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Nitrogen Management Practices and Colored Plastic Mulch Films Affecting Spider Mites and Aphids on Winter Strawberry in a High Tunnel

Kevin Philip Durden

University of Arkansas, Fayetteville

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By

Kevin P. Durden
Southwest Missouri State University
Bachelor of Science in Industrial Management, 1997
Drury University
Bachelor of Science in Biology, 2007
Missouri State University
Masters of Science in Plant Science, 2009

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University of Arkansas

This thesis is approved for recommendation to the Graduate Council.

Dr. Donn T. Johnson
Thesis Director

Dr. Timothy J. Kring
Committee Member

Dr. M. Elena Garcia
Committee Member

Abstract

Off season high tunnel strawberry production has the potential to augment income for Arkansas fruit growers during an unproductive time of the year, however management guidelines do not exist. At the University of Arkansas Agricultural Research and Extension Center in Fayetteville, AR studies were conducted to evaluate the effects of four nitrogen (46-0-0 urea fertilizer) fertigation rates (0.75, 0.50, 0.25, 0.0 kg N/day/ha) and red or black colored plastic mulch films on densities of twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), cotton aphid, *Aphis gossypii* Glover (Hemiptera: Aphididae), numbers of parasitized cotton aphids, and fruit yield weight. Foliar and petiole nitrogen content were evaluated in nitrogen fertigation trials. In the nitrogen fertigation experiment twospotted spider mites, cotton aphids and parasitized cotton aphids were sampled from the younger and older leaves of strawberry plants. Cowpeas, *Vigna unguiculata* L. Walp. (Fabales: Fabaceae), were planted and incorporated into the soil to supplement available nitrogen. Nitrogen fertigation treatments did not have the expected effect on foliar or petiole nitrogen levels. Preplanting nitrogen levels due to the cover crop of cowpeas, may have been provided sufficient nitrogen to the strawberry plants for the duration of the experiment to nullify the effect of the nitrogen treatments. Therefore, any significant differences in strawberry fruit yield, twospotted spider mite, cotton aphid, or parasitized aphid numbers would not be attributable to nitrogen fertigation treatments, and none were found. There were no significant differences among nitrogen fertilization treatments in the numbers of twospotted spider mites on the younger or older leaves except for one sample date, 8 January. However there were significantly more cotton aphids and parasitized cotton aphids in the older leaves compared to the younger leaves. There were no significant differences in strawberry fruit yield, twospotted spider mite, cotton aphid, or parasitized cotton aphids in the red or black plastic mulch experiment, although lack of sufficient

replication limited results. Future experiments may compare interaction effects of several high tunnel plastic film covers with different light transmitting characteristics and different color mulches on strawberry yields and aphid and mite densities inside high tunnels versus in open fields.

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1.0 Introduction: Off Season Winter Production of Strawberry

1.1 High Tunnels

Off season strawberry production has the potential to provide growers with income during a traditionally unproductive period of the year. However, management practices affecting off season strawberry production in a high tunnel do not exist for northwest Arkansas. High tunnel cropping systems are not analogous to greenhouses. High tunnels usually lack active, permanent heating and cooling systems and require only irrigation and fertilizer as active inputs (Lamont 2009, Giacomelli 2009, Demchak 2009). Pesticide use is greatly reduced in high tunnels (Giacomelli 2009) because environmental conditions that contribute to their breakdown are greatly altered. Because high tunnels only passively augment environmental conditions, they are typically used for season extension, bringing a crop to production a few weeks earlier in the spring, or allowing production a few weeks later in the fall. In some situations it is possible to produce crops off season with high tunnels (Lamont 2009). Strawberry (*Fragaria* × *ananassa*) (Duchesne) is the most widely grown high tunnel small fruit crop in the world (Lamont 2009). Disease management, herbivorous mammals and arthropods, plant nutrition and the prolonged harvest period are challenges faced when growing strawberry off season in Arkansas (Garcia et al. 2013).

1.2 Strawberry

Arkansas growers harvested 85 ha of strawberries in 1999, the most recent records for Arkansas (USDA NASS 2009). Those acres produced 5,830 kg per ha. Principle strawberry production areas in the United States are California and Florida. In 2012 strawberry growers in Florida received $2.42 per kg for fresh strawberries and $1.94 per kg in California. Strawberries produced in December 2008 were worth $4.59 per kg, whereas July produced strawberries were

worth \$1.45 per kg (USDA NASS 2009). Washington, Oregon, New York and North Carolina also have in excess of 40ha of strawberries in production.

A study in Florida determined that growing strawberries in greenhouses had the potential to provide 150% more profit compared to conventional outdoor grown strawberries and that strawberries grown organically in greenhouses were likely to be 950% more profitable (Cantliffe et al. 2008). Approximately 140ha of strawberries were grown in Arkansas in 2013, with Camino Real, St Festival, Chandler, Albion and Camarosa being the dominate cultivars, with Chandler being the prevalent cultivar (J. Goodson, Personal Interview).

1.2.1 Strawberry Physiology

Wild strawberries are found in temperate areas worldwide. The USDA Germplasm Resources Information Network states that there are 22 species of *Fragariinae*. Strawberry plants have 7 chromosomes, but can be diploid (2n), tetraploid (4n), pentaploid (5n), hexaploid (6n), octaploid (8n) or decaploid (10n). Because wild strawberries are widely distributed and easy to harvest, strawberries have only recently been domesticated. The strawberry of commerce, *Fragaria × ananassa* (Duschesne), also known as the dessert strawberry, was first described by Philip Miller in 1759 and named as such in 1766 by Antoine Nicholas Duschesne of the Royal Garden at Versailles. It is a hybrid of *F. chiloensis* (Duschesne) × *F. virginiana,* (Duschesne) both new world species. A great number of commercial cultivars have been produced from the dessert strawberry since 1800 (Hancock 1999).

The physiological development of strawberry inflorescences is dependent upon a number of genetic (cultivar) cues and environmental (temperature, day length, light intensity) factors. Flowering is classified as either short day, day neutral or long day. Long day plants begin to produce flowers when day lengths are longer than 12 hours and temperatures are under 30°C (Hancock 1999). Long day plants only fruit for a short period, typically in June, and are called

"June Bearing". Because of the short production time, long day plants are not suited for commercial production, but are often found in the home garden. Short day plants will flower when day lengths are less than 14 hours and temperatures are less than 15°C. If temperatures are above 15°C then short day plants will only flower between 8-12 hours of day length. Day neutral plants are not affected by photoperiod. Crowns and flowers develop approximately 3 months after planting. Day time temperatures above 30°C tend to inhibit bud initiation (Hancock 1999).

1.2.2 Strawberry Nutrition

Strawberries require proper nutrition for fruit growth, firmness, total soluble solids and production of volatiles (Hancock 1999) and recommended foliar nutrition levels have been established (Table 1). The proper soil pH range for strawberry is 5.5-6.5 (Domoto 2008). Excessive nitrogen can lead to soft fruit, delayed ripening, reduced yields, increased susceptibility to powdery mildew and an increase in mite load (Hancock 1999). Reduced boron can lead to decreased pollen production, delayed or reduced germination, reduced fruit size, and reduced root development. Reduced zinc leads to small leaves and low fruit yield. Suboptimal levels of iron cause reduced plant vigor and chlorotic leaves (Hancock 1999). Proper levels of calcium are necessary for proper berry firmness. Increased nitrogen levels do not have a positive effect on the overall taste of the strawberry (Ojeda-Real et al. 2009). Miner et al. (1997) recommend an optimum rate of 120 kg N/ha/season based upon a field grown plasticulture system with drip irrigation in loamy sand or sandy loam soils. It is recommended to apply half of the nitrogen in the fall with the remainder applied in the spring via fertigation.

1.3 Soil Mulch Film Color

Colored mulch films modify the microenvironment of the plants grown in them compared to bare ground. Changes include root-zone temperature and the quantity and quality of light reflected onto the crop (Decoteau et al. 1989). Kasperbauer (2000) noted that red mulch treatments increased reflection of red and far-red light causing an increase in yield and size of strawberries compared to those raised on black mulch or soil alone. Loughrin and Kasperbauer (2002) reported significant increases in total sugars (18.2%), terpenoids and other volatiles associated with aroma in strawberries grown over red mulch film. However, organic acids did not increase (Kasperbauer et al., 2001). Exposure to far red (710-850 nm) and red (630-740 nm) light for five minutes at the end of the photoperiod lead to thinner leaves, longer stems, larger chloroplast, more grana per chloroplast, and fewer thylakoid layers per granum (Kasperbauer and Hamilton, 1984).

