THE EFFECTS OF COLOR PLASTIC MULCHES AND ROW COVERS ON THE GROWTH AND PRODUCTION OF OKRA AND SUMMER SQUASH

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THESIS ABSTRACT

THE EFFECTS OF COLOR PLASTIC MULCHES AND ROW COVERS ON THE GROWTH AND PRODUCTION OF OKRA AND SUMMER SQUASH

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Okra [*Abelmoschus esculentus* (L.) Moench‘Clemson Spineless’] and summer squash [*Cucurbita pepo* (L) ‘Prelude II’] was grown on an Orangeburg sandy loam soil in Shorter, AL. Okra and summer squash were direct seeded in single rows. The experiment consisted of twelve experimental treatments as follows: (1) Black plastic mulch (BPM) + spunbonded row cover (RC), (2) BPM, (3)White plastic mulch (WPM) + RC, (4) WPM, (5) Red plastic mulch (RPM) + RC, (6) RPM, (7) Bare soil (BS) + RC, (8) BS, (9) Silver plastic mulch (SPM) +RC, (10) SPM, (11) Blue plastic mulch (BLUPM) + RC, (12) BLUPM. Soil temperatures were five to seven degrees lower than air temperatures in all treatments. The use of darker colored plastic mulches increased early and total yield of summer squash and okra compared to bare soil with and without row cover. Increased soil and air temperatures did not always correlate to an increase in yield. Because of this finding it is believed that the plant’s phytochrome and blue light responses were activated by the colored mulches. Further studies need to be performed to have a better understanding of the effects of vegetable crops grown with row covers and various colored plastic mulches.

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INTRODUCTION

Plastic (polyethylene) mulches have been used in vegetable production in the United States since the 1950’s. Black plastic mulch is the standard plastic used in vegetable production. Black plastic alters the plant’s growing environment by generating warmer soil temperatures (Dodds et al., 2003; Hanna et al., 2003) and holding more soil moisture (Ham et al., 1991; Lamont, 1993) than bare soil. It is due to this altered growing environment that researchers have recorded higher yields (Brown et al., 1995; Leib et al., 2002; Summers and Stapleton, 2002 Ibarra- Jíménez and Flores-Valásquez, 1999), earlier harvests (Lamont, 1993; Ibarra-Jíménez et al., 2000; Bonanno and Lamont, 1987), and cleaner fruit (Brown and Channell-Butcher 2001; Loughrin and Kasperbauer; 2002) using black plastic instead of bare soil. Sometimes black plastic mulches can create soil temperatures that are too high and this will cause deleterious effects to plant growth (Diaz-Perez et al., 2000; Orzolek and Murphy, 1993).

Other mulch colors besides black have been used by growers and researchers in vegetable production. White plastic mulch has been shown usually to generate cooler soil temperatures than black plastic (Lamont, 1993; Díaz-Perez and Batal 2002). White plastic is preferred during the summer growing season in warmer regions of the world compared to black plastic because it has the ability to maintain soil moisture while having cooler temperatures. The use of silver plastic mulch has resulted in less disease (Csizinszky et al., 1995; Lamont et al., 1990) in certain vegetable crops. Red plastic mulch has shown increased yield in tomato (Decoteau et al., 1989) and other crops (Decoteau et al., 1990; Kasperbauer, 1992). It is believed that red plastic mulch generates a positive phytochrome response within specific vegetable crops. A greater yield for some vegetable crops has been found using blue plastic mulch (Csizinszky et al., 1995).

Row covers are used to insulate a plant's growing environment and can promote early yield. Floating spunbonded polyester row covers are used with various vegetable crops (Wells and Loy; 1985; Shadbolt et al., 1962). Floating row covers have been shown to alter the plant's micro-environment by increasing temperatures for the crop during the day and into the night (Arancibia and Motsenbocker, 2002). The response of a plant to row covers is greatly dependent on the temperature in the region during the time the row covers are installed (Bonanno et al., 1987; Contreras and Sánchez del Castillo, 1990).

The use of row covers with plastic mulch has been shown to generate earlier and increased yields than row covers and plastic mulch used separately (Brown and Channell-Butcher, 1999a; Farías-Larios et al., 1998; Purser, 1993; Powell, 2000). Brown et al., (1998) observed that row covers with plastic mulch increased yield in 'Georgia Jet' sweet potatoes. Gerber and Brown (1982) found superior and earlier yields of 'Gold Star' muskmelon with the combination of row covers and plastic mulch. 'Market 76' cucumbers exhibited a positive increase in early and total yield with the addition of row covers to plastic mulch (Wolfe et al.,1989). Lamont et al. (2000) found the use of plastic mulch with row cover did not produce greater yields than the plastic mulch and bare soil treatments.

Research into growing vegetable crops with various colored plastic mulches along with spun-bonded row covers has been limited. Most research with color plastic mulches was done to identify growth effects of mulches but not in conjunction with the use of row covers. In addition minimal studies have been reported for okra and summer squash production with various color plastic mulches and row covers. The purpose of this study was to evaluate the effects of color plastic mulches and row covers on the growth and production of okra and summer squash.

LITERATURE REVIEW

Plants Growing Environment

Plastic mulches are used to adjust the growing environment of a crop or group of crops. The most popular beneficial effect of most plastic mulches is an increase in temperature which has shown to be beneficial to most plants. There are numerous other advantages to color plastic mulches such as improved fruit quality (Brown and Lewis, 1986; Brown and Channell-Butcher, 2001; Lamont, 1996), reduced weed problems (Lourduraj et al., 1997; Khan et al., 1990a; Munguia et al., 1998), reduced water evaporation (Batra et al., 1985; Maynard, 1987; Lamont, 1996), increased yield (Baker et al., 1999; Brown et al., 1995; Farias-Larios et al., 1999; Lamont et al., 2005; May et al., 2005), reduced fertilizer leaching (Mahbub and Zimmerman, 2006; Clarkson,1960), reduced soil compaction (Gough, 2001; Lamont, 1996), improved phytochrome response (Kasperbauer et al., 1992; Bradburne et al., 1989), and other benefits (Benoit and Ceustermans, 2000; Bextine et al., 2001; Boyhan et al., 2000; Brown et al., 1993; Caldwell and Clarke, 1999; Csizinszky et al., 1995). Certain color plastic mulches have been recommended for specific crops and for certain periods during the growing season.

Plastic Mulch

Polyethylene plastic was generated for commercial use in 1939. Polyethylene plastic is made from polyethylene resin which is in the form of pellets. The pellets are heated and then processed into bendable sheets of plastic film by either the “slot casting” or “blown bubble” process (Clarke, 1987). Polymer resins are used to form the mulch films. Some of the most commonly selected mulch films include low density polyethylene (LDPE), linear density polyethylene (LLDPE), high density polyethylene (HDPE), and metallocene (LLDPE) (Fleck-Arnold, 2000). The LLDPE resins tend to create films with puncture resistance and mechanical stretch properties. The HDPE resins produce films with reliable moisture and vapor barriers. The metallocene resins add strength and stretch properties to films. These different resins can usually not be mixed together to bestow all the best properties into a single film (Flack-Arnold, 2000). The ideal plastic mulch film should have enough flexibility and rigidity to be easily removed from a growing environment. This is done by the use of various polymer blends that are combined with the proper thermal and ultraviolet stabilizers.

The main polyethylene used in mulches is low-density polyethylene, which is created by polymerization of ethylene by high pressure (Lamont, 1993). The typical plastic mulch used in the U.S. is 1.25 millimeters thick and 48 inches (122cm) wide and comes in rolls 2400 ft (731m) long with a width of anywhere from 36 to 60 inches (91 to 152 cm) depending on the crop and cropping system in place (Lamont, 1993). The two types of plastic mulch are either smooth or embossed. The embossed has a diamond-shaped pattern that helps decrease the shrinking and swelling of the plastic, which can result in the loosening of the mulch from a raised bed. Numerous additives are added into plastic to improve specific properties of the finished product. Some of the additives that can be added are antiblock agents, antioxidants, pigments for color, flame retardants, and photodegradable additives (Wright, 1968).

Plastic Mulch Primary Effects

Soil Warming

Polyethylene (plastic) mulch was first noted for its ability to increase soil temperature in the 1950’s (Emmert, 1957). Due to the monetary value of many horticultural crops, it is beneficial to adjust the soil’s microclimate to prolong the growing season and increase the plant’s growth (Tarara, 2000). The heating properties of plastic such as “reflectivity, absorptivity, and transmittancy” and their interaction with the sun’s radiation will have a direct effect on the soil temperatures beneath the plastic mulch (Schales and Sheldrake, 1963). Plant growth requires radiation as a source of energy for photosynthesis, the means by which the radiation from the sun is converted to chemical energy (Rajapaske and Kelly, 1994). Hares and Novak (1992) gave a formula for the radiation of mulch as:

$$Rn_m = \alpha_m Rs\,(1 + \rho^{*}\,\tau_m \rho_s) + \varepsilon_m\,\varepsilon_{sky}\,\sigma\,T^4{}_{sky}\,(1 + \rho^{*}{}_{ir}\,\tau_{m,\,ir}(1 - \varepsilon_s)) + \rho^{*} ir \varepsilon_m\,\varepsilon_s \sigma T^4{}_s + \rho^{*} ir\,(\varepsilon^2{}_m \sigma T^4{}_m)\,(1 - \varepsilon_s) - 2\sigma\varepsilon_m\,T^4{}_m$$

Where Rs is global irradiance (Wm^{-2}); T_{sky}, T_s, and T_m are the temperatures of the sky, soil, and mulch (K), respectively; ε sky, ε_s, and ε_m are the emissivities or infrared absorptances of the sky, soil, and mulch respectively; α_m is the shortwave absorptance of the mulch; ρ_s is the shortwave reflectance of the soil; τ_m, ir is the transmittance of the mulch in the longwave spectrum, σ is the Stefan-Boltzmann constant ($Wm^{-2}\,K^{-4}$). The optical properties used here, represent the average optical properties over a wavelength interval, weighted by the distribution of radiation in the emission spectra of interest. The variables ρ and $\rho^{*}{}_{ir}$ represent the internal reflection functions for shortwave and longwave radiation, respectively. These functions give rise to the multiple reflection of radiation between the top layer of soil and the mulch. Van der Hulst (1980) gave the formula for ρ^* and ρir as follows:

$\rho^* = (1 - \rho_s\rho_m)-1 = 1 + \rho_s\rho_m + \rho_s^2{}_m^2 + \ldots$

$\rho^* ir = [1- \rho_{m,ir}(1-\varepsilon s)] -1 = 1 + \rho_{m,ir} (1-\varepsilon s) + \rho_{m,\, ir}^2 (1-\varepsilon_s^2) + \ldots$

where ρ_m is the shortwave reflectance of the lower mulch surface and $\rho_{m,ir}$ is the reflectance of the mulch in the infrared spectrum. The formula demonstrates that the reflection's actions account for the initial incident radiation in the layer and amplify the effect with repeated reflections between the soil surface and the underside of the mulch.

Net radiation is defined as the sum of absorbed shortwave and long wave radiation minus emitted long wave radiation (Ham and Kluitenberg, 1994). The radiation plastic mulch receives will be shortwave radiation reflected from underlying soil, global irradiance, and long wave radiation transmitted by the sky and soil. The radiation that is released from the soil and emitted from the mulch is also of importance when factoring net radiation (Ham and Kluitenberg; 1994; Liakatas et al., 1986). Munguia et al. (1999) found that net radiation is higher in the plastic mulch field than in the non-plastic mulch field. This is significant because it indicates the spectral properties of the plastic mulch had a substantial effect on the short and longwave. There are three non-radiative components to radiant energy at the soil surface: conduction of heat into the ground; the flux of latent heat in connection with evaporation from the soil; and convection of sensible heat into the layer of air between the soil surface and the mulch. The rate at which a soil increases or decreases heat over a period of twenty-four hours is closely associated with the diurnal cycle of surface temperature and can be estimated from the classical theory of heat flow in a semi-infinite homogeneous medium (Monteith, 1973). The formula can be written as:

$$T\ (z,t) = T + A_0 \exp(-z/D) \sin(\omega t - z/D)$$

where T is the mean surface temperature, t is time, depth is z, A_0 is the temperature amplified at $z = 0$, ω is the frequency of oscillation, and D is the damping depth given by $(2k/\omega)^{1/2}$ where k is the thermal diffusivity of the soil. The term $A_0 \exp(-z/D)$ is the amplitude at depth z and z/D is the phase lag of temperature wave at z.

