# Investigating the Use of Raw and Pelleted Wool as an Alternative Mulch for Vegetable Production

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*Special thanks to Jaelyn Whaley, SDSU Extension Sheep Field Specialist for peer review of this report.*

**May, 2026**

## Introduction

Recycling resources that would otherwise be waste to gain tangible benefit is a key principle of sustainability. Raw wool has the potential to be one such resource. Many sheep producers find themselves with unusable and unsalable wool that could be utilized for horticultural benefits, particularly as a mulch. The natural properties of wool, including its thermal insulation and nitrogen-rich chemical structure (being about 9% nitrogen), lends itself as a viable alternative to other mulching types while potentially providing additional benefits.

There are two main ways wool can be used for mulching purposes. The first is raw, unprocessed wool from sheep producers. This method creates an occlusive mat of wool fibers that covers the surface of the soil, which can reduce weed pressure. In addition to its raw form, the more commonly investigated use of wool is in its pelletized form. For this method, pellets of wool are applied to the soil and are either worked into the top few inches or left on the surface. It has been noted that wool pellets can serve as an organic alternative to commercial nitrogen fertilizer for spinach and tomato without compromising yield (Bradshaw & Hagen, 2022).

The purpose of this study was to evaluate both methods of wool mulching and their individual effects on reducing weeds and promoting pepper growth compared to other, more commonly used mulch types. In addition to its effects on peppers, this investigation also sought to capture the mulch types' effects on their respective soil microbiomes, gaining a broader view of the impact on soil health.

## Materials and Methods

### Location and Experimental Design

All field research was conducted at the SDSU Specialty Crop Research Field in Brookings, SD. Soil sampling at 6 inches deep in both the high tunnel and field was done both pre- and post-season and sent to Ward Laboratories, Inc. for analysis.

The experimental design was a randomized complete block design with eight different mulch types, each with four replications (two in a high tunnel and two in a field). The mulch types and abbreviations used in this study are summarized in Table 1. Each replication had a linear, east-west orientation, with the order of the mulch types randomized in each replication. Each individual mulch plot was approximately three feet wide and ten feet long (Figure 1) to make the total length for each replication 83 feet, including a buffer plant at the end of each replication.

| Mulch | Abbreviation |
|---|---|
| Bare Ground | BG |
| Cardboard | C |
| Landscape Fabric | LF |
| Wool Pellets Mixed | PM |
| Wool Pellets Surface | PS |
| Raw Wool | RW |
| Straw | ST |
| White Tarp | WT |

Table 1. Abbreviations used in this study for each mulch type.

Figure 1. Example of the dimensions of a single mulch plot (three feet by ten feet). Landscape Fabric is pictured here.

### Mulch Installation

Cardboard (C) was recycled from the SDSU campus and local restaurants; Landscape Fabric (LF) was purchased from Tessman Co (Sioux Falls, SD); Wool Pellets either mixed (PM) or on the surface (PS) were from Wild Farms Valley 9-0-2; Raw wool (RW) was supplied by Wayward Springs LLC (Aurora, SD); Straw (ST) was purchased at Runnings (Brookings, SD); White Tarp (WT) was obtained from Farm Plastic Supply. RW and ST mulch types were installed to a depth of three inches of material (Figure 2). PM and PS plots contained wool pellets at a density of 0.32 ounces per square foot. C, LF, RW and WT plots were secured using landscape staples as needed. After installation of the mulch plots, one line of drip irrigation was laid for each replication, and one HOBO brand soil probe was buried three inches deep under each mulch plot.

Figure 2. Raw wool was installed in a layer three inches deep.

### Planting Peppers

The pepper plants used in the study were purchased as transplants from Medary Acres (Brookings, SD) and were either the Jupiter Green or Orange Blaze variety. Each variety was planted in one replication of both the high tunnel and field. Transplants were installed on June 4 in a single row with 18 inches between plants.

### Pepper Irrigation and Fertilization

Peppers were irrigated two times per week for approximately 70 minutes. In the event of rain in the field, the irrigation events in those replications were temporarily reduced while the high tunnel irrigation was maintained. Temperatures above 90° F for multiple days warranted an additional 30 minutes of watering per irrigation event. Peppers were fertigated twice during the growing season (June 29 and August 4) with Nature's Source 10-4-3 Fertilizer using a Dosatron Injector set at 1:200. Lines were open for 4.5 hours for each fertilization event.

