Assessing Biodegradable Mulch Duration and Nutsedge Suppression during Late Summer Cucumber Production in Mississippi and Louisiana

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Abstract: Environmental concerns as well as labor costs associated with the use of polyethylene plastic mulch have turned producers’ focus to alternative mulch treatments. A preliminary study was conducted to evaluate nutedge control, mulch degradation, and cucumber yields on biodegradable mulches at two locations (Louisiana and Mississippi). Mulch treatments included two paper-based mulch products, two biodegradable plastic mulches, the industry standard non-biodegradable black plastic mulch, and an unmulched control. The heavy weight paper-based mulch was able to hold back nutsedge (p ≤ 0.05) at similar rates as the two biodegradable plastic mulches and industry standard plastic mulch, while the light weight paper mulch and unmulched plots were ineffective at reducing emerged sedges. There were no statistical differences in nutsedge control (averaging < 14 emerged plants per 1.5 m subplots) between all mulch materials at the conclusion of the study in the Mississippi location. Combining both states yield data, the heavy weight mulch (8.7 fruit, 5.3 lb) performed comparably to the industry standard plastic mulch (5.8 fruit, 3.5 lb) in terms of both average fruit number and average weights harvested off 9.1 m rows at each harvest date.

Keywords: polyethylene mulch; Cucumis sativa; Cyperus rotundus; Cyperus esculentus

1. Introduction

Purple nutedge (Cyperus rotundus L.) and yellow nutedge (Cyperus esculentus L.) are two of the most economically damaging weeds and have been reported to cause 20–90% yield losses in agronomic and horticultural crops worldwide [1]. There are many practices for nutedge control in both agronomic and horticultural crops, including the use of cultural practices such as narrower crop row spacing and intercropping practices; physical control such as shallow and deep tillage; soil solarization; and mulching. Other control methods include herbicide usage and fumigation. While herbicide usage can be an effective method for controlling nutedge plants, doing so is not organically approved. Moreover, herbicides labeled for nutedge control are often cost prohibitive for small vegetable producers (personal correspondence with members of the Louisiana Fruit and Vegetable Growers’ Association). Plastic mulch such as polyethylene is a popular weed suppression method utilized by vegetable farmers across the world. Plastic mulches provide many benefits including weed control, improved soil moisture retention, and increased soil temperature during the early spring when air temperature is lower [2]. While plastic mulch typically
provides excellent weed control, it is not effective (without assistance from fumigants) at controlling yellow or purple nutsedge [3]. Additionally, the overuse of plastics in modern agriculture has raised environmental concerns because of its persistence in the soil and threat to sustainable ecosystems [4]. Disposal options for plastic mulches are limited. Agricultural plastic recycling is limited in the United States. There are no United States policies requiring or encouraging farmers to recycle agricultural plastics. Programs are voluntary and limited by market demand for recycled plastic [5]. Some areas of the Gulf South provide plastic mulch recycling programs such as the Florida Agricultural Plastic Recyclers (FLAG), but facilities are limited. Difficulty removing soil and other debris from plastic mulches makes it challenging to recycle [6]. To our knowledge, there are no existing recycling programs in either Mississippi or Louisiana where this research was conducted.

There are several ways that farmers dispose of plastic mulches. Disposal methods include on-farm burning, plowing into fields, permanently storing on the farm in non-cultivated areas, or disposal in landfills [7]. These practices are not eco-friendly. Burning plastics can release harmful pollutants such as volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), dioxin, and other toxic pollutants into the atmosphere [8,9]. Landfilling has been a common disposal destination for plastic. Growers must incur the costs of hauling and disposal at landfills. Some studies have indicated that the removal of polyethylene plastic mulches and landfill costs can be as much as $584/ha [10]. According to statistics from the Environmental Protection Agency [11], nearly 27 million tons of plastic were deposited into landfills in 2017, constituting 19.2% of all solid waste in landfills. In addition to the environmental concerns of using plastic mulches, the cost of laying and removal of plastic mulch creates economic concerns for farmers. An economic analysis, carried out by the South Georgia Vegetable Industry in 2018, found that the removal of plastic mulch required four workers at $14.53/h at rate of 2 h per acre totaling $116.24 per acre [12].