The color of plastic mulch will determine the plastic's energy-radiating abilities. Black plastic mulch is the most common color of plastic used in vegetable production. Black plastic films retain a greater realm of the solar energy radiated on it and therefore become hot. With black plastic mulch, the incoming radiation is first absorbed by the plastic and then transferred to the soil through conduction. The effect of plastic mulch on soil temperatures, temperatures of the soil surface, and the optical properties of the plastic material is determined by the plastics optical properties (Ham et al., 1993). Black plastic has intense shortwave transmittance and high shortwave absorptance so it is expected to raise soil temperatures the fastest (Tarara, 2000; Ham and Kluitenberg; 1994; Dobbs et al., 2003; Heißner et al., 2005). Beneath black film, the soil temperature may be ten to fifteen degrees hotter than on bare soil (Stevens et al, 1991; Splittstoesser, 1990). The highest midday soil temperatures are usually found on plastic mulches with high shortwave absorptance (black) or a high short wave transmittance (clear) (Tarara, 2000). Black mulch usually produces the hottest soil temperature compared to other colored mulches (Díaz-Perez and Batal, 2002; Lira-Saldivar et al., 2000; Infante et al., 1998; Jiménez et al., 2003; Khan et al., 1998). White plastic mulch is created by converging titanium dioxide. The white mulch film reflects radiant energy which makes it possible for the soil under it to have a decreased temperature in comparison to black mulch (Stevens et al., 1991). White plastic reflects 48% of the solar radiation toward the canopy (e.g., 385 $W{\cdot}m^{-2}$ at an incident 800 $W{\cdot}m^{-2}$). This is why total radiation toward the canopy is higher above a white plastic (785-870 $W{\cdot}m^{-2}$) than above a black plastic (500-600 $W{\cdot}^{-2}$) (Tarara, 2000). Due to white plastic having a lower temperature than black plastic, its longwave radiation is somewhat lower (Tarara, 2000). White plastic seems to have the ability to reduce soil heating during the day and trap the soil's heat under the mulch during the night (Ham et al., 1993). White film is used in areas with an intense level of solar radiation and areas where it is required to reduce the transmitted radiation and soil temperature. White plastic is also used to raise the amount of reflected light on the lower and middle plant leaves (Stevens et al., 1991). In other experiments, various color mulches have netted the highest soil temperature when compared to other colored plastic mulches. Csizinszky et al. (1995) and Orzolek et al. (2003) found blue to have the highest soil temperature amongst treatments. Orzolek and Murphy (1993) and Stapleton and Duncan (1994) had results that red plastic mulch created the highest soil temperatures among color plastic mulches. Silver plastic mulch usually results in lower soil temperatures than the other color plastic mulches with white plastic mulch being the exception (Lamont et al., 2000; Lamont, 1993; Liakatas et al., 1986).

There must be intimate contact between color plastic mulch and the soil surface to increase soil temperature. If mulch has been installed snugly and is in exact contact with the soil, the layer of air between plastic and soil is reduced and the heat is transferred by conduction, which will lead to a rise in temperature (Tarara, 2000). A growing area in which the mulch-surface contact is not consistent that will create deviations in soil temperature (Heißner et al., 2005.) Only when color plastic mulch has a tight fit to the soil will the soil's temperature rise (Quasha and Evans, 1967). Ham and Kluitenberg (1994) found that increasing the contact resistance (degree of contact between the soil and plastic mulch) caused the temperature of the mulch to increase but the soil temperature to decrease. It was only through a decrease in contact resistance that the soil temperature increased. With increased contact resistance, colored mulch can continue to absorb shortwave radiation, but can not transfer the energy to the soil through conduction. Other aspects to consider in the effectiveness of plastic mulches to heat a soil are: the amount rainfall; the type of soil; the thickness and width of the mulch; soil moisture; and intensity of the sunlight; humidity of the surrounding environment; and the plant canopy.

Air Warming

Convection arises when the buoyancy forces produced on a volume of air by temperature variations prevail against the viscous forces that retard air movement (Tanner, 1974). Convective heat transport between the plastic and the atmosphere is created by the shape and properties of the plastic surface and the temperature level between the boundary layer and the plastic as defined by (Ham and Kluitenberg, 1994)

$$H = CV \, \frac{(T_a - T_m)}{R_{a,\,h}}$$

where H is the convective heat transfer, Ta is air temperature (K), Tm is the temperature of mulch, Cv is the heat capacity of the air (Jm -3 K -1), and $R_{a,\,h}$ is the aerodynamic resistance of heat transfer (sm^{-1}). Aerodynamic resistances are estimated using surface similarity theory (Ham and Kluitenberg; 1994)

$$r_{a,h} = \frac{1}{u^* k_v} \quad [\ln \left(\frac{z-d}{z_h} \right) + \Psi_h$$

where u* is friction velocity measured from wind speed at height z1 ($m\ s^{-1}$), d is displacement height (m), z_h is the roughness length for heat transfer (m), kv is von Karman's constant (0.41), and Ψ_h is a diabatic influence function. Above ground effects of plastic mulch are mainly due to the optical properties of the mulch and the fact that plastic acts as a barrier to evaporation (Tarara , 2000; Waggoner et al., 1960). Clarkson (1960) was able to show that the greatest temperature difference between mulched and non-mulched areas occurred at the surface of the plastic as compared to the soil surface and two inches over the plastic and soil surfaces. In both cases the temperature of the air above the plastic was higher than the temperature of the air above the bare soil.

Secondary Effects of Color Plastic Mulch

Earlier Growth and Production

The use of color plastic mulch has resulted in more growth and earlier yields than the use of bare soil. The earlier a grower can produce a quality crop, the greater the chance the grower will be able to get his or her produce to the market before a competitor. A grower's ability to produce an early crop is not only beneficial in outperforming competitors but it gives the crop a chance to mature before the onset of disease. Brown et al. (1992) and Decoteau et al. (1989) found earlier growth in tomatoes with the use of plastic mulch. Rangarajan and Ingall (2001) ascertained that the use of red, silver, and blue plastic mulch increased earliness of radicchio head formation compared to bare soil. In an experiment performed in Virginia, Powell (2000) recorded earlier growth of watermelon with the use of color plastic mulch. Color plastic mulch reduced the number of days for eggplant to flower (Valdaz-Fields et al., 2002). The use of red and black plastic mulch helped establish earlier yield of bell pepper than the use of bare soil (Wells, 1999).

Fewer Weeds

Plastic mulch reduces the weed population in vegetable field crops in comparison to bare soil. A weed will compete with a crop for nutrients, light, and moisture. Plastic mulch creates a barrier to herbicide dissipation into the atmosphere and thus renders herbicide more effective. Unlike bare soil, plastic mulch reduces the amount of light in the photosynthetically active range (PAR) of 400-700nm from reaching the soil beneath the plastic mulch. Reducing PAR beneath the plastic mulch helps to prevent the growth and limit the germination of weeds (Ngouajio and Ernest, 2005). Weed control with plastic mulch has been found by a wide array of researchers (Clarkson and Frazier, 1957; Lourduraj et al. 1997; Rahman and Shadeque, 1999; Saikia et al., 1997; Lamont, 1993). It is this reduction in weeds that helps make the use of plastic mulch more economical for the grower.

Greater Soil Moisture

Plastic mulch helps maintain soil moisture for improved plant growth and development. Drip tape is the preferred means of irrigating vegetables when using plastic mulch. The use of drip tape along with plastic mulch not only allows a vegetable crop to receive adequate moisture but it is also more cost efficient than overhead irrigation. One of the most popular reasons for using plastic mulch is its ability to maintain soil moisture (Orzolek et al., 1993; Lamont, 1996). Numerous studies have concluded that soil beneath plastic mulch and drip tape will have higher soil moisture than bare soil with drip tape (Gough, 2001; Mahbub and Zimmerman, 2003; Infante et al. 1998). Liakatas et al. (1996) documented that the ability of plastic mulches to alter the plant's microenvironment was due in part to its ability to restrict soil water evaporation. When comparing drip irrigation to furrow irrigation, Tiwari et al. (1998) established a 40% reduction in water application with the use of black plastic mulch in conjunction with drip irrigation. Kirknak et al. (2003) discovered that the plastic mulches' ability to improve soil moisture in the process it improves nitrogen availability for plants.

Less Leaching of Fertilizer

When a fertilizer is used for a crop, it is important to the grower for economic and environmental reasons to get the maximum growth effects from the fertilizer. Plastic mulches have shown to improve the availability of fertilizers to plants by reducing the leaching . Reduced leaching occurs when plastic mulch acts as a barrier to rainfall and thus prevents rainwater from seeping through the soil and taking nutrients below the point of contact for roots. Farias-Larios et al. (1999) reported that use of plastic mulch reduced the use of synthetic fertilizers in honey dew melon production. Okra researchers have reported that plastic mulch reduced leaching of synthetic fertilizers (Lamont, 1996; Orzolek and Lamont, 1999; Schales and Sheldrake, 1963). Mahbub and Zimmerman (2006) concluded that plastic mulch gives growers the ability to inject liquid fertilizers at specifically timed intervals. This technique provides the developing plant with nutrients at that precise time they are needed. Due to the fact that plastic mulch allows less leaching of nutrients, Zheng and Wang (1986) found that the use of plastic mulch increased the absorption of N and K in cucumbers. Vethamoni and Balakrishnan (1990) found greater N-P-K absorption in okra with use of plastic mulch.

Improved Fruit Quality

Improved fruit quality is another beneficial aspect of the use of plastic mulches. Fruit quality is measured by cleanliness, taste, insect damage, etc. Csizinszky et al. (1998) and Benoit and Ceustermans (2000) detected less insect damage to vegetable crops grown on colored plastic mulch. Turnips grown on blue plastic mulch were found to have a “sharp” taste while those grown on green plastic mulch were found to have a “sweet” taste (Antonious et al., 1996). Bell peppers from plots grown on plastic mulch were found to be cleaner than those grown on bare soil (Brown and Channell-Butcher, 2001). Fruit quality improvement that plastic mulch offers is vital to growers when attempting to sell a vegetable crop.

More Positive Benefits of Colored Plastic Mulch

There are other positive benefits to using plastic mulch for vegetable crop production. Delgadillo et al. (2002) reported that silver-black plastic mulch was effective in controlling whiteflies during watermelon production. Researchers have found plastic mulch to be a deterrent to aphids and other insects that feed on vegetable crops (Stapleton and Summers, 2002; Brown et al., 1993; Benoit and Ceustermans 2000; Boyhan et al., 2000; Caldwell and Clarke, 1999). Plastic mulch has been found to help conserve water compared to bare ground soil (Powell, 2000; Mahbub and Zimmerman, 2006; Waggoner et al., 1960). Khan et al. (1993) observed that plastic mulch could be successfully used to intercrop watermelon and okra. Plastic mulch has the capacity to generate higher concentrations of dissolved solutes (any material in the soil solution) than bare soil (Munguia et al., 1998). The dissolving of solutes was beneficial for the growth and yield of the muskmelon crop. Vivrina and Roka (2000) and Russo et al., (1997) reported that the use of plastic mulch reduced erosion in vegetable fields.