### Growing Season Data Collection

Weed counts and biomass of each plot, pepper plant health metrics, and soil moisture and temperature were measured at regular intervals throughout the growing season. To collect weeds, two 25 by 25 centimeter PVC quadrants were thrown randomly onto each mulch plot. Weeds within the quadrant were separated into grass and broadleaf, counted and subsequently dried and weighed. Mulch plots were either hand-weeded (C, LF, PS, RW, ST, WT) or cultivated with a stirrup hoe (BG, PM) following data collection. Weed data were collected on July 3, July 17, August 6, and August 22. Plant health metrics included measuring the height, width, and average SPAD reading of the two middle plants in each mulch treatment. These data were taken on July 4, August 4, August 28, and September 26. Soil moisture and temperature were monitored via HOBO soil probes set at 30 minute intervals between sensor readings. These data were collected every two weeks throughout the growing season.

### Pepper Harvest Data Collection

Peppers of either variety were harvested from three central plants in each mulch plot on a weekly basis between July-October. Jupiter Green peppers were harvested when their size exceeded approximately two inches in diameter. Orange Blaze peppers were harvested when their outer color had turned approximately 80% orange. Total count and weight of both marketable and unmarketable fruit from each mulch plot were collected separately. Unmarketable fruit included those with sunscald, blossom end rot, insect damage, other biotic diseases, less than two inch diameter or were severely misshapen.

### Statistical Analysis

Analysis of variance (ANOVA) and mean separation were conducted using the GLIMMIX procedure in SAS (version 9.4; SAS Institute, Cary, NC). Location (field or high tunnel) and mulch treatment (n = 8) were fixed effects to test for main effects and interactions for all pepper yield, pepper biomass, pepper width x height, and pepper SPAD responses. Replication (n = 2) and all interactions with fixed effects were considered random terms in the linear model. An interaction between location and mulch treatments was found for on round of SPAD readings, and data was further analyzed as mulch treatments within each location. To account for field variability while avoiding type II errors, all treatment means were separated using the unrestricted least significant difference procedure ($\alpha = 0.05$).

Repeated measures analysis was used with the MIXED procedure in SAS to detect differences among grass and broadleaf weed biomass and counts across four sampling dates. Least square means (LSM) ($\alpha = 0.05$) were analyzed using "PDIFF" to detect differences. If there were interactions between the mulch treatment and sampling date, the LSMs were calculated for all mulch x date combinations with lowercase letters reflecting differences among mulch treatments and uppercase letters representing differences among sampling dates.

### Microbiome Data Collection and Analysis

BG, LF, RW and ST plots in the high tunnel were selected for microbiome analysis. To collect soil samples, three 25 by 25 centimeter PVC quadrants were thrown randomly onto each plot and soil at a depth of 6 inches was collected into sterile bags. The three biological replicates were pooled for each plot. Samples were kept on ice before undergoing DNA extraction utilizing the Qiagen DNeasy PowerSoil Pro Kit according to the manufacturer's instructions. Three technical replicates of each sample were extracted and DNA quality and concentration were assessed with Nanodrop. Samples were sent to the SDSU Genomic Sequencing Facility (Brookings, SD) for full length 16S rRNA gene PCR and sequencing utilizing ONT long-read. Demultiplexed raw reads were trimmed, quality filtered, and clustered into 97% identity OTUs and were taxonomically classified using the NCBI RefSeq database. The resulting OTU table and metadata were imported into MicrobiomeAnalyst to analyze taxonomic abundance and alpha diversity according to established protocol (Chong et al., 2020).

## Results

### Weed Counts and Biomass

Grass weed counts and average biomass were found to be different among mulch treatments across the growing season. C, LF, RW, ST and WT had the least amount of grass weeds for the first three weed data collection events (Table 2). PM and PS were found to have relatively similar grass weed counts to BG across the season. This trend is also reflected in the biomass data, as C, LF, RW, ST and WT had lower average grass weed biomass compared to BG (Figure 3). Broadleaf weed counts and biomass were also found to differ among mulch treatments across the season. C, LF, RW, ST and WT had fewer broadleaf weeds for the first two weed data collection events and remained consistently low throughout the growing season (Table 3). Furthermore, the broadleaf weed biomass of C, LF, ST and WT mulch types were lower than BG and PS (Figure 4).