In a field study of tomato cv. 'Sunny' (*Lycopersicon esculentum*) (Mill.), six mulch colors were used to study their effect on fruit yield and insect vectors (Csizinszky et al. 1995). There were high fruit yields from tomatoes grown in blue mulch compared to white mulch in the fall of 1988. In the spring of 1989 marketable yields of tomatoes grown on red mulch film were higher than those grown on black mulch in the early season. In the fall of 1989 tomatoes that were under stress from tomato mottle virus, had higher yields of large fruit on orange mulch films compared to white mulch films. Marketable yields of tomato fruit were reduced on yellow mulch in the fall of 1988 and 1989.

Mulch color also affects numbers of insects on plants. Green peach aphid, *Myzus persicae* (Sulzer), counts were reduced on tomato cv. 'Sunny' grown over aluminum coated mulch film (Csizinszky et al. 1995). Fewer whiteflies (Hemiptera: Aleyrodidae) were counted on tomato cv. 'Sunny' grown over yellow, aluminum and orange mulches (Csizinszky et al.

1995). Tomatoes grown in orange and aluminum mulches early in the fall of 1989 had delayed symptom development of tomato mottle virus, increased yields and decreased numbers of whiteflies. Colors of soil mulch films can be selected as much for their effect on the arthropods present as their effect on modifying the microenvironment for the plant (Csizinszky et al. 1995).

1.4 Strawberry Pests in Arkansas

There are several arthropod pests of field grown strawberries (Johnson et al. 2003). Among those are the strawberry weevil or clipper, *Anthonomus signatus* (Say) (Coleoptera: Curculionidae), twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae) (TSSM), cyclamen mite, *Steneotarsonemus pallidus* (Banks) (Acari: Tarsonemidae) a complex of aphids (Hemiptera: Aphididae), leafhoppers (Hemiptera: Cicadellidae) and Eastern flower thrips, *Frankliniella tritici* (Fitch) (Hemiptera: Thripidae). Two of the most common arthropod pests of Arkansas strawberry are the cotton aphid, *Aphis gossypii* Glover (Hemiptera: Aphididae) and the twospotted spider mite. Aphids do not generally become a major pest of field grown strawberry, but the cotton aphid can become a pest to strawberry grown in a greenhouse (Rondon et al. 2005). Treatment recommendations for winter strawberry grown in Arkansas high tunnels have not been established for any arthropod pests.

1.4.1 Twospotted Spider Mite

Twospotted spider mite, a cosmopolitan mite, represents the most pervasive arthropod pest of small fruits grown in high tunnels (Heidenreich et al. 2012, Gerson and Weintraub 2012). Spider mite pests in field grown strawberries in British Colombia do not reach high levels until later in the summer season (July and August), after traditional harvest dates of *cv*. 'Totem' strawberry, a short day strawberry variety (Raworth and Clements 1996). The economic threshold for TSSM on strawberries grown in open fields in Poland is 1-2 mites per leaflet pre-bloom, 2-3 mites per leaf after bloom, and 5-6 mites per leaf post-harvest in spring (Labanowska

and Bielenin 2000, 2002). Infestations of up to 5 TSSM mites per leaflet have no significant effect on yield (English-Loeb 2003) and thus the treatment threshold of 10 mites per leaflet would be more appropriate. English-Loeb (2003) sampled leaflets but reported results as per leaf. The economic threshold in La Plata, Brazil is 50 TSSM mites per leaf on strawberry (Greco et al. 2005). High tunnel cropping systems may extend the cropping season or produce a crop during the winter. However, spider mite densities in the winter may reach damaging levels on strawberry (Johnson et al. 2013).

When environmental conditions inside high tunnels reach or exceed temperatures of 85°F and relative humidity levels fall below 50% outbreaks of TSSM should be expected (Hamilton et al. 2004). Female TSSM complete their life cycle fastest at 35°C (95°F) (Wrensch 1985). Female TSSM oviposit for 2-3 weeks and lay in excess of 100 eggs inside webbing. As plant health declines due to mite feeding, TSSM must disperse for survival. Although TSSM do not balloon, as they do not have trailing strands of silk, they may be carried on a slight breeze (Hoy 2011). Dispersal outdoors is typically wind born or by walking. However, in greenhouses, walking or human activities are responsible for mite dispersal (Gerson and Weintraub 2012). Similar dispersal of TSSM among strawberry plants in high tunnels may be by random walking or human activity and not by wind (Greco et al. 2005), except when end walls are opened for cooling (Blomgren and Frisch 2007).

Control of spider mites in strawberry has traditionally been with acaricides. There are several OMRI approved acaricides such as JMS Stylet Oil (JMS Flower Farms, Vero Beach, FL), SAF-T-SIDE (Lawn and Garden Products Inc., Fresno, CA) and SuffOil-X (BioWorks, Victor, NY). Several chemicals to control TSSM on strawberry are recommended, apply Acramite 50WS, Agri-Mek 0.1EC, Athena 0.8EC, Danitol 2.4EC, Kelthane 50WP, Kanemite 15SC, Oberon 2SC, Portal, Fujimite, Savey 50DF, or Zeal (Bordelon 2013). Acramite 50WS

provided a significantly lower level of control of TSSM in late season, field grown, strawberry 'Florida Elyana' compared to; MK936/CGA293343 SC + Induce, Abamectin 84 SC + Induce, Agri-Mek 0.15 EC + Induce or Zoro 0.15 EC + Induce five days after initial applications (Price 2010). Acramite, Agri-Mek, Kanemite, Oberon, and JMS Stylet oil provided comparable reduction in accumulated mite days compared to untreated control of TSSM on field grown strawberry cultivar 'Chandler' (Burrack and Chapman 2010). Brigade increased accumulated mite days compared to untreated control (Burrack and Chapman 2010). However, improper acaricide use and a mite's short life cycle have led to resistance in TSSM (Sato et al. 2011, Gerson and Weintraub 2012, Van Leeuwen et al. 2010).

There are several *Phytoseiid* mites that are effective biological control predators of plant feeding *Tetranychid* mites, longevity, temperature ranges, developmental time, predation rates, potential secondary food sources and reproductive capacity were considered when selecting potential predatory mites for release against TSSM or other pest mite species (Greco et al. 1999, Pratt et al. 1999, Escudero and Ferragut 2005, Gotoh et al. 2003, Rhodes and Liburd 2009, Stavrinides et al. 2010, Hoy 2011, Shelton 2012).

1.4.2 Aphids

Blackman and Eastop (1984) listed several aphids found on strawberry in North America. The most common species were: *Chaetosiphon minor* (Forbes), *C. jacobi* (Hille Ris Lambers), *C. thomasi* Hille Ris Lambers, strawberry aphid, *C. fragaefolii* (Cockerell), strawberry root aphid, *A. forbesi* Weed, cotton aphid, *A. gossypii* Glover, *Macrosiphum rosae* (L.), potato aphid, *M. euphorbiae* (Thomas). The cotton aphid was found on strawberry plants during the winter of 2012-2013 in Fayetteville, AR (Johnson et al. 2013).

Strawberry plants that have excessive nitrogen levels tend to have high levels of aphids (Zalom et al. 2010, Jett 2013). Aqueel and Leather (2010) found that the English grain aphid,

Stiobion avenae (F.) and the bird cherry-oat aphid, *Rhopalosiphum padi* (L.) responded to plants with increased nitrogen levels with increases in adult weight, fecundity and longevity. Results of manipulating nitrogen levels in apple, *Malus domesitca* (Borkh) had inconclusive results (Haltrich et al. 2000, Papp et al. 2001). In Budapest, Hungary, several apple cultivars (Gloster, Mutsu, Jonagold, Jonathan M41, Idared, Kovelit and Jonathan) were observed to vary in susceptibility to the apple aphid, *A. pomi* De Geer, and the rosy leaf curling aphid, *Dysaphis devecta* (Walker) depending on the nitrogen fertilization rate (0, 50, 100, 200 kg/ha). Idared and Jonagold apples given 50 kg/ha of ammonium nitrate had the lowest levels of *A. pomi* and *D. plantaginea* in 1995 and highest levels of *A. pomi* and *D. plantaginea* in 1996. *Aphis pomi* were always present in higher densities than *D. plantaginea.* Therefore, nitrogen fertilization rates were not shown to predict levels of aphid infestation (Haltrich et al. 2000, Papp et al. 2001). Aphid size, weight, color, fecundity and intrinsic rate of increase may be linked to increased nitrogen fertilization, however these may also be influenced by temperature (Nevo and Coll 2001). In comparison, the cotton aphid was found to have a reduced intrinsic rate of increase on chrysanthemum fertilized with a high rate of 240 mg of 15-10-30 fertilizer/liter compared to lower rates of 80 or 160 mg/liter (Bethke et al. 1998). A 2006 study in France determined that numbers of the green peach aphid were found to remain static for 4 weeks with low rate of nitrogen (0.05mM N) (0.700 mg N/l on one year old peach, *Prunus persica* (L.) grown in a growth chamber. As nitrogen levels increased [3 mM (42.02 mg N/l), 6 mM (84.04 mg N/l), 10mM (140.07 mg N/l)], numbers of aphids increased with time. However, at high rate of 15 mM (210.11 mg N/l) nitrogen the aphid numbers decreased over time (Suage et al. 2010).

