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Using Shade for Fruit and Vegetable Production

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Introduction

Sunlight is the primary energy source plants use in photosynthesis to convert carbon dioxide and water into sugars, which the plant uses to make stems, leaves, roots, and fruits. Without this source of energy, life is not possible. There are various forms of solar (sun) radiation, which differ in wavelength and intensity. These include x-ray (highly energetic), ultra-violet (can damage biological tissue), infra-red (causes heating of matter), and visible (what plants use and we see) radiation. Sunlight enters the earth's atmosphere as shortwave radiation and is absorbed by anything it contacts including clouds, buildings, the land, and plants. Some of this radiation is re-emitted as lower energy, longwave infra-red radiation. Plants intercept both short- and long-wave radiation (Fig. 1). This radiation accumulation causes plant tissue to experience a rise in temperature. Among most plant species, photosynthesis increases if carbon dioxide and water are available as plant temperatures rise. This acceleration of photosynthesis can stabilize plant temperature by diverting light energy to a photosynthetic pathway that makes chemical energy. However, if the leaves or fruit are exposed to harmful ultraviolet radiation or they accumulate too much light radiation, damage to cells and tissues occurs. If not repaired, this tissue damage eventually leads to cell/tissue death, which is a common plant disorder called sunburn.

Stomata play an important role in the process of photosynthesis. In addition to letting carbon dioxide enter the leaf, some water is lost (transpired) by the leaf. Losing water via transpiration helps cool the plant and dissipate some of the short- and long-wave energy absorbed. While all above ground plant parts (stems, leaves, flowers, and fruits) have stomata, leaves tend to cool most efficiently because they have a large surface area and are quite thin. Interestingly, most fruits have many stomata while they are growing but some, like apple, pepper, and tomato have very few functional stomata once they mature. Thus, sun exposed fruits of these species accumulate excess energy above that needed for photosynthesis. This accumulation of energy increases temperature and can lead to sunburn.

Excess light energy in plants can also be transferred from the plant by convection. Convection is heat loss by moving air currents. When the plant is warmer than the surrounding air, heat transfers from plant tissues to the surrounding air. Convection transfer increases as the temperature gradient between the plant and the surrounding air increases and as airflow (wind) increases.

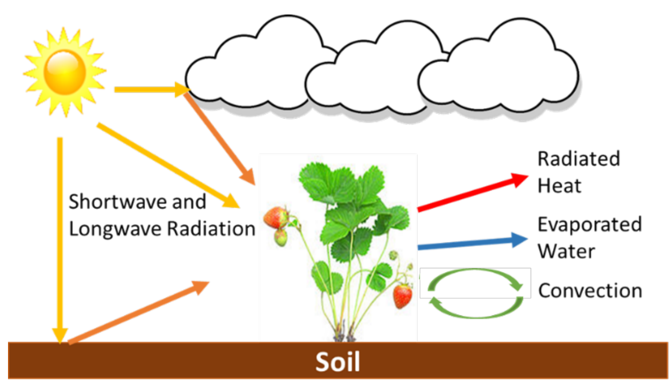

Figure 1. Energy balance diagram showing incoming solar radiation and energy transfer.

Sunburn injury is common on fruits in Utah due to high solar radiation levels and air temperatures, low relative humidity, and high elevations. Ultraviolet (UV) radiation is greater at higher elevations and is the greatest contributor to damage. Excess absorbed energy is the greatest contributor to cell death and sunburn. Solar injury can be reduced by natural (increased leaf coverage) or artificial (cloth screening) shade. Both methods help decrease the amount of radiation that reaches the fruit and mitigates sunburn damage. In one Utah study, 52% of field grown, unshaded bell peppers fruits were sunburned (unmarketable) while no fruit were sunburned if grown under horizontally oriented shade cloth. Although using shade cloth increases production costs, returns increase dramatically in high-value crops that see significant losses due to sunburn.

