Evaluation of the impact of mulch on crop productivity in Florida 91 tomato and pepper varieties

by

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Abstract

In northeastern Kansas, USA, agricultural practices are challenged by environmental factors, which can impact crop yields and farming sustainability. Primary factors for stress in crop growth include drought, extreme temperatures, frost and freeze events, flooding, wind stress, pests and diseases, soil degradation and erosion. Agricultural practices in northern Kansas are subject to environmental, physical, or biological stress. Crop growers must negotiate these issues when implementing conservation methods (e.g., water conservation and retention, crop rotation, resilient varieties) to aid in crop production. Understanding the stress experienced by plants, organisms, or their system is important for addressing challenges and successfully adapting solutions through thoughtful planning, flexibility, and innovation.

I investigated the total weight and total number of fruit of two crop types: Florida 91 tomatoes and two varieties of sweet peppers, California Wonder and Outsider. My objective was to compare crop performance in terms of total weight per plant and total number of fruits under outdoor environmental growing conditions. My experimental approach utilized a randomized complete block design with four replications for each variety. I tested Florida 91 tomato yield production under three mulch varieties of hemp hurd, straw, and plastic material compared to a bare soil plot. The pepper study compared two sweet pepper varieties grown under hemp hurd.

I collected data over an 18-week study in the 2023 growing season and evaluated individual plants for total weight and total number per soil cover at weekly interval harvest. There was no significant difference in weight between tomato treatments and in all pepper varieties. Nonetheless, Florida 91 tomatoes are more suited for high-yield production, and sweet peppers excelled, under mulched soil coverage. I found the soil cover positively affected tomato weight and production consistency throughout the growth season. My results can provide

valuable insights into agricultural practices aimed at optimizing yield and crop management for both tomatoes and sweet peppers through sustainable conservation methods.

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Dedication

I would like to dedicate this to my grandparents.

Introduction

The human population is approximately 8 billion and predicted to reach 10 billion by 2050 (Searchinger et al., 2013; Searchinger et al., 2019). The population increase will likely result in increased food consumption, production, and transportation; as well as environmental pressures on consumption levels, production trends, and patterns (Capone et al., 2014). In short, as the global population increases, there is an increasing demand for sustainable food systems. In 1996, the World Food Summit determined food security as, "food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (World Food Summit, 1996). Food consumption is influenced by several factors, which can be categorized into food availability, food accessibility, and food choice. These factors are influenced by a variety of elements such as geography, demography, disposable income, socioeconomic status, urbanization, globalization, religion, culture, marketing, and consumer attitude (Capone et at., 2014). To mitigate negative impacts of these factors and optimize the food system; agricultural research focuses on developing stable and efficient methods for positive outcomes in quality production, availability, and accessibility of crops (Massimi et al., 2023).

Exacerbated by climate change, agricultural crop production yields are predicted to decrease (Kallenbach et al., 2019). Among the key challenges facing agriculture are drought, high evaporation rates, and the temporal distribution of precipitation, all of which contribute to water scarcity, one of the primary factors limiting crop production and agricultural development (El-Beltagi et al., 2022). The rising global population and increasing demand further intensify the pressure on these already strained resources (Capone et al., 2014; El-Beltagi et al., 2022). As water availability declines, it becomes crucial to enhance soil moisture through various approaches to mitigate these challenges (El-Beltagi et al., 2022). To prevent a reduction in crop yield production, agroecosystem management using nature-based solutions can effectively balance environmental sustainability and economic viability. This approach offers practical strategies to address both concerns (Rodrigo-Comino et al., 2020).

Sustainable agricultural goals are driven by the focus on increasing yields while reducing seasonal inputs and operational costs (Lahmar et al., 2012). This approach supports a low-input system designed to minimize production inputs and operation expenses, while prioritizing quality production (Sosibo et al., 2022). Methods such as minimum or low-tillage practices, soil cover maintenance, and crop rotation are key components of this approach (Lahmar et al., 2012). Additionally, agricultural practices incorporating an understanding of the local ecosystem, leveraging available technology, and a focus on creating a sustainable food system can enhance food and water security (Rodrigo-Comino et al., 2020). Proper implementation of agricultural practices, considering local natural resources, helps lower environmental impact, reduces erosion, and avoid hazardous effects by promoting soil management improvements and preventing economic deterioration (Karandish, 2021; Peterson et al., 2003). Soil health is determined by their soil biological properties (Sainju et al., 2022). Management of soil health can be practiced through traditional sustainable cover crop use, also known as; mulch, catch crops, forage crops, green manure, and living mulch (Bergtold et al., 2017; Çerçioğlu et al., 2025).