As an alternative to the unsustainable practice of plastic mulch for weed suppression and its costly removal, biodegradable mulches are receiving notice by vegetable producers. One of the benefits of using biodegradable mulches is that they can be composted and incorporated into the soil at the end of the growing season, thereby reducing the environmental and financial impacts imposed by plastic mulches. Cowan [13] found that under high tunnel tomato production and in open field tomato production, biodegradable mulches performed comparably to traditional polyethylene plastic mulches for weed control. Additionally, recent studies have indicated that paper-based mulches may be effective in nutsedge control [3,14]. Beyond weed suppression and the ability to degrade, Wortman et al. [15] tested bio fabrics (biodegradable fabrics) that were permeable, allowing water to penetrate the row top. This water permeable quality may be beneficial to growers who cannot afford drip irrigation but who still need to organically control weeds. Finally, biodegradable mulches have been tested against polyethylene plastic mulches for vegetable production with several studies indicating yields between bioplastic mulches and polyethylene plastic mulches are often very similar [16–18]. Maintaining high yield and therefore high profits is of upmost importance to commercial growers.

A quality biodegradable mulch should have durability during the growing season followed by rapid decomposition after soil incorporation. Some concerns with using biodegradable mulches may include installation difficulties, quick breakdown of the material, and reduced capacity for season-long weed suppression. Organic growers may be concerned with the raw materials used to make biodegradable mulches such as GMO corn. Bioplastic films have been shown to degrade more slowly than paper-based mulches with some products degrading in 13–24 months after soil incorporation, depending on local climatic conditions [19].

The objective of this study was to evaluate the field performance, durability, and nutsedge control of four biodegradable products in comparison with polyethylene plastic mulch and an untreated control (bare soil control) across field grown cucumber crops in Louisiana and Mississippi.
2. Materials and Methods

2.1. Description of Location and Mulch Treatments

Biodegradable mulch was evaluated in two locations, the Louisiana State University Agricultural Center (LSU AgCenter) Botanic Gardens in Baton Rouge, LA, located at lat. 30°24′32.1012″ N by long. 91°6′21.0132″ W, and the Mississippi State University Beaumont Horticultural Unit in Beaumont, MS, located at lat. 30°5′9.78″ N by long. 94°6′6.66″ W. The Mississippi location is in USDA zone 8b with a McLaurin fine sandy loam soil type. The Louisiana location is in USDA zone 9a with a very fine sandy loam soil type. The COVID-19 pandemic delayed mulch installation and planting until 1 July 2020, at the Louisiana location and mulch installation on 22 July 2020 with a planting date of 27 July 2020 at the Mississippi location. Typical planting dates for cucumber production in Louisiana and Mississippi would be mid to late March through September for spring summer and early fall harvests [20,21]. Five mulch treatments and an untreated bare row control treatment were evaluated at each location. The mulches included two paper-based mulches: Heavy Weight Weed Guard paper mulch (Sunshine Paper Co. Aurora, CO, USA), and Light Weight Weed Guard Plus 3–3-3 paper mulch (Sunshine Paper Co., Aurora, CO, USA). Two biodegradable plastic mulches were also evaluated: a maize mulch manufactured from cornstarch (Sunshine Paper Co., Aurora, CO, USA) and a biodegradable plastic mulch, Bio 360 Mater-Bi, made from non-GMO cornstarch (Dubois Agrinovation, Simcoe, ON N3Y 4K2, Canada). A black polyethylene plastic synthetic 1.0 mil mulch (Berry, Evansville, IN, USA) served as the industry standard (Table 1). Black mulch was selected despite the late planting date. Typically, a white mulch would be used for summer plantings in Louisiana and Mississippi. However, the biodegradable mulches selected for this project were black to dark brown in color. White or light-colored biodegradable mulches were not available. All mulches were black in color except the paper mulches. The Light Weight Weed Guard Plus 3–3-3 was labeled as brown but appeared dark purple in color, and the Heavy Weight Weed Guard was also labeled as brown but appeared a lighter purple color. Additionally, each location had unmulched, bare ground control plots not sprayed with herbicide. Table 1 provides attributes of each mulch used in this study including details such as the manufacturer, thickness, price per linear meter, and color.