| Grass weed count (no./square foot) | | | | |
|---|---|---|---|---|
| **Mulch** | **July 3** | **July 17** | **Aug 6** | **Aug 22** |
| BG | 52 aA | 17 aB | 7 aC | 2 aD |
| C | 3 bA | 1 bA | 0 bA | 0 bA |
| LF | 4 bA | 1 bA | 0 bA | 0 bA |
| PM | 69 aA | 20 aB | 2 bC | 2 abC |
| PS | 57 aA | 10 abB | 3 bC | 1 abC |
| RW | 10 bA | 1 bA | 1 bA | 1 abA |
| ST | 10 bA | 6 bA | 1 bA | 1 abA |
| WT | 3 bA | 0 bA | 1 bA | 0 bA |

Table 2. Differences in grass weed count among mulch types. No differences were detected between the high tunnel and field, so values here reflect four replications of each mulch type. Lowercase letters indicate differences within columns and uppercase letters indicates differences within rows. BG=Bare Ground; C=Cardboard; LF=Landscape Fabric; PM=Wool Pellets Mixed; PS= Wool Pellets Surface; RW=Raw Wool; ST= Straw; WT= White Tarp

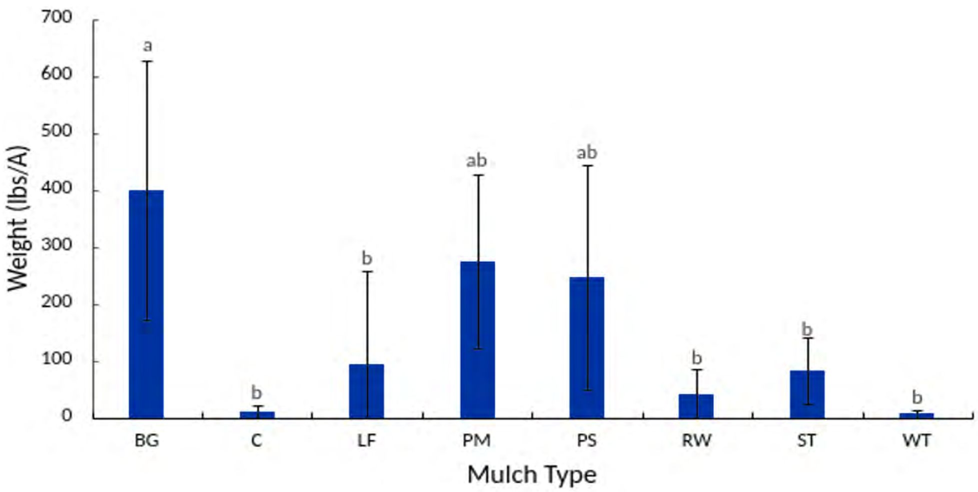


Figure 3. Differences in average grass weed biomass among mulch types. No differences were detected between the high tunnel and field, so values here reflect four replications of each mulch type. BG=Bare Ground; C=Cardboard; LF=Landscape Fabric; PM=Wool Pellets Mixed; PS= Wool Pellets Surface; RW=Raw Wool; ST= Straw; WT= White Tarp

| Broadleaf weed count (no./square foot) | | | | |
|---|---|---|---|---|
| **Mulch** | **July 3** | **July 17** | **Aug 6** | **Aug 22** |
| BG | 16 bA | 8 abB | 4 aB | 5 aB |
| C | 2 cA | 1 bA | 0 bA | 0 bA |
| LF | 3 cA | 1 bA | 0 abA | 0 bA |
| PM | 34 aA | 11 aB | 3 abC | 4 aC |
| PS | 22 bA | 4 abB | 3 abB | 4 aB |
| RW | 3 cA | 1 bA | 2 abA | 1 bA |
| ST | 2 cA | 1 bA | 2 abA | 1 abA |
| WT | 1 cA | 0 bA | 0 abA | 0 bA |

Table 3. Differences in broadleaf weed count among mulch types. No differences were detected between the high tunnel and field, so values here reflect four replications of each mulch type. Lowercase letters indicate differences within columns and uppercase letters indicates differences within rows. BG=Bare Ground; C=Cardboard; LF=Landscape Fabric; PM=Wool Pellets Mixed; PS= Wool Pellets Surface; RW=Raw Wool; ST= Straw; WT= White Tarp