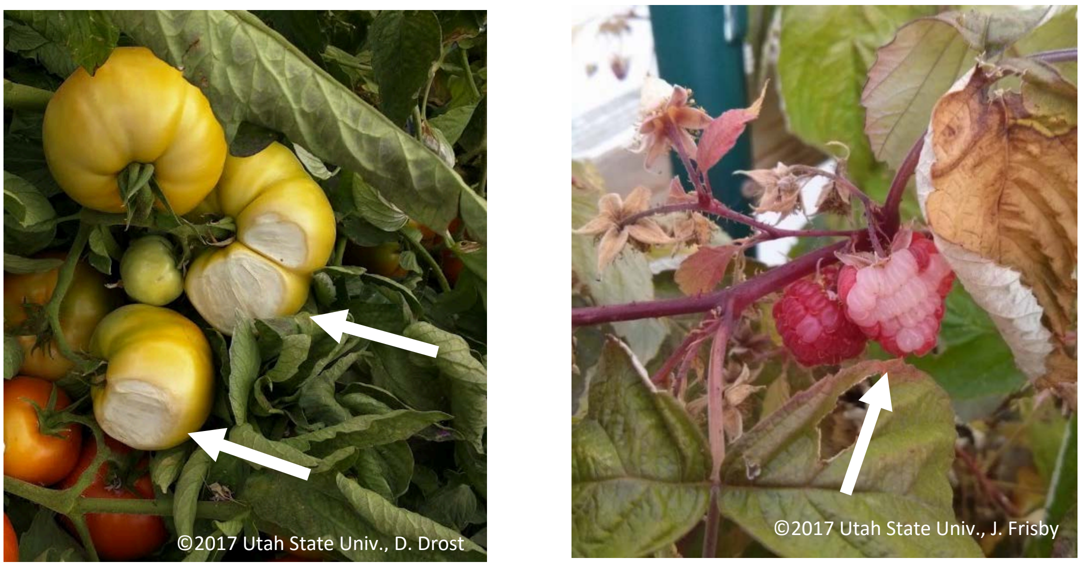

Figure 2. Sunburn (white arrows) on tomato (left) and raspberry (right).

TYPICAL FRUIT SURFACE TEMPERATURE (FST) AT WHICH SUNBURN DAMAGE OCCURS AND DESCRIPTION OF DAMAGE.

CROP	FST (°F)	Damage Description
SOLANACEOUS (TOMATO/PEPPER/ EGGPLANT)	100-113	Begins as yellow/brown discoloration on sun-exposed side of fruit. Discolored flesh becomes tough. As damage continues, flesh becomes thin, leathery, dry, and white and may allow rot organisms to enter the fruit (Fig. 2).
CUCURBITS (MELON, SQUASH, CUCUMBER)	100-104	Yellowing of the skin exposed to the sun, becomes white with continued exposure. Secondary fungal infection is common where sunburn is severe.
LEGUMES (BEAN, PEA)	>90 flower drop	Starts as small water-soaked spots that turn reddish-brown and can grow together to form large discolored regions. Damage during pod development stunts seed growth on the sun-exposed side, causing pods to curve or grow in a C shape.
SWEET CORN	95-120	Growth slows and fertilization is significantly reduced when silk temperatures exceed 95°F. Silks can dry out or be damaged leading to zippering (undeveloped kernels, Fig. 5) from poor pollination (110-120°F).
APPLES	113-125	Sunburn necrosis appears as a sunken dark brown patch on the side-exposed to the sun, browning or bleaching occurs at lower temperatures.
STRAWBERRY	105-120	Fruits soften and turn a murky pink color on the sun-exposed side.
RASPBERRY/ BLACKBERRY	105-110	Berries are an aggregate of drupelets. Individual drupelets on the sun-exposed side turn white and eventually shrivel (Fig. 2).

*FST=Fruit Surface Temperature; direct sunlight causes FST to exceed air temperature by 25-30°F.

There are three types of sunburn. Photo-oxidative sunburn occurs when fruits that have been shaded are suddenly exposed to direct sunlight (i.e. branch/vine damage). These fruits become damaged because they are not acclimated to high light levels. Photo-oxidative sunburn happens at relatively low fruit temperatures (90 to 100°F). The damaged tissue is typically white (bleached) and covers a large section of the exposed side of the fruit. Fruits already colored often appear wrinkled and feel soft (Fig. 3). The second type is sunburn browning. This sunburn damages fruit pigments, resulting in brownish discoloration (sometimes bronze, yellow, or bleached). Browning occurs at higher temperatures (100 to 115°F) than photo-oxidative sunburn (Fig. 4). The third is sunburn necrosis where the skin and/or tissue of the fruit dies. The damaged cells are superheated (110 to 125°F) which causes tissue to die and turn white or brown in color (Fig. 4). Regardless of the type of sunburn injury, sunburn damage renders the fruit of most crops unmarketable. Additionally, the damaged cells are an entry point for fungus and bacteria allowing the fruit to rot (Fig. 4) and resulting in increased disease inoculum in the field.