Yield Response of Squash to Plastic Mulch

Many studies have been completed on yield effects of squash grown with plastic mulch. Brown et al. (1996a), Dickerson et al. (2003), and Infante et al. (1998) reported that black plastic mulch did not have an effect on summer squash yields compared to bare ground treatments. Caldwell and Clarke (1999) found aluminum-covered mulch reduced cucumber beetles yet still had no significant difference in yield then squash grown on black plastic. Orzolek and Murphy (1993) and Stapleton and Duncan (1994), reported significantly higher yields of zucchini squash on various color (red, yellow, gray, blue and black) mulches in relation to that of bare soil treatments. The use of black plastic mulch caused a significant increase in yield with calabaza and butternut squash (Rulevich et al., 2003). By reducing aphid populations and thus the onset of virus infection, Brown et al. (1996b) established 96% higher yields of summer squash with aluminum plastic mulch than with bare soil. Boyhan et al. (2000) revealed increased yields of summer squash with the use of reflective mulch. Summers and Stapleton (2002) noted that significantly higher yields of zucchini squash when grown on reflective mulch as compared to that grown on bare soil.

Yield Responses of Okra to Plastic Mulch

Research has been done on the affect of plastic mulch on okra yield. In research that took place in India, Batra et al. (1985) found higher yield of okra with polyethylene mulch compared to bare soil. Due to plastic mulch's ability to reduce weeds and reduce leaching of fertilizers, both Vethamoni and Balakrishnan (1990) and Brown and Lewis (1986) recorded higher yield in okra grown on black mulch instead of bare soil. In an experiment conducted in Florida, Simone et al. (2002) reported that different varieties of okra had significantly higher yields when grown on plastic mulch rather than bare soil. The use of plastic mulch created significantly higher yields of okra compared to bare soil due to improved moisture retention in the soil (Lourduraj et al., 1997; Tiwari et al., 1998; Saikia et al., 1997). The increase in ambient temperatures provided by plastic mulch has been cited as a factor in okra grown on plastic mulch has out yielded okra grown on bare soil (Khan et al., 1990a; Khan et al., 1990b; Lamont, 1999; Incalcaterra and Vetrano, 2000; Brown and Channell-Butcher, 1999b).

Row Covers

Row covers act to protect seedlings from frost, heavy rains, periods of dry weather, and cool winds without blocking needed moisture and sunlight from a crop (Goc, 1985; Jenson, 2000). Row covers are used to amplify the temperature of the plant's growing environment and help promote earlier yield. The microenvironment created by row covers produces earliness, greater yields, and overwintering protection to vegetable crops (Wolfe et al., 1989; Ibarra et al., 2001; Loy and Wells, 1975). Parchment paper row covers were the original row covers used for field-grown vegetable crop production (Wittwer and Lucas, 1956). In the experiment, the parchment paper row covers were used to protect celery plantings from frost and wind of western Michigan. The next row covers produced were made from polyethylene plastic. In this experiment the polyethylene row covers produced earlier yield than the paper mulches used in the study (Hall, 1963). Shadbolt and McCoy (1962) discovered that plastic row covers increased yield and early plant development. Polyethylene row covers were used for a cucumber planting in California in 1958 (Hall, 1963). In this experiment the polyethylene row covers produced earlier yield than the paper mulches used in the study. It was deduced that plants that are allowed to grow to maturity under unventilated cover will become stunted compared to those that are grown under ventilated condition (Shadbolt et al., 1962). The opening of plastic covers is also needed to decrease humidity and water condensation (Loy and Wells; 1982). Slitted polyethylene row covers created day time temperatures four to five degrees higher than outside temperatures (Loy and Wells, 1975). This increase in temperature allowed pistillate flowering in muskmelons to mature earlier than those on bare soil or on black polyethylene mulch treatments. Wells and Loy (1985) found slitted row covers helped to increase the yield of muskmelon in an experiment that occurred in New Hampshire.

In the early 1980's, spunbonded polyester row covers were introduced. The Federal Trade Commission's definition for polyester fiber as follows: a manufactured fiber forming substance in any long-chain synthetic polymer composed of at least 85% by weight of a substituted aromatic carboxylic acid, including but not restricted to substituted terephthalic units, p $(\text{-R-O-CO-C}_6\text{H}_4\text{-CO-O-})_X$ and parasubstituted hydroxyl-benzoate, p$(\text{-R-O-CO-C}_6\text{H}_4\text{-O})_X$ (http://www.fibersource.com). Spunbonded polyester row covers are made from a thin mesh of white synthetic fibers which hold in heat. Water can penetrate the row cover and thus allow for overhead irrigation or rain to hydrate the plants. A spunbonded polyester row cover also keeps the soil moist by allowing rain water to reach plants and thus helps to prevent soil compaction. The weight of polyester row covers can range from 0.3 to about 2.0 oz/sq yd (10 to 68 grams/sq meter) (Penn State, 2003). Spunbonded row covers in the 0.5 to 1.25 oz (14.2g to 35.5g) range render 1.1ºC frost protection in the spring and even greater frost protection in the fall (Penn State, 2003).

The more the temperature rises outside of a row cover, the higher the temperature will be inside of a row cover. Floating row covers vary in width from 6 to 50 ft (1.83 to 15.24m) and up to 800 ft (244m) in length. The lightest (under 14.2 g) of the spunbonded polyester row covers is used principally for insect exclusion while the heaviest (49.6g) of the covers is used for frost protection (Penn State, 2003). The covers are bound by placing soil, stones, or long pins on the edges. Spunbonded polymers of polyester transmit about 80% of photosynthetic photon flux density (PPFD) (Wells and Loy, 1985). The reduction in light transmission through spunbonded covers should not factor in the growth of young plants in full or partial sunlight since the photonflux density of full sun is well above the light saturation point of crop plants (Wells and Loy, 1985; Goc, 1985). When using row covers for insect control, it is essential to make sure the edges of row covers are held in place with no openings (Wells, 2000). There should be a complete seal around the edges of the row cover.

The spunbonded row covers offers adequate light transmission to growing plants along with the same yields, disease resistance, and insect protection as polyethylene row covers (Loy and Wells, 1982). As young plants grow taller, they lift the row cover so that it floats on top without harming them. Row covers are used primarily for peppers, sweet corn, melons, summer squash, tomatoes, and strawberries (Wells, 2000).

Row covers do offer some disadvantages to growers. Spunbonded polyester row covers can give way to weed pressure under the cover. If plastic mulch is not used, weeds can steadily develop and become established in the field (Wells, 2000; Penn State, 2003). It is important to sterilize the soil if row covers are used without plastic mulch. If the vegetable seed used is not free of insects, it is possible for row covers to increase insect damage (Wells, 2000). The insect damage will occur because the row covers will provide a protective environment for insect growth and development. It is vital that all seed used with row covers be of free insects and diseases since row covers can create an ideal environment for insect and disease problems to develop (Wells, 2000).

Row Covers to Decrease Insect Populations and Disease

There have been a multitude of studies conducted to illustrate the ability of row covers to exclude harmful insects from vegetable crops. Bextine et al. (2001) discovered that row covers prevented the transmission of yellow vine disease (a phloem limited bacterium) in squash plants. The disease is transmitted by spotted cucumber beetles (*Diabrotica undecimpunctata howardi*), striped cucumber beetles (*Acalymma vitatum*), and squash bugs (*Anasa tristis*). The disease did not occur in squash with row coves because the row covers prevented the access of harmful insects that act as vectors for the disease to plants. Other tests have shown the effectiveness of row covers in preventing the spread of disease to vegetable crops (Webb and Linda, 1992, Natwick and Laemmlen, 1993; Loy and Wells, 1982; Perring et al., 1989). In Mexico, the use of floating row covers eliminated the infestation of aphids and greatly reduced whitefly nymphs on plant foliage of muskmelon (Farias-Larios et al., 1998). Cucumber beetle, an insect which is a vector of disease in squash and other cucurbits, has been prevented from spreading disease through the use of row covers (Loy and Bushnell, 1984). Lopez (1998), noted that virus symptoms such as mosaic spots, mottling, leaf curling, and stunting and yellowing of leaves was delayed with the use of row covers for seven weeks after plant emergence compared to two weeks in uncovered plants.

Row Covers Effect on Air Temperatures

Row covers are used to raise the air temperature in a crop's growing environment. The intended purpose of higher air temperatures is earlier plant germination and growth. The earlier a crop emerges and produces a yield, the earlier a grower can get the crop to market and hopefully produce a profit. In Lebanon, Rubeiz and Freiwat (1999) noted significant increases in air temperature with the use of row covers instead of bare soil. Researchers in North Carolina revealed that by using row cover, minimum, maximum and mean temperatures were increased when compared to bare soil (Bonanno and Lamont, 1987). Many other scientists have found row covers raise air temperatures compared to bare soil (Brown and Channell-Butcher, 1999a; Lamont et al., 1999; Hemphill and Crabtree, 1988; Ibarra-Jimenez et al., 2004). Ortho Wells, a plant scientist at the University of New Hampshire, has a method for determining the incremental rise in temperature under polyester spunbonded row covers (Goc, 1985). When temperatures outside the cover reach 23.9ºC, air inside the cover will be between 28.1ºC to 29.4ºC. When it is 29.4ºC outside, the inside temperature under the cover will be between 35ºC to 36.1ºC. A temperature of 35ºC will give a temperature of about 45.7ºC.

Row Covers Effect on Soil Temperatures

Row covers not only have the ability to increase air temperatures but they also can increase soil temperatures. Loy and Wells (1982) recorded a 5ºC increase in soil temperature with the use of row covers and black plastic mulch compared to that of bare soil. Orozco-Santos et al. (1999) found a 5 to 8ºC rise in soil temperature with the use of row cover and plastic mulch. This increase in soil temperature correlated to greater yields of cantaloupe compared to bare soil treatments. Brown et al. (1998) believed that an increase in the yields of sweet potatoes was a direct result of increased soil temperatures caused by the use of row cover with plastic mulch. In Mexico, Ibarra-Jiménz et al. (2004) revealed increased soil temperatures with the use of black plastic mulch and row covers. Plastic mulch with row covers generated higher soil temperatures and greater yields of muskmelon as opposed to bare soil treatments (Farias-Larios et al., 1998). Bonanno and Lamont (1987) recorded that row covers with plastic mulch resulted in increased soil temperatures but had no effect on the yield of muskmelon. In Louisiana, row covers with plastic mulch were credited with increased soil temperatures. The increased soil temperatures were beneficial in producing a greater total yield of a watermelon crop.

Response of Squash to Microclimate Modifications from Row Covers and Plastic Mulch

Squash has been shown to react favorably to the microclimate modifications that result from plastic mulch and plastic mulch with row covers. Orzolek and Murphy (1993) disclosed that the mulches that generated the highest temperatures also produced the highest yields of squash. Purser (1993) established significant yields of squash in Alaska with the use of plastic mulch and row covers. An increase in the height and maturity of squash plants was the result of the increase in temperature created by plastic mulch with row covers (Brown et al., 1993; Brown et al., 1996). The use of row covers with plastic mulch can give squash plants protection from frost which helps to increase plant maturity (Dickerson et al., 2003). Lopez (1998) reported that the increased temperatures (soil and air) and the conservation due to the use of row covers with plastic mulch resulted in higher leaf number and stem length in squash plants. Squash grown on plastic mulch has been proven to produce earlier maturing larger squash plants than those grown on bare soil alone (Infante et al., 1998; Summer and Stapleton, 2002). There can be problems that result from the microclimate modification that results from the use of row covers and plastic mulch. Contreras and Sánchez del Castillo (1990) reported that temperatures inside row covers with plastic mulch treatments were so high that they caused plant injury to pumpkin plants which are in the cucurbit family.

Response of Okra to Microclimate Modifications from Row Covers and Plastic Mulch

The microclimate modification created from plastic mulch and plastic mulch with row covers has a dynamic effect on okra development. Khan et al. (1993) and Brown and Lewis (1986) revealed earlier seed emergence of okra grown with plastic mulch and with plastic mulch with row covers in comparison to bare soil. More branching of okra plants was discovered with the use of plastic mulch with and without row covers instead of bare soil treatments (Khan et al., 1990b; Batra et al., 1985). The use of plastic mulch resulted in increased plant height in experiments in India (Vethamoni and Balakrishnan, 1990; Lourduraj et al., 1997). Plastic mulch with and without row covers has been documented to increase the amount of pods per plant when compared to bare soil (Khan et al., 1991; Rahman and Shadeque, 1999; Saikia et al., 1997).