No insecticides are recommended for aphids on field grown strawberry in the midwest, as aphids are not typically an economic pest of strawberry in field plantings but are in high tunnels (Johnson et al. 2013, Bordelon et al.2013). Cotton aphid can become an economic pest in

greenhouses (Rondon et al. 2005). Admire Pro, Provado 1.6F and Actara are recommended to control aphids on field grown strawberry (Studebaker 2013). Malathion 57EC is also labeled for control of aphid on strawberry (Loveland Products, Greely, Colorado). Price and Nagle (2013) found that Assail 30SG, Movento 2SC+ Non-ionic surfactant (NIS): Induce, Movento 2SC+ NIS, NAI-2302 15%EC+ NIS, and NNI-0101 20% SC+ NIS all controlled cotton aphids compared to untreated check.

Aphids are attacked by a wide range of natural enemies. There are several taxa of aphid predators including: Coccinellidae, Syrphidae and Neuroptera larvae, as well as larvae of the predatory gall midge, *Aphidoletes aphidimyza* (Rondani) (Diptera: Cecidomyiidae) (Royal Horticultural Society 2011). Braconid wasps of the subfamily Aphidinae are parasitoids of aphids. Females oviposit directly into the aphid, the wasp completes its development inside the aphid and emerges as an adult (Starý 1970). The braconid *A. matricariae* is commonly found on aphid in greenhouses and it is known to parasitize 40 different aphids (Ramakers 1989) including *A. gossypii* (Sanchez et al. 2011) though not in great numbers. Longevity and development time are dependent upon temperature, food resources (honeydew and water) day length and relative humidity (Starý 1970). *Aphidius matricariae* were able to complete their life cycle at temperatures from 10°C to 30°C, with times ranging from 31.4 ± 4.09 d for development from oviposition to mummy at 10°C and 6.2 ± 1.01 d at 30°C (Zamani et al. 2007) and the average virgin female contains 93 eggs in her ovaries (Starý 1970). A joint study in Belgium, found that the potato aphid *M. euphorbiae* could be maintained below economic thresholds on strawberries grown in a greenhouse with the parasitic wasps, *Aphelinus abdominalis* (Dalman) (Hymenoptera: Aphelinidae), *Aphidius matricariae* (Haliday) (Hymenoptera: Braconidae), and *A. ervi* Haliday (Hymenoptera: Braconidae) provided that temperatures were above 15°C (Sterk and Meesters 1997).

1.5 Objective

The objectives of this study are (1) to quantify the cumulative effects of four nitrogen fertigation rates on densities of spider mites, aphids, parasitized aphids; foliar and petiole nitrogen levels; and strawberry fruit yield and (2) to provide preliminary data describing the effects of red or black plastic mulch film on spider mites aphids and parasitized aphids and strawberry fruit yield in strawberry produced in winter in a high tunnel.

2.0 Materials and Methods

2.1 High Tunnel Construction

A Haygrove high tunnel (Haygrove Inc., Mount Joy, PA) (61m x 7.3m wide x 3.7m tall) was constructed at the University of Arkansas Agricultural Research and Extension Center (AAREC) in Fayetteville, AR (36° 6'6.40"N, 94°10'4.61"W). The tunnel was covered with Visqueen Luminance THB AF 5S (bpi.visqueen Horticultural Products, Ardeer, Stevenston, United Kingdom) supplied with the high tunnel kit. This was a 6 mil polyethylene film that is UV stabilized, engineered to have high diffusion, and reduces daytime temperatures by blocking transmission of far-red light. The tunnel contains four rows of plastic covered raised beds (15 cm high x 75 cm wide) with strawberries on silt loam soil spaced 15.5 cm on centers. The east row of strawberries was a two (2012- 2013) year bio-fumigation study. The north portion of the west row was an experiment determining the effects on strawberry yield of covering raised beds with either red or black plastic mulch. The south part of the west row was quantifying percentage phytophthora (*Phytophthora fragariae* (Hickman) (Peronosporales: Pythiaceae) in strawberry transplants dipped in Aleite® as bare roots or plugs before planting. The middle two rows contained 'St. Festival' strawberry plants subjected to four nitrogen fertigation rates.

2.1.1 Preplanting Preparations

The high tunnel covers Captina silt loam soil, a moderately well drained silt loam to silty clay loam soil (USDA, WSS 2013). Soil in the high tunnel was bio-fumigated by planting a cover crop of white mustard, *Sinapis alba* L. (Brassicales: Brasicaceae), in the summer of 2011. Cowpeas, *Vigna unguiculata* (L.) (Walp). (Fabales: Fabaceae), were planted in May 2012 and then incorporated into the soil in July 2012. From July to August 2012 the soil was covered with a clear 4 mill Visqueen polyethylene film (Lowes, Fayetteville, AR) to solarize it, raising temperatures to sterilize the soil and hastening the breakdown of the cowpea cover crop. Beds were formed with a 15 x 75 cm vegetable bed shaper. Fertigation lines were installed over the top of the newly formed beds and covered with black plastic mulch film. After solarization (1 September 2012) the soil was pH 5.5 and the NO_3-N was 59 kg /ha. Row middles were covered with black plastic ground cover to retain heat, block moisture and prevent the establishment of weeds.

2.1.2 Fertigation and Pesticide Application

Irrigation lines were laid out with a separate line for each nitrogen treatment connected to a single manifold and valved to allow application of fertilizer to individual treatments. Urea fertilizer was dissolved in 1000 ml of water and 1 ml of Super Signal Blue (Upstart Products, Titusville, Florida) marker dye added. The fertilizer solution was injected into all blocks of each treatment simultaneously with a Dosmatic MicroDos ® 2% Injector (Carrollton, TX). To ensure complete fertilizer application, a tap was opened at the end of each circuit and the irrigation was run until the blue marker dye no longer appeared in the irrigation system. Application of nitrogen fertilizer began on 25 October 2012 and continued weekly until the study was concluded in late May 2013. Pesticides applications (Table 3) were necessary to prevent the establishment of fungal pathogens and to reduce mite load when spider mite loads approached

1500 cumulated mite days. Applications were made with Stihl SR450 gas powered, airblast back pack sprayer (Stihl Inc. Virginia Beach, Virginia).

2.1.3 Pollinators

When strawberries began to produce flowers, common eastern bumble bees, *Bombus impatiens* (Cresson) (Hymenoptera: Apidae) (Biobest, Wayzata, MN) were introduced into the high tunnel for pollination. Hives were replaced to augment numbers of bumble bees as needed.

2.2 Nitrogen Study

We compared the estimated numbers of TSSM, cotton aphids and parasitized cotton aphids per leaflet on *cv* "St. Festival" strawberry plants grown under four different nitrogen treatments. Higher levels of nitrogen in the strawberry plants were hypothesized to lead to greater numbers higher levels of TSSM, aphids, parasitized aphids and strawberry fruit yields.

2.2.1 Experimental Design

On 18 September 2012, *cv* 'St. Festival' strawberries were planted and grown until 28 May 2013 in a high tunnel. The experiment was set up as a randomized complete block, with five blocks. Each plot had 28 strawberry plants in two rows (30 × 35 cm spacing). Four plants at either end of the plot were left as a buffer zone between treatment plots. Each N treatment was applied once a week by direct injection into the irrigation system. Miner et al. (1997) set the optimum rate of nitrogen for strawberries at 120 kg/N/ha/day with half applied in the fall and the balance applied thru drip irrigation at the rate of 0.7 kg/N/ha/day. Fertigation treatments, as urea were 0.75 kg N/day/ha, 0.50 kg N/day/ha, 0.25 kg N/day/ha and 0.0 kg N/day/ha. Actual application rates were 0.0g per week, 12.39g per week, 24.80g per week and 37.40g per week of 46-0-0 urea fertilizer injected to 140 plants in each trial.