Sunburn Management

There are a number of biological and physical methods to reduce sunburn damage to a crop.

Biological control options: One simple approach is to identify and plant sunburn-resistant cultivars (that produce more foliage or that have a fruit color that reflects more sunlight). Some cultivars may be listed as heat tolerant but that does not necessarily mean they are sunburn-resistant. Second, use good agricultural practices to grow healthy plants because good leaf cover will naturally shade the fruit. Provide adequate water, fertilizer, and monitor plants closely for insects and diseases that can cause defoliation or leaf curling. Large healthy leaves provide good shade as long as the fruits set and grow within the plant canopy. In the case of tree fruits, proper training, pruning and fruit thinning will reduce, but not eliminate the risk of sunburn. Finally, train workers in proper harvesting techniques. It is very common for sunburn occurence to increase after harvest begins. Care should be taken to avoid cutting or breaking off vines, leaves, or branches during harvest. Bell peppers, tomato, summer squash, and cucumbers are particularly prone to photo-oxidative sunburn when harvesters break open the plant canopy, resulting in direct sun exposure to remaining fruits. Providing trellising for crops with heavy fruit load (like tomato and pepper) to support branches so they do not open when fruit becomes full-sized will reduce photo-oxidative sunburn. Shading harvested fruit will also reduce the risk of post-harvest sunburn.

Figure 3. Photo-oxidative sunburn on tomato (left) and red peppers that wrinkled due to sunburn damage after coloring (right).

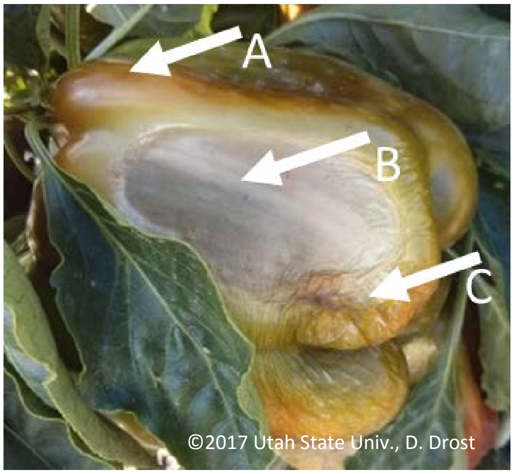

Figure 4. Pepper with sun damage: browning (A) and necrosis (B). The fruit is also infected with soft rot (C).

Figure 5. Sun damage to corn. Picture used with permission from Robert Nielsen, Purdue University.

Physical control options: For some crops, such as apple, there are sprays available that can be applied like a sunscreen to reduce sun damage. However, sunscreens need to be reapplied regularly, can be washed off by rain, and must be washed off before the crop is sold. Sunscreens are not suitable for soft fruits such as berries and tomatoes. Shade cloth is a highly effective option to reduce sunburn for many crops. Shade cloth should be constructed over the crop sometime during the growing season to decrease the amount of radiation (short/long-wave) that reaches the fruit.

Shade and the Plant Environment

Shade cloth impacts air and fruit surface temperature as well as incoming solar radiation (Fig. 6). A common response when shade is used is a reduction in air temperature during the day and a slight elevation in temperature at night (Fig. 6a). At night, the shade cloth reflects some of the longwave radiation, resulting in a rise in air temperature. Fruit surface temperature, the most important temperature for indicating sunburn potential, is significantly reduced during the day-time hours. In a North Logan, UT study, unshaded fruit temperature was over 120 °F in the late afternoon, while shaded fruit were more than 20 °F cooler at the same time (Fig. 6b). When solar radiation levels are reduced, damage from the sun will decrease. Clouds do provide shade as noted in Fig. 6c (August 12 cloudy; August 13 clear).

While shade cloth is typically used to reduce fruit loss due to sunburn, it also provides other benefits. When the correct level of shading is used, total crop yield should remain high. Research done with tomato reported leaf area of shaded plants increased by 40% compared to unshaded plants and total marketable yield increased by nearly 50%. These differences were due not only to a reduction in sunburn but also increased fruit quality, because shaded fruits had less cracking, blossom end rot, and cat-facing. Shading also alters plant architecture. Plants grown under shade are taller, have larger leaves, and possibly more nodes. Shading increases relative humidity under the structure and decreases wind. An increase in relative humidity decreases evaporation which causes soil and plants to retain more moisture under shade. Careful water management is needed to avoid excessively wet conditions that may lead to fruit rot or fungal growth. There are decreased water requirements for crops grown under shade. Fig. 7 shows higher water levels in soil under shade compared to unshaded soil. Additional benefits of shading include a decrease in cold damage during radiative frosts later in the year because shade cloth traps some longwave radiation (Fig. 6a).

