Deterioration of Potentially Biodegradable Alternatives to Black Plastic Mulch in Three Tomato Production Regions

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Abstract. Four potentially biodegradable mulch products (BioAgri, BioTelo, WeedGuardPlus, and SB-PLA-10) were evaluated during 2010 in three contrasting regions of the United States (Knoxville, TN; Lubbock, TX; and Mount Vernon, WA) and compared with black plastic mulch and a no-mulch control for durability, weed control, and impact on tomato yield in high tunnel and open field production systems. WeedGuardPlus, BioTelo, and BioAgri had the greatest number of rips, tears, and holes (RTH) and percent visually observed deterioration (PVD) at all three sites (P ≤ 0.05), and values were greater in the open field than high tunnels, likely as a result of high winds and greater solar radiation and rainfall. SB-PLA-10 showed essentially no deterioration at all three sites and was equivalent to black plastic in both high tunnels and the open field. Weed growth at the sites did not differ in high tunnels as compared with the open field (P > 0.05). Weed growth at Knoxville and Mount Vernon was greater under SB-PLA-10 (P ≤ 0.02), likely as a result of the white, translucent nature of this test product. Tomato yield was greater in the high tunnels than open field at all three sites (P ≤ 0.03), except for total fruit weight at Knoxville (P ≤ 0.53). Total number of tomato fruit and total fruit weight were lowest for bare ground at both Knoxville (150 × 10^4 fruit/ha and 29 t·ha^-1; P ≤ 0.04) and Mount Vernon (44 × 10^4 fruit/ha and 11 t·ha^-1; P ≤ 0.008). At Knoxville, the other mulch treatments were statistically equivalent, whereas at Mount Vernon, BioAgri had among the highest yields (66 × 10^4 fruit/ha and 16 t·ha^-1). There were no differences in tomato yield resulting from mulch type at Lubbock.

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Since its introduction to agriculture in the 1950s, polyethylene plastic has become the standard mulch used by specialty crop growers to control weeds, conserve soil moisture, increase crop yield, modify soil temperature, and shorten the time to harvest (Hill et al., 1982; Schonbeck, 1998; Schonbeck and Evanylo, 1998; Shogren, 2000). Plastic mulch has contributed significantly to the economic viability of farmers worldwide (Takakura and Fang, 2001); by 2006, it was estimated that plastic mulch covered ≈162,000 ha in the United States alone (P. Bergholtz, personal communication). Disadvantages of plastic mulches include their long-term persistence in the environment as well as the economic costs of yearly removal and disposal. These costs hinge on available labor, equipment, and infrastructure (Olsen and Gounder, 2001; Schonbeck, 1995) and in 2004 were estimated to be ≈$250 per hectare (Shogren and Hochmuth, 2004).

The recycling of agricultural plastics is available in limited areas of the United States. Major obstacles to the recycling of agricultural plastics include: 1) contamination resulting from soil and mixing of different plastic (resin) types; 2) high cost of long-distance transport of plastic wastes from remote collection sites; and 3) high price of the recycled resin as compared with virgin resin on the open market (Garthe and Kowal, 1993). As a result of the difficulty and expense of agricultural plastic recycling, many growers choose to dispose of this waste through local landfills (Olsen and Gounder, 2001; Shogren, 2000). However, some growers burn their plastic waste (Shogren and Hochmuth, 2004), which has deleterious effects on environmental and human health.

The ideal agricultural mulch would be made from renewable, natural, and sustainable raw products; have low overall environmental impact (for raw materials, manufacturing, and disposal); be affordable (in purchase, application, removal, and disposal); suppress weeds; sustain crop yields; and retain functionality throughout the cropping season (Miles et al., 2009). Costs associated with mulch removal and disposal could be avoided if degradeable or biodegradable mulches were tilled into the soil after harvest (Anderson et al., 1995; Olsen and Gounder, 2001). Environmental costs could also be reduced if the mulches were compostable.