Table 1. Mulch brands trials in the 2020 Louisiana/Mississippi biodegradable mulch experiment.

| Mulch Type               | Manufacturer               | Plastic/Paper | Polymer             | Thickness (mil.) | Cost Per Linear Meter | Color     |
|-------------------------|----------------------------|---------------|---------------------|------------------|-----------------------|-----------|
| Weed Guard Plus with 3-3-3 fertilizer | Sunshine Paper Co. | Paper          | Cellulose           | 9                | $0.63                 | Brown    |
| Heavy weight Weed Guard | Sunshine Paper Co.         | Paper          | Cellulose           | 13               | $0.82                 | Brown    |
| Bio 360                 | Dubois Agrinovation        | Plastic        | Mater-Bi (corn starch) | 0.6             | $0.17                 | Black    |
| Maize Mulch             | Sunshine Paper Co.         | Plastic        | Corn starch         | 6                | $0.79                 | Black    |
| Conventional Plastic Mulch | Berry Plastics Corp.     | Plastic        | Black embossed non-degradable | 1.0             | $0.11                 | Black    |

2.2. Field Preparation and Planting Descriptions

Prior to laying mulch treatments, the field was prepared by diskng and tilling and forming raised beds. Raised beds were fertilized with an all-purpose fertilizer 13N–5.7P–10.8K as a pre-plant application. A rate of 100 lb of actual nitrogen was applied to the field using the previously mentioned complete fertilizer as recommended by the Southeastern U.S. Vegetable Crop Handbook [22]. Sidedress applications of fertilizer were not made in either location. Preemergent and post-emergent herbicides were not used in this study so as not to interfere with the weed pressure subjected to the mulches. After fertilization, and prior to mulch application, purple nutsedge tubers (Azlin Seed Service, Leland, MS, USA)
were planted at a rate of two tubers per linear 0.3 m in each 9.1 m plot down the center of the raised bed. Simultaneous with mulch treatments, a single line of drip-tape (Netafim, Fresno, CA, USA) (emitters on 0.3 m centers) was installed. Cucumber (Cucumis sativus var. Dasher II) seeds were sown into 50 count cell trays (T.O. Plastics, Inc., Clearwater, MN, USA) and filled with a medium containing fine sphagnum moss, peat moss, vermiculite, dolomite, and a long-lasting wetting agent (Sunshine® Mix #3; Sungro Horticulture, Agawam, MA, USA). The seeds were planted on 10 June 2020 and transplanted into the test plots on 1 July for the Louisiana location, which was also the same day as the mulch treatments were laid. Due to initial transplant loss at the Louisiana location, cucumber seeds were directly seeded into the LSU field on 8 July 2020, 7 days after mulch application to ensure a stand of plants. The transplants were delivered and transplanted into the Mississippi location on 27 July 2020. The Mississippi location continued replanting any transplant losses for two weeks after initial planting. Transplants were planted in a single row on 0.3 m center spacing at both locations. Rain and temperature data were collected at each location (Table 2). The original cucumber transplants planted in the Baton Rouge plots died shortly after transplanting and were then reseeded into the mulch plots on 7 July 2020, whereas only transplants were used in the Beaumont location. All mulches were laid easily with Mississippi State University’s (MSU) single row Rain-Flo 2600 plastic layer (Rain Bird, Azusa, CA, USA), while LSU AgCenter’s mulch layer is a much older, single row PS200 model (Kennco Manufacturing Inc., Ruskin, FL, USA). Both layers were capable of laying the standard polyethylene plastic mulch and the biodegradable plastic mulches and the lightweight paper mulch. However, the heavyweight paper mulch was a bit more difficult to lay, especially with the older Kennco model mulch layer. Table 2 shows further environmental differences in the two locations and presents information regarding weekly rainfall and temperature throughout the study. Heat and water may play a role in degradation rates of the mulch materials.