2.2.2 Nitrogen Foliar and Petiole Sampling

Foliar and petiole samples from each plot were collected by every two weeks between November 2012 and February 2013. Samples were collected on late morning or early afternoon on sunny days, and 8 of the most recent trifoliates were collected for each experimental unit. Samples placed in appropriately labeled bags and taken to the horticulture field lab. They were washed twice with deionized water, petioles separated from leaves and both were placed in appropriately labeled bags (McGinnis et al. 2013). Samples were processed for nitrogen content at the Soils Testing and Research Laboratory at the University of Arkansas Altheimer lab in Fayetteville Arkansas.

2.2.3 Arthropod Sampling

A randomly selected fully expanded central leaflet, from the younger portion of the canopy and a randomly selected fully expanded central leaflet from the older portion of the canopy were detached from five of the 20 plants in each trial of the nitrogen treatment plots. Leaf samples were bagged and labeled with the treatment number, block, date, and location in the canopy. Leaf samples were stored in a refrigerator at 8°C until processed. Mites were removed from leaves with a mite brushing machine (BioQuip Products, Inc., Rancho Dominguez, CA) onto 13 cm glass plates coated with dilute dish detergent (Henderson and McBurnie 1943). Twospotted spider mites, cotton aphids and parasitized cotton aphids (mummies and aphids containing clearly visible parasitoid larvae) were counted per plate section under a stereomicroscope. An estimation of arthropods per leaflet was made using the sequential section sampling protocol developed by Morgan et al. (1955). Counts of mobile twospotted spider mites, cotton aphids, and parasitized cotton aphids were recorded for each plot approximately every two weeks from 12 December 2012 to 18 January 2013.

2.2.4 Strawberry Sampling

Beginning on 27 November 2012 strawberries were harvested weekly. Harvest was conducted twice weekly as dictated by fruit load. Fruit weights for each treatment were measured and recorded for each sample period.

2.3 Colored Plastic Mulch Study

A preliminary colored mulch study was initiated to compare levels of spider mites, aphids and the percentage of aphids parasitized on strawberries grown on red or black mulch films. On 19 September 2012, cv. 'Radiance' strawberries were planted in two treatments with three blocks alternating 1.0 mill SRM red plastic mulch and 1.0 mill black embossed mulch film (both from Irrigation Mart, Ruston, LA). Each plot was 4.25m long and contained 22 plants (40 × 35 cm spacing), four plants from either end of the plot were used as buffer plants and data from them were not included in the results.

Randomly selected central leaflets were detached from 10 of the 14 plants in each colored plastic mulch plot. Samples were handled, processed and recorded as above.

2.4 Data Analysis

Estimation of all arthropods per strawberry leaflet were made by following the sequential sampling protocol established in Morgan et al. (1955). The number of sections necessary to count is dependent upon the number of arthropods counted per section. In all cases 20 sections per plate were counted.

Equation for estimating arthropods per leaflet (Morgan et al., 1955):

$$M_l = (M_c \times 50.48) \div (\#\, sections \times \#\, leaflets)$$

Where: M_l = # of mites per leaflet; M_c = # of mites counted; *# leaflets* = # of leaflets brushed; *# sections* = # of sections of disk counted

Cumulative mite days (CMD) are calculated by:

$$CMD_f = CMD_i + \left(\frac{M_f - M_i}{2}\right) \times \Delta_t$$

Where: CMD_f = final # CMD CMD_i = initial # CMD M_i = initial # mites per leaflet

Mf = following # mites per leaflet Δ_t = # days between sample dates

Statistical analyses were performed using JMP Pro 10.0 (SAS Institute, 2012). All tests were one-way ANOVA ($p < 0.05$). Means were separated with Student's t-test ($p < 0.05$). Results of all one-way ANOVA can be seen in Appendices A-E.

3.0 Results

3.1 Nitrogen Study

3.1.1 Foliar and Petiole Nitrogen

On 8 January 2013 there were significant differences in foliar nitrogen levels between the highest rate of 0.75 kg N/day/ha treatment and the other treatments (F = 5.519; df = 3, 2; P = 0.036) (Table 3). There were no differences in petiole nitrogen levels between the four nitrogen fertigation treatments on any dates (Table 4).

3.1.2 Strawberry Fruit Yield

Data from early harvest dates (27 November 2012, 4 December 2012 and 7 December 2012) were excluded because of missing data points, as many plants were not producing fruit yet. There were no significant differences in mean weights of strawberry fruit yield (g) among nitrogen fertigation treatments (F = .252; df = 3, 732; P = 0.859) (Table 5). Cumulative strawberry fruit yields for the entire season were 60,188.3g for the 0.0 kg N/day/ha treatment, 60,085.5g for the 0.25 kg N/day/ha treatment, 63,870.5g for the 0.50 kg N/day/ha, and 60,170.2g for the 0.75 kg N/day/ha treatment.

3.1.3 Twospotted Spider Mites

There were no significant differences in mean numbers of twospotted spider mites per leaflet between the older and younger strawberry plant canopy (F = 0.215; df = 1, 194; P = 0.640). Mean mite numbers per leaflet were 18.9 ± 2.36 SEM (older) and 17.1 ± 2.90 SEM (younger) of five sample dates from 12 December 2012 to 18 January 2013. (Table 6).

On 18 January 2013 just prior to pesticide application there were significant differences among nitrogen treatments in cumulative mite days (CMD) (F =5.690; df = 3, 32; P = 0.003). There was a greater number of CMD in the 0.75 kg N/day/ha treatment compared to the 0.25 kg N/day/ha treatment or 0.0 kg N/day/ha treatment. The 0.50 kg N/day/ha treatment was intermediate (Table 7).

3.1.4 Cotton Aphids

There were significant differences between the mean numbers of cotton aphids in the younger (2.4 ± 0.29 SEM) and older (15.9 ± 1.29 SEM) canopy of strawberries (F = 114.295; df = 1, 194; P < 0.001) from12 December 2012 to 18 January 2013 (Table 8).

3.1.5 Parasitized Cotton Aphids

The mean numbers of cotton aphids parasitized were significantly different between the older leaves (4.67 ± 0.45 SEM) and younger leaves (0.5 ± 0.07 SEM) (F = 852.680; df = 1, 194; P = 0.001). (Table 9).

3.2 Colored Plastic Mulch

3.2.1 Strawberry Fruit Yield

There were no significant differences in mean weights of strawberry fruit yield (g) between red and black mulch treatments (F=0.157; df= 1, 224; P= 0.692). Means and SEM were black 226.9g ± 16.95 and red 217.6g ± 16.55. Total berry weights were 25876.4g black and 24805.6g red.

3.2.2 Twospotted Spider Mites

There were no significant differences of mean numbers of spider mites per leaflet between red or black plastic mulch treatments on any dates (Table 10).

3.2.3 Cotton Aphids

There were no significant differences of mean numbers of cotton aphids per leaflet between red or black plastic mulch treatments on any dates (Table 11).

.3.2.4 Parasitized Cotton Aphids

There were no significant differences of mean numbers of parasitized cotton aphids per leaflet between red or black plastic mulch treatments on any dates (Table 12).

4.0 Discussion

4.1 Nitrogen Study

Nitrogen fertigation treatments did not have any consistent effect on foliar or petiole nitrogen levels. Differences in foliar nitrogen levels 8 January 2012 may have been caused by a leak in the irrigation system. Because nitrogen fertigation treatments had no effect on either foliar or petiole nitrogen levels in strawberry any differences in mite or insect numbers could not be attributed to manipulation of nitrogen levels. Accordingly, the treatments had no consistent or expected effects on strawberry fruit yield or numbers of twospotted spider mites, cotton aphids, or parasitized cotton aphids.