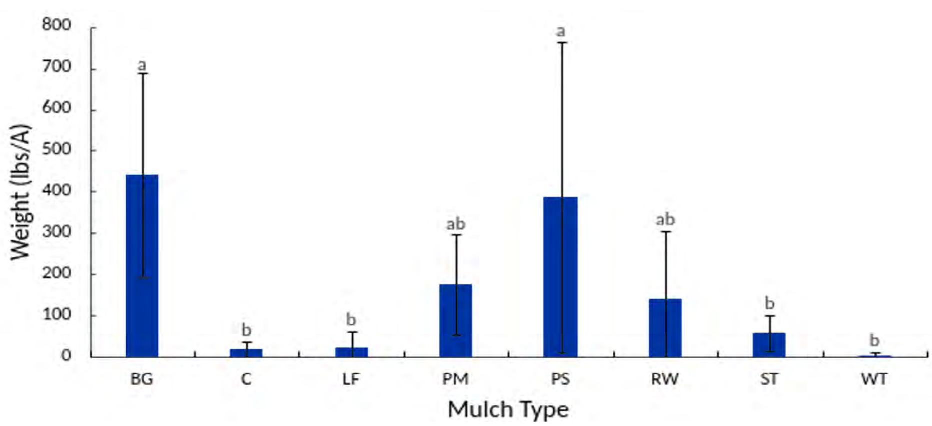


Figure 4. Differences in average broadleaf weed biomass among mulch types. No differences were detected between the high tunnel and field, so values here reflect four replications of each mulch type. BG=Bare Ground; C=Cardboard; LF=Landscape Fabric; PM=Wool Pellets Mixed; PS= Wool Pellets Surface; RW=Raw Wool; ST= Straw; WT= White Tarp

## Pepper Plant Growth

Height and width of pepper plants did not vary much between mulch types across the season (Table 4,5). LF and WT peppers were found to be taller than PM in the third data collection event, and WT peppers continued to be taller than PS into the final data collection event. Additionally, RW and LF plants were wider than PM plants for the second data collection event and WT plants were wider than PS plants at the final data collection event. SPAD values were found to differ across mulch treatments in the field at the end of the season (Table 6). Particularly, LF and PM plants had higher SPAD readings compared to C (p=0.043).

| Plant Height (in) | | | | |
|---|---|---|---|---|
| **Mulch** | **Jul 4** | **Aug 4** | **Aug 28** | **Sept 26** |
| BG | 10.43 | 14.72 | 17.52 ab | 19.09 ab |
| C | 9.79 | 16.44 | 18.6 ab | 19.98 ab |
| LF | 11.17 | 16.68 | 19.6 a | 19.69 ab |
| PM | 10.48 | 15.16 | 15.3 b | 17.62 ab |
| PS | 10.88 | 15.75 | 16.5 ab | 16.83 b |
| RW | 10.93 | 17.86 | 18.46 ab | 19.09 ab |
| ST | 11.27 | 17.52 | 17.37 ab | 19.1 ab |
| WT | 11.32 | 17.12 | 19.73 a | 21.26 a |
| *p-value* | *0.831* | *0.343* | *0.21* | *0.42* |

Table 4. Differences in average plant height among mulch types across the growing season. No differences were detected between the high tunnel and field, so values here reflect four replications of each mulch type. Lowercase letters indicate differences within columns. BG=Bare Ground; C=Cardboard; LF=Landscape Fabric; PM=Wool Pellets Mixed; PS= Wool Pellets Surface; RW=Raw Wool; ST= Straw; WT= White Tarp

| Plant Width (in) | | | | |
|---|---|---|---|---|
| **Mulch** | **Jul 4** | **Aug 4** | **Aug 28** | **Sept 26** |
| BG | 9.05 | 14.42 ab | 22.25 | 19.09 ab |
| C | 9.60 | 16.98 ab | 23.38 | 19.98 ab |
| LF | 9.01 | 18.51 a | 24.11 | 19.69 ab |
| PM | 9.50 | 13.44 b | 20.23 | 17.62 ab |
| PS | 9.01 | 15.5 ab | 21.55 | 16.83 b |
| RW | 9.45 | 18.95 a | 24.36 | 19.1 ab |
| ST | 8.81 | 15.95 ab | 23.23 | 19.1 ab |
| WT | 9.06 | 18.26 ab | 20.57 | 21.26 a |
| *p-value* | *0.895* | *0.23* | *0.351* | *0.518* |