Table 2. Environmental condition differences at the two biodegradable mulch study locations for the 2020 mulch trial.

| Date       | Baton Rouge, LA Weekly Rainfall (cm) | Baton Rouge, LA Weekly Temperature °C Range | Beaumont, MS Weekly Rainfall (cm) | Beaumont, MS Weekly Average Temperature °C Range |
|------------|--------------------------------------|---------------------------------------------|----------------------------------|-----------------------------------------------|
| 1–4 July   | 13.5                                 | 29–34                                       | Trial not begun                  | Trial not begun                                |
| 5–11 July  | 2.7                                  | 24–32                                       | Trial not begun                  | Trial not begun                                |
| 12–18 July | 2.4                                  | 30–35                                       | Trial not begun                  | Trial not begun                                |
| 19–25 July | 6.0                                  | 27–34                                       | Trial not begun                  | Trial not begun                                |
| 26 July–1 Aug | 4.5                             | 22–34                                       | 2.8                             | 23–31                                         |
| 2–8 Aug    | 0.7                                  | 27–35                                       | 0.05                            | 21–33                                         |
| 9–15 Aug   | 4.4                                  | 27–36                                       | 9.6                             | 23–33                                         |
| 16–22 Aug 16–22 | 0.08                 | 28–36                                       | 4.0                             | 21–32                                         |
| 23–29 Aug  | 1.7                                  | 22–33                                       | 6.7                             | 23–81                                         |
| 30 Aug–5 Sept | 2.9                              | 23–36                                       | 0.13                            | 24–34                                         |
| 6–11 Sept  | 1.9                                  | 20–35                                       | 0.3                             | 21–33                                         |

2.3. Experimental Design and Statistics

All mulch treatments were replicated three times in 9.1 m by 1.2 m plots using a complete randomized block design. Each plot was further subdivided into three smaller 1.5 m plots for mulch percent coverage and sedge data collection. Once cucumbers began to mature, they were harvested twice a week for three weeks in Louisiana and twice a week for two weeks in Mississippi. The Louisiana location was harvested in 2020 on August 25 and 29 and September 2, 5, 9 and 16. The Mississippi location was harvested in 2020 on September 1, 5, 8, and 11. For each 9.1 m plot, total number of fruit and total fruit weight...
were collected at each harvest. Throughout the entire study, in each of the smaller 1.5 m plots, percent mulch coverage ratings (visual rating from 0 to 100%) and number of sedge plants penetrating the mulch were counted weekly. Mulch coverage was visually rated by visually estimating the amount of visible mulch on the soil surface in each sub plot. Data were analyzed using SAS (version 9.2; SAS Institute, Cary, NC, USA) Proc Mixed with Duncan’s test at $p \leq 0.05$.

3. Results

3.1. Baton Rouge, Louisiana Results

3.1.1. Louisiana Mulch Coverage

Most mulches held up well throughout the course of the 2020 summer season except for the Light Weight Weed Guard Plus 3–3-3 paper mulch and the untreated (no mulch) control. Visual estimation ratings of each of the five subplots were collected throughout the study (Figure 1). On the last week of data collection, week 11, the average mulch coverage of the polyethylene non-biodegradable black plastic mulch plots was 92.8% and remained intact better than all other biodegradable mulch treatments. In week 11, the maize mulch had an average percent coverage of 82.8%, the bioplastic mulch had an average percent coverage of 69.4%, and the Heavy Weight Weed Guard paper mulch had an average coverage of 46.1%. The Light Weight Weed Guard Plus 3–3-3 paper mulch rapidly began declining one week after installation. At 11 weeks after initiation, the lightweight paper mulch had an average coverage of 5%, equivalent to the no mulch treatment when considering percent coverage. Differences were observed between each mulch trialed at $p \leq 0.05$ with the non-biodegradable polyethylene mulch provided the highest level of percent coverage, followed by maize, bioplastic, Heavy Weight Weed Guard, Light Weight Weed Guard Plus 3–3-3, and untreated control in descending order. The goals for using biodegradable mulch are for the mulch to remain intact throughout the growing season to decrease weed pressure but also to break down fast enough so that labor costs are saved from removing it at the end of the season. While the polyethylene plastic mulch held up well, it requires removal and added labor cost at the end of the season. All degradable mulches, both plastic and paper, could easily be tilled into the soil or were visibly gone four months after the study began (data not shown). The ability to remain intact through to harvest was an important factor in reducing weed pressure.

