and disease problems (Gibson et al., 2000).

Herbs are considered the fresh or dried leaves of plants that are used as a food flavoring; this includes herbaceous plants like basil and woody plants like bay and rosemary (Anderson and Schnelle, 2010). Herbs may be sold fresh cut, dried, or as live plants. A survey conducted in Kentucky found that most restaurants surveyed were interested in fresh basil, chives, cilantro, parsley, and rosemary; all of these represent a potential market for local growers (Anderson and Schnelle, 2010).

Basil

Basil is one of the most popular culinary herbs, used in tomato sauces, pesto, in salads, and in flavored oils (Simon et al., 1999; Williamson, 2008). The word basil is thought to come from the Greek word basilicon, meaning kingly herb and the Greek word basilicus, the mythical king of serpents (Tucker and DeBaggio, 2009a). The second meaning is thought to have led to the dislike of basil into the Victorian age. The genus name for basil, *Ocimum,* is thought to have come from the Greek word that means aromatic or fragrant (Pflasterer et al., 2006; Tucker and DeBaggio, 2009a). The Romans (living in the Roman Empire) believed that basil would cause injury to the stomach, kidneys, and eyesight, cause madness, and lead to liver troubles (Tucker and DeBaggio, 2009a). In contrast to the Romans, Hindus in India believed that a leaf of basil buried with the dead would serve as a passport to heaven (Pflasterer et al., 2006).

Figure 1.1 Sweet Basil (Photo by author, 2012)

Beginning in the seventeenth century, the English used basil to keep away flies and other pests as well as a spice in their food (Pflasterer et al., 2006). New cultivars of the genus that were developed in the early twentieth century have also led to the popularity of basil. Seven species in the genus are used in cooking as well as being used in wreaths and potpourris; they are *Ocimum americanum*, *O. basilicum*, *O.*

campechianum, *O. x citriodorum*, *O. gratissimum*, *O. kilimandscharicum*, and *O. tenuiflorum* (Tucker and DeBaggio, 2009a). *Ocimum basilicum* (sweet basil) (Figure 1.1) is the most popular basil used in cooking (Williamson, 2008); it will be the basil species focused on hereafter.

The genus *Ocimum* is in the Lamiaceae family (the mint family) and has the classic characteristics of the mint family such as square stems and opposite leaves. *Ocimum* also has flowers in the axils of the leaves or as loose flower spikes (Tucker and DeBaggio, 2009a).

All sweet basil cultivars can be cultivated at temperatures between 7 to 27 degrees Celsius (°C) and in soil pH 4.3 to 8.2 (Simon, 1995). Sweet basil is characterized as having an aroma like French tarragon, a sweet licorice scent, attributed to the aroma compound methyl chavicol (Tucker and DeBaggio, 2009a). Sweet basil grows to about 49 centimeters (cm) in height, 42 cm in width with green leaves, stems, and green flower spikes with white flowers (Simon et al., 1999). Two other popular cultivars of sweet basil include 'Genovese', which has a lavender-like floral aroma attributed to linalool, and is typically used to make pesto; and Thai basil 'Siam Queen' (Figure 1.2) which has a stronger licorice scent than sweet basil, and a higher percentage of methyl chavicol, and is used in salads, sauces,

Figure 1.2. Thai Basil 'Siam Queen' (Photo by author, 2012)

and Thai cooking (Tucker and DeBaggio, 2009a; Williamson, 2008). 'Genovese' basil (Figure 1.3) is characterized as growing to 49 cm in height, 46 cm in width, with green leaves, stems, and flower spikes with white flowers. 'Siam Queen' grows to about 35 cm in height, 44 cm in width, with green-purple leaves, green stems, and flower spikes with pink to purple flowers (Simon et al., 1999).

Germination rates should be above 80% with emergence in about 5 days at 21°C (Gibson et al., 2000; Simon, 1995). Grown in a greenhouse, sowing to transplanting takes about 2 to 3 weeks and transplanting to a finished crop takes another 2 to 3 weeks. Total crop time is about 4 to 6 weeks (Gibson et al., 2000). Recommended fertilizer rates are 75 to 150 ppm N continuous liquid feed with 20-10-20 or 15-0-15 N-P-K fertilizer. Insect pests to monitor on basil include thrips, caterpillars, and slugs with powdery mildew and fusarium wilt being the major disease problems (Gibson et al., 2000). *Fusarium oxysporum* f. sp. *basilicum* is the cause of fusarium wilt of basil. Symptoms include stunting of young basil plants before wilting, a downward bending or cupping of the leaves (Pundt and Smith, 2005). In the later stages of fusarium wilt, brown streaks are seen on the stem. Fusarium wilt is an above ground infection which will leave the root system unaffected; this helps to distinguish fusarium wilt from other wilting caused by

Figure 1.3. 'Genovese' basil (Photo by author, 2012)

root rot diseases (Pundt and Smith, 2005). Fusarium wilt is a hard disease to manage so starting with disease-free seeds and sterile media is essential (Pundt and Smith, 2005).

Cilantro

The botanical name of cilantro (Figure 1.4), *Coriandrum sativum*, is derived from the Greek word koriannon which means bedbug because the aroma resembles that of a bedbud ((Mangan and VanVranken, 2004; Tucker and DeBaggio, 2009b). The aroma is a combination of the compounds linalool, 2-decenal, 2-dodenenal, decanal, and 2-tetradecenal (Tucker and DeBaggio, 2009b). The seed of cilantro is commonly known as coriander and the plant is known as Chinese parsley or cilantro, a term used in the United States and Latin America (Tucker and DeBaggio, 2009b). Cilantro, which resembles parsley, is in fact in the same family, Apiaceae (Mangan and VanVranken, 2004).

Figure 1.4. Cilantro (Photo by author, 2012)

Cilantro is characterized as an annual that has two life stages. The first stage resembles flat-leaf parsley on long stems that grow from a crown. The second stage occurs about 30 days later, with the appearance of a tall flower stalk that rises from the crown and ends in an umbel with white to pink flowers that produce the coriander seeds (Tucker and DeBaggio, 2009b). The mature plant height varies from 20 to 90 cm.

Cilantro is used in many different cuisines from salads, sauces, and soups to salsa, guacamole, and in Brazil with scallions (Mangen and VanVranken, 2004; Tucker and Debaggio, 2009b). Cilantro leaves do not retain flavor upon drying but can be frozen or stored in oil (Tucker and DeBaggio, 2009b).

Cilantro seeds have a low germination percentage but usually germinate in about seven days at 21°C (Gibson et al., 2000). The seed of cilantro is actually a fruit with two embryos which means with 100 % germination two plants would germinate per cell (Mangen and VanVranken, 2004). The time from sowing to transplanting is around 2 to 3 weeks with transplanting to finishing in another 2 to 3 weeks; with a total production time of 4 to 6 weeks (Gibson et al., 2000). Recommended fertilizations rates are 75 to 150 ppm N as a constant liquid feed of a 20-10-20 or 15-0-15 N-P-K fertilizer. Cilantro plants grow poorly during the summer heat, and will bolt because cilantro is a long day plant (Gibson et al., 2000). If the media temperature can be kept between 28 and 32°C, successful summer production is possible. Researchers have successfully used 75% shade cloth to achieve a mean afternoon soil temperature of 30°C when mean afternoon air temperature is 40°C (Sarada et al., 2011).

Bacterial leaf spot caused by *Pseudomonas syringae* is the most common disease problem of cilantro. Symptoms consist of angular leaf lesions between the veins that are first water soaked and translucent, drying over time (Mangen and VanVranken, 2004). Techniques for control include buying uncontaminated seeds, disinfecting benches and pots, avoiding water splash between plants, discarding infected plants, and removing plant debris which can harbor bacteria (Mangen and VanVranken, 2004; Pundt and Smith, 2005).

Parsley

Parsley (Figure 1.5) (*Petroselinum crispum*) is one of the most recognizable herbs since it is commonly seen as a garnish on dinner plates (Gill and Merrill, 2010). The genus name comes from the Greek word petros which means rock, which is thought to allude to where parsley is commonly seen growing which includes cliffs and rocks (Tucker and DeBaggio, 2009c). Parsley is in the family Apiaceae (Umbelliferae), the same family as the carrot and cilantro (Gill and Merrill, 2010; Tucker and DeBaggio, 2009c). Three types of parsley are grown in the United States, common (curled-leaf, variety *crispum*), plain (flat-leaved, variety *neopolitanum*) and Hamburg or turnip-rooted (variety *tuberosum*); (Tucker and DeBaggio, 2009c). Parsley is often used in salads, soups, and stews along with its use as a garnish mentioned earlier (Anderson, 2011). Parsley is an excellent source of vitamins A and C, niacin, riboflavin, iron, and calcium (Gill and Merrill, 2010). Dehydrated parsley flakes retain their characteristic flavor and green color and are produced from parsley grown in commercial fields (Stephens, 2009).

Figure 1.5. Parsley (Photo by author, 2012)

Parsley is a biennial that grows to about 75 cm in height with greenish-yellow flowers in umbels (Tucker and DeBaggio, 2009c). Parsley is mainly grown for its foliage in its first year. In its second year parsley leaves become bitter after the emergence of the flower stalk (Tucker and DeBaggio, 2009c). Parsley leaves are triangular in outline with three lobes which grow from crowns just like cilantro (Tucker and DeBaggio, 2009c).

The parsley aroma is thought to be mainly due to para-1,3,8-menthatriene (Tucker and DeBaggio, 2009c).

Parsley seed germination is described as being erratic and low even under optimal conditions (Simon et al., 1988). The slow germination can be attributed to a high concentration of heraclenol which can be leached out if soaked in water over night (Kato et al., 1978; Tucker and DeBaggio, 2009c). The presence of heraclenol has also been suggested as the reason weeds have a difficult time establishing in parsley fields (Kato et al., 1978). Sowing to transplanting of parsley takes about 3 to 4 weeks; transplanting to a finished product takes another 4 to 5 weeks. Total crop time is about 7 to 9 weeks in the greenhouse (Gibson et al., 2000). Parsley should be fertilized on a constant liquid feed at 125 ppm N 20-10-20 or 15-0-15 N-P-K fertilizer (Gibson et al., 2000). Spider mites are a major pest on parsley and should be scouted for weekly. Parsley also has problems with aster yellows, leaf scorch, leaf spot, powdery mildew, and *Pythium* root rot (Gibson et al., 2000).

Parsley is very sensitive to overwatering especially in the seedling stage and as a result is very susceptible to *Pythium* (Gibson et al., 2000; Pundt and Smith, 2005). Seedlings infected with *Pythium*, or one of the other damping-off fungi, will often collapse with a dark, necrotic stem canker at the soil line. Mature plants can also show symptoms including leaf yellowing, wilting, and stunting of the plants. Discolored, black or brown roots will also be present; the outer cortex of the root will slough off leaving the central core (Pundt and Smith, 2005). Control measures include sterile media, sanitizing pots between uses, bottom heat to promote quicker germination, avoiding over-watering,

promoting air flow, getting rid of infected plants or trays, and management of insects like fungus gnats, which may spread the disease (Pundt and Smith, 2005).

Environmental Factors and Aroma Compounds

The quality of reflected light from colored mulches affected aroma in work conducted in South Carolina where sweet basil 'Italian Sweet' was grown over black, blue, green, red, white, or yellow mulch (Loughrin and Kasperbauer, 2001). Basil leaves of plants grown over green or yellow mulches released higher amounts of aroma compounds compared to those grown on the blue, red or white mulches (Loughrin and Kasperbauer, 2001). Reflected blue light reduced the accumulation of aroma compounds in the basil leaves. The green and yellow mulches reflected less blue light than the other mulches tested. Black mulch was shown to produce higher aroma compound levels than the blue, red, or white mulches (Loughrin and Kasperbauer, 2001).

Drought stress will decrease yield but usually increases the level of aroma compounds linalool and methyl chavicol in sweet basil (Tucker and DeBaggio, 2009a).

Different altitudes can also affect aroma compounds. Darjeeling tea grown at high altitudes has higher levels of linalool, which is the main component in the aroma (Bhattacharya and Sen-Mandi, 2011). The higher levels of ultra-violet exposure at higher altitudes enhances the activity of the enzyme β-D glucosidase which in turn produces higher amounts of linalool, resulting in the strong aroma in Darjeeling tea (Bhattacharya and Sen-Mandi, 2011).

Environmental Effects on Cuticle Composition

Light intensity and temperature can affect cuticle composition. As light intensity increases wax thickness increase in *Brassica* species, carnations, and barley (Shepherd

and Griffiths, 2006). Fatty acid chain length in the cuticle decreased in barley as light intensity increased (Shepherd and Griffiths, 2006). In low temperatures *Brassica* species produce more wax in the cuticle than under high temperatures but high day time temperatures during leaf development reduced the quantities of alkanes, primary alcohols, fatty acids, and alkyl esters in the cuticle (Shepherd and Griffiths, 2006). Some *Brassica* species showed an increase in wax concentration as relative humidity decreased (Shepherd and Griffiths, 2006).

Photosynthesis

A basic definition of photosynthesis is the process by which plants convert light energy into chemical energy held in the bonds of sugars like glucose (Carter, 1996). The chemical reaction of photosynthesis is $6CO_2 + 6H_2O$ + light energy $\rightarrow C_6H_{12}O_6 + 6O_2$ (Carter, 1996). Photosynthetically active radiation (PAR) is defined as the wavelengths 400 to 700 nm (Decoteau, 1998). Photosynthesis takes place in the chloroplast, specifically in the thylakoid membrane where the chlorophyll molecule is embedded (Carter, 1996). The chlorophyll molecule absorbs blue and red light, with red being the most actively absorbed (Skye Instruments, UK). Blue light has wavelengths around 455 to 500 nanometers (nm) and red light is found around 620 to 755 nm, with far-red light starting around 755 nm (Hart, 1988a). Other sources list blue light around 400 to 520 nm and red light from 610 to 750 nm, with far-red light from 750 to 1000 nm (Spectrum, 2008). All plants have two reaction centers in the thylakoid membrane, photosystem I and photosystem II (Vermaas, 2007). The electron transfer through photosystem I and photosystem II results in water oxidation and NADP reduction. The electron flow from water to NADP produces an electron gradient across the thylakoid membrane. This

electron gradient is used to produce ATP which, with NADP, can be used to fix carbon in the Calvin Cycle (Vermaas, 2007).

Calvin Cycle

The Calvin cycle involves three phases: carbon fixation, reduction, and the regeneration of the CO_2 acceptor ribulose bisphosphate (RuBP); the Calvin cycle reaction is $3CO_2 + 6$ NADPH + 5 H_2O + 6 ATP → 6 glyceraldehyde-3-phosphate (G3P) + 6 H^+ + 6 $NADP^+$ + 6 ADP + 8 P_i (Ng and Smith, 2002). In phase one, rubisco catalyzes the bonding of $3CO_2$ to 3RuBP which instantly creates six 3-phosphoglycerate (3-PG). Six ATP, from photosystem I and II, phosphorylate the 3-PGs into six 1,3-bisphosphoglycerate. Six NADPH are then used to reduce 1,3-bisphosphoglycerate to six G3P molecules. One molecule of G3P is used at this point to make organic compounds like glucose. The other five G3P are used to regenerate RuBP with aid of ATP (Ng and Smith, 2002). The light reactions and the Calvin Cycle result in the end products of the equation for photosynthesis mentioned earlier.

Photomorphogenesis

Photomorphogenesis describes the ways light acts to regulate plant growth and development, independent of photosynthesis (Decoteau, 1998). The two major photoreceptors that are responsible for photomorphogenesis are phytochrome, which absorbs red and far-red light, and the blue light receptors commonly called cryptochrome (Decoteau, 1998; Hart, 1988a). Phytochrome is found in two isomeric forms, the red light absorbing P_r (absorption at 660 nm) and the far-red light absorbing P_{fr} (absorption at 730 nm) (Hart, 1988a). The far-red light absorbing P_{fr} is considered the biologically active form. The ratio of the two forms depends on the ratio of red and far-red light in the

environment (Hart, 1990a). The amount of P_{fr} present determines the extent of the phytochrome response. Phytochrome is involved in the regulation of over 100 responses including germination, stem growth (internode elongation), leaf development, pigment synthesis, and flowering (Hart, 1990a). Red light has been shown to inhibit internode elongation and promote lateral branching; far-red light has been shown to negate these effects (Rajapakse and Shahak, 2007). Blue light affects stem growth (inhibits), phototropism, stomatal opening, chloroplast development, and pigment synthesis the mechanism of action is not understood (Hart, 1988b; Hart, 1990a).

Measuring Light

Light varies in duration (energy over time), quality (color), and intensity (amount of light at each wavelength) (Torres and Lopez, 2010). Light intensity (quantity) can be measured by three methods: photometric, radiometric, or quantum methods (Hart, 1988c).

A photometric sensor consists of a photoselective cell which converts radiant energy into an electric current. The photocell and the filters around it are designed so that the spectral sensitivity of the sensor matches that of the human eye, which is sensitive in the green region of the spectrum (550 nm) (Hart, 1988c). The foot candle is the unit used in the United States for the photometric reading. Foot candles are measuring brightness as perceived by the human eye, instead of what is perceived by chlorophyll or phytochrome. This makes the use of photometric measurement inappropriate for measuring the effects of light intensity in relation to plants (Hart, 1988c).

Radiometric methods measure energy in joules or watts, when integrated over time (Hart, 1988c). A radiometer uses a thermopile across which energy generates a

temperature induced electromotive force. This makes the device sensitive to all forms of radiant energy in the daylight spectrum (Hart, 1988c). This means radiometric readings report total radiant energy without regard to PAR. A photon is single pulse of light in the visible region of the spectrum. This makes radiometric measurement inappropriate for measuring the number of photons, and it is the number of photons present that determines photochemical change, the phytochrome or photosynthetic response (Hart, 1988c).

A quantum sensor consists of a photosensitive cell, which transforms radiant energy into an electric current, and filters, which 'quantum correct' the response to between 400 and 700 nm (PAR) (Hart, 1988c). This measure gives the researcher the quantity of photons available for photosynthesis and can be expressed as moles per meter squared per second (mol/m^2s) or as watts per meter squared (W/m^2) (Hart, 1988c). This is an instantaneous measure of light that is used to study the effects of light intensity on plant growth (Torres and Lopez, 2010). Although better than photometric or radiometric methods, the quantum method is still an instantaneous reading and it does not represent the amount of light received by the plant in a day. Daily light integral (DLI) is a more appropriate measure for the effect of light intensity on plant growth (Torres and Lopez, 2010).

DLI is the amount of PAR light received over the entire day and the units are moles per meter squared per day (mol/m^2d) (Torres and Lopez, 2010). Typical DLI measurements in a greenhouse do not usually exceed 25 mol/m^2d, because of the glazing materials, the superstructure, cloud cover, and shading (Torres and Lopez, 2010). DLI in a greenhouse can influence root and shoot growth of seedlings, finished plant quality, and crop time. Crops that require a DLI of 3 to 6 mol/m^2d are considered low-light plants, 6

to 12 mol/m^2d are medium-light plants, and 12 to 18 mol/m^2d are high-light plants (Runkle, 2011; Torres and Lopez, 2010). Acceptable quality ferns can be produced with 2 mol/m^2d and high light requiring plants like roses and lettuce and tomatoes need at least 12 mol/m^2d (Torres and Lopez, 2010). DLI helps growers to know when supplemental light is needed and keeping track of DLI with data loggers can be an important tool for producing high quality plants. Two of the most popular light sources for supplemental lighting are high-intensity discharge (HID) metal halide and high pressure sodium lamps. Metal halide lights have high output in the blue and red regions of the spectrum and lack far-red light, which can be supplemented through the use of incandescent bulbs (Rajapakse and Shahak, 2007). High pressure sodium emits light rich in the wavelengths 550 to 620 nm, which is the orange to red region of the spectrum (Hart, 1988d). Both are good sources for supplemental lighting and are used in the horticulture industry.

The quality of light can be measured using a spectroradiometer. A spectroradiometer works by using a scanning monochromator (a prism or diffraction grating plus filters) (Hart, 1988c). The monochromator continually surveys the spectrum and disperses the light into its monochromatic components for individual detection and quantification by a photosensor (Hart, 1988c). The spectral distribution of the radiant energy is recorded on a graph with either the units micromole per meter squared per second per wavelength (μmol/m^2 s nm) or watts per meter squared (W/m^2) (Hart, 1988c; Rajapakse and Shahak, 2007).

ChromatiNet®: Colored Shade Cloth

The ChromatiNet® (Figure 1.6) (colored shade cloth) is designed to modify light in either the ultra-violet, visible, or far-red spectral regions; the cloth also enhances the relative content of scattered vs. direct light and absorbs infra-red radiation (Shahak et al., 2004). The fraction of light that passes through the holes, in the shade cloth, remains unchanged in its quality, while the light hitting the threads comes out spectrally modified and scattered (Shahak et al., 2004). The colored shade cloths are manufactured in the following colors: blue, grey, pearl, red, white, and yellow. The blue shade cloth is designed to absorb ultra-violet (UV), red, and far-red; while enriching the blue spectral region. The red shade cloth absorbs UV, blue, and green and enriches the red and far-red spectral region. The yellow shade cloth is designed to reduce the UV and blue; enriching the green, yellow, red, and far-red wavelengths. The white shade cloth absorbs UV and enriches the wavelengths blue, green, yellow, red, and far-red. The pearl and grey shade cloths do not enrich or absorb the different wavelengths but the pearl is designed to scatter the light to a higher extent than the other shade cloth colors mentioned (Rajapakse and Shahak, 2007). Traditional black shade cloth does not scatter light (Shahak et al., 2004).

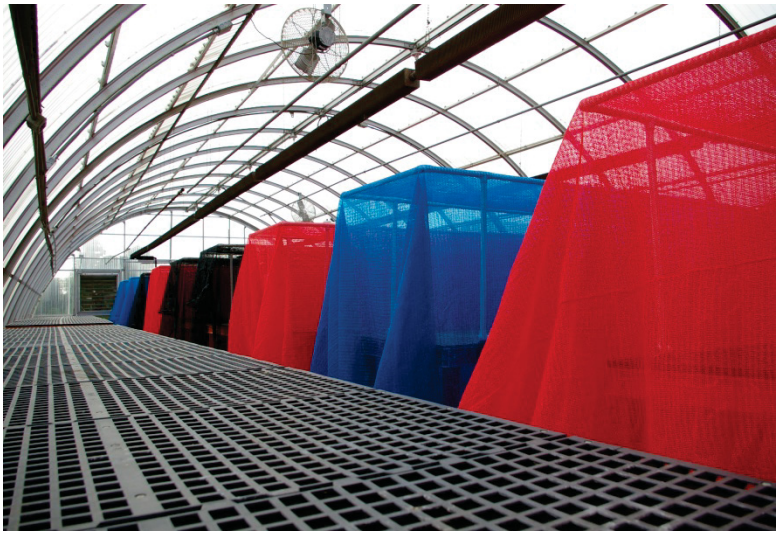

Figure 1.6. ChromatiNet® (Photo by author, 2012)

Effects of Colored Shade Cloth on Plant Growth

The effects of colored shade cloth have been studied on a number of crops including *Pittosporum variegatum*, *Dracaena deremensis* 'Janet Craig', *Dracaena marginata* 'Colorama' and *Phalaenopsis*.

Pittosporum was grown under 50% green, blue, red, black, grey, or Aluminet® shade cloth in Israel (Oren-Shamir et al., 2001). Blue shade cloth reduced branching, internode length, and decreased the yield of commercial branching (cut foliage) but variegation of *Pittosporum* was enhanced. The effect of the blue shade cloth is caused by the lack of far-red light in the growing environment (Oren-Shamir et al., 2001). The red and grey shade cloths increased the number of lateral branches of *Pittosporum* plants compared to those grown under the black shade cloth. The red shade cloth stimulated stem elongation and produced the longest branches (Oren-Shamir et al., 2001). Photosynthetic rates under the green, red, black, or Aluminet® shade cloth showed no statistically significant differences. The grey shade cloth induced higher photosynthetic rates, while the plants under the blue shade cloth consistently had lower photosynthetic rates (Oren-Shamir et al., 2001). The lower photosynthetic rates of the blue shade cloth treated plants were thought to be due to the increased level of variegation (Oren-Shamir et al., 2001).

Dracaena 'Janet Craig' was grown under 70% black, red, blue, or grey shade cloth, the weave of the cloth with 70% covered by the fabric and 30% open (Kawabata et al., 2007). These authors found that the red shade cloth transmitted 32% of the PAR light compared to 24%, 21%, and 20% for the gray, blue, and black shade cloths, respectively. The red shade cloth produced the greatest number of new leaves but they were smaller

and thicker than the leaves under the other shade cloth treatments (Kawabata et al., 2007). Furthermore, the blue shade cloth treated plants had lower chlorophyll levels compared to the black shade cloth, with a chlorophyll reading of 48.2 versus 52.9 M (SPAD-502 leaf chlorophyll meter index of relative chlorophyll content from 0.0 to 99.9); the chlorophyll readings under the red was 50.6 M. The authors thought that the lower levels of red light under the blue shade cloth may have contributed to the reduced levels of chloropyll (Kawabata et al., 2007). A grower evaluation of the plants showed that the smaller leaves of the red shade cloth grown plants reduced marketability (Kawabata et al., 2007).

Dracaena 'Colorama' grown under red shade cloth produced more new cane growth (20.2 cm compared to 10.4 cm for the black) and more new leaves (26.2 compared to 18 for the black) compared to the other treatments (Kawabata et al., 2007). The red shade cloth grown plants grew taller while maintaining a full appearance (Kawabata et al., 2007).

Phalaenopsis species were grown under 50% black, blue, or red shade cloth (Leite et al., 2008). The red shade cloth treated plants bloomed in April and May compared to May and June for the plants grown under black or blue shade cloth respectively; this earlier bloom was contributed to the higher amount of red and far-red light transmitted by the red shade cloth (Leite et al., 2008). Red light has been shown to promote the synthesis of gibberellin, which can promote blooming and internode elongation (Leite et al., 2008). Blue shade cloth treated plants had a higher leaf area (320.67 cm^2 versus 283.58 cm^2 for the black) and leaf fresh weight (73.45 g compared to 61.72 g for the black) compared to the black and red shade cloth treatments (Leite et al.,

2008). The fact that the plants were larger under the blue shade cloth contradicts the literature presented thus far and is thought to be because *Phalaenopsis* are adapted to low light levels and because they are crassulacean acid metabolism (CAM) plants (Leite et al., 2008).

Red shade cloth has also been shown to develop longer and thicker stems on lisianthus, sunflower, and *Trachelium* compared with black shade cloth grown plants (Shahak et al., 2008). Bell pepper (*Capsicum annuum*) grown under red shade cloth increased yield of fruit compared to black shade cloth grown plants, usually an increase of 115% to 135%. More fruit are produced per bell pepper plant, which contributes to the yield increase, without affecting fruit size (Shahak et al., 2008). Lettuce heads were 20% to 30% larger when grown under red or pearl shade cloths compared to the equivalent black or blue shade cloth (Shahak et al., 2008).

Apical Dominance

The term apical dominance refers to the inhibition of growth of lateral buds or shoots by a growing point or growth control involving a biochemical signal from a shoot apex (Cline, 1997; Sachs and Thimann, 1967). Endogenous auxin is involved in the repression of lateral shoot growth to varying degrees (Cline, 1997). In some plants apical dominance is negligible as in *Arabidopisis* and *Coleus*, lateral bud outgrowth continues from the time of formation without the need for decapitation of the apical bud (Cline, 1997). In other plants inhibition of lateral bud growth is intermediate or partial as in bean and petunia; this involves a certain level of lateral bud growth without removal of the apical bud (Cline, 1997). Plants like *Helianthus*, *Tradescantia*, and *Ipomoea* have what is called complete apical dominance, with no release of lateral bud growth without

decapitation of the apical bud (Cline, 1997). Cline (1997) describes lateral bud formation in four steps: lateral bud formation (Stage 1), imposition of inhibition (apical dominance) (Stage 2), initiation of lateral bud outgrowth following decapitation (Stage 3), and subsequent elongation and development of the lateral bud into a branch (Stage 4). Stage 1 is characterized as the promotion of lateral bud formation by cytokinins; stage 2 is repression of lateral bud outgrowth by auxin from the apical bud; stage 3 involves the release of lateral buds after decapitation of the apical bud, this action is promoted by cytokinins; and in stage 4, auxin and gibberellins promoted the growth and development of the lateral buds (Cline, 1997). Cytokinins cause bud initiation in begonia and tobacco and cytokinins are in high concentrations in root cuttings of *Cichorium endive* before the formation of buds (Sachs and Thimann, 1967). Release of apical dominance with direct applications of cytokinins to lateral buds during stage 3 can be repressed by applications of auxin to the decapitated stumps of the removed apical buds (Cline, 1997). Lateral shoots during stage 4 start producing their own auxin and gibberellins which enhance elongation (Cline, 1997). Endogenous auxin also stimulates the formation of cytokinins in buds but external auxin applications only inhibit auxin production (Sachs and Thimann, 1967).

Plant Growth Regulators

Plant growth regulators (PGRs) are described as chemicals that are designed to affect plant growth and/or development (Latimer, 2009). Plant growth regulators can be used for control of plant height (chemical growth retardants), stimulation of lateral branching, or for promoting flower initiation (Bailey and Whipker, 1998). PGRs used for promoting lateral branching are usually called chemical pinchers because they inhibit the

growth of terminal shoots or they enhance the growth of lateral branches (Latimer, 2009). These PGRs can be used in replacement of mechanical pinching which also stimulates lateral branching (Latimer, 2009).

PGRs can be applied in four different ways: dips, drenches, sprays, and sprenches. Dipping the plants shoots into a PGR solution works as long as each plant remains in the solution for the same amount of time and as long as each shoot is approximately the same size (Bailey and Whipker, 1998). Liner dips refers to dipping or soaking the media of a transplant into a solution of a PGR before transplanting into the final container (Blanchard and Runkle, 2005). Drenches are applied to the media after planting and generally have less effect on flower and bract size along with providing a longer lasting growth regulation than sprays (Latimer, 2009). Drenches can be easily applied because drench volume can be measured out and applied at the same rate to each plant (Latimer, 2009). Sprays are generally applied to achieve a short term response (Runkle, 2010). Sprays should be applied on a known area basis regardless of how many plants are in the area (Bailey and Whipker, 1998). The target tissue of each PGR will be on the label but generally most PGRs are taken up by the leaves and stems, although certain PGRs can be taken up by the stems and roots (Latimer, 2009). The correct physiological stage is very important, if there are no sites on the plant for lateral shoot development, PGRs cannot enhance shoot development (Latimer, 2009). Sprenches are used with media active PGRs and involves spraying a high volume of a foliar spray that results in runoff into the media; sprenches are generally applied when a moderately long-lasting response is desired along with moderate height control (Latimer, 2009; Runkle, 2010). Sprays and sprenches are

generally applied multiple times during the production time, whereas drenches are applied usually once (Runkle, 2010).

Dikegulac sodium

Dikegulac sodium is the active ingredient in Augeo a product marketed by OHP, Inc. (Mainland, PA). The mode of action for dikegulac sodium is to disrupt the cell wall integrity of the apical meristem and other active meristematic areas (Arzee et al., 1977). In *Helianthus*, chlorosis was evident after treatment with dikegulac sodium but regreening occurred after the leaves reached a mature size (Arzee et al., 1977). Research with *Zinnia* and *Helianthus* also showed that dikegulac sodium is rapidly transported to the areas of rapidly growing tissue, within hours of application (Arzee at al., 1977). Dikegulac sodium reduced height and leaf area of *Helianthus* at concentrations of 500 and 750 micro grams per milliter (µg/ml); stem girth increased at 500 µg/ml (Bhattacharjee and Gupta, 1984). Dikegulac sodium increased the number of lateral branches on new and mature growth along with increasing the number of inflorescences of lavender (Porter and Shaw, 1983). An increase in shoot number, leaf area, and shoot dry weight was seen in Boston fern at 500 milligrams per liter (mg/L) dikegulac sodium (Carter et al.,1996). In florist azalea, dikegulac sodium at 3900 mg/L increased the number of shoots per pruned shoot compared to the control; uniform chlorosis persisted through the ninth week after application (Bell et al., 1997). Applications of dikegulac sodium also increased branching of bell pepper; although yield was decreased (Matta, 1984).

Benzyladenine

Benzyladenine (BA) is a synthetic cytokinin in the product called Configure (Fine Americas, Inc., Walnut Creek, CA). An application of BA on petunia 'Improved Charlie' resulted in darker green foliage and improved the ratio of flowers to foliage (Carey et al., 2008). The petunia plants were also taller than controls at concentrations of 20 to 40 mg/L and the greatest number of shoots was seen at concentrations of 20 to 80 mg/L BA (Carey et al., 2008). Basal shoots increased in *Coreopsis* 'Moonbeam' with a concentration of 500 mg/L BA (Farris et al., 2009). Hosta offsets increased in BA treated plants at both 30 and 60 days after treatment at the rate of 2500 mg/L BA depending on cultivar (Garner et al., 1997). The number of lateral shoots increased in *Dieffenbachia* 'Welkeri' at the rates of 1000 and 2000 mg/L BA compared to control, ethephon, and dikegulac sodium (5 shoots compared to 1 on average) (Wilson and Nell, 1983). BA applied on *Peperomia obtusifolia* increased the mean number of lateral branches at 500 mg/L (9 branches compared with 4 branches for controls) (Henny, 1985).

Ethephon

Ethephon, the active ingredient of Florel (Monterey Lawn and Garden Products Inc., Fresno, CA), readily enters the plant and breaks down to ethylene. Ethephon increased the number of nodes produced by the main shoots of petunia, while having no effect on height (Haver and Schuch, 2001). Ethephon increased the number of primary shoots on *Coreopsis*, *Veronica*, and *Dianthus* treated with 600 or 800 mg/L ethephon (Glady et al., 2007). *Scabiosa* 'Butterfly Blue' showed an increase in foliage growth which was proportional to the concentration of ethephon applied (250, 500, 750, or 1000 ppm) at 52 DAT (days after treatment) (Banko et al., 2001). Ethephon decreased height

of *Achillea* 'Weser River Sandstone,' *Echinacea* 'Bravado,' *Leucanthemum* 'Thomas Killen,' *Monarda* 'Blue Stocking,' and *Phlox* 'Summer Snow' (Hayashi et al., 2001). Inflorescences per pot were increased at an ethephon concentration of 500 mg/L applied twice in *Achillea* 'Weser River Sandstone,' *Coreopsis* 'Moonbeam,' *Leucanthemum* 'Thomas Killen,' and *Monarda* 'Blue Stocking' (Hayashi et al., 2001).

Thigmotropism and Seismotropism

Thigmotropism is defined as the directional response of a plant to physical contact with a solid object (Hart, 1990b). Seismotropism deals with the responses of plants to vibrations or flexure (Hart, 1990b). Both types of stimulation are thought to bring about changes in the cell membrane through the action of changing permeability towards ions or growth regulators (Hart, 1990b). Mechanical stimulation whether by contact in the case of thigmic stress, or by flexure, seismic stress, usually inhibits extension in aerial organs and, or internode elongation, which produces shorter, thicker plants (Hart, 1990b). The effects of contact, whether by insects or by inanimate objects, and the effects of the wind, seismic stress, can impose rapid effects on plant growth (Hart, 1990b). Research has shown that simply rubbing the plant or brushing the plant with 5 to 10 strokes per day can cause reduced internode elongation (Hart, 1990b). The effects of physical contact or the wind can impose effects on growth in minutes; these effects can last several hours before the plant resumes normal growth (Hart, 1990b).

Mechanical Stimulation

The optimum dose response for mechanical stimulation on tomato has been shown to be between 10 and 40 brush strokes per day (Garner and Bjorkman, 1996). Treatment of tomato with brushing decreased shoot dry weight (69 mg compared to 88

mg for controls) and stem length compared to controls regardless of the time of day of treatment (morning versus evening) (Garner and Bjorkman, 1996). Comparing the use of impedance to brushing has also been studied with tomatoes. The impedance used by Garner and Bjorkman (1997) involved the use of 5 millimeter (mm) plexiglass applied at a pressure of 66 $N \cdot m^{-2}$. Brushing was applied using a piece of polystyrene foam (3 x 20 x 30 cm) at a rate of 20 strokes once per day. The use of impedance and brushing were equivalent in decreasing plant height and dry weight; stem diameter was slightly increased with impedance compared to brushing plants (Garner and Bjorkman, 1997). Brushing applied to pansy plants at a rate of 20 strokes per day reduced petiole elongation without causing damage and shoot dry weight decreased with increasing brushing intensity (Garner and Langton, 1997). Brushing also decreased leaf area and shoot dry weight of broccoli seedlings compared to controls (Latimer, 1990).

Volatile Compound Analysis: Gas Chromatography-Mass Spectroscopy

As described in the gas chromatography-mass spectroscopy manual Bioinstrumentation class (1998), chromatography is the process by which mixtures of chemicals are separated into their individual components. Separation occurs when the mixture is injected into a mobile phase such as helium gas. The mobile phase then carries the mixture into a stationary phase called a column, usually made out of glass or stainless steel. The mixture interacts with the stationary phase, separating out the compounds that interact quickly from those that interact slowly; temperature also plays a role separating compounds based on boiling point. As the compounds separate they enter a detector that sends an electronic signal to a computer which calculates the time from injection to when the compound was detected, this is called the retention time. The graph created by the

computer is called a chromatogram; the peaks represent the signal generated when the compounds were detected and the strength of the signal as an abundance. After the compounds pass through the GC column they enter the mass spec detector. After the compounds enter the mass spec they are bombarded by a stream of electrons which causes them to break apart into fragments. A group of four electromagnets then direct the fragments into the detector. The computer then determines the mass to charge ratio which is recorded in a graph called a mass spectrum. The mass spectrum is then compared to a list of likely matches in the library on the computer; a list is then generated of likely identifications along with statistical probability of match.

Sensory Testing: Triangle Test

The triangle test is a type of difference test that determines if a statistically significant difference exists between samples (Larmond, 1982). In a triangle test panelists receive three coded samples, two of the samples are the same and one sample is different. The panelists are then asked to select the odd sample, or the sample that is different. The triangle test is useful for ensuring quality of samples from different production lots. It can also be used to determine if ingredient substitution or some other change in manufacturing results in a detectable difference in the product (Larmond, 1982). The analysis of the triangle test is based on the probability that if there is no detectable difference, the odd sample will be selected by chance one-third of the time (Larmond, 1982).

Literature Cited

Anderson, B. and R. Schnelle. 2010. Culinary herbs. University of Kentucky Cooperative Extension Service. 7 November 2011. <http://www.uky.edu/Ag/CDBREC/introsheets/herbs.pdf>.

Anderson, C. 2011. Parsley. University of Arkansas Division of Agriculture. FSA 6091.

Anderson, R. and W. Jia. 1996. Greenhouse production of garlic chives and cilantro. 5 November 2011. <http://www.hort.purdue.edu/newcrop/proceedings1996/v3-594.html>.

Arzee, T., H. Langenauer, and J. Gressel. 1977. Effects of dikegulac, a new growth regulator, on apical growth and development of three compositae. Bot. Gaz. 138(1):18-28.

Bailey, D. and B. Whipker. 1998. Best management practices for plant growth regulators used in floriculture. North Carolina State University Cooperative Extension. Horticulture Information Leaflet 529.

Banko, T., M. Stefani, and M. Dills. 2001. Growth and flowering response of 'May Night' salvia and 'Butterfly Blue' scabiosa to growth retardants. J. Environ. Hort. 19(3):145-149.

Bell, M., R. Larson, and D. Bailey. 1997. Vegetative growth responses of florist azalea to dikegulac, GA_{4+7}, and 6-benzylamino purine. HortScience 32(4):690-693.

Bhattacharya, S. and S. Sen-Mandi. 2011. Variation in antioxidant and aroma compounds at different altitude: A study on tea (Camellia sinensis L. Kuntze) clones of Darjeeling and Assam, India. African J. Biochem. Research 5(5):148-159.

Bhattacharjee, A. and K. Gupta. 1984. Differential responses of sunflower (*Helianthus annuus* cv. Modern) towards high and low concentrations of dikegulac sodium. Can. J. Bot. 62:495-500.

Bioinstrumentation class. 1998. Gas chromatography-mass spectroscopy. 21 November 2011. < http://www.gmu.edu/depts/SRIF/tutorial/gcd/gc-ms2.htm>.

Blanchard, M. and E. Runkle 2005. PGR liner dips on bedding plants. Michigan State University Extension. Greenhouse Product News. December. 28 February 2012. < http://www.onhort.com/PGR-Liner-Dips-On-Bedding-Plants-article6568>.

Carey, D., B. Whipker, I. McCall, and W. Buhler. 2008. Cytokinin based PGR affects growth of vegetative petunia. Proc. PGRSA 35. 21 November 2011. < http://pgrsa.org/archive/2008_Proceedings/data/papers/oral/029.pdf>.

Carter, J. 1996. Photosynthesis. 9 November 2011. <http://biology.clc.uc.edu/courses/bio104/photosyn.htm>.

Carter, J., B. Singh, and W. Whitehead. 1996. Dikegulac, but not benzyladenine, enhances the aesthetic quality of boston fern. HortScience 31(6):978-980.

Cline, M. 1997. Concepts and terminology of apical dominance. Amer. J. Bot. 84(9):1064-1069.

Farris, M., G. Keever, J. Kessler, and J. Olive. 2009. Benzyladenine and cyclanilide promote shoot development and flowering of 'Moonbeam' coreopsis. J. Environ. Hort. 27(3):176-182.

Garner, J., G. Keever, D. Eakes, and J. Kessler. 1997. Benzyladenine-induced offset formation in hosta dependent on cultivar. HortScience 32(1):91-93.

Garner, L. and F. Langton. 1997. Brushing pansy (*Viola tricolor* L.) transplants: A flexible, effective method for controlling plant size. Sci. Hort. 70:187-195.

Garner, L. and T. Bjorkman. 1997. Using impedance for mechanical conditioning of tomato transplants to control excessive stem elongation. HortScience 32(2):227-229.

Garner, L. and T. Bjorkman. 1996. Mechanical conditioning for controlling excessive elongation in tomato tranplants: sensitivity to dose, frequency, and timing of brushing. J. Amer. Soc. Hort. Sci. 121(5):894-900.

Gibson, J., B. Whipker, and R. Cloyd. 2000. Success with container production of twelve herb species. North Carolina State University Cooperative Extension. Horticulture Information Leaflet 509.

Gill, D. and T. Merrill. 2010. Growing parsley in Louisiana. LSU AgCenter. 7 November 2011. <http://text.lsuagcenter.com/en/lawn_garden/home_gardening/vegetables/Include+Parsley+In+Your+Winter+Garden.htm>.

Glady, J., N. Lang, and E. Runkle. 2007. Effects of ethephon on stock plant management of *Coreopsis verticillata*, *Dianthus caryophyllus*, and *Veronica longifolia*. HortScience 42(7):1616-1621.

Hart, J. 1988a. General introduction. p. 1-7. In: Light and plant growth. Unwin Hyman Ltd., Boston.

Hart, J. 1988b. Photoreceptors. p. 71. In: Light and plant growth. Unwin Hyman Ltd., Boston.

Hart, J. 1988c. Radiant energy. p. 25-29. In: Light and plant growth. Unwin Hyman Ltd., Boston.

Hart, J. 1988d. Daylight and artificial light. p. 34-51. In: Light and plant growth. Unwin Hyman Ltd., Boston.

Hart, J. 1990a. Phototropism. p. 125-126. In: Plant tropisms and other growth movements. Unwin and Hyman Ltd, Boston.

Hart, J. 1990b. Thigmotropism. p. 139-143. In: Plant tropisms and other growth movements. Unwin and Hyman Ltd, Boston.

Haver, D. and U. Schuch. 2001. Influence of root restriction and ethylene exposure on apical dominance of petunia (*Petunia* x *hybrid* Hort. Vilm.-Andr.). J. Plant Growth Regulat. 35:187-196.

Hayashi, T., R. Heins, A. Cameron, and W. Carlson. 2001. Ethephon influences flowering, height, and branching of several herbaceous perennials. Sci. Hort. 91:305-323.

Henny, R. 1985. BA induces lateral branching of *Peperomia obtusifolia*. HortScience 20(1):115-116.

Kato, T., M. Kobayashi, N. Sasaki, Y. Kitahara, and N. Takahashi. 1978. The coumarin heraclenol as a growth inhibitor in parsley seeds. Phyochemistry 17:158-159.

Kawabata, A., J. Lichty, K. Kobayashi, and W. Sahai. 2007. Effects of photoselective shade cloths on potted *Dracaena deremensis* 'Janet Craig' and *Dracaena marginata* 'Colorama'. Journal of Hawaiian and Pacific Agriculture. 14:49-54. 16 November 2011. <hilo.hawaii.edu/academics/cafnrm/research/documents/Andrewkawabata.pdf>.

Larmond, E. 1982. p. 20. Laboratory methods for sensory evaluation of food. Agri. Canada, Ottawa, ON. Publication 1637.

Latimer, J. 2009. Selecting and using plant growth regulators on floriculture crops. Virginia Cooperative Extension Publication 430-102.

Latimer, J. 1998. Mechanical conditioning to control height. HortTechnology 8(4):529-534.

Latimer, J. 1990. Drought or mechanical stress affects broccoli transplant growth and establishment but not yield. HortScience 25(10):1233-1235.

Leite, C., R. Ito, L. Gerald, R. Ganelevin, and M. Fagnani. 2008. Light spectrum management using colored nets aiming to controlling the growth and the blooming of *Phalaenopsis sp*. Acta Hort. 770:177-184.

Loughrin, J. and M. Kasperbauer. 2001. Light reflected from colored mulches affects aroma and phenol content of sweet basil (*Ocimum basilicum* L.) leaves. J. Agric. Food Chem. 49. 1331-1335.

Mangen, F. and R. VanVranken. 2004. Cilantro coriandrum sativum. World Crops for the Northeastern United States. 5 November 2011. <http://www.worldcrops.org/crops/Cilantro.cfm>.

Matta, F. 1984. Effects of hand-pinching and dikegulac-sodium sprays on *Capsicum annuum*. HortScience 19(2):284-285.

Ng, S. and E. Smith. 2002. The calvin cycle process. 9 November 2011. <https://www.msu.edu/~smithe44/calvin_cycle_process.htm>.

Oren-Shamir, M., E. Gussakovsky, E. Shpiegel, A. Nissim-Levi, K. Ratner, R. Ovadia, Y. Giller, and Y. Shahak. 2001. Coloured shade nets can improve the yield and quality of green decorative branches of *Pittosporum variegatum*. J. Hort. Sci. Biotechnol. 76:353-361.

Pflasterer, G., L. Naeve, R. Jauron, and D. Nelson. 2006. Growing and using basil. Iowa State University Extension. RG 801.

Porter, N. and M. Shaw. 1983. Increasing growing points and oil yields in lavender by growth regulator sprays. J. Plant Growth Regulat. 2:151-158.

Pundt, L. and T. Smith. 2005. Pest management for herb bedding plants grown in the greenhouse. New England Greenhouse Conference. 5 November 2011. < http://www.hort.uconn.edu/ipm/greenhs/htms/herbmanl.pdf>.

Rajapakse, N. and Y. Shahak. 2007. Light quality manipulation by horticulture industry. p. 290-307. In: Light and plant development. Blackwell Publishing, Ames, Iowa.

Runkle, E. 2011. Lighting greenhouse vegetables. Michigan State University Extension. Greenhouse Product News. p. 42. December. 3 May 2012. < http://flor.hrt.msu.edu/assets/Uploads/Lightingvegetables.pdf>.
Runkle, E. 2010. Spray versus sprench versus drench. Michigan State University Extension. Greenhouse Product News. p. 66. July. 21 November 2011. < http://www.flor.hrt.msu.edu/assets/Uploads/Spray-sprench-drench.pdf>.