Additionally, sustainable conservation methods can include a variety of soil cover practices. Covering the soil surface around garden plants with mulch improves soil quality and water retention, while also reducing the accumulation of fertilizer and pesticides (Sosibo et al., 2022; Yang et al., 2022). Beyond water and soil benefits, mulch helps regulate soil temperature, providing more stable conditions in which support plant root development and growth (Deng et al., 2019; Haapala et al., 2015; Ren et al., 2016). These soil health improvements are further enhanced by increased microbial activity, reduction of weeds and invasive plants, and better crop production. (El-Beltagi et al., 2022). Studies on soil water retention, particularly those taking atmospheric data, such as climate conditions, highlight how mulch applications can improve water retention under specific environmental circumstances (Findeling and De Louvigny, 2003). These findings stress the importance of selecting the appropriate mulch materials based on regional environmental factors to maximize effectiveness.

Following the importance of selecting mulch materials based on regional atmospheric conditions, mulch practices can promote sustainable agriculture by enhancing water-use efficiency and moisture retention (Ren et al., 2016). Improved water retention facilitates deeper root distribution, which in turn strengthens nutrient extraction and boosts microbial biomass carbon (Ren et al., 2016). Additionally, the increase in organic matter within the soil profile provides energy to microbes, further supporting root development (Rasmussen and Collins, 1991). Mulch applications also have the potential to increase crop yield, reduce irrigation needs, and lower overall agricultural water consumption (Chen et al., 2019; Haapala et al., 2015).

By enhancing water efficiency, retention, and storage, mulch significantly reduces the demand for irrigation (Haapala et al., 2015; Sosibo et al., 2022). Furthermore, mulch helps retain moisture in the soil, where nutrients, water content, and temperature work together to improve organic matter and carbon processes (Rasmussen and Collins, 1991). It also delays accumulation of soil salinity in the upper layers (Chen et al., 2019). In addition to soil coverage, mulch enhances weed and pest control, reducing the need for herbicides or hand-weeding (Haapala et al., 2015; Anzalone et al., 2010). Another advantage is reduction in labor requirements, along with the improvements to soil structure, porosity, and deep drainage through increased infiltration and soil water storage (Anzalone et al., 2010; Lahmar et al., 2012; Sosibo et al., 2022; Yang et al., 2022). Proven to improve semi-arid environments, mulching practices conserve soil moisture, modify soil physical conditions, control weed growth, and retain soil moisture (Chakraborty et al., 2008). While mulch is effective in improving moisture retention in the soil, the effects of growth and survival depend on the plant species. The impact can vary across different types of plants (Fehmi and Kong, 2012).

As various soil coverage materials offer numerous benefits, the effects of plastic mulch have been studied in regions of China, where it has been found to influence soil conditions under irrigation and precipitation (Ren et al., 2016; Wu et al., 2019). A study in North China plains (Chen et al., 2019) demonstrated when plastic mulch is combined with irrigation can improve removal of salt from the soil profile. Plastic used as a soil cover has advantages in short-term benefits of fewer weed problems, reduced soil water evaporation, earlier and higher yields (Brodhagen et al., 2017; Steinmetz et al., 2016). Also included in advantages for plastic mulches, in an economic system, plastic mulch has a competitive advantage (Cirujeda et al., 2012).

However, unlike biodegradable mulches, plastic mulch poses environmental challenges (Steinmetz et al., 2016). It is not biodegradable, can only be used once, and eventually breaks down into microplastics through polyethylene degradation, leading to residual film pollution (Deng et al., 2019; Oliveira et al., 2020). Polyethylene residues include chemical compounds such as phthalate esters, di-ethylhexyl phthalate, aldehydes, and ketones (Oliveira et al., 2020). Polyethylene residues include chemical compounds such as phthalate esters and aldehydes, which have several adverse environmental impacts and can negatively affect the postharvest process (Cirujeda et al., 2012). After the one-time use, plastic mulch is required to be removed and disposed at the end of growing season (Oliveira et al., 2020). Environmental issues associated with plastic mulch include blockage of soil and plant water infiltration systems, impaired soil percolation, and disruption of water and nutrient movement (Oliveira et al., 2020; Wu et al., 2019). Additionally, negative effects of plastic mulch are difficult in irrigation, soil profile germination and root growth, as well as lead to accumulation of harmful substances from polyethylene degradation (Oliveira et al., 2020; Wu et al., 2019).