Table 5. Differences in average plant width among mulch types across the growing season. No differences were detected between the high tunnel and field, so values here reflect four replications of each mulch type. Lowercase letters indicate differences within columns. BG=Bare Ground; C=Cardboard; LF=Landscape Fabric; PM=Wool Pellets Mixed; PS= Wool Pellets Surface; RW=Raw Wool; ST= Straw; WT= White Tarp

| SPAD Values | | | |
|---|---|---|---|
| **Mulch** | **Jul 4** | **Sept 26** | |
| | | **HT** | **FD** |
| BG | 67.90 | 67.88 | 64.68 abc |
| C | 64.05 | 71.90 | 57.93 c |
| LF | 68.60 | 70.88 | 69.03 a |
| PM | 62.55 | 71.05 | 70.88 a |
| PS | 69.28 | 70.43 | 63.43 abc |
| RW | 71.00 | 70.00 | 67.38 abc |
| ST | 67.74 | 69.40 | 60.15 abc |
| WT | 72.33 | 73.42 | 61.08 abc |
| *p-value* | *0.059* | *0.829* | *0.043* |

Table 6. Differences in average SPAD readings among mulch types early in the season (July 4) and late in the season (September 26). Lowercase letters indicate differences within columns. BG=Bare Ground; C=Cardboard; LF=Landscape Fabric; PM=Wool Pellets Mixed; PS= Wool Pellets Surface; RW=Raw Wool; ST= Straw; WT= White Tarp

### Soil Temperature and Water Content

Soil temperature varied among mulch treatments most significantly during the months of June and July but no differences were noted in September and October (Table 7). C, RW, and ST had cooler soil temperatures compared to the other mulch treatments in June (p=0.004), whereas in July it is noted that C, RW, and ST were cooler than BG, LF, PM and PS (p=0.005). In addition to soil temperature, soil water content also differed among mulch treatments but only for the months of July and August (Table 8). PS had lower water content than ST in both months.

| Mulch | June | July | Aug. | Sept. | Oct. |
|---|---|---|---|---|---|
| BG | 71 a | 78 a | 75 a | 69 | 70 |
| C | 68 b | 74 c | 73 c | 69 | 68 |
| LF | 71 a | 78 a | 75 ab | 69 | 69 |
| PM | 71 a | 78 a | 74 abc | 69 | 69 |
| PS | 71 a | 78 a | 75 ab | 68 | 69 |
| RW | 68 b | 74 bc | 73 abc | 68 | 68 |
| ST | 67 b | 73 c | 72 c | 68 | 67 |
| WT | 70 a | 77 ab | 73 abc | 68 | 68 |
| *p-value* | *0.004* | *0.005* | *0.104* | *0.682* | *0.682* |

Table 7. Differences in average, monthly soil temperature (°F) among mulch treatments. No differences were detected between the high tunnel and field, so values here reflect four replications of each mulch type. Lowercase letters indicate differences within columns. BG=Bare Ground; C=Cardboard; LF=Landscape Fabric; PM=Wool Pellets Mixed; PS= Wool Pellets Surface; RW=Raw Wool; ST= Straw; WT= White Tarp

| Mulch | June | July | Aug. | Sept. | Oct. |
|---|---|---|---|---|---|
| BG | 0.28 | 0.24 ab | 0.23 ab | 0.21 | 0.21 |
| C | 0.28 | 0.25 ab | 0.21 ab | 0.20 | 0.10 |
| LF | 0.26 | 0.23 ab | 0.20 ab | 0.19 | 0.19 |
| PM | 0.28 | 0.27 ab | 0.25 ab | 0.23 | 0.23 |
| PS | 0.26 | 0.22 b | 0.20 b | 0.18 | 0.18 |
| RW | 0.28 | 0.28 ab | 0.23 ab | 0.21 | 0.21 |
| ST | 0.29 | 0.30 a | 0.28 a | 0.24 | 0.24 |
| WT | 0.28 | 0.25 ab | 0.22 ab | 0.22 | 0.22 |
| *p-value* | *0.95* | *0.37* | *0.38* | *0.68* | *0.68* |

Table 8. Differences in average, monthly water content (ft3/ft3) of soil among mulch treatments. No differences were detected between the high tunnel and field, so values here reflect four replications of each mulch type. Lowercase letters indicate differences within columns. BG= Bare Ground; C=Cardboard; LF=Landscape Fabric; PM=Wool Pellets Mixed; PS= Wool Pellets Surface; RW=Raw Wool; ST= Straw; WT= White Tarp