Runkle, E. 2009. Brushing plants for height control. Michigan State University Extension. Greenhouse Product News. p. 58. February. 21 November 2011. < http://www.flor.hrt.msu.edu/assets/Uploads/Brushingplantsforheightcontrol.pdf>.

Sachs, T. and K. Thimann. 1967. The role of auxins and cytokinins in the release of buds from dominance. Amer. J. Bot. 54(1):136-144.

Sarada, C., G. Kalidasu, T. Y. D. Reddy, and P. V. Reddy. 2011. Weather modification for off-season production of coriander (*Coriandrum sativum* L.) for leaf. J. Agrometeorology 13(1):54-57.

Shahak, Y., E. Gussakovsky, E. Gal, and R. Ganelevin. 2004. Colornets: Crop protection and light-quality manipulation in one technology. Acta Hort. 659:143-151.

Shahak, Y., G. Elazar, Y. Offir, and D. Ben-Yakir. 2008. Photoselective shade netting integrated with greenhouse technologies for improved performance of vegetable and ornamental crops. Acta Hort. 797:75-80.

Shepherd, T. and D. W. Griffiths. 2006. The effects of stress on plant cuticular waxes. New Phytologist 171:469-499.

Simon, J., J. Rabin, and L. Clavio. 1988. Parsley: A production guide. Purdue University Cooperative Extension Service. HO-202.

Simon, J. 1995. New crop factsheet basil. 5 November 2011. <http://www.hort.purdue.edu/newcrop/cropfactsheets/basil.html>.

Skye Instruments Ltd, UK. Light measurement guidance notes. 9 November 2011. <http://www.skyeinstruments.com/wp-content/uploads/LightGuidanceNotes.pdf>.

Simon, J., M. Morales, W. Phippen, R. Vieira, and Z. Hao. 1999. Basil: A source of aroma compounds and a popular culinary and ornamental herb. p. 499-505. In: J. Janick (ed.), Perspectives on new crops and new uses. ASHS Press, Alexandria, VA. 5 November 2011. <http://www.hort.purdue.edu/newcrop/proceedings1999/v4-499.html>.

Stephens, J. 2009. Parsley. University of Florida IFAS Extension. HS 638.

Torres, A. and R. Lopez. 2010. Measuring daily light integral in a greenhouse. Purdue University Cooperative Extension. HO-238-W.

Tucker, A. and T. DeBaggio. 2009a. *Ocimum*, p. 337-346. In: The encyclopedia of herbs. Timber Press, Inc., Portland, Oregon.

Tucker, A. and T. Debaggio. 2009b. *Coriandrum sativum*. p. 213-216. In: The encyclopedia of herbs. Timber Press, Inc., Portland, Oregon.

Tucker, A. and T. DeBaggio. 2009c. *Petroselinum crispum*. p. 393-396. In: The encyclopedia of herbs. Timber Press, Inc., Portland, Oregon.

Vermaas, W. 2007. An introduction to photosynthesis and its applications. 9 November 2011. <http://bioenergy.asu.edu/photosyn/education/photointro.html>.

Williamson, J. 2008. Basil. Clemson Cooperative Extension. HGIC 1327.

Wilson, M. and T. Nell. 1983. Foliar applications of BA increase branching of ‘Welkeri’ dieffenbachia. HortScience 18(4):447-448.

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Herb Culture and Use

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Introduction

Most botanists would define an herb as a plant that dies back to the ground each year without forming woody stem tissue. This definition limits the number of plants technically called herbs. Most gardeners include plants that have culinary, medicinal, aromatic, or ornamental uses. This definition would include lavender, rosemary, and bay, which form woody stems.

Many families in the 18th and 19th centuries had their own herb gardens. These herbs were used for flavoring foods, as preservatives, and for medicinal uses. Herb gardening is also on the rise in recent years as more people grow herbs for fresh use, drying, or freezing. An interest in medicinal herbs has also bolstered interest in herb gardening.

Purple coneflower (*Echinacea* spp.) *(Photo by John Freeborn)*

Most herbs can be grown successfully with a minimum of effort. Several are drought-tolerant, some are perennials, and many are resistant to insects and diseases. They are versatile plants, providing flavors for seasoning food and fragrances for room-freshening potpourri.

Herbs can be planted with vegetables or mixed in garden beds with annuals, perennials, shrubs, and trees. And with their enticing scents, diverse textures, attractive shapes, and countless shades of green and gray, herbs are often used to make a landscape that appeals to the senses of touch and smell, as well as sight.

The classic use for herbs in the landscape is the formal garden. Many intricate designs have been drawn and planted using the beauty of herb plants to enhance the pattern of the garden; diamonds, compasses, and knots are among the most popular designs. The knot garden is especially intriguing; herbs with various textures and colors are planted carefully and trimmed neatly to create the appearance of ropes looping over and under each other. The effect is striking, especially when viewed from an upper-story window.

Herb theme gardens are also popular. There are Biblical gardens, scent gardens, tea gardens, witch's gardens, kitchen gardens, and apothecary gardens, to name a few.

Site

When selecting a site to plant your herbs, keep in mind that culinary herbs are native to the Mediterranean, Northern Europe, and Asia; therefore, the plant's native habitat must be taken into consideration.

Start with a small herb garden that can be easily constructed and maintained, but leave space around it so you can plan its expansion during the long, cold, winter months. Most annual and perennial herbs grow best in six to eight hours of full sun.

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Formal garden layout. *(Photo by Shawn Appling)*

Choose a soil that is fertile and loamy for best results. Although many of the herbs will live in poor ground, for the healthiest plants and best harvest, they need good soil to thrive. Most herbs require a soil pH of 6.3 to 6.8 for optimum growth, but lavender prefers a pH of 6.5 to 7.0.

Prepare the soil to a depth of 8 inches. If it is heavy or has poor drainage, amend it with composted organic matter. Raised beds are an excellent solution to this problem. Fill them with a mixture of garden soil and compost or use a premixed, soilless potting medium.

Plant perennial herbs in an area that will not be disturbed by tilling. Those that spread by runners — such as the mints — should be given a large, isolated area or must be contained in some fashion (to a depth of 10 to 12 inches) to prevent them from taking over the garden.

Some tender perennials need protection from winter winds. Plant on an eastern exposure, if possible. Evergreen trees and shrubs can be used to break the wind and create a "microclimate" for the herbs. Rocks are often incorporated into the design of herb gardens to provide focal points and windbreaks and to help keep roots cool and moist during the heat of summer.

Cool season herbs such as cilantro, dill, anise, and parsley need to be planted in the spring or fall. If summertime planting is desired, shade must be provided for these plants.

Propagation

Annual herbs are best started from seed. When starting small seeds indoors, the easiest method is to sow them directly into individual pots filled with seed-starting mix at about six weeks before the last frost date. Cover the seed with a thin layer of moist seed-starting mix or milled sphagnum moss. Later, thin the seedlings to four or five per pot. Larger seeds may also be started by this method, then thinned to one plant per pot. Keep the soil surface moist by misting until the plants are established.

Herb garden with raised beds. *(Photo by Shawn Appling)*

Although many perennial varieties may be started from seed, it is often easier to get plants from your local nursery or a reputable mail-order company. In addition, many culinary herbs, such as tarragon, can only be propagated asexually; seed-grown plants lack the oils that give them flavor. Propagate them from root divisions or cuttings taken in the summer, after new growth has hardened.

Root the cuttings in a window box or some other suitable container, preferably covered with plastic to maintain high humidity. About 5 inches of clean, coarse sand is a good rooting medium. Keep the sand moist and out of direct sunlight when the plants are young. In four to six weeks, move the plants to pots or cold frames for the winter.

Many other herbs can also be propagated from stem cuttings, including rosemary, thyme, lemon verbena, scented geraniums, oregano, and wormwood. Transplant all herb plants after the danger of severe frost has passed. Control weeds during the growing season to

Oregano (*Origanum spp.*). *(Photo by Shawn Appling)*

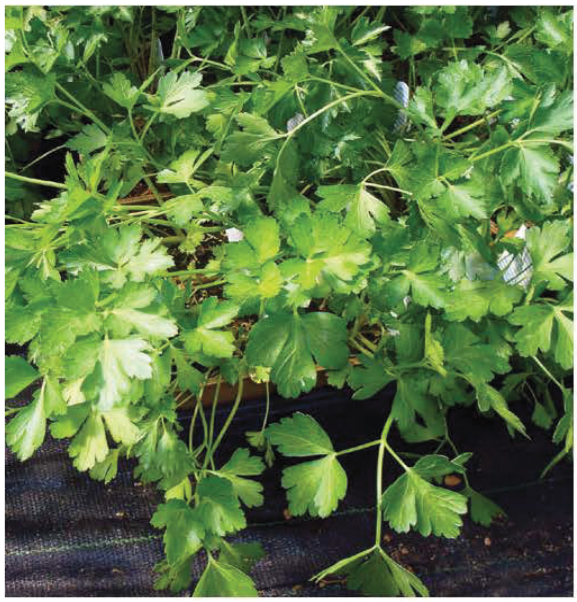
prevent competition for water and nutrients, which are needed by your herbs. A light mulch (about 1 inch) will conserve soil moisture and help control weeds.

Most of the herbs that have a mature height shorter than 12 inches may be grown in 6-inch pots as indoor plants. There are many dwarf varieties of the larger herbs that would be appropriate indoors, as well. Spicy globe basil, dwarf sage, winter savory, parsley, chives, and varieties of oregano and thyme are some of the best choices for windowsill culture. When given proper care in a sunny window, they will supply sprigs for culinary use through all seasons.

Culture

Although many herbs are considered drought-tolerant, some moisture is needed to maintain active growth. For a continual supply of fresh-cut herbs, periodic irrigation during dry intervals is needed. As with all plants, a thorough watering with a period of drying is preferred over frequent sprinkling. Annual herbs require a higher level of available soil moisture than most perennial herbs.

Proper nutrient balance is very important. Weak, succulent growth can be caused by over-fertilization, making the plant susceptible to disease and insect pests. Rapid growth also dilutes the concentration of essential oils that impart the distinctive flavor to the culinary herb.



Parsley (Petroselinum crispum) *(Photo by Shawn Appling)*

Inadequate fertilizer can severely limit new growth, predisposes the plant to insect and disease problems, and increases the susceptibility of tender perennials to winter injury. A light application of fertilizer to perennials in early spring should promote new root and shoot growth and ensure vigor in the new growing season. Generally, adequate herb growth can be achieved with one-quarter to one-half the quantity of nitrogen recommended for vegetables in your area. Sequential harvests of annual herbs will be facilitated by light applications of fertilizer after each heavy harvest.

The high concentration of essential oils in healthy, actively growing herbs repels most insects. However, aphids and spider mites can be a problem. Aphids seem to be more prevalent in crowded conditions with rapidly growing, succulent plants. Spider mites thrive in dry conditions and can be controlled by spraying the plants with plain water at regular intervals — especially during periods of drought. Because there are very few labeled pesticides for use on herbs, the best defense against pests is preventative cultural management, such as good sanitation, removal of weak or infested growth, and regular pruning.

Periodic, judicious pruning promotes vigorous, sturdy plants that are less susceptible to disease and winter injury. If they are allowed to grow unchecked, some herbs will take on a gangly, unkempt appearance. If you are lavish in your use of herbs, regular harvesting for use in cooking, potpourri, and flower arrangements should keep your herbs sufficiently pruned.

Harvesting

It is best to harvest your herbs in the morning, just after the dew has dried, but before the sun gets hot. The concentration of essential oils is highest at this point. Harvest your herbs for fresh use all season, but for drying, cut just before the plants bloom. This will ensure the maximum concentration of essential oils. When harvesting, cut just above the first joint of tender growth — it takes the plant longer to send out new shoots from woody growth.

Perennial herbs can have half of their foliage pruned back. Plants experiencing drought should not be cut back until the stress has passed. Also, stop making large harvests of the perennial herbs in late summer or fall. This will allow time for new growth to harden and gather carbohydrates in preparation for winter. However, small harvests can be made during most of the

fall. Sage flavor may actually be improved by two or three frosts prior to harvest.

If you are interested in saving seed for the next season, choose one or two plants of each variety and allow them to bloom and go to seed. Harvest the seed heads when they change from green to brown or gray, and dry them thoroughly to ensure a good germination rate.

Drying

The best dried herbs are those that have been dried rapidly, without excessive heat or exposure to sunlight. When harvesting to dry, it is often necessary to spray the plants with a garden hose the day before cutting to clean dirt and dust off the leaves. The next morning, after the leaves have dried, make your harvest. Remove dead or damaged leaves and make small bunches of the herbs. Tie the stems together and hang them in a temperate, well-ventilated, darkened room that has little dust. Label each bunch, because several of the herbs look similar when dried.

Herbs may also be dried by removing the leaves and spreading them in a single layer on cookie sheets or foil, though it is preferable to use trays made of window screening for maximum air circulation. Again, remember to label the different varieties for accurate identification after drying.

French tarragon (*Artemesia dracunulus*).
(Photo by Shawn Appling)

Herb leaves are dry if they crumble into powder when rubbed between your hands. When the drying process seems to be complete, fill a small glass container with the herb and seal it. Put it into a hot oven for about 15 minutes or microwave it (don't use a metal cover!) for about five minutes, then check for condensation on the inside of the jar. If there is moisture present, let the rest of the herbs dry more. A harvest that is not completely dry when stored may succumb to molds. If necessary, herbs may be dried on cookie sheets in an oven set for 110° F or lower, though there will be some loss of essential oils using this method.

Basil (*Ocimum basilicum*) *(Photo by Joyce Latimer)*

When completely dry, store whole leaves in airtight containers — preferably of dark glass or some material that will not let in light — in a cool-to-temperate place out of direct sunlight. This will ensure good flavor and color in your seasonings.

To conserve essential oils, do not crush the herb until you add it to your cooking. When cooking, use greater quantities of fresh herbs; although they often have better flavor than dried herbs, they are usually not as strong.

Recipe Conversions for Herbs

1 tablespoon of finely cut fresh herbs
equals
1 teaspoon of crumbled dried herbs
equals
1/4 to 1/2 teaspoon of ground dried herbs

(Swinerton 2010)

Storage Life of Herbs and Spices

Seasoning	Storage time
Whole	2 to 5 years
Ground spices	6 months to 2 years
Leafy herbs	3 months to 2 years

(Hertzler 2001)

Herb Culture and Use

Common name *Scientific name*	Height	Plant spacing	Cultural hints	Uses
Annuals				
Basil *Ocimum basilicum*	20-24″	24-36″	Grow from seed. Sun.	Use in anything with tomatoes.
Borage *Borago officinalis*	24″	12″	Grow from seed, self-sowing. Dry, sunny areas.	Use young leaves in salads for cucumber flavor.
Chamomile, German chamomile *Matricaria recutita*	8-24″	6-12″	Grow from seed. Prefers a sandy, well-drained soil with a pH of 7.0-7.5 and lots of sun. Blooms in early to midsummer. Self seeds.	Leaves and flowers used in tea — two teaspoons dried material per cup. Steep covered to preserve essential oils.
Chervil *Anthriscus cerefolium*	10″	3-6″	Sow in early spring. Partial shade.	Aromatic leaves used in soups and salads. Smells like tarragon.
Cilantro, coriander *Coriandrum sativum*	24″	18″	Grow from seed. Sow in spring in sun or partial shade.	Seeds used in confections; leaves used in salads, Mexican, Asian foods.
Dill *Anethum graveolens*	24-48″	12″	Grow from seed sown in early spring. Sun or partial shade.	Feathery foliage and seeds used in flavoring and pickling.
Parsley *Petroselinum spp.*	12″	6″	Grow from seed started in early spring. Slow to germinate. Sun. Biennial.	Brings out flavors of other herbs. High in vitamin C.
Perennials				
Catnip *Nepeta cataria*	36-48″	18″	Grow from seed or division. Hardy; sun or shade.	Leaves for soothing tea.
Chamomile, Roman chamomile *Chamaemelum nobilis*	4-12″	12-18″	Hardy, evergreen groundcover; used around steppingstones. Low maintenance, full sun. Blooms late spring through early fall.	Flowers used in tea.

Herb Culture and Use (cont.)

Common name *Scientific name*	Height	Plant spacing	Cultural hints	Uses
Perennials (cont.)				
Chives, garlic chives *Allium spp.*	12″	12″	Little care. Divide when overcrowded. Grow from seed or division.	Good indoor pot plant; cut long strands at base. Mild onion or garlic flavor.
Echinacea, purple cone flower *Echinacea spp.*	24-48″	18-24″	Grow from seed or plants; self sows. Hardy, full sun, drought-tolerant.	Roots (primary part used), leaves, and flowers used in teas.
French tarragon *Artemesia dracunulus*	24″	24″	Grow from cuttings or division. Sun or semishade.	Aromatic seasoning; principal flavor in bearnaise sauce. Great with fish or chicken.
Lavender *Lavendula spp.*	24″	18″	Propagate from cuttings. Grows in dry, rocky, sunny locations. High lime soil. Requires pH of 6.5-7.2.	Use for sachets, potpourri.
Lemon balm *Melissa officinalis*	24-48″	18-24″	Hardy; grow from seed in full sun. Well-drained site.	Leaves provide lemon scent and flavor to drinks, salads, and dishes.
Lemon verbena *Aloysia triphylla*	36″	36″	Tender perennial; propagate from cuttings. Sun or partial shade.	Strongest lemon scent. Used in teas or potpourri.
Lovage *Levisticum officinale*	36-48″	30″	Rich, moist soil. Grow from seed planted in late summer. Sun or partial shade.	In the carrot family; strong celery flavor.
Mints *Mentha spp.*	12-36″	18″	Grow from cuttings or division. Sun or partial shade.	Aromatic; used as flavoring. Unusual varieties include orange, blue balsam, ginger, and chocolate.
Oregano *Origanum spp.*	24″	9″	Grow from seed, cuttings, or division. Sun.	Flavoring for tomato dishes, pasta.
Rosemary *Rosmarinus spp.*	36-72″	12-36″	Grows in well-drained, non-acid soil from cuttings. Sun. Marginally hardy; plant in protected site.	Leaves flavor sauces, poultry, soups. Good for meats and rice. Grown as topiary, bonsai.
Sage *Salvia spp.*	18″	12″	From seed or cuttings. Sun. Renew every 3-4 years.	Seasoning for meats, especially pork, and herb teas.
Thyme *Thymus spp.*	8-12″	12″	Light soil, well-drained. Renew every 2-3 years. Grow from cutting or division. Sun.	Aromatic foliage for seasoning. Varieties include lemon, orange, nutmeg, and wooly.

Other Uses of Herbs

Herb Bread

Add 1/2 teaspoon sage,1/2 teaspoon thyme, and1/2 teaspoon marjoram per pound of yeast dough *(Hertzler 2001)*.

Herbal Teas

Fresh or dried leaves of herbs such as lemon balm, peppermint, chamomile, rosemary, and catnip can be used to make tea. Herbal teas are made by steeping the leaves in hot water or placing the leaves in boiling water for several minutes *(McLaurin and McLaurin 2011)*.

Resources

Alabama Cooperative Extension. 2010. *Growing Herbs*. Publication ANR-1164. www.aces.edu/pubs/docs/A/ANR-1164/ANR-1164.pdf.

Hertzler, Ann. 2001. *Herbs and Spices*. Virginia Cooperative Extension. Publication 348-907. http://pubs.ext.vt.edu/348/348-907/348-907_pdf.pdf.

McLaurin, Wayne J., and Sylvia R. McLaurin. 2011. *Herbs in Southern Gardens*. University of Georgia Cooperative Extension. Bulletin 1170. www.caes.uga.edu/applications/publications/files/pdf/B%20 1170_2.pdf.

Stephens, James M. 2011. *Herbs in the Florida Garden*. Horticultural Sciences Department, University of Florida Extension. Publication CIR570. (Originally published 1994.) http://edis.ifas.ufl.edu/pdffiles/VH/VH02000.pdf.

Swinerton, Stephanie K. 2010. *Spice It Up!* Virginia Cooperative Extension. Publication 348-739. http://pubs.ext.vt.edu/348/348-739/348-739.html.

Trinklein, David H. 2005. *Growing Herbs at Home*. University of Missouri Extension. Publication G 6470. http://extension.missouri.edu/explorepdf/agguides/hort/g06470.pdf.

Lavender *(Photo by Shawn Appling)*

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Chapter 3

PLANT GROWTH REGULATION OF THREE HERB SPECIES

Abstract

The effect of plant growth regulators (PGRs) or mechanical stimulation on branching was assessed on sweet basil (*Ocimum basilicum* L.), cilantro (*Coriandrum sativium* L.), and parsley (*Petroselinum crispum* (Mill.) Nyman ex A.W. Hill). The following treatments were applied to sweet basil, cilantro, and parsley, at two to three days after transplanting: dikegulac sodium at 0, 100, 200, 400, or 800 mg/L; benzyladenine at 0, 75, 150, 300, or 600 mg/L; metaconazole at 0, 37.5, 75, 150, or 300 mg/L; mechanical stimulation as brushing at 0, 10, or 40 strokes applied twice daily. Ethephon was applied to basil at 0, 250, 350, or 500 mg/L. Dikegulac sodium decreased sweet basil plant height as rate increased. Dikegulac sodium increased lateral branching of sweet basil at 100 mg/L. Dikegulac sodium had no significant effect on growth or lateral branching of cilantro or parsley. Benzyladenine had no significant effect on growth or lateral branching of sweet basil, cilantro or parsley. Metaconazole had no significant effect on growth or lateral branching of sweet basil, cilantro, or parsley. Ethephon slightly increased lateral branching of sweet basil as rate increased. Mechanical stimulation resulted in a significant decrease in plant height, plant width, number of branches, and number of leaders on sweet basil, cilantro, and parsley.

Introduction

Greenhouse herb production is becoming an increasingly important aspect of commercial greenhouse production in the United States. Data from the USDA 2009 Census of Horticultural specialties reported that 323 operations were specializing in

growing herbs. The value of herb production along with other food crops grown undercover represent the fastest growing market in horticulture with a 148 percent increase in value from $223 million in 1998 to $553 million in 2009 (USDA, 2010).

Herb production presents several advantages to commercial greenhouse operations. Herb production can be easily added to bedding plant production operations because herbs have similar cultural requirements and they can be grown in a range of growing media (Gibson et al., 2000). Herb seed is relatively inexpensive and herbs have quick production times of about four to six weeks depending on species. Herbs also have few insect and disease problems (Gibson et al., 2000).

Plant growth regulators (PGRs) are described as chemicals that are designed to affect plant growth and/or development (Latimer, 2009). Plant growth regulators can be used for control of plant height (chemical growth retardants), stimulation of lateral branching, or for promoting flower initiation (Bailey and Whipker, 1998). PGRs used for promoting lateral branching are usually called chemical pinchers because they inhibit the growth of terminal shoots or they enhance the growth of lateral branches (Latimer, 2009). These PGRs can be used in replacement of mechanical pinching which also stimulates lateral branching (Latimer, 2009).

Mechanical stimulation is a way to limit stem elongation and may avoid the detrimental effects of stress based treatments (Garner and Bjorkman, 1996). The changes in plant growth caused by mechanical stimulation occur without long term inhibition of plant growth once treatments are ceased (Garner and Bjorkman, 1996). Mechanical stimulation in the form of brushing can be applied by using any non-abrasive material

such as bond typing paper, cardboard, polyvinyl chloride pipe, or by a wooden dowel (Garner and Bjorkman, 1996).

In this study the effect of plant growth regulators (PGRs) or mechanical stimulation (brushing) on branching was assessed on sweet basil (*Ocimum basilicum* L.), cilantro (*Coriandrum sativium* L.), and parsley (*Petroselinum crispum* (Mill.) Nyman ex A.W. Hill). Two objectives of applying these treatments were to increase lateral branching and to increase fresh weight for cut herb production or as a potted plant. The PGRs investigated were dikegulac sodium, benzyladenine, ethephon, and metaconazole. None of these PGRs are currently labeled for herb production.

Methods and Materials

Sweet basil, cilantro, and parsley seed (Wetsel, Inc., Harrisonburg, VA) were planted into 128 plug trays, using a germination mix (Conrad Fafard, Inc., Agawam, MA) on March 4, 2011 (cilantro and parsley), March 14, 2011 (sweet basil) and April 11, 2011 (ethephon treated sweet basil). One seed was planted into each cell in the plug trays. The plug trays were placed on heat mats in a double poly greenhouse with temperature set points of 22°C during the day/13°C at night. High pressure sodium lights (12 hours day length) were used for supplemental lighting; mean daily light integral (DLI) during the experiment was 30 $mol \bullet m^{-2} \bullet d^{-1}$. Sweet basil, cilantro, and parsley seedlings were potted up into 10.2 cm square pots (706 mL) using a peat lite mix (Fafard 3B, Conrad Fafard, Inc), when the roots had reached the sides of the plug cells and the second set of true leaves had fully expanded. The transplants were then allowed to grow out for about a week before treatment on April 8, 2011 (sweet basil) and April 12, 2011 (cilantro and parsley). Sweet basil, cilantro, and parsley were treated with dikegulac sodium (Augeo,

OHP, Inc., Mainland, PA) at 0, 100, 200, 400, or 800 mg/L; benzyladenine (Configure, Fine America, Inc., Walnut Creek, CA) at 0, 75, 150, 300, or 600 mg/L; metaconazole (Tourney, Valent USA Corp., Walnut Creek, CA) at 0, 37.5, 75, 150, or 300 mg/L; mechanical stimulation as brushing at 0, 10, or 40 strokes applied twice daily. Ethephon (Florel, Monterey Lawn and Garden Products Inc., Fresno, CA) was applied to sweet basil at 0, 250, 350, or 500 mg/L on May 4, 2011. PGR treatments were applied using a handheld CO_2 sprayer at a volume of 210 mL/m². Temperature and relative humidity at the time of treatment were 21°C and 46% on April 8, 2011; 22°C and 49% on April 12, 2011; 17°C and 52% on May 4, 2011. Each crop constituted a separate experiment. Treatments were arranged in a completely randomized design with six single plant replications. Plant height (from rim of pot to top of plant in cm), width (largest width and width measurement perpendicular to largest width in cm), number of branches, number of leaders (terminal shoot or branch, that has side shoots or branches growing from them) and notes on phytotoxicity were collected at 0, 2, and 4 weeks after treatment (WAT). Data were analyzed using SAS regression analysis (SAS Institute Inc., Cary, NC).

Results and Discussion

The treatment of sweet basil with dikegulac sodium resulted in a linear decrease in height as rate increased at 2 and 4 WAT (Table 3.1). Dikegulac sodium caused a quadratic decreased width response in sweet basil at 2 and 4 WAT, but only the highest rate , 800 mg/L, reduced plant width (Table 3.1). The number of sweet basil lateral branches decreased as dikegulac sodium rate increased at 2 WAT but there were no significant effects at 4 WAT (Table 3.2). This effect is different from results in *Capsicum annuum* which showed an increase in the number of branches compared to control plants

at 722 mg/L dikegulac sodium (Matta, 1984). Dikegulac sodium had no effect on the number of leaders of sweet basil at 2 and 4 WAT (Table 3.2).

Benzyladenine had no significant effect on sweet basil plant height or width (Table 2.3), number of branches, or on the number of leaders at 2 or 4 WAT (Table 3.4).

Metaconazole had no significant effect on sweet basil height or width (Table 3.5), number branches, or number of leaders at 2 or 4 WAT (Table 3.6).

Ethephon treated sweet basil showed no significant effect on height or width at 2 and 3 WAT (Table 3.7). Ethephon increased the number of branches of sweet basil as rate increased at 2 WAT but had no significant effect at 3 WAT (Table 3.8). In previous research by Glady et al. (2007) ethephon increased the number of primary shoots on *Coreopsis*, *Veronica*, and *Dianthus* treated with 600 or 800 mg/L ethephon. Ethephon also increased lateral branching in purple passion plant (*Gynura aurantiaca* (Blume) DC.) as rates increased (250, 500, 1000 mg/L) (Chen et al., 2002). Ethephon had no significant effect on the number of leaders of sweet basil at 2 and 3 WAT (Table 3.8).

Brushing significantly decreased sweet basil plant height and width with increasing intensity at 2 and 4 WAT (Table 3.9). Basil lateral branching was significantly decreased with increasing brushing intensity at 2 and 4 WAT (Table 3.10). Brushing with 40 strokes twice per day resulted in severe mechanical damage on sweet basil plants while 10 strokes caused slight mechanical damage on sweet basil plants.

Cilantro height was not significantly affected by dikegulac sodium at 2 or 4 WAT (Table 3.11). Dikegulac sodium decreased the width of cilantro as rate increased at 2 WAT but had no significant effect at 4 WAT (Table 3.11). The number of leaf stalks of cilantro was not significantly affected by dikegulac sodium at 2 or 4 WAT (Table 3.11).

Benzyladenine had no significant effect on cilantro plant height at 2 or 4 WAT (Table 3.12). Cilantro plant width was decreased as benzyadenine rate increased at 4 WAT but there was no significant effect at 2 WAT (Table 3.12). The number of leaf stalks was not affected by benzyladenine (Table 3.12).

Cilantro plant height was increased quadratically with increasing metaconazole rates with maximum height at 75 mg/L compared to control plants at 2 WAT; there was no significant effect on cilantro plant height at 4 WAT (Table 3.13). Metaconazole had no significant effect on cilantro plant width or on the number of leaf stalks at 2 and 4 WAT (Table 3.13).

Brushing also had a significant effect on cilantro height and width (Table 3.14). Cilantro height was decreased with increasing intensity of brushing at 2 and 4 WAT. Brushing also decreased cilantro width and lateral branching at 2 and 4 WAT (Table 3.14).

Dikegulac sodium had no significant effect on parsley plant height, width, or number of leaf stalks at 2 and 4 WAT (Table 3.15). There was no significant effect of benzyladenine on parsley plant height, width, or number of leaf stalks at 2 or 4 WAT (Table 3.16).

Parsley plant height, width, and number of leaf stalks were not significantly affected by metaconazole at 2 or 4 WAT (Table 3.17).

The effects of benzyladenine on sweet basil, cilantro, and parsley are different from results in *Peperomia obtusifolia* (L.) A. Dietr. where the mean number of lateral branches of plants treated with 500 mg/L BA were increased (9 branches compared with 4 branches for controls) (Henny, 1985).

As seen with sweet basil and cilantro, parsley plant height and width were both decreased at 2 WAT with 10 and 40 brushing strokes compared to control plants (Table 2.18). Other researchers reported reduced stem elongation associated with brushing, which resulted in more compact plants than controls (Latimer and Thomas, 1991). Latimer and Thomas (1991) found that brushing with 25 cycles per day (one cycle equaled one back and forth motion) decreased stem length and leaf area of tomato transplants which also developed tougher stems. Cilantro plants brushed with 10 strokes also had a more upright appearance compared to controls which may be indicative of increased stem strength.

Conclusions

At the rates applied, dikegulac sodium decreased basil plant height as rate increased at 2 and 4 WAT. Dikegulac sodium could be used in basil production to reduce plant height, but the rate of 800 mg/L caused damage. Brushing decreased the height, width, and the number of branches of basil as intensity increased at 2 and 4 WAT. Mechanical stimulation as brushing could be used to reduce height during basil production. Brushing also decreased the height and width of cilantro and parsley at 2 and 4 WAT. In the case of cilantro, the brushed plants appeared to have stronger stems and a more upright appearance at the brushing intensity of 10 strokes, this observation would need to be studied further.

The dikegulac sodium rate 400 mg/L, benzyladenine rate 300 mg/L, ethephon rate 350 mg/L and the brushing rate of 10 strokes twice daily from this study will be used to evaluate the growth of sweet basil, Genovese basil, Thai basil, cilantro, and parsley under colored shade cloth. These rates were chosen because they did not produce phytotoxic

effects. Height, width, lateral branching, and number of leaders data will be collected to see if there are interactions with the use of benzyladenine, dikegulac sodium, ethephon, or brushing under black, blue, or red shade clothes.

Literature Cited

Bailey, D. and B. Whipker. 1998. Best management practices for plant growth regulators used in floriculture. North Carolina State University Cooperative Extension Horticulture Information Leaflet 529.

Chen, J., R. Henny, R. Caldwell. 2002. Ethephon suppresses flowering and improves the aesthetic value of purple passion plant (*Gynura aurantiaca*). J. Environ. Hort. 20:228-231.

Garner, L. and T. Bjorkman. 1997. Using impedance for mechanical conditioning of tomato transplants to control excessive stem elongation. HortScience 32(2):227-229.

Gibson, J., B. Whipker, R. Cloyd. 2000. Success with container production of twelve herb species. North Carolina State University Horticultural Information Leaflet 509.

Glady, J., N. Lang, and E. Runkle. 2007. Effects of ethephon on stock plant management of *Coreopsis verticillata*, *Dianthus caryophyllus*, and *Veronica longifolia*. HortScience 42(7):1616-1621.

Latimer, J. 2009. Selecting and using plant growth regulators on floriculture crops. Virginia Cooperative Extension Publication 430-102.

Latimer, J. and P. Thomas. 1991. Application of brushing for growth control of tomato transplants in a commercial setting. HortTechnology 1:109-110.

Matta, F. 1984. Effects of hand-pinching and dikegulac-sodium sprays on *Capsicum annuum*. HortScience 19(2):284-285.

USDA. 2010. 2009 Census of Horticultural Specialties. 2007 Census of Agriculture 3:3. http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Census_of_Horticulture/HORTIC.pdf. August 12, 2011.

Table 3.1. Effect of dikegulac sodium on sweet basil plant height at 2 and 4 weeks after treatment (WAT). (n = 6)

	Height (cm)		Width (cm)	
Dikegulac sodium Rate	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**
Untreated Control	12.8	34.0	13.1	18.0
100 mg/L	15.2	35.3	14.8	19.3
200 mg/L	13.5	33.7	14.8	21.2
400 mg/L	13.5	31.5	14.2	19.8
800 mg/L	9.5	23.8	12.3	17.8
Regression	0.0114L*	0.0018L	0.0095Q	0.0331Q
R^2	0.2077	0.2990	0.2918	0.2230

***L, Linear; Q, Quadratic**

Table 3.2. Effect of dikegulac sodium on sweet basil number of branches and number of leaders at 2 and 4 weeks after treatment (WAT). (n = 6)

	Number of Branches		Number of Leaders	
Dikegulac sodium Rate	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**
Untreated Control	8.2	15.8	1.0	4.3
100 mg/L	8.7	21.0	1.0	4.8
200 mg/L	8.5	22.2	1.0	5.8
400 mg/L	8.0	21.0	1.0	5.2
800 mg/L	7.0	16.8	1.0	4.2
Regression	0.0062L*	0.6548L	N/A	0.5678L
R^2	0.2382	0.0072	N/A	0.0118

***L, Linear**

Table 3.3. Effect of benzyladenine on sweet basil plant height and width at 2 and 4 weeks after treatment (WAT). (n = 6)

	Height (cm)		Width (cm)	
Benzyladenine Rate	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**
Untreated Control	13.5	36.3	13.75	23.7
75 mg/L	14.5	34.2	13.6	22.2
150 mg/L	14.8	32.2	14.5	24.4
300 mg/L	14.5	32.0	13.0	24.8
600 mg/L	13.7	35.8	13.75	23.2
Regression	0.8313L*	0.9201L	0.7418L	0.8935L
R^2	0.0016	0.0004	0.0039	0.0006

***L, Linear**

Table 3.4. Effect of benzyladenine on sweet basil plant number of branches and number of leaders at 2 and 4 weeks after treatment (WAT). (n = 6)

	Number of Branches		Number of Leaders	
Benzyladenine Rate	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**
Untreated Control	8.7	18.2	1.0	4.2
75 mg/L	8.3	21.8	1.0	4.0
150 mg/L	9.3	23.7	1.0	5.0
300 mg/L	8.3	29.5	1.0	6.0
600 mg/L	8.0	16.5	1.0	4.7
Regression	0.2297L*	0.7001L	N/A	0.5016L
R^2	0.0511	0.0054	N/A	0.0163

***L, Linear**

Table 3.5. Effect of metaconazole on sweet basil plant height and width at 2 and 4 weeks after treatment (WAT). (n = 6)

	Height (cm)		Width (cm)	
Metaconazole Rate	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**
Untreated Control	12.7	31.5	15.3	22.2
37.5 mg/L	15.3	37.2	13.7	22.9
75 mg/L	16.7	38.5	14.2	23.3
150 mg/L	15.0	36.3	13.4	23.3
300 mg/L	15.2	34.5	14.7	22.7
Regression	0.4703L*	0.9235L	0.9244L	0.8619L
R^2	0.0188	0.0003	0.0003	0.0011

***L, Linear**

Table 3.6. Effect of metaconazole on sweet basil plant number of branches and number of leaders at 2 and 4 weeks after treatment (WAT). (n = 6)

	Number of Branches		Number of Leaders	
Metaconazole Rate	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**
Untreated Control	8.3	16.2	1.0	4.3
37.5 mg/L	8.5	25.3	1.0	6.0
75 mg/L	8.3	27.7	1.0	6.2
150 mg/L	8.7	21.8	1.0	5.8
300 mg/L	8.5	20.7	1.0	5.8
Regression	0.7637L*	0.9348L	N/A	0.4481L
R^2	0.9079	0.0002	N/A	0.0207

***L, Linear**

Table 3.7. Effect of ethephon on sweet basil plant height and width at 2 and 3 weeks after treatment (WAT). (n = 6)

	Height (cm)		Width (cm)	
Ethephon Rate	**2 WAT**	**3 WAT**	**2 WAT**	**3 WAT**
Untreated Control	25.0	37.5	14.6	21.8
250 mg/L	26.0	37.5	14.7	21.2
350 mg/L	26.5	38.5	15.2	21.8
500 mg/L	22.2	34.7	14.6	20.8
Regression	0.3636L*	0.4557L	0.8174L	0.2576L
R^2	0.0376	0.0255	0.0025	0.0578

***L, Linear**

Table 3.8. Effect of ethephon on sweet basil plant number of branches and number of leaders at 2 and 3 weeks after treatment (WAT). (n = 6)

	Number of Branches		Number of Leaders	
Ethephon Rate	**2 WAT**	**3 WAT**	**2 WAT**	**3 WAT**
Untreated Control	9.8	21.3	1.3	5.7
250 ppm	10.3	19.8	1.8	6.3
350 ppm	11.5	25.2	2.3	6.7
500 ppm	12.2	24.7	1.8	7.0
Regression	0.0460L*	0.1996L	0.3391L	0.0802L
R^2	0.1689	0.0736	0.0416	0.1326

***L, Linear**

Table 3.9. Effect of brushing on sweet basil plant height and width at 2 and 4 weeks after treatment (WAT). (n = 6)

	Height (cm)		Width (cm)	
Brushing Rate	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**
Untreated Control	14.0	38.0	13.9	20.4
20 strokes	10.3	21.3	12.3	16.8
40 strokes	5.5	10.0	8.7	10.8
Regression	< 0.0001L*	< 0.0001L	0.0001L	< 0.0001L
R^2	0.7883	0.9012	0.6160	0.7294

***L, Linear**

Table 3.10. Effect of brushing on sweet basil plant number of branches and number of leaders at 2 and 4 weeks after treatment (WAT). (n = 6)

	Number of Branches		Number of Leaders	
Brushing Rate	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**
Untreated Control	8.2	21.0	1.0	7.0
20 strokes	8.0	12.7	1.0	3.5
40 strokes	5.7	10.3	1.0	3.3
Regression	0.0016L*	0.0012L	N/A	0.0276L
R^2	0.4733	0.4904	N/A	0.2684

***L, Linear**

Table 3.11. Effect of dikegulac sodium on cilantro plant height, width, and number of leaf stalks at 2 and 4 weeks after treatment (WAT). (n = 6)

	Height (cm)		Width (cm)		Number of Leaf Stalks	
Dikegulac sodium Rate	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**
Untreated Control	18.5	32.5	30.1	52.1	10.0	34.8
100 mg/L	18.7	33.3	33.5	55.7	9.5	26.3
200 mg/L	16.3	32.3	30.2	51.7	8.3	30.3
400 mg/L	15.7	32.8	27.7	51.3	8.7	30.2
800 mg/L	15.8	31.8	26.4	52.2	8.8	31.8
Regression	0.0755L*	0.6532L	0.0048L	0.6167L	0.4590L	0.9162L
R^2	0.1085	0.0073	0.2511	0.0091	0.0197	0.0004

***L, Linear**

Table 3.12. Effect of benzyladenine on cilantro plant height, width, and number of leaf stalks at 2 and 4 weeks after treatment (WAT). (n = 6)

	Height (cm)		Width (cm)		Number of Leaf Stalks	
Benzyladenine Rate	2 WAT	4 WAT	2 WAT	4 WAT	2 WAT	4 WAT
Untreated Control	18.2	30.5	24.6	48.5	23.8	31.0
75 mg/L	17.7	32.7	29.3	50.7	20.2	28.8
150 mg/L	18.8	33.0	30.0	50.3	21.7	34.7
300 mg/L	18.0	30.5	28.0	47.7	24.3	31.3
600 mg/L	16.0	31.8	24.5	44.7	18.5	35.2
Regression	0.2659L*	0.9901L	0.4497L	0.0223L	0.2043L	0.1773L
R^2	0.0440	5.6E-06	0.0206	0.1729	0.0569	0.0640

***L, Linear**

Table 3.13. Effect of metaconazole on cilantro plant height, width, and number of leaf stalks at 2 and 4 weeks after treatment (WAT). (n = 6)

	Height (cm)		Width (cm)		Number of Leaf Stalks	
Metaconazole Rate	2 WAT	4 WAT	2 WAT	4 WAT	2 WAT	4 WAT
Untreated Control	18.2	33.5	32.0	51.4	20.3	37.7
37.5 mg/L	18.2	28.8	33.3	51.2	26.2	44.0
75 mg/L	19.3	33.0	30.4	51.9	24.2	38.3
150 mg/L	13.8	32.5	30.7	47.1	20.8	42.0
300 mg/L	18.5	29.2	31.7	49.6	24.2	41.8
Regression	0.0471Q*	0.2734L	0.6432L	0.3654L	0.7598L	0.6153L
R^2	0.2026	0.0427	0.0078	0.0293	0.0034	0.0091

***L, Linear; Q, Quadratic**

Table 3.14. Effect of brushing on cilantro plant height, width, and number of leaf stalks at 2 and 4 weeks after treatment (WAT). (n = 6)

	Height (cm)		Width (cm)		Number of Leaf Stalks	
Brushing Rate	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**
Untreated Control	15.3	30.2	30.7	48.6	22.5	38.5
20 strokes	12.5	32.8	29.8	38.2	21.5	35.3
40 strokes	9.8	19.7	22.5	27.6	16.3	28.0
Regression	0.0103L*	0.0122L	0.0024L	< 0.0001L	0.0071L	0.0166L
R^2	0.3458	0.3326	0.4462	0.7119	0.3731	0.3088

***L, Linear**

Table 3.15. Effect of dikegulac sodium on parsley plant height, width, and number of leaf stalks at 2 and 4 weeks after treatment (WAT). (n = 6)

	Height (cm)		Width (cm)		Number of Leaf Stalks	
Dikegulac sodium Rate	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**
Untreated Control	14.3	31.8	19.8	50.8	11.0	22.3
100 mg/L	14.5	30.3	22.9	48.3	9.8	21.0
200 mg/L	16.2	31.5	22.3	51.2	8.3	19.7
400 mg/L	16.2	33.3	20.9	49.0	10.2	21.3
800 mg/L	14.2	30.8	18.4	43.9	10.7	22.8
Regression	0.8706L*	0.9902L	0.1247L	0.0530L	0.7341L	0.7041L
R^2	0.0010	5.46E-06	0.0821	0.1272	0.0042	0.0052

***L, Linear**

Table 3.16. Effect of benzyladenine on parsley plant height, width, and number of leaf stalks at 2 and 4 weeks after treatment (WAT). (n = 6)

	Height (cm)		Width (cm)		Number of Leaf Stalks	
Benzyladenine Rate	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**
Untreated Control	16.8	34.2	21.8	49.9	9.5	21.7
75 mg/L	15.7	31.7	20.5	48.1	9.7	17.7
150 mg/L	14.8	29.7	21.4	50.3	9.2	19.3
300 mg/L	16.8	30.8	24.3	52.5	11.5	21.3
600 mg/L	16.0	31.5	20.8	44.8	11.0	23.7
Regression	0.9828L*	0.5419L	0.9319L	0.1654L	0.3153L	0.2890L
R^2	1.69E-05	0.0134	0.0003	0.0676	0.0360	0.0401

***L, Linear**

Table 3.17. Effect of metaconazole on parsley plant height, width, and number of leaf stalks at 2 and 4 weeks after treatment (WAT). (n = 6)

	Height (cm)		Width (cm)		Number of Leaf Stalks	
Metaconazole Rate	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**
Untreated Control	12.2	32.3	18.9	42.6	8.0	18.2
37.5 mg/L	13.5	34.0	22.0	46.3	14.0	29.8
75 mg/L	15.7	28.7	22.1	50.3	9.0	21.3
150 mg/L	14.5	31.8	21.8	49.5	9.3	25.0
300 mg/L	13.2	30.8	20.9	46.3	9.3	21.3
Regression	0.8563L*	0.5664L	0.6541L	0.5589L	0.5364L	0.8355L
R^2	0.0012	0.0119	0.0073	0.0123	0.0138	0.0016

***L, Linear**

Table 3.18. Effect of brushing on parsley plant height and width at 2 weeks after treatment (WAT). (n = 6)

Brushing Rate	**Height (cm)**	**Width (cm)**
Untreated Control	12.3	19.4
20 strokes	8.8	15.2
40 strokes	6.2	11.0
Regression	< 0.0001L	< 0.0001L
R^2	0.6276	0.7047

***L, Linear**

Chapter 4

Colored Shade Cloth Affects the Growth of Basil Cultivars

Abstract

The effect of colored shade cloth and plant growth regulators (PGRs) or mechanical stimulation (brushing) on branching were assessed on sweet basil (*Ocimum basilicum* L.), Thai basil (*Ocimum basilicum* 'Siam Queen' L.), and Genovese basil (*Ocimum basilicum* 'Genovese' L.). All crops were grown under conventional black, blue, or red ChromatiNet® shade cloth. Subplot treatments included: dikegulac sodium at 400 ppm; benzyladenine at 300 ppm; ethephon at 350 ppm; or, mechanical stimulation as brushing at 10 strokes applied twice daily. We assessed volatile components on all crops and conducted a sensory panel on sweet basil. Red shade cloth increased the number of branches and shoot fresh weight in sweet basil, Thai basil, and Genovese basil compared to black or blue shade treatments. Benzyladenine increased the number of branches compared to control plants in sweet basil and Thai basil. Volatile compound analysis indicates that linalool mean peak area was significantly higher in red shade cloth grown sweet basil plants and eugenol mean peak area was higher in black shade cloth grown sweet basil plants. Linalool mean peak area was also significantly higher in red shade cloth grown Thai basil plants and methylchavicol mean peak area was higher in blue and red shade cloth grown plants. Genovese basil had a higher camphor mean peak area in blue shade cloth grown plants and eugenol was higher in blue shade cloth grown Genovese basil plants. Sensory panel results showed a preference for the appearance of sweet basil grown under red shade cloth but there was no difference in determination of aroma between the shade cloth colors. Red shade cloth can be used to grow sweet basil,

Thai basil, and Genovese basil plants that have more branches and a higher fresh weight. The appearance of sweet basil grown under red shade cloth is preferred by the consumer over black and blue shade treatments. The sensory analysis shows that the difference in the volatile compounds did not have a significant influence in the aroma or preference of sweet basil.

Introduction

Basil (*Ocimum basilicum* L.) is one of the most popular culinary herbs, used in tomato sauces, pesto, in salads, and in flavored oils (Simon et al., 1999; Williamson, 2008). In North America, basil is sold as a fresh cut and as a dried product (Simon et al., 1999). Basil is also being sold as a potted plant for major grocery store chains and in many big box stores. The most popular cultivars for the fresh market and garden include cultivars that have dark green leaves and a rich spicy aroma such as sweet basil and Genovese basil (*Ocimum basilicum* 'Genovese' L.) (Simon et al., 1999).