In contrast to plastic mulch, organic mulch offers a sustainable alternative, as the material is biodegradable and enhances soil health. Organic mulch promotes environmental benefits through biodegradation (Oliveira et al., 2020). Organic mulches, such as compost, straw, or wood chips, provide numerous benefits without environmental concerns associated with plastic. One study found their participants were more likely to pay an increase of $0.12/pound (USD) of strawberries grown with biodegradable mulch when they were informed about the benefits of biodegradable mulch (Chen et al., 2019). Given the challenges of water scarcity and frequent droughts in many regions, the strategic use of mulch can play a crucial role in conserving and improving soil resilience. In areas where water is scarce, implementing strategies to enhance water use efficiency is found to be both effective and environmentally friendly, while also supporting sustainable agricultural practices (Deng et al., 2019).

Organic mulch offers numerous benefits, such as improving soil structure, enhancing microbial growth, and promoting healthy soil ecosystems (Kader et al., 2017). Among the various organic mulch options, hemp hurd, derived from the inner core of hemp plant stalk, has unique and highly mentionable properties (Frassinetti et al., 2018). This lightweight material is soft, fibrous, strong, and sturdy (Jemison, 2024; Visković et al., 2023). Hemp hurd has advantages in agriculture, including improved soil moisture retention over other mulch types, wind resistance from displacement, soil insulation from temperature extremes, weed suppression, prevention of seed germination, and support of soil life as it breaks down naturally (Gramig et al., 2021; Visković et al., 2023).

The addition of soil cover amendments to enhance crop productivity through soil moisture retention is an important practice, particularly in drought-prone regions (Yang et al., 2022). On a global scale, regions experiencing frequent droughts, water limitations, and a reduction in available water resources are facing significant challenges in applying conservation practices (Cano et al., 2018). Semi-arid areas, particularly in western North America, represent large agricultural zones vulnerable to these constraints. Intensive agricultural practices in these regions contribute to soil degradation, making it even more susceptible to wind erosion, a common issue in semi-arid and temperate climates (Sosibo et al., 2022). In response, conservation agriculture practices have been increasingly adopted by farmers worldwide, as they face growing pressures to meet crop requirements in vulnerable environments. Among these practices, the use of soil cover over garden crops is widely used to conserve water, retain soil moisture, improve water efficiency, modify physical soil characteristics, and control weed growth (Deng et al., 2019; Stelli et al., 2018).

Studies on agriculture in semi-arid climate zones worldwide have shown soil types vary significantly (Ren et al., 2016; Findeling and De Louvigny, 2003; Sosibo et al., 2022). Variations in soil composition play a critical role in determining agricultural productivity, water retention capabilities, and the success of crops (Fehmi and Kong, 2012). In semi-arid regions, where water scarcity and limited rainfall often limit agricultural practices, understanding the diversity in soil type is crucial for optimizing farming practices (Fehmi and Kong, 2012). Understanding soil composition differences, researchers can develop tailored strategies for soil management, irrigation practices and crop selection (Fehmi and Kong, 2012). These differences in soil composition influence how amendments impact crop performance, making it essential to understand the local soil type in order to tailor agricultural practices and optimize soil cover use.

In addition to soil management, pest control is another aspect to optimize crop yield (Massimi et al., 2023). One traditional method to manage pests is to apply trap crops, which is used to deter pests from the cover crop (Parvais and Khan, 2024). The trap crop attracts pests, thereby diverting their attention from the cover crop (Kumar et al., 2012). This method also facilitates for easy identification and removal of pests' eggs and larvae and has been found to be less destructive on the cover crops (Parvais and Khan, 2024). Kumar et al. (2012) suggest using marigold as a trap crop in tomato production, recommending a 5:1 ratio of marigold to tomato plants to combat the tomato fruit borer. They concluded this method could be an effective adaptation for pest management (Kumar et al., 2012).