### Pepper Yield

The number of marketable fruit per plot varied slightly among the mulch types tested (Table 9). WT yielded more peppers than ST, but the weight of harvest per plot did not differ significantly. Additionally, no differences were noted in the number or weight of unmarketable fruit.

| Mulch | Marketable | | Unmarketable | |
|---|---|---|---|---|
| | Count | Weight (lbs) | Count | Weight (lbs) |
| BG | 10 ab | 7 | 4 | 0.35 |
| C | 12 ab | 8.5 | 5 | 0.6 |
| LF | 13 ab | 10 | 6 | 0.3 |
| PM | 9 ab | 10 | 5 | 0.32 |
| PS | 10 ab | 7.5 | 4 | 0.38 |
| RW | 12 ab | 13 | 4 | 0.57 |
| ST | 8 b | 7.25 | 3 | 0.48 |
| WT | 15 a | 12.5 | 5 | 0.69 |
| *p-value* | *0.267* | *0.629* | *0.58* | *0.385* |

Table 9. Differences in average count and weight of marketable and unmarketable pepper harvest among mulch types. No differences were detected between the high tunnel and field or between varieties, so values here reflect four replications of each mulch type. Lowercase letters indicate differences within columns. BG=Bare Ground; C=Cardboard; LF=Landscape Fabric; PM=Wool Pellets Mixed; PS= Wool Pellets Surface; RW=Raw Wool; ST= Straw; WT= White Tarp

## Microbiome

Bacterial taxonomic abundances across the mulch types tested did not vary significantly (Figure 5). Actinomycetota and Pseudomonadota were the most dominant taxa detected across all mulch types tested. Alpha diversity did not vary significantly between mulch types tested (Figure 6).

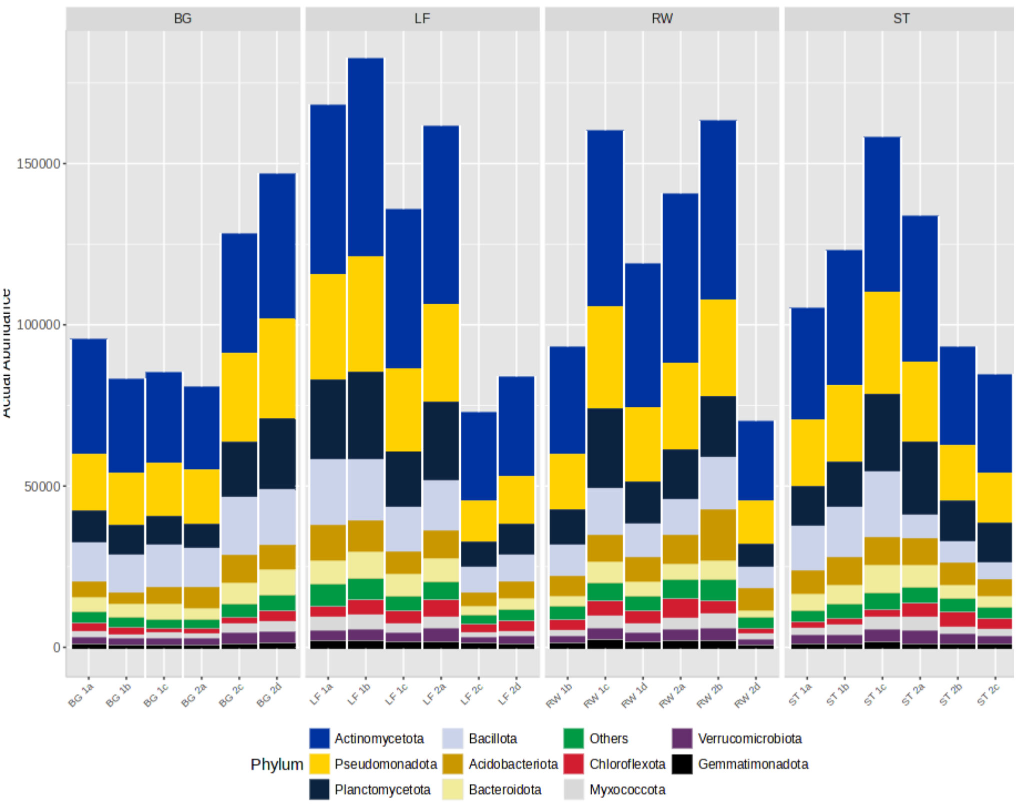


Figure 5. Taxonomic abundances found in each mulch type. Two biological and six technical replicates were used for each mulch type. BG=Bare Ground; LF=Landscape Fabric; RW=Raw Wool; ST=Straw.