Mean foliar nitrogen levels for the fertigation treatments were 2.87% for 0.0, 0.25, and 0.75 kg N/day/ha treatment but and 2.82% for 0.75 kg N/day/ha treatment. Hancock (1999) recommends 2.0-2.8% foliar nitrogen (Table 1). Mean petiole nitrogen levels were 1534.4 for 0.0 kg N/day/ha, 1623.3 for 0.25 kg N/day/ha, 1652.9 for 0.50 kg N/day/ha and 1572.9 for 0.75 kg N/day/ha. Petiole nitrogen levels should be between 1500-2000 ppm during the fall establishment period, but should be 3000-4000 ppm during the fruiting period (Hasssell and

Poling 2006) in perennial grown strawberries in North Carolina. Hancock (1999) mentions that excessive nitrogen levels may lead to reduced yield and increased mite levels, although nitrogen levels in this study were lower than what was deemed excessive. The cover crop of cowpeas (May to July 2012) incorporated high amounts of nitrogen into the soil (soil N was 59kgN/ha on 1 September 2012). Thus, it seemed likely that soil nitrogen levels were sufficient for the entire growing season and the strawberries were not able to incorporate the applied nitrogen in to their tissue or the N flowed off the beds during application.

Significant differences in mite numbers on strawberry leaves were observed on 30 Dec. (older leaves) and 11 Jan. (younger leaves) could not be attributed to manipulation of soil or plant nitrogen levels. A malfunction of the irrigation system in one specific area during these dates may have led to increased numbers on mites.

Younger and older portions of the strawberry canopy were sampled to determine if there were differences in spatial distribution in densities of TSSMs and cotton aphids. The mean numbers of TSSM per leaflet were similar in the younger and older portions of the canopy whereas cotton aphid numbers per leaflet were greater in the older than younger portion of the canopy. While controlled studies which include corrections based on leaf area size are needed, future sampling for cotton aphids on strawberries grown in a high tunnel during winter may possibly be restricted to the older portion of the canopy whereas TSSM can be sampled from any portion of the canopy with mature leaves. Future studies should also include absolute sampling of plants to obtain a measurement of the accuracy of the relative methods (leaf sampling) in estimating arthropod density.

Dengate (2008) states that increased nitrogen levels in plants often have higher levels of herbivory because the increased nitrogen allows for faster development, growth and greater number of offspring. Dara (2013) and Cowles (2005) report that strawberry plants with

increased foliar nitrogen level have greater spider mite loads. The lack of significant differences in mean numbers of spider mites per leaflet in this study was thus expected due to the similar levels of N detected in foliar and petiole samples across all treatments. Similarly, strawberry fruit yield among the four nitrogen fertigation treatments were not different as the measured N levels were not influenced by the treatment.

Numerous studies (Zalom et al. 2010, Jett 2013, Aqueel and Leather 2010) found that increased levels of nitrogen lead to increased cotton aphid levels, weight and fecundity. However, the lack of significant differences in cotton aphid levels or levels of parasitized cotton aphids among any of the nitrogen treatment groups in my study should be attributed only to the lack of nitrogen levels among treatments. Increases of nitrogen levels above the recommended value might have different results.

4.2 Colored Plastic Mulch

There were no significant differences in strawberry fruit yield or the numbers of spider mites, cotton aphids or parasitized cotton aphids between the red and black plastic mulch film treatments. Greater replication (3 used in this study) would have allowed for a more complete evaluation of mulch colors. Previous studies documented that strawberries grown on red mulch in an open field have higher fruit yield than those grown on black mulch. It is probable that strawberries grown in black mulch are warmer than those grown on red mulch and that increased temperatures may lead to increased rate of reproduction of spider mites. This may be influenced by the materials used to construct the high tunnel. This tunnel was covered with Visqueen Luminance THB AF 5S, which according to the manufacture's literature reduces day time temperatures by blocking the transmission of far-red light and block UV to 380 nm. Given that this experiment was intended to show how reflecting far-red light back to the strawberry plants affected yields, a different tunnel cover allowing transmission of far-red light might yield the

different results mentioned above by Kasperbauer (2000). Light transmission in the high tunnel could easily be analyzed with a handheld spectroradiometer to determine what wavelengths are transmitted by a variety of polyethylene films to determine which might be better suited to increase fruit yields in offseason production of strawberry in high tunnels. Everhart (2010) maintains that infra-red blocking films may reduce photosynthetic active radiation by 85%, a figure that significantly reduced production of strawberry yield. Loughrin and Kasperbaur (2002) noted that increased red and far-red light lead to increased strawberry yield. It is reasonable to suggest that a reduction of these same wavelengths of light could reduce the same qualities. Sakai and Osakabe (2010) mentioned that spider mites made no attempt to shield themselves from the more damaging, higher energy UV-B light (280 to 315 nm) in the absence of UV-A light (315-400 nm). The UV-B light was lethal to all life stages of spider mite. The polyethylene film Visqueen Luminance used in high tunnels blocks out all of UV-B light and most of UV-A light up to 380 nm. A plastic film that allows more UV-B could potentially help maintain spider mite levels below treatment thresholds.

4.3 Summary

An unintended consequence of this study suggest that the addition of cover crops has the ability to greatly raise the preplanting soil nitrogen level, to the point that nitrogen fertigation treatments may be un-necessary or at least ineffective. Excessive nitrogen could lead to increased loads of arthropod pests and reducing nitrogen may make the environment of the high tunnel less suitable to those pests, although we could not adequately address this question. Increased replication may increase our ability to detect differences in strawberry fruit yields and arthropod numbers in red colored plastic mulch trials as compared to black plastic mulch treatments. Both of these factors should be addressed in future experiments and may lead to a sustainable off season strawberry production method in high tunnels.

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6.0 Tables

Table 1. Recommended foliar nutrient levels for strawberry from Pritts and Handley (1998).

Nutrient	Deficient	Sufficient	Toxic
N (%)	1.9	2.0 - 2.8	4.0
P (%)	0.2	0.3 - 0.40	0.5
K (%)	1.3	1.5 - 2.5	3.5
Ca (%)	0.5	0.7 - 1.7	2
Mg (%)	0.25	0.3 - 0.5	0.8
S (%)	0.35	0.4 - 0.6	0.8
B (ppm)	23	30 - 70	90
Fe (ppm)	40	60 - 250	350
Mn (ppm)	35	50 - 200	350
Cu (ppm)	3	6 - 20	30
Zn (ppm)	10	20 - 50	80

Table 2. Pesticides applied with a backpack sprayer to off-season strawberry plants grown in a high tunnel at the University of Arkansas Agricultural Research and Extension Center, Fayetteville, Arkansas (September 2012 to April 2013).

Date	**Compound**	**Formulation**	**Active ingredient**	**Application rate**
21 Sep. 12	Aliette	WDG	Aluminum tris (O-ethyl phosphonate)	5.0 #/Ac
25 Oct. 12	Entrust	SC	Spinosad	6.0 oz/Ac
6 Nov. 12	Rally	40WSP	myclobutanil	5.0 oz/Ac
14 Jan. 13	Captan	50W	Captan	3-6 lbs./Ac
	Rally	40WSP	myclobutanil	5.0 oz/Ac
21 Jan. 13	Agri-Mek	0.15EC	Abamectin	16.0 oz/Ac
5 Feb. 13	Captan	50W	Captan	3-6 lbs./Ac
26 Apr. 13	Entrust	SC	Spinosad	6.0 oz/Ac
	Agri-Mek	0.15EC	Abamectin	16.0 oz/Ac
	Actinovate	SP	*Streptomyces lydicus*	6-12 oz/Acre

Table 3. Effects of four nitrogen (N) fertigation rates on mean foliar nitrogen (± SEM) of strawberry cv. 'Strawberry Festival' leaves in a high tunnel at the Arkansas Agricultural Research and Extension Center, Fayetteville, AR (6 November 2012 to 5 February 2013).

Date	**N Fertigation rate (kg N/day/ha)**			
	0.00	**0.25**	**0.50**	**0.75**
6 Nov. 2012	2.9 ± 0.04	2.9 ± 0.06	2.9 ± 0.06	2.9 ± 0.07
20 Nov. 2012	2.7 ± 0.07	2.8 ± 0.04	2.9 ± 0.06	2.8 ± 0.09
5 Dec. 2012	3.0 ± 0.03	3.0 ± 0.01	2.9 ± 0.09	2.9 ± 0.06
18 Dec. 2012	2.9 ± 0.05	2.9 ± 0.02	2.9 ± 0.03	2.9 ± 0.02
8 Jan. 2013	2.8 ± 0.02a	2.7 ± 0.03a	2.8 ± 0.02a	2.6 ± 0.03b
5 Feb. 2013	2.9 ± 0.08	2.9 ± 0.02	2.8 ± 0.02	2.8 ± 0.09
Average	2.87	2.87	2.87	2.82

Means within a row not followed by the same letter are significantly different ($P < 0.05$; Students t- test)

Table 4. Effects of four nitrogen (N) fertigation rates on mean petiole nitrogen (ppm) (± SEM) of strawberry cv. 'Strawberry Festival' leaves in a high tunnel at the Arkansas Agricultural Research and Extension Center, Fayetteville, AR (6 November 2012 to 5 February 2013).