Greenhouse herb production is becoming an increasingly important aspect of commercial greenhouse production in the United States. Data from the USDA 2009 Census of Horticultural specialties reported that 323 operations were specializing in growing herbs. The value of herb production along with other food crops grown undercover represent the fastest growing market in horticulture with a 148 percent increase in value from $223 million in 1998 to $553 million in 2009 (USDA, 2010).

Shade is often used in the summer to protect plants from high light intensities (Nelson, 2003). High light intensity can damage the chloroplasts, and cause leaf and petal burn. Shading maybe accomplished by spraying a white-wash (diluted latex paint solution) on the greenhouse or by installing shading fabric over or inside the greenhouse

(Nelson, 2003). Shade cloth can be purchased in different densities of weave providing shade values from 20% to 90%; 50% is the most commonly used shade cloth (Nelson, 2003).

ChromatiNet® (colored shade cloth) is designed to modify light in either the ultra-violet, visible, or far-red spectral regions; the cloth also enhances the relative content of scattered vs. direct light and absorbs infra-red radiation (Shahak et al., 2004). The fraction of light that passes through the holes, in the shade cloth, remains unchanged in its quality, while the light hitting the threads comes out spectrally modified and scattered (Shahak et al., 2004). The blue shade cloth is designed to absorb ultra-violet (UV), red, and far-red radiation; while enriching the blue spectral region (Figure 4.1). The red shade cloth absorbs UV, blue, and green radiation and enriches the red and far-red spectral region (Figure 4.2). The effects of colored shade cloth have been studied on a number of crops including *Pittosporum variegatum* (Thunb.) W.T. Aiton (Oren-Shamir et al., 2001), *Dracaena deremensis* 'Janet Craig' (L.) Ker Gawl, *Dracaena marginata* 'Colorama' Lam. (Kawabata et al., 2007), and *Phalaenopsis* Blume (Leite et al., 2008).

Pittosporum was grown under 50% green, blue, red, black, grey, or Aluminet® shade cloth in Israel (Oren-Shamir et al., 2001). Blue shade cloth reduced branching, internode length, and decreased the yield of commercial branching (cut foliage) but variegation of *Pittosporum* was enhanced. The red and grey shade cloth increased the number of lateral branches of *Pittosporum* plants compared to those grown under the black shade cloth. The red shade cloth stimulated stem elongation and produced the longest branches (Oren-Shamir et al., 2001).

Dracaena ‘Janet Craig’ was grown under 70% black, red, blue, or grey shade cloth, the weave of the cloth with 70% covered by the fabric and 30% open (Kawabata et al., 2007). The red shade cloth produced the greatest number of new leaves but they were smaller and thicker than the leaves under the other shade cloth treatments. A grower evaluation of the plants showed that the smaller leaves of the red shade cloth grown plants reduced marketability (Kawabata et al., 2007).

Dracaena ‘Colorama’ grown under red shade cloth produced more new cane growth (20.2 cm compared to 10.4 cm for the black) and more new leaves (26.2 compared to 18 for the black) compared to the other treatments (Kawabata et al., 2007). The red shade cloth grown plants grew taller while maintaining a full appearance (Kawabata et al., 2007).

Phalaenopsis species were grown under 50% black, blue, or red shade cloth (Leite et al., 2008). The red shade cloth treated plants bloomed in April and May compared to May and June for the plants grown under black or blue shade cloth respectively; this earlier bloom was attributed to the higher amount of red and far-red light transmitted by the red shade cloth. Blue shade cloth treated plants had a higher leaf area and leaf fresh weight compared to the black and red shade cloth treatments. The fact that the plants were larger under the blue shade cloth contradicts the literature presented thus far and is thought to be because *Phalaenopsis* are adapted to low light levels and because they are crassulacean acid metabolism (CAM) plants (Leite et al., 2008).

Plant growth regulators (PGRs) are described as chemicals that are designed to affect plant growth and/or development (Latimer, 2009). Plant growth regulators can be used for control of plant height (chemical growth retardants), stimulation of lateral branching,

or for promoting flower initiation (Bailey and Whipker, 1998). PGRs used for promoting lateral branching are usually called chemical pinchers because they inhibit the growth of terminal shoots or they enhance the growth of lateral branches (Latimer, 2009). These PGRs can be used in replacement of mechanical pinching which also stimulates lateral branching (Latimer, 2009).

Mechanical stimulation is a way to limit stem elongation and may avoid the detrimental effects of stress based treatments (Garner and Bjorkman, 1996). The changes in plant growth caused by mechanical stimulation occur without long term inhibition of plant growth once treatments are ceased (Garner and Bjorkman, 1996). Mechanical stimulation in the form of brushing can be applied by using any non-abrasive material such as bond typing paper, cardboard, polyvinyl chloride pipe, or by a wooden dowel (Garner and Bjorkman, 1996).

Sweet basil is characterized as having an aroma like French tarragon, a sweet licorice scent, attributed to the aroma compound methyl chavicol (Tucker and DeBaggio, 2009a). Two other popular cultivars of sweet basil include ‘Genovese’ which has a lavender-like floral aroma attributed to linalool and is typically used to make pesto; and Thai basil ‘Siam Queen’ which has a stronger licorice scent than sweet basil and a higher percentage of methyl chavicol, and is used in salads, sauces, and Thai cooking (Tucker and DeBaggio, 2009a; Williamson, 2008).

The effects of colored shade cloth and plant growth regulators (PGRs) or mechanical stimulation on growth were assessed on sweet basil, Thai basil, and Genovese basil. The ideal plant for fresh cut production would be a plant with an increased fresh weight. A plant with an increase in the number of branches without excess height, which

makes shipping difficult, would be ideal for growers. The shade cloth colors investigated were conventional black, blue ChromatiNet, and red ChromatiNet shade cloth. The following PGRs were investigated as subplot treatments: dikegulac sodium, benzyladenine, and ethephon. None of these PGRs are currently labeled for use during basil production.

Methods and Materials

Sweet basil (Wetsel, Inc., Harrisonburg, VA), Thai basil, and Genovese basil (W. Atlee Burpee & Co.) were planted into 128 plug trays, using a germination mix (Conrad Fafard, Inc., Agawam, MA) on April 29, 2011 (Sweet Basil Replication 1), July 6, 2011 (Sweet Basil Replication 2), July 13, 2011 (Thai Basil Replication 1), July 28, 2011 (Genovese Basil), August 23, 2011 (Sweet Basil Replication 3), and September 8, 2011 (Thai Basil Replication 2). One seed was planted into each cell in the plug trays. All species were potted up into 10.2-cm square pots (706 mL) using a peat lite mix (Fafard 3B, Conrad Fafard, Inc), when the roots had reached the sides of the plug cells and the second set of true leaves had fully expanded. The transplants were then allowed to grow out for about a week before treatment on May 25, 2011 (Sweet Basil Replication 1), July 18, 2011 (Sweet Basil Replication 2), August 9, 2011 (Thai Basil Replication 1), August 22, 2011 (Genovese Basil), September 9, 2011 (Sweet Basil Replication 3), and October 3, 2011 (Thai Basil Replication 2).

Treatments were arranged in a split-plot design. The main plot included the conventional black, blue ChromatiNet, or red ChromatiNet (Green-Tek, Inc. WI, USA) shade cloth with three replications of each plot randomly assigned to greenhouse benches (Figure 4.3). Spectral distribution under the conventional black, blue ChromatiNet, and

red ChromatiNet shade cloth was graphed using a Li-Cor Spectroradiometer, courtesy of Dr. Faust, Clemson University (Figure 4.4). Sub-plot treatements were an untreated control, dikegulac sodium (Augeo, OHP, Inc., Mainland, PA) at 400 mg/L; benzyladenine (Configure, Fine America, Inc., Walnut Creek, CA) at 300 mg/L; ethephon (Florel, Monterey Lawn and Garden Products Inc., Fresno, CA) at 350 mg/L; mechanical stimulation as brushing at 10 strokes applied twice daily. The brushing technique consisted of a wooden dowel and one back and forth motion counted as one stroke. After Sweet Basil Replication 1 the brushing technique was change to a gentler method; a piece of ground cloth cut into strips suspended from a PVC pipe. PGR treatments were applied using a handheld CO_2 sprayer at a volume of 210 mL/m². Temperature and relative humidity at the time of treatment were 20°C and 90% on May 25, 2011; 24°C and 80% on July 18, 2011; 22°C and 80% on August 9, 2011; 22°C and 80% on August 22, 2011; 20°C and 86% on September 9, 2011; 20°C and 46% on October 3, 2011. Twelve high pressure sodium lights (400 watt) were used for supplemental lighting beginning September 19, 2011 to increase the DLI at plant level by 2 to 3 $mol \bullet m^{-2} \bullet d^{-1}$ (Figure 4.5). All plants were grown in a polycarbonate greenhouse with temperature set points during the day of 21°C and at night of 15°C. Environmental data were collected using HOBO data loggers (Onset Computer Corporation, Bourne, MA) placed under black, blue ChromatiNet, and red ChromatiNet treatments; unshaded environmental data were collected by a WatchDog data logger (Spectrum Technologies Inc., Plainfield, IL) (Table 4.1). Measurements included plant height (from rim of pot to top of plant in cm), width (largest width and width measurement perpendicular to largest width in cm), number of branches, number of leaders (terminal shoot or branch that has

side shoots or branches growing from them), shoot fresh weight, and notes on phytotoxicity at 0 days after treatment (DAT) and at finish, which depended on time of the year. Data were analyzed using JMP statistical software, Tukey-Kramer HSD (SAS Institute Inc., Cary, NC).

Volatile compound analysis was conducted on Sweet Basil Replication 2, Sweet Basil Replication 3, Thai Basil Replication 2, and Genovese Basil to determine whether or not important volatile compounds were being affected by the treatments. Two gram leaf samples of each treatments were placed in 20 mL headspace vials and sealed with AlumiTin, 20 mm caps. Headspace vials were placed into a Hewlett Packard GC 5890 with a 5972 series Mass Selective Detector (MS). HP 5MS column dimensions 30 m x 0.25 mm, film thickness 0.25 µm. Extraction fiber (DVB/CAR/PDMS) was injected into vials and then exposed for 30 minutes at 40°C. The extraction fiber was desorbed for 5 minutes in the injection port. Temperature in MS started at 45°C (intial) for 1 minute and then increased to 210°C at a rate of 10°C per minutes. MS temperature was held at 210°C for 5 minutes. Injection port temperature was 250°C and transfer line temperature 220°C, the carrier gas was helium at 25 cm/sec. A Kovats Standard was run through the MS to help identify compounds (Figure 4.6). The retention times of the major aroma compounds were then compared to the Kovats Standards using the website Flavornet (http://www.flavornet.org/flavornet.html).

Sweet Basil Aroma Panel Study only included shade cloth color treatments. The shade cloth color treatments were conventional black, blue ChromatiNet, and red ChromatiNet. An unshaded control treatment was also included. Sweet basil seeds were planted into 128 plug trays, using a germination mix on October 24, 2011. Treatments

were begun on November 18, 2011. Treatments were arranged in a completely randomized design with ten single plant replications under each shade color. A sensory analysis panel (triangle test) was conducted. Sweet basil leaf samples were placed in sealed glass jars (two to three leaves per jar) for the aroma evaluation. Sweet basil photograph lineups for a picture preference analysis were selected from sweet basil plants that were representative of the plants grown under conventional black, blue ChromatiNet, or red ChromatiNet shade treatments. The sensory analysis was conducted by respondents in a cubicle in a room parallel to the sensory kitchen, which was separated by a wall with revolving doors that allowed for samples to be passed to respondents. Respondents were passed the first set of basil leaf samples through a rotating door and asked to select the odd sample (two of the samples were the same). After they returned the leaf samples a set of three pictures were sent through the door and they were asked to select the picture of the plant they would be most likely purchase. Each respondent was given the sweet basil leaf samples and the sweet basil pictures in a different completely randomized order. This process was then repeated for basil leaf samples reps two and three and for basil picture set two.

A PGR drench experiment was also carried out on sweet basil to determine if applying dikegulac sodium or benzyladenine to the growing media, after planting the seeds, would affect branching and shoot fresh weight. Sweet basil seeds were sown in 10.2 cm square pots (706 mL) using a peat lite mix (Fafard 3B, Conrad Fafard, Inc) on September 14, 2011. On September 14, 2011, dikegulac sodium was applied as a drench (volume applied was 50 mL) at 0, 40, or 80 mg/L and benzyladenine was applied as a drench at 0, 30, or 60 mg/L. Temperature and relative humidity at the time of treatment

were 23°C and 80%. Treatments were arranged in a completely randomized design with eight single plant replications. Sweet basil seed germination data were collected at 6, 8, and 13 days after treatment (DAT). Plant height (from rim of pot to top of plant in cm), width (average of largest width and width measurement perpendicular to largest width in cm), number of branches, number of leaders (terminal shoot or branch, that has side shoots or branches growing from them), shoot fresh weight, and notes on phytotoxicity were collected at 0, 4, and 7 weeks after treatment (WAT).

Results

Sweet Basil Replication 1. Plant height was greater under both blue and red shade cloth compared to the black shade cloth treatment (Table 4.2). There was also a significant interaction between shade cloth color and PGR treatment with respect to plant height. Height was decreased under the red shade cloth when benzyladenine was used compared to control plants but was not different from control plants under the black and blue shade cloth treatments. Brushing decreased plant height compared to control plants under all three shade cloth colors. Sweet basil plant width was increased by red and blue shade clothes compared to the conventional black shade cloth; plant width was increased under red shade cloth compared to blue shade cloth plants (Table 4.2). A decrease in sweet basil plant width was seen in brushing treated plants compared to control plants; there was no interaction between shade cloth color and PGR treatments. Sweet basil plant shoot fresh weight was increased by the blue and red shade cloth compared to both the black shade cloth treatment (Table 4.2). A decrease was seen in shoot fresh weight in brushing treated sweet basil plants compared to control plants; no interaction was seen between shade cloth treatments and PGR treatments.

We saw an increase in the number of branches in the red and blue shade cloth treatments compared to the black shade cloth plants; red shade cloth treated plants had an increase in the number of branches compared to blue shade cloth plants (Table 4.3). There was an interaction between shade cloth color and PGR treatment with respect to the number of branches. Benzyladenine increased the number of branches under the black shade cloth treatment but was not statistically different from control plants under the black and red shade cloth treatments. The number of leaders was not affected by the shade cloth treatment. Brushing decreased the number of leaders of sweet basil under the red shade cloth compared to control plants but was not statistically different under black and blue shade cloth treatments (Table 4.3).

Sweet Basil Replication 2. Plant height was increased by the red shade cloth treatment compared to black and blue shade cloth treated plants (Table 4.4). Height was not affected by the PGR treatments and there was no interaction between PGRs and shade cloth treatments. Black and red shade cloth treatments increased width compared to the blue shade cloth treated sweet basil plants. Width was not affected by the PGR treatments and there was no interaction between PGRs and shade cloth treatments (Table 4.4). Sweet basil plant shoot fresh weight was increased under red shade compared to black and blue shade cloth treated plants (Table 4.4). Dikegulac sodium decreased shoot fresh weight compared to control plants; there was no interaction between PGRs and shade cloth treatments. Sweet basil number of branches and number of leaders were increased under the red shade cloth treatments compared to black and blue shade cloth treated plants; PGR treatments had no effect and no interaction was seen between PGRs and shade cloth treatments (Table 4.4).

Sweet Basil Replication 3. Plant height and width were greater under the red shade cloth compared to black and blue shade cloth treated plants (Table 4.5). There were no significant effects of PGR treatments and no interactions between PGRs and shade cloth colors. Sweet basil shoot fresh weight was increased under the red shade cloth treatment compared to black and blue shade cloth treated plants but there was no significant effects of the PGRs and no interaction between PGRs and shade cloth treatments (Table 4.5). Red shade cloth increased the number of branches compared to black and blue shade cloth treated plants (Table 4.5). An increase in number of branches was also seen in benzyladenine and ethephon treated plants compared to control plants; there was no interaction between PGRs and shade cloth treatments. The number of leaders in sweet basil was slightly increased in red shade cloth treatments compared to black and blue shade cloth treated plants; there was no effect from PGRs and no interaction between PGRs and shade cloth treatments (Table 4.5).

Sweet Basil Aroma Panel. Sweet basil plants were only subjected to shade cloth color treatments. Plant height increased in unshaded plants compared to black, blue, and red shade cloth treated plants but red shade cloth treated plants showed an increase in height compared to black and blue shade treatments (Table 4.6). Plant width was also increased in unshaded plants compared to black, blue, and red shade cloth treated plants but red shade cloth treated plants showed an increase in width compared to black and blue shade treatments (Table 4.6). Sweet basil had an increase in shoot fresh weight in unshaded plants compared to black, blue, and red shade cloth treated plants but red shade cloth treated plants showed an increase in shoot fresh weight compared to black and blue shade treatments (Table 4.6). Shoot dry weight was increased in the unshaded sweet basil

compared to all three shade cloth treatments but red shade cloth treated plants had increased dry weight compared to black shade cloth treated plants (Table 4.6). Sweet basil plant number of branches increased in the unshaded plants compared to black, blue, and red shade cloth treated plants but red shade cloth treated plants showed an increase in number of branches compared to black and blue shade treatments (Table 4.6). The number of leaders increased in unshaded plants compared to black, blue, and red shade cloth treated plants (Table 4.6).

Aroma panel analysis of sweet basil leaf samples grown under black, blue, or red shade cloth were not statistically significant ($p > 0.05$). Red shade cloth treated sweet basil plants from the two sets of aroma panel pictures were selected 94 out of 132 (71%) respondents which is statistically significant ($p \leq 0.05$). To be significant at 0.05 alpha level, 54 out of 132 respondents needed to select the red shade cloth grown plants.

Thai Basil Replication 1. Thai basil plants were only treated with the subplot treatments untreated control and dikegulac sodium. Seed germination problems were encountered during the heat of early August. Plant height was not affected by the shade cloth treatments but dikegulac sodium did decrease height compared to control plants (Table 4.7). Plant width was increased under the red shade cloth treatment compared to blue shade cloth treated plants (Table 4.7). Dikegulac sodium decreased plant width compared to control plants. Shoot fresh weight was increased in red shade cloth treated Thai basil plants compared to black shade cloth treated plants; a decrease in shoot fresh weight was seen in dikegulac sodium treated plants compared to control plants (Table 4.7). The red shade cloth treatment increased the numbers of branches and leaders of Thai

basil compared to black and blue shade cloth treated plants; there was no difference between dikegulac sodium plants and control plants (Table 4.7).

Thai Basil Replication 2. The colored shade cloth treatments did not have an effect on plant height of Thai basil (Table 4.8). Ethephon decreased height of Thai basil compared to control plants and there was no interaction between shade cloth color and PGRs. Thai basil width was increased under black and red shade treatments compared to blue shade cloth treated plants; there were no PGR effects on plant width (Table 4.8). Width was increased more by red shade cloth than by the black shade cloth treatments. Shoot fresh weight was increased under the red shade cloth treatment compared to black and blue shade cloth treated Thai basil plants (Table 4.8). There was an interaction between shade cloth color and PGR treatments in regard to shoot fresh weight. Ethephon decreased shoot fresh weight under both the blue and red shade cloth treatments compared to control plants but there was not a difference under the black shade cloth treatment.

Thai basil numbers of branches were increased under the red shade cloth treatment compared to black and blue shade shade cloth treated plants (Table 4.9). Benzyladenine increased the number of branches compared to control plants while ethephon reduced branching. The number of leaders increased under the red shade cloth treatment compared to black and blue shade cloth plants; there was no difference between the PGR treatments and control plants (Table 4.9).

Genovese Basil. Genovese basil plant height was greater under blue and red shade cloth treatments compared to the black shade cloth treated plants (Table 4.10). Ethephon decreased Genovese basil plant height compared to control plants there were no

significant interactions. Width was greater under the red shade cloth treatment compared to black and blue shade cloth treated plants; there was no difference in plant width between the PGRs and control plants (Tabe 4.10). Genovese basil shoot fresh weight increased in the red shade cloth treated plants compared to black and blue shade treatments (Table 4.10). Ethephon decreased Genovese basil shoot fresh weight compared to control plants. The number of branches of Genovese basil increased under the red shade cloth treatment compared to the black and blue shade cloth treated plants; there was no PGR effect on the number of branches and no interactions (Table 4.10). Red shade cloth increased the number of leaders of Genovese basil during compared to the blue shade cloth treated plants but not the black shade cloth (Table 4.10). Ethephon decreased the number of leaders of Genovese basil compared to control plants.

Sweet Basil Replication 2 Volatile Compound Analysis. The peak areas are identified by comparing them to the known compounds in the MS library and then double checked by using the Kovats Standards. The Kovats Standard allows us to confirm the identity of a compound by comparing standardized retention time. The major aroma compounds of sweet basil and Genovese basil are 1,8-cineole (Kovats number 1030), linalool (Kovats number 1100) camphor (Kovats number 1139), and eugenol (Kovats number 1364); in Thai basil, the major aroma compounds are 1,8-cineole (Kovats number 1030), linalool (Kovats number 1100), camphor (Kovats number 1139), methylchavicol (Kovats number 1200), and methyleugenol (Kovats number 1407); (Simon et al., 1999). An example of the chromatograms of the sweet basil treatments is in Figure 4.7. Mean peak area of 1,8-cineole was not affected by shade cloth color or by the PGR treatments (Table 4.11). Linalool mean peak area was higher under the red shade

cloth treated plants compared to the blue shade treatments but to not compared to the black shade cloth treatment. Mean peak area of linalool was not different from the control plants under the PGR treatments. Camphor mean peak area was not affected by the shade cloth treatments or by the PGR treatments. Mean peak area of eugenol was higher under the black shade cloth treatment compared to blue and red shade cloth treated plants; PGR effects were not significant and there were no interactions.

Sweet Basil Replication 3 Volatile Compound Analysis. Mean peak area of 1,8-cineole was higher under blue and red shade cloth treatments compared to black shade cloth treated plants; PGR treatments were not significantly different (Table 4.12). Linalool mean peak area was higher under the red shade cloth treated plants compared to the black and blue shade treatments. Mean peak area of linalool was not different from the control plants under the PGR treatments. Camphor mean peak area was not affected by the shade cloth treatments or by the PGR treatments. Mean peak area of eugenol was higher under the black shade cloth treatment compared to blue and red shade cloth treated plants; there were no significant interactions.

Thai Basil Replication 2 Volatile Compound Analysis. An example of the chromatograms for the Thai basil treatments is in Figure 4.8. Mean peak area of 1,8-cineole was not affected by shade cloth treatments or by PGR treatments (Table 4.13). Linalool mean peak area was higher in the red shade cloth treated plants compared to black and blue shade cloth treatments; PGR treatments had no significant effect. Camphor mean peak area was not affected by shade cloth treatments or by PGR treatments. Mean peak area of methylchavicol was higher under the blue and red shade cloth treatments compared to black shade cloth treated plants; there was no affect from

the PGR treatments. Mean peak area of methyleugenol was not affected by shade cloth treatments or by PGR treatments and there were no interactions.

Genovese Basil Volatile Compound Analysis. An example of the chromatograms for the Genovese basil treatments is in Figure 4.9. Mean peak area of 1,8-cineole was higher under black and blue shade cloth treatments compared to red shade cloth treated plants; PGR treatments were not significantly different (Table 4.14). Linalool mean peak area was not affected by shade cloth treatments or by PGR treatments. Camphor mean peak area was higher in the blue shade cloth treatments compared to the red shade cloth treated plants and PGRs had no effect. Mean peak area of eugenol was higher under the blue shade cloth treatment compared to black and red shade cloth treated plants; there was no affect from the PGR treatments. There were no interactions between shade cloth color and PGRs.

Sweet Basil Drench Study. Sweet basil plant height was decreased by dikegulac sodium at 80 mg/L and by benzyladenine at 30 and 60 mg/L drenches at 4 WAT; dikegulac sodium at 40 mg/L was not significantly different from control plants (Table 4.15). At 7 WAT sweet basil plant height was decreased by dikegulac sodium at 80 mg/L and by benzyladenine at 60 mg/L; the other treatments were not significantly different compared to control plants. Sweet basil plant width was decreased by dikegulac sodium at 80 mg/L and by both benzyladenine treatments compared to control plants at 4 and 7 WAT (Table 4.15). At 4 WAT the number of branches was decreased by all PGR treatments compared to control plants (Table 4.15). Sweet basil plant branching at 7 WAT was not significantly different compared to control plants for dikegulac sodium at 40 mg/L or benzyladenine at 30 mg/L; the higher rate of both PGRs decreased the

number of branches compared to control plants. Number of sweet basil plant leaders were slightly increased by dikegulac sodium at 40 mg/L compared to control plants (Table 4.15). Sweet basil plant fresh weight was decreased by the PGR treatments compared to control plants at 7 WAT (Table 4.15). Germination data were not significantly different among treatments at 6, 8, 13 DAT (Table 4.16; Table 4.17; Table 4.18).

Discussion

The effects of the red shade cloth treatments on increasing branching of sweet basil, Thai basil, and Genovese basil were consistent with results seen in *Pittosporum* where red shade cloth treated plants showed an increased in branching compared to those grown under the black shade cloth (Oren-Shamir et al., 2001). An increase in new cane growth and in new leaves was also seen by Kawabata et al. (2007) in *Dracaena* 'Colorama' grown under red shade cloth. The red shade cloth treatment increased fresh weight in sweet basil, Thai basil, and Genovese basil compared to the black and blue shade cloth treatments. *Phalaenopsis* plants had a higher leaf fresh weight under blue shade cloth compared to the black and red shade cloth treatments (Leite et al., 2008). The increase in fresh weight seen in sweet basil, Thai basil, Genovese basil grown under red shade cloth was also seen by Shahak et al. (2008) in lettuce heads which were 20% to 30% larger when grown under red or pearl shade cloths compared to the equivalent black or blue shade cloth. The higher amount of energy under the red shade cloth in the red and far-red spectrum contributed to the increase in the number of branches and fresh weight. Shahak et al. (2008) also said that the increase in the red spectrum under the red shade cloth led to the increase in growth of *Pittosporum variegatum*, *Fatsia japonica* (Thunb.) Decne. & Planch., *Monstera deliciosa* Liebm.

Benzyladenine increased the number of branches in Sweet Basil Replication 1, Sweet Basil Replication 3, and Thai Basil Replication 2. This same effect was seen in basal shoots in *Coreopsis* 'Moonbeam' where shoots increased in plants treated with 500 mg/L benzyladenine (Farris et al., 2009). Henny (1985) also saw an increase in mean number of lateral branches of *Peperomia obtusifolia* at 500 mg/L benzyladenine (9 branches compared with 4 branches for controls).

During Sweet Basil Replication 3 ethephon increased the number of branches; this has also been seen in *Coreopsis*, *Veronica*, and *Dianthus* treated with 600 or 800 mg/L ethephon (Glady et al., 2007). Banko et al. (2001) saw an increase in foliage growth which was proportional to the concentration of ethephon applied (250, 500, 750, or 1000 ppm) in *Scabiosa* 'Butterfly Blue'.

Aroma compounds have also been assessed in sweet basil 'Italian Sweet' grown over black, blue, green, red, white, or yellow mulch (Loughrin and Kasperbauer, 2001). Loughrin and Kasperbauer (2001) saw a reduction in aroma compounds in basil plant leaves grown over blue mulch. This is in contrast to our results in Genovese basil where eugenol mean peak area was higher in plants grown under blue shade cloth and in Thai basil where methylchavicol mean peak area was higher under blue shade cloth. Black mulch was shown to produce aroma compound levels higher than the blue, red, or white mulches (Loughrin and Kasperbauer, 2001). Sweet basil and Genovese basil plants had increased eugenol and 1,8-Cineole grown under black shade cloth but the blue and red shade cloth showed increases in the other compounds contrary to the results in plants grown above black mulch. The difference between black shade cloth and black mulch may be because light intensity is decreased under black shade cloth and it is not

decreased over black mulch. Light quality may also be different in the environment above the black mulch than it was under our black shade cloth.

Aroma panel results showed an increase in marketability of sweet basil grown under red shade cloth which is contrary to results seen in a grower evaluation of *Dracaena* 'Janet Craig' where the smaller leaves of the red shade cloth grown plants reduced marketability (Kawabata et al., 2007). We did not evaluate leaf area but there were no observations of reduced leaf size in the sweet basil, Genovese basil, and Thai basil plants grown under red shade cloth.

Conclusions

The red shade cloth treatment increased branching and shoot fresh weight in sweet basil, Thai basil, and Genovese basil compared to black and blue shade treatments. This shows that red shade cloth can be used in place of conventional black shade cloth to produce a product more desirable to consumers. The increase in height under the red shade cloth treatment may be problem for growers when they ship the product. The blue shade cloth did not reduce the height of the plants compared to black shade cloth treated plants which means that blue shade cloth cannot be used as a growth retardant. Sensory panel results show that sweet basil plants can be grown under red or blue shade cloth without the aroma differing from the black shade cloth grown plants. PGR treatments did not work on a consistent basis; further research may be needed to assess usefulness of benzyladenine which seemed to work better in the winter grown plants.

Volatile analysis results were consistent among the basil plants sampled. These results show that linalool mean peak area was higher in red shade cloth grown plants in sweet basil and Thai basil. Eugenol mean peak area was higher in sweet basil plants

grown under black shade cloth but this contrasted with Thai basil where the increase was under the red shade cloth and in Genovese basil which had a higher mean peak area under blue shade cloth. These results show that volatile mean peak area varies by cultivars but more research would need to be conducted to confirm these results. In the case of sweet basil, the aroma panel shows that the changes in the levels of the volatile compounds in sweet basil did not have an influence on the aroma of sweet basil.

Literature Cited

Bailey, D. and B. Whipker. 1998. Best management practices for plant growth regulators used in floriculture. North Carolina State University Cooperative Extension. Horticulture Information Leaflet 529.

Banko, T., M. Stefani, and M. Dills. 2001. Growth and flowering response of 'May Night' salvia and 'Butterfly Blue' scabiosa to growth retardants. J. Environ. Hort. 19(3):145-149.

Farris, M., G. Keever, J. Kessler, and J. Olive. 2009. Benzyladenine and cyclanilide promote shoot development and flowering of 'Moonbeam' coreopsis. J. Environ. Hort. 27(3):176-182.

Garner, L. and T. Bjorkman. 1996. Mechanical conditioning for controlling excessive elongation in tomato tranplants: sensitivity to dose, frequency, and timing of brushing. J. Amer. Soc. Hort. Sci. 121(5):894-900.

Glady, J., N. Lang, and E. Runkle. 2007. Effects of ethephon on stock plant management of *Coreopsis verticillata*, *Dianthus caryophyllus*, and *Veronica longifolia*. HortScience 42(7):1616-1621.

Henny, R. 1985. BA induces lateral branching of *Peperomia obtusifolia*. HortScience 20(1):115-116.

Kawabata, A., J. Lichty, K. Kobayashi, and W. Sahai. 2007. Effects of photoselective shade cloths on potted *Dracaena deremensis* 'Janet Craig' and *Dracaena marginata* 'Colorama'. Journal of Hawaiian and Pacific Agriculture. 14:49-54. 16 November 2011. <hilo.hawaii.edu/academics/cafnrm/research/documents/Andrewkawabata.pdf>.

Latimer, J. 2009. Selecting and using plant growth regulators on floriculture crops. Virginia Cooperative Extension. Publication 430-102.

Leite, C., R. Ito, L. Gerald, R. Ganelevin, and M. Fagnani. 2008. Light spectrum management using colored nets aiming to controlling the growth and the blooming of *Phalaenopsis sp*. Acta Hort. 770:177-184.

Loughrin, J. and M. Kasperbauer. 2001. Light reflected from colored mulches affects aroma and phenol content of sweet basil (*Ocimum basilicum* L.) leaves. J. Agric. Food Chem. 49. 1331-1335.

Nelson, P. 2003. Light and temperature. p. 401-405. In: Greenhouse operation and management. 6th ed. Prentice Hall, New Jersey.

Oren-Shamir, M., E. Gussakovsky, E. Shpiegel, A. Nissim-Levi, K. Ratner, R. Ovadia, Y. Giller, and Y. Shahak. 2001. Coloured shade nets can improve the yield and quality of

green decorative branches of *Pittosporum variegatum*. J. Hort. Sci. Biotechnol. 76:353-361.

Shahak, Y., E. Gussakovsky, E. Gal, and R. Ganelevin. 2004. Colornets: Crop protection and light-quality manipulation in one technology. Acta Hort. 659:143-151.

Shahak, Y., G. Elazar, Y. Offir, and D. Ben-Yakir. 2008. Photoselective shade netting integrated with greenhouse technologies for improved performance of vegetable and ornamental crops. Acta Hort. 797:75-80.

Simon, J., M. Morales, W. Phippen, R. Vieira, and Z. Hao. 1999. Basil: A source of aroma compounds and a popular culinary and ornamental herb. p. 499-505. In: J. Janick (ed.), Perspectives on new crops and new uses. ASHS Press, Alexandria, VA. 5 November 2011. <http://www.hort.purdue.edu/newcrop/proceedings1999/v4-499.html>.

Tucker, A. and T. DeBaggio. 2009. *Ocimum*, p. 337-346. In: The encyclopedia of herbs. Timber Press, Inc., Portland, Oregon.

USDA. 2010. 2009 Census of Horticultural Specialties. 2007 Census of Agriculture 3:3. http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Census_of_Horticulture/HORTIC.pdf. August 12, 2011.

Williamson, J. 2008. Basil. Clemson Cooperative Extension. HGIC 1327.

Figure 4.1. Blue ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia. (Photo by author, 2012)

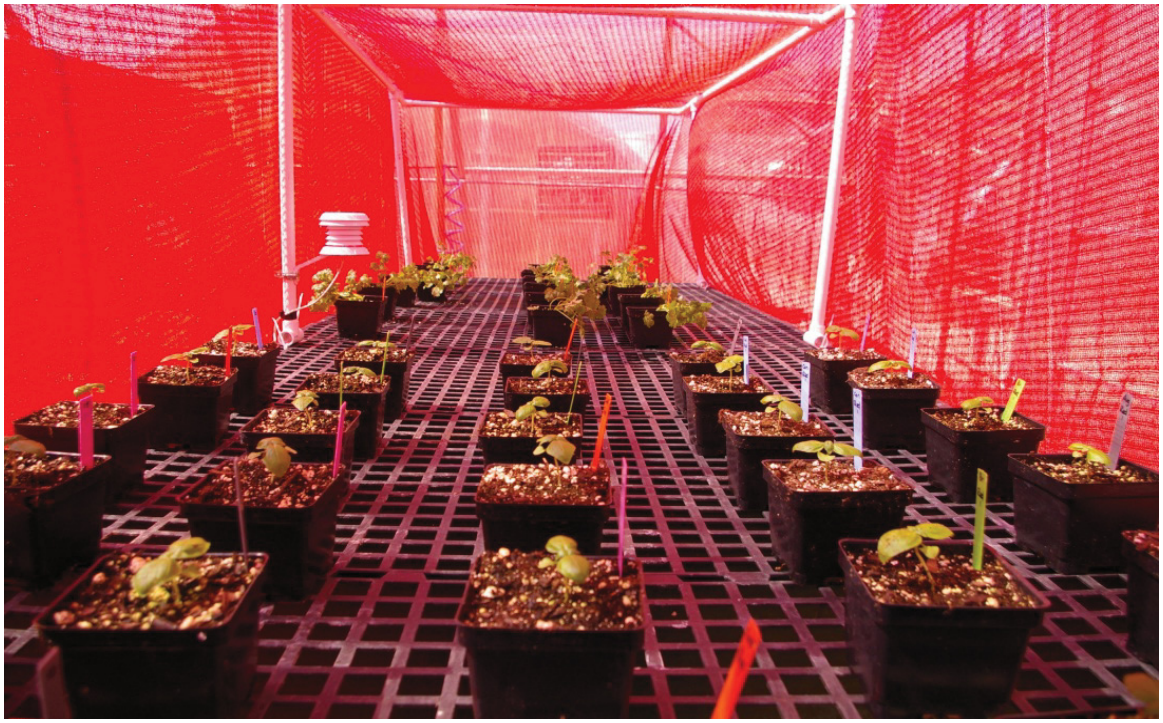

Figure 4.2. Red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia. (Photo by author, 2012)

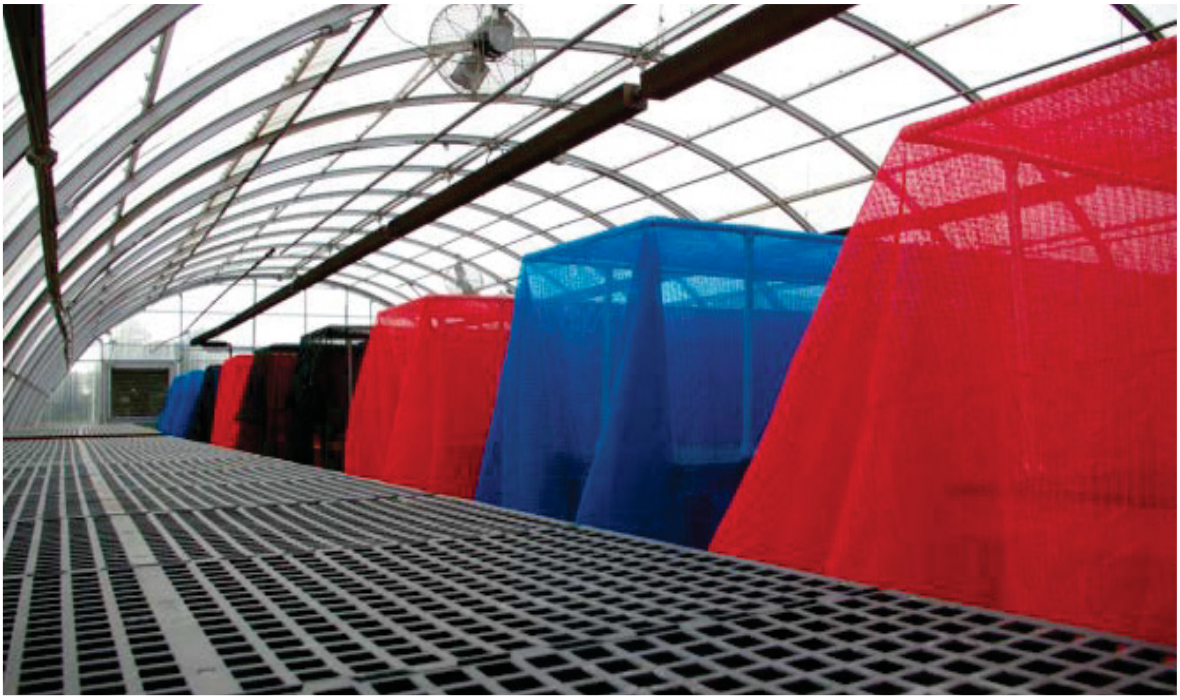

Figure 4.3. Conventional black, blue ChromatiNet, and red ChromatiNet shade cloth were randomly assigned to benches in greenhouse F-8; Virginia Tech, Blacksburg, Virginia. (Photo by author, 2012)

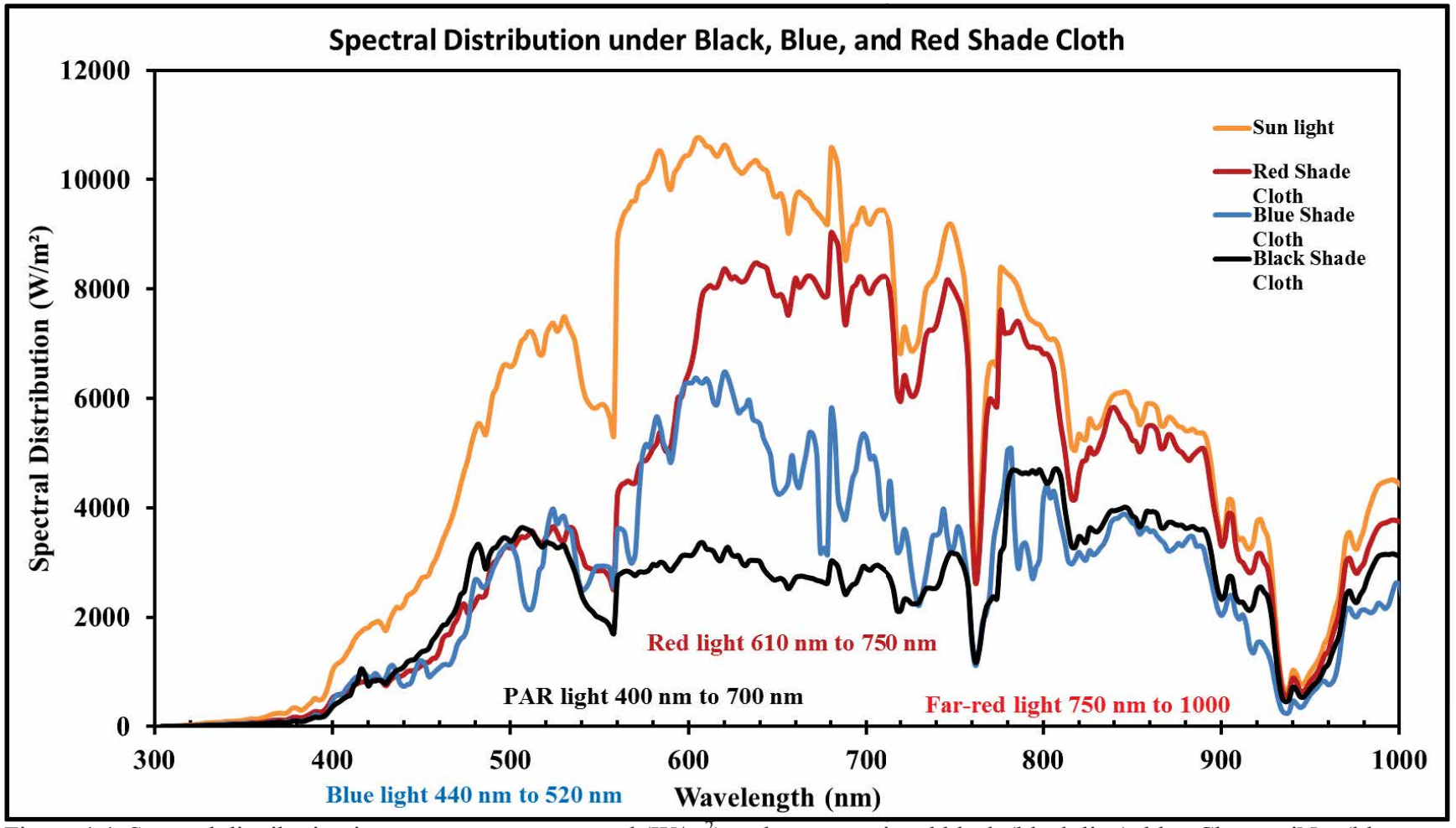

Figure 4.4. Spectral distribution in watts per meter squared (W/m^2) under conventional black (black line), blue ChromatiNet (blue line), and red ChromatiNet (red line) relative to sunlight (gold line). Graph made using a Li-Cor Spectroradiometer Courtesy of Dr. Faust, Clemson University.

Figure 4.5. Conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8 under supplemental lighting started on September 19, 2011; Virginia Tech, Blacksburg, Virginia. (Photo by author, 2012)

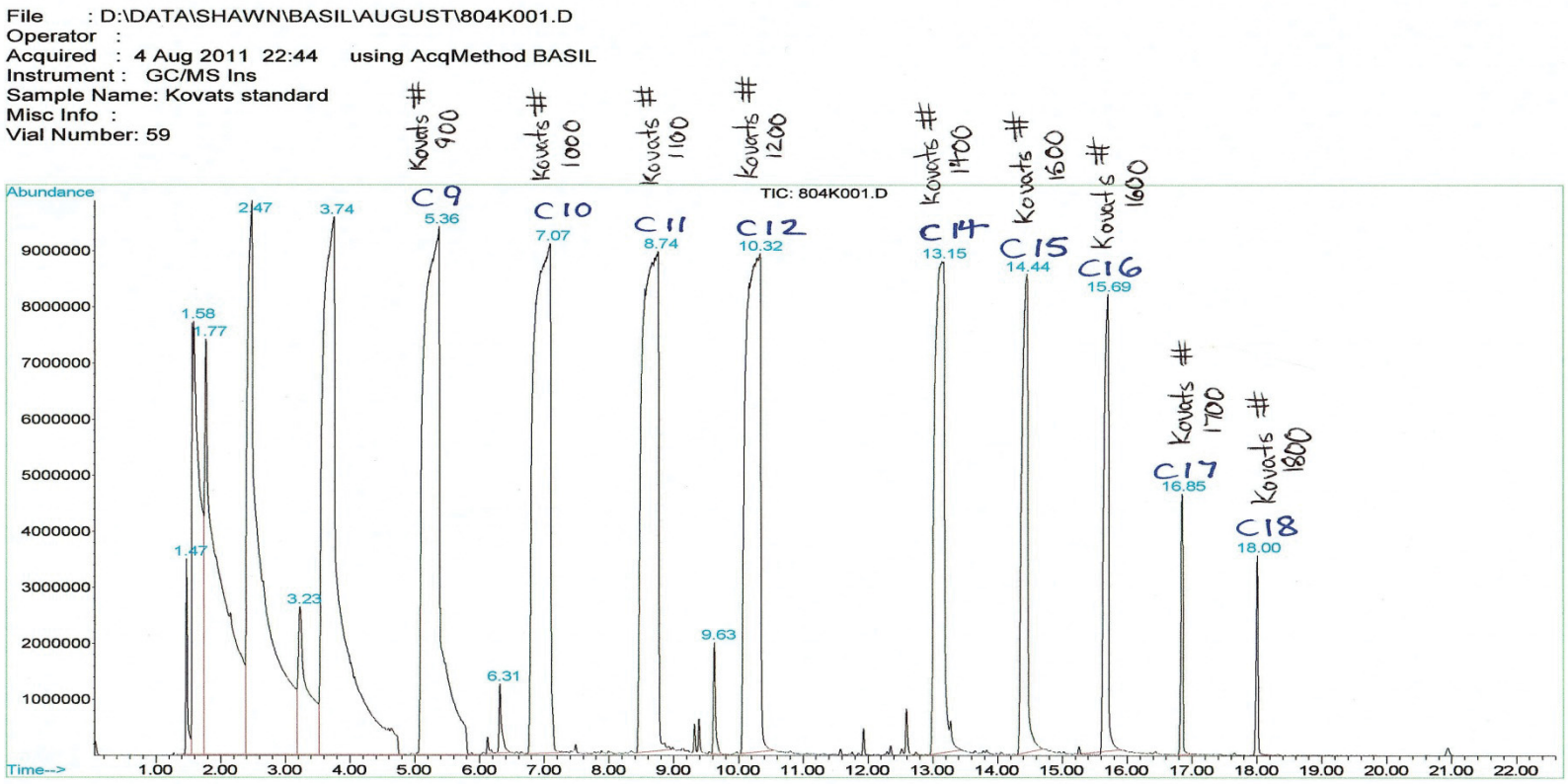

Figure 4.6. Kovats Standards used to confirm the identity of aroma compounds using the Flavornet website.