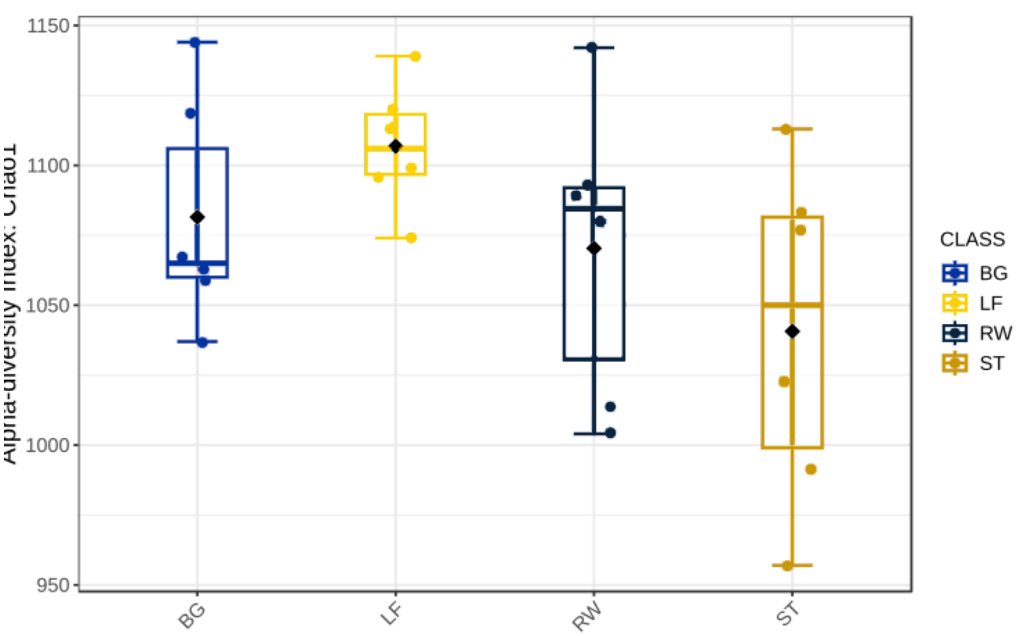


Figure 6. Differences in alpha diversity (Chao1) among mulch types. Two biological and six technical replicates were used for each mulch type. BG=Bare Ground; LF=Landscape Fabric; RW=Raw Wool; ST=Straw.

## Discussion

This study was conducted over one growing season with limited replications. While the conclusions drawn from these data are certainly suggestive, more substantial investigation is needed. Nevertheless, Raw Wool mulch appears to be an effective weed management strategy, especially against grass weeds, as it performed similarly to some of the more occlusive mulch types like Landscape Fabric and White Tarp. The distinct advantage of Raw Wool over these types, however, was the maintenance of cooler soil temperature, especially over the months of June and July.

The performance of Raw Wool differed significantly to Pellets Mixed or Pellets Surface. When considering weed biomass and count, Pellets Mixed or Surface behaved more similarly to the Bare Ground control compared to the Raw Wool. This trend is also apparent in the average monthly soil temperatures, where elevated temperatures were associated with the Bare Ground and Pellets mulch types. Between the two Pellets mulch types themselves, it appears that either mixing them into the soil or leaving them on the surface didn't significantly change their performance of any parameter.

Despite the differences found in weed suppression and soil temperature, there were only small differences in pepper yield. It was found that White Tarp produced a greater number of peppers than Straw, but further replication is warranted to substantiate this observation. In addition to yield, this first year study did not find any differences in bacterial alpha diversity across the mulch types tested.

## Conclusion

From this preliminary study, Raw Wool appears to be an effective weed management strategy that may help with reducing soil temperature. Multi-seasonal investigation may help further delineate any differences in pepper yield based on these observations.

## Acknowledgments

We would like to thank lab members, Extension colleagues, local farmers, the South Dakota Specialty Producers Association, the SDSU Extension Master Gardener Volunteer Program, and the SD Natural Resources Conservation Service who contributed time, insights, and materials to this project. Special thanks go to Malisa Niles, Jaelyn Whaley, Robin Buterbaugh, Patty DeZeeuw, Shannon Mutschelknaus, Gabby Thooft, Kristina Harms, and Karissa Bickett.

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P-00396