Degradable plastic agricultural mulches were first introduced in the 1980s, but those products were photodegradable rather than biodegradable, and they disintegrated or fragmented into smaller pieces of plastic (Riggle, 1998). A major issue at the time these products entered the market was a lack of consensus regarding the definition of “degradable.” In the last decade, U.S. stakeholders (researchers, manufacturers, marketers, etc.) have created standards to define degradation and established widely accepted testing strategies to evaluate the behavior of degradeable products [American Society for Testing and Materials/Institute for Standards Research (ASTM, 2004)]. According to ASTM D 883-11 (ASTM, 2011), “degradation” is “a deleterious change in the chemical structure, physical properties, or appearance of a plastic” irrespective of cause, whereas “biodegradation” “results from the action of naturally-occurring micro-organisms such as bacteria, fungi, and algae.” Although there are currently ASTM standards for measuring bio-degradation in specific environments such as accelerated bioreactor landfill conditions [D 5526-94(2011)el (ASTM, 2011c), D 7475-11 (ASTM, 2011d)], anaerobic digesters...
The use of degradable or biodegradable mulches could reduce or eliminate costs associated with plastic mulch removal and disposal as well as decrease the total amount of disposed plastic waste. However, there are many questions and concerns regarding the efficacy, degradability, and potential residues of biodegradable petroleum-based mulches (Greer and Dole, 2003; Hochmuth, 2001; Shogren, 2000). As a result, alternative mulches such as paper and starch have been created from non-petroleum feedstocks. Numerous paper mulch products have been tested over the last century with variable results (Brault and Stewart, 2002; Flint, 1928; Knavel and Mohr, 1967; Shogren, 2000). The density and fiber orientation of paper mulches may impact light penetration, which can influence both weed seed germination and growth beneath the mulch. Weeds growing under paper mulch can push the mulch off the soil surface resulting in tearing (Miles et al., 2005). Use of paper mulch is further limited by its heavier weight, which is two to four times greater than that of plastic mulch and incurs increased costs and labor for shipping and handling. In addition, paper mulch can be very difficult to lay with mechanical mulch laying equipment (Sorkin, 2006). However, as a result of its natural fiber composition, paper mulch remains of high interest to growers concerned about the negative impacts of non-degradable plastic mulch.

Mulch film products composed primarily of starch are relatively new to the market, are similar in appearance (weight, density, and texture) and handling properties compared with standard polyethylene mulches, and may be a viable alternative to polyethylene-based mulch (Kijchavengkul et al., 2008; Rangarajan et al., 2003). New experimental materials such as spunbond (SB) polyacetic acid (PLA) have recently been developed as potential alternatives to polyethylene mulches (Wadsworth et al., 2009). However, it is unclear how starch- and PLA-based mulch alternatives perform in high tunnel (HT) and open field (OF) production systems across diverse environments. The objective of this study was to evaluate and compare three mulch products marketed as biodegradable (two starch-based and one cellulose-based), and one experimental PLA-based product, to black plastic mulch under two production systems (HTs and OF) in three contrasting regions (Knoxville, TN; Lubbock, TX; Mount Vernon, WA) in the United States. Mulch deterioration, weed control attributes, and impact on tomato yield were the principal performance factors measured.

**Materials and Methods**

**Plot establishment and maintenance**

This study was conducted in 2010 at three distinct and diverse field sites: the University of Tennessee, Knoxville East Tennessee Research & Education Center (lat. 35°52'52" N, long. 83°55'27" W, elevation 270 m) located in the subtropical southeast with a hot and humid summer climate (22 °C average daily temperature and 73% average relative humidity) and Dewey silt loam, a fine kaolinitic thermic Typic Paleudults with 6.8 soil pH and 13 g organic matter/kg soil; the Texas A&M AgriLife Research & Extension Center at Lubbock (lat. 33°41'38" N, long. 101°49'51" W, elevation 993 m) located on the High Plains with a hot and dry summer climate (22.5 °C average daily temperature and 59% average relative humidity) and Acuflay clay loam, a fine mixed thermic Aridic Paleustolls (Sorkin, 2006). However, as a result of its heavy weight, which is two to four times greater than paper mulch is further limited by its heavier weight, which is two to four times greater than paper mulch. Paper mulches such as paper and starch have been created from non-petroleum feedstocks. Natural fiber composition, paper mulch reduces or eliminates costs and may be the result of abiotic and/or biotic factors.