![Figure 1: Mulch coverage throughout the study at the Baton Rouge, LA location. Mulch treatments with different letters are statistically significant at $p < 0.05$ using SAS Proc GLM with Duncan. Untrt Control = un-mulched raised beds; Maize p = biodegradable maize plastic mulch; Bioplastic = biodegradable bioplastic mulch; Conventional p = black polyethylene plastic mulch; HW Paper No Fert = heavy weight paper mulch without impregnated fertilizer; LW Paper Fert = light weight paper mulch with impregnated 3–3-3 fertilizer within the mulch.](image-url)
3.1.2. Louisiana Weed Prevention

Prior to purposely planting nutsedge tubers into the field for this study, the Baton Rouge field location had a heavy natural infestation of sedge, including yellow, purple, and flatsedge types. Figure 2 displays the average number of sedge plants emerging through each of the 1.5 m subplots over the duration of the study. At the conclusion of the study (11 weeks), the untreated control plots were completely covered with sedge and grass and broadleaf weeds. Sedge populations were too numerous to count accurately, with estimated populations exceeding 1000 plants per subplot. The Light Weight Weed Guard Plus 3–3-3 treatments were not effective, averaging 383 sedges per subplot. The number of sedge plants emerging through the bioplastic, Heavy Weight Weed Guard, and the black polyethylene plastic mulch were not significant. The bioplastic, maize, Heavy Weight Weed Guard, and the black polyethylene plastic mulch allowed 44.4, 44.4, 22.7, and 7.6 sedges, respectively, per subplot at the conclusion of the trial.

![Figure 2.](image)

**Figure 2.** Individual sedge plants emerging through mulch treatments at the Baton Rouge, LA location. Mulch treatments with different letters are statistically significant at p ≤ 0.05 using SAS Proc GLM with Duncan. Untrt Control = un-mulched raised beds; Maize p = biodegradable maize plastic mulch; Bioplastic = biodegradable bioplastic mulch; Conventionalp = black polyethylene plastic mulch; HW Paper No Fert = heavy weight paper mulch without impregnated fertilizer; LW Paper Fert = light weight paper mulch with impregnated 3–3-3 fertilizer within the mulch.

3.1.3. Louisiana Yields by Mulch Treatment

In the Louisiana location, the heavy weight paper mulch yielded more cucumbers in terms of number of fruits harvested per plot, as shown in parentheses hereafter (9.0), than the maize mulch (4.8), Light Weight Weed Guard Plus 3–3-3 (1.8), and the untreated check plots (0) at any one harvest date. The Heavy Weight Weed Guard did not yield a higher number of fruit than the black polyethylene plastic mulch (8.4) or the bioplastic mulch (5.9) at any one harvest. In terms of fruit weight, the Heavy Weight Weed Guard yielded more pounds of fruit (5.9 lb) than the bioplastic mulch (3.3 lb), maize mulch (2.5 lb), Light Weight Weed Guard Plus 3–3-3 (0.8 lb), and unmulched check plots (0 lb) at any one harvest. Heavy Weight Weed Guard yielded the same fruit weight (5.9 lb) as the synthetic standard plastic mulch (5.1 lb) at any one harvest date. Based on the results of the data from the Baton Rouge location, growers considering switching to a biodegradable mulch would not lose yields as compared to the standard synthetic mulches by choosing the...
Heavy Weight Weed Guard (Table 3). The ability of the heavy weight paper mulch to produce similar and even more fruit and fruit weight as compared to the polyethylene standard may have been because of soil temperature. Some research suggests [14] that soil beneath heavy weight paper mulches run about 1 °C cooler than plastic mulches. We did not measure soil temperature in this study, but it may explain why production was similar, as these cucumbers were growing in extremely warm conditions. Table 3 provides average harvested cucumber number and average fruit weight for each mulch treatment over the course of the season.