Timing Shade Application

The timing of shade cloth installation varies by crop. Bell peppers and tomatoes are most susceptible to sunburn at the mature-green stage and somewhat susceptible at the immature-green stage. When tomatoes and peppers turn red, they are more resistant (reflect more sunlight) to sunburn. Cucumber and summer squash should be shaded once flowering begins. Apples are susceptible once fruit are golf-ball sized. Apple growers apply shade immediately after flowering. Small soft fruits (strawberry/brambles) should be shaded when fruit begin to form. Shade cloth can be applied earlier, but waiting until fruit set ensures plants grow to their maximum vegetative capacity before sunburn protection is needed. Shade can be removed after harvest or when conditions that promote sunburn cease. Storing the cloth under cover during winter months will exgtend its life.

Shade Cloth Options

Before purchasing shade cloth, evaluate the percent light reduction and shade color options. Shade cloth can provide anywhere from 10 to 90% shade. For most fruits and vegetables, 20 to 40% shade is ideal. Cloths with a very low shade percentage are at a higher risk of tearing under field conditions. Research shows that shade cloth

and red shade cloth are also available. Some shade cloth fabrics have strands of reflective aluminum woven in the fabric that relect up to 95% of the UV light. Fabric color impacts what and how Netting are used to manipulate the spectra of radiation reaching the crop and to scatter radiation radiation moves through the netting. Colored. Scattered radiation means the light is more diffuse which has been shown to increase photosynthetic radiation use efficiency, yields, and affect flowering.