**Insect and disease management practices varied by site.** At Knoxville, late blight was managed with four sprays of copper hydroxide (Champ WG; Albaugh, Inc., Ankeny, IA) applied at 3.4 kg ha⁻¹ per application until the end of the growing season, except when rain fell daily from 27 June through 12 July and totaled 210 mm; all plots, including those inside the HTs, remained under water for more than 1 week. At Mount Vernon, water was applied by drip irrigation once per week at 134 m³ ha⁻¹ per application starting at transplanting and thereafter water was applied twice per week at 134 m³ ha⁻¹ per application until the end of the growing season, except when rain fell daily from 27 June through 12 July and totaled 210 mm; all plots, including those inside the HTs, remained under water for more than 1 week. At Mount Vernon, water was applied by drip irrigation once per week at 134 m³ ha⁻¹ per application starting at transplanting and thereafter water was applied twice per week at 66 m³ ha⁻¹ per application from 12 Aug. until the end of the growing season.
Table 1. Mulch treatments evaluated in high tunnel and open field tomato culture at Knoxville, Lubbock, and Mount Vernon in 2010.

| Mulch product          | Company                          | Mulch composition                                      |
|------------------------|----------------------------------|--------------------------------------------------------|
| BioAgri® Ag-Film       | BioHag, Palm Harbor, FL          | Cornstarch and non-disclosed biopolymers; biodegradable and compostable; 0.02 mm; black |
| BioTelo Agri           | Dubois Agrinovation, Waterford, Ontario, Canada | Cornstarch and non-disclosed biopolymers; biodegradable and compostable; 0.02 mm; black |
| Weed Guard Plus®       | Sunshine Paper Co. LLC, Aurora, CO | Cellulosic; biodegradable control; 0.23 mm; black      |
| SB-PLA-10              | NatureWorks LLC, Blair, NE       | Experimental nonwoven spunbond, white, translucent,100% poly(lactic acid); 0.64 mm; white |
| Plastic                | Pliant Corp., Schaumburg, IL     | Standard agricultural polyethylene plastic (control); 0.03 mm; black |

Table 2. Tomato planting dates and growing environment characteristics in high tunnels (HT) and the open field (OF) at Knoxville, Lubbock, and Mount Vernon during 2010.

| Location          | HT       | OF       | HT       | OF       | HT       | OF       |
|-------------------|----------|----------|----------|----------|----------|----------|
|                   | Tomato planting |         | Mulch removal |         | No. d mulch in place |         |
| Knoxville         | 26 Mar.  | 5 May    | 11 Aug.  | 8 Oct.   | 149      | 99       |
|                   | 5 May    | 27 May   | 11 Aug.  | 15 Oct.  | 154      | 154      |
|                   |         | 7 May    |          |          | 146      | 146      |
|                   |         |         |          |          | 136      |          |
|                   | Avg. solar radiation (µmol·m⁻²·s⁻¹) | | Avg. soil temp. at 5 cm depth | | Avg. daily maximum air temp. (°C) | | Avg. daily minimum air temp. (°C) | |
| BioAgri®          | 26.2     | 27.0     | 26.2     | 25.6     | 18.9     | 17.7     |
| BioTelo           | 27.0     | 26.8     | 25.9     | 26.6     | 19.3     | 18.1     |
| SB-PLA-10         | 26.5     | 26.6     | 24.9     | 24.6     | 18.7     | 17.0     |
| Weed Guard Plus   | 25.7     | 26.3     | 26.9     | 26.6     | 18.3     | 16.7     |
| Black plastic     | 27.8     | 27.3     | 27.2     | 28.2     | 19.8     | 18.9     |
| Bare ground       | 26.9     | 27.6     | 24.9     | 25.2     | 18.7     | 16.8     |
| Avg. solar radiation (µmol·m⁻²·s⁻¹) | 369 | 513 | 315 | 486 | 324 | 397 |
| Relative humidity (%) | 74.1 | 79.2 | 66.2 | 66.7 | 79.7 | 81.3 |
| Avg. wind speed (km·h⁻¹) | 0 | 1.9 | 0.2 | 6.4 | 1.1 | 3.3 |
| Total rainfall (mm) | 0 | 156 | NA* | 333.5 | 0 | 235.5 |

*At Knoxville, data collected in the high tunnel from 9 Apr. until 11 Aug. as a result of sensor malfunction and 6 May until 11 Aug. in the open field; at Lubbock, data collected in the high tunnel from 9 June until 8 Oct., and in the open field from 17 May to 2 Sept. as a result of weather monitoring sensor delays and malfunctions; at Mount Vernon, data collected from 25 May to 8 Oct.