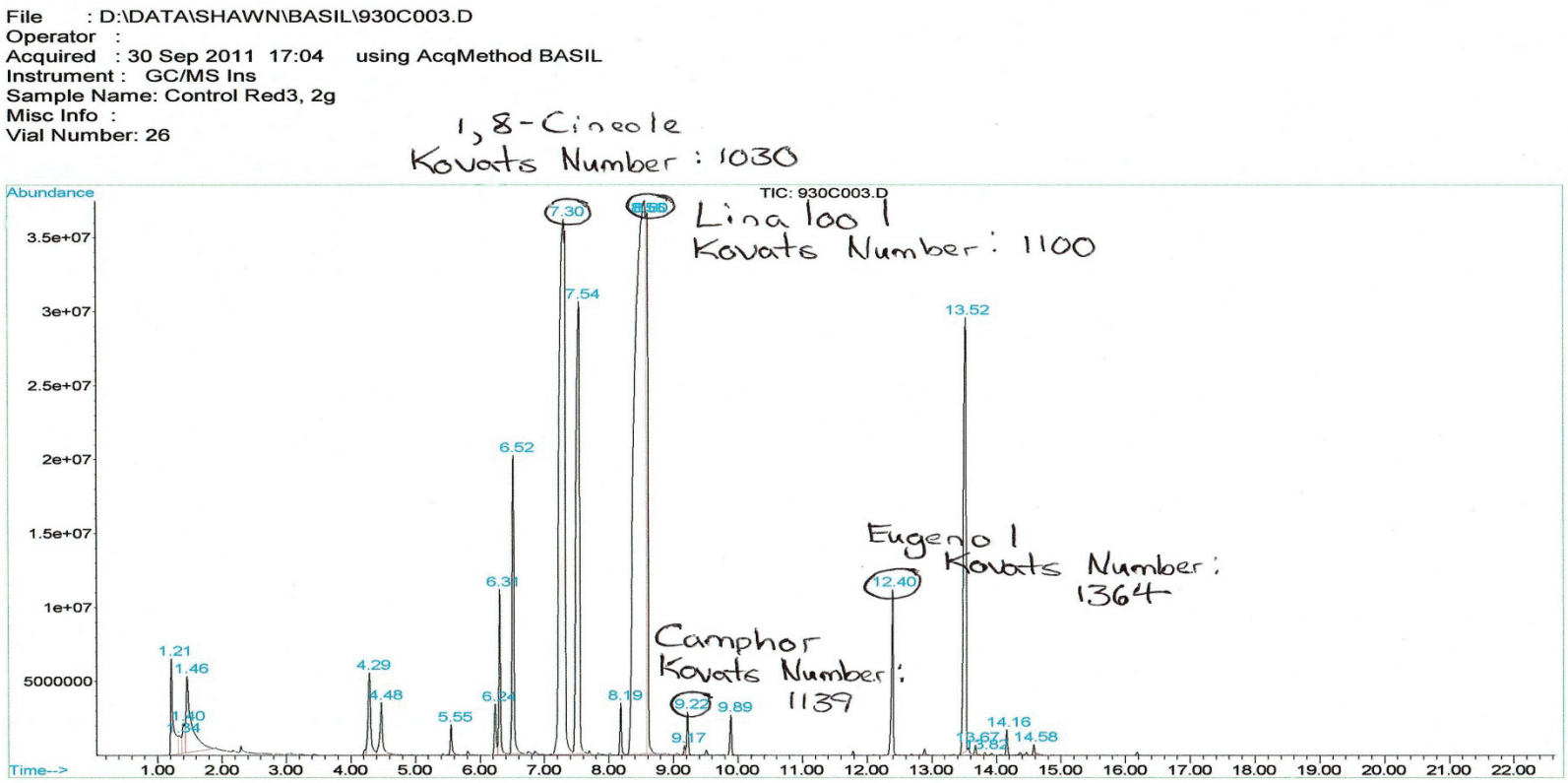

Figure 4.7. Sweet Basil Volatile Analysis Chromatgram.

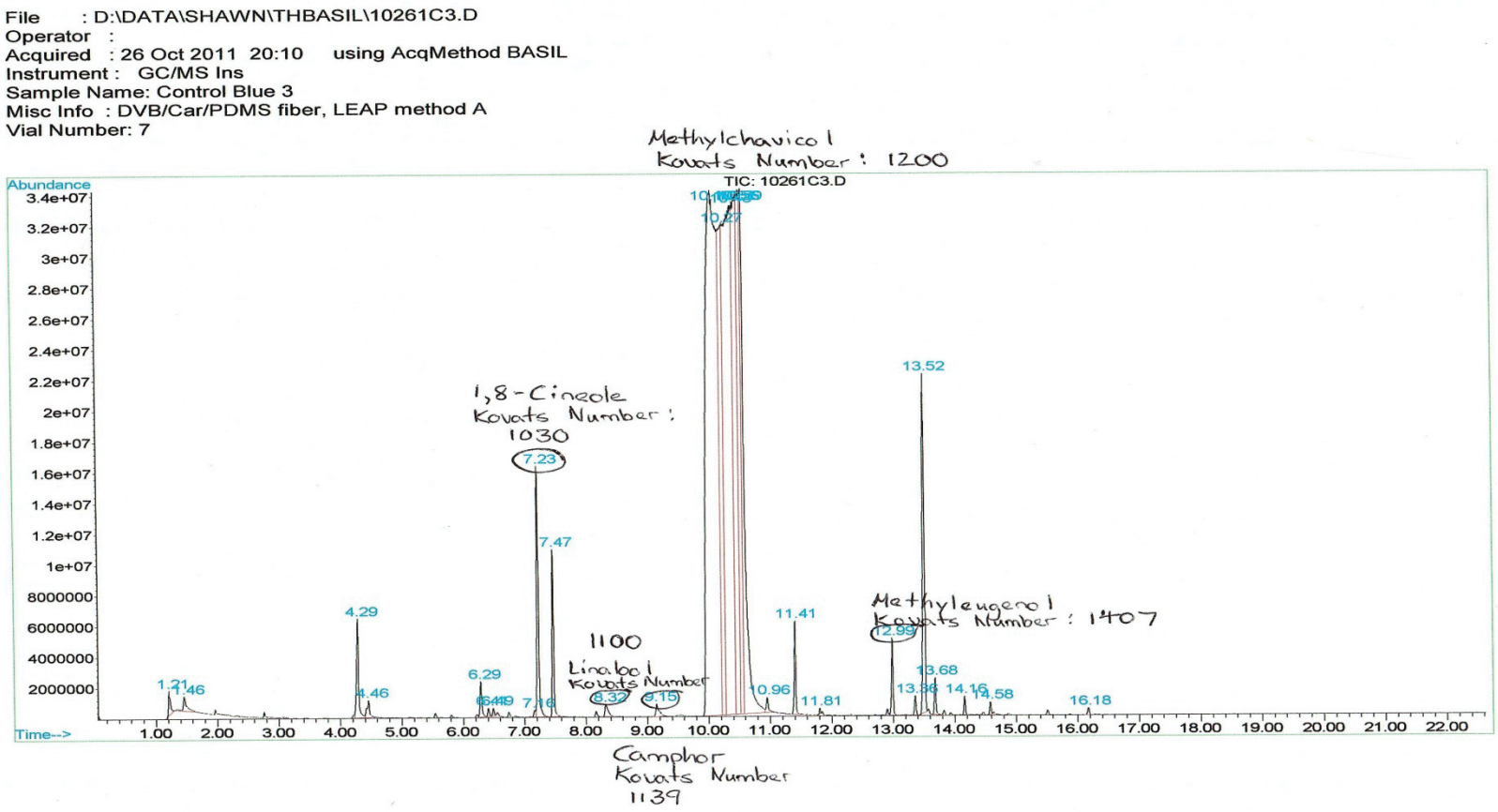

Figure 4.8. Thai Basil Volatile Analysis Chromatgram.

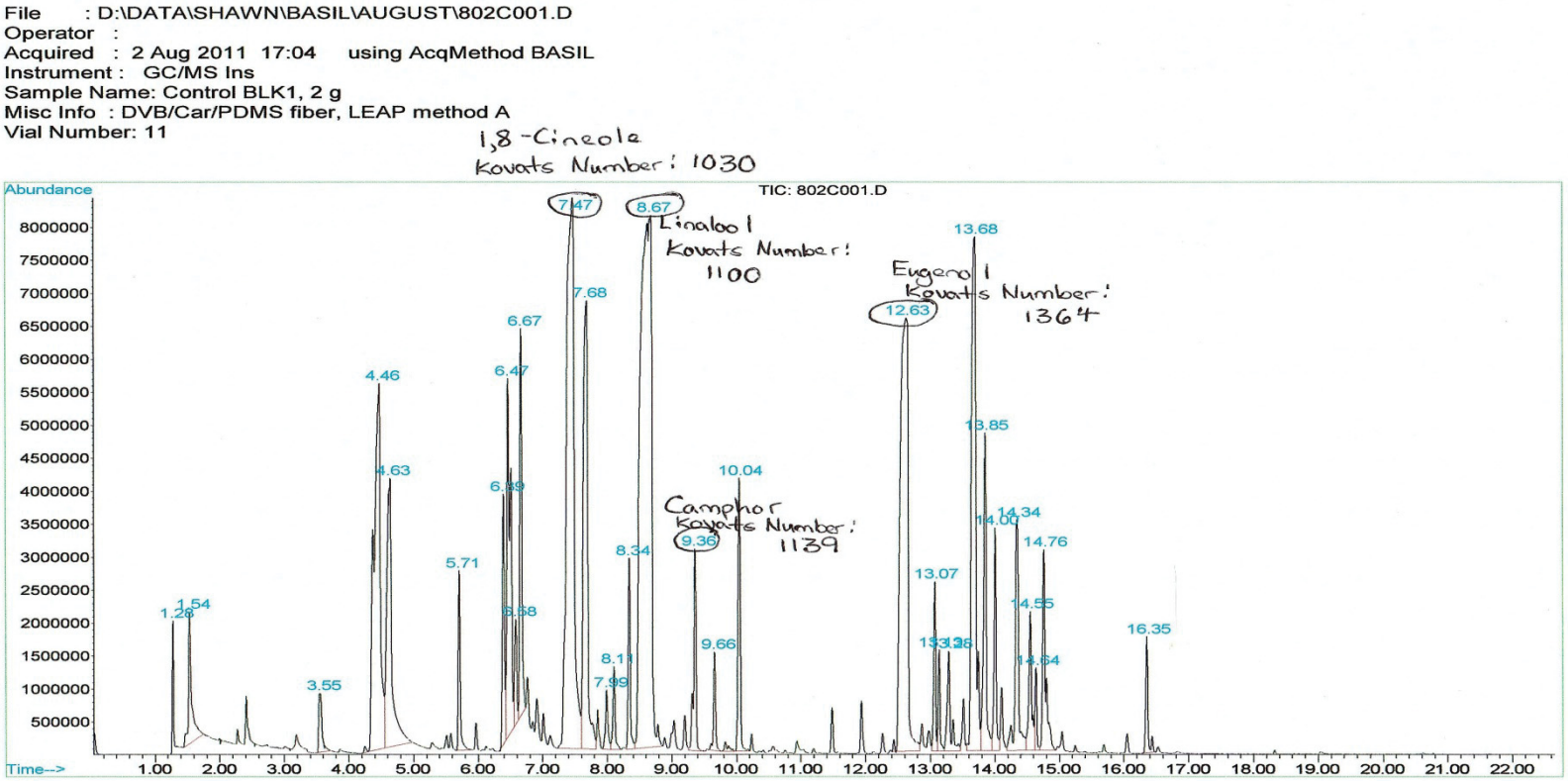

Figure 4.9. Genovese Basil Volatile Analysis Chromatgram.

Table 4.1. Environmental conditions during sweet basil, Thai basil, and Genovese basil replications.

Cultivar Replication	Date (2011)	Mean DLI (mol•m^{-2}•d^{-1})			Mean Temperature (°C)			Mean RH (%)		
		Black	Blue	Red	Black	Blue	Red	Black	Blue	Red
Sweet Basil Replication 1	5/24-6/13	16.8	16.2	16.6	25.7	26.0	26.3	62.9	63.0	62.9
Sweet Basil Replication 2	7/18- 8/2	15.0	13.6	13.1	29.0	28.6	26.0	63.5	63.0	63.1
Sweet Basil Replication 3	9/9- 9/28	8.4	7.4	7.0	23.7	23.7	23.7	64.2	64.1	64.1
Sweet Basil Aroma Panel	11/18-12/19	5.5a[Y]	4.4b	6.0a	20.4a	19.9b	20.3a	46.3	48.7	46.7
Thai Basil Replication 1	8/9-8/22	12.9a	12.9a	7.8b	26.3	26.7	26.6	58.4	58.0	58.0
Thai Basil Replication 2	10/3-10/24	9.5	9.1	9.6	22.3	22.4	22.3	50.4	51.6	50.4
Genovese Basil	8/23-9/6	10.3a	10.7a	6.8b	25.1	25.7	25.6	65.3	64.5	65.6

[X]Supporting data in Appendix 4.1.

[Y] Any two means within a row not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 4.2. *Sweet Basil Replication 1*. Effect of shade color and PGR treatment on plant height, width, and shoot fresh weight at 19 days after treatment (DAT). (n = 6)

	Height (cm)			Width (cm)	Fresh Weight (g)
Shade Cloth Color					
Black Shade	32.0b[X]			22.4c	39.6c
Blue Shade	35.0a			24.9b	43.6b
Red Shade	36.9a			26.4a	52.2a
Color effect	0.0002			< 0.0001	< 0.0001
LSD	1.16			0.59	1.55
PGR Treatment	**Black**	**Blue**	**Red**		
Control	32.2ab	41.5a	44.7a	25.3a	49.4a
Dikegulac sodium	34.9ab	35.9a	41.1ab	25.5a	47.3a
Benzyladenine	39.0a	34.4a	35.3b	25.7a	47.7a
Ethephon	31.4b	37.3a	38.3ab	24.6a	44.9a
Brushing	22.9c	25.8b	24.9c	21.8b	36.5b
PGR effect	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
LSD	3.40	3.38	2.64	0.78	2.00
Shade Color*PGR		0.0150		0.6222	0.0913

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 4.3. *Sweet Basil Replication 1*. Effect of shade color and PGR treatment on plant number of branches and number of leaders at 19 days after treatment (DAT). (n = 6)

	Number of Branches			**Number of Leaders**		
Shade Cloth Color						
Black Shade	22.3c[X]			8.8		
Blue Shade	29.2b			6.8		
Red Shade	37.1a			7.0		
Color effect	< 0.0001			0.1209		
LSD	2.13			1.00		
PGR Treatment	**Black**	**Blue**	**Red**	**Black**	**Blue**	**Red**
Control	21.8b	31.5	45.4a	8.8	6.8a	8.5a
Dikegulac sodium	27.3ab	29.3	36.0ab	11.7	6.4a	7.2ab
Benzyladenine	32.6a	30.3	35.2ab	9.4	6.1a	6.3ab
Ethephon	18.3b	27.2	43.4a	4.0	6.9a	8.2a
Brushing	20.3b	23.2	25.6b	6.7	5.3a	4.8b
PGR effect	0.0010	0.2635	0.0006	0.1234	0.4010	0.0002
LSD	3.63	3.98	4.75	2.98	0.89	0.85
Shade Color*PGR		0.0019			0.0113	

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 4.4. *Sweet Basil Replication 2*. Effect of shade color and PGR treatment on plant height, width, shoot fresh weight, number of branches, and number of leaders at 15 days after treatment (DAT). (n = 6)

	Height (cm)	**Width (cm)**	**Fresh Weight (g)**	**Number of Branches**	**Number of Leaders**
Shade Cloth Color					
Black Shade	15.7b[X]	14.1a	9.7b	9.5b	1.5b
Blue Shade	16.2b	12.3b	9.7b	9.9b	1.2b
Red Shade	19.5a	15.1a	14.9a	18.3a	3.7a
Color effect	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
LSD	0.50	0.62	0.28	0.62	0.16
PGR Treatment					
Control	17.9	13.8	12.0a	12.2	2.0
Dikegulac sodium	16.2	13.8	10.8b	12.4	2.1
Benzyladenine	17.0	13.5	11.1ab	13.1	2.1
Ethephon	17.7	14.6	11.6ab	12.8	2.2
Brushing	17.1	13.4	11.8a	12.5	2.2
PGR effect	0.0599	0.5897	0.0040	0.8318	0.8109
LSD	0.64	0.80	0.36	0.81	0.21
Shade Color*PGR	0.8896	0.3881	0.3319	0.9499	0.8164

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 4.5. *Sweet Basil Replication 3*. Effect of shade color and PGR treatment on plant height, width, shoot fresh weight, number of branches, and number of leaders at 18 days after treatment (DAT). (n = 6)

	Height (cm)	**Width (cm)**	**Fresh Weight (g)**	**Number of Branches**	**Number of Leaders**
Shade Cloth Color					
Black Shade	18.5b[X]	13.6b	15.9b	9.4b	1.1b
Blue Shade	18.1b	13.7b	15.4b	9.5b	1.1b
Red Shade	22.6a	16.1a	22.3a	10.8a	1.5a
Color effect	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0001
LSD	0.73	0.34	0.65	0.31	0.09
PGR Treatment					
Control	20.4	14.5	18.2	8.9c	1.2
Dikegulac sodium	19.2	14.3	17.7	9.6bc	1.3
Benzyladenine	19.5	14.1	17.8	10.4ab	1.3
Ethephon	18.9	14.7	16.6	11.2a	1.2
Brushing	20.6	14.8	19.2	9.4bc	1.2
PGR effect	0.3032	0.5308	0.0599	< 0.0001	0.8609
LSD	0.94	0.44	0.84	0.40	0.12
Shade Color*PGR	0.9633	0.5055	0.7800	0.8998	0.5740

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 4.6. *Sweet Basil Aroma Panel*. Effect of shade color on plant height, width, shoot fresh weight, shoot dry weight, number of branches, and number of leaders at 31 days after treatment (DAT). (n = 10)

	Height (cm)	**Width (cm)**	**Fresh Weight (g)**	**Dry Weight (mg)**	**Number of Branches**	**Number of Leaders**
Shade treatment						
Unshaded Control	19.0a[X]	15.3a	20.9a	1,900a	10.2a	2.4a
Black Shade	9.8c	11.9c	5.3c	400c	4.4c	1.0b
Blue Shade	10.4c	11.1c	6.1c	500bc	4.3c	1.0b
Red Shade	14.2b	13.6b	8.2b	600b	5.6b	1.0b
Color effect	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
LSD	1.25	0.45	0.67	0.07	0.44	0.17

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 4.7. *Thai Basil Replication 1*. Effect of shade color on plant height, width, shoot fresh weight, number of branches, and number of leaders at 13 days after treatment (DAT). (n = 6)

	Height (cm)	**Width (cm)**	**Fresh Weight (g)**	**Number of Branches**	**Number of Leaders**
Shade Cloth Color					
Black Shade	23.7	24.5ab[X]	17.1b	16.0b	2.1b
Blue Shade	24.2	23.6b	19.0ab	16.9b	1.7b
Red Shade	23.7	25.6a	20.9a	19.7a	3.8a
Color effect	0.6532	0.0025	< 0.0001	< 0.0001	< 0.0001
LSD	0.64	0.55	0.81	0.8037	0.2408
PGR Treatment					
Control	24.7	25.2	19.9	17.5	2.5
Dikegulac sodium	23.0	24.0	18.0	17.6	2.6
PGR effect	0.0013	0.0073	0.0052	0.8881	0.5113
LSD	0.52	0.45	0.66	0.6562	0.1966
Shade Color*PGR	0.9988	0.9996	0.7415	0.2251	0.3116

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 4.8. *Thai Basil Replication 2*. Effect of shade color on plant height, width, and shoot fresh weight at 21 days after treatment (DAT). (n = 6)

	Height (cm)	**Width (cm)**	**Fresh Weight (g)**		
Shade Cloth Color					
Black Shade	19.1	22.8b		17.5b	
Blue Shade	18.9	21.1c		17.7b	
Red Shade	19.1	24.7a		22.8a	
Color effect	0.8275	< 0.0001		< 0.0001	
LSD	0.42	0.41		0.44	
PGR Treatment			**Black Shade**	**Blue Shade**	**Red Shade**
Control	19.3a[X]	23.4	17.0	18.9a	25.1a
Dikegulac sodium	19.3a	23.3	17.7	17.8ab	22.8a
Benzyladenine	19.4a	22.4	18.8	18.8a	23.9a
Ethephon	17.8b	22.4	17.5	15b	19.8b
Brushing	19.4a	22.8	16.7	17.7ab	22.7a
PGR effect	0.0092	0.1778	0.2292	0.0018	< 0.0001
LSD	0.54	0.53	0.93	1.03	1.01
Shade Color*PGR	0.8993	0.6727		0.0108	

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 4.9. *Thai Basil Replication 2*. Effect of shade color on plant number of branches and number of leaders at 21 days after treatment (DAT). (n = 6)

	Number of Branches	**Number of Leaders**
Shade Cloth Color		
Black Shade	14.1b[X]	2.0b
Blue Shade	15.0b	2.1b
Red Shade	17.8a	3.1a
Color effect	< 0.0001	< 0.0001
LSD	0.39	0.16
PGR Treatment		
Control	15.8b	2.5abc
Dikegulac sodium	15.5b	2.5ab
Benzyladenine	18.1a	3.0a
Ethephon	14.0c	1.9c
Brushing	14.8bc	2.1bc
PGR effect	< 0.0001	< 0.0001
LSD	0.50	0.20
Shade Color*PGR	0.1120	0.0974

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 4.10. *Genovese Basil*. Effect of shade color on plant number of branches and number of leaders at 14 days after treatment (DAT). (n = 6)

	Height (cm)	**Width (cm)**	**Fresh Weight (g)**	**Number of Branches**	**Number of Leaders**
Shade Cloth Color					
Black Shade	22.2b[X]	16.1b	17.7b	11.8b	2.0ab
Blue Shade	25.0a	16.7b	18.4b	11.5b	1.5b
Red Shade	26.4a	17.9a	24.4a	14.0a	2.3a
Color effect	0.0001	< 0.0001	< 0.0001	0.0004	0.0177
LSD	1.08	0.39	0.89	0.7300	0.27
PGR Treatment					
Control	27.1a	17.0ab	22.3a	12.5	2.1a
Dikegulac sodium	26.7a	17.6a	22.3a	12.8	2.0a
Benzyladenine	24.4a	16.7ab	20.3a	13.0	2.4a
Ethephon	20.1b	16.3b	15.8b	11.5	1.3b
PGR effect	< 0.0001	0.0271	< 0.0001	0.2364	0.0018
LSD	1.21	0.42	0.99	0.81	0.30
Shade Color*PGR	0.4423	0.1120	0.3794	0.5994	0.4586

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 4.11. *Sweet Basil Replication 2*. Mean peak area of main volatile compounds. (n = 3)

	1,8-Cineole	**Linalool**	**Camphor**	**Eugenol**
Shade Cloth Color				
Black Shade	6.94×10^8	8.14×10^8ab[X]	9.10×10^7	3.59×10^8a
Blue Shade	6.70×10^8	7.34×10^8b	7.81×10^7	1.68×10^8b
Red Shade	6.68×10^8	9.29×10^8a	1.58×10^8	2.24×10^8b
Color effect	0.8228	0.0063	0.4328	0.0008
LSD	4.72×10^7	5.64×10^7	6.51×10^7	4.61×10^7
PGR Treatment				
Control	6.35×10^8	8.08×10^8ab	8.43×10^7	2.46×10^8
Dikegulac sodium	6.67×10^8	6.63×10^8b	7.18×10^7	2.28×10^8
Benzyladenine	6.66×10^8	7.27×10^8b	2.24×10^8	3.38×10^8
Ethephon	6.98×10^8	9.73×10^8a	7.79×10^7	2.25×10^8
Brushing	7.20×10^8	9.58×10^8a	8.67×10^7	2.15×10^8
PGR effect	0.6773	0.0004	0.3385	0.2479
LSD	6.09×10^7	7.28×10^7	8.40×10^7	5.95×10^7
Shade Color*PGR	0.9486	0.2957	0.4848	0.9354

[X] Any two means within a column not followed by the same letter are significantly different at $P \leq 0.05$ using the Tukey-Kramer HSD

Table 4.12. *Sweet Basil Replication 3*. Mean peak area of main volatile compounds. (n = 3)

	1,8-Cineole	**Linalool**	**Camphor**	**Eugenol**
Shade Cloth Color				
Black Shade	1.86×10^9b[X]	3.02×10^9b	8.06×10^7	8.06×10^8a
Blue Shade	2.17×10^9a	3.28×10^9b	5.95×10^7	2.97×10^8b
Red Shade	2.13×10^9a	4.15×10^9a	5.54×10^7	1.91×10^8b
Color effect	0.0011	0.0002	0.4638	0.0018
LSD	7.98×10^7	2.44×10^8	2.15×10^7	1.66×10^8
PGR Treatment				
Control	2.16×10^9	3.61×10^9	4.60×10^7	4.30×10^8
Dikegulac sodium	2.05×10^9	3.07×10^9	9.09×10^7	7.37×10^8
Benzyladenine	2.15×10^9	3.49×10^9	8.56×10^7	3.31×10^8
Ethephon	1.91×10^9	3.43×10^9	4.21×10^7	3.04×10^8
Brushing	1.99×10^9	3.82×10^9	6.12×10^7	3.55×10^8
PGR effect	0.1141	0.2235	0.2952	0.2701
LSD	1.03×10^8	3.15×10^8	2.78×10^7	2.15×10^8
Shade Color*PGR	0.1068	0.6095	0.8940	0.9959

[X] Any two means within a column not followed by the same letter are significantly different at $P \leq 0.05$ using the Tukey-Kramer HSD

Table 4.13. *Thai Basil Replication 2*. Mean peak area of main volatile compounds. (n = 3)

	1,8-Cineole	**Linalool**	**Camphor**	**Methylchavicol**	**Methyleugenol**
Shade Cloth Color					
Black Shade	2.37×10^8	3.02×10^7b[X]	3.33×10^7	3.83×10^9b	8.90×10^7
Blue Shade	2.94×10^8	4.22×10^7b	4.02×10^7	4.46×10^9a	1.19×10^8
Red Shade	2.81×10^8	7.82×10^7a	5.40×10^7	4.62×10^9a	1.12×10^8
Color effect	0.5319	0.0015	0.1919	0.0015	0.4097
LSD	5.25×10^7	1.24×10^7	1.13×10^7	2.04×10^8	2.33×10^7
PGR Treatment					
Control	3.08×10^8	3.28×10^7	3.31×10^7	4.05×10^9	1.06×10^8
Dikegulac sodium	3.05×10^8	7.04×10^7	4.85×10^7	4.41×10^9	1.13×10^8
Benzyladenine	2.83×10^8	5.41×10^7	5.25×10^7	4.36×10^9	1.26×10^8
Ethephon	2.25×10^8	4.27×10^7	3.77×10^7	4.10×10^9	7.51×10^7
Brushing	2.35×10^8	5.09×10^7	4.05×10^7	4.60×10^9	1.15×10^8
PGR effect	0.6282	0.2074	0.6605	0.2122	0.5569
LSD	6.62×10^7	1.57×10^7	1.43×10^7	2.57×10^8	2.93×10^7
Shade Color*PGR	0.6183	0.883	0.5933	0.1753	0.8565

[X] Any two means within a column not followed by the same letter are significantly different at $P \leq 0.05$ using the Tukey-Kramer HSD

Table 4.14. *Genovese Basil*. Mean peak area of main volatile compounds. (n = 3)

	1,8-Cineole	**Linalool**	**Camphor**	**Eugenol**
Shade Cloth Color				
Black Shade	9.45×10^{8}a	1.43×10^{9}	3.52×10^{7}ab	1.57×10^{8}b
Blue Shade	9.38×10^{8}a	1.39×10^{9}	4.43×10^{7}a	4.05×10^{8}a
Red Shade	8.41×10^{8}b	1.54×10^{9}	2.13×10^{7}b	1.31×10^{8}b
Color effect	0.0061	0.4925	0.0454	0.0096
LSD	3.17×10^{7}	1.30×10^{8}	8.72E+06	1.04×10^{8}
PGR Treatment				
Control	9.25×10^{8}	1.45×10^{9}	3.54×10^{7}	3.12×10^{8}
Dikegulac sodium	8.70×10^{8}	1.62×10^{9}	3.71×10^{7}	2.38×10^{8}
Benzyladenine	8.97×10^{8}	1.44×10^{9}	3.91×10^{7}	1.93×10^{8}
Ethephon	9.40×10^{8}	1.32×10^{9}	2.27×10^{7}	1.81×10^{8}
PGR effect	0.2795	0.2829	0.3735	0.5876
LSD	3.77×10^{7}	1.50×10^{8}	1.01×10^{7}	8.99×10^{7}
Shade Color*PGR	0.4070	0.8287	0.8371	0.3723

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 4.15. *Sweet Basil Drench Study*. Effect on plant height, width, number of branches, number of leaders, and shoot fresh weight at 4 and 7 weeks after treatment (WAT). (n = 8)

	Height (cm)		Width (cm)		Number of Branches		Number of Leaders		Fresh Weight (g)
PGR treatment	**4 WAT**	**7 WAT**	**4 WAT**	**7 WAT**	**4 WAT**	**7 WAT**	**4 WAT**	**7 WAT**	**7 WAT**
Untreated Control	3.6a[X]	18.1a	6.9a	16a	3.1a	9.8a	1.0	1.1b	36.58a
Dikegulac sodium 40 mg/L	2.9ab	17.4a	6.4ab	15.5a	2.1b	9.9a	1.0	1.5a	30.49b
Dikegulac sodium 80 mg/L	1.0c	2.2c	1.8c	5.2c	0.5cd	3.4c	1.0	1.0b	2.71d
Benzyladenine 30 mg/L	2.1b	15.3a	5.3b	15.4a	1.1c	9.4a	1.0	1.3ab	29.95b
Benzyladenine 60 mg/L	1.0c	7.6b	2.8c	11.5b	0.0d	6.1b	1.0	1.0b	13.41c
PGR effect	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	n/a	0.0407	< 0.0001
LSD	0.29	1.31	0.42	0.95	0.34	0.71	n/a	0.18	1.94

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 4.16. *Sweet Basil Drench Study*. Effect on seed germination at 6 days after treatment (DAT). (n = 8)

PGR Treatment	Mean Number of Germinated Seeds (out of 8 total)	Percent Germination
Untreated Control	6.4	0.80
Dikegulac sodium 40 mg/L	5.7	0.71
Dikegulac sodium 80 mg/L	5.6	0.70
Benzyladenine 30 mg/L	5.0	0.62
Benzyladenine 60 mg/L	5.5	0.69
PGR effect	0.4098	
LSD	1.99	

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 4.17. *Sweet Basil Drench Study*. Effect on seed germination at 8 days after treatment (DAT). (n = 8)

PGR Treatment	Mean Number of Germinated Seeds (out of 8 total)	Percent Germination
Untreated Control	6.6	0.83
Dikegulac sodium 40 mg/L	5.7	0.72
Dikegulac sodium 80 mg/L	5.7	0.72
Benzyladenine 30 mg/L	5.7	0.72
Benzyladenine 60 mg/L	5.7	0.72
PGR effect	0.6163	
LSD	1.94	

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 4.18. *Sweet Basil Drench Study*. Effect on seed germination at 13 days after treatment (DAT). (n = 8)

PGR Treatment	Mean Number of Germinated Seeds (out of 8 total)	Percent Germination
Untreated Control	6.7	0.84
Dikegulac sodium 40 mg/L	5.7	0.72
Dikegulac sodium 80 mg/L	5.9	0.73
Benzyladenine 30 mg/L	5.6	0.70
Benzyladenine 60 mg/L	5.7	0.72
PGR effect	0.4123	
LSD	1.84	

[x] Any two means within a column not followed by the same letter are significantly different at $P \leq 0.05$ using the Tukey-Kramer HSD

Appendix 4.1. DLI, Temperature, and Relative Humidity Graphs for Basil Replications

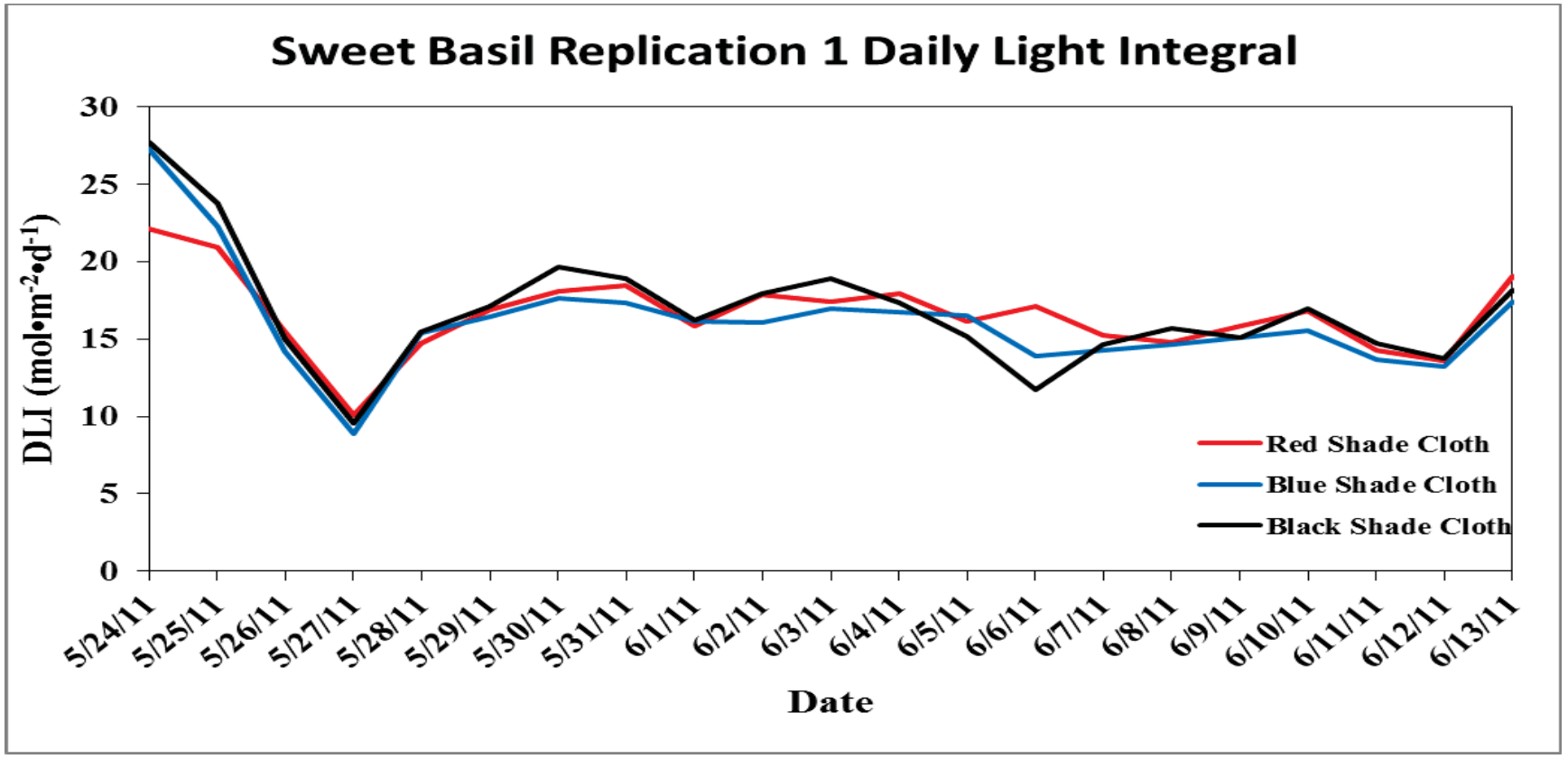

Figure 4.1a. *Sweet Basil Replication 1*. Daily light integral (DLI mol•m^{-2}•d^{-1}) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia. Unshaded data logger was not saving data correctly during experiment.

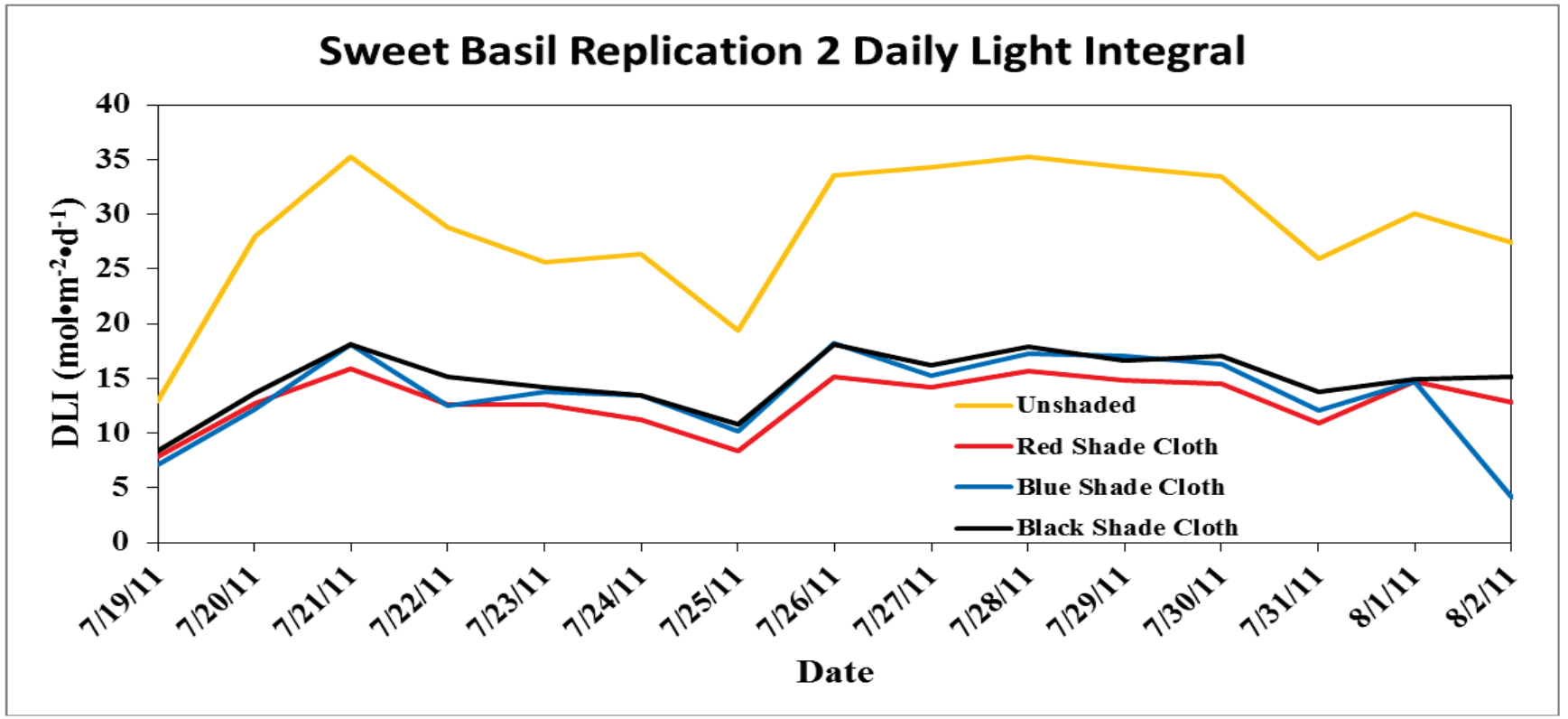

Figure 4.2a. *Sweet Basil Replication 2*. Daily light integral (DLI mol•m^{-2}•d^{-1}) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

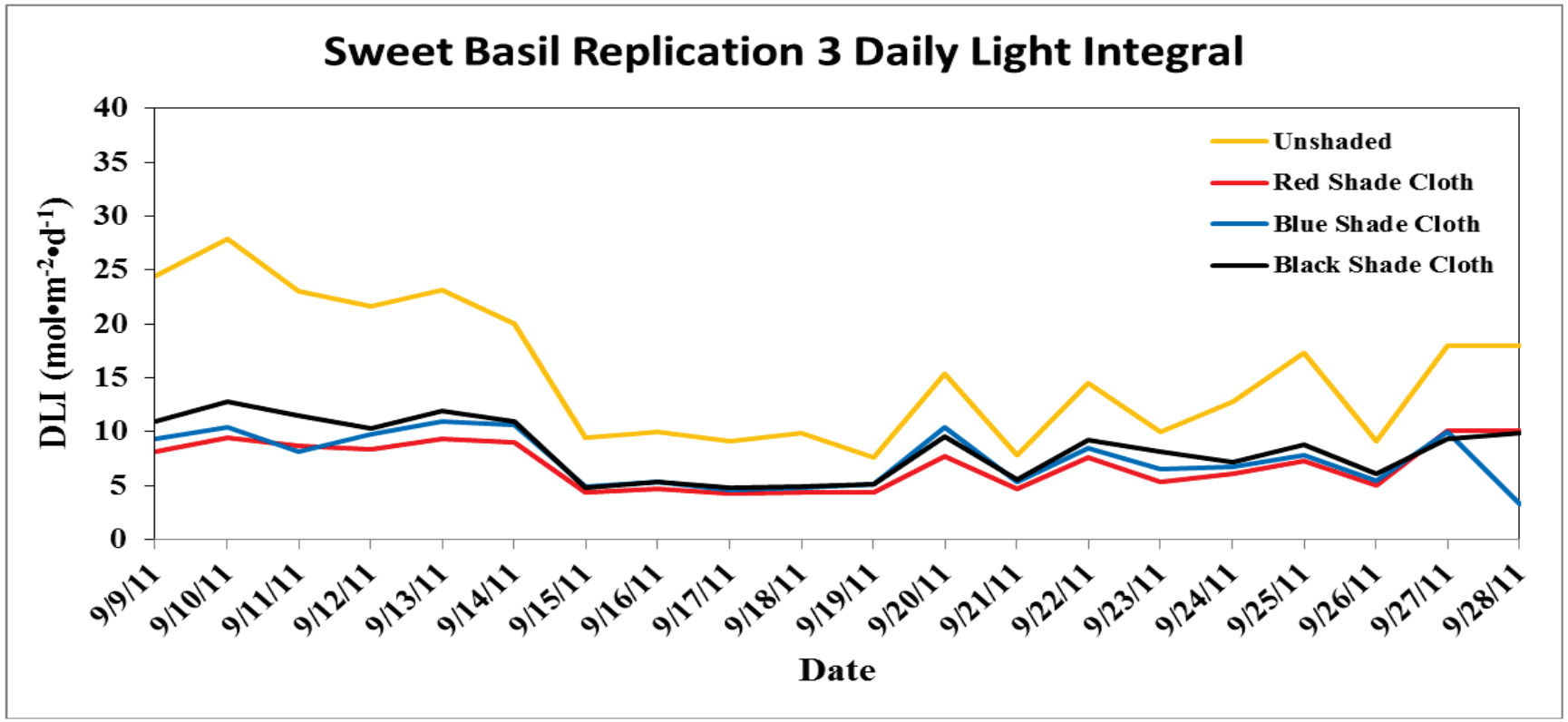

Figure 4.3a. *Sweet Basil Replication 3*. Daily light integral (DLI mol•m^{-2}•d^{-1}) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

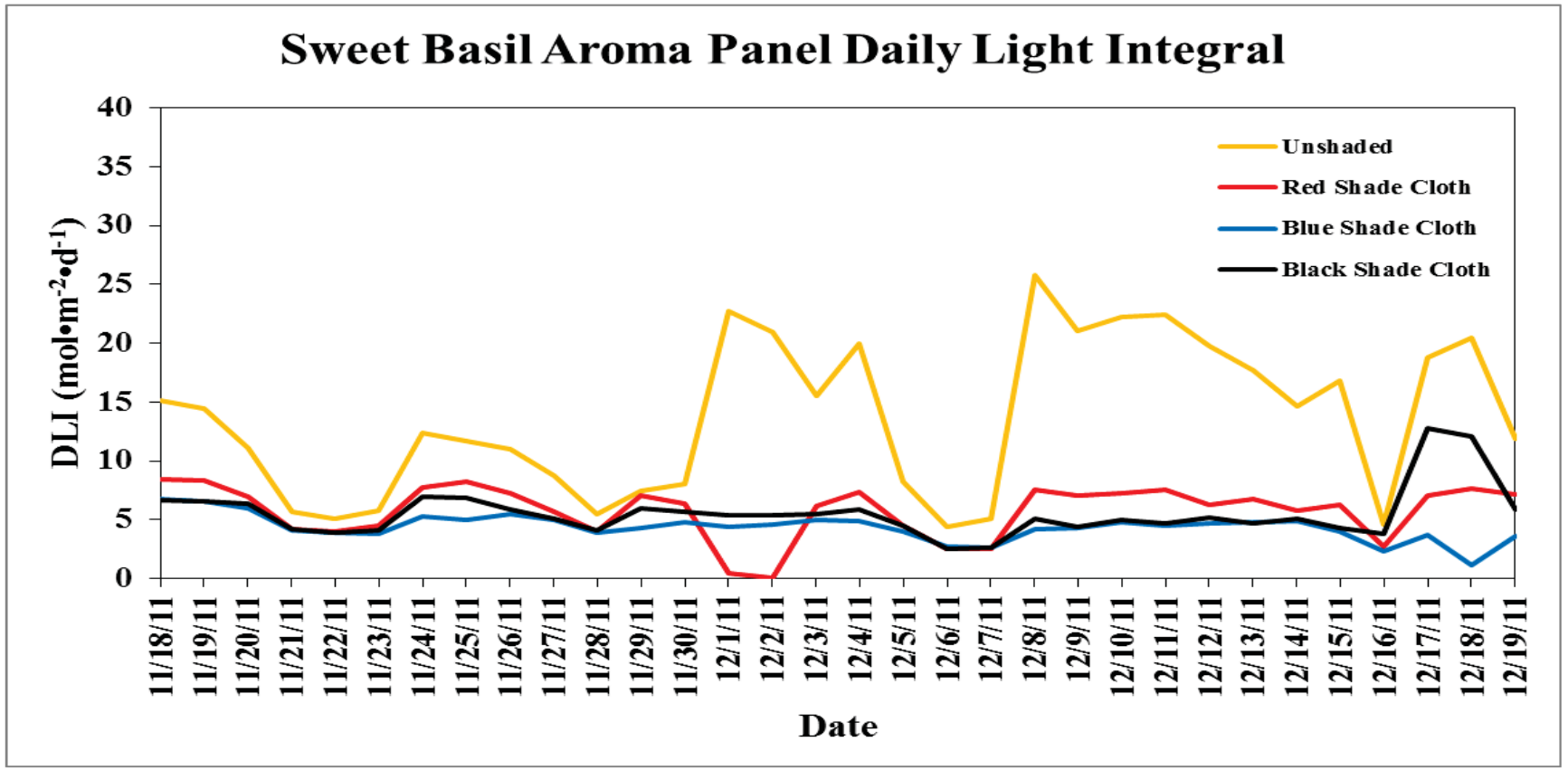

Figure 4.4a. *Sweet Basil Aroma Panel*. Daily light integral (DLI mol•m^{-2}•d^{-1}) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

