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Assessing the potential for spunbond, nonwoven biodegradable fabric as mulches for tomato and bell pepper crops

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ABSTRACT

Polyethylene film is commonly used in intensive vegetable production, but disposal concerns have growers seeking sustainable alternatives. Potentially biodegradable plastic films (bioplastics) and fabrics (biofabrics) can be made from renewable materials, are compostable, and may degrade in the soil after the growing season, but there are questions about the field performance of these products. A two-year study was conducted in tomato (*Solanum lycopersicum* L.) and bell pepper (*Capsicum annuum* L.) across two climatically diverse locations in Illinois, USA to compare performance among two bioplastic films (Eco Film and Bio Telo) and four experimental spunbond, nonwoven biofabrics (3M Company). Soil temperature and moisture, mulch durability and deterioration, weed suppression, and crop yield data were collected throughout each growing season. Bioplastic films began deteriorating as early as 3–5 weeks after transplanting crops, which contributed to increased weed emergence and evaporative soil water loss. In contrast, the BK-1-270 biofabric mulch did not deteriorate during the growing season, increased soil moisture throughout the season by up to 3.0% relative to bare soil, and eliminated weed competition. Bioplastic films increased soil temperatures by as much as 1.7 °C in northern Illinois and 2.3 °C in central Illinois, whereas soil temperatures were not different between bare soil and biofabrics. Increased soil temperature can hasten crop development and increase yield in cooler climates, but can also contribute to physiological stress and root disease in warmer climates. Biofabric and bioplastic mulches did not increase tomato or pepper fruit yields relative to bare soil. However, biofabrics may be useful in situations where soil warming is not desirable (e.g., warmer climates), but moisture conservation and weed control are essential (e.g., organic cropping systems).

1. Introduction

Specialty crop growers are seeking affordable options for weed control that provide other agronomic benefits (e.g., soil warming and water conservation) and are not deleterious to their local or global environment. Polyethylene (PE) mulch films are most commonly used for intensive cultivation of fruits and vegetables (Lamont, 2005) and are typically the most cost-effective option for growers (Cirujeda et al., 2012); however, the short-term economic and long-term environmental costs of PE disposal have led many growers to consider alternatives. Possible alternatives to PE include organic mulches derived from agricultural or urban byproducts and waste (e.g, straw mulch and newspaper mulch; Monks et al., 1997), paper-based mulches (e.g., WeedGuardPlus), or potentially biodegradable plastics (bioplastics) and fabrics (biofabrics) (Miles et al., 2012).

Organic mulches are an attractive option because they provide opportunities for growers to recycle on-farm agricultural by-products or urban waste products at little to no cost. Moreover, organic mulches may serve as a source of nutrients as they decompose throughout the growing season (Parr et al. 2011). The permeability of organic mulches may also increase soil moisture relative to impermeable plastic mulch during periods of sufficient precipitation (Warnick et al., 2006). Wheat straw and chopped newspaper waste can suppress weeds when applied in a thick layer (>7.6 cm), but this benefit is accompanied by substantially cooler soil temperatures early in the growing season (Monks et al., 1997; Larsson and Båth, 1996; Warnick et al., 2006). Unfortunately, reduced soil temperature beneath organic mulches can lead to reductions in crop yield (Olsen and Gounder, 2001). In addition to these agronomic drawbacks, organic mulches can be difficult and costly to apply on a commercial scale.

Abbreviations: PE, polyethylene; WAT, weeks after transplanting.

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Paper-based mulches are a commercially available alternative to PE and are popular because of their low cost (Olsen and Gounder, 2001) and potential status as an approved input in USDA certified organic crop production. There is also some evidence that vegetable crop yields in paper-based mulch systems can be competitive with those in PE mulch (Jenni et al., 2004; Cirujeda et al., 2012). Unfortunately, paper-based mulches often degrade too quickly during the growing season, especially the buried edges of the mulch, leading to weed infestation and reduced crop yield (Weber, 2003; Martin-Closas et al., 2008; Miles et al., 2012; Cowan et al., 2014). Degradation of paper-based mulch can be slowed through polymerization (e.g., adding oil to the paper), but this adds considerable mess, time, and expense to the mulching operation (Shogren and Hochmuth, 2004). Soil temperatures are also considerably lower beneath paper-based mulches relative to bare soil, bioplastics, and PE, which further contributes to yield loss in warm season crops (Cowan et al., 2014).

Bioplastic films have properties similar to PE and include polyhydroxyalkanoates, polylactides, polycaprolactone, aliphatic polyesters, polysaccharides, copolymers, or some combination of the above (Kasirajan and Ngouajio, 2012). Like PE, bioplastic films are typically effective in increasing soil temperatures relative to bare soil contributing to increased crop growth rate and yield (Ngouajio et al., 2008; Martin-Closas et al., 2008; Miles et al., 2012; Cowan et al., 2014). Despite the similarities, most bioplastic films have lower tensile strength and mechanical resistance compared to PE (Martin-Closas et al., 2008). As a result, bioplastic films often deteriorate faster than PE during the growing season and are more susceptible to rips, tears, and holes, which threaten its capacity for season-long weed suppression (Martin-Closas et al., 2008; Moreno and Moreno, 2008; Ngouajio et al., 2008; Waterer, 2010; Miles et al., 2012). Even in cropping situations where the agronomic performance of bioplastic films is comparable to PE, the significantly higher cost of these products continues to limit on-farm adoption (Olsen and Gounder, 2001).