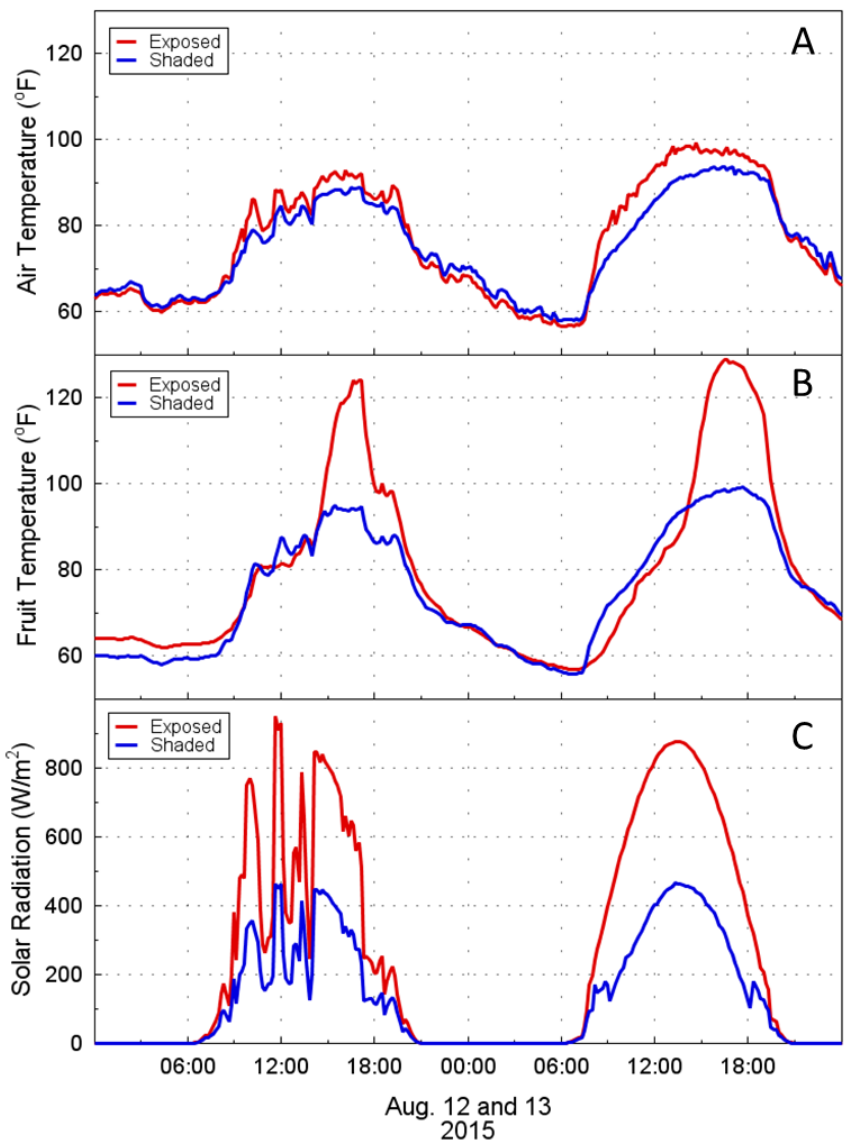

Figure 6. Response of air temperature (A), fruit surface temperature (B), and solar radiation (C) under 30% shade cloth compared to no shade (exposed) over two days in August in North Logan, Utah.

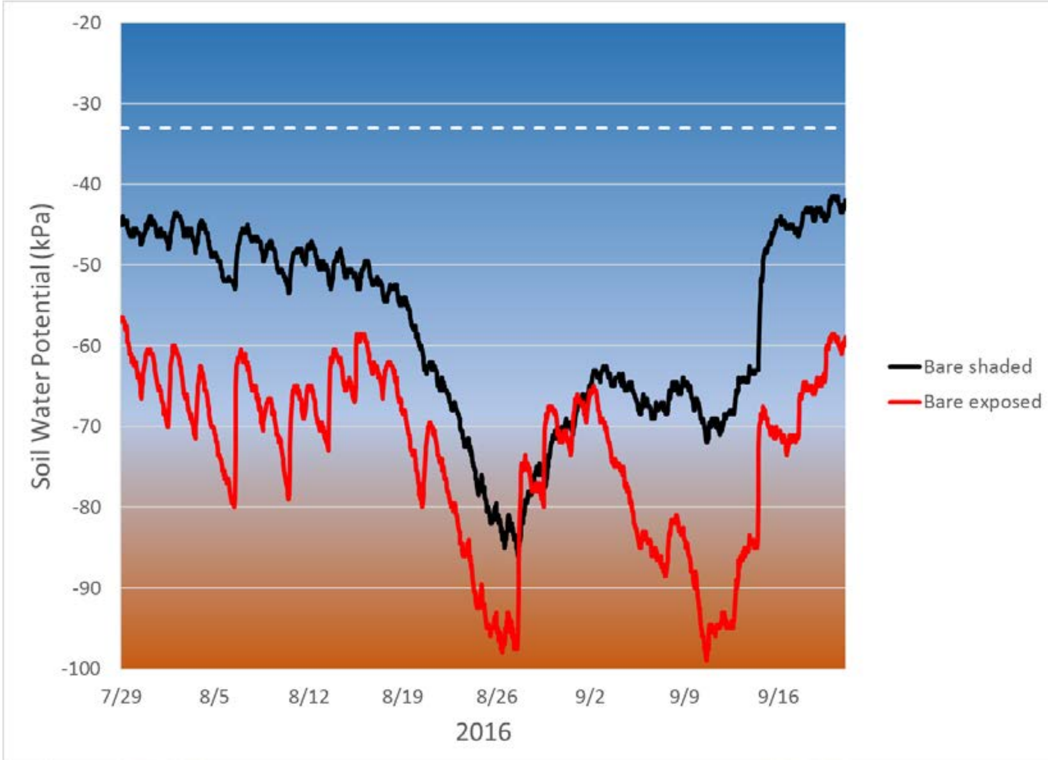

Figure 7. Soil moisture levels (-kPa) of bare soil with and without shade. Soil fully saturated with water is 0 kPa and field capacity (white dotted line) is around -33 kPa, depending on soil type. Targeted irrigation occurred at about -60 kPa. Lower readings mean the soil is drier so plants must work harder to extract water from the soil.

Shade Cloth Orientation

Shade cloth is most commonly installed *horizontally* (Fig. 8) over the crop, providing complete shade. When deciding what height to install the shade cloth, consider the working environment under the shade cloth, cost of materials, and edge effects. Leave enough space beneath the cloth for easy movement and equipment accessibiltiy. One Utah raspberry grower needed to build a higher trellis to accommodate longer canes when growing under shade. Plants on the edge of the field are susceptible to sun damage from low-angled sunlight in the early morning and late evening. Shade cloth should be extended to the ground. Otherwise, a strip of shade cloth installed along the east, west, and south sides can be added (Fig. 8). Using quality materials for shade cloth support (posts, wires, fasteners) is important for long-term use and to ensure high wind events don't damage the structure. Initial cost of installation can be high, but increased productivity and fruit quality over the life of the structure will offset these costs if the producer has a market for the crop.