Table 3. Cucumber production differences in mulch treatments in the 2020 LSU MSU biodegradable mulch trials.

| Location     | Mulch Type             | Avg. Number of Fruit Harvested at Each Harvest Date | Total Weight (lb) of Fruit Harvested at Each Harvest Date |
|--------------|------------------------|----------------------------------------------------|----------------------------------------------------------|
| Louisiana    | Heavy weight paper     | 9.0a                                               | 5.9a                                                     |
| Louisiana    | Polyethylene black plastic | 8.4ab                                           | 5.1ab                                                    |
| Louisiana    | Bioplastic mulch       | 5.9ab                                              | 3.3bc                                                    |
| Louisiana    | Maize mulch            | 4.8bc                                              | 2.5cd                                                    |
| Louisiana    | Light weight paper mulch | 1.8cd                                           | 0.8de                                                    |
| Louisiana    | Un-mulched control     | 0d                                                 | 0e                                                       |
| Mississippi  | Heavy weight paper     | 8.3AB                                              | 4.4AB                                                    |
| Mississippi  | Polyethylene black plastic | 0.5C                                           | 0.2C                                                     |
| Mississippi  | Bioplastic mulch       | 10.2AB                                             | 5.0AB                                                    |
| Mississippi  | Maize mulch            | 9AB                                                | 5.0AB                                                    |
| Mississippi  | Light weight paper mulch | 11.1A                                          | 6.2A                                                     |
| Mississippi  | Un-mulched control     | 5.2BC                                              | 2.4BC                                                    |

Mean comparison within columns by SAS Proc Mixed with Duncan at $p \leq 0.05$. Means with the same letter do not differ at the 5% significance level. The Louisiana and Mississippi data are not compared to each other in this table; therefore, means within columns with capital letters and lower-case letters are not compared to one another.

3.2. Beaumont, Mississippi Location Results

3.2.1. Mississippi Mulch Coverage

While growers want biodegradable mulches to breakdown quickly at the end of the season, their ability to hold back weed pressure throughout the season is very important. Figure 3 depicts the visual ratings from 0 to 100% of mulch material remaining on the top portion of the row throughout the study at the Mississippi location. The polyethylene plastic mulch and bioplastic mulches held up very well throughout the study, providing 100% and 90% coverage, respectively. By 7 weeks after mulch installation (the last week of data collection at the Mississippi location), coverage of the other biodegradable mulches was significantly lower than the conventional and bioplastic with the Light Weight Weed Guard Plus 3–3-3 having 70% coverage, and the maize mulch having 56.7% coverage. Heavy Weight Weed Guard provided only 3.3% coverage, and the un-mulched control provided no coverage. Mulch coverage data was not collected in week 6 at the MSU location. The sharp increase observed with lightweight paper mulch coverage was attributed to a change in the person collecting data in weeks 5 and 7. The new data collector did not rate the percent coverage as accurately as the initial person. Visual estimates of mulch were collected by standing directly over the 1.5 m subplots and estimating the amount of intact mulch remaining on top of the row (Figure 3).
Figure 3. Mulch coverage throughout the study at the Beaumont, MS location. Mulch treatments with different letters are statistically significant at $p \leq 0.05$ using SAS Proc GLM with Duncan. Unttrt Contol = un-mulched raised beds; Maize $p =$ biodegradable maize plastic mulch; Bioplastic = biodegradable bioplastic mulch; Conventional $p =$ polyethylene black plastic mulch; HW Paper No Fert = heavy weight paper mulch without impregnated fertilizer; LW Paper Fert = light weight paper mulch with impregnated 3–3-3 fertilizer within the mulch.