Included in plant management practices, structural cultivation management is a method to grow plants vertically through physical structures to aid in upright growth, supporting plants with a trellis system or stakes (Dipple et al., 2022). The purpose for upright plant management is to provide physical support in vertical growth, particularly those with weaker stems or plants leaning from weight growth (Jakpa and Hardi, 2021). Physical structures are used for crops like tomatoes and pepper plants, to aid in upright growth, (Ogundare et al., 2015; Jakpa and Hardi, 2021). The upright growth provides ease of sun rays to soil, increasing temperatures efficiently in the soil (Ogundare et al., 2015). This system promotes less contact with the soil, and circulates air freely (Dipple et al., 2022). Addition of plant management with the use of mulch with vertical support has proven to increase crop yields (Ogundare et al., 2015).

Building on the broader challenges faced by drought-prone regions, western Kansas exemplifies a critical area of concern due to its ongoing water scarcity, reliance on groundwater, and the rapid depletion of Ogallala Aquifer (OA) (Anandhi and Kannan, 2018). This region is characterized by low annual rainfall, high evaporation, and frequent droughts. The declining levels of the OA highlight the urgent need for sustainable practices focused on improving water retention (Cano et al., 2018). While my study is based in northeastern Kansas, understanding the water challenges in neighboring regions such as western Kansas provide valuable context for the broader issues surrounding groundwater sustainability in this part of the country.

Despite the critical need for effective water retention practices, there remains uncertainty regarding the best choice of mulch material to improve crop yields under specific environmental conditions throughout the growing season. In-depth studies are necessary to identify the most effective mulch materials for drought-prone climates and varying soil types within the United States. By improving agricultural techniques and addressing environmental, economic, and social challenges, research aims to enhance food security and reduce barriers of access to sufficient and safe crops.

My study focuses on testing various mulch types to determine their effects on crop growth and productivity. Specifically, I examined three mulch types; hemp hurd, straw mulch, and plastic compared to a bare soil control, applied over Florida 91 tomato variety to evaluate their impact on performance, aiming to determine suitable mulch material for improving performance. The hypothesis for the tomato trial is soil cover will significantly differ from bare soil control in terms of total weight and total number of fruits. Additionally, I conducted a comparative study on two sweet pepper varieties – California Wonder and Outsider – observing growth under a single mulch type, hemp hurd, to further explore its effects on crop productivity.

The use of hemp hurd on all pepper plants is used as I am testing for significant difference between California Wonder and Outsider. The pepper study hypothesis is California Wonder will have a significant difference from Outsider. This comprehensive approach aims to identify the most effective mulch materials for enhancing agricultural output in drought-prone climates in northeastern Kansas.

Methods

I conducted this study during the summer growth season of 2023 at the Willow Lake Student Farm (WLSF) of Kansas State University (KSU), located in Manhattan, Kansas, USA. The WLSF is positioned at a latitude of 39.24983° and a longitude of -96.57244°, within a humid continental climate (Beck et al., 2023; U.S. Department of Agriculture, Natural Resources Conservation service, n.d.). The WLSF is characterized with Eudora silt loam, rarely flooded soil (U.S. Department of Agriculture, Natural Resources Conservation service, n.d.). The farm receives an annual precipitation of 0.87 m and has an average annual temperature of 12.1°C (National Centers for Environmental Information, n.d.).

The mean temperature during the growing season of the research study was 24°C, and the total rainfall for the period was 265.12 mm. Potential pests in the study area included: gophers (*Geomys bursarius),* raccoons (*Procyon lotor*), tomato hornworms (*Manduca quinquemaculata*), tobacco hornworms (*Manduca sexta*), and both brown (*Euschistus servus*) and green (*Chinavia halaris*) stink bugs (Griffin and Khan, 2021). The plot treatments were designed with consideration for rows, placement, and spacing (Fig. 1) modified from Google Earth (2023) to highlight the plot layout.

For the tomato experimental design, I used a randomized complete block design (RCBD) to evaluate three mulch types and a control across four rows of the plot. I assigned one of the three mulch treatments, hemp hurd, straw mulch, and plastic fabric, along with a bare soil control to each row, resulting in 4 replications of the soil cover types. Each tomato plot contained 4 plants spaced 1.2 meters apart. Each row of the plot measured 28 meters in length and 1 meter in width. With a result of a total of 16 plots, I measured the total area of the tomato experiment at $112m^2$.