Note: All statistical analyses were performed using PROC MIXED in SAS (Statistical Analysis System Version 9.2 for Windows™, SAS Institute, Cary, NC). At Knoxville and Lubbock, data were analyzed as a completely randomized split plot design. At Mount Vernon, data were analyzed as a randomized complete block split plot design. Statistical analyses at all three locations compared production system (main plots), mulch (subplots), and production system × mulch interactions. At Knoxville and Lubbock the Kenward and Roger (1997) method was used to determine denominator df (DDFM) for F-tests in the analysis, whereas at Mount Vernon, the Satterthwaite (1946) method was used to determine DDFM. Treatment means were compared for significant differences using Fisher’s least significant difference test at alpha level 0.05. Main effects are presented for weed management and fruit yield data as a result of no significant production system × mulch interactions. However, as a result of a high incidence of significant production system × mulch interactions, RTH and PVD data were analyzed separately by production system using PROC GLM in SAS. Weed measurements and fruit yield data were analyzed as a split plot using PROC MIXED in SAS as a result of no significant production system × mulch interactions. At all three field sites, a hand-weeded bare ground treatment was included in the mean comparisons for fruit yield to relate the bare ground means to previously established regional yields.
Some data required transformation before analysis to meet the assumptions of normality and homogeneity of variance for ANOVA; the most appropriate transformation was selected using the range method described by Kirk (1982).

**Results**

**Environmental comparison.** The length of time that mulch was in place was indicative of the length of the cropping season and was 40% longer in HTs than in the OF at Knoxville, equivalent at Lubbock, and 7% longer in HTs than the OF at Mount Vernon (Table 2). At Knoxville, environmental data were only measured for 123 d in the HT (87% of the study period) and 96 d in the OF (97% of the study period) as a result of equipment malfunctions. Nevertheless, measured growing degree-days (base 10 °C) were greater in HTs than in the OF, and this finding may have been the result of the greater number of measurement days. At Mount Vernon, growing degree-days were measured 136 d in both HTs (93% of the study period) and the OF (100% of the study period) as a result of late arrival of the weather monitoring equipment. Similar to Knoxville, there were 36% more growing degree-days in the HT than at Mount Vernon.

The average soil temperature at 5 cm was 8.2 °C lower at Mount Vernon than at Knoxville and Lubbock (Table 2). Soil temperatures were similar in HTs and OFs at Lubbock and Knoxville, whereas at Mount Vernon, the average soil temperature was 1.5 °C warmer in the HT than the OF. Average soil temperatures tended to be highest for black plastic mulch at all three sites in both HTs and the OF and lowest for paper mulch at Knoxville and Mount Vernon and for SB-PLA-10 mulch and bare ground at Lubbock. In all cases, soil temperature was elevated under black plastic mulch as compared with bare soil, a difference of 1.7 °C on average. The average soil temperature was similar to or greater than the average air temperature in all cases except Lubbock HTs where the average mulch soil temperature was 2.3 °C lower than the average air temperature, potentially as a result of decreased solar radiation in the HT. Average solar radiation (PAR) was decreased 28%, 35%, and 18% in HTs vs. the OF during the same measurement period at Knoxville, Lubbock, and Mount Vernon, respectively. Reduced PAR in HTs compared with the OF at Knoxville and Lubbock was likely the result of dust coating the HT plastic covering at those sites. Relative humidity was 7% and 2% lower in HTs than the OF at Knoxville and Mount Vernon, respectively, but approximately equivalent at Lubbock. Average wind speed (km h⁻¹) was two- to 32-fold lower in HTs compared with the OF at all three sites with maximum wind gust speeds exceeding 30 km h⁻¹ in the OF during 24 d at Knoxville, 70 d at Lubbock, and 14 d at Mount Vernon. The maximum wind gust speed exceeded 30 km h⁻¹ in HTs only during 1 d and only at Mount Vernon.