Figure 8. Horizontal shade plus side panels over bell peppers. (Day Family Farms, Layton).

Vertical shade cloth is suspended directly above the crop (Fig. 9). When rows are oriented north-south, this provides shade to the rows on either side thus protecting fruit from solar radiation when the sun is low in the sky, such as in the hot afternoon. Leaf canopy provides shade during mid-day. Vertical shade allows for easy worker access to the field

Figure 9. Vertical shade over bell peppers. (Day Family Farms, Layton).

without having to suspend the shade cloth high above the crop. The posts can be used both to tie-up the crop and to support the shade.

Shade can also be installed over a *high tunnel or greenhouse*. Either attach the shade cloth on top of the plastic or remove the plastic and replace it with cloth. In these situations, no additional support structure is necessary and shading is provided on the sides and directly above the crop. *Low-tunnel* shade structures can also be constructed over individual rows (Fig. 10). Low-tunnels are first covered with plastic in the spring to enhance early plant growth and then covered with shade later in the season.

Figure 10. Low-tunnel shade structures oriented east to west with shade on the south.

Regardless of orientation of the shade cloth, use high-quality shading materials, be careful during installation, and securely attach to sturdy structures that are properly anchored and tensioned. If large structures are erected, anti-billowing wires should be installed above the cloth at regular intervals. Proper tension of wires reduces chaffing of wires and billowing of cloth during storms. Wires should be checked for fabric wear and retightened or replaced as needed throughout a growing season. A strong windstorm can break poles, rip the cloth, and damage suspension wires if the structure is not properly designed and installed. If high winds are common in your area, purchasing insurance for your structure and seeking professional help during the design and installation is recommended.

Cost

The cost of shade varies depending on the design you choose. Shade cloth costs $0.10 to$ 0.30 per square foot depending on the percent shade, fabric size, and the manufactures source. Knitted shade cloth has a functional life of 7 to 10 years if properly installed. Poles (framing), suspension wire, clips for securing the fabric, and pole anchorage all add to the cost of building the structure.

An enterprise budget for red bell peppers grown under horizontal shade is available for calculating costs for your operation. Shade structures can be expensive so carefully weigh the pros and cons of shading before deciding to install shade over your crop. It is a good idea to install shade over a test area to see if shade works for your crop and operation. As with all new practices, there is a learning curve to using shade cloth. Accurately track the number of fruits lost to sun damage each year and estimate the cost of this damage. In a Utah study on red bell peppers (Day, 2014), 52% of unshaded fruit were damaged due to sun injury. Vertically shaded peppers fruits had 23% sunburn. However, under horizontal shade, no fruits were damaged. Based on current fruit prices, using shade cloth was justified. When considering shade for your operation, careful research and planning improves your chances of success.

Additional Resources

Day, S.S. 2014. Biological and mechanical approaches to sunscald management in bell pepper production. Graduate Theses and Dissertations. Utah State University. Paper 3900. http://digitalcommons.usu.edu/etd/3900/

Johnson, G. 2016. Sunburn in fruiting vegetables and fruit crops and sunburn protection. University of Delaware. Cooperative Extension. https://extension.udel.edu/weeklycropupdate/?p=9562

Kittas, C. N. Rigakis, N. Katsoulas, and T. Bartzanas. 2009. Influence of shading screens on microclimate, growth and productivity of tomato. Proc. IS on Protected Cultivation in Mild Winter Climate. Acta Hort. 807

Stamps, R.H. 2009. Use of colored shade netting in horticulture. HortScience 44(2):239-241.

USDA NASS, Utah Field Office. 2014. Utah Agricultural Statistics and Utah Department of Agricultural and Food 2014 Annual Report. Page 83. http://ag.utah.gov/documents/AnnualReport

Structures and Fabric Suppliers

American Clay Works and Supply Company (ACW) http://www.acwsupply.com/index.php/downloadable-catalog

Farmtek.com http://www.farmtek.com/farm/supplies/home

Greenhouse Megastore http://www.greenhousemegastore.com/

Fabric Suppliers

US Netting https://www.usnetting.com/

Gemplers.com http://www.gemplers.com/shade-cloth

Shade Design Consulting

GIDCO Ag. Design and Consulting. http://gidcoagshades.com/

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