For the pepper experimental design, I followed a RCBD for the plot setup, to evaluate pepper productivity grown under hemp hurd. The outdoor field consisted of a single row, 28 meters long and 1 meter wide. Each pepper variety (California Wonder and Outsider) had 4 replications, with 4 plants per replication. A total of 8 plots were applied, each 2.4 meters in length.

The cultivars used in this study were Florida 91 tomatoes and California Wonder sweet peppers, both purchased from Harris Seeds, and Outsider was purchased from Seedway. The tomato study consisted of a control treatment of bare soil, while I acquired three materials as soil cover for my study. I obtained Hemp Hurd, which consists of hemp by-products, received from Prairie Band Ag, Holton, Kansas, USA. Straw Mulch, a natural, organic wheat plant material; was from Ebert Farms, Saint George, Kansas, USA. The Plastic Fabric, a synthetic covering, was purchased from Home Depot.

For plant preparation, I started seeds of Florida 91 tomatoes and both pepper varieties in a greenhouse during the last week of March 2023. I tracked key measurements at weekly intervals from this point onward. During germination, the plants were watered every three days. As seedlings developed to the early vegetative growth stage, I adjusted watering to every other day, providing fertilized water every third day to provide nutrients using the Throckmorton Greenhouse watering supply. To prepare plants for transplanting, I gradually reduced watering as part of the plant hardening process. The study lasted eighteen weeks, during which I monitored plant growth, collected data, and analyzed the results.

For site preparation, I used minimal tillage with a gas-powered tiller prior to transplanting. After seven weeks, once the plants reached the early vegetative growth stage with sufficient height and root development, I transplanted them into an open field. In week eight, I manually applied mulch at a depth of 8 cm. For the tomatoes, mulch was applied as determined by the RCBD. For the peppers, I applied a layer of hemp hurd to the soil surface of the pepper row. I added extra layers of mulch after significant rainfall during the field period.

For the tomato plant maintenance, I implemented a trap crop method using marigold to deter pests from the tomatoes. I placed the marigold trap crops at each end of the tomato rows. I implemented a trellis system to support the growth of the tomato plants, and followed the Florida Weave method (Kelbert et al., 1966). For pepper plant maintenance, I used stakes for each pepper plant stem to aid in upright growth. I used spacer plants, "Yummy Sweet" peppers, to separate every two replications.

I provided supplementary irrigation to the plants during drought conditions when rainfall was insufficient, ensuring adequate moisture for growth. Irrigation was applied manually to tomato and pepper plant stems, with the peppers also receiving additional watering through a soaker hose. The estimated amount of water for tomato plants was 355 ml 3 times per week, and the pepper plants had an estimated supplementary of watering 22.5 gal of water 3 times per week during extreme heat and lack of precipitation. I performed manual weeding between plants and rows in all plots, using tools such as a garden hoe and scuffle hoe, as well as hand removing weeds. Along the edges of the garden plot, I used a gas-powered cultivator to minimize disruption to the soil depth while aiding in additional weed management. No fertilizer, pesticides, or herbicides were used during the outdoor field period.

For tomato data collection, the tomatoes selected for this study had to meet the U.S. Grade A standard outlined by the USDA (Agricultural Marketing Service, 1997). I selected three tomato plants from each plot for harvest in each trial based on ripeness indicators, including color, firmness, and size. This method was adapted from the standard agricultural grading procedures (Agricultural Marketing Service, 1997). This method includes ensuring harvested fruit used for the study is of similar characteristics; mature, well developed, not overripe or soft, and free from damage. For each plot treatment, I recorded the tomatoes weight and number of fruits, removing the stems before recording their weight. I grouped the harvested fruit from plots by soil cover for data analysis. I began harvesting in the twelfth week of this study and continued data collection weekly for six weeks. The final harvest was determined based on a performance-based criterion: when the tomato plants produced fewer than half the number of fruits compared to the initial harvest.

The tomato harvest results were grouped by soil cover type for each observation. The total weight from each row was pooled by soil cover type and the harvest observations were summed for further analysis. I used the total weight and total fruit number for each soil cover type to calculate both the overall production and the average weight and fruit number for each soil cover type. This allowed me to assess the effect of mulch type compared to the control.