**Mulch deterioration.** The number of RTH at Lubbock and Mount Vernon differed as a result of production system (P ≤ 0.05) and mulch treatment (P ≤ 0.05), and there were significant (P ≤ 0.05) interactions between production system and mulch treatment on most rating dates; thus, the data are presented separately by HTs and the OF (Table 3). At Lubbock HTs, the number of RTH ranged from 0 to 1.5 early in the season and did not differ by mulch treatment. By midseason, WeedGuardPlus had significantly greater RTH (P = 0.003) than the other treatments except BioAgri. At the end of the season, the number of RTH was greatest for WeedGuardPlus followed by BioTelo and BioAgri (P < 0.0001). In the OF, BioTelo and BioAgri had more RTH than other treatments at the beginning of the season (P < 0.0005), but by the end of the season, WeedGuardPlus had more RTH than any other treatment (P < 0.0001). At the end of the season, the average number of RTH in HTs was similar to the average number in the OF for all mulch treatments except BioTelo, which had two times the number of RTH in the HT as compared with the OF.

In HTs at Mount Vernon, BioTelo had a higher number of RTH than the other mulches later in the season (P ≤ 0.001), but the RTH was not significantly different from BioAgri and/or WeedGuardPlus RTH during the season. In the OF, WeedGuardPlus, BioTelo, and BioAgri had the highest number of RTH during the season (P ≤ 0.01), although at the end of the season, WeedGuardPlus had a greater number of RTH than the other mulches (P < 0.0001). At Mount Vernon, the final average number of RTH for mulch treatments in HTs (11.06) was approximately equal to that in the OF at Lubbock (10.12), whereas the average number in the OF at Mount Vernon (28.98) was more than twice as much as at Lubbock (10.12). On four dates a coalescence of RTH caused the numbers of RTH to be fewer than on the preceding rating date.

At both Knoxville and Mount Vernon, PVD differed as a result of mulch treatment (P ≤ 0.05) and there was a significant interaction between production system and mulch type (P ≤ 0.05); therefore, PVD data (Fig. 1) from both sites are presented separately for HTs and the OF. In HTs at Knoxville, PVD range was 0% to 3.6% at the beginning of the season (P = 0.16) and 0% to 21.4% at the end of the season (P = 0.37). BioAgri and BioTelo had the greatest PVD midseason (P = 0.04), but none of the PVD values were significantly different at the end of the season (P = 0.37). In the OF at Knoxville, PVD range was 0.5% to 2.5% at the beginning of the season (P = 0.11) and 0.5% to 33.3% at the end of the season (P = 0.0003). Whereas PVD for BioTelo at Knoxville was greater than the other treatments early in the season (P ≤ 0.003), it was similar (P ≤ 0.005) to BioAgri and WeedGuardPlus from midseason onward. In HTs at Mount Vernon, PVD range was 0% to 0.8% at the beginning of the season (P = 0.06) and 0% to 11.8% at the end of the season (P = 0.0004). In the OF at Mount Vernon, PVD range was 0% to 3.3% at the beginning of the season (P = 0.005) and 1.3% to 34.0% at the end of the season (P = 0.003). Throughout the season in both HTs and the OF at Mount Vernon, WeedGuardPlus had the greatest PVD followed by BioTelo and BioAgri (P ≤ 0.001). At both Knoxville and Mount Vernon, SB-PLA-10 showed very little PVD in HTs and the OF throughout the season (0% to 1.3%) and the PVD was not significantly different from black plastic PVD on any of the evaluation dates. There was an increase in black plastic PVD midseason in the HT at Knoxville as a result of inadvertent tearing by workers in the field. Overall average PVD was 58% greater at the end of the season in the OF than in HTs at Knoxville but two and a half times greater at Mount Vernon.

**Weed assessment.** Number of weeds and weed fresh weight at tomato first flower and final harvest did not differ as a result of production system at either Knoxville or Mount Vernon (P > 0.05); however, the numbers did differ by mulch treatments at both sites (Table 4). There was no significant interaction between production system and mulch treatment at either Knoxville or Mount Vernon (P > 0.05). At both Knoxville and Mount Vernon, SB-PLA-10 had the greatest number of weeds at first flower (P < 0.0001) and final harvest (P ≤ 0.02) as well as the greatest weed fresh weight at first flower (P < 0.0001) and final harvest (P ≤ 0.009). The other mulch treatments at Knoxville and Mount Vernon did not differ significantly from each other for weed number and weight at either first flower or final harvest, although BioTelo was not significantly different from SB-PLA-10 at final harvest at Mount Vernon.