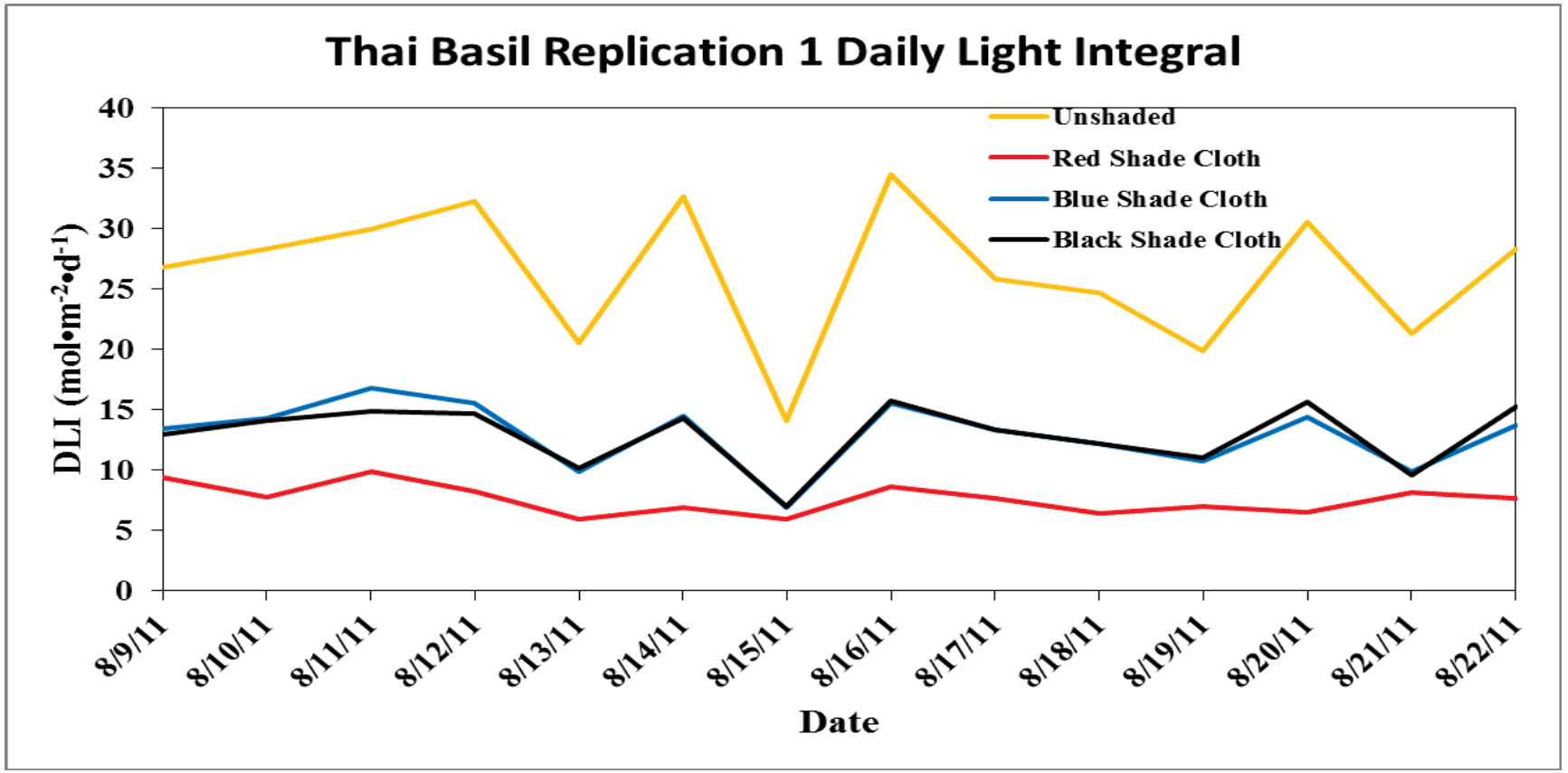

Figure 4.5a. *Thai Basil Replication 1*. Daily light integral (DLI mol•m^{-2}•d^{-1}) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

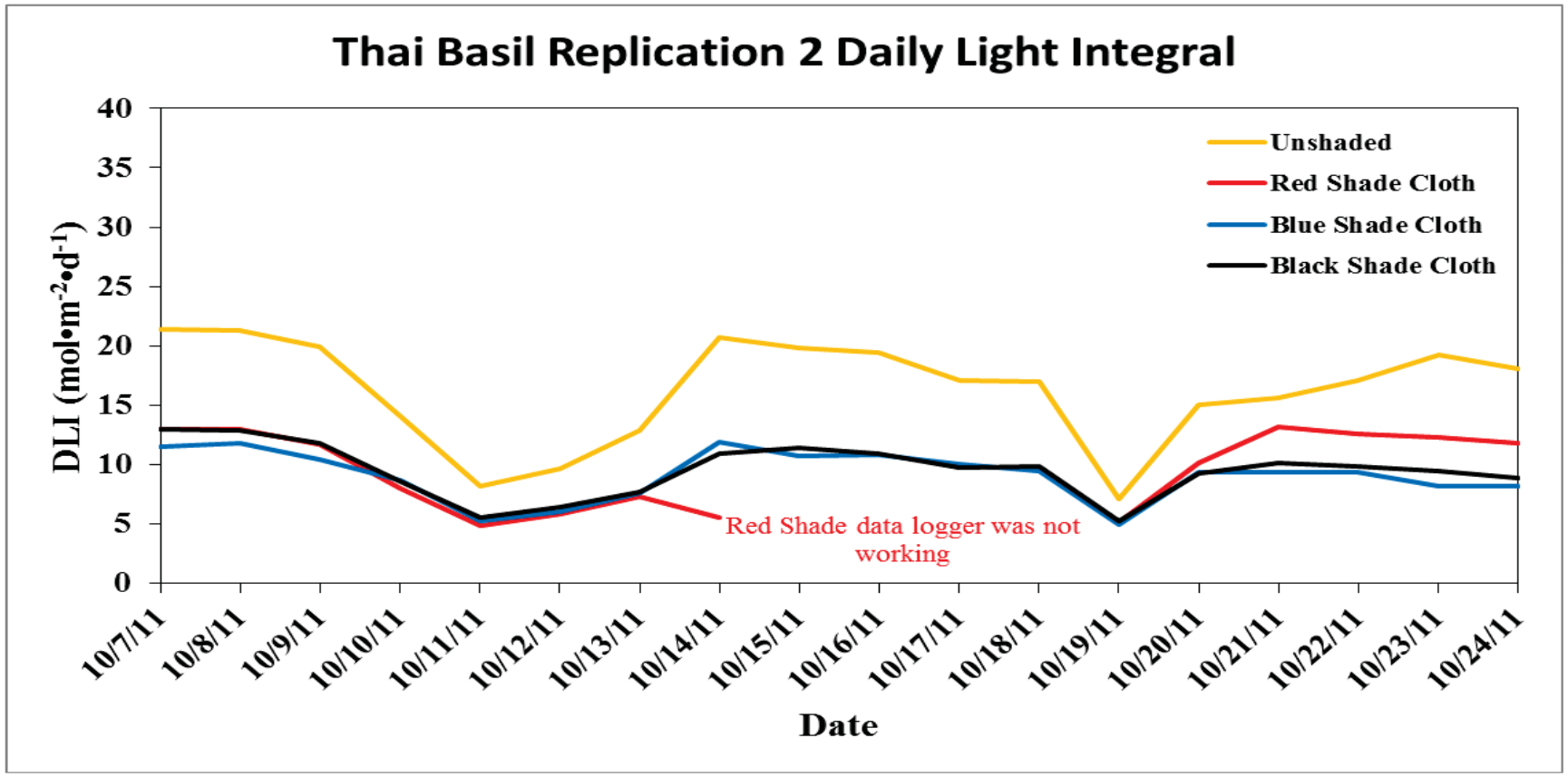

Figure 4.6a. *Thai Basil Replication 2*. Daily light integral (DLI mol•m^{-2}•d^{-1}) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

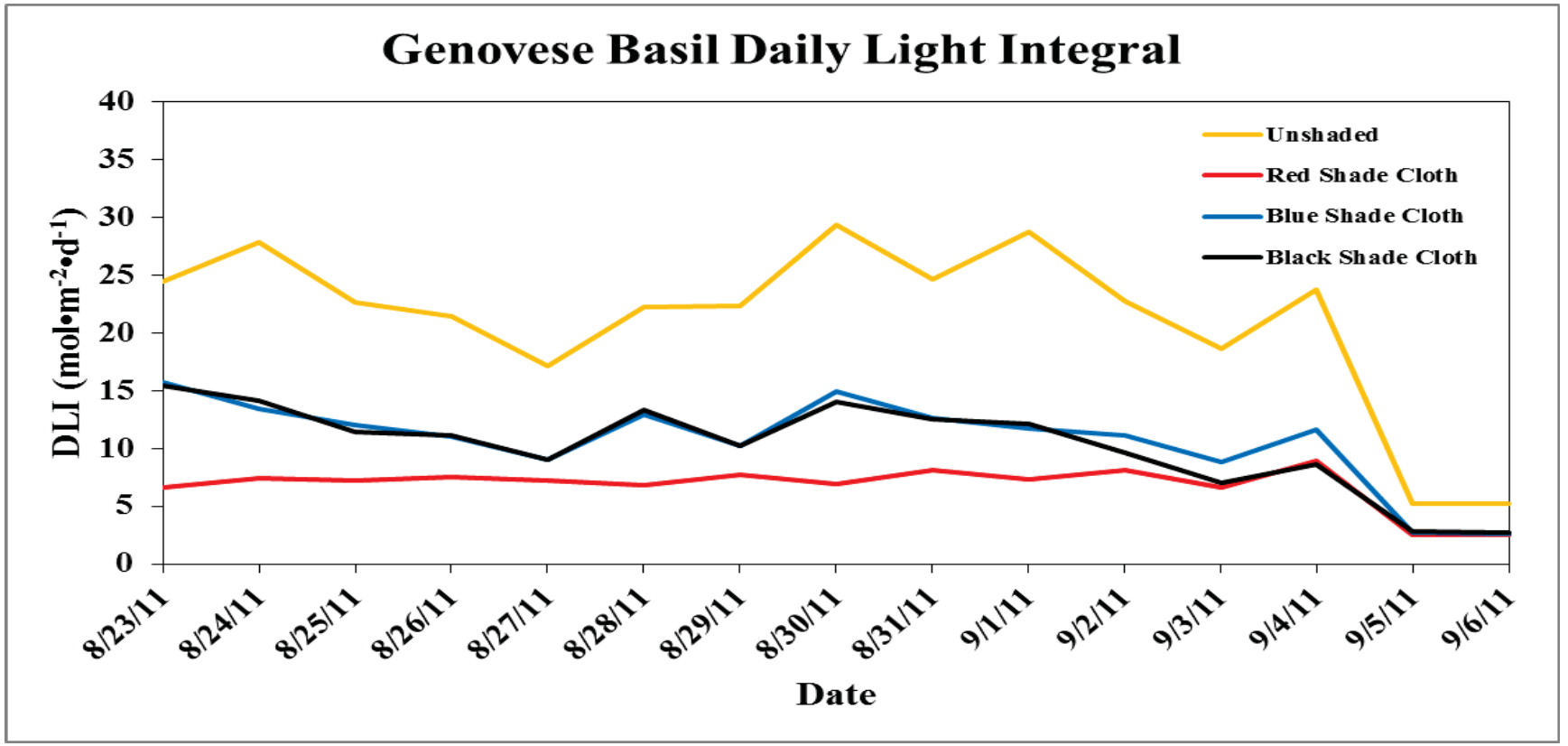

Figure 4.7a. *Genovese Basil*. Daily light integral (DLI mol•m^{-2}•d^{-1}) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

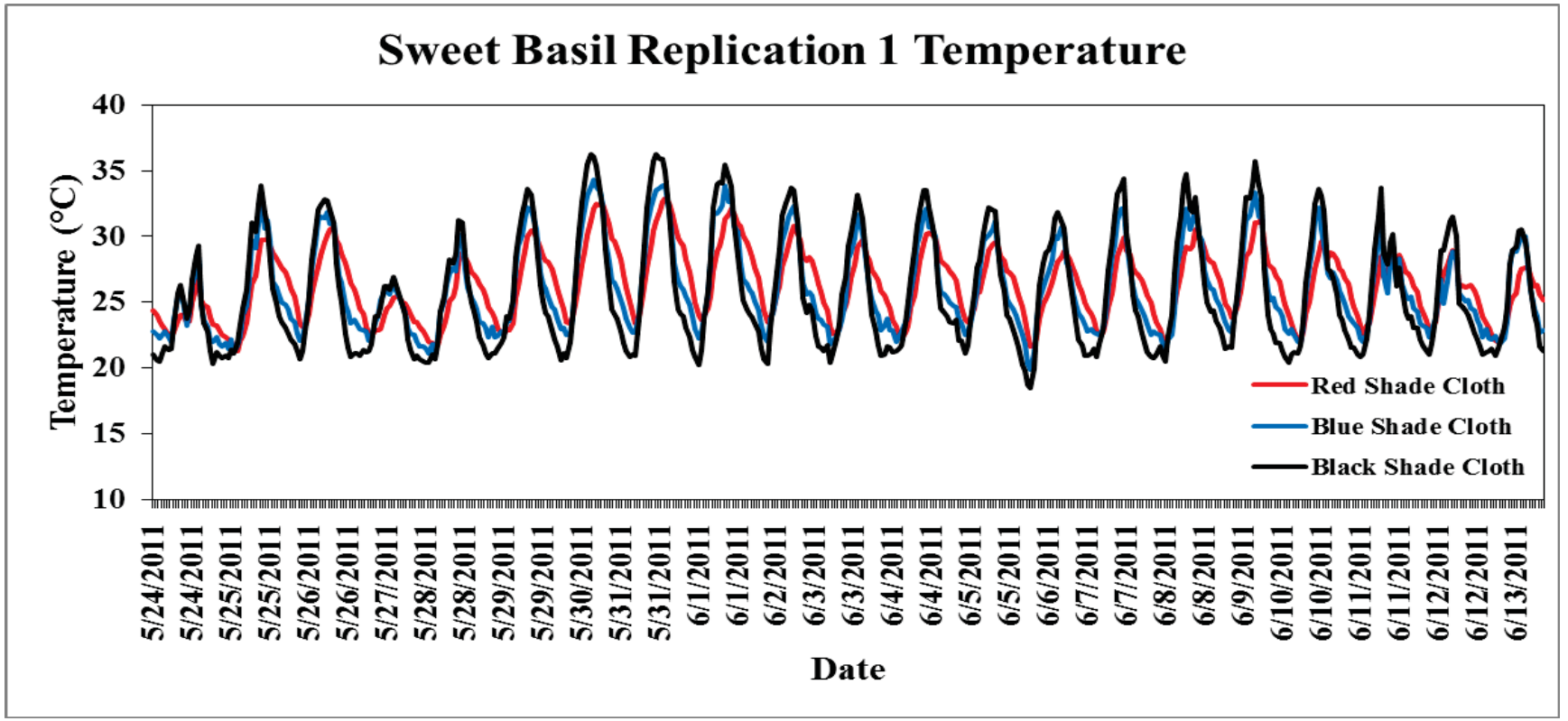

Figure 4.8a. *Sweet Basil Replication 1*. Temperature (°C) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

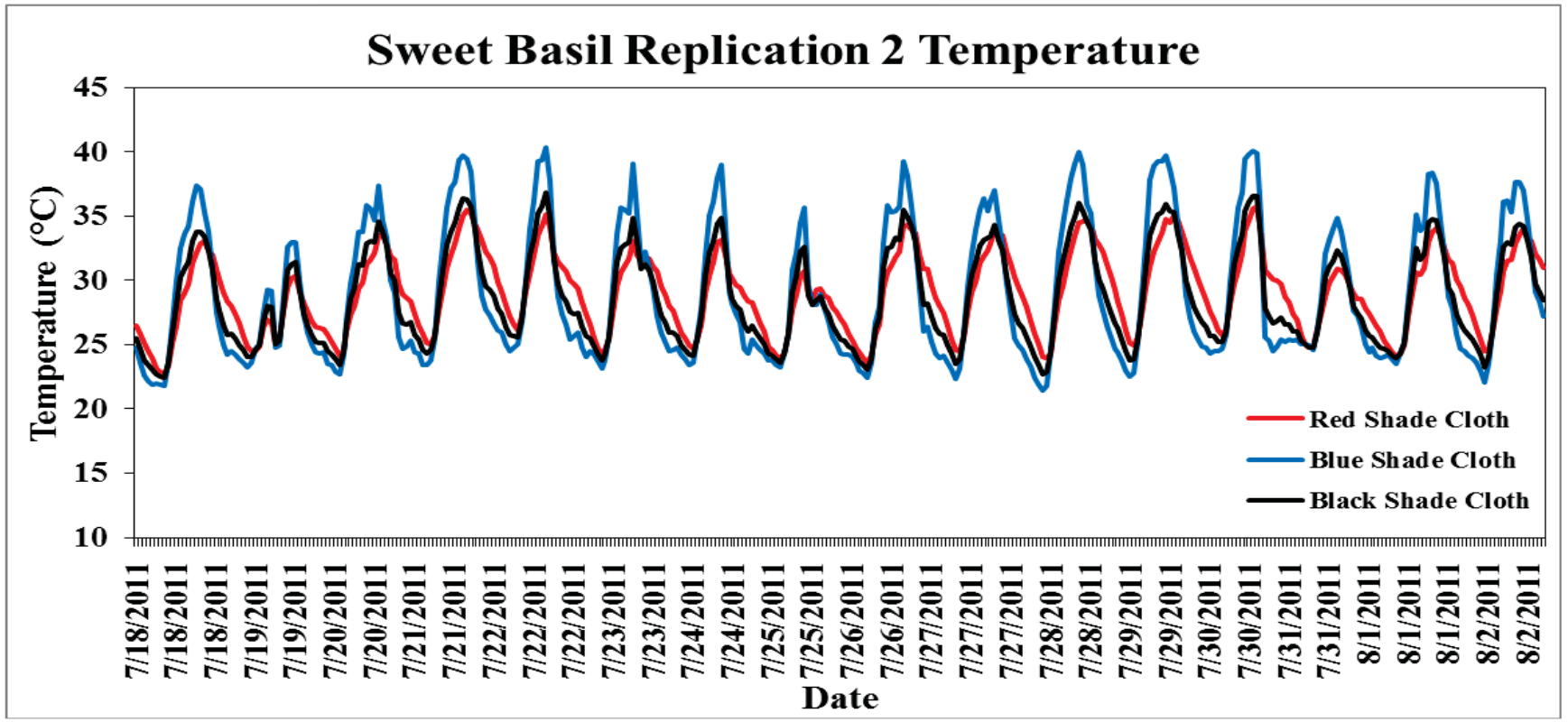

Figure 4.9a. *Sweet Basil Replication 2*. Temperature (°C) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

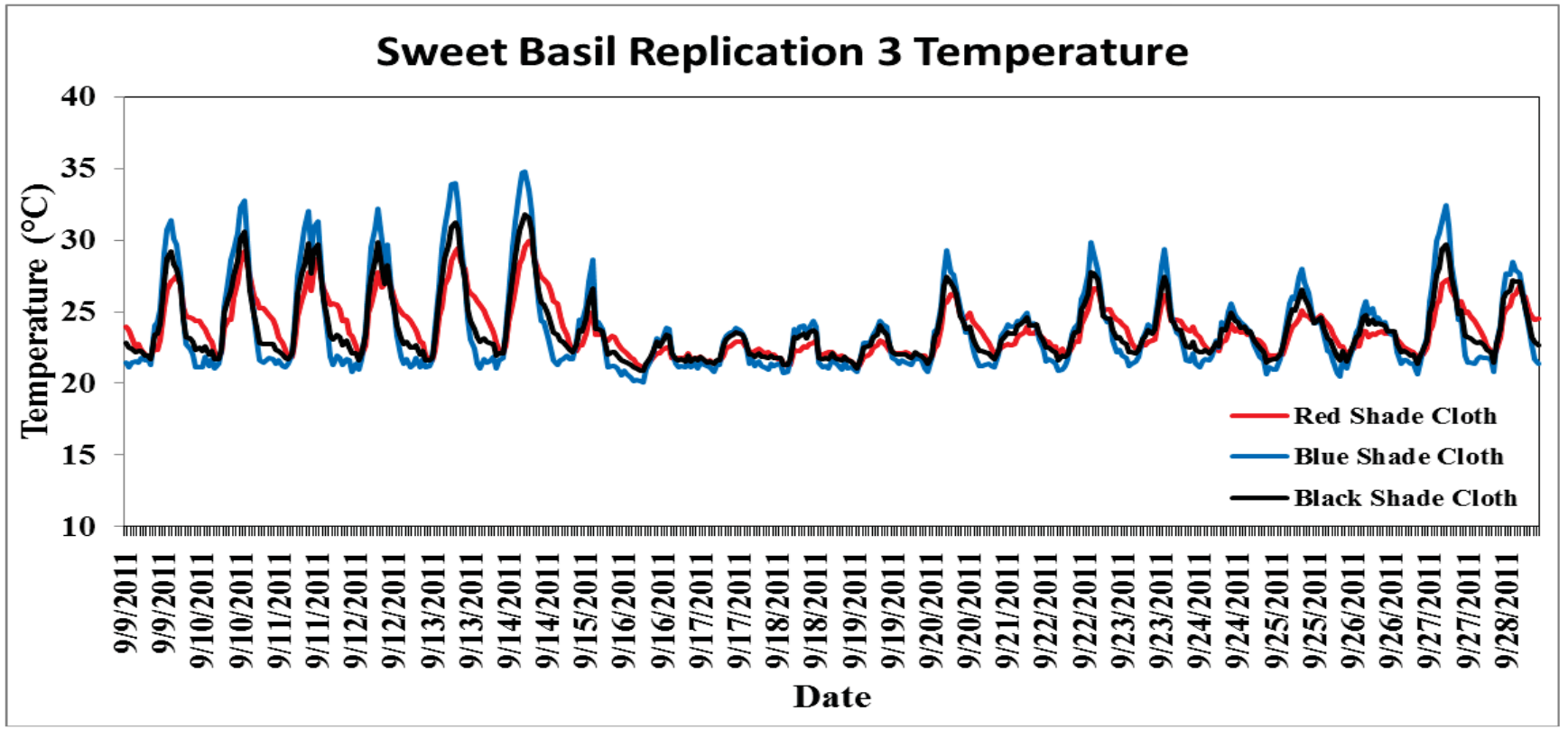

Figure 4.10a. *Sweet Basil Replication 3*. Temperature (°C) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

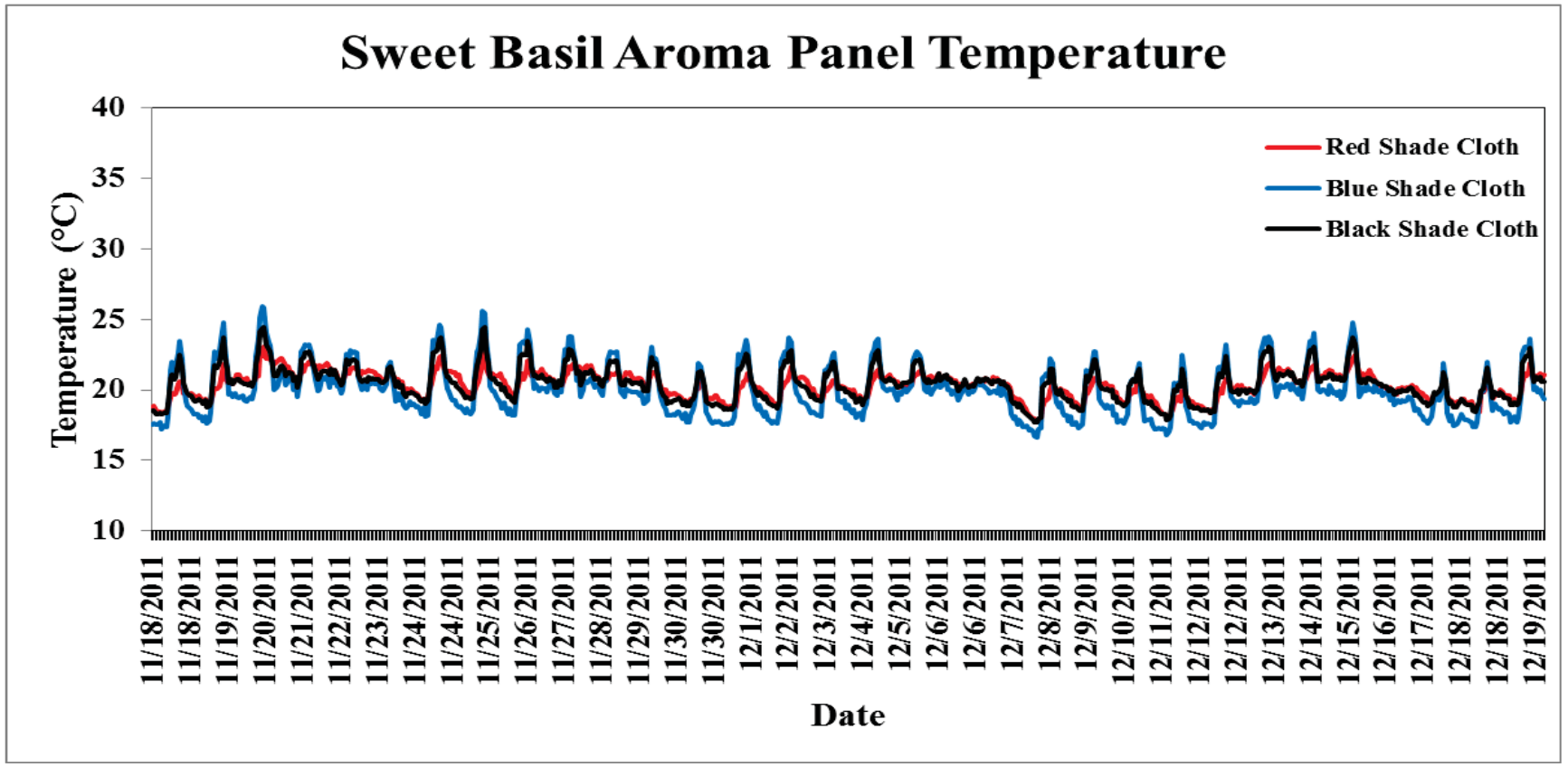

Figure 4.11a. *Sweet Basil Aroma Panel*. Temperature (°C) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

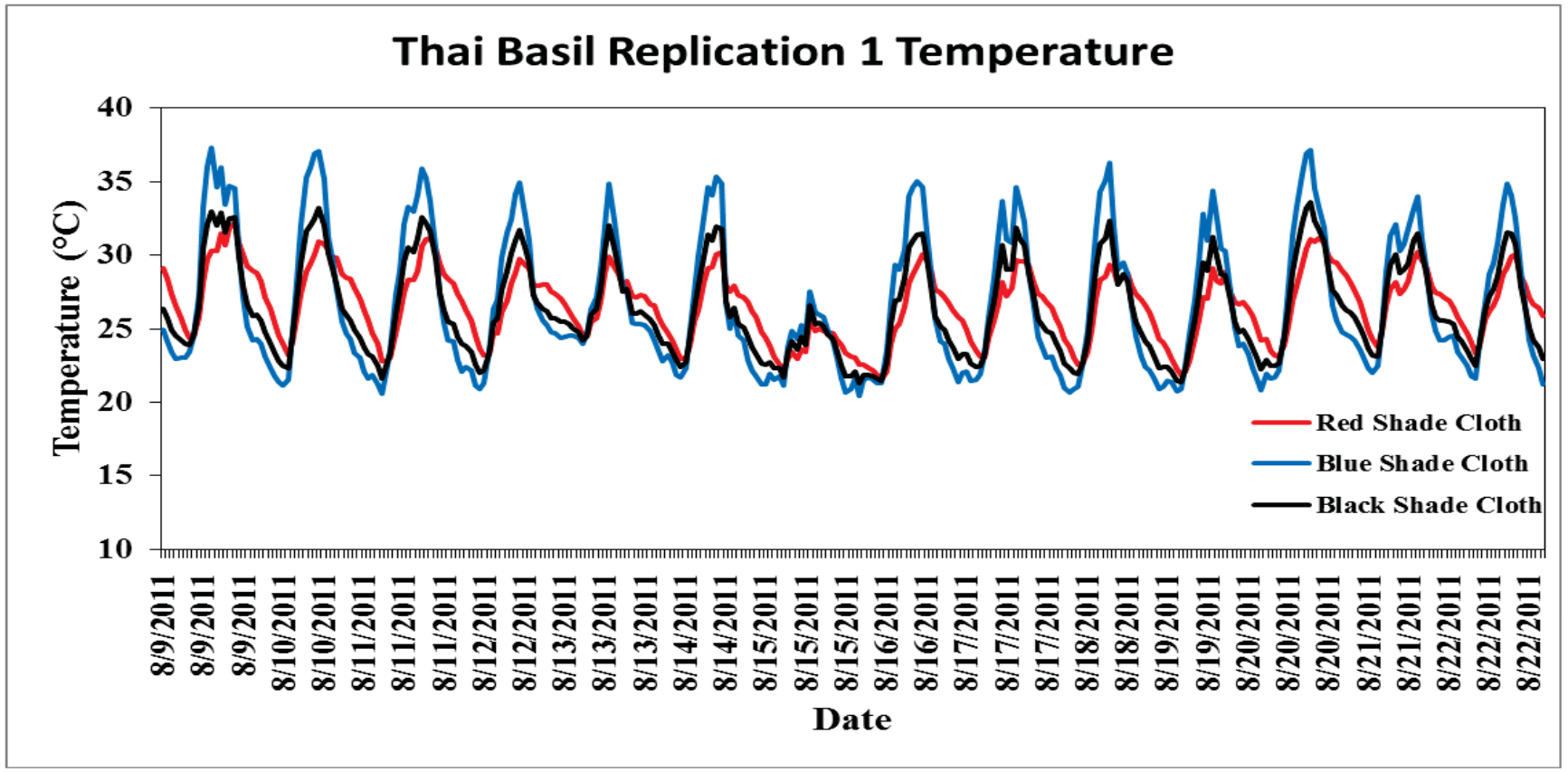

Figure 4.12a. *Thai Basil Replication 1*. Temperature (°C) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

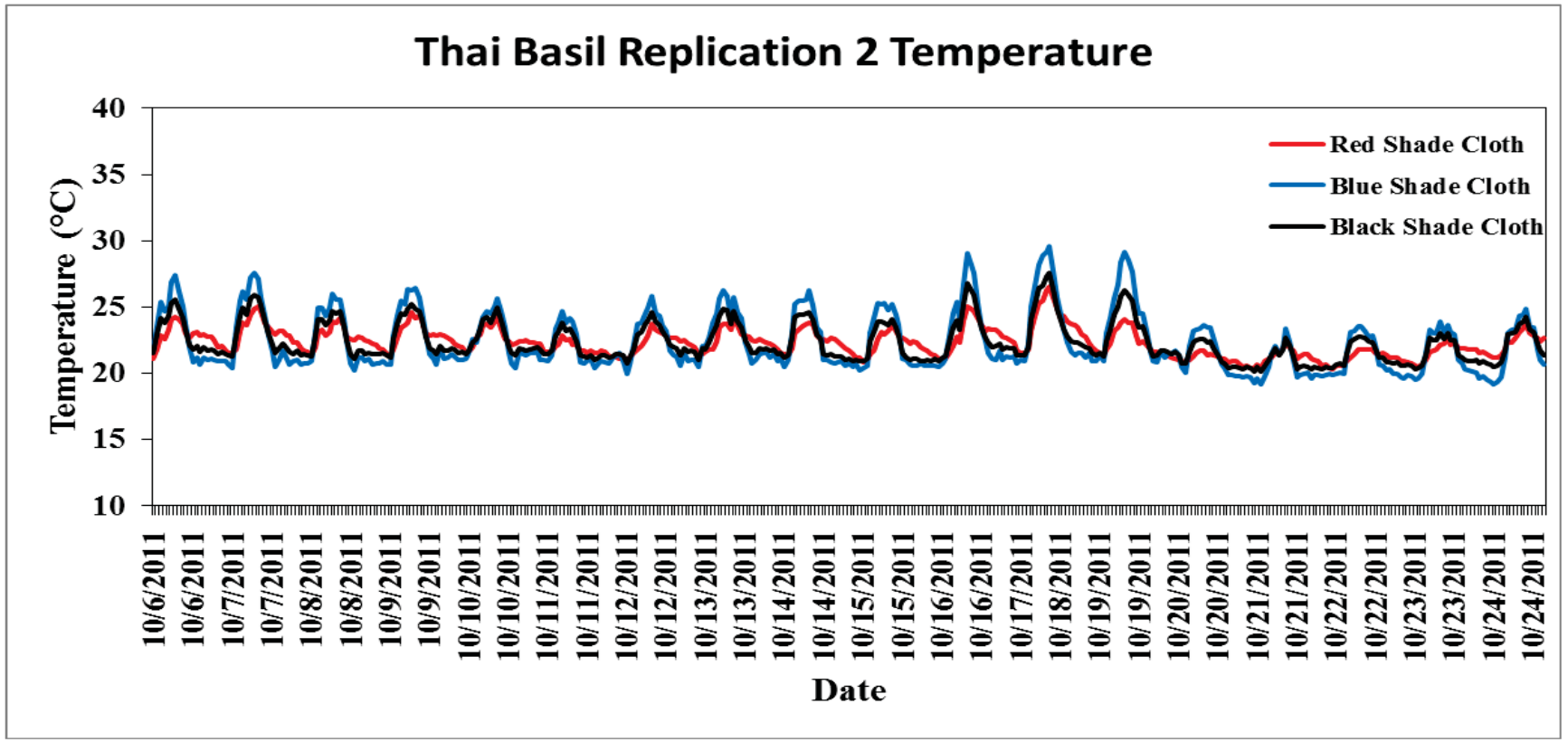

Figure 4.13a. *Thai Basil Replication 2*. Temperature (°C) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

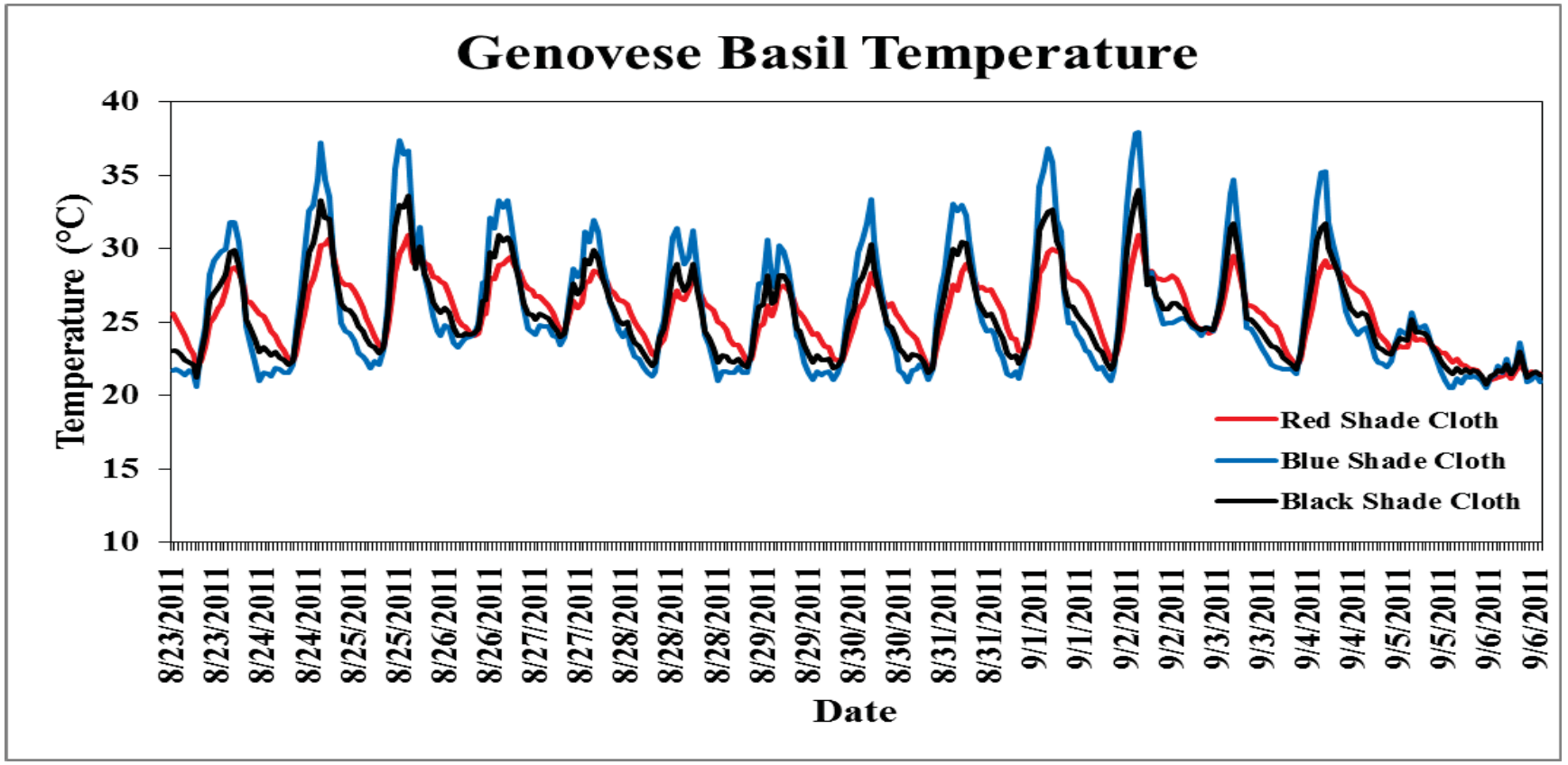

Figure 4.14a. *Genovese Basil*. Temperature (°C) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

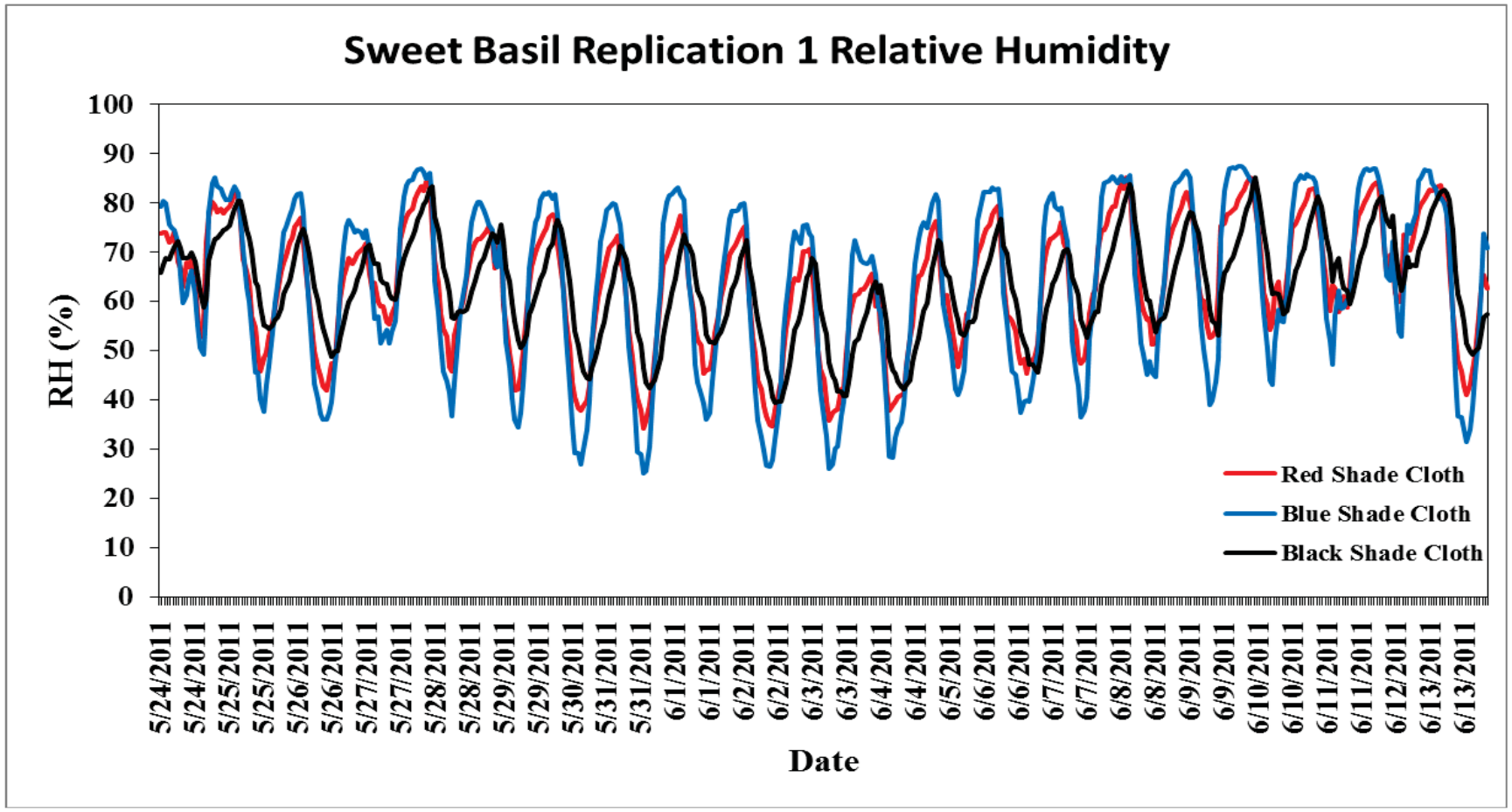

Figure 4.15a. *Sweet Basil Replication 1*. Relative humidity (%) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

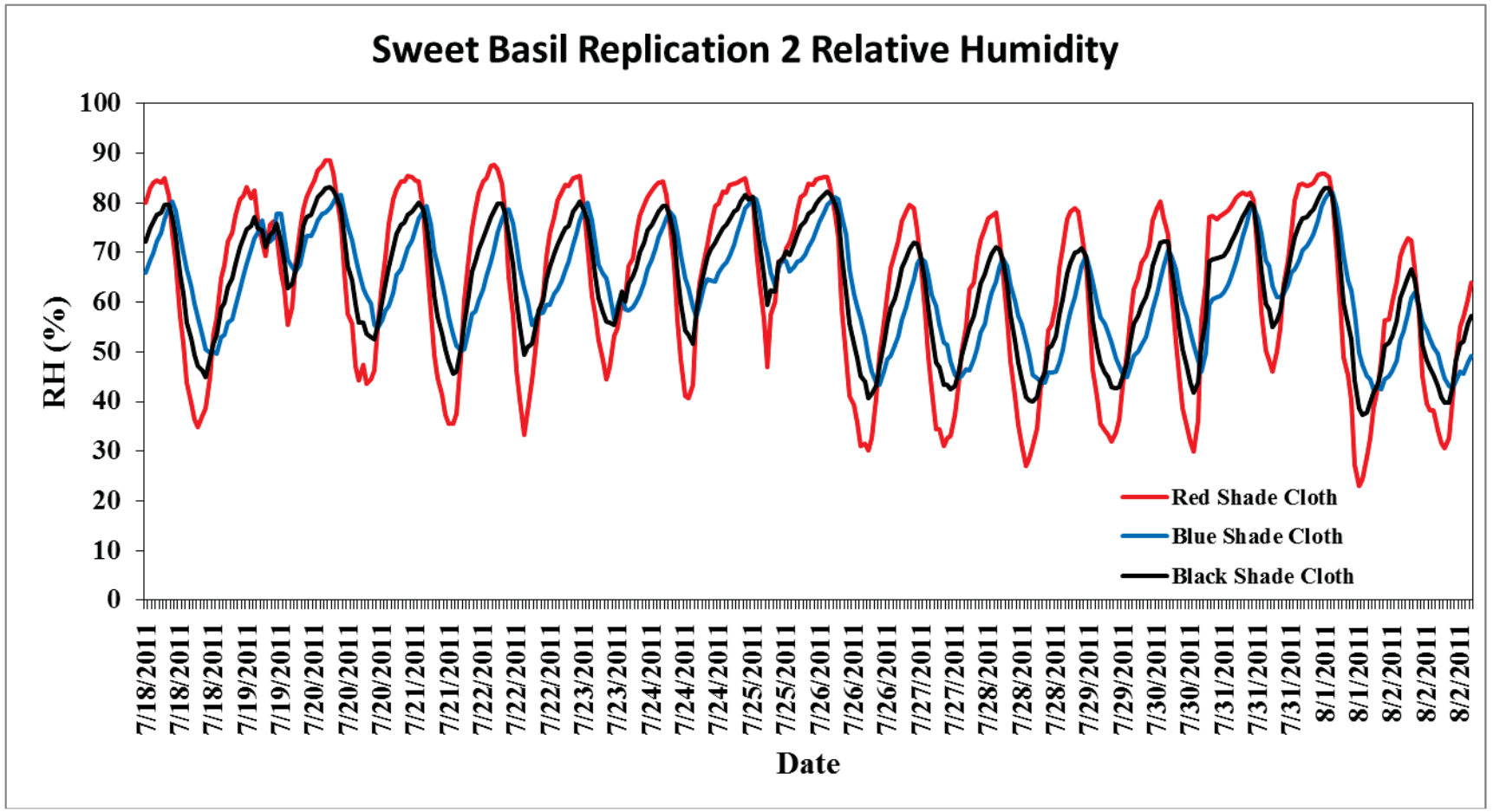

Figure 4.16a. *Sweet Basil Replication 2*. Relative humidity (%) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

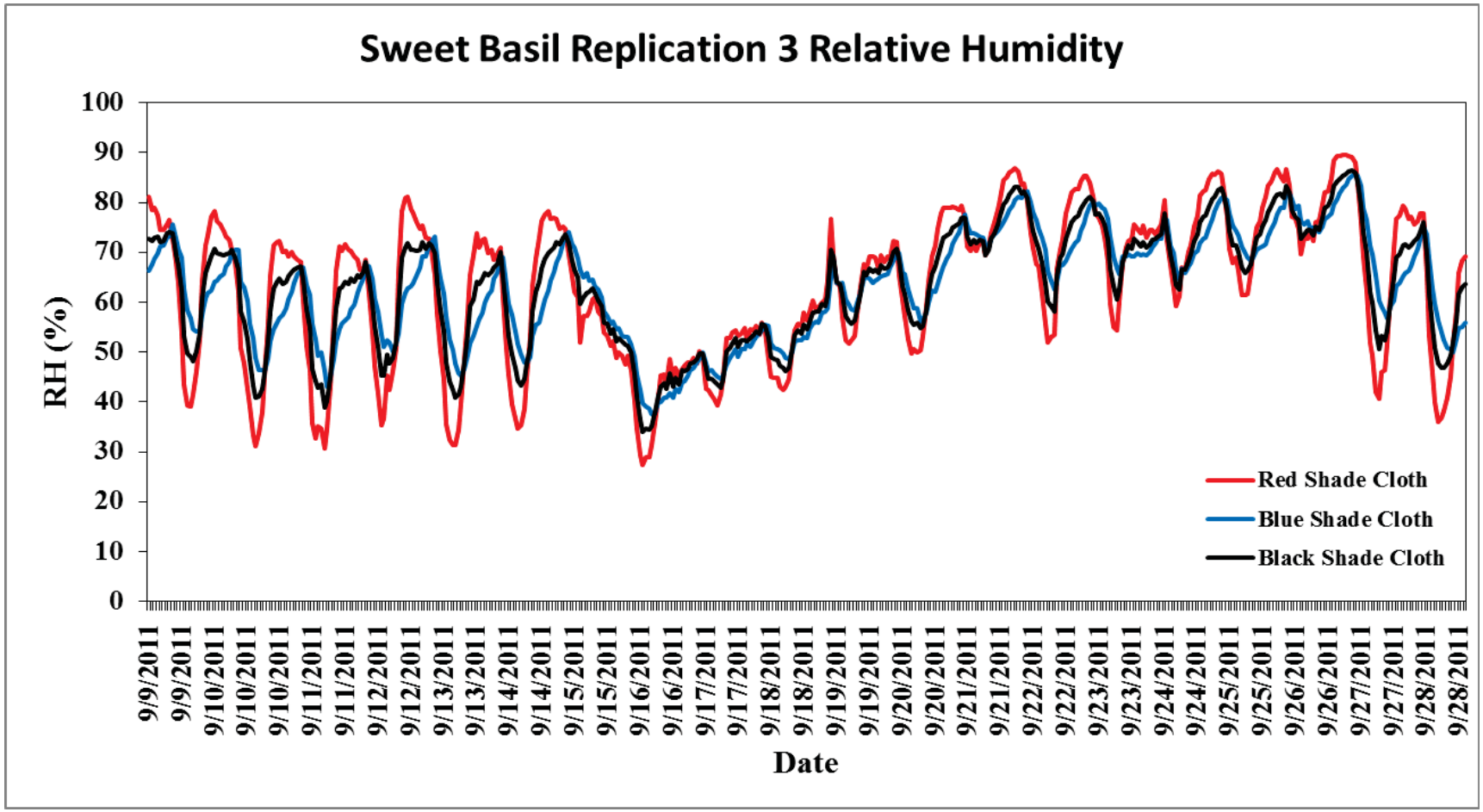

Figure 4.17a. *Sweet Basil Replication 3*. Relative humidity (%) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