Yield Response of Squash to Plastic Mulch

Many studies have been done on yield effects of squash grown with plastic mulch. Brown et al. (1996a), Dickerson et al. (2003), and Infante et al. (1998) reported that black plastic mulch did not have an effect on summer squash yields compared to bare ground soil. Caldwell and Clarke (1999) found aluminum covered mulch reduced cumber beetles yet still had no significant difference in yield than squash grown on black plastic. Orzolek and Murphy (1993) and Stapleton and Duncan (1994), uncovered significantly higher yields of zucchini squash on various color (red, yellow, gray, blue and black) mulches in relation to that of bare soil treatments. The use of black plastic mulch caused a significant increase in yield with calabaza and butternut squash (Rulevich et al., 2003). By reducing aphid populations and thus the onset of virus infection, Brown et al. (1996b) established 96% higher yields of summer squash with aluminum plastic mulch than with bare soil. Boyhan et al. (2000) revealed increased yields of summer squash with the use of reflective mulch. Summers and Stapleton (2002) noted that significantly higher yields of zucchini squash when grown on reflective mulch as compared to that grown on bare soil.

Yield Responses of Okra to Plastic Mulch

Research has been done on the affect of plastic mulch on okra yield. In research that took place in India, Batra et al. (1985) found higher yield of okra with polyethylene mulch compared to bare soil. Due to plastic mulch’s ability to reduce weeds and reduce leaching of fertilizers, both Vethamoni and Balakrishnan (1990) and Brown and Lewis

(1986) recorded higher yield in okra grown on black mulch instead of bare soil. In an experiment conducted in Florida, Simone et al. (2002) reported that different varieties of okra had significantly higher yields when grown on plastic mulch rather than bare soil. The use of plastic mulch created significantly higher yields of okra compared to bare soil due to improved moisture retention in the soil (Lourduraj et al., 1997; Tiwari et al., 1998; Saikia et al., 1997). The increase in ambient temperatures provided by plastic mulch is a reason okra grown on plastic mulch has out yielded okra grown on bare soil (Khan et al., 1990a; Khan et al., 1990b; Lamont, 1999; Incalcaterra and Vetrano, 2000; Brown and Channell-Butcher 1999b).

Earth's Light Absorption

Radiation from the sun reaching the earth ranges from 290 to 1000nm (Senger and Schmidt, 1994). Radiation is restricted by water vapor, CO_2 and the ozone layer. The visible light spectrum is between 380 to 750nm. The first law of photochemistry (Lamar University, 1998), states that only light which is absorbed by a system can induce a chemical reaction. The next law of photochemistry, also known as Stark-Einstein Law asserts that an atom or molecule undergoing a photochemical process absorbs only a single photon (Lamar University, 1998). Another way to state it is for every quantum of radiation that is absorbed; one molecule of the substance reacts. The absorption spectra (Hart, 1988) gives an example of the basic photo responses of pigments to different wavelengths and irradiation.

$$R_\lambda \quad \alpha \quad N_\lambda t \varepsilon_\lambda \Phi_\lambda$$

In this formula for a basic photoresponse, (λ) is the wavelength, (R) is the function of fluence rate (N), duration of exposure (t), absorption coefficient of the photoreceptor (ε) and quantum yield of the photoreceptor (Φ). The most efficient wavelengths will be those where the least number of photons is required to render an effect.

Photomorphogenesis

Photomorphogenesis is the ability of light to regulate plant growth and development independent of photosynthesis (Decoteau et al. 1993). Photomorphogenesis is the non-photosynthetic influence of light on growth, germination, reproduction, and, development in plants (Hart, 1988). Other plant processes that are a product of photomorphogenesis are flowering, internode elongation, abscission, chlorophyll development, root shoot growth, and lateral bud outgrowth (Decoteau, 2000). Photomorphogenic pigments are used in the process of photomorphogenesis. Plant pigments will recognize variations in the growing environment such as direction and duration of light, light quality and quantity (Cosgrove, 1994). With the information a plant receives from its photomorphogenic pigments, it will modify its growth (vegetative and reproductive) in accordance with the growing environment. Photomorphogenic pigments modify and regulate plant growth processes and thus have a significant impact on plant shape size and the direction of plant growth (Cosgrove, 1994). The photomorphogenic pigments include phytochrome, blue light, and UV absorbing receptors. The most often studied receptors in plasticulture research with vegetable crops are phytochrome and blue light.

Phytochrome

There are several receptors that must be stimulated during photomorphogenesis. Phytochrome is the photoreceptor responsible for light-regulated growth responses. The phytochrome molecule is a dissolvable chromoprotein with subunits that are made up of a linear tetrapryrrole chromophore covalently linked to a polypeptide of 120 to 127000 mol. wt. depending on the plant species (Vierstra et al., 1984; Pratt, 1982). Phytochrome exists within plants in two interconvertible structures. One structure of phytochrome absorbs only red light (p_r), which is the inactive structure which maintains a plant's response and transduction. When the p_r light is absorbed it will undergo a chemical change and become the other structure. The other structure of phytochrome, which is the active structure, is the far-red (p_{fr}). The p_{fr} maintains a plant's response and transduction (Rajapakse and Kelly, 1994; Sager et al., 1988). When the p_{fr} is adsorbed, it changes to become the other structure that is only p_r absorbing. It is the ability of phytochrome to constantly switch from p_r to p_{fr} and vise versa that gives the molecule its regulatory function. The photoconversion of p_r to p_{fr} in the cell produces copious morphogenic responses while the reverse process of p_{fr} to p_r stops the initiation of the responses (Quail, 1984).

Phytochrome receptors have the ability to detect wavelengths from 300-800nm. Red (R) light is absorbed from 660 to 680nm and far-red (FR) light is absorbed from 730 to 740nm (Decoteau et al.1993; Rajapakse and Kelly, 1994; Kasperbauer, 1999). The ratio between the two structures in the plant relies on the ratio of p_{fr} to p_r light and controls the use of resources within the plant (Kaplan, 1991.). p_{fr} formation starts a transduction mechanism that results in modified expression of specific genes and eventually in modified growth and development suited for the prevailing light surroundings (Quail, 1991). **Fig (1.)** Quail (1991), illustratates this:

$$\begin{tikzcd} p_r \arrow[r, shift left, "\text{Red}"] & p_{fr} \arrow[l, shift left, "\text{Far-Red}"] \arrow[r] & \text{modified gene expression} \arrow[r] & \text{morphogenesis} \end{tikzcd}$$

(Fig. 1)

perception transduction response

Research by USDA scientists Dr. Harry A. Borthick and Dr. Sterling B. Hendricks led to the discovery of the phytochrome molecule. Dr. Michael J. Kasperbauer, another research scientist with USDA, concluded that phytochrome triggers a competition response in plants grown closely together. In a field planted spacing experiment, it was concluded that plants grown closely together allotted more photosynthate and thus plants developed narrow leaves, longer internodes, and shorter roots then plants grown further apart (Kasperbauer, 1973). It was this research conducted by Dr. Kasperbauer that helped to reveal that it was an increases FR: R ratio (higher than that of full sunlight) inside the phytochrome that increased the shoot-to-root biomass ratio in plants. A lower FR: R ratio (below that of full sun light) will produce larger roots and a lower shoot-to-root ratio (Kasperbauer and Hunt, 1992). It is from such research that the idea of color mulches other than the usual (black, white, clear, and silver) was created. The purpose of assorted color mulches is to reflect FR: R ratios that result in phytochrome regulation that possible enhance plant growth and yield with smaller added cost to the producer. In there research, Orzolek et al., (2003) revealed that blue plastic mulch reflected (510 to 720nm) range, and red plastic mulch reflected (380 to570nm) range. To quote Louis Pons (2003) “Colored-mulch technology relies greatly on fooling plants into behaving as if they face stiffer competition for sunlight than they actually do. This is achieved when they receive high amounts of FR light. Plants reflect FR and sense reflected FR to gauge how close and dense other vegetation around them is. To stay ahead of what’s perceived as competition, they develop larger shoots”.

Research has been performed on crops and their phytochrome response to color plastic mulches. Tomato plants grown with red plastic mulch produced higher marketable yields then those grown with black plastic mulch (Decoteau et al. 1989). The scientist who conducted the study believes the findings were related to the effect the red plastic mulch had on the plant’s phytochrome regulatory system. In a study of tomato production, Orzolek et al. (2000) found silver and red plastic mulches to have the greatest reflected FR: R ratios. This study also revealed an increase in marketable fruit yield in tomato using silver or red mulch as compared to standard black plastic. Bell pepper plants grew taller and were heavier when grown on red plastic which exposed them to a greater FR: R ratio (Decoteau et al. 1990). Longer leaves and higher shoot/root ratios were found in turnip plants grown on blue and green mulches that reflected higher FR: R ratios than on white plastic mulches that generated lower FR: R ratios (Antonious et al., 1996). Kasperbauer and Hunt (1998), found red plastic mulch to produce greater tomato yields then black plastic mulch. These researchers believed the higher yields were due to the red plastic mulch’s superior ability to produce a greater FR: R ratio compared to black plastic mulch. The study went on to explain that the high FR: R ratio caused by the red plastic mulch generated a phytochrome induced response that controls photosynthate allocation to maturing plant parts such as maturing fruit. In research performed in Iowa, Taber et al. (2005) noted that red plastic mulch with a FR: R ratio greater than olive colored mulch had higher tomato yields for two out of three years. Cotton, a plant related to the vegetable crop okra, was determined to produce longer and thinner cotton fibers when grown on plastic mulches (green and red) with higher FR: R ratios than with the lower FR: R producing white plastics used in the study (Kasperbauer and Thibodeaux, 1997). Bradburne et al. (1989) recorded that white plastic mulch produced lower FR: R ratios then other colored plastic mulches and thus created shorter cotton plants with thicker leaves. In New Hampshire, Loy et al. (1998) found no difference in early yield, total yield, and fruit size of tomatoes grown on red, black, and red on black (coextruded) plastic mulch.

Blue Light

Plants have shown a multitude of different responses when treated with blue (λ400-500nm) light. Blue light treatments have shown to effect morphological, metabolic, and directional reactions in plants (Senger and Schmidt, 1994). Some of the documented findings on plant response to blue light include: phototropism (Sachs, 1864; Lipson, 1980; Shropshire, 1980); enzyme synthesis (Hart, 1988; Ruyters, 1982); chloroplasts development in leaves (Akoyunoglou et al., 1980); and stomatal opening (Kendrick and Kronenberg, 1994; Zieger et al., 1982; Hart, 1988). It has been reasoned by Hart (1988), that blue light activates stomatal opening through promoting K^+ uptake and thus water is taken into the guard cells of the plant. A light-induced outflow of protons is what generates an inward flux of K^+. Kadaman-Zahavi and Ephrat (1976) found blue light would reduce stem elongation. In a study with tomatoes, blue light restricted hypocotyl elongation in plants missing in labile phytochrome (Adamse et al.

1988). It was discovered that when high amounts of R and no blue light was given to sorghum, taller plants were generated. These findings were comparable to the effects of high FR irradiance. Blue light photoreceptors are the receptors accredited for light absorption in certain responses to blue radiation. The blue light photoreceptors are believed to be flavin and carotenoid molecules (Dörnemann and Senger, 1984; Hart, 1988; Attridge, 1990). As far as an evolutionary stand point, blue photoreceptors are older than phytochrome (Kendrick and Kronenberg, 1994).