**Fruit yield.** There was no significant interaction in tomato fruit number or weight (P > 0.05) between production system and mulch treatment at any of the sites. Total tomato fruit number was 42% greater in HTs than in the OF at Knoxville (P < 0.0001); however, there was no difference in total fruit weight (P = 0.53) by production system at Mount Vernon (Table 5). At Lubbock, tomato fruit number was 74% greater in HTs than in the OF (P = 0.02) and total fruit weight was 60% greater (P < 0.03). At Mount Vernon, tomato fruit number was five times greater in HTs than in the OF (P = 0.0008) and total fruit weight was nine times greater (P = 0.0005). Mulch treatment affected total number of tomato fruit and fruit weight at Knoxville (P = 0.04 and P = 0.04, respectively) and Mount Vernon (P = 0.008 and P = 0.004, respectively) but not at Lubbock (P = 0.46 and P = 0.23, respectively). Total fruit number and yield were lowest for bare ground at both Knoxville (150 × 10³ fruit/ha and 29 t ha⁻¹) and at Mount Vernon (44 × 10³ fruit/ha and 11 t ha⁻¹). At Knoxville, none of the other
mulch treatments was significantly different from one another but at Mount Vernon, BioAgri tended to have the highest yield (66 × 10^4 fruit/ha and 16 t/ha). At Lubbock, the highest yield appeared to be in WeedGuardPlus (477 × 10^4 fruit/ha and 55 t/ha) and SB-PLA-10 (503 × 10^4 fruit/ha and 56 t/ha); whereas these differences were not significant, likely as a result of large variation between plants within a treatment, they represented an increase of 27% and 33%, respectively, compared with the lowest yielding treatments (bare ground and black plastic).

### Discussion

At all three sites, mulch deterioration was greater in the OF than in HTs. Soil and air temperatures were elevated in HTs as compared with the OF at Mount Vernon but did not result in accelerated mulch degradation. Deterioration was likely greater in the OF than HTs as a result of higher wind speed (blowing soil particles potentially abraded mulch), greater solar radiation, and increased rainfall. In our study, the greatest mulch deterioration occurred at Knoxville and at Mount Vernon, the sites with the highest relative humidity (average 77% and 81%, respectively). Whereas Lubbock received one major rain event during the study (210 mm from 27 June to 12 July), the moisture drained from the site relatively quickly so that plots were dry within a few weeks. Thus, overhead moisture may play a larger role than temperature or incident radiation in the deterioration of these mulch products. Other studies have also found that potentially biodegradable products (corn starch, paper, and/or PLA-based) exhibited different levels of deterioration (decreased molecular weight and increased water solubility) as a result of increased environmental moisture, temperature, and light (Hakkarainen, 2002; Ho et al., 1999; Kijchavengkul et al., 2008).

At all three sites, mulch deterioration as measured visually in the field through RTH and PVD was greatest for the three commercially advertised biodegradable mulches, WeedGuardPlus, BioAgri, and BioTelo, and was insignificant for the experimental SB-PLA-10 mulch and black plastic. Deterioration of starch and paper-based mulches started earlier in the OF than in HTs at Knoxville, whereas at Mount Vernon, only paper-based mulch deterioration was earlier in the OF compared with HTs. WeedGuardPlus deteriorated at the soil interface at all three sites and remained intact for a significant portion of the growing season. At Knoxville, mulch deterioration generally remained below 10% until early July, which was much higher than halfway through the tomato production season, and final mulch deterioration was 20% to 30%. At Mount Vernon, deterioration
of all mulches except WeedGuardPlus remained below 5% throughout the tomato production season. WeedGuardPlus in HTs had low deterioration by the end of the season, ≈10%, but had higher deterioration in the OF, ≈30%. At Lubbock, mulch deterioration in both HTs and the OF as measured by RTH was equivalent to mulch deterioration in the HTs at Mount Vernon. At Knoxville and Mount Vernon, weed number and weight declined between first flower and final harvest, likely as a result of competition under SB-PLA-10 and weed death from lack of light under the other mulches. These results indicate that all of the potentially biodegradable mulches included in this study likely have an adequate lifespan in the field, and weed growth did not increase with mulch deterioration later in the season. The HTs had no effect on weed number or weight compared with the OF at any of the three sites, indicating