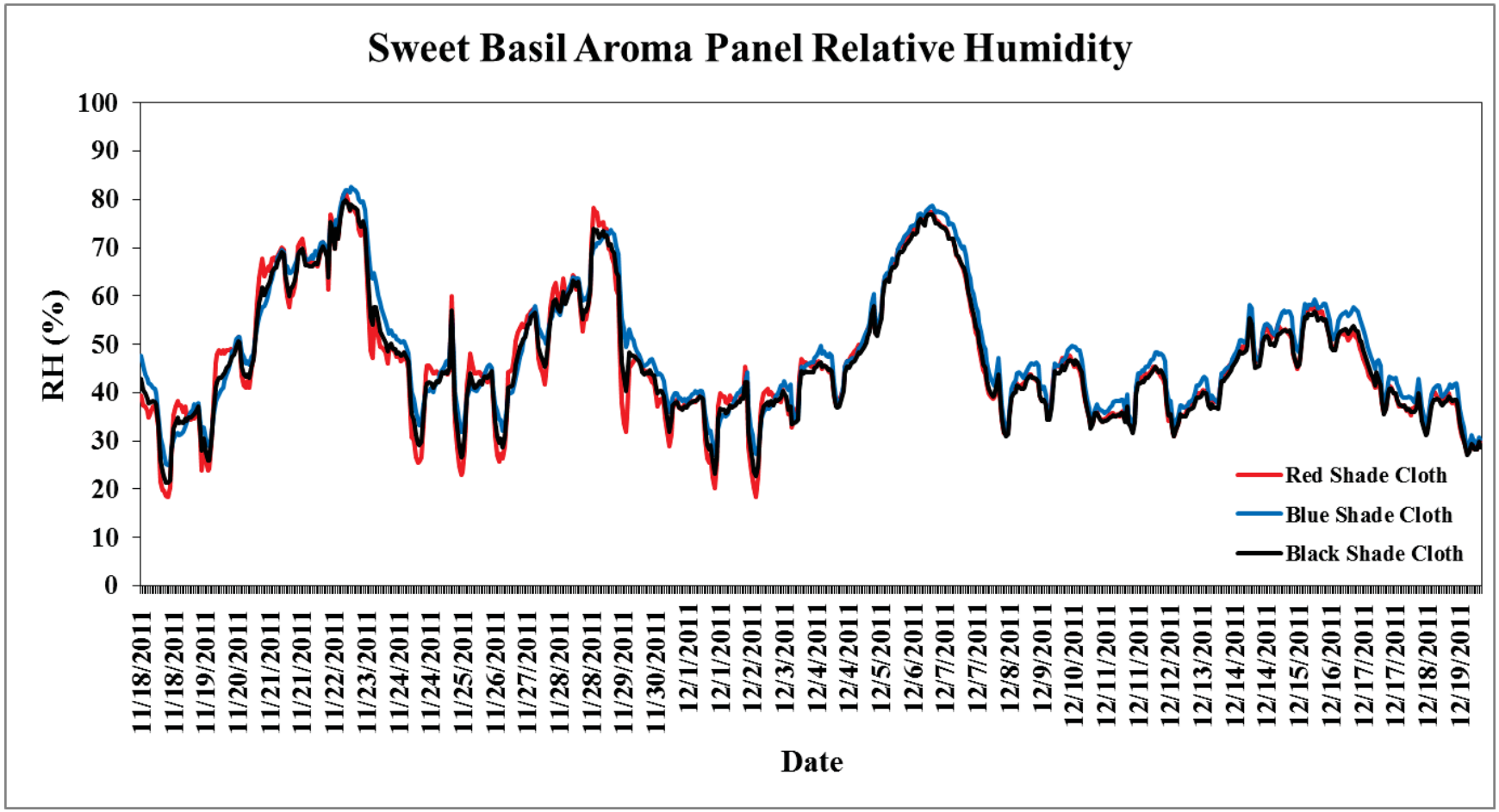

Figure 4.18a. *Sweet Basil Aroma Panel*. Relative humidity (%) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

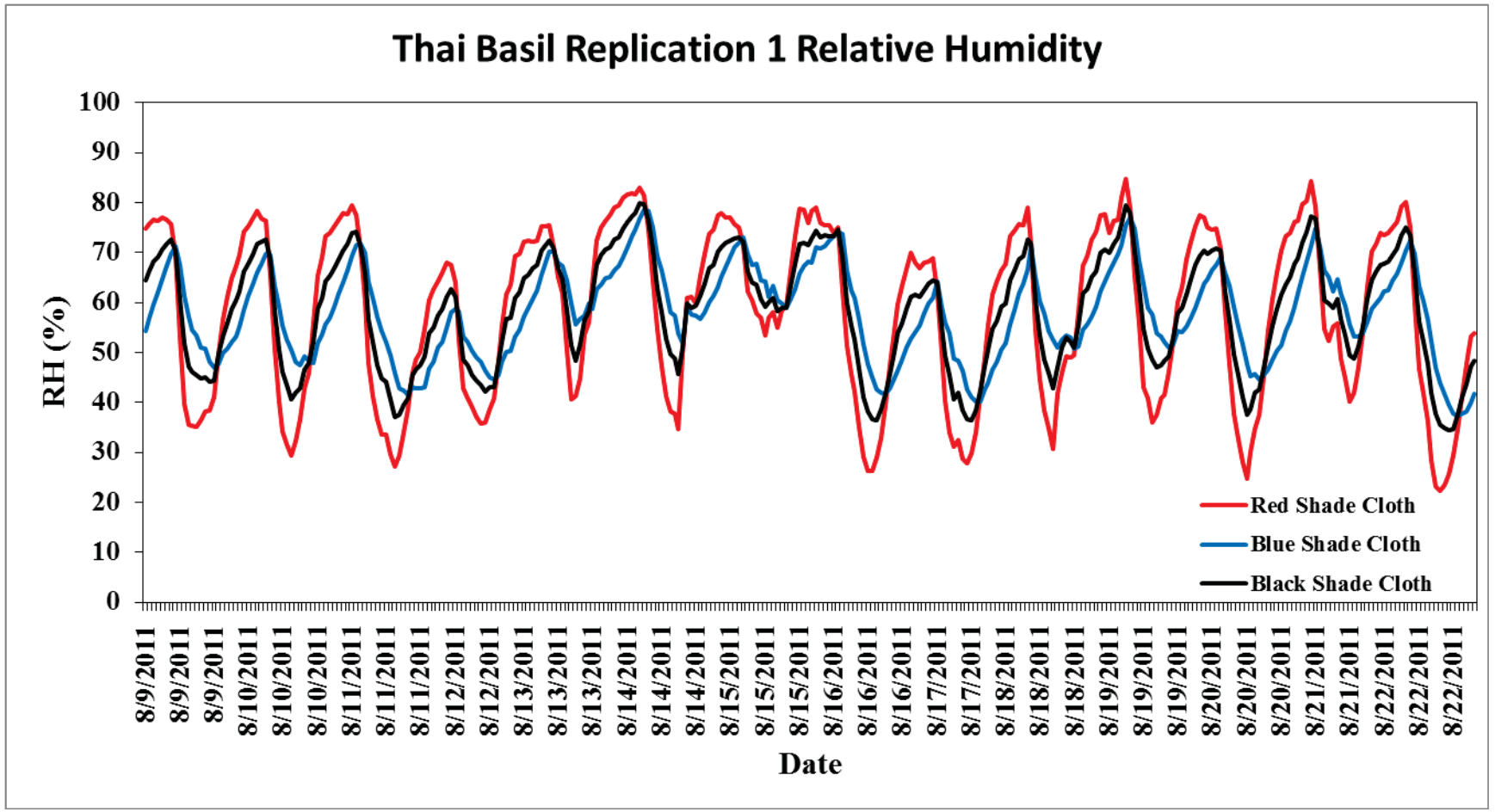

Figure 4.19a. *Thai Basil Replication 1*. Relative humidity (%) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

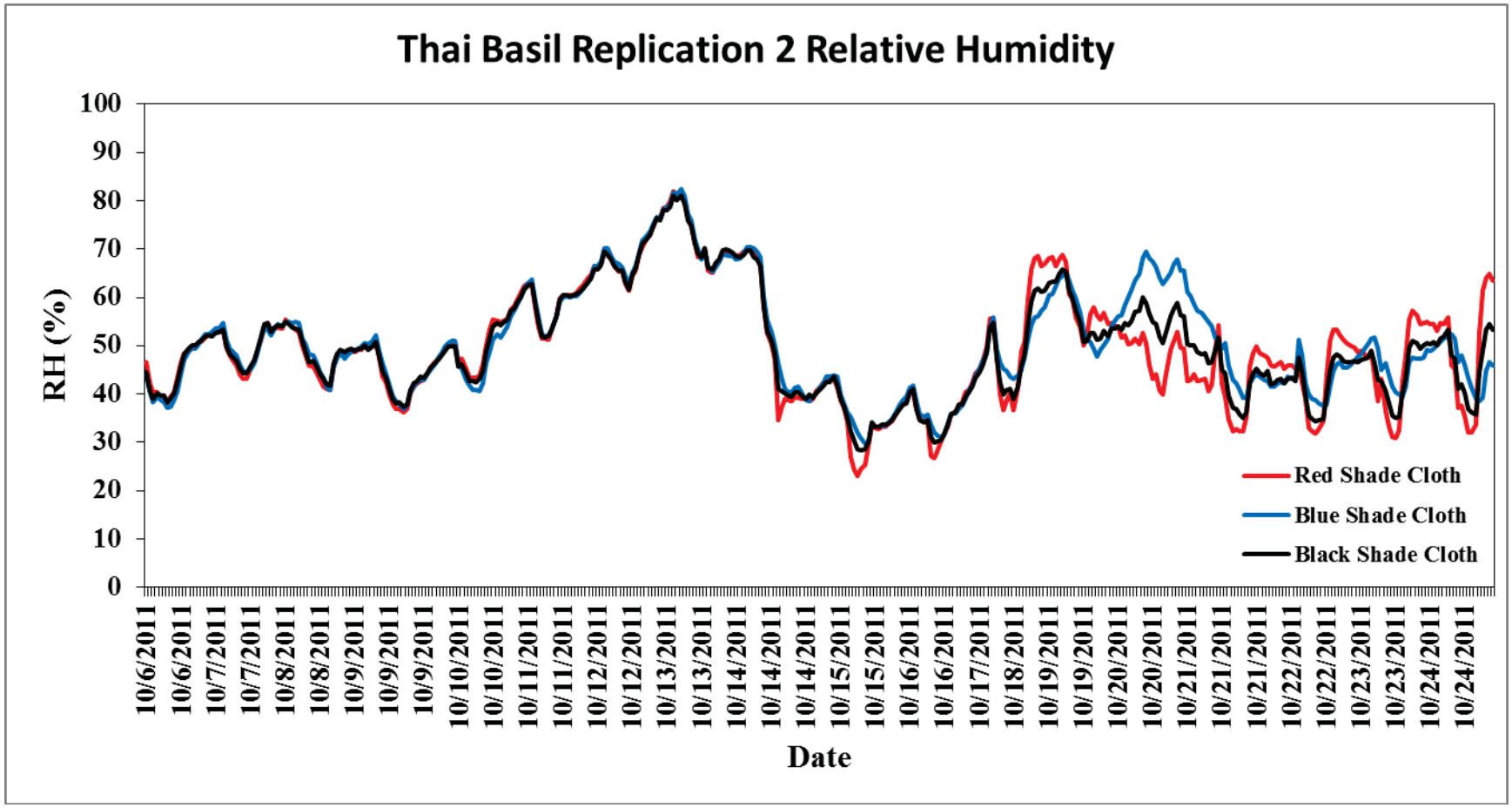

Figure 4.20a. *Thai Basil Replication 2*. Relative humidity (%) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

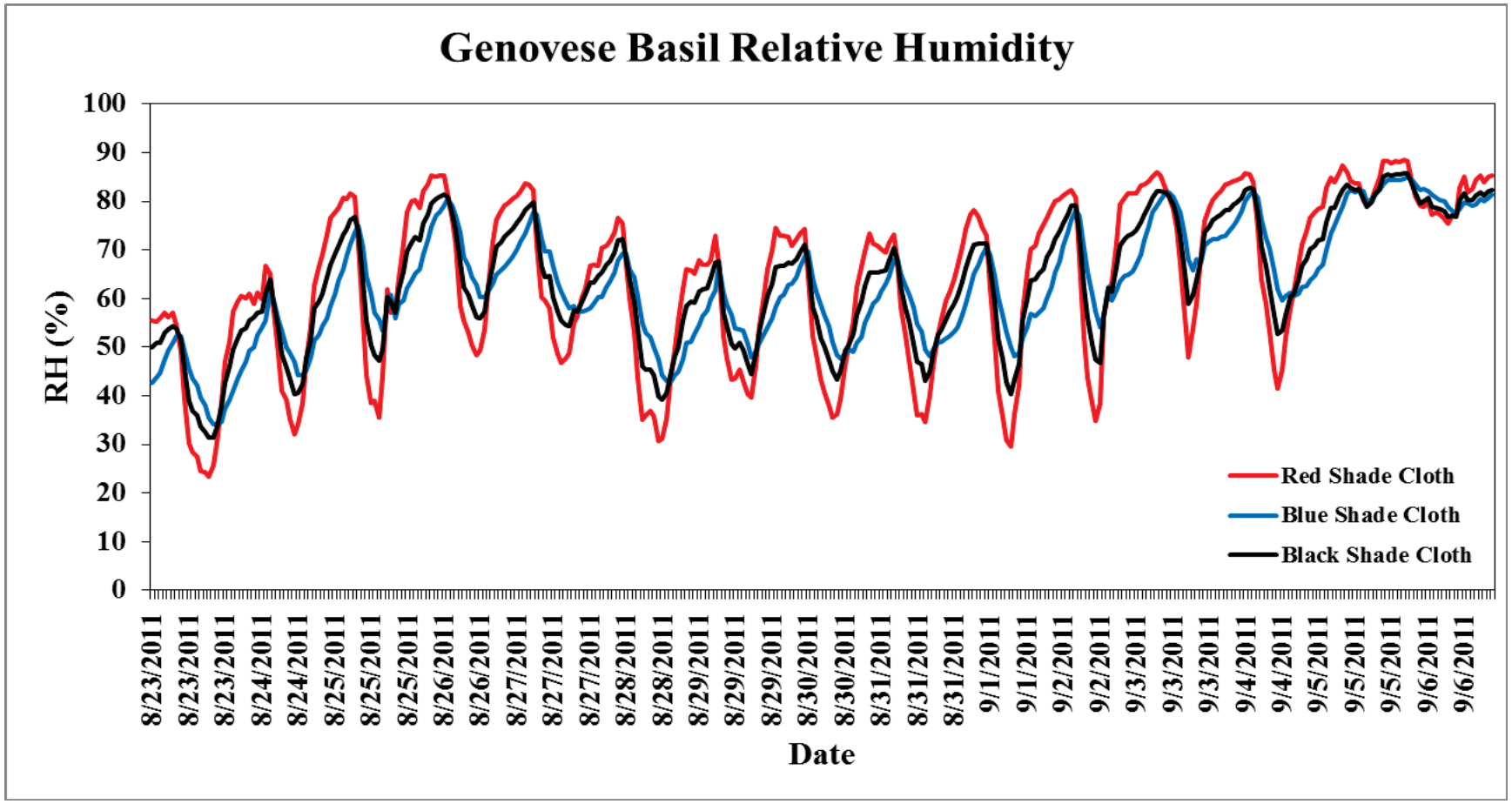

Figure 4.21a. *Genovese Basil*. Relative humidity (%) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

Chapter 5

Colored Shade Cloth Affects the Growth of Cilantro and Parsley

Abstract

The effect of colored shade cloth and plant growth regulators (PGRs) or mechanical stimulation (brushing) were assessed on cilantro (*Coriandrum sativum* L.) and parsley (*Petroselinum crispum* (Mill.) Nyman ex A.W. Hill). All crops were grown under conventional black, blue ChromatiNet®, or red ChromatiNet® shade cloth. Subplot treatments included: dikegulac sodium at 400 ppm; benzyladenine at 300 ppm; ethephon at 350 ppm; or, mechanical stimulation as brushing at 10 strokes applied twice daily. We assessed volatile compounds of cilantro and parsley. Benzyladenine increased the number of branches compared to control plants in cilantro and parsley. Number of leaf stalks and shoot fresh weight also increased in cilantro plants grown under red shade cloth compared to black or blue shade treatments. Red shade cloth increased shoot fresh weight of parsley plants compared to black or blue treatments. Red shade cloth can be used to grow cilantro and parsley plants that have more branches and a higher fresh weight. Volatile compound analysis showed no significant difference between cilantro and parsley grown under the three shade cloth colors which may mean that consumer will not be able to tell the difference between black, blue, and red shade cloth grown plants.

Introduction

Cilantro (*Coriandrum sativum* L.) is used in many different cuisines from salads, sauces, and soups to salsa, guacamole, and in Brazil with scallions (Mangen and VanVranken, 2004; Tucker and Debaggio, 2009a). Cilantro leaves do not retain flavor upon dry but can be frozen or stored in oil (Tucker and DeBaggio, 2009a). Cilantro is

commonly sold as a fresh cut product or as potted plant in most grocery store chains. The seed of cilantro is commonly known as coriander and the foliage is known as Chinese parsley or cilantro, a term used in the United States and Latin America (Tucker and DeBaggio, 2009a). The aroma is a combination of the compounds linalool, 2-decenal, 2-dodenenal, decanal, and 2-tetradecenal (Tucker and DeBaggio, 2009a). Cilantro, which resembles parsley, is in the same family, Apiaceae (Mangan and VanVranken, 2004).

Parsley (*Petroselinum crispum* (Mill.) Nyman ex A.W. Hill) is one of the most recognizable herbs since it is commonly seen as a garnish on dinner plates (Gill and Merrill, 2010). Three types of parsley are grown in the United States, common (curled-leaf, variety *crispum*), plain (flat-leaved, variety *neopolitanum*) and Hamburg or turnip-rooted (variety *tuberosum*) (Tucker and DeBaggio, 2009b). Parsley is often used in salads, soups, and stews along with its use as a garnish mentioned earlier (Anderson, 2011). Parsley is an excellent source of vitamins A and C, niacin, riboflavin, iron, and calcium (Gill and Merrill, 2010). Dehydrated parsley flakes retain their characteristic flavor and green color and are produced from parsley grown in commercial fields (Stephens, 2009). Parsley is also commonly sold as fresh cut product and as potted plants in most grocery store chains. The aroma of parsley is thought to be mainly due to para-1,3,8-menthatriene (Tucker and DeBaggio, 2009b).

Greenhouse herb production is becoming an increasingly important aspect of commercial greenhouse production in the United States. Data from the USDA 2009 Census of Horticultural specialties reported that 323 operations were specializing in growing herbs. The value of herb production along with other food crops grown

undercover represent the fastest growing market in horticulture with a 148 percent increase in value from $223 million in 1998 to $553 million in 2009 (USDA, 2010).

Shade is often used in the summer to protect plants from high light intensities (Nelson, 2003). High light intensity can damage the chloroplasts, and cause leaf and petal burn. Shading maybe accomplished by spraying a white-wash (diluted latex paint solution) on the greenhouse or by installing shading fabric over or inside the greenhouse (Nelson, 2003). Shade cloth can be purchased in different densities of weave providing shade values from 20% to 90%; 50% is the most commonly used shade cloth (Nelson, 2003).

ChromatiNet® (colored shade cloth) is designed to modify light in either the ultra-violet, visible, or far-red spectral regions; the cloth also enhances the relative content of scattered vs. direct light and absorbs infra-red radiation (Shahak et al., 2004). The fraction of light that passes through the holes, in the shade cloth, remains unchanged in its quality, while the light hitting the threads comes out spectrally modified and scattered (Shahak et al., 2004). The blue shade cloth is designed to absorb ultra-violet (UV), red, and far-red radiation; while enriching the blue spectral region (Figure 5.1). The red shade cloth absorbs UV, blue, and green radiation and enriches the red and far-red spectral region (Figure 5.2). The effects of colored shade cloth have been studied on a number of crops including *Pittosporum variegatum* (Thunb.) W.T. Aiton (Oren-Shamir et al., 2001), *Dracaena deremensis* ‘Janet Craig’ (L.) Ker Gawl, *Dracaena marginata* ‘Colorama’ Lam. (Kawabata et al., 2007), and *Phalaenopsis* Blume (Leite et al., 2008).

Pittosporum was grown under 50% green, blue, red, black, grey, or Aluminet® shade cloth in Israel (Oren-Shamir et al., 2001). Blue shade cloth reduced branching,

internode length, and decreased the yield of commercial branching (cut foliage) but variegation of *Pittosporum* was enhanced. The red and grey increased the number of lateral branches of *Pittosporum* plants compared to those grown under the black shade cloth. The red shade cloth stimulated stem elongation and produced the longest branches (Oren-Shamir et al., 2001).

Dracaena 'Janet Craig' was grown under 70% black, red, blue, or grey shade cloth, the weave of the cloth with 70% covered by the fabric and 30% open (Kawabata et al., 2007). The red shade cloth produced the greatest number of new leaves but they were smaller and thicker than the leaves under the other shade cloth treatments (Kawabata et al., 2007). A grower evaluation of the plants showed that the smaller leaves of the red shade cloth grown plants reduced marketability (Kawabata et al., 2007).

Dracaena 'Colorama' grown under red shade cloth produced more new cane growth (20.2 cm compared to 10.4 cm for the black) and more new leaves (26.2 compared to 18 for the black) compared to the other treatments (Kawabata et al., 2007). The red shade cloth grown plants grew taller while maintaining a full appearance (Kawabata et al., 2007).

Phalaenopsis species were grown under 50% black, blue, or red shade cloth (Leite et al., 2008). The red shade cloth treated plants bloomed in April and May compared to May and June for the plants grown under black or blue shade cloth respectively; this earlier bloom was contributed to the higher amount of red and far-red light transmitted by the red shade cloth (Leite et al., 2008). Blue shade cloth treated plants had a higher leaf area and leaf fresh weight compared to the black and red shade cloth treatments (Leite et al., 2008). The fact that the plants were larger under the blue

shade cloth contradicts the literature presented thus far and is thought to be because *Phalaenopsis* are adapted to low light levels and because they are crassulacean acid metabolism (CAM) plants (Leite et al., 2008).

Plant growth regulators (PGRs) are described as chemicals that are designed to affect plant growth and/or development (Latimer, 2009). Plant growth regulators can be used for control of plant height (chemical growth retardants), stimulation of lateral branching, or for promoting flower initiation (Bailey and Whipker, 1998). PGRs used for promoting lateral branching are usually called chemical pinchers because they inhibit the growth of terminal shoots or they enhance the growth of lateral branches (Latimer, 2009). These PGRs can be used in replacement of mechanical pinching which also stimulates lateral branching (Latimer, 2009).

Mechanical stimulation is a way to limit stem elongation and may avoid the detrimental effects of stress based treatments (Garner and Bjorkman, 1996). The changes in plant growth caused by mechanical stimulation occur without long term inhibition of plant growth once treatments are ceased (Garner and Bjorkman, 1996). Mechanical stimulation in the form of brushing can be applied by using any non-abrasive material such as bond typing paper, cardboard, polyvinyl chloride pipe, or by a wooden dowel (Garner and Bjorkman, 1996).

The effects of colored shade cloth and plant growth regulators (PGRs) or mechanical stimulation on growth were assessed on cilantro and parsley. The shade cloth colors investigated were conventional black, blue ChromatiNet, and red ChromatiNet shade cloth. The following PGRs were investigated as subplot treatments: dikegulac

sodium, benzyladenine, and ethephon. None of these PGRs are currently labeled for use during cilantro or parsley production.

Methods and Materials

Cilantro and parsley seeds (Wetsel, Inc., Harrisonburg, VA) were planted into 128 plug trays, using a germination mix (Conrad Fafard, Inc., Agawam, MA) on April 22, 2011 (Cilantro Replication 1), April 22, 2011 (Parsley Replication 1), June 17, 2011 (Cilantro Replication 2), September 14, 2011 (Cilantro Replication 3), October 11, 2011 (Parsley Replication 2), November 29, 2011 (Cilantro Replication 4). One seed was planted into each cell in the plug trays. All species were potted up into 10.2-cm square pots (706 mL) using a peat lite mix (Fafard 3B, Conrad Fafard, Inc), when the roots had reached the sides of the plug cells and the second set of true leaves had fully expanded. The transplants were then allowed to grow out for about a week before treatment on May 25, 2011 (Cilantro Replication 1), May 25, 2011 (Parsley Replication 1), July 6, 2011 (Cilantro Replication 2), October 11, 2011 (Cilantro Replication 3), November 15, 2011 (Parsley Replication 2 application 1), November 29, 2011 (Parsley Replication 2 application 2), and December 19, 2011 (Cilantro Replication 4).

Treatments were arranged in a split-plot design. The main plot included the conventional black, blue ChromatiNet, or red ChromatiNet (Green-Tek, Inc. WI, USA) shade cloth with three replications of each plot randomly assigned to greenhouse benches (Figure 5.3). Spectral distribution under the conventional black, blue ChromatiNet, and red ChromatiNet shade cloth was graphed using a Li-Cor Spectroradiometer, courtesy of Dr. Faust, Clemson University (Figure 5.4). Sub-plot treatments were an untreated control, dikegulac sodium (Augeo, OHP, Inc., Mainland, PA) at 400 mg/L;

benzyladenine (Configure, Fine America, Inc., Walnut Creek, CA) at 300 mg/L; ethephon (Florel, Monterey Lawn and Garden Products Inc., Fresno, CA) at 350 mg/L; mechanical stimulation as brushing at 10 strokes applied twice daily; changed to 20 strokes once daily for Cilantro Replication 4. The brushing technique consisted of a wooden dowel and one back and forth motion counted as one stroke. After Cilantro and Parsley Replication 1 the brushing technique was change to a gentler method; a piece of ground cloth cut into strips suspended from a PVC pipe. PGR treatments were applied using a handheld CO_2 sprayer at a volume of 210 mL/m². Temperature and relative humidity at the time of treatment were 20°C and 90% on May 25, 2011 (Cilantro and Parsley Replication 1); 21°C and 81% on July 6, 2011; 19°C and 73% on October 11, 2011; 18°C and 82% on November 15, 2011; 20°C and 55% on November 29, 2011; 25°C and 20% on December 19, 2011. Twelve high pressure sodium lights (400 watt) were used for supplemental lighting beginning September 19, 2011 to increase the DLI at plant level by 2 to 3 $mol \cdot m^{-2} \cdot d^{-1}$ (Figure 5.5). All plants were grown in a polycarbonate greenhouse with temperature set points during the day of 21°C and at night of 15°C. Environmental data were collected using HOBO data loggers (Onset Computer Corporation, Bourne, MA) placed under black, blue ChromatiNet, and red ChromatiNet treatments; unshaded environmental data were collected by a WatchDog data logger (Spectrum Technologies Inc., Plainfield, IL) (Table 5.1). Measurements included plant height (from rim of pot to top of plant in cm), width (largest width and width measurement perpendicular to largest width in cm), number of branches, number of leaders (terminal shoot or branch that has side shoots or branches growing from them), shoot fresh weight, and notes on phytotoxicity at 0 days after treatment (DAT) and at

finish, which depended on time of the year. Data were analyzed using JMP statistical software, Tukey-Kramer HSD (SAS Institute Inc., Cary, NC).

Volatile component analysis was conducted on Cilantro Replication 3, Cilantro Replication 4, Parsley Replication 1, and Parsley Replication 2 to determine whether or not important volatiles were being affected by the treatments. Two gram leaf samples of each treatment were placed in 20 mL headspace vials and sealed with AlumiTin, 20 mm caps. Headspace vials were placed into a Hewlett Packard GC 5890 with a 5972 series Mass Selective Detector (MS). HP 5MS column dimensions 30 m x 0.25 mm, film thickness 0.25 μm. Extraction fiber (DVB/CAR/PDMS) was injected into vials and then exposed for 30 minutes at 40°C. The extraction fiber was desorbed for 5 minutes in the injection port. Temperature in MS started at 45°C (intial) for 1 minute and then increased to 210°C at a rate of 10°C per minutes. MS temperature was held at 210°C for 5 minutes Injection port temperature was 250°C and transfer line temperature 220°C, the carrier gas was helium. A Kovats Standard was run through the MS to help identify compounds (Figure 5.6). The retention times of the major aroma compounds were then compared to the Kovats Standards using the website Flavornet (http://www.flavornet.org/flavornet.html). The Kovats Standard allows us to confirm the identity of a compound by comparing standardized retention time.

Results

Cilantro Replication 1. There was no interaction between shade cloth color and PGRs for cilantro plant height, width, number of leaf stalks, and shoot fresh weight (Table 5.2). Cilantro plant height was greater under the red shade cloth treatment compared to both the blue and black shade cloth treated plants; the blue and black shade

cloth treatments were not statistically different. Plant height was not different among PGR treated plants and control plants. Cilantro plant width was not affected by shade cloth color. A decrease in width was seen in brushing treated plants compared to control plants. Red shade cloth increased the number of leaf stalks compared to black and blue shade cloth treatments; the black and blue shade cloth treated plants were not statistically different. The PGR treatments were not different from the control in regards to the number of leaf stalks. Shoot fresh weight was increased under the red shade cloth compared to black and blue shade cloth treated plants; the black and blue shade cloth treatments were not statistically different. There was no statistical difference between PGR treatments and control plants.

Cilantro Replication 2. No interaction was seen between shade cloth color and the PGR treatments for cilantro plant height, width, number of leaf stalks, and shoot fresh weight (Table 5.3). Although main plot effects were significant, there was also no statistical difference between PGR treatments and the control plants in regards to height, width, number of leaf stalks, and shoot fresh weight. Cilantro plant height was increased under the black and red shade cloth treatments compared to the blue shade cloth treated plants; there was no statistical difference between the black and red shade cloth treatments. Red shade cloth increased cilantro plant width compared to the blue shade cloth treated plants but was not statistically different from the black shade cloth treatment; the black and blue shade cloth treatments were not statistically different. The number of leaf stalks was increased under the black shade cloth compared to blue and red shade cloth treated plants; there was no statistical difference between the blue and red shade cloth treatments. Shoot fresh weight was increased under both the black and red

shade cloth treatments compared to the blue shade cloth treated plants; there was no statistical difference between the black and red shade cloth treatments.

Cilantro Replication 3. There was no interaction between shade cloth color treatments and the PGR treatments cilantro plant height, width, number of leaf stalks, and shoot fresh weight (Table 5.4). Height was greater under the black and red shade cloth treatments compared to the blue shade cloth treated plants; there was no statistical difference between the black and red shade cloth treatments. The brushing treatment decreased cilantro plant height compared to control plants. Cilantro plant width was also greater under the black and red shade cloth treatments compared to the blue shade cloth plants; there was no statistical difference between the black and red shade cloth plants. Dikegulac sodium and ethephon decreased plant width compared to control plants. The number of leaf stalks was not affected by shade cloth color or by the PGR treatments. Shoot fresh weight was increased under the red shade cloth treatment compared to the black and blue shade cloth treated plants; the black and blue shade cloth treatments were not statistically different. Dikegulac sodium, ethephon, and brushing decreased shoot fresh weight compared to control plants.

Cilantro Replication 4. There were no interactions between shade cloth color and PGR treatments for plant height, width, number of leaf stalks, and shoot fresh weight (Table 5.5). The black and red shade cloth treatments increased cilantro plant height compared to blue shade cloth treated plants; there was no statistical difference between black and red shade cloth plants. Height was decreased by dikegulac sodium, benzyladenine, and brushing treatments compared to the control plants. The red shade cloth treatment increased plant width compared to black and blue shade cloth treated

plants; there was no statistical difference between the black and blue shade cloth treatments. There was no difference in plant width between PGR treatments and control plants. The shade cloth treatments had no effect on the number of leaf stalks. Benzyladenine increased the number of leaf stalks compared to control plants. Cilantro plant shoot fresh weight was increased under the red shade cloth treatment compared to the black and blue shade cloth treated plants; there was no statistical difference between the black and blue shade treatments. A decrease in shoot fresh weight was seen in the ethephon treated cilantro plants compared to control plants.

Parsley Replication 1. No interaction was seen between shade cloth colors and PGR treatments for plant height, width, number of leaf stalks, and shoot fresh weight (Table 5.6). Parsley plant height was greater under the red shade cloth compared to the black and blue shade cloth treatments; there was no difference between the black and blue shade cloth treated plants. Brushing decreased plant height compared to the control plants. Plant width was greater under the red shade cloth treatment compared to the blue shade cloth treated plants but there was no statistical difference between red shade cloth plants and black shade cloth treated plants; black shade cloth treated plants were not statistically different from the blue shade cloth treated plants. The brushing treatment decreased plant width compared to control plants. The red shade cloth treatment increased the number of leaf stalks compared to the blue shade cloth treated plants but was not statistical different from the black shade cloth treatment. Black and blue shade cloth treatments were not statistical different. The PGR treatments had no effect on the number of leaf stalks. Shoot fresh weight was increased under the red shade cloth treatment compared to black and blue shade cloth treated plants; there was statistical

difference between the black and blue shade cloth treatments. The brushing treatment decreased shoot fresh weight compared to the control plants.

Parsley Replication 2. There was no interaction between shade cloth color and PGR treatment for parsley plant height, width, number of leaf stalks, and shoot fresh weight (Table 5.7). Plant height was greater under the red shade cloth treatment compared to the black and blue shade cloth treated plants; the black and blue shade cloth treatments were not statistical different. Dikegulac sodium and brushing decreased parsley plant height compared to control plants. Parsley plant width was greater under the red shade cloth compared to the blue shade cloth treated plants; there was no statistical difference between the red shade cloth treated plants and the black shade cloth treatment. Black and blue shade cloth plant width was not statistical different. The brushing treatment decreased parsley plant width compared to control plants. Shade cloth color had no effect on the number of leaf stalks. Benzyladenine increased the number of leaf stalks compared to control plants. Red shade cloth increased shoot fresh weight compared to black and blue shade cloth treated plants; black shade cloth treated had an increase in shoot fresh weight compared to blue shade cloth treated plants. Shoot fresh weight was increased by the benzyladenine treatment compared to control plants.

Cilantro Replication 3 Volatile Compound Analysis. The aroma of cilantro is attributed to a combination of the compounds nonane (Kovats number 900), linalool (Kovats number 1100), decanol (Kovats number 1263), and 2-dodecanal (Kovats number 1462); (Tucker and DeBaggio, 2009b). An example of the cilantro treatment chromatograms is in Figure 5.7. There were no interactions between shade cloth color and PGR treatment for mean peak area of nonane, linalool, and decanol (Table 5.8). The

blue shade cloth treatment had a higher nonane mean peak compared to red shade cloth treated plants; black and blue shade cloth plants were not significantly different. There were no PGR effects on mean peak area of nonane. Linalool and decanol mean peak area was not significantly different for shade cloth treatments and PGR treatments.

Cilantro Replication 4 Volatile Compound Analysis. There were no interactions between shade cloth color and PGR treatment for mean peak area of nonane, linalool, decanol, and dodecanal (Table 5.9). There were also no shade cloth effects and no PGR treatment effects on mean peak area of nonane, linalool, and dodecanal. Decanol mean peak area was higher in the red shade cloth treated plants compared to the blue shade cloth treatments; the black and blue shade cloth treatments were not significantly different from each other. Dikegulac sodium treated plants had a higher mean peak area of decanol compared to control plants.

Parsley Replication 1 Volatile Compound Analysis. The aroma of parsley is thought to be mainly due to para-1,3,8-menthatriene (Kovats number 1115); (Tucker and DeBaggio, 2009c). An example of the parsley treatment chromatograms is in Figure 5.8. 1,3,8-p-menthatriene mean peak area was higher in red shade cloth grown plants compared to black shade cloth plants; there was no statistical difference between black and blue shade cloth treatments (Table 5.10). There was no PGR effect on the mean peak area of 1,3,8-p-menthatriene; there was also no interaction between shade cloth color and PGR treatment.

Parsley Replication 2 Volatile Compound Analysis. Mean peak area of 1,3,8-p-menthatriene was higher in the red shade cloth treated plants compared to the blue shade cloth treatments; there was no statistical difference between black and blue shade cloth

treatments (Table 5.11). There was no PGR effect on the mean peak area of 1,3,8-p-menthatriene; there was also no interaction between shade cloth color and PGR treatment.

Discussion

The increase in the number of leaf stalks caused by the red shade cloth treatments on cilantro and parsley were consistent with results seen in *Pittosporum* where red shade cloth treated plants showed an increased in branching compared to those grown under the black shade cloth (Oren-Shamir et al., 2001). An increase in new cane growth and in new leaves was also seen by Kawabata et al. (2007) in *Dracaena* 'Colorama' grown under red shade cloth. The increase in shoot fresh weight seen in cilantro and parsley grown under red shade cloth was also seen by Shahak et al. (2008) in lettuce heads, which were 20% to 30% larger when grown under red or pearl shade cloths compared to the equivalent black or blue shade cloth. This shows that red shade cloth can be used successfully to produce cilantro and parsley plants with an increase in the number of leaf stalks and with an increase in fresh weight which can benefit the fresh cut market or container plant producers.

Benzyladenine increased the number of branches in Cilantro Replication 4 and Parsley Replication 2. This same effect was seen in basal shoots in *Coreopsis* 'Moonbeam' where shoots increased at 500 mg/L benzyladenine (Farris et al., 2009). Henny (1985) also saw an increase in mean number of lateral branches of *Peperomia obtusifolia* at 500 mg/L benzyladenine (9 branches compared with 4 branches for controls). The effect of benzyladenine seemed to be a seasonal effect because the effect

was only seen in late fall and early winter plants. More research would need to be conducted to show the significance of benzyladenine in cilantro and parsley production. Loughrin and Kasperbauer (2001) saw a reduction in aroma compounds in basil plant leaves grown over blue mulch. This is in contrast to Cilantro Replication 3 where nonane increased under blue shade cloth. Black mulch was shown to produce aroma compound levels higher than the blue, red, and white mulches (Loughrin and Kasperbauer, 2001). The results in cilantro and parsley showed that the black shade cloth treatments were not significantly different from blue and red shade cloth treated plants.

Conclusions

The red shade cloth treatment increased shoot fresh weight in three out of four of the cilantro replications and in both of the parsley replications. This shows that the red shade cloth can be used in place of conventional black shade cloth to produce plants with a higher fresh weight, which means that fresh cut products sold on a per weight basis would lead to increased profit. The increase in height under the red shade cloth treatment may be problem for growers when they ship the product. The blue shade cloth did not reduce the height of the plants compared to black shade cloth treated plants which means that blue shade cloth cannot be used as a growth retardant. PGR treatments did not work on a consistent basis; further research may be needed to assess usefulness of benzyladenine which seem to work better in the winter grown plants. Volatile compounds analysis results were not consistent in the cilantro replications. Parsley plants also did not show a consistent difference between the two replications in 1,3,8-p-menthtriene mean peak area which means that aroma may not differ between the shade cloth treatments,

which means that consumers may not be able to distinguish the difference between black, blue, or red shade cloth treated plants.

Literature Cited

Anderson, B. and R. Schnelle. 2010. Culinary herbs. University of Kentucky Cooperative Extension Service. 7 November 2011. <http://www.uky.edu/Ag/CDBREC/introsheets/herbs.pdf>.

Bailey, D. and B. Whipker. 1998. Best management practices for plant growth regulators used in floriculture. North Carolina State University Cooperative Extension. Horticulture Information Leaflet 529.

Farris, M., G. Keever, J. Kessler, and J. Olive. 2009. Benzyladenine and cyclanilide promote shoot development and flowering of 'Moonbeam' coreopsis. J. Environ. Hort. 27(3):176-182.

Garner, L. and T. Bjorkman. 1996. Mechanical conditioning for controlling excessive elongation in tomato tranplants: sensitivity to dose, frequency, and timing of brushing. J. Amer. Soc. Hort. Sci. 121(5):894-900.

Gill, D. and T. Merrill. 2010. Growing parsley in Louisiana. LSU AgCenter. 7 November 2011. <http://text.lsuagcenter.com/en/lawn_garden/home_gardening/vegetables/Include+Parsley+In+Your+Winter+Garden.htm>.

Henny, R. 1985. BA induces lateral branching of *Peperomia obtusifolia*. HortScience 20(1):115-116.

Kawabata, A., J. Lichty, K. Kobayashi, and W. Sahai. 2007. Effects of photoselective shade cloths on potted *Dracaena deremensis* 'Janet Craig' and *Dracaena marginata* 'Colorama'. Journal of Hawaiian and Pacific Agriculture. 14:49-54. 16 November 2011. <hilo.hawaii.edu/academics/cafnrm/research/documents/Andrewkawabata.pdf>.

Latimer, J. 2009. Selecting and using plant growth regulators on floriculture crops. Virginia Cooperative Extension. Publication 430-102.

Leite, C., R. Ito, L. Gerald, R. Ganelevin, and M. Fagnani. 2008. Light spectrum management using colored nets aiming to controlling the growth and the blooming of *Phalaenopsis sp*. Acta Hort. 770:177-184.

Loughrin, J. and M. Kasperbauer. 2001. Light reflected from colored mulches affects aroma and phenol content of sweet basil (*Ocimum basilicum* L.) leaves. J. Agric. Food Chem. 49. 1331-1335.

Mangen, F. and R. VanVranken. 2004. Cilantro coriandrum sativum. World Crops for the Northeastern United States. 5 November 2011. <http://www.worldcrops.org/crops/Cilantro.cfm>.

Nelson, P. 2003. Light and temperature. p. 401-405. In: Greenhouse operation and management. 6th ed. Prentice Hall, New Jersey.

Oren-Shamir, M., E. Gussakovsky, E. Shpiegel, A. Nissim-Levi, K. Ratner, R. Ovadia, Y. Giller, and Y. Shahak. 2001. Coloured shade nets can improve the yield and quality of green decorative branches of *Pittosporum variegatum*. J. Hort. Sci. Biotechnol. 76:353-361.

Shahak, Y., E. Gussakovsky, E. Gal, and R. Ganelevin. 2004. Colornets: crop protection and light-quality manipulation in one technology. Acta Hort. 659:143-151.

Shahak, Y., G. Elazar, Y. Offir, and D. Ben-Yakir. 2008. Photoselective shade netting integrated with greenhouse technologies for improved performance of vegetable and ornamental crops. Acta Hort. 797:75-80.

Stephens, J. 2009. Parsley. University of Florida IFAS Extension. HS 638.

Tucker, A. and T. Debaggio. 2009a. *Coriandrum sativum*. p. 213-216. In: The encyclopedia of herbs. Timber Press, Inc., Portland, Oregon.

Tucker, A. and T. DeBaggio. 2009b. *Petroselinum crispum*. p. 393-396. In: The encyclopedia of herbs. Timber Press, Inc., Portland, Oregon.

USDA. 2010. 2009 Census of Horticultural Specialties. 2007 Census of Agriculture 3:3. http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Census_of_Horticulture/HORTIC.pdf. August 12, 2011.

Figure 5.1. Blue ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia. (Photo by author, 2012)

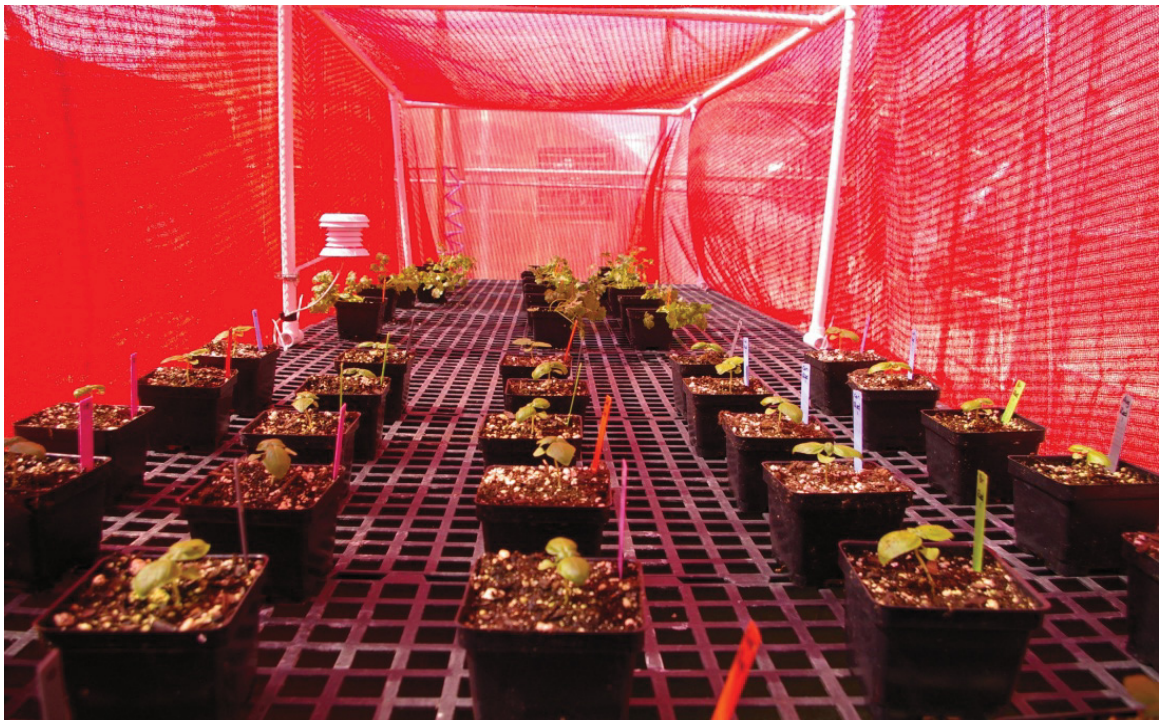

Figure 5.2. Red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia. (Photo by author, 2012)

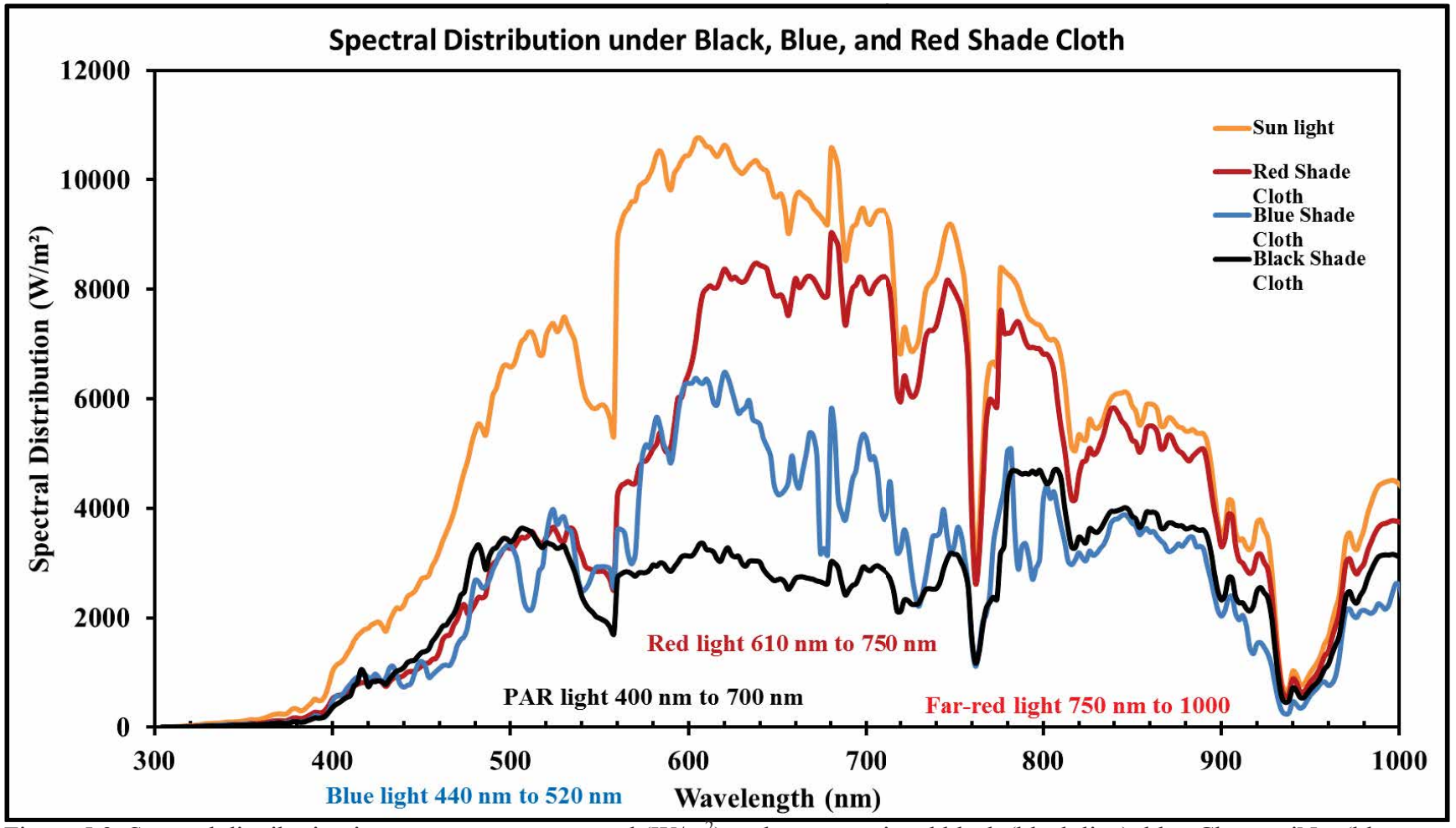

Figure 5.3. Spectral distribution in watts per meter squared (W/m^2) under conventional black (black line), blue ChromatiNet (blue line), and red ChromatiNet (red line) relative to sunlight (gold line). Graph made using a Li-Cor Spectroradiometer Courtesy of Dr. Faust, Clemson University.