Date	**N Fertigation rate (kg N/day/ha)**			
	0.00	**0.25**	**0.50**	**0.75**
6 Nov. 2012	1406.7 ± 104.08b	1786.7 ± 165.23ab	1973.3 ± 84.13a	1500.0 ± 31.80b
20 Nov. 2012	1600.0 ± 79.74	1526.7 ± 119.73	1566.8 ± 88.52	1406.7 ± 105.37
5 Dec. 2012	2106.7 ± 108.68b	2513.3 ± 79.65a	2333.3 ± 40.96ab	2446.7 ± 133.46ab
18 Dec. 2012	1366.7 ± 110.97	1206.7 ± 53.67	1266.7 ± 139.22	1342.7 ± 186.18
8 Jan. 2013	1226.7 ± 68.70	1240.0 ± 58.38	1286.7 ± 113.81	1266.7 ± 22.05
5 Feb. 2013	1500.0 ± 77.32	1466.7 ± 40.15	1491.0 ± 74.01	1474.7 ± 128.98
Average	1534.4	1623.3	1652.9	1572.9

Means within a row not followed by the same letter are significantly different ($P < 0.05$; Students t- test)

Table 5. Effects of four nitrogen (N) fertigation rates on mean strawberry fruit yield (g) (± SEM) per 20 plant treatment of strawberry cv. ‘Strawberry Festival’ fruit in a high tunnel at the Arkansas Agricultural Research and Extension Center, Fayetteville, AR (27 November 2012 to 28 May 2013).

N Fertigation rate (kg N/day/ha)	**Yield (g)**
0.00	323.2 ± 18.31
0.25	321.5 ± 18.65
0.50	339.5 ± 18.58
0.75 (recommended)	318.7 ± 19.20

Table 6. Effects of nitrogen fertigation rates on mean numbers (± SEM) of twospotted spider mites per strawberry cv. 'Strawberry Festival' leaflet in a high tunnel at the Arkansas Agricultural Research and Extension Center, Fayetteville AR (12 December 2012 to 18 January 2013).

	Sampled	**Nitrogen Fertigation Rates (kg N/day/ha)**			
Date	**Leaves**[a]	**0.00**	**0.25**	**0.50**	**0.75**
12 Dec.12	Y	3.5 ± 1.31	4.3 ± 2.36	11.5 ± 6.57	3.9 ± 1.69
	O	10.7 ± 9.2	9.6 ± 7.37	27.3 ± 10.56	10.4 ± 4.02
19 Dec.12	Y	1.3 ± 0.41	1.3 ± 1.07	43.3 ± 25.21	18.5 ± 12.49
	O	15.8 ± 11.27	22.4 ± 13.44	14.4 ± 7.47	14.5 ± 11.01
30 Dec.12	Y	2.4 ± 1.13	9.7 ± 8.12	17.0 ± 6.41	32.1 ± 25.14
	O	6.2 ± 2.34b	11.7 ± 7.28ab	5.8 ± 2.29b	53.9 ± 25.74a
11 Jan.13	Y	17.7 ± 15.78ab	1.5 ± 0.53b	23.4 ± 13.45ab	61.9 ± 24.18a
	O	12.2 ± 7.56	11.1 ± 6.97	34.9 ± 10.71	36.9 ± 14.52
18 Jan.13	Y	6.7 ± 3.22b	11.1 ± 6.64b	45.3 ± 13.44a	27.2 ± 4.88ab
	O	21.3 ± 8.74	21.0 ± 14.99	16.9 ± 5.02	21.9 ± 4.58

Means within a row not followed by the same letter are significantly different ($P < 0.05$; Students t- test)
[a] Y, young leaves; O, older leaves

Table 7. Effects of four nitrogen (N) fertigation rates on mean cumulative mite days (CMD) (± SEM) of twospotted spider mites per strawberry cv. 'Strawberry Festival' leaflet in a high tunnel at the Arkansas Agricultural Research and Extension Center, Fayetteville, AR on 18 January 2013.

N Fertigation rate (kg N/day/ha treatment)	**CMD**
0.00	344.4 ± 109.96b
0.25	493.3 ± 172.62b
0.50	683.6 ± 138.02ab
0.75 (recommended)	1300.0 ± 387.81a

Means within a row followed by the same letter are not significantly different (*P* <0.05; Students t- test

Table 8. Effects of nitrogen fertigation rates on mean numbers (± SEM) of cotton aphids per strawberry cv. 'Strawberry Festival' leaflet in a high tunnel at the Arkansas Agricultural Research and Extension Center, Fayetteville AR (12 December 2012 to 18 January 2013).

	Sampled	**Nitrogen Fertigation Rates (kg N/day/ha)**			
Date	**Leaves**[a]	**0.0**	**0.25**	**0.50**	**0.75**
12 Dec.12	Y	3.1 ± 1.39	2.3 ± 0.90	2.5 ± 1.09	5.9 ± 3.30
	O	8.0 ± 2.57	9.7 ± 2.45	8.0 ± 2.31	3.2 ± 1.71
19 Dec.12	Y	0.9 ± .029	0.8 ± 0.25	1.0 ± 0.22	1.0 ± 0.31
	O	17.6 ± 4.42	28.7 ± 5.62	16.5 ± 3.34	18.0 ± 4.30
30 Dec.12	Y	4.3 ± 1.38	1.8 ± 0.84	2.4 ± 0.86	2.4 ± 1.35
	O	19.1 ± 2.11	13.2 ± 4.50	18.8 ± 7.05	22.2 ± 5.88
11 Jan.13	Y	4.2 ± 0.90a	3.2 ± 0.63ab	1.8 ± 0.30b	1.8 ± 1.07b
	O	17.2 ± 2.37	10.1 ± 2.70	11.2± 4.35	10.2 ± 3.80
18 Jan.13	Y	1.5 ± 0.70	2.5 ± 0.76	2.7 ± 1.40	1.8 ± 0.69
	O	14.2 ± 2.77	13.2 ± 3.64	13.7 ± 2.79	14.3 ± 2.97

Means within a row followed by the same letter are not significantly different (*P* <0.05; Students t- test) [a] Y, young leaves; O, older leaves

Table 9. Effects of nitrogen fertigation rates on mean numbers (± SEM) of parasitized cotton aphids per strawberry cv. 'Strawberry Festival' leaflet in a high tunnel at the Arkansas Agricultural Research and Extension Center, Fayetteville AR (12 December 2012 to 18 January 2013).

	Sampled	**Nitrogen Fertigation Rates (kg N/day/ha)**			
Date	**Leaves**[a]	**0.00**	**0.25**	**0.50**	**0.75**
12 Dec. 12	Y	0.4 ± 0.21	0.4 ± 0.16	0.5 ± 0.34	0.0 ± 0.09
	O	2.6 ± 0.80	3.1 ± 1.32	2.2 ± 1.20	0.6 ± 0.44
19 Dec. 12	Y	0.7 ± 0.29	0.2 ± 0.14	0.0 ± 0.17	0.2 ± 0.09
	O	3.0 ± 0.84	5.2 ± 1.44	3.5 ± 1.09	2.5 ± 1.31
30 Dec. 12	Y	0.6 ± 0.31	0.2 ± 0.22	0.9 ± 0.53	0.6 ± 0.30
	O	5.5 ± 0.74	2.3 ± 0.58	2.9 ± 0.33	3.5 ± 0.80
11 Jan. 13	Y	1.4 ± 0.42	1.0 ± 0.30	0.3 ± 0.42	0.2 ± 0.19
	O	10.0 ± 1.75	4.4 ± 1.18	3.2 ± 2.15	3.3 ± 1.58
18 Jan. 13	Y	0.9 ± 0.22	1.1 ± 0.35	0.9 ± 0.33	0.3 ± 0.20
	O	10.0 ± 1.22	9.6 ± 3.18	7.6 ± 2.32	8.0 ± 2.95

Y, young leaves; O, older leaves

Table 10**.** Effects of nitrogen fertigation rates on mean numbers (± SEM) of twospotted spider mite per strawberry cv. 'Radiance' leaflet as affected by red and black plastic mulch treatments in a high tunnel at the Arkansas Agricultural Research and Extension Center, Fayetteville AR (12 December 2012 to 18 January 2013).