![Fig. 1. Percent visual degradation (PVD) per bed area (1.5 m × 0.6 m) of mulch treatments in high tunnels (HT) and the open field (OF) at Knoxville and Mount Vernon in 2010. Bars represent the SEM, value ranges for treatments with limited degradation are small thus error bars are not evident.](image)

![Table 4. Total weed number and fresh weight (g) per 0.6 m² associated with mulch treatments at tomato first flower and final harvest at Knoxville and Mount Vernon in 2010.](table)

| Field location | First flower | Final harvest | First flower | Final harvest |
|----------------|--------------|---------------|--------------|---------------|
|                | Weed no. (plot) | Weed wt (g/plot) | Weed no. (plot) | Weed wt (g/plot) |
| High tunnel    | 11.3 | 15.0 | 3.4 | 41.6 |
| Open field     | 9.2 | 13.6 | 3.0 | 54.1 |
|                 | 0.38 | 0.84 | 0.50 | 0.51 |
| Mulch treatment| BioAgri 2.3 b | 4.6 b | 0.0 b | 0.0 b |
|                 | BioTelo 2.1 b | 1.9 b | 0.0 b | 0.0 b |
|                 | WeedGuardPlus 1.8 b | 0.7 b | 0.0 b | 0.0 b |
|                 | SB-PLA-10 123.7 a | 190.8 a | 16.0 a | 47.4 a |
|                 | Black plastic 0.3 b | 0.5 b | 0.0 b | 0.0 b |

*Knoxville weed number data and weed weight data at first flower were square root transformed for analysis and means separation; means presented are backtransformed.

*Knoxville weed number data at final harvest were log10 transformed for analysis and means separation; means presented are backtransformed.

*Mount Vernon first flower weed number data were square root transformed for analysis and means separation; means presented are backtransformed.

*Mount Vernon final harvest weed number and weight data were reciprocal transformed for analysis and means separation; means presented are backtransformed.

*Means within a column followed by the same letter are not significantly different (P > 0.05) as determined by least square means in the PROC MIXED model (SAS Version 9.2 for Windows®; SAS Institute, Cary, NC).
weed management strategies will likely not need to change as a result of production system.

Table 5. Total number of tomato fruit (10⁴/ha) and weight (t·ha⁻¹) associated with production system and mulch treatment at Knoxville, Lubbock, and Mount Vernon in 2010.¹

| Production system | Knoxvill | Lubbock | Mount Vernon |
|-------------------|----------|---------|--------------|
|                   | Fruit no. (10⁴/ha) | Fruit wt (t·ha⁻¹) | Fruit no. (10⁴/ha) | Fruit wt (t·ha⁻¹) | Fruit no. (10⁴/ha) | Fruit wt (t·ha⁻¹) |
| High tunnel       | 226 ¹   | 38      | 549 a    | 58 a     | 94 a   | 24 a      |
| Open field        | 160 b   | 36      | 315 b   | 37 b     | 18 b   | 3 b       |
| P value           | <0.0001 | 0.53    | 0.02    | 0.03     | 0.0008 | 0.0005    |
| Mulch treatment   |          |         |         |          |        |           |
| BioAgri           | 201 y   | 38 y    | 408     | 44       | 66 x   | 16 w      |
| BioTelo           | 192 y   | 37 y    | 403     | 45       | 64 xy  | 16 wx     |
| WeedGuardPlus     | 197 y   | 38 y    | 477     | 54       | 55 xy  | 13 xy     |
| SB-PLA-10         | 202 y   | 39 y    | 503     | 56       | 50 y   | 12 yz     |
| Black plastic     | 216 y   | 41 y    | 408     | 42       | 56 xy  | 13 wxy    |
| Bare ground       | 150 z   | 29 z    | 395     | 42       | 44 z   | 11 z      |
|                  | 0.04    | 0.04    | 0.46    | 0.23     | 0.008  | 0.004     |

¹Total fruit number and total weight of fruit were calculated based on seven plants in each plot; spacing was 1.8 m between beds and 0.6 m in the bed.

²Means within a column followed by the same letter are not significantly different (P > 0.05) as determined by Fisher’s protected least significant difference test.
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