3.2.2. Mississippi Weed Prevention

Prior to purposely-planting nutsedge tubers into the field for this study, the Beaumont, MS field did not have a natural sedge infestation. The population of sedges penetrating through mulches at the two locations was drastically different. The Beaumont, MS location had much better drainage than the Baton Rouge location. The Baton Rouge location stayed extremely wet. Yellow nutsedge and annual sedges such as rice flatsedge ($Cyperus iria$) prefer low oxygen high moisture areas, unlike purple nutsedge, which thrives in drier soils [21]. Figure 4 displays the average number of sedges emerging through each of the 1.5 m subplots over the course of the study. At the conclusion of the Mississippi study in week 7, there were no statistical differences in the number of sedges emerging through the mulch treatments. The un-mulched treatment averaged 12.2 sedges per 1.5 m subplot. The maize mulch, bioplastic mulch, Light Weight Weed Guard Plus 3–3-3 paper mulch, black polyethylene plastic mulch, and Heavy Weight Weed Guard paper mulch averaged 10.2, 10.1, 3.5, 1.0, and 0.2 sedge plants per 1.5 m subplot, respectively, at the end of the seven-week data collection period. Interestingly, at the Beaumont, MS location, although not significantly different, there was a trend of fewer sedges emerging through the Heavy Weight Weed Guard paper mulch when compared to the black polyethylene plastic mulch. However, at the Baton Rouge location, there was a trend of fewer sedges emerging through the black polyethylene plastic mulch, although not statistically less than the Heavy Weight Weed Guard paper mulch.
blocks for number of cucumber fruit harvested. However, when considering cucumber fruit harvested, the bioplastic mulch (7.6), maize (6.5), and polyethylene black plastic mulch (8.7) outperformed the lightweight paper mulch (4.7) mulch treatments and the untreated check plots. When yield data from both states were combined, heavy weight paper mulch and the Mississippi data suggest using lightweight paper mulch with impregnated 3-3-3 fertilizer within the mulch.

3.2.3. Mississippi Yield by Mulch Treatment

At the Beaumont, Mississippi location, the mulch treatments produced different results than those observed in Louisiana. The synthetic plastic mulch provided the lowest cucumber yields when compared to yields from all other mulch treatments in Mississippi. The Light Weight Weed Guard Plus 3–3-3 paper mulch (11.1), Heavy Weight Weed Guard paper mulch (8.3), bioplastic mulch (10.2), and maize mulch (9.0) yielded more fruit than both the synthetic standard plastic mulch (0) and the untreated check plots (5.2) at any one harvest at the Beaumont location. The poor yield results in the black polyethylene plastic plots may be attributed to high temperatures at time of transplanting. In terms of total harvest cucumber weight (lb/plot), the Light Weight Weed Guard Plus 3–3-3 paper mulch (6.2 lb) outperformed the untreated check (2.4 lb) and the synthetic standard plastic mulch (0.2 lb) but did not produce different fruit weight as compared to the other mulch treatments. In terms of fruit weight, all mulches produced more weight compared to the polyethylene black plastic mulch (0.2 lb). However, there were no weight differences in any of the trialed mulches verses the untreated check plots except for the Light Weight Weed Guard Plus 3–3-3 (6.2 lb), providing higher yield weights than the untreated check plots (2.4 lb) (Table 3).

3.3. Overall Yield Data (States Combined)

When Louisiana and Mississippi yield data were combined, differences occurred in location ($p < 0.01$) and plastic type ($p < 0.0014$); however, there were no differences in blocks for number of cucumber fruit harvested. However, when considering cucumber weight, differences did not occur in location or block, but there were differences in plastic type ($p < 0.0007$). Data from the two locations were pooled, as the Louisiana data suggest growers use heavyweight paper mulch and the Mississippi data suggest using lightweight paper mulch. When yield data from both states were combined, heavy weight paper mulch (8.7) outperformed the lightweight paper mulch (4.7) mulch treatments and the untreated control plots (2.1) in terms of fruit number harvested (Table 4). In terms of number of cucumber fruit harvested, the bioplastic mulch (7.6), maize (6.5), and polyethylene black plastic mulch (8.7) outperformed the lightweight paper mulch (4.7) mulch treatments and the untreated control plots (2.1) in terms of fruit number harvested (Table 4). In terms of number of cucumber fruit harvested, the bioplastic mulch (7.6), maize (6.5), and polyethylene black plastic mulch (8.7) outperformed the lightweight paper mulch (4.7) mulch treatments and the untreated control plots (2.1) in terms of fruit number harvested (Table 4).
plastic mulch (5.8) were not statistically different from one another or the heavyweight paper mulch (8.7). All mulches except the lightweight paper mulch outperformed total fruit number harvest except the untreated control (Table 4). In terms of harvested fruit weight (lb/plot), the heavy weight paper mulch (5.3 lb) outperformed the lightweight mulch (2.5 lb) and un-mulched control plots (0.9 lb) when both states data were pooled. Table 4 depicts average yields of cucumbers in terms of weight and number of fruits. This is important, as some growers market their produce by weight and others by number of fruits. In regard to this experiment, growers would question if the different mulches affected fruit yields.