Hatt et al. (1993) and Kasperbauer and Loughrin (2004) have found white plastic mulch to reflect more blue light then the other color plastics used in their experiments. Antonious et al. (1996) reported that turnip roots grown on white plastic mulch reflected the largest amounts of blue light of the color plastic mulches used in the experiment. The turnips grown on white plastic mulch had the least distinct flavor among the turnips grown on the other color plastic mulches. Decoteau et al. (1988) believed that shorter stems and more auxiliary growth could result from the blue light reflected from the use of white plastic mulch with tomatoes. Field- grown cotton propagated more boll fibers and seed per plant when grown over color plastic mulches that reflected less blue and higher FR: R ratios (Kasperbauer and Hunt, 1992). Kasperbauer and Loughrin (2004) revealed that red plastic mulch that reflected low amounts of blue light along with higher amounts of FR: R produced higher yields of butter beans.

Objective

The objective of the study was to compare twelve combinations of color plastic mulch and spunbonded polyester row cover and their affect on the earliness and yield of okra (*Abelmoschus esculentus* L. ‘Clemson Spineless’) and summer squash (*Cucurbita pepo* L. ‘Prelude II’). Sparse research has been done in the southeastern United States in regards to the growth of okra and summer squash production with the use of color plastic mulches and row covers. It is hypothesized that the treatments evaluated will have an effect on the growth and production of okra and summer squash.

MATERIALS AND METHODS

2003-2004 Season

The research was conducted at the E.V. Smith Research Experiment Station at Auburn University near Shorter, Alabama. The soil type is an Orangeburg sandy loam, fine-loamy siliceous thermic Typic Kandiudult.

Field plots to evaluate the effects of color plastic mulches and row covers on the growth and production of okra (*Abelmoschus esculentus* L. Moench 'Clemson Spineless') and summer squash (*Cucurbita pepo* L. 'Prelude II') were established in May 2003 and April 2004. The okra plots were 3.04 meters long and 1.52 meters wide. The squash plots were 6.08 meters long and 1.52 meters wide. The colored plastic mulch and plastic drip irrigation lines were applied simultaneously on raised beds (15.24 cm in height) prepared with a medium-sized tractor attached to a plastic layering machine. The experimental plots were arranged in randomized complete block design for both okra and squash with four replications. Okra was direct-seeded into the field on May 8, 2003 and April 28, 2004. Squash was direct-seeded into the field on May 8, 2003 and April 20, 2004. A soil pH 7 was recorded for okra and squash plots for the year 2003. In 2004, a soil pH of 6.2 was recorded for the okra plots and a pH of 6.1 was recorded for the squash plots.

The experiment consisted of twelve experimental treatments as follows: (1) Black plastic mulch (BPM) + spunbonded row cover (RC), (2) BPM, (3)White plastic mulch (WPM) + RC, (4) WPM, (5) Red plastic mulch (RPM) + RC, (6) RPM, (7) Bare soil (BS)

+ RC, (8) BS, (9) Silver plastic mulch (SPM) +RC, (10) SPM, (11) Blue plastic mulch (BLUPM) + RC, (12) BLUPM. Six, 111 meters strips of black plastic were laid out in both okra and squash plots. For okra, 1.52 meter by 0.91 meter sections of black plastic were cut and removed from the soil and replaced with white, blue, red or silver plastic mulch treatments, while the uncut sections remained in place and served as the BPM treatment. For the okra control treatment, black plastic was cut and removed from the soil to expose the bare soil underneath the plastic. For squash, 6.08 meter by 0.91 meter sections of black plastic were removed and replaced with silver, white, blue, and red pieces of plastic. Sections of black plastic remained in place and served as the BPM treatment. For the squash control treatment, the black plastic was cut out to expose the bare soil underneath the plastic. For the okra plots, 2-meter-wide row cover strips were spread over designated treatments on May 19, 2003 and on April 28, 2004. The squash plot row cover strips were installed for the designated treatments on May 20, 2003 and April 26, 2004. The width of cover used for squash was the same as that used for okra plots. The edges of the row cover strips were tucked into the soil around the edges of each plot and left to float loosely in an effort not to hinder the growth-height of the plants as to well as prevent the loss of captured heat. The plastic drip irrigation tape was applied together with the BPM and was left in place for all treatments.

The plastic mulch used for the silver, red, white and black plastic was manufactured by Ken-Bar Inc., 25 Walkers Brook Drive, Reading, MA 01867-0704 and was 1.5 millimeters thick and 91.44 centimeters wide. The blue plastic mulch used in the experiment came from Pliant Corp., 1475 Woodfeild Road, Suite 700, Schamburg, IL 60173 and was 1.25 millimeters thick and 152 centimeters wide. The row cover used was manufactured by Reemay Inc. 70 Old Hickory Blvd.; Old Hickory, TN 37138. The row cover was 170.18 centimeters by 775.2 meters. The plastic drip irrigation tape was ten millimeters thick with 30.48 centimeter spacing. The drip irrigation tape was produced by Toro Ag Products Inc. 1588 North Marshall Avenue, El Cajon, California 92020.

The soil temperature was measured with a soil probe thermometer "Taylor® Switchable Digital Thermometer" Taylor Precision Products LP, 2311 W. 22nd Street Oak Brook, IL 60523. The soil temperature was measured to a depth of 10.16 centimeters in each plot. The air temperature was taken with Taylor® Indoor/Outdoor Thermometers Taylor Precision Products LP, 2311 W. 22nd Street ,Oak Brook, IL 60523 . The sensors of the thermometers were attached to the heat conducting wire and were placed in the center of each plot with and without row covers at 12.7 cm above ground level.

The stem diameter for both okra and squash were taken with a Mitutoyo Digimatic Caliper 500-196 ^{CE} The caliper measurements were taken 5.08 centimeters above ground level around the base of the plants. The same procedure was followed for the squash, and measurements were taken at 5.08 centimeters above the ground level. Height measurements for both okra and squash were taken by using a meter stick. Canopy heights were taken by measuring from the base of the plant to the tip of the highest leaf. Plant heights were taken for all treatments for both years on the day that the row covers were removed. The amount of branching per okra plant was hand counted by counting all branches over 7.62 centimeters in length. The yield of both okra and squash were size separated and weighed using a 120 model scale, Turner Scale Inc. 581-B

George Todd Dr., Montgomery, AL 36117. Marketable and non-marketable fruit were weighed separately and recorded.

Pre-plant fertilizer and pesticides were applied to the okra plots in the years 2003 and 2004 in accordance with soil testing recommendations from Auburn University Soil Testing Lab (Auburn, AL). In 2003, 0.01 kilograms per hectare (kg/ ha) of phosphorous was applied, while in 2004, 0.02 kg/ha of phosphorous was applied. Potassium at a rate of 0.04kg/ha of was applied to the plots in 2003 and 2004. Magnesium was applied at a rate of 0.04 kg/ha in 2003 and 0.01kg/ha in 2004. Calcium was applied to the plots at the rate of 0.22 kg/ha in 2003 and at the rate of 0.15kg/ha in 2004. Nitrogen was applied at a rate of 0.01 kg/ha in both years 2003 and 2004. One hundred and ninety-seven kg/ha of ammonium nitrate (34-0-0) were incorporated into the soil before planting in 2003 while 209.44 kg/ha of ammonium nitrate were used in 2004. No limestone was added to the okra plots either year. Prior to the laying of the plastic mulch, *Pic Brom 33*(67% CH_3 Br 33% Chloropicrin) was applied to the soil at the rate of 336kg/ha on April 17, 2003 and March 27, 2004, respectively .

Liquid calcium nitrate fertilizer and addition pesticides were applied to the okra plots while the plants were developing. Sixty-one and six-tenth (61.6) kg/ha of calcium nitrate was injected into the soil through plastic drip fertigation tubes from May 30 to August 28, 2003. N- P- K (20-20-20) at the rate of 53.54 kg/ha was injected into the soil at various times from May 30 to August 28, in 2003. From May 18 to August 12, 2004, a total of 117.6 kg/ha of N- P- K (20-20-20) were applied to the plots. In May 2003 and 2004, 1.17 liters/ha of Treflan® were applied to the plots. In May of 2003, 2.34 liters/ha of Round-Up® were applied between the rows of the okra plots. In May of 2004, 4.67

liters/ha of Round-Up® were applied between the rows of the okra plots. Sevin 80S was applied at a rate of 4.48 kg/ha in June 2003 and at a rate of 1.4 kg/ha in June of 2004.

Pre-plant fertilizer and pesticides were applied to the squash plots in the years 2003 and 2004 in accordance with the soil test recommendations from Auburn University Soil Testing Lab (Auburn, AL). Phosphorous was applied at the rate of 0.03 kg/ha in 2003 while 0.04 kg/ha of phosphorous was applied in 2004. Potassium was applied at the rate of 0.08 kg/ha in 2003 and 2004. The plots received 0.06 kg/ha of magnesium applied in 2003 and 0.02 kg/ha of magnesium in 2004. Liquid calcium was applied through drip irrigation at a rate of 1.09 kg/ha in 2003 and 0.23 kg/ha in 2004. No limestone was added to the squash plots in 2003 and 2004. In 2003, 197 kg/ha of ammonium nitrate (34-0-0) was applied to the plots while in 2004, 209.44 kg/ha of ammonium nitrate were applied. Prior to the laying of the plastic mulch, *Pic Brom 33*(67% CH_3 Br 33% Chloropicrin) was applied at a rate of 336 kg/ha on April 17, 2003 and on March 27, 2004 respectively.

Fertilizers and pesticides were applied to the squash plots while the plants were developing. N- P- K (20-20-20) was injected into the soil through drip fertigation tubes at the rate of 29.2 kg/ha at intervals from May 30 to July 8, 2003. Sixty one point six (61.6) kg/ha of N- P- K (20-20-20) was injected into the soil through drip fertigation tubes at intervals from May 11, to June 25, 2004. Liquid calcium nitrate at the rate of 20.5 kg/ha was injected into the soil from June 6 to June 28, 2003. In May of 2003 and 2004, 4.67 liters/ha of Curbit® herbicide were sprayed in the squash plots for weed control. Between the squash rows, 2.34 liters/ha of Round –Up® were sprayed in May 2003 and 4.67 liters/ha were sprayed in 2004. In May, 0.70 liters/ha of Asana XL were applied in 2003 and 2.82 liters/ha were applied in 2004. Manex®, at the rate of 3.73 liters/ha, was used to control diseases in 2003 while 15 liters/ha were used in 2004. In June of 2003, a total of the following was applied to the squash plots: 0.88 liters/ha of Ambush; 2.24 kg/ha (50wp) of Endosulfan. Also in June of 2003, three separate applications of 2.92 liters/ha of Bravo WS and 0.58 liters/ha of Topsin M were applied to the squash plots. In July 2, 2003, 92 liters /ha Bravo WS and 0.70 liters/ha of Asana XL were sprayed onto the plots of squash. In May 2004, Sevin 80S was sprayed at a rate of 1.4 kg/ha along with Bravo Weather Stick at 2.34 liters/ha. The row covers were removed from the okra plots on June 19, 2003 and June 7, 2004, respectively. The row covers were removed from the squash plots in June 3, 2003 and May 24, 2004 respectively.

Okra was harvested from July 3 to September 8 in 2003 and from June 21 to August 27 in 2004. Squash was harvested from June 9 to July 14 in 2003 and from May 25 to July 2 in 2004. Both okra and squash were harvested every-other-day with weekends being the exception. Yield differences among treatments were determined by weighing marketable and non-marketable fruits at each harvest date. Fruit for both okra and squash were considered marketable or non-marketable by their size, shape, color, and presence of insect or disease damage. Data was analyzed using the SAS System, ver. 9.1. (SAS, 2003).

RESULTS AND DISCUSSION

Okra Marketable and Non-Marketable Early and Total Yields 2003

Table 1 shows that for 2003, there was little significant difference among okra treatments in regards to earliness of yield. For early yield, BPM+RC, WPM+RC, BS+RC, and SPM+RC produced the lowest early marketable yield while the other treatments had the highest early marketable yield. The total okra yield for 2003 was highest for the treatments: BPM+RC, BPM, WPM, RPM, BLUPM+RC, and BLUPM. There was no difference in early non-marketable yield for okra during 2003. For the total non-marketable okra yield BS+RC was significantly lower than all other treatments except for BS and SPM+RC. Although the remaining total non-marketable treatments had a significantly higher total non-marketable yield, there was no difference among these treatments.