Date	**Black**	**Red**
19 Dec. 12	4.5 ± 2.06	0.4 ± 2.06
30 Dec. 12	7.3 ± 3.53	0.0 ± 3.53
11 Jan. 13	3.7 ± 1.64	0.1 ± 1.64
18 Jan. 13	1.3 ± 0.40	0.0 ± 0.40

Table 11. Effects of nitrogen fertigation rates on mean numbers (± SEM) of cotton aphid per strawberry cv. 'Radiance' leaflet as affected by red and black plastic mulch treatments in a high tunnel at the Arkansas Agricultural Research and Extension Center, Fayetteville AR (12 December 2012 to 18 January 2013).

Date	**Black**	**Red**
19 Dec. 12	2.0 ± 1.27	4.0 ± 1.27
30 Dec. 12	5.2 ± 1.74	7.1 ± 1.74
11 Jan. 13	7.4 ± 1.85	12.0 ± 1.85
18 Jan. 13	11.5 ± 3.47	5.4 ± 3.47

Table 12**.** Effects of nitrogen fertigation rates on mean numbers (± SEM) of parasitized cotton aphid per strawberry cv. 'Radiance' leaflet as affected by red and black plastic mulch treatments in a high tunnel at the Arkansas Agricultural Research and Extension Center, Fayetteville AR (12 December 2012 to 18 January 2013).

Date	**Black**	**Red**
19 Dec. 12	1.0 ± 0.43	1.3 ± 0.43
30 Dec. 12	1.7 ± 0.29	1.0 ± 0.29
11 Jan. 13	2.5 ± 1.10	4.2 ± 1.10
18 Jan. 13	3.1 ± 1.28	1.4 ± 1.28

7.0 Appendices

7.1 Appendix A

Appendix A. Biological characteristics and ranges of environmental constraints of predatory mite species that prey on twospotted spider mites (TSSM).

Predatory Mite Species	**Longevity (Days)**	**Develop time (Days)**	**% RH**	**°C**	**TSSM eggs eaten per day**	**Other food source**	**Eggs per female**
Neoseiulus californicus	20	4	40-80	15-35	5.3	pollen	41
Galendromus occidentalis	45	4	40-80	15-35	20-25	none	35
Neoseiulus fallacis	10-15	7	na	na	20-25	pollen	20-50
Phytoseiulus persimilus	50	5	>70	17-27	20	none	60

Sources: Greco et al., (1999), Rhodes and Liburd, (2009), Gotoh et al., (2003), Escudero and Ferragut, (2005), Stavrinides et al., (2010), Hoy, (2011), Rhodes and Liburd, (2009), Greenmethods.com, (2012), Shelton, (2012), Pratt et al. (1999)

7.2 Appendix B

Appendix B. ANOVA results of effects of four nitrogen fertigation rates on mean percentage of foliar nitrogen in leaflets of strawberry cv. 'Strawberry Festival' in a high tunnel at Arkansas Agricultural Research and Extension Center, Fayetteville, AR (December 2012 to April 2013).

Date	**Source**	**df**	**Mean Square**	***F* ratio**	***Prob > F***
6 Nov. 12	Treatment	3	0.003	0.2728	0.843
	Block	2	0.030	2.174	0.195
20 Nov. 12	Treatment	3	0.012	0.671	0.600
	Block	2	0.000	0.045	0.956
5 Dec. 12	Treatment	3	0.011	0.881	0.501
	Block	2	0.001	0.138	0.873
18 Dec. 12	Treatment	3	0.003	0.851	0.514
	Block	2	0.001	0.305	0.747
8 Jan. 13	Treatment	3	0.012	5.519	0.036
	Block	2	0.008	3.369	0.104
5 Feb. 13	Treatment	3	0.004	0.277	0.839
	Block	2	0.000	0.015	0.984

7.3 Appendix C

Appendix C. ANOVA results of effects of four nitrogen fertigation rates on mean petiole nitrogen (ppm) in leaflets of 'Strawberry Festival' in a high tunnel at Arkansas Agricultural Research and Extension Center, Fayetteville, AR (December 2012 to April 2013).

Date	Source	df	Mean Square	*F* ratio	*Prob > F*
6 Nov. 12	Treatment	3	203822.0	4.409	0.058
	Block	2	28933.0	0.626	0.566
20 Nov. 12	Treatment	3	21366.7	0.539	0.672
	Block	2	14700.0	0.379	0.704
5 Dec. 12	Treatment	3	95511.0	0.2.537	0.153
	Block	2	204400.0	5.429	0.045
18 Jan. 12	Treatment	3	16012.0	0.231	0.871
	Block	2	69265.3	1.000	0.421
8 Jan. 13	Treatment	3	2166.7	0.100	0.956
	Block	2	9700.0	0.449	0.657
5 Feb. 13	Treatment	3	689.2	0.023	0.994
	Block	2	2986.1	0.100	0.905

7.4 Appendix D

Appendix D. ANOVA results of mean strawberry fruit yield (g) of strawberry cv. 'Strawberry Festival' as affected by four nitrogen fertigation rates (%) in a high tunnel at Arkansas Agricultural Research and Extension Center, Fayetteville, AR (December 2012 to May 2013).

Date	**Source**	**DF**	**Mean Square**	***F* ratio**	***Prob > F***
11 Dec. 12	Treatment	3	16773.9	3.183	0.063
	Block	4	5193.1	0.985	0.451
17 Dec. 12	Treatment	3	6816.1	1.894	0.184
	Block	4	16721.9	4.648	0.017
21 Dec. 12	Treatment	3	10067.2	2.578	0.102
	Block	4	12279.2	3.145	0.055
24 Dec 12	Treatment	3	414.5	0.116	0.948
	Block	4	2871.4	0.805	0.545
30 Dec. 12	Treatment	3	2949.9	0.558	0.652
	Block	4	1287.5	0.558	0.652
4 Jan. 13	Treatment	3	1166.1	0.612	0.620
	Block	4	1061.5	0.557	0.697
10 Jan. 13	Treatment	3	2205.2	0.451	0.720
	Block	4	962.1	0.197	0.935

Appendix D. Continued

Date	Source	DF	Mean Square	*F* ratio	***Prob > F***
18 Jan. 13	Treatment	3	7230.2	1.567	0.248
	Block	4	13004.9	2.818	0.073
25 Jan.13	Treatment	3	11559.9	1.22	0.344
	Block	4	15381.4	1.623	0.231
1 Feb. 13	Treatment	3	4606.9	0.914	0.463
	Block	4	34907.5	6.927	0.004
8 Feb. 13	Treatment	3	15734.3	1.258	0.332
	Block	4	1917.9	1.258	0.332
12 Feb.13	Treatment	3	19613.9	1.367	0.299
	Block	4	17760.6	1.238	0.346
15 Feb. 13	Treatment	3	2137.1	0.431	0.783
	Block	4	6381.2	1.289	0.328
19 Feb. 13	Treatment	3	7626.8	0.243	0.864
	Block	4	61834.2	1.975	0.162
25 Feb. 13	Treatment	3	6584.9	0.462	0.713
	Block	4	23809	1.671	0.220
5 Mar. 13	Treatment	3	10412.8	0.549	0.658
	Block	4	26341.9	1.389	0.295
8 Mar. 13	Treatment	3	1325.1	0.186	0.903
	Block	4	1328.4	0.229	0.916

Appendix D. Continued

Date	Source	DF	Mean Square	*F* ratio	*Prob > F*
11 Mar. 13	Treatment	3	7499.9	1.812	0.198
	Block	4	2639.4	0.651	0.637
15 Mar. 13	Treatment	3	1601.8	0.719	0.559
	Block	4	3640.7	1.632	0.228
21 Mar. 13	Treatment	3	620.2	0.231	0.872
	Block	4	1668.1	0.702	0.605
28 Mar. 13	Treatment	3	4545.4	1.158	0.365
	Block	4	8289.7	2.262	0.123
2 Apr. 13	Treatment	3	6147.5	0.264	0.849
	Block	4	21774.4	0.936	0.475
7 Apr. 13	Treatment	3	13719.9	1.159	0.365
	Block	4	25948.1	2.193	0.131
12 Apr. 13	Treatment	3	11497.8	0.622	0.613
	Block	4	30087.4	1.629	0.230
15 Apr. 13	Treatment	3	39300.2	0.694	0.572
	Block	4	92730.5	1.639	0.228