Table 4. Cucumber yield as influenced by mulch treatments in the 2020 Louisiana and Mississippi biodegradable mulch trials, both states combined.

| Mulch Type                  | Avg. Number of Fruit Harvested at Each Harvest Date | Total Weight (lb) of Fruit Harvested at Each Harvest Date |
|-----------------------------|-----------------------------------------------------|----------------------------------------------------------|
| Heavy Weight Paper          | 8.7a                                                 | 5.3a                                                     |
| Bioplastic Mulch            | 7.6ab                                                | 4.0ab                                                    |
| Maize Mulch                 | 6.5ab                                                | 3.5ab                                                    |
| Polyethylene Black Plastic  | 5.8ab                                                | 3.5ab                                                    |
| Light Weight Paper Mulch    | 4.7bc                                                | 2.5bc                                                    |
| Un-mulched Control          | 2.0c                                                 | 0.9c                                                     |

Mean comparison within columns by SAS Proc Mixed with Duncan’s test at $p \leq 0.05$. Means with the same letter within columns do not differ at the 5% significance level.

4. Discussion

Concluding this preliminary study, the paper mulches were of great interest to researchers at both locations, especially for our organic growers who battle weed pressure. Similar to Moore and Wszelaki [3], where paper mulches held back nutsedge and allowed greater pepper production, the heavy weight paper mulch held back more weeds than all other biodegradable mulches trialed at the Baton Rouge, Louisiana location. While the paper mulches held no advantage to sedge control in Mississippi, they were not worse than any other mulches in the study. Commercial farmers can be reassured after this first-year project that paper mulches would indeed hold back some weed pressure while still degrading so that removal is not of concern. Paper mulches were degrading at the end of harvest and were totally broken down within four months of the study initiation. Similar results were found with Ghimire et al. [14], where paper mulches in the pie pumpkin trial were broken down to less than 10% by the end of the study. In week seven at the Beaumont Mississippi location, the lightweight paper was intact by an average of 40% coverage, while the heavy weight paper was intact with only 3% coverage. At the Baton Rouge location, by week 11, the heavy weight paper had an average coverage of 46.1% and the lightweight paper mulch an average coverage of 5%. Cucumbers are a much quicker crop compared to pumpkins; therefore, our degradation at the end of the study was not as drastic as the Ghimire et al. [14] study but did follow similar suit. While preferably the mulches should stay intact throughout the entire harvest period to prevent weeds, even in a decomposing condition, the heavy weight paper mulch was comparable in weed prevention to the synthetic plastic mulch in the Baton Rouge, Louisiana location, and both the heavy and lightweight paper mulches were better than the black polyethylene plastic mulch in weed prevention at the Beaumont, Mississippi location.

Yields from heavy weight paper mulch were statistically the same as those from the black polyethylene plastic mulch at the Baton Rouge, Louisiana location and better than the polyethylene black plastic mulch at the Beaumont, Mississippi location. These results are similar to Cowan et al. [13], where biodegradable mulches performed comparably to standard polyethylene mulch treatments. The paper mulch color visually appeared
to be purple. This trial was conducted in the heat of the summer; it is thought that the yields were increased with the heavy weight paper mulch because of less heat retention and because comparable numbers of weeds were suppressed. The paper mulches did not require physical removal from the field, which would reduce labor costs for the producer. Furthermore, the heavy weight and lightweight paper mulches were both Organic Materials Review Institute (OMRI) approved for those growers interested in organic production. If commercial producers are interested in using paper-based mulch products, they will need to allot time for adjusting plastic mulch layers. In this preliminary study, the paper mulch performed well and warrants further investigation in the deep southern portion of the US for organic production.

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