Table 1. Effect of colored plastic mulch and row cover on okra earliness and total yield in 2003

	Marketable yield/ha		Non- Marketable yield/ha	
Cover[z]	Early[y] (kg/ha)[x]	Total (kg/ha)	Early (kg/ha)	Total (kg/ha)
BPM + RC	189bc[w](1.2%)[v]	15140a	87a(1.1%)	7996a
BPM	433a(2.9%)	13701abc	181a(2.3%)	7328ab
WPM + RC	105c(0.7%)	10536bcdef	151a(1.9%)	5967abc
WPM	311abc(2.1%)	12335abcd	43a(0.5%)	6576abc
RPM + RC	225abc(1.5%)	9281def	141a(1.8%)	4712abc
RPM	319abc(2.1%)	13557abc	233a(2.9%)	6857abc
BS + RC	149bc(1%)	7409f	14a(0.2%)	3057d
BS	300abc(2%)	8115ef	62a(0.8%)	4328cd
SPM + RC	192bc(1.3%)	8848def	135a(1.7%)	4423cd
SPM	422a(2.8%)	10073cdef	227a(2.8%)	5848abc
BLUPM + RC	254abc(1.7%)	11856abcde	235a(2.9%)	5986abc
BLUPM	335ab(2.2%)	14093ab	222a(2.8%)	7901a

[z] BPM + RC = black plastic mulch; RC = spunbonded polyester row cover; WPM + RC = white plastic mulch + spunbonded polyester row cover; WPM = white plastic mulch; RPM = red plastic mulch; BS = bare soil; SPM = silver plastic mulch; BLUPM = blue plastic mulch;

[y] First 3 weeks of harvest period

[x] kilograms per hectare

[w] means separation within columns by Waller-Duncan K-ratio t multiple range test, 5% level. Means with different lower case letters are significantly different, ($p<.05$)

[v] % of total yield

Okra Air and Soil Temperatures 2003

Okra air and soil temperatures are shown in Table 2 for the year 2003. The air temperature readings were highest in treatments that used row covers. There was no significant difference among BPM+RC, WPM+RC, RPM+RC, SPM+RC and BLUPM+RC treatments. Among the treatments with row covers, there was a significant difference between SPM+RC and BS+RC with SPM+RC having the higher air temperature. The plastic mulch with row covers had higher air temperatures than bare soil which is in agreement with other research (Bonanno and Lamont; 1987; Ibarra-Jiménez et al., 2004). The okra soil temperatures for 2003 were highest on RPM, BLUPM+RC, and BLUPM. All of these treatments were darker colored plastic mulches. The findings correlate with Csizinsky et al. (1995) who revealed BLUPM to have a higher soil temperature compared to other (orange, red, aluminum, white, yellow) colored mulches and Gough (2001) who found the warmest soil temperatures under red mulch.

Table 2. Effect of colored plastic mulch and row cover on okra air and soil temperature and wet weight for 2003.

	Temperature (°C) [y]	
Cover [z]	Air	Soil
BPM + RC	38.4ab[x]	30.1b
BPM	33.7cd	30.1b
WPM + RC	38.4ab	28.8c
WPM	34.3c	28.5cd
RPM + RC	38.0ab	30.2b
RPM	33.5d	30.5ab
BS + RC	36.5bc	27.9de
BS	33.0d	28.8c
SPM + RC	39.7a	27.5e
SPM	33.5d	27.5e
BLUPM + RC	38.9ab	30.3ab
BLUPM	34.2cd	31.1a

[z] BPM + RC = black plastic mulch; RC = spunbonded polyester row cover; WPM = white plastic mulch; RPM = red plastic mulch; BS = bare soil; SPM = silver plastic mulch; BLUPM = blue plastic mulch;

[y] Degrees Celsius

[w] means separation within columns by Tukey's studentized range test, 5% level. Means with different lower case letters are significantly different, ($p \leq .05$)

Okra Plant Height and Stem Diameter 2003

Table 3 illustrates the findings from research conducted on okra plant height and stem diameter in 2003. The okra plant height for 2003 was affected by the use of plastic mulch and row covers. The tallest okra plant heights were recorded on: BPM+RC, WPM+RC, RPM+RC, and BLUPM+RC. The shortest okra plants developed on WPM, RPM, BS, SPM+RC, SPM, and BLUPM. Among the plastic mulch plus row cover treatments, SPM+RC produced the lowest okra plant height. These results show that with the exception of SPM+RC, okra plants would grow taller on plastic mulch with row cover than with plastic mulch without row cover or bare soil. Brown and Channell-Butcher (1999) also found that the use of plastic mulch with row cover generated taller okra plants than the use of just plastic mulch or bare soil. The largest stem diameters of okra in 2003 were from the BPM+RC, BPM, WPM+RC, RPM+RC, SPM, BLUPM+RC, and BLUPM treatments. The smallest stem diameters for okra were grown with the WPM, RPM, BS+RS, BS, and the SPM+RC treatments. Excluding the SPM+RC treatment, the most expansive okra stems were created using plastic mulch with row covers instead when compared to other treatments.

Table 3. Effect of colored plastic mulch and row cover on okra plant height and stem diameter in 2003.

Cover ^{z}	Plant height (cm) ^{y}	Stem diameter (mm)^v
BPM + RC	37.60a^w	12.7ab
BPM	30.30bc	10.6abcde
WPM + RC	33.58ab	12.3abc
WPM	22.75d	8.7de
RPM + RC	34.03ab	11.2abcd
RPM	27.03cd	9.6cde
BS + RC	29.60bc	10.1bcde
BS	25.63cd	9.8cde
SPM + RC	22.85cd	8.3e
SPM	26.65cd	10.5abcde
BLUPM + RC	37.68a	12.9a
BLUPM	28.88bcd	10.2abcde

^{z} BPM + RC = black plastic mulch; RC= spunbonded polyester row cover; WPM = white plastic mulch;
RPM = red plastic mulch; BS = bare soil; SPM = silver plastic mulch; BLUPM = blue plastic mulch;
^{y} centimeters
^{v} millimeters
^{w} means separation within columns by Waller-Duncan K-ratio t multiple range test, 5% level. Means with different lower case letters are significantly different, ($p<.05$)

Okra Wet weight and Branch count 2003

Table 4 shows the results from the okra wet weight and branch count experiment. The 2003 wet weights for okra were highest for BPM+RC, BPM, WPM+RC, RPM+RC, SPM+RC SPM, and BLUPM+RC treatments. The lightest okra plant weights were found on WPM, RPM, BS+RC, BS, and BLUPM. Results of these treatments demonstrated that the plastic mulch plus row cover treatments had the heaviest okra weights. The most okra branches grew from the use of BPM+RC, WPM+RC, RPM+RC, and BLUPM+RC treatments. The fewest okra branches developed from the use of the BPM, WPM, RPM, BS, SPM, and BLUPM treatments. SPM+RC is the only row cover plus plastic mulch treatment that did not result in significantly higher number of okra branches. Khan et al. (1990a) noted that more okra branches were developed from plastic mulch plus row covers than bare soil.

Table 4. Effect of colored plastic mulch and row cover on okra wet weight and branch count 2003

Cover [z]	Wet weigh (kg) [y]	Branch count [x]
BPM + RC	0.19ab[v]	7.9a
BPM	0.16ab	3.7cde
WPM + RC	0.22ab	7.3a
WPM	0.10b	3.8cde
RPM + RC	0.16ab	6.8ab
RPM	0.10b	3.4cde
BS + RC	0.09b	4.3cd
BS	0.11b	2.3e
SPM + RC	0.17ab	5.3bc
SPM	0.19ab	3.1de
BLUPM + RC	0.28a	7.1ab
BLUPM	0.15b	4.2cde

[z] BPM + RC = black plastic mulch; RC = spunbonded polyester row cover; WPM = white plastic mulch; RPM = red plastic mulch; BS = bare soil; SPM = silver plastic mulch; BLUPM = blue plastic mulch.

[y] kilograms

[x] Number of branches 7.62 centimeters or longer

[v] means separation within columns by Duncan Multiple Range K-ratio t test, 5% level. Means with different lower case letters are significantly different, ($p \leq .05$)

Okra Marketable and Non-Marketable Yield 2004

Okra marketable and non-marketable yields are shown on Table 5. The treatments with the largest early okra yields were BPM, RPM+RC, RPM, BLUPM, and BLUPM+RC while WPM+RC, WPM, BS+RC, BS and SPM+RC had the lowest early marketable yield. The results show that the darker plastic mulches generated the greatest early okra yields. Plastic mulch has been identified for its ability to produce earlier yields of okra than bare soil (Simone et al., 2002; Incalcaterra and Vetrano, 2000). BPM+RC, WPM+RC, BLUPM+RC, and BLUPM were the four treatments with the highest total marketable okra yields for 2004. Three of the four treatments used row covers. BS and BS+RC had the lowest total marketable yield of all treatments. Khan et al., (1990a) and Brown and Lewis (1986) also found BPM+RC to produce higher okra yield than bare soil. The largest non-marketable early yield for okra was obtained with BPM and BLUPM. Except for the RPM and BLUPM+RC, all other treatments had non-marketable early yields that were significantly lower than the BPM and BLUPM treatments. Total non-marketable yields were highest on all treatments except for WPM, RPM, BS+RC, and BS, which exhibited the lowest total non-marketable yields.

Table 5. Effect of colored plastic mulch and row cover on the earliness and total yield of okra in 2004

	Marketable yield/ha		Non-Marketable yield/ha	
Cover [z]	Early[w] (kg/ha) [y]	Total (kg/ha)	Early (kg/ha)	Total (kg/ha)
BPM + RC	733dc[x](5.8%)[v]	12562a	276cde(5.9%)	4696a
BPM	1307a(10.4%)	9043bc	728ab(15.5%)	4149ab
WPM + RC	647cde(5.2%)	11553ab	179de(3.8%)	4166ab
WPM	709cde(5.6%)	8397bc	219de(4.7%)	2040cde
RPM + RC	903abc(7.2%)	7723c	245cde(5.2%)	3295abc
RPM	1298ab(10.3%)	7612c	571bc(12.2%)	2622bcde
BS + RC	262e(2.1%)	3368d	72e(15.3%)	1177de
BS	330de(2.6%)	2686d	231de(4.9%)	1079e
SPM + RC	655cde(5.2%)	8375bc	180de(3.8%)	2932abcd
SPM	853bc(6.8%)	7488c	381cde(8.1%)	2940abcd
BLUPM + RC	936abc(7.5%)	9798abc	491bcd(10.5%)	3679abc
BLUPM	1225ab(9.8%)	10239abc	928a(19.8%)	4550a

[z] BPM + RC = black plastic mulch; RC = spunbonded polyester row cover; WPM = white plastic mulch; RPM = red plastic mulch; BS = bare soil; SPM = silver plastic mulch; BLUPM = blue plastic mulch.

[y] kilograms per hectare

[x] means separation within columns by Waller-Duncan K-ratio t test, 5% level. Means with different lower case letters are significantly different, ($p<.05$)

[w] First three weeks of harvest

[v] % of total yield

Okra Air and Soil Temperatures 2004

The effect of colored plastic mulch and row covers on okra air temperature in 2004 is shown in Table 6. BPM+RC, WPM+RC and SPM+RC treatments had the highest okra air temperatures while BS+RC had the lowest. All other treatments were intermediate to the highest and lowest okra air temperature treatments. Other experiments have also shown higher air temperatures with the use of plastic mulch and okra when growing okra (Brown and Channell-Butcher, 1999a and Khan et al., 1990a). BPM, RPM+RC, BLUPM+RC, and BLUPM had the highest soil temperatures in the okra plots in 2004. Bare ground soil having cooler soil temperatures than the soil underneath darker colored plastic mulches has been noted by previous research (Perez and Batal, 2001; Rangarajan and Ingall, 2001).