Appendix D. Continued

Date	Source	DF	Mean Square	*F* ratio	*Prob* > *F*
19 Apr. 13	Treatment	3	86315	0.789	0.522
	Block	4	187889	1.719	0.210
23 Apr. 13	Treatment	3	105697	1.125	0.377
	Block	4	73842	0.786	0.555
26 Apr. 13	Treatment	3	6058	0.1687	0.915
	Block	4	173124	4.82	0.015
30 Apr. 13	Treatment	3	12941.7	0.492	0.694
	Block	4	84489.6	3.212	0.052
3 May 13	Treatment	3	10622.8	0.321	0.809
	Block	4	31675	0.958	0.464
7 May 13	Treatment	3	6846.4	0.307	0.819
	Block	4	19905.1	0.89	0.499
10 May 13	Treatment	3	7631.4	0.129	0.940
	Block	4	48044.4	0.815	0.539
14 May 13	Treatment	3	17923.5	0.782	0.526
	Block	4	23668.8	1.032	0.429

Appendix D. Continued

Date	Source	DF	Mean Square	*F* ratio	*Prob > F*
17 May 13	Treatment	3	207.7	0.013	0.997
	Block	4	33879.6	2.133	0.139
21 May 13	Treatment	3	2880.4	0.144	0.931
	Block	4	7322.6	0.368	0.826
24 May 13	Treatment	3	274.9	0.114	0.949
	Block	4	851.6	0.355	0.835
28 May 13	Treatment	3	124478	1.103	0.385
	Block	4	114786	1.017	0.437

7.5 Appendix E

Appendix E. ANOVA results of effects of four nitrogen fertigation rates on mean number of twospotted spider mites per strawberry cv. 'Strawberry Festival' leaflet in a high tunnel at Arkansas Agricultural Research and Extension Center, Fayetteville, AR (December 2012 to January 2013).

Date	**Source**	**DF**	**Mean Square**	**F ratio**	**Prob > F**
12 Dec. 12	Treatment	3	378.423	2.058	0.125
	Block	4	358.937	1.952	0.126
19 Dec. 12	Treatment	3	793.813	0.979	0.415
	Block	4	837.663	1.033	0.406
30 Dec. 12	Treatment	3	3030.07	3.827	0.019
	Block	4	1386.86	1.752	0.163
11 Jan. 13	Treatment	3	3539.57	4.107	0.014
	Block	4	887.37	1.03	0.407
18 Jan. 13	Treatment	3	624.891	1.544	0.222
	Block	4	511.535	1.264	0.304

7.6 Appendix F

Appendix F. ANOVA results of percentage of aphids parasitized per leaflet on strawberry cv. 'Strawberry Festival' as affected by four nitrogen fertigation rates (%) in a high tunnel at Arkansas Agricultural Research and Extension Center, Fayetteville, AR (December 2012 to April 2013).

Date	**Canopy position**	**Source**	**DF**	**Mean Square**	**F ratio**	**Prob > F**
12 Dec. 12	Lower	Treatment	3	5.960	0.884	0.477
		Block	4	2.325	0.345	0.843
	Upper	Treatment	3	0.249	0.767	0.534
		Block	4	0.147	0.452	0.770
19 Dec. 12	Lower	Treatment	3	7.011	0.736	0.551
		Block	4	18.330	1.924	0.171
	Upper	Treatment	3	0.454	1.965	0.173
		Block	4	0.553	2.396	0.108
30 Dec. 12	Lower	Treatment	3	9.200	3.380	0.054
		Block	4	5.904	2.169	0.134
	Upper	Treatment	3	0.422	0.489	0.697
		Block	4	0.562	0.652	0.637
11 Jan. 13	Lower	Treatment	3	51.556	2.657	0.096
		Block	4	32.642	1.682	0.218
	Upper	Treatment	3	1.673	2.099	0.154
		Block	4	1.636	2.053	0.151

Appendix F. continued

Date	Canopy position	Source	DF	Mean Square	*F* ratio	*Prob > F*
18 Jan. 13	Lower	Treatment	3	7.224	0.169	0.915
		Block	4	29.315	0.686	0.615
	Upper	Treatment	3	0.610	1.136	0.374
		Block	4	1.678	3.124	0.056

7.7 Appendix G

Appendix G. ANOVA results of percentage of cotton aphids parasitized per leaflet on strawberry cv. 'Strawberry Festival' as affected by four nitrogen fertigation rates (%) in a high tunnel at Arkansas Agricultural Research and Extension Center, Fayetteville, AR (December 2012 to April 2013).

Date	Canopy position	Source	DF	Mean Square	F ratio	Prob > F
12 Dec. 12	Lower	Treatment	3	5.960	0.884	0.477
		Block	4	2.325	0.345	0.843
	Upper	Treatment	3	0.249	0.767	0.534
		Block	4	0.147	0.452	0.770
19 Dec. 12	Lower	Treatment	3	7.011	0.736	0.551
		Block	4	18.330	1.924	0.171
	Upper	Treatment	3	0.454	1.965	0.173
		Block	4	0.553	2.396	0.108
30 Dec. 12	Lower	Treatment	3	9.200	3.380	0.054
		Block	4	5.904	2.169	0.134
	Upper	Treatment	3	0.422	0.489	0.697
		Block	4	0.562	0.652	0.637
11 Jan. 13	Lower	Treatment	3	51.556	2.657	0.096
		Block	4	32.642	1.682	0.218
	Upper	Treatment	3	1.673	2.099	0.154
		Block	4	1.636	2.053	0.151

Appendix G. continued

Date	**Canopy position**	**Source**	**DF**	**Mean Square**	***F* ratio**	***Prob > F***
18 Jan. 13	Lower	Treatment	3	7.224	0.169	0.915
		Block	4	29.315	0.686	0.615
	Upper	Treatment	3	0.610	1.136	0.374
		Block	4	1.678	3.124	0.056

7.8 Appendix H

Appendix H. ANOVA results of percentage of twospotted spider mites per leaflet on strawberry cv. **'**Radiance**'** leaflet as affected by red and black plastic mulch treatments in a high tunnel at the Arkansas Agricultural Research and Extension Center, Fayetteville AR (12 December 2012 to 18 January 2013).

Date	**Source**	**DF**	**Mean Square**	***F* ratio**	***Prob* > *F***
19 Dec. 12	Treatment	1	25.493	1.000	0.423
	Block	2	29.825	1.170	0.461
30 Dec. 12	Treatment	1	80.365	1.072	0.409
	Block	2	74.950	1.000	0.500
11 Jan. 13	Treatment	1	18.730	1.151	0.396
	Block	2	14.663	0.901	0.526
18 Jan. 13	Treatment	1	285.572	0.897	0.444
	Block	2	318.285	1.000	0.500

7.9 Appendix I

Appendix I. ANOVA results of percentage of cotton aphid per leaflet on strawberry cv. 'Radiance' leaflet as affected by red and black plastic mulch treatments in a high tunnel at the Arkansas Agricultural Research and Extension Center, Fayetteville AR (12 December 2012 to 18 January 2013).

Date	**Source**	**DF**	**Mean Square**	***F* ratio**	***Prob > F***
19 Dec. 12	Treatment	1	6.116	0.625	0.512
	Block	2	3.727	0.381	0.724
30 Dec. 12	Treatment	1	5.617	0.306	0.636
	Block	2	6.912	0.377	0.727
11 Jan. 13	Treatment	1	32.118	1.560	0.338
	Block	2	45.008	2.186	0.314
18 Jan. 13	Treatment	1	56.581	0.780	0.470
	Block	2	195.067	2.689	0.271

7.10 Appendix J

Appendix J. ANOVA results of percentage of parasitized cotton aphids per leaflet on strawberry cv. **'Radiance'** leaflet as affected by red and black plastic mulch treatments in a high tunnel at the Arkansas Agricultural Research and Extension Center, Fayetteville AR (12 December 2012 to 18 January 2013).

Date	**Source**	**DF**	**Mean Square**	***F* ratio**	***Prob* > *F***
19 Dec. 12	Treatment	1	0.170	0.155	0.732
	Block	2	0.520	0.476	0.678
30 Dec. 12	Treatment	1	0.680	1.306	0.372
	Block	2	0.138	0.265	0.790
11 Jan. 13	Treatment	1	4.247	0.581	0.525
	Block	2	3.100	0.424	0.702
18 Jan. 13	Treatment	1	4.247	0.430	0.580
	Block	2	12.837	1.299	0.435