Figure 5.4. Conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8 under supplemental lighting started on September 19, 2011; Virginia Tech, Blacksburg, Virginia. (Photo by author, 2012)

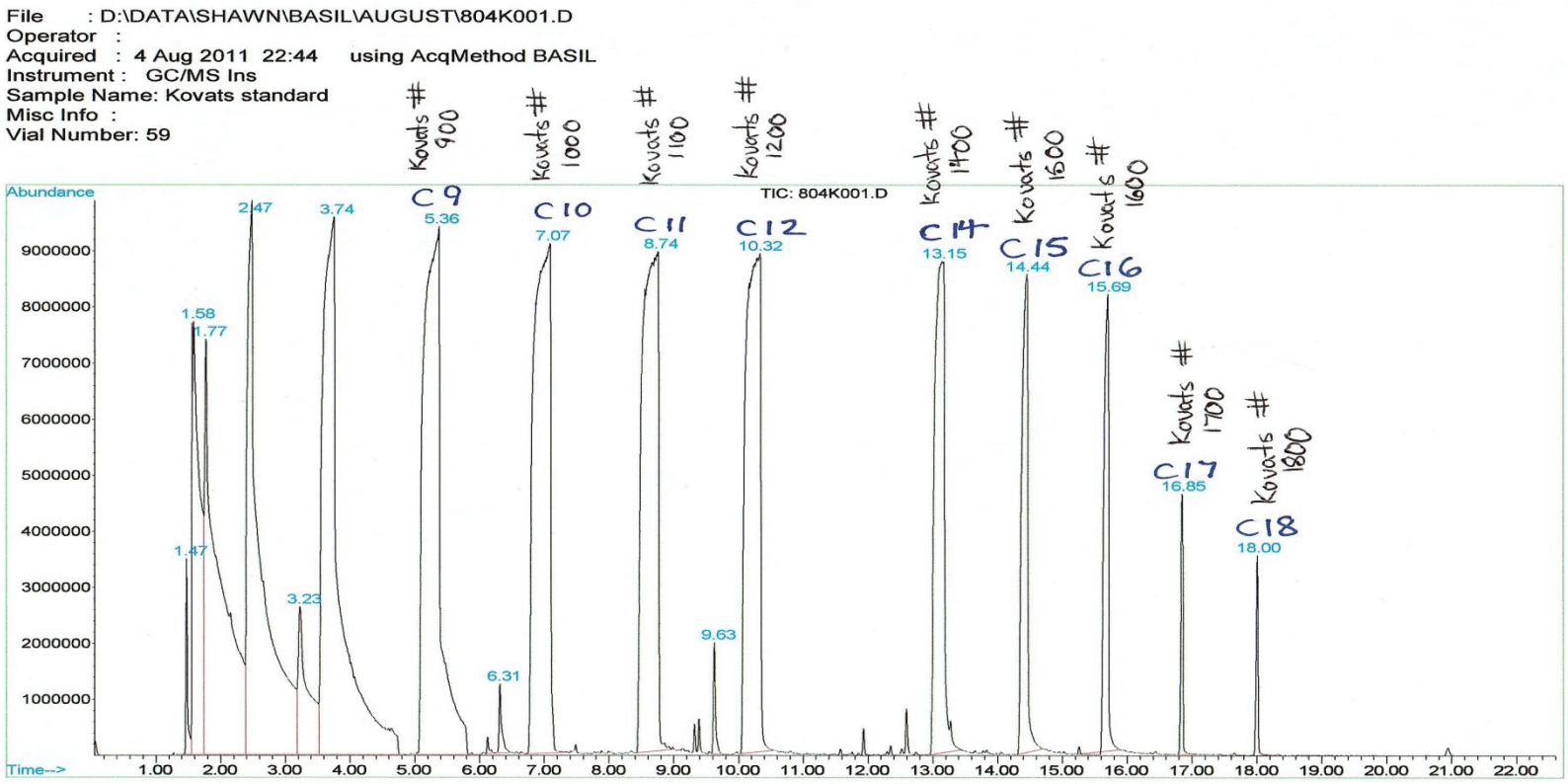

Figure 5.5. Kovats Standards used to confirm the identity of aroma compounds using the Flavornet website.

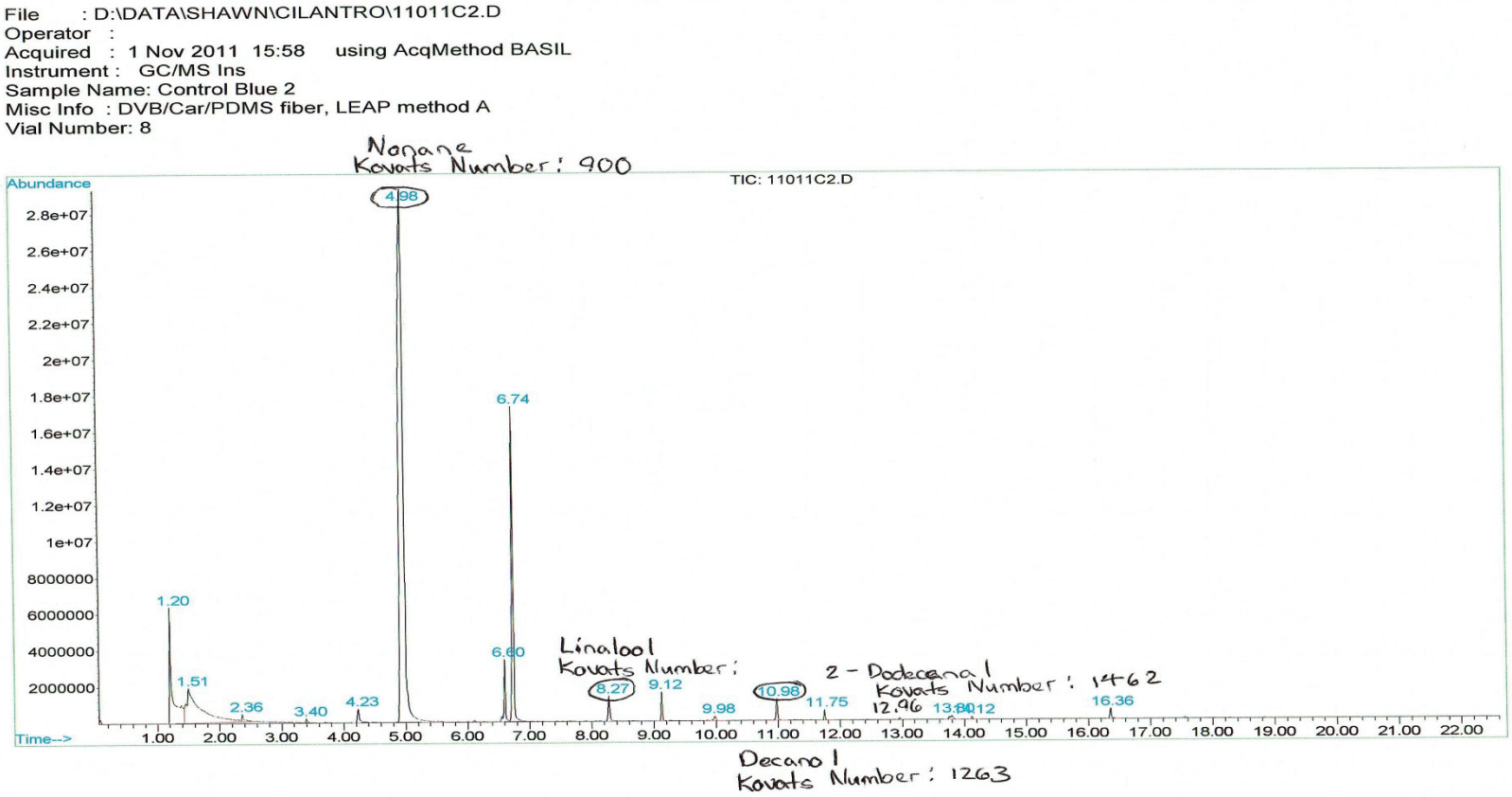

Figure 5.6. Cilantro Volatile Analysis Chromatgram.

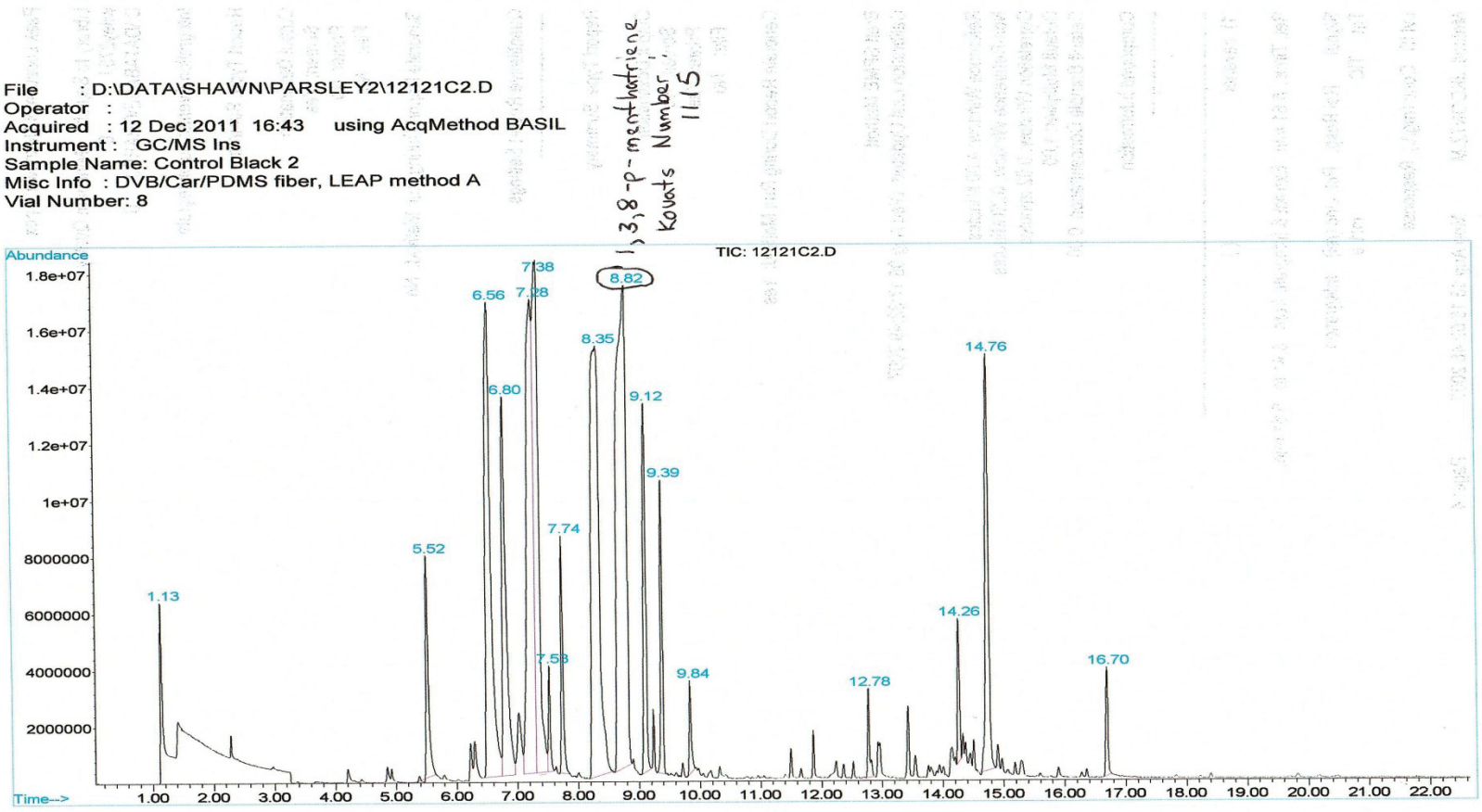

Figure 5.7. Parsley Volatile Analysis Chromatgram.

Table 5.1. Environmental Conditions during Cilantro and Parsley replications.

Species Replication	Date (2011)	Mean DLI (mol•m^{-2}•d^{-1})			Mean Temperature (°C)			Mean RH (%)		
		Black	Blue	Red	Black	Blue	Red	Black	Blue	Red
Cilantro Replication 1	5/24-6/14	16.8	16.0	16.5	25.7	26.0	26.3	62.9	63.0	62.9
Cilantro Replication 2	7/6-7/22	13.7	12.5	12.8	27.8	27.5	27.7	64.3	64.1	64.3
Cilantro Replication 3	10/11-10/31	8.1	7.7	8.5	21.9	21.8	21.8	49.4	51.1	49.1
Cilantro Replication 4	12/19-1/13/12	4.2	3.9	5.4	20.1	19.9	19.5	35.2	37.0	36.2
Parsley Replication 1	5/24-6/16	17.3	15.5	16.2	25.7	26.0	26.3	62.9	63.0	62.9
Parsley Replication 2	11/15-12/9	5.0	4.5	5.5	20.5	20.1	20.4	50.3	52.1	50.3

[X]Supporting data in Appendix 5.1

Table 5.2. *Cilantro Replication 1*. Effect of shade color and PGR treatment on plant height, width, number of leaf stalks, and shoot fresh weight at 20 days after treatment (DAT). (n = 6)

	Height (cm)	**Width (cm)**	**Number of Leaf Stalks**	**Shoot Fresh Weight (g)**
Shade Cloth Color				
Black Shade	23.9b[X]	36.0	25.6b	40.3b
Blue Shade	23.8b	36.1	25.6b	39.9b
Red Shade	26.9a	36.0	30.2a	62.5a
Color effect	< 0.0001	0.9814	< 0.0001	< 0.0001
LSD	0.65	0.84	1.17	2.92
PGR Treatment				
Control	25.0ab	37.8a	28.1ab	50.0
Dikegulac sodium	25.1ab	36.9a	26.3ab	48.3
Benzyladenine	24.1ab	37.3a	29.5a	50.0
Ethephon	26.3a	36.0a	26.9ab	47.8
Brushing	23.9b	32.4b	25.0b	41.6
PGR effect	0.0396	< 0.0001	0.0331	0.1581
LSD	0.83	1.09	1.51	3.77
Shade Color*PGR	0.2871	0.4144	0.7501	0.9538

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 5.3. *Cilantro Replication 2*. Effect of shade color and PGR treatment on plant height, width, number of leaf stalks, and shoot fresh weight at 16 days after treatment (DAT). (n = 6)

	Height (cm)	**Width (cm)**	**Number of Leaf Stalks**	**Shoot Fresh Weight (g)**
Shade Cloth Color				
Black Shade	12.8a[X]	17.7ab	17.3a	7.4a
Blue Shade	10.3b	16.4b	14.6b	5.5b
Red Shade	12.5a	17.9a	15.4b	7.7a
Color effect	< 0.0001	0.034	< 0.0001	< 0.0001
LSD	0.48	0.62	0.58	0.53
PGR Treatment				
Control	12.2	17.4	15.7	6.6
Dikegulac sodium	11.6	17.5	15.4	6.4
Benzyladenine	11.8	17.2	16.2	7.5
PGR effect	0.4603	0.8932	0.3282	0.0794
LSD	0.48	0.62	0.58	0.53
Shade Color*PGR	0.1965	0.3370	0.1569	0.0771

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 5.4. *Cilantro Replication 3*. Effect of shade color and PGR treatment on plant height, width, number of leaf stalks, and shoot fresh weight at 20 days after treatment (DAT). (n = 6)

	Height (cm)	**Width (cm)**	**Number of Leaf Stalks**	**Shoot Fresh Weight (g)**
Shade Cloth Color				
Black Shade	19.6a[X]	27.2a	16.8	17.3b
Blue Shade	17.4b	24.2b	17.4	16.1b
Red Shade	20.7a	26.4a	17.8	21.3a
Color effect	0.0003	0.001	0.1576	< 0.0001
LSD	0.82	0.82	0.55	0.8
PGR Treatment				
Control	20.9a	27.9a	17.3	20.8a
Dikegulac sodium	18.1ab	24.5b	17.8	16.1c
Benzyladenine	20.2ab	27.6a	17.7	20.3ab
Ethephon	19.0ab	24.1b	17.0	16.5c
Brushing	18.0b	25.4ab	16.7	17.5bc
PGR effect	0.0219	0.0003	0.5099	< 0.0001
LSD	1.06	1.06	0.72	1.04
Shade Color*PGR	0.5907	0.3856	0.1027	0.1348

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 5.5. *Cilantro Replication 4*. Effect of shade color and PGR treatment on plant height, width, number of leaf stalks, and shoot fresh weight at 25 days after treatment (DAT). (n = 6)

	Height (cm)	**Width (cm)**	**Number of Leaf Stalks**	**Shoot Fresh Weight (g)**
Shade Cloth Color				
Black Shade	14.0a[X]	16.7b	13.6	6.7b
Blue Shade	11.8b	16.2b	14.5	5.9b
Red Shade	14.3a	20.5a	14.7	10.0a
Color effect	< 0.0001	< 0.0001	0.0792	< 0.0001
LSD	0.59	0.63	0.54	0.44
PGR Treatment				
Control	15.2a	18.4ab	13.5b	8.0a
Dikegulac sodium	13.0b	19.1a	14.0b	7.9ab
Benzyladenine	12.6b	17.2ab	16.1a	7.7ab
Ethephon	13.4ab	16.6b	13.8b	7.6b
Brushing	12.7b	17.6ab	13.9b	6.4ab
PGR effect	0.0027	0.0236	0.0004	0.0328
LSD	0.75	0.81	0.65	0.56
Shade Color*PGR	0.2090	0.6948	0.1892	0.7883

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 5.6. *Parsley Replication 1*. Effect of shade color and PGR treatment on plant height, width, number of leaf stalks, and shoot fresh weight at 22 days after treatment (DAT). (n = 6)

	Height (cm)	**Width (cm)**	**Number of Leaf Stalks**	**Shoot Fresh Weight (g)**
Shade Cloth Color				
Black Shade	18.0b[X]	31.5ab	11.9ab	15.5b
Blue Shade	18.1b	30.2b	11.5b	14.3b
Red Shade	19.2a	32.9a	13.2a	17.8a
Color effect	0.0053	0.0109	0.0149	0.0006
LSD	0.67	0.89	0.62	0.92
PGR Treatment				
Control	21.8a	33.2a	11.5	16.3a
Dikegulac sodium	22.1a	34.2a	13.1	16.9a
Benzyladenine	21.5ab	31.1a	13.0	16.8a
Ethephon	21.4ab	32.6a	11.8	16.5a
Brushing	19.2b	26.7b	11.8	13.1b
PGR effect	0.0110	< 0.0001	0.1479	0.0072
LSD	0.87	1.15	0.80	1.18
Shade Color*PGR	0.8153	0.9496	0.8663	0.9266

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 5.7. *Parsley Replication 2*. Effect of shade color and PGR treatment on plant height, width, number of leaf stalks, and shoot fresh weight at 24 days after treatment (DAT). (n = 6)

	Height (cm)	**Width (cm)**	**Number of Leaf Stalks**	**Shoot Fresh Weight (g)**
Shade Cloth Color				
Black Shade	17.8b[X]	24.9ab	8.5	10.4b
Blue Shade	18.3b	24.3b	8.0	8.8c
Red Shade	19.9a	26.2a	8.4	11.7a
Color effect	0.0005	0.0246	0.0719	< 0.0001
LSD	0.57	0.68	0.22	0.47
PGR Treatment				
Control	20.0ab	26.2ab	8.2b	11.3b
Dikegulac sodium	16.7c	23.9bc	8.1b	8.1c
Benzyladenine	20.7a	27.5a	9.2a	13.1a
Ethephon	18.2bc	25.4ab	8.0b	9.3c
Brushing	17.7c	22.6c	8.0b	9.6c
PGR effect	< 0.0001	< 0.0001	< 0.0001	< 0.0001
LSD	0.73	0.89	0.29	0.61
Shade Color*PGR	0.1974	0.1841	0.3343	0.3330

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Table 5.8. *Cilantro Replication 3*. Mean peak area of main volatile compounds. (n = 3)

	Nonane	**Linalool**	**Decanol**
Shade Cloth Color			
Black Shade	1.89×10^9ab[X]	4.67×10^7	3.44×10^7
Blue Shade	2.15×10^9a	8.86×10^7	7.42×10^7
Red Shade	1.86×10^9b	6.27×10^7	6.81×10^7
Color effect	0.0312	0.1462	0.2069
LSD	1.14×10^8	2.09×10^7	2.35×10^7
PGR treatment			
Control	1.93×10^9	7.98×10^7	8.10×10^7
Dikegulac sodium	1.79×10^9	4.77×10^7	6.95×10^7
Benzyladenine	1.99×10^9	7.35×10^7	3.88×10^7
Ethephon	2.00×10^9	4.54×10^7	5.80×10^7
Brushing	2.12×10^9	8.36×10^7	4.71×10^7
PGR effect	0.2790	0.4727	0.6515
LSD	1.47×10^8	2.69×10^7	3.04×10^7
Shade Color*PGR	0.4634	0.8707	0.6400

[X] Any two means within a column not followed by the same letter are significantly different at $P \leq 0.05$ using the Tukey-Kramer HSD

Table 5.9. *Cilantro Replication 4*. Mean peak area of main volatile compounds. (n = 3)

	Nonane	**Linalool**	**Decanol**	**2-dodecenal**
Shade Cloth Color				
Black Shade	2.22×10^9	3.26×10^8	1.69×10^8ab[X]	6.21×10^7
Blue Shade	2.50×10^9	2.63×10^8	1.12×10^8b	5.94×10^7
Red Shade	2.38×10^9	3.27×10^8	2.54×10^8a	6.61×10^7
Color effect	0.1229	0.1762	0.0403	0.7732
LSD	1.29×10^8	3.82×10^7	5.36×10^7	9.31×10^6
PGR Treatment				
Control	2.28×10^9	3.59×10^8	1.19×10^8b	5.35×10^7
Dikegulac sodium	2.46×10^9	2.97×10^8	3.42×10^8a	6.47×10^7
Benzyladenine	2.21×10^9	2.61×10^8	7.80×10^7b	6.07×10^7
Ethephon	2.39×10^9	3.19×10^8	1.73×10^8ab	6.28×10^7
Brushing	2.49×10^9	2.92×10^8	1.79×10^8ab	7.11×10^7
PGR effect	0.4313	0.3826	0.0078	0.6922
LSD	1.67×10^8	4.93×10^7	6.92×10^7	1.20×10^7
Shade Color*PGR	0.9301	0.6738	0.3362	0.7977

[X] Any two means within a column not followed by the same letter are significantly different at $P \leq 0.05$ using the Tukey-Kramer HSD

Table 5.10. *Parsley Replication 1*.
Mean peak area of main volatile compounds. (n = 3)

	1,3,8-p-menthatriene
Shade Cloth Color	
Black Shade	$1.82 \times 10^9 b^X$
Blue Shade	$2.34 \times 10^9 ab$
Red Shade	$2.83 \times 10^9 a$
p-value	0.0109
LSD	2.87×10^8
PGR Treatment	
Control	2.11×10^9
Dikegulac sodium	2.23×10^9
Benzyladenine	2.25×10^9
Ethephon	2.34×10^9
Brushing	2.72×10^9
p-value	0.5561
LSD	3.70×10^8
Shade Color*PGR	0.9399

[X] Any two means within a column not followed by the same letter are significantly different at $P \leq 0.05$ using the Tukey-Kramer HSD

Table 5.11. *Parsley Replication 2*.
Mean peak area of main volatile compounds. (n = 3)

	1,3,8-p-menthatriene
Shade Cloth Color	
Black Shade	2.47×10^9ab[X]
Blue Shade	1.49×10^9b
Red Shade	3.16×10^9a
Color effect	0.0173
LSD	5.52×10^8
PGR Treatment	
Control	1.79×10^9
Dikegulac sodium	2.11×10^9
Benzyladenine	2.54×10^9
Ethephon	2.94×10^9
Brushing	2.48×10^9
PGR effect	0.5568
LSD	7.12×10^8
Shade Color* PGR	0.8676

[X] Any two means within a column not followed by the same letter are significantly different at P≤ 0.05 using the Tukey-Kramer HSD

Appendix 5.1. DLI, Temperature, and Relative Humidity Graphs for Cilantro and Parsley Replications

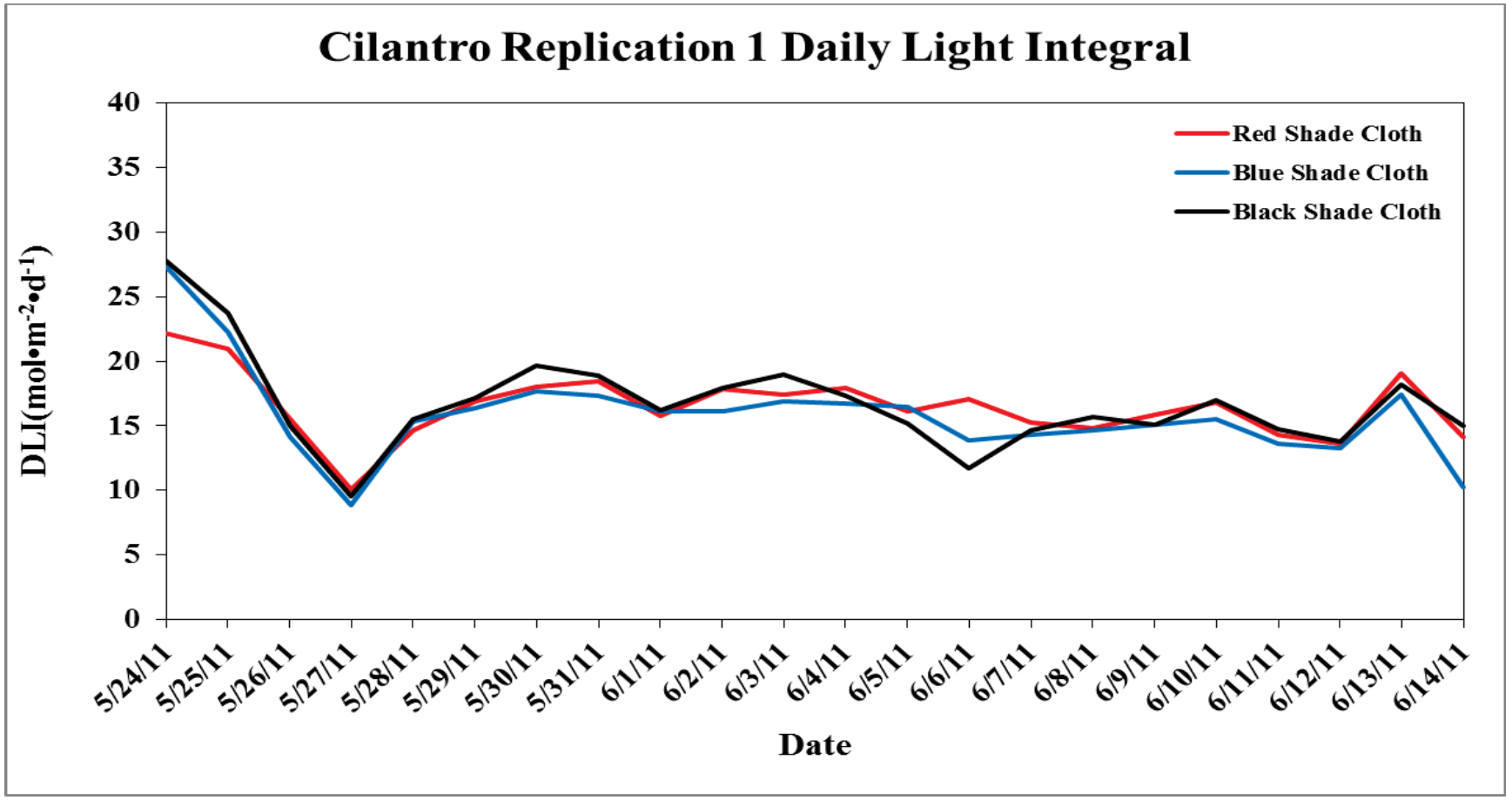

Figure 5.1a. *Cilantro Replication 1*. Daily light integral (DLI mol•m^{-2}•d^{-1}) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia. Unshaded data logger was not saving data correctly during experiment.

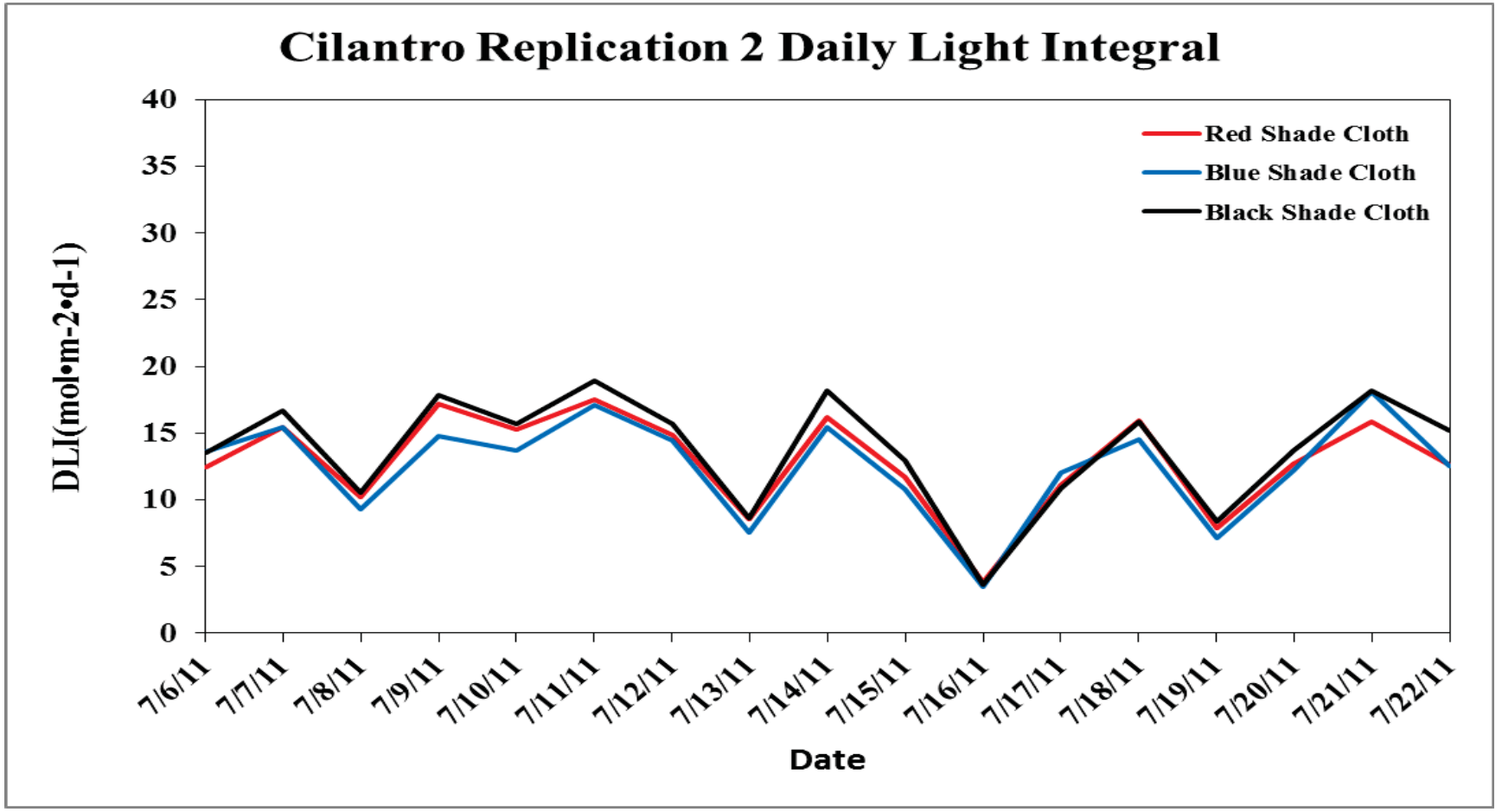

Figure 5.2a. *Cilantro Replication 2*. Daily light integral (DLI mol•m^{-2}•d^{-1}) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia. Unshaded data logger was not saving data correctly during experiment.

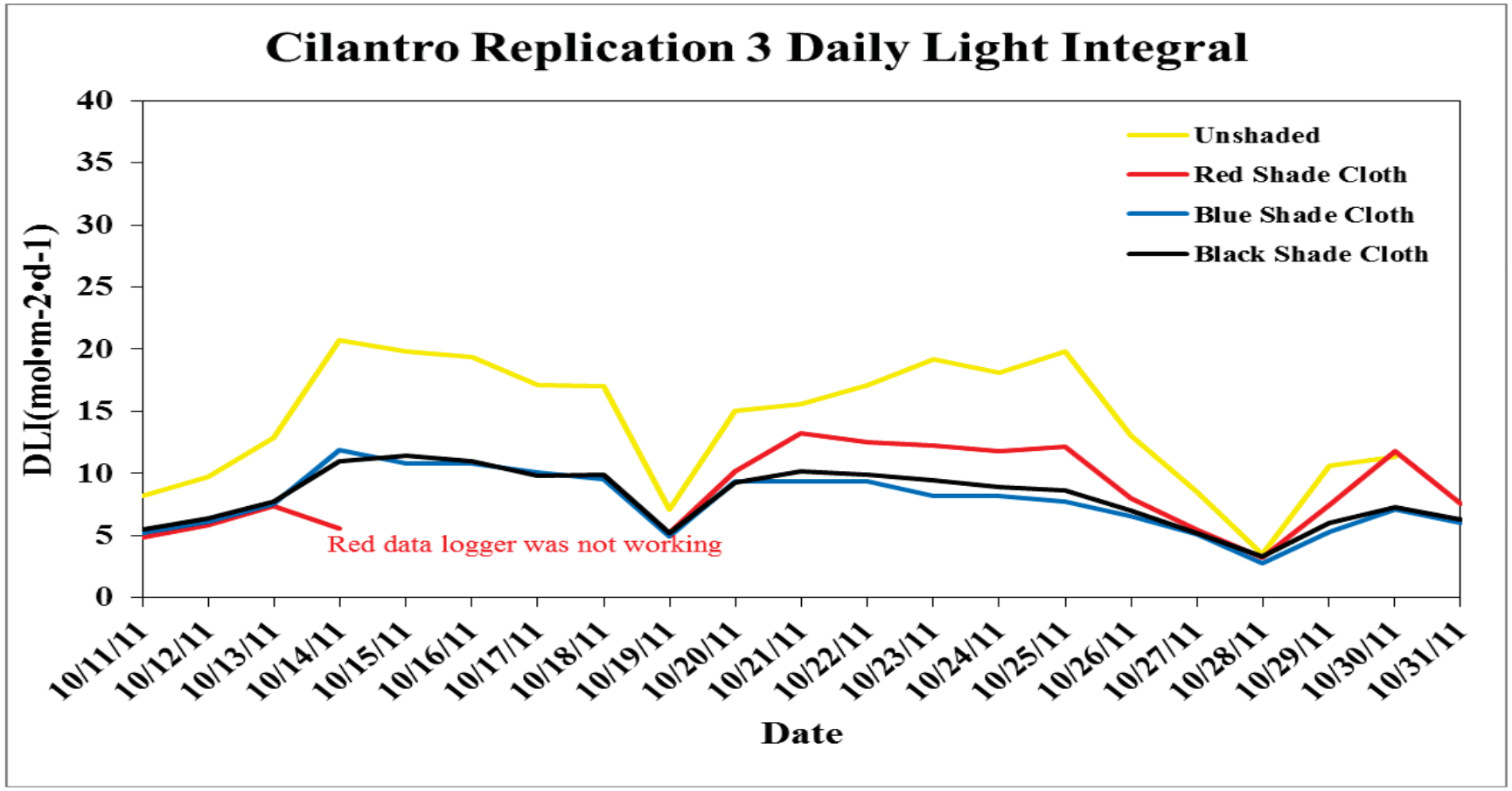

Figure 5.3a. *Cilantro Replication 3*. Daily light integral (DLI mol•m^{-2}•d^{-1}) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

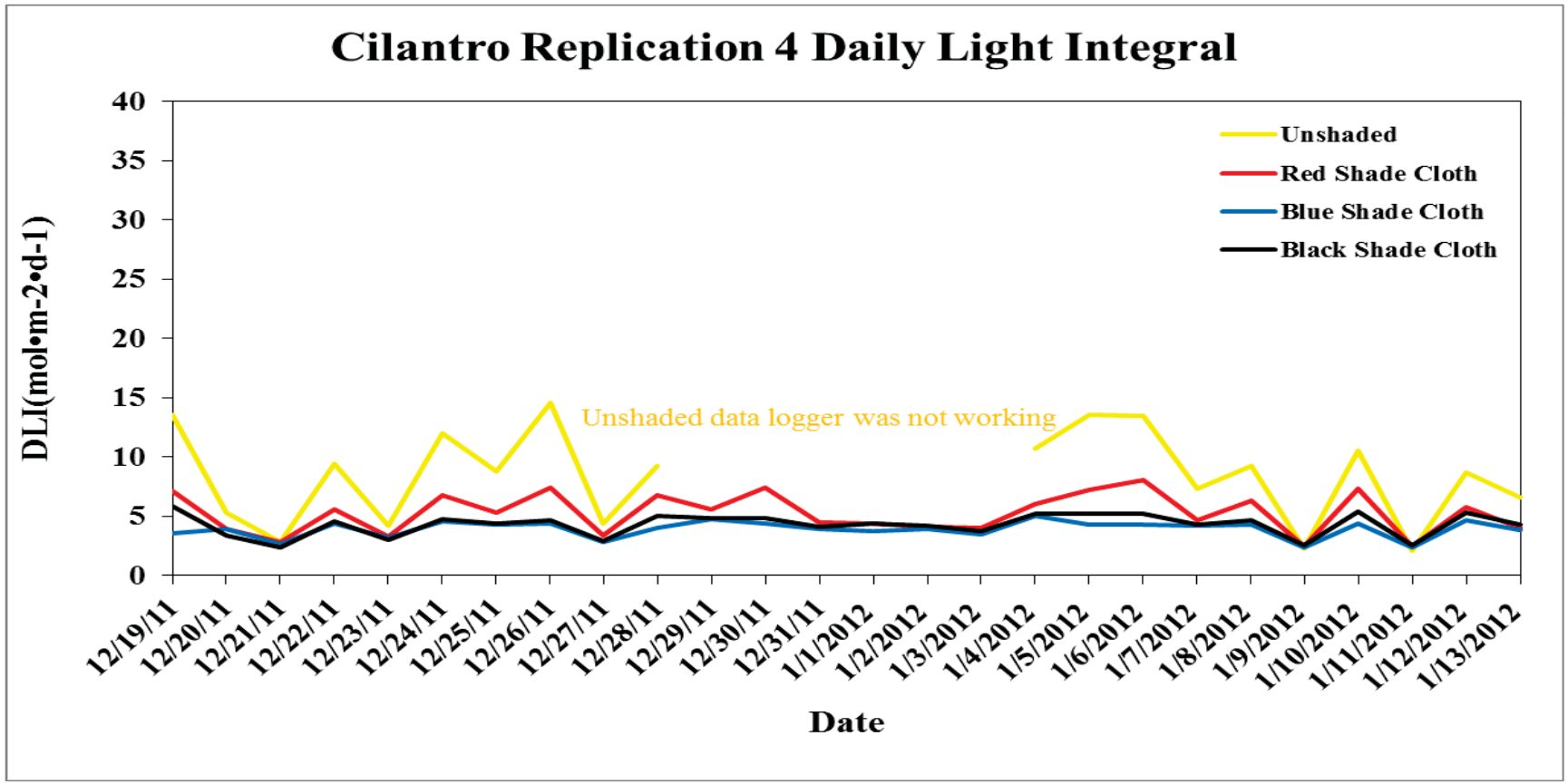

Figure 5.4a. *Cilantro Replication 4*. Daily light integral (DLI mol•m^{-2}•d^{-1}) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

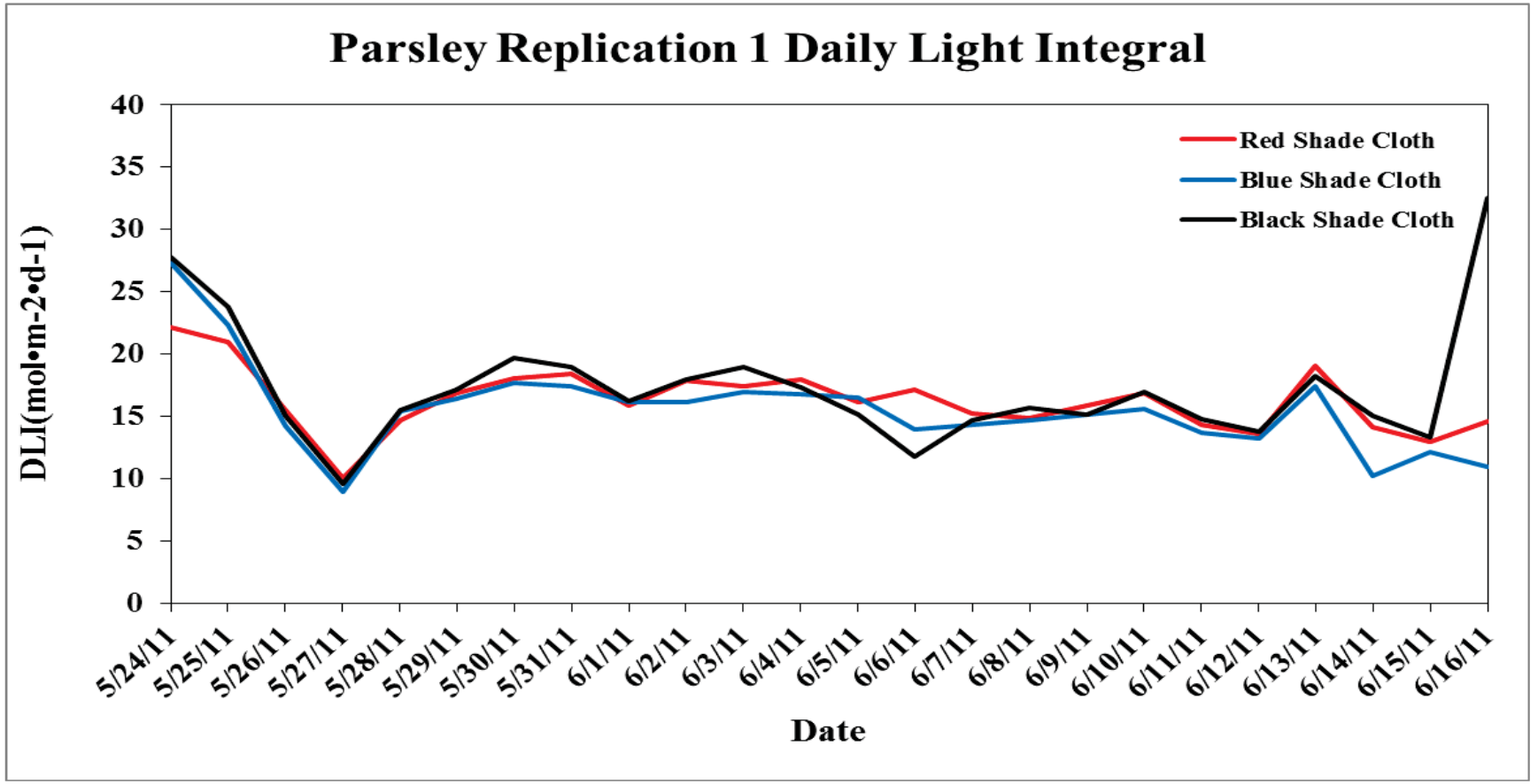

Figure 5.5a. *Parsley Replication 1*. Daily light integral (DLI mol•m^{-2}•d^{-1}) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia. Unshaded data logger was not saving data correctly during experiment.

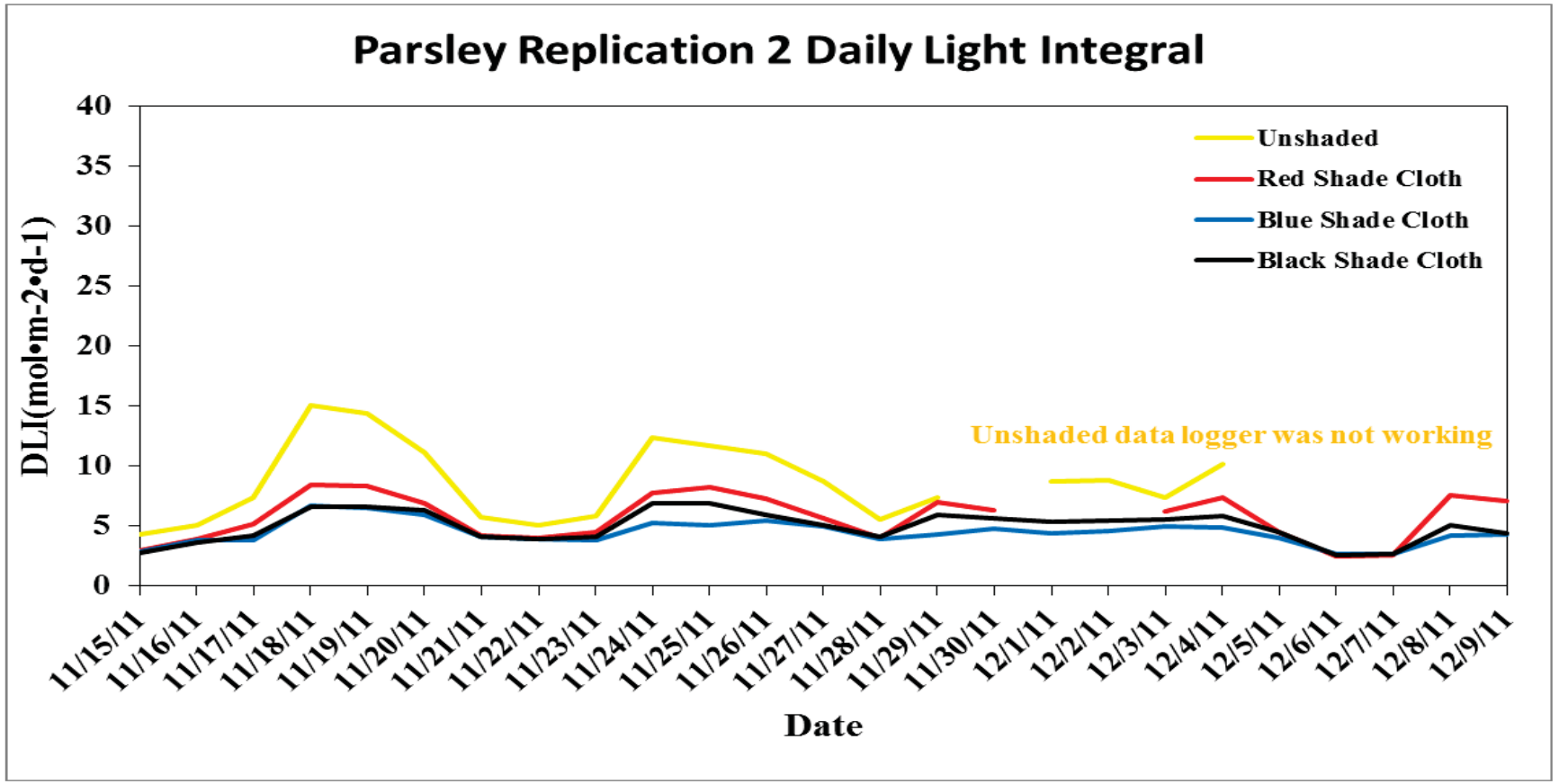

Figure 5.6a. *Parsley Replication 2*. Daily light integral (DLI mol•m^{-2}•d^{-1}) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia. Unshaded data logger was not saving data correctly during experiment.