Table 6. Effect of colored plastic mulch and row cover on okra air and soil temperature in 2004

Cover z	Air Temperature (°C) [y]	Soil Temperature (°C)
BPM + RC	37.5a[x]	31.2b
BPM	32.2d	32.2ab
WPM + RC	36.1abc	29.2c
WPM	32.0d	28.3cd
RPM + RC	35.6abcd	30.8b
RPM	32.3cd	31.7ab
BS + RC	31.1d	27.1d
BS	33.1bcd	28.9c
SPM + RC	36.7ab	28.6cd
SPM	33.0bcd	28.2cd
BLUPM + RC	34.0abcd	31.6ab
BLUPM	31.6d	32.9a

[z] BPM + RC = black plastic mulch; RC = spunbonded polyester row cover; WPM = white plastic mulch; RPM = red plastic mulch; BS = bare soil; SPM = silver plastic mulch; BLUPM = blue plastic mulch;

[y] degrees Celsius

[x] means separation within columns by Tukey's studentized range test, 5% level. Means with different lower case letters are significantly different, ($p \leq .05$)

Okra Plant Height and Stem Diameter 2004

Table 7 shows the okra plant height and stem diameter for the year 2004. The BPM+RC, WPM+RC, RPM+RC, and BLUPM+RC had the largest average stem diameters while WPM, BS+RC, and BS had the smallest average stem diameters. All other treatments were intermediates to the highest and lowest treatment stem diameters As in 2003, the 2004 okra treatments with row covers averaged the tallest okra plants. The treatments that generated the greatest average plant height for okra were BPM+RC, WPM+RC, RPM+RC, and BLUPM+RC while the shortest average plant height was produced with WPM, SPM+RC, and SPM. In both years, the BPM treatments averaged taller okra plants than the BS treatments. This data correlates with the findings of other researchers (Saikia et al., 1997; Brown and Channell-Butcher, 1999b).

Table 7. Effects of colored plastic mulch and row cover on okra stem diameter and plant height in 2004

Cover [z]	Stem diameter (mm) [y]	Plant height (cm) [x]
BPM + RC	17.2a [w]	38.9a
BPM	11.1b	31.1bc
WPM + RC	15.3a	37.2ab
WPM	7.5cd	21.6e
RPM + RC	16.9a	40.9a
RPM	10.8b	29.4cd
BS + RC	5.5d	31.5bc
BS	6.5cd	22.7de
SPM + RC	11.2b	25.59cde
SPM	9.1bc	25.2cde
BLUPM + RC	15.1a	41.74a
BLUPM	10.7b	29.2cd

[z] BPM + RC = black plastic mulch; RC = spunbonded polyester row cover; BPM = black plastic mulch; WPM = white plastic mulch; RPM = red plastic mulch; BS = bare soil; SPM = silver plastic mulch; BLUPM = blue plastic mulch;

[y] millimeters

[x] centimeters

[w] means separation within columns by Waller-Duncan multiple range test, 5% level. Means with different lower case letters are significantly different, ($p<.05$)

Okra Wet Weight and Branch Count 2004

Table 8 shows the okra wet weights and branch count for 2004. In 2004 the largest wet weights were recorded from BPM+RC, BPM, WPM+RC, RPM+RC, and BLUPM+RC while WPM, RPM, BS+RC, BS, SPM+RC, SPM and BLUPM had the lowest . Similar to 2003, the 2004 wet weights were heavier on most of the plastic mulch plus row cover treatments in comparison to the BS treatment. In 2004, the treatments, BPM+RC, WPM+RC, RPM+RC, and BLUPM+RC registered the highest average branch count for okra. The lowest amount of okra branches were produced using RPM, BS+RC, and BS. Khan et al. (1998) and Rahman and Shadeque (1999) also recorded having fewer branches on bare soil compared to plastic mulch with or without row covers.

Table 8. Effect of colored plastic mulch and row cover on okra wet weight and branch count 2004

Cover [z]	Wet weight (kg) [y]	Branch count [x]
BPM + RC	0.33a[w]	7.3a
BPM	0.20abc	3.8de
WPM + RC	0.24abc	6.0ab
WPM	0.10bcd	4.1bcde
RPM + RC	0.23abc	5.6abcd
RPM	0.16bcd	3.6def
BS + RC	0.01d	2.2ef
BS	0.03d	1.8f
SPM + RC	0.11bcd	4.9bcd
SPM	0.07cd	3.8cde
BLUPM + RC	0.26ab	5.8abc
BLUPM	0.14bcd	4.0bcde

[z] BPM + RC = black plastic mulch; RC = spunbonded polyester row cover; WPM = white plastic mulch; RPM = red plastic mulch; BS = bare soil; SPM = silver plastic mulch; BLUPM = blue plastic mulch;

[y] kilograms

[x] Number of branches 7.62 centimeters or longer

[w] means separation within columns by Duncan's Multiple Range test, 5% level. Means with different lower case letters are significantly different, (p<.05)

Squash Early and Total Marketable and Non-Marketable Yield 2003

Early and total marketable and early and total non-marketable yields are shown in Table 9. BS+RC produced lower early and total squash yields compared to all other treatments except for the BS treatment for the year 2003. BS+RC had lower early squash yields compared to all other treatments excluding the BS treatment. Dickerson et al. (2003) reported earlier squash yield with plastic mulch with or without row cover compared to bare soil BS+RC had the smallest total yield compared to all treatments except for BS. Bryan (1966) and Orzolek et al (2003) reported more squash yield with the use of plastic much plus row cover or without row cover compared to bare soil. BS+RC had lower early non-marketable squash yields than all other treatments except for BS.

The BS+RC total non-marketable squash yield was significantly smaller than all treatments except for BS.

Table 9. Effect of colored plastic mulch and row cover on summer squash yield 2003

	Marketable yield/ha		Non-Marketable yield/ha	
Cover [z]	Early(kg/ha)[y]	Total (kg/ha)	Early(kg/ha)	Total (kg/ha)
BPM + RC	1514a[x](76.8%)[w]	1971a	908ab(42.2%)	1984a
BPM	1367a(75.7%)	1805a	1046a(48.6%)	2030a
WPM + RC	1396a(70.8%)	1800a	852ab(39.6%)	1959a
WPM	1478a(75%)	1970a	935ab(43.4%)	2020a
RPM + RC	1341a(68%)	1763a	979a(45.5%)	1935a
RPM	1493a(75.7%)	1938a	950a(41.4%)	2152a
BS + RC	580c(29.4%)	872c	334c(15.5%)	638c
BS	874bc(44.3%)	1087bc	556bc(25.8%)	1165bc
SPM + RC	1166ab(59.1%)	1773a	815ab(37.9%)	1787ab
SPM	1403a(71.2%)	1596ab	940ab(43.7%)	1769ab
BLUPM + RC	1339a (69.7%)	1691a	919ab(42.7%)	1815ab
BLUPM	1441a (73.1%)	1858a	979a(45.5%)	787ab

[z] BPM + RC = black plastic mulch; RC = spunbonded polyester row cover; WPM = white plastic mulch; RPM = red plastic mulch; BS = bare soil; SPM = silver plastic mulch; BLUPM = blue plastic mulch;

[y] kilograms per hectare

[x] means separation within columns by Duncan's multiple range test, 5% level. Means with different lower case letters are significantly different, (p<.05)

[w] % of total yield

Squash Early and Total Marketable and Non-Marketable Yield 2004

Table 10 shows early and total marketable and early and total non-marketable yield for 2004. Except for BPM+RC, BPM, WPM, RPM, and BLUPM+RC, blue plastic mulch treatment produced the highest early yield while WPM+RC, RPM+RC, BS+RC, BS, SPM+RC and SPM exhibited the lowest early marketable yield. Earlier squash yield with row cover plus plastic mulch compared to bare soil has been accomplished (Brown et al. 1993). BS+RC treatments had significantly lower total marketable yield for all treatments except for BPM+RC and BLUPM. Many researchers have found the use of plastic mulch with or without row covers to generate greater yields of squash then squash grown on bare soil (Brown et al., 1993b; Orzolek and Murphy, 1993; Dickerson et al., 2003). Except for BPM, WPM+RC, WPM, RPM+RC, RPM, SPM+RC, SPM, BLUPM+RC, and BLUPM, BPM+RC and BLUPM had the highest early non-marketable yield. No treatment was significantly higher than the BS treatment for total non-marketable squash yield except for the BPM+RC treatment.

Table 10. Effect of colored plastic mulch and row cover on the growth and production of summer squash earliness and total yield 2004

	Marketable yield/ha		Non-Marketable yield/ha	
Cover [z]	Early (kg/ha)[y]	Total (kg/ha)	Early (kg/ha)	Total (kg/ha)
BPM + RC	969ab[x] (37.7%)[w]	2567a	1017a (33%)	3085a
BPM	702ab (27.3%)	1885abc	569ab (18.4%)	1719abc
WPM + RC	556bc (21.7%)	1514abc	811ab (26.3%)	1967abc
WPM	683ab (26.6%)	1620abc	558ab (18.1%)	1658abc
RPM + RC	527bc (20.5%)	1401abc	704ab (22.8%)	1955abc
RPM	609ab (23.7%)	1748abc	490ab (15.9%)	1497bc
BS + RC	197c (7.7%)	559c	229b (7.4%)	716c
BS	527bc (20.5%)	1221bc	289b (9.4%)	1306bc
SPM + RC	578bc (22.5%)	1510abc	513ab (16.6%)	1353bc
SPM	528bc (20.6%)	1529abc	621ab (20.1%)	1768abc
BLUPM + RC	802ab (31.2%)	1894abc	933a (30.2%)	2410ab
BLUPM	1109a (43.2%)	2499ab	842ab (27.3%)	2543ab

[z] BPM + RC = black plastic mulch; RC = spunbonded polyester row cover; WPM = white plastic mulch; RPM = red plastic mulch; BS = bare soil; SPM = silver plastic mulch; BLUPM = blue plastic mulch.

[y] kilograms per hectare

[x] means separation within columns by Duncan Multiple Range test, 5% level. Means with different lower case letters are significantly different, ($p<.05$)

[w] % of total yield

Squash Air and Soil Temperatures 2003

Table 11 shows the effect of colored plastic mulch and row covers on summer squash air and soil temperatures in 2003.The SPM+RC treatment had the highest air temperature reading when compared to all the treatments in 2003. The second group of treatments with the highest air temperature readings was BPM+RC, WPM+RC, RPM+RC, BS+RC, and BLUPM+RC. SPM gave the lowest air temperature among all treatments. Other scientist have recorded higher air temperatures with the use of row cover with plastic mulch compared to plastic mulch without row cover or bare soil (Loy and Wells, 1975; Moreno et al., 2002). The squash soil temperatures for 2003 were highest with the darker colored plastic mulch treatments as follows: BPM+RC, BPM, RPM+RC, RPM, BLUPM+RC, and BLUPM. The coolest soil temperatures were found using WPM+RC, , BS, SPM+RC, and SPM. Gough (2001) noted that the darker colored plastics generated warmer soil than bare soil.

Table 11. Effect of colored plastic mulch and row cover on summer squash air and soil temperature in 2003.