A fourth alternative to PE are potentially biodegradable, spunbond, nonwoven fabric mulches (hereafter, "biofabrics"). Biofabrics are typically composed of polylactic acid or polylactic acid in combination with polyhydroxyalkanoate (Cowan et al., 2014) and are much thicker and heavier than PE or bioplastic films, but can still be applied with conventional mulch layers. One line of experimental biofabrics (SB-PLA-10/11/12; Natureworks, LLC; Blair, NE, USA) has been tested in vegetable cropping systems with some success (Miles et al., 2012; Cowan et al., 2014). The fabrics were more durable than bioplastics during the growing season (e.g., less deterioration and rips, tears, and holes) and black fabrics provided season long weed suppression (n.b., the white, translucent fabrics did not provide acceptable weed control; Cowan et al., 2013). Biofabrics are biologically-based and compostable, but recent studies suggest these materials may be slow to degrade in the soil (Li et al., 2014; Dharmalingam et al., 2015).

The field performance and durability of bioplastics and biofabrics may vary among regional climates and local microclimatic and soil conditions. For example, weed suppression may vary according to local seedbank abundance and community composition, and soil moisture retention may vary according to local precipitation, vapor pressure deficit, and permeability of the mulch (Warnick et al., 2006). Moreover, durability of mulch is likely related to the wind speed at a specific site as demonstrated by increased durability of potentially biodegradable mulches in high tunnels compared to open field environments (Miles et al., 2012). Exposure to UV radiation, which may be influenced by crop canopy architecture, local climate, or cropping system (e.g., high tunnel vs. field), will also speed degradation of mulches (Briassoulis, 2007). Crop yield response to potentially biodegradable mulches is also variable across climates. Miles et al. (2012) observed increased tomato yield in a bioplastic film compared to bare soil in northwestern Washington, USA, but no difference in yield among biomulches and bare soil in Texas, USA. Thus, it seems the benefits of bioplastic films may be greater in cooler climates where there is greater potential for early season soil warming.

The objective of this study was to evaluate the field performance and durability of four experimental spunbond, nonwoven biofabrics in comparison to two commercially available bioplastic films and a bare soil control in vegetable cropping systems of central and northern Illinois, USA.

2. Materials and methods

2.1. Site characteristics and experimental design

Five field trials were conducted in 2013 and 2014 with two crops at two locations. One trial was conducted in 2013 at the University of Illinois Sustainable Student Farm in Urbana, Illinois, USA (40.08 N, 88.22 W; elev. = 221 m; loam soil texture: 31% sand, 45% silt, and 24% clay) in fresh market tomato (*Solanum lycopersicum* cv. Estiva). Four additional trials in 2014 compared processing tomato (cv. San Marzona) and bell pepper (*Capsicum annuum* cv. Revolution) between a central and northern location in Illinois. The central trials were conducted in Urbana, Illinois (as in 2013) and the northern trials were conducted at the University of Illinois Horticultural Research Center in St. Charles, Illinois, USA (41.91 N, 88.36 W, elev. = 223 m; silt loam soil texture: 6% sand, 71% silt, and 23% clay). Climatic conditions across years and sites are summarized in Table 1.

Each trial was arranged as a randomized complete block design with four replicate blocks and seven experimental treatments including, four experimental spunbond, nonwoven biofabrics of varying thickness, weight, and color (3M Company; St. Paul, Minnesota, USA), Eco Film bioplastic film (Cortec Corporation, St. Paul, Minnesota, USA), Bio Telo bioplastic film (Dubois Agrinovation; Saint-Remi, Quebec, Canada), and a bare soil control. Mulch properties are summarized in Table 2. Experimental units were 3.72 m^2 (1.22 m × 3.05 m) and included five tomato plants spaced 0.61 m apart or seven pepper plants spaced 0.45 m apart. Three of the five trials were located on "alternate" sites for moveable high tunnels at the University of Illinois Sustainable Student Farm for direct comparison with biodegradable mulch trials in the adjacent high tunnel (Wortman, unpublished data); thus, trials were limited to a total area of 260 m^2 (the area of one high tunnel). Plot size was relatively small, but similar to the area used in recent studies on potentially biodegradable mulches to successfully detect differences in mulch and crop performance (e.g., Miles et al., 2012; Cowan et al., 2014).

2.2. Cropping system management

Prior to laying mulches in each trial, the entire experimental area was roto-tilled and raised-beds were shaped (approximately 0.61 m bed tops). Drip irrigation line was laid down the middle of raised-beds. Mulches were cut to length, laid on top of raised beds and drip line, and the mulch edges were buried. Crop seedlings, which were started from seed in a heated greenhouse six to eight weeks prior, were transplanted into cut 7.5 × 7.5 cm square crop holes within each experimental unit. Tomato plants were transplanted on 17 May in 2013, 13 June at Urbana in 2014, and 9 June at St. Charles in 2014. Pepper plants were transplanted on 13 June at Urbana and 9 June at St. Charles in 2014. Pepper plants in select treatments became infected by *Pythium* spp. at St. Charles shortly after transplanting and infected plants were removed and replaced by healthy transplants on 18 June.