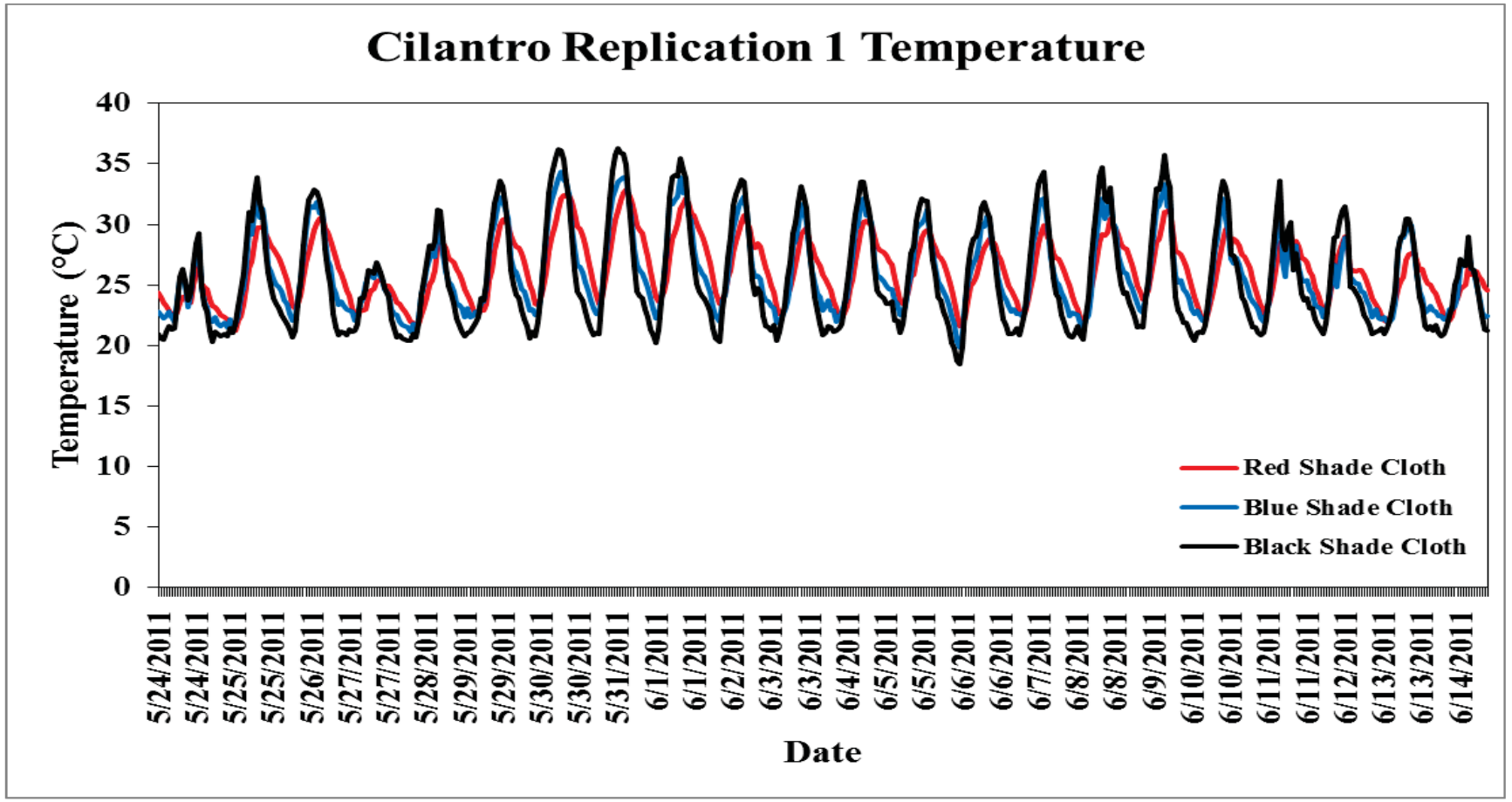

Figure 5.7a. *Cilantro Replication 1*. Temperature (°C) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

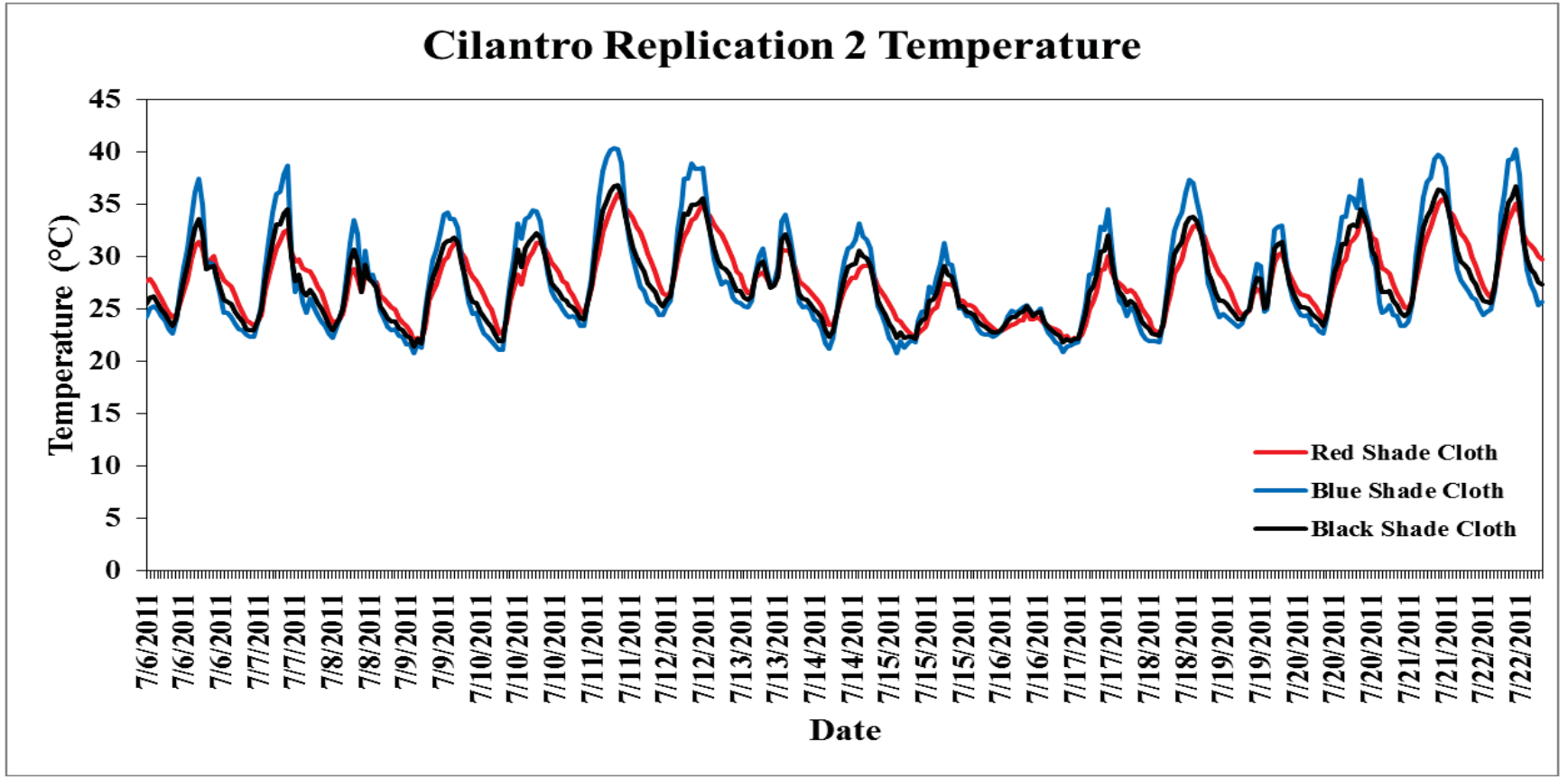

Figure 5.8a. *Cilantro Replication 2*. Temperature (°C) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

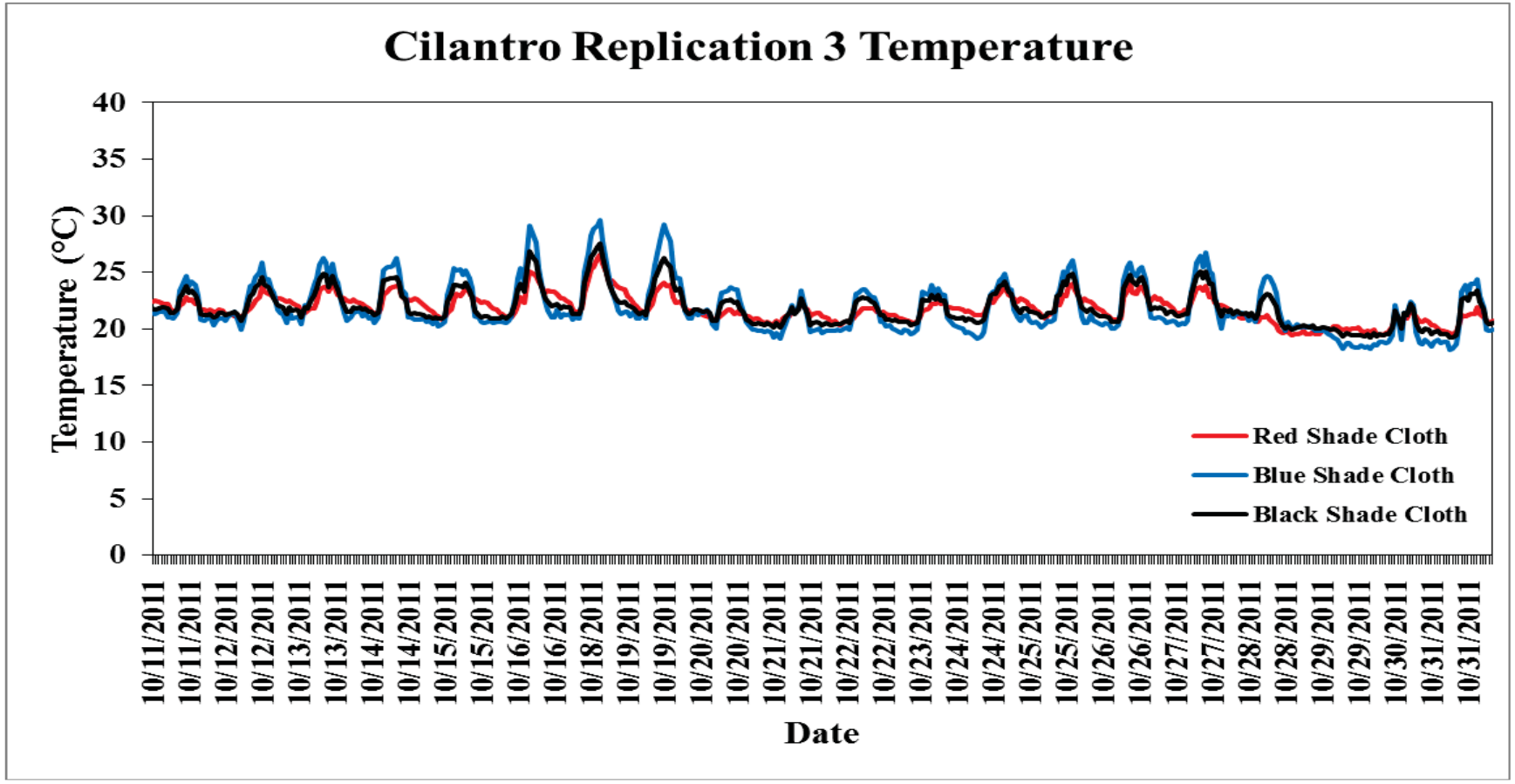

Figure 5.9a. *Cilantro Replication 3*. Temperature (°C) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

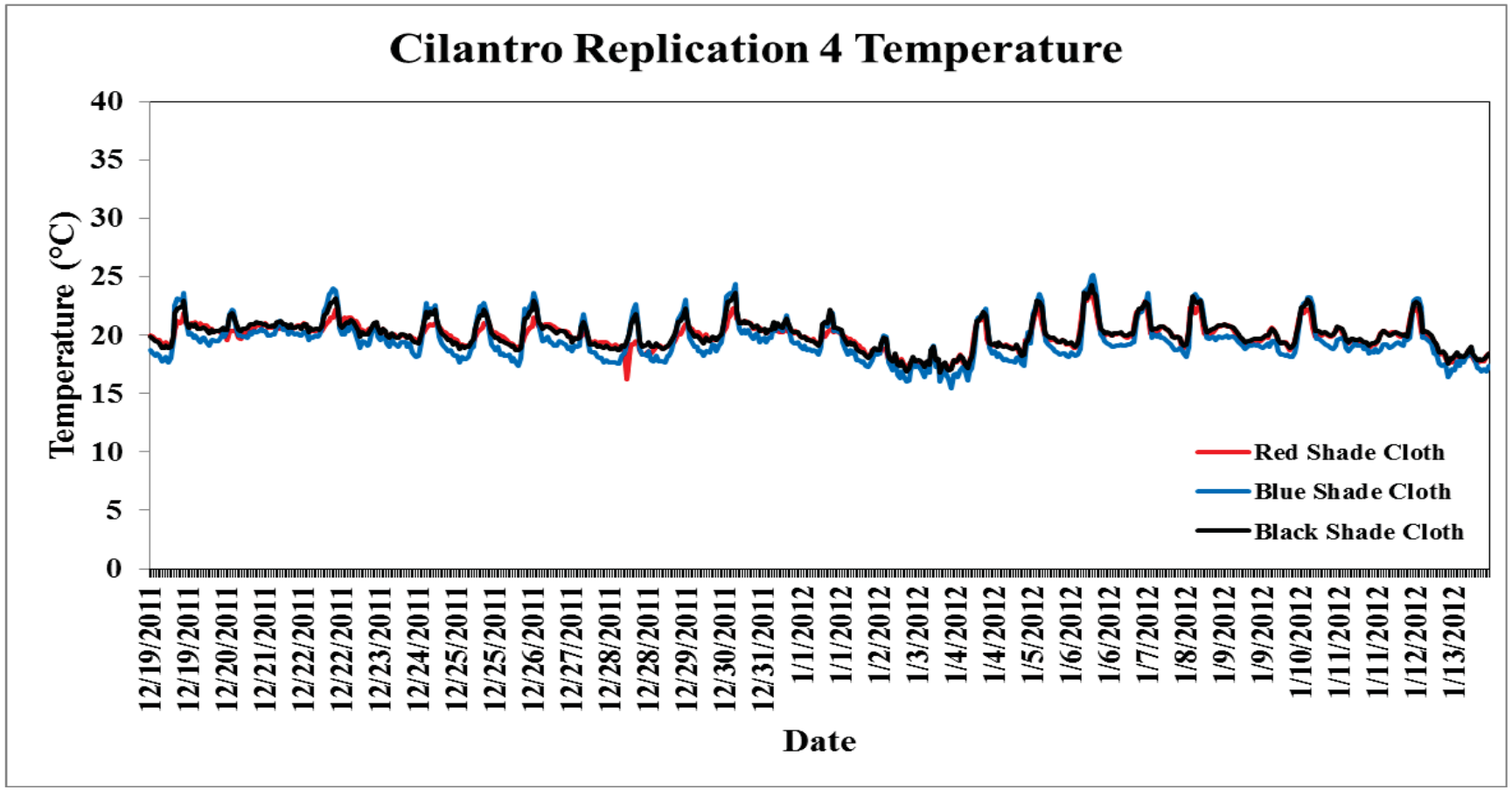

Figure 5.10a. *Cilantro Replication 4*. Temperature (°C) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

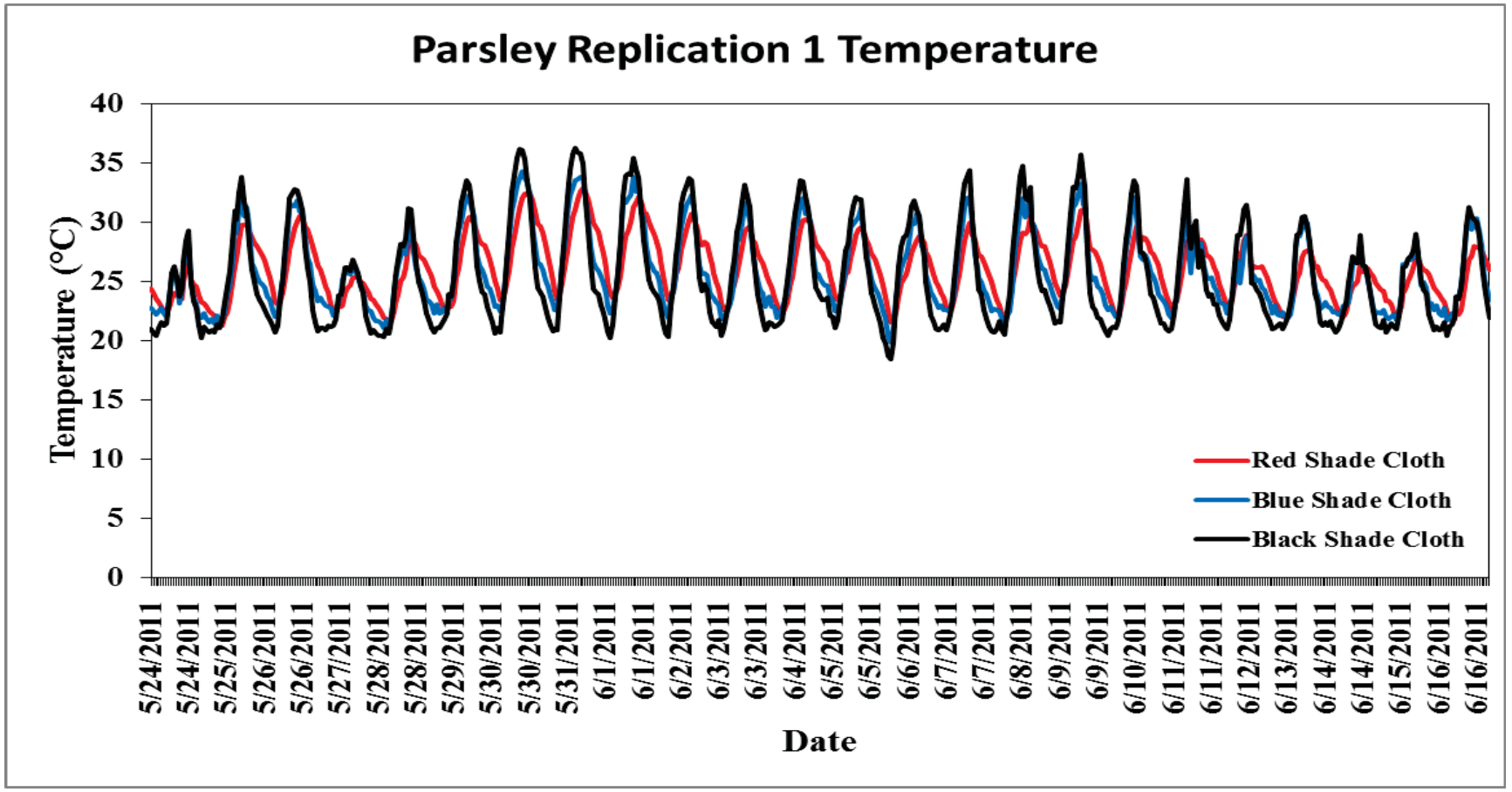

Figure 5.11a. *Parsley Replication 1*. Temperature (°C) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

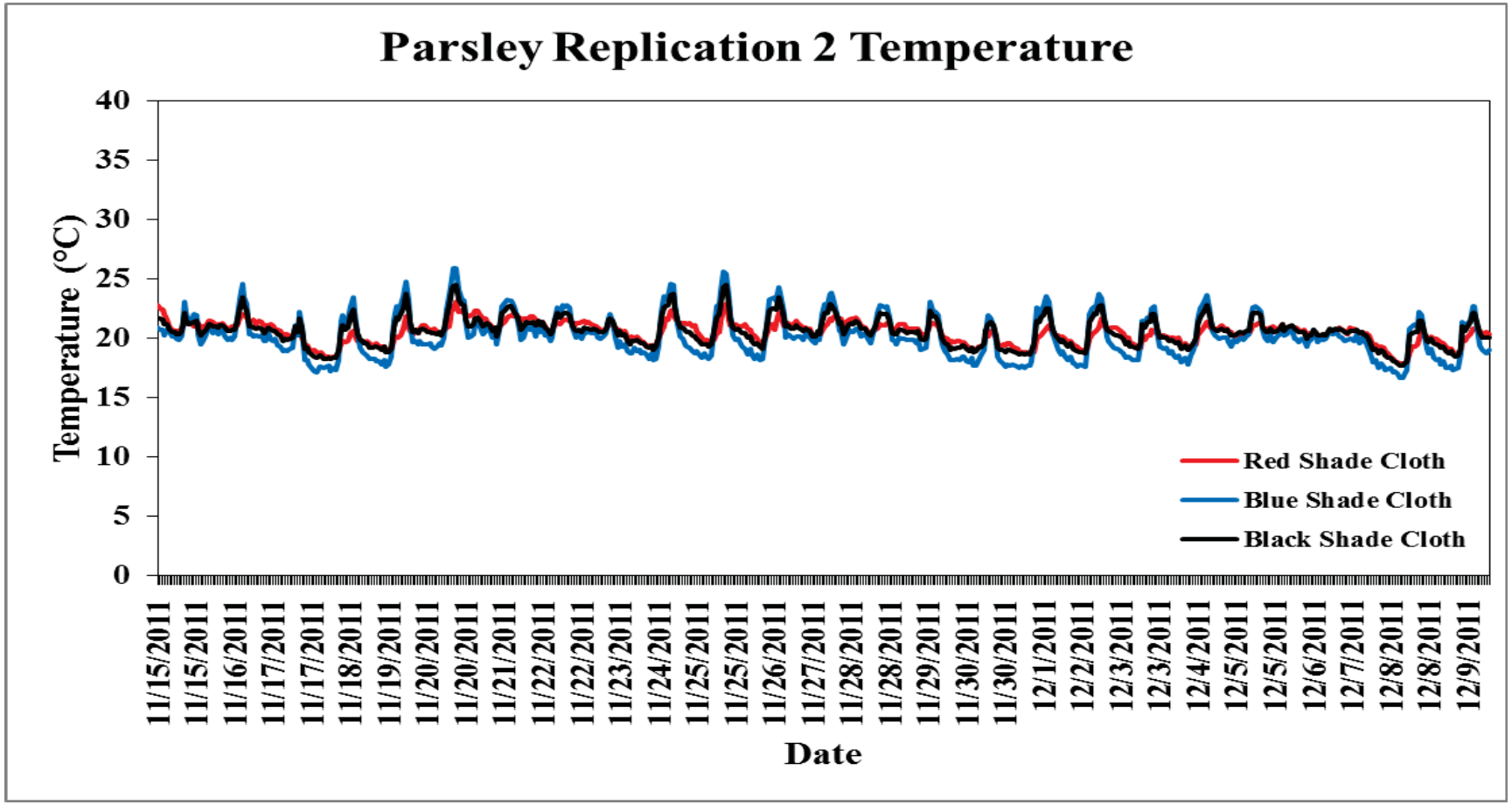

Figure 5.12a. *Parsley Replication 2*. Temperature (°C) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

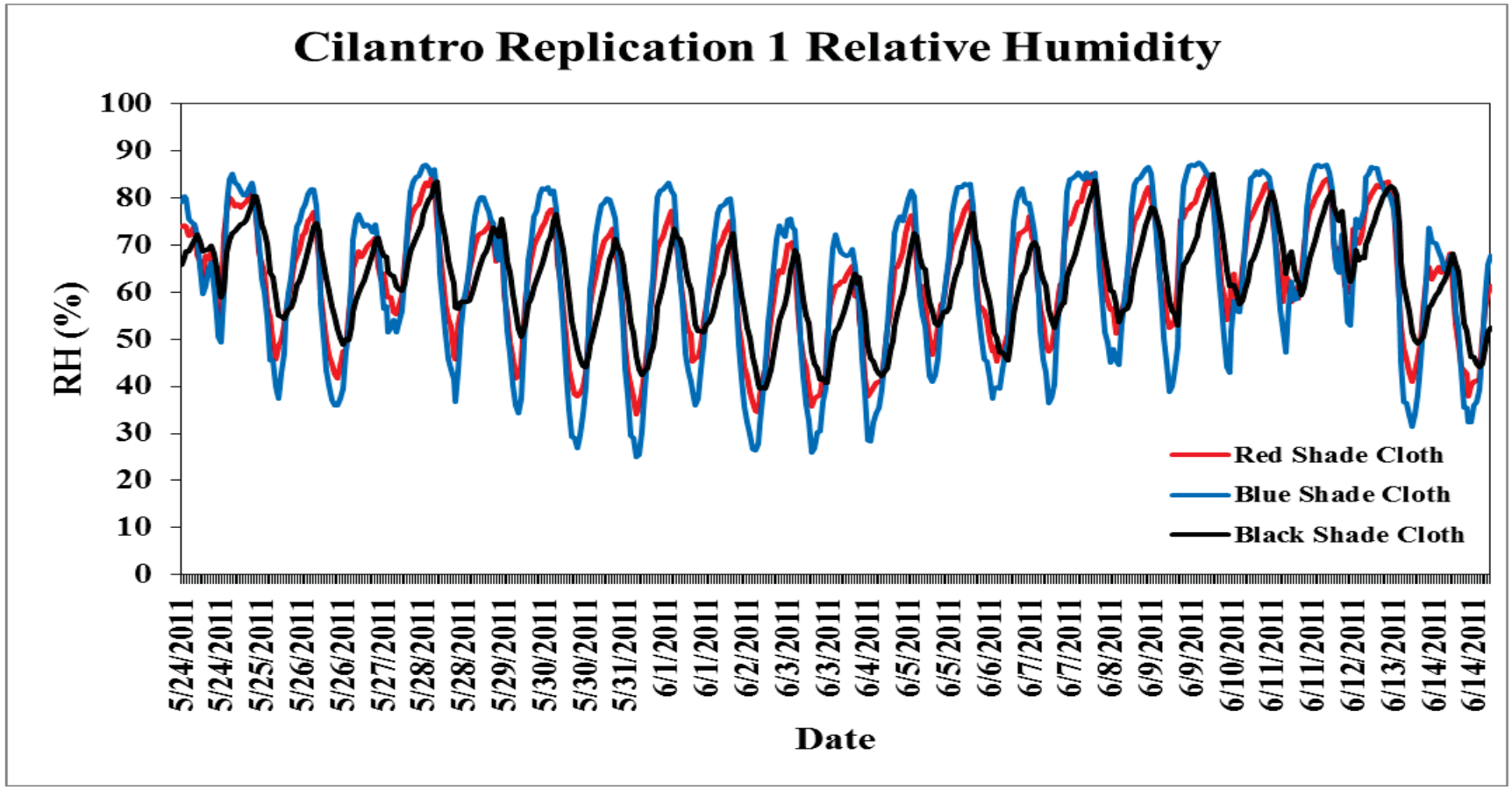

Figure 5.13a. *Cilantro Replication 1*. Relative humidity (%) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

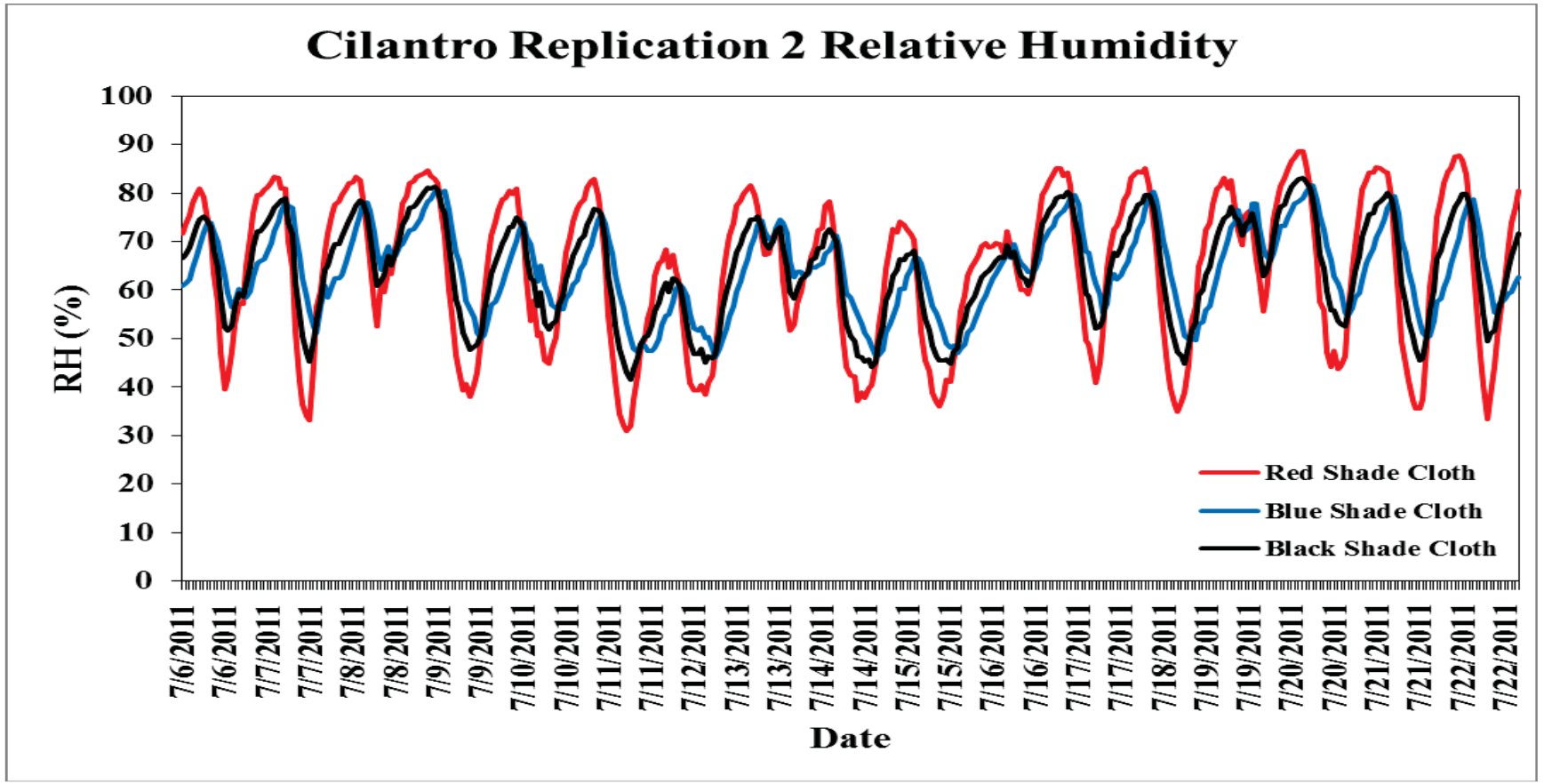

Figure 5.14a. *Cilantro Replication 2*. Relative humidity (%) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

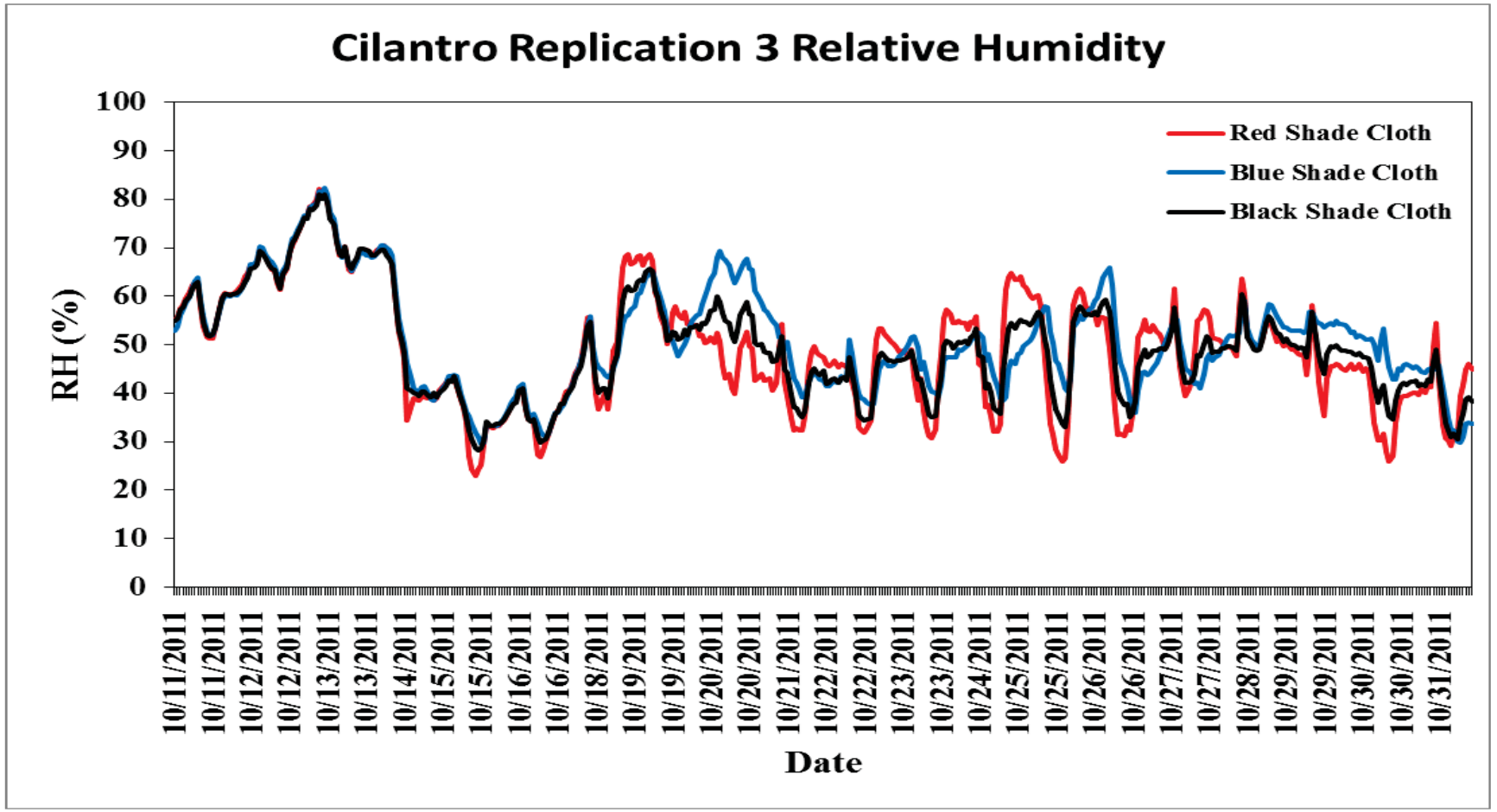

Figure 5.15a. *Cilantro Replication 3*. Relative humidity (%) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

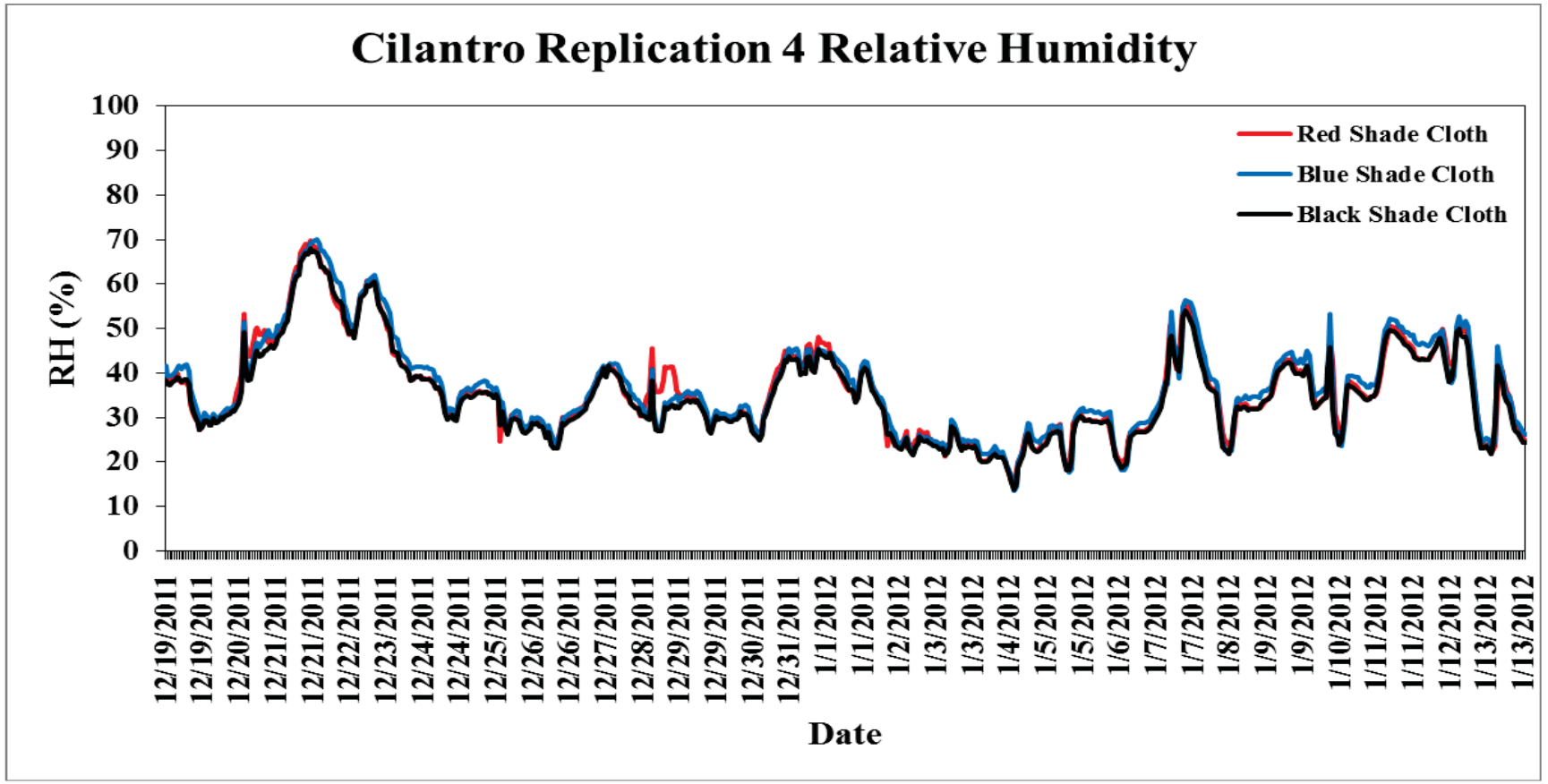

Figure 5.15a. *Cilantro Replication 4*. Relative humidity (%) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

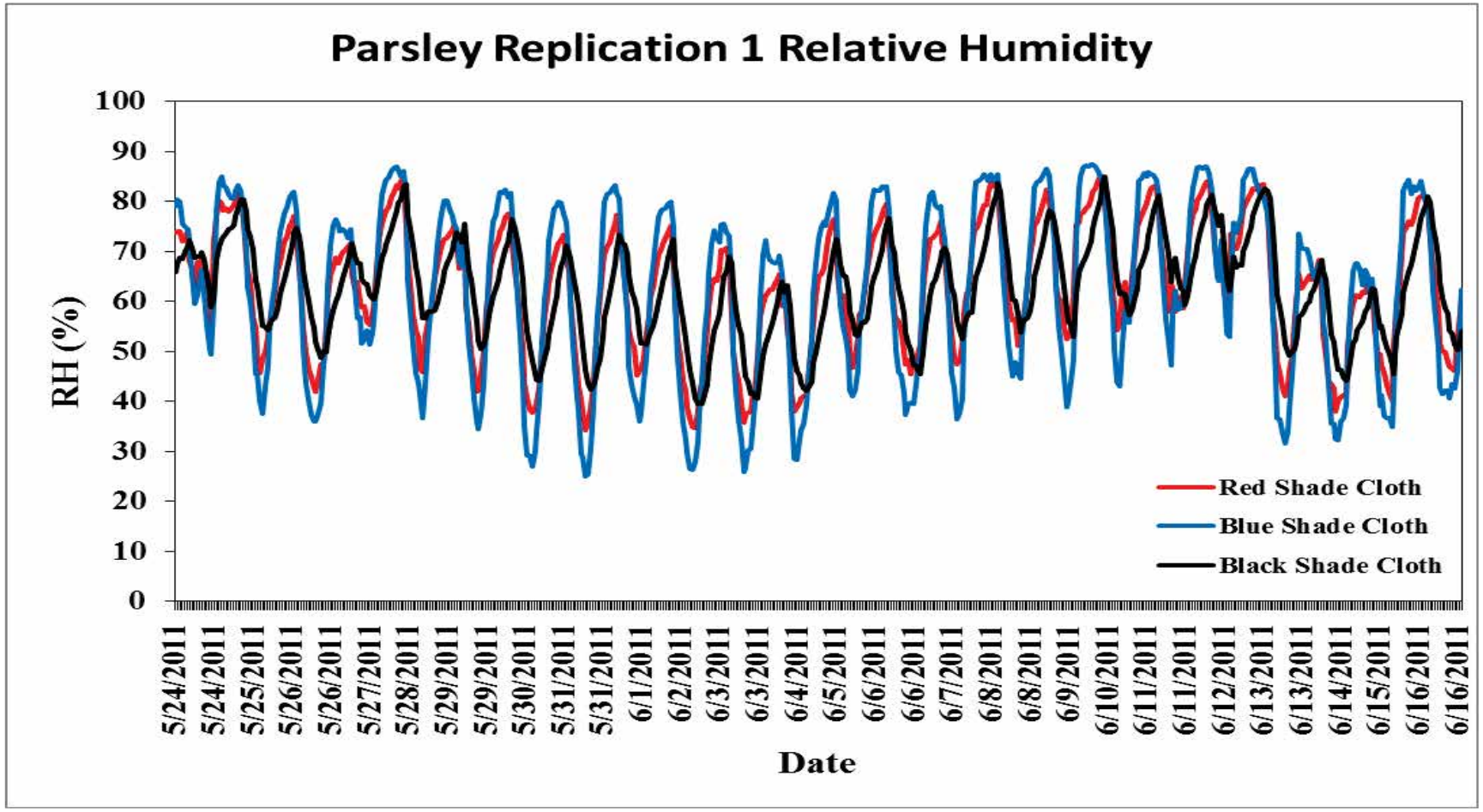

Figure 5.17a. *Parsley Replication 1*. Relative humidity (%) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.

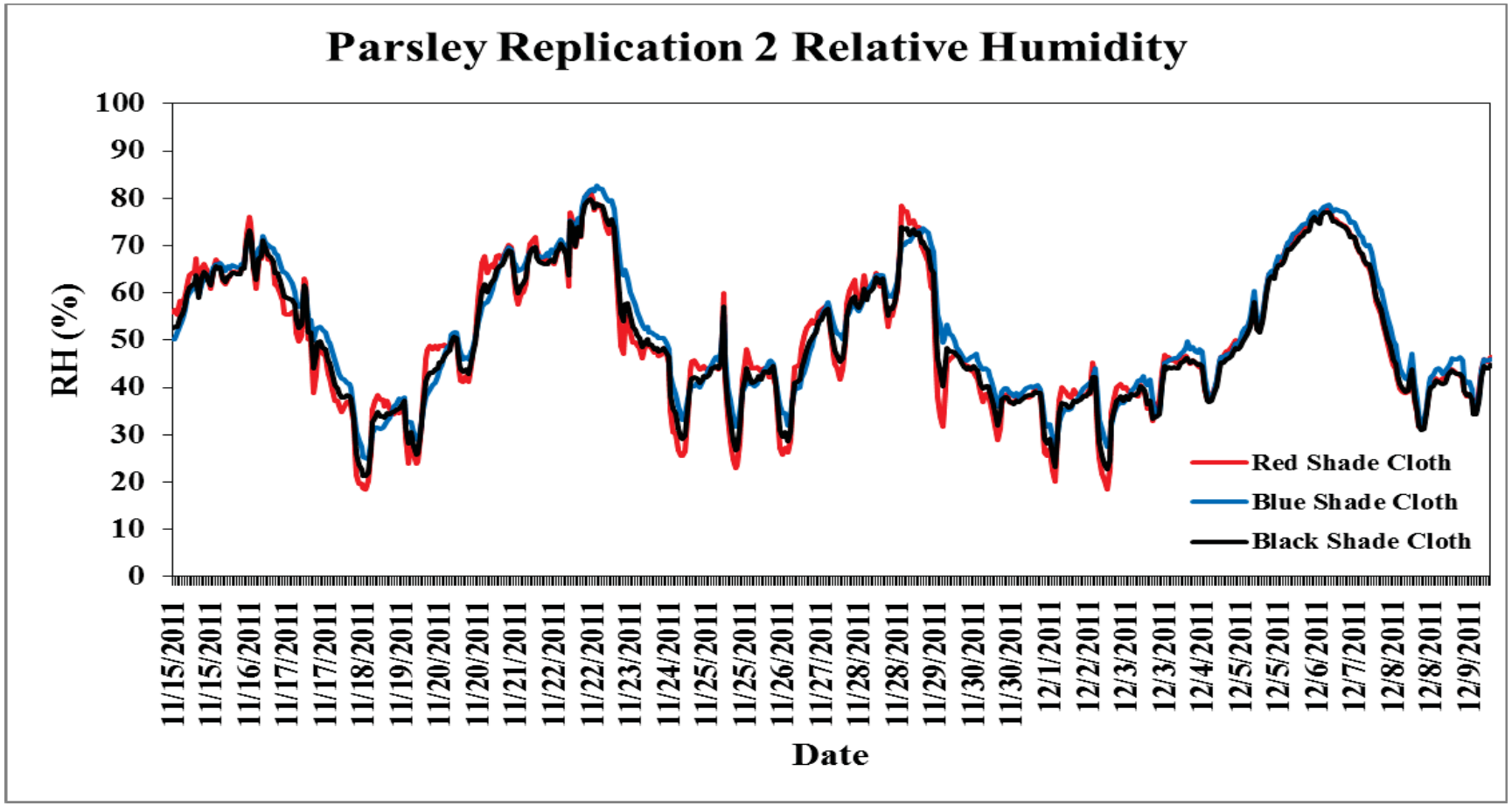

Figure 5.18a. *Parsley Replication 2*. Relative humidity (%) under conventional black, blue ChromatiNet, and red ChromatiNet shade cloth in greenhouse F-8; Virginia Tech, Blacksburg, Virginia.