	Temperature (°C) [y]	
Cover [z]	Air	Soil
BPM + RC	37.3b[x]	28.5a
BPM	33.4c	28.2ab
WPM + RC	36.4b	26.7cd
WPM	33.8c	26.2d
RPM + RC	36.8b	27.8abc
RPM	33.2c	27.9abc
BS + RC	37.0b	27.0cd
BS	33.0c	26.1d
SPM + RC	40.1a	25.7d
SPM	28.1d	25.6d
BLUPM + RC	37.6b	28.8a
BLUPM	34.1c	28.9a

[z] BPM + RC = black plastic mulch; RC = spunbonded polyester row cover; WPM = white plastic mulch; RPM = red plastic mulch; BS = bare soil; SPM = silver plastic mulch; BLUPM = blue plastic mulch;

[y] Degrees Celsius

[x] means separation within columns by Tukey's studentized range test, 5% level. Means with different lower case letters are significantly different, ($p<.05$)

Squash Air and Soil Temperatures 2004

Table 12 displays the squash air and soil temperatures for 2004. In 2004, the highest air temperatures were from WPM+RC, RPM+RC, SPM+RC, SPM, and BLUPM+RC while all other treatments produced significantly lower air temperatures. In both years 2003 and 2004, row covers had higher air temperatures than treatments without row covers. Other scientists have also noted similar results with the use of row covers while growing squash (Rubeiz and Freiwat, 1999). In 2004, the BPM+RC, BPM, WPM+RC, RPM+RC, RPM, BLUPM+RC, and BLUPM treatments had the warmest soil temperatures while BS+RC, SPM+RC, and SPM had the coolest soil temperatures. The darker colored mulches produced the warmest soil temperatures. Gough (2001) and Decoteau et al., (1989) noted also warmer soil temperatures with darker colored mulches compared to lighter colored mulches.

Table 12. Effect of colored plastic mulch and row cover on summer squash air and soil temperature in 2004

	Temperature (°C) [y]	
Cover [z]	Air	Soil
BPM + RC	38.0cd	30.0ab
BPM	37.8cd	30.5a
WPM + RC	40.5abc	29.7abc
WPM	38.4bcd	28.7cd
RPM + RC	40.2abcd	29.9abc
RPM	37.7cd	30.2a
BS + RC	38.5bcd	27.5de
BS	37.8cd	28.8bcd
SPM + RC	41.0ab	28.1de
SPM	39.2abcd	27.2e
BLUPM + RC	41.7a	30.3a
BLUPM	37.4d	30.5a

[z] BPM + RC = black plastic mulch; RC = spunbonded polyester row cover; WPM = white plastic mulch; RPM = red plastic mulch; BS = bare soil; SPM = silver plastic mulch; BLUPM = blue plastic mulch;

[y] Degrees Celsius

[x] means separation within columns by Tukey's studentized range test, 5% level. Means with different lower case letters are significantly different, (p<.05)

Squash Stem Diameter and Plant Height 2003-2004

Summer squash stem diameter and plant height for the years 2003 and 2004 are shown in Table 13. BS+RC and BS treatments had significantly lower stem diameters than BPM, WPM, RPM, SPM+RC, SPM, and BLUPM treatments, but not significantly lower than BPM+RC, WPM+RC, RPM+RC, and BLUPM+RC. The tallest squash plants were grown on the BPM+RC, WPM+RC, RPM+RC, SPM+RC, and BLUPM+RC treatments while the shortest squash plants were grown on BS. All Other treatments produced intermediate results. These treatments indicated that plastic mulch with row cover will create taller squash plants than bare soil. Brown et al. (1993) and Lopez (1998) also found that squash grew taller with the use of row covers plus plastic mulch than without the use of row covers with plastic mulch.

Table 13. Effects of colored plastic mulch and row cover on squash stem diameter and plant height 2003-2004

Cover [z]	Stem diameter (mm) [y]	Plant height (cm) [x]
BPM + RC	28.4ab[w]	54.5a
BPM	30.1a	38.4b
WPM + RC	28.1ab	51.2a
WPM	30.7a	38.6b
RPM + RC	27.9ab	50.9a
RPM	29.8a	39.0b
BS + RC	25.5b	36.8b
BS	25.5b	30.6c
SPM + RC	30.1a	49.1a
SPM	29.5a	38.7b
BLUPM + RC	28.3ab	53.3a
BLUPM	30.7a	42.0b

[z] BPM + RC = black plastic mulch; RC = spunbonded polyester row cover; WPM = white plastic mulch; RPM = red plastic mulch; BS = bare soil; SPM = silver plastic mulch; BLUPM = blue plastic mulch;

[y] millimeters

[x] centimeters

[w] means separation within columns by Duncan's multiple range test, 5% level. Means with different lower case letters are significantly different, (p<.05)

Squash Wet Weight 2004

Table 14 illustrates the squash wet weights for 2003-2004. In 2003-2004, the BS treatment had significantly lower squash wet weight than all of the other treatments used in the study except for BS+RC treatment. Brown et al., (1993) also recorded BS to have a lower wet weight of squash than plastic mulch treatments.

Table 14. Effects of colored mulch plastic mulch and row cover on squash wet weight 2003-2004.

Cover [z]	wet weigh (kg) [y]
BPM + RC	0.50ab[w]
BPM	0.42ab
WPM + RC	0.52ab
WPM	0.47ab
RPM + RC	0.48ab
RPM	0.47ab
BS + RC	0.19bc
BS	0.11c
SPM + RC	0.47ab
SPM	0.59a
BLUPM + RC	0.50ab
BLUPM	0.52ab

[z] BPM + RC = black plastic mulch; RC = spunbonded polyester row cover; WPM = white plastic mulch; RPM = red plastic mulch; BS = bare soil; SPM = silver plastic mulch; BLUPM = blue plastic mulch.

[y] kilograms

[x] means separation within columns by Waller Duncan K-Ratio test, 5% level. Means with different lower case letters are significantly different, ($p<.05$)

SUMMARY

There were patterns in the data collected for okra and summer squash for the years 2003 and 2004. The soil temperatures were five to seven degrees lower than air temperatures in all treatments. The increase in air temperature was the result of row covers with plastic mulch. When BS soil temperatures were compared to BS air temperatures, there still was an average of five to seven degree higher temperatures of BS air over BS soil temperature. If soil or air temperatures were too high, it would cause plant injury or death (Contreras and Sánchez del Castillo, 1990). The lack of plant injury or death in both years of the research study demonstrates that soil and air temperatures did not rise to a deleterious level.

The various growth parameters used in the okra studies gave incite to growth enhancing capabilities of plastic mulch with and without row covers. In general, row cover treatments generated taller plants than their non-row cover counter parts. In 2003, the BPM, WPM, RPM, and BLUPM treatments were shorter than their row cover counterparts. This means four of the five plastic mulch treatments produce taller okra plants with row cover compared to those without row cover. In both years 2003 and 2004, the okra stem diameter was larger on BPM+RC and BLUPM+RC treatments compare to SPM+RC. The largest okra wet weight was found in 2003 with BLUPM+RC, BPM+RC, BPM, WPM+RC, RPM+RC, SPM+RC, SPM. Five out of the seven of the aforementioned treatments used row covers, showing the effectiveness of row cover in increasing okra wet weight. The number of okra branches increased significantly at times with the use of row covers. In both years, the row cover treatments (with the exception of PSM+RC) had the most branches compared to the bare soil treatments.

BPM, WP, RPM+RC, RPM, BS, SPM and BLUPM+RC had no significant difference on the earliness of okra yield in 2003. There was no significant difference among BPM, RPM, BLUPM+RC, and BLUPM in the earliness of okra yield in 2004. There was no significant difference between BPM+RC, BPM, WPM+RC, BLUPM+RC, and BLUPM in total yield of okra in 2004. The four treatments (BPM+RC, BPM, BLUPM+RC, and BLUPM) displayed some of the highest total yield of okra in 2003 and 2004. The bare soil treatments produced the lowest total marketable yield of okra in 2004. In 2003 and 2004, BPM, RPM, and BLUPM+RC were among the treatments with the greatest okra yields. This research indicates that the plastic mulch treatments, regardless of color, will produce a higher earlier and total yield of okra than bare mulch soil. The non-marketable early yield of okra was not affected by any treatment in 2003. In 2004, BPM and BLUPM developed more early non-marketable fruit than the other treatments. The total non-marketable yields of okra for 2003 and 2004 were not significantly different among most of the treatments. In 2003 the BS+RC treatment had less total non-marketable fruit than all but two of the other treatments. In 2004, the BS treatment had less total non-marketable fruit than eight of the twelve total treatments. This result demonstrated that treatments which produce the highest marketable yield will in turn also produce large amounts of culls due to the shear volume of fruit created by the plant.

In 2003, the squash air temperature was highest on SPM+RC and lowest on SPM. In 2004, the highest air temperature for squash was found on WPM+RC, RPM+RC, SPM+RC, SPM, and BLUPM+RC. In both years, 2003 and 2004, SPM+RC had high air temperatures. The squash soil temperatures were the highest in 2003 on BPM+RC, BPM, RPM+RC, RPM, BLUPM+RC, and BLUPM. In 2004, BPM+RC, BPM, WPM+RC, RPM+RC, BLUPM+RC, and BLUPM were the treatments which rendered the warmest soil temperatures. For both years, 2003 and 2004, BPM+RC, BPM, RPM+RC, BLUPM+RC, and BLUPM were the treatments with the highest soil temperatures. From this data it could be concluded that darker colored mulches will generate higher soil temperatures when compared to BS+RC and BS. The squash stem diameters were similar when comparing most of the twelve treatments to each other. The BS+RC and BS treatments had smaller squash stems compared to BPM, WPM, RPM, SPM+RC, SPM, and BLUPM. These findings indicated that the use of plastic mulch will increase soil temperatures compared to bare soil with and without row covers. The tallest squash plants were grown on the BPM+RC, WPM+RC, RPM+RC, SPM+RC, and BLUPM+RC. The shortest squash plants were grown on BS. The experimental results indicated that plastic mulch with row cover will create taller squash plants than bare soil. The squash wet weights were similar when comparing the vast majority of the treatments. There was a difference between SPM and BS+RC. BS had a wet weight that was lighter than all treatments except for BS+RC.

In 2003, there was no significant difference in the earliness of summer squash yield among the mulch treatments. The BS +RC treatment was lower in early yield for all other treatments except for BS. There was no significant difference among darker plastic treatments with regards to earliness in summer squash in 2004. In some instances, over 70% of the total squash yield was collected during the early period of harvesting. The total yield of summer squash in 2003 and 2004 showed no difference among mulch treatments but was significantly higher than the bare soil treatment. In 2003, BS+RC generated lower total yields for all other treatments except for BS. In 2004, the only difference in total squash yield was between BPM+RC and BPM. The results have shown that for squash early and total yields, BS+RC is inferior to all other treatments. This may be due to the weeds that were able to grow underneath the row covers during the early stages of squash development. Competition with weeds is a major obstacle to growing vegetable crops with row covers on bare soil (Penn State, 2003; Wells, 2000). The early non-marketable yield of squash showed no contrast between plastic mulch treatments. BS+RC generated lower yields of early non-marketable squash compared to every treatment except BS. In 2004, BPM+RC and the BLUPM+RC produced more early non-marketable fruit than BS+RC and BS. The same trend for non-marketable early yield of squash continued for total marketable squash in 2003. BS+RC yields were only equivalent to the BS treatment. The 2004 total non-marketable yield of squash showed differences in yield between the BPM+RC, BLUPM+RC, and BLUPM treatments compared to the BS+RC treatment. As with okra, the squash treatments that produced the most total marketable yield would also produce the most non-marketable yield and vice versa.

CONCLUSION

This experiment enables certain conclusions to be reached. It is concluded that the use of dark colored plastic mulches can increase early and total yield of summer squash and okra compared to bare soil with and without row covers. With increased earliness and crop yield, farmers can possibly generate greater revenue depending on the marketing opportunities. If weeds infiltrate a growing environment with bare soil and no plastic mulch, it will make it harder for the vegetable crop to reach its full yielding potential. The FR: R and blue light reflectance from the various plastic mulches was not measured during this experiment. Since warmer air and soil temperatures did not always correlate to greater yield, it is possible that the FR: R and blue light reflected from the plastic mulches could have had a positive effect on the growth and yield of vegetable crops (Decoteau et al., 1989; Hatt et al., 1993). More research needs to be done to know the effect that row covers with various colored plastic mulches have on the earliness and production of vegetable crops.

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