The cumulative weight was calculated by summing the weight of tomatoes collected after each observation, starting with Observation 1 through Observation 6. The tomato total weight for each soil cover was then calculated for a complete sum and expressed in kilograms.

The cumulative fruit number was obtained by summing the number of fruits harvested after each observation, from Observation 1 to Observation 6. The total number of fruits for each soil cover was then calculated by summing the fruits from each row. This total was used for further analysis.

I used the total weight (kg), and the number of tomato fruits harvested per soil cover for data analysis. The data was summed and averaged by soil cover type and harvest number to assess the impact of different soil covers on tomato yield during the 2023 harvest period. The average tomato weight (kg) and average number of fruits for each soil cover were calculated based on six harvests per soil cover type. To determine yield efficiency, the specimen to yield ratio was calculated by dividing the average number of fruits by the average weight (kg) for each soil cover.

To visualize how the results were distributed across the four treatments, I created a boxplot for both weight and number of fruits. The boxplot shows the central tendency and variability of weight and number of fruits for each soil cover type, while also identifying any outliers present in the data. An ANOVA test was conducted to determine whether there were statistically significant differences between the mean tomato weight of the four soil cover types. Additionally, an ANOVA test was used to determine whether there are statistically significant differences in tomato number of fruit between the soil cover types.

For the pepper data collection, I harvested from each sweet pepper plants within the plot replication. The peppers harvested in this study had to meet the U.S. Grade No. 1 standard, as outlined by the USDA (Agricultural Marketing Service, 2005). This standard ensures peppers have a uniform color, are firm to the touch, free from wrinkles or blemishes, and show no signs of damage such as cracks or rot. The peppers found within this criterion were harvested and used in this study to maintain consistency of high-quality samples. I recorded data on total weight (kg) and total number of fruits. For each pepper variety, I took three observations of total weight and total number of fruits per plant. To build the structure for statistical testing, each pepper type harvest observations were calculated for statistics. I then analyzed the data to determine any significant differences between weight and number of fruits between the two pepper varieties, using a Welch Two-Sample t-test.

To determine if there is a statistical significance between the means of California Wonder and Outsider, a t-test was found most appropriate through the Welch Two-Sample t-test. In this study of two independent groups, the pepper types of California Wonder and Outsider, the comparison of mean weight and number of fruits between the two groups is appropriate because I am interested in whether the average weight or average number of fruits differs between the two pepper types, which has real-world data, and the variability between groups can differ. The aim of the statistical analysis was to test whether there is a significant difference in weight and number of fruits between the two pepper types, and was used as this test does not assume the two groups have equal variances as well as the normality assumption is more appropriate with a smaller sample size.

Statistical analysis of the experiment data was conducted using an analysis of variance (ANOVA) for the tomato results and a Welch Two-Sample t-test for the pepper results, to identify significant differences between crop trials. From the statistical test results, there is no need to further assess differences, such as the use of the post-hoc test; Duncan's Multiple Range Test (DMRT) to compare the means of all groups to determine where significant differences lie, as there is not enough evidence to suggest significance.

I collected weather data for the outdoor field period, including temperature and precipitation. I gathered daily minimum, average, and maximum temperature values in Celsius (°C). I collected daily precipitation data in millimeters (mm). The weather data, covering the outdoor field period from May 15, 2023, through September 18, 2023, for Manhattan, Kansas, came from the Office of the Kansas State Climatologist in the College of Agriculture. Daily temperature data (Fig. 2) highlight the daily average, minimum, and maximum temperatures (°C). Daily precipitation levels (Fig. 3) are shown a bar chart (mm).

Throughout the study, I observed average temperatures to have exceeded the optimal range for both tomatoes (18.33°C-29.44°C) and peppers (18.33°C-23.89°C). The temperature fluctuations lead to both heat and cold stress. I noted cold stress when temperatures fell below 18.33°C, additionally noting heat stress for tomatoes when temperatures rose above 29.44°C and pepper heat stress when temperatures rose above 23.89°C.

I observed heat stress for tomatoes most in July and August, while peppers experienced heat stress most throughout June, July, and August. Tomatoes experienced heat stress on 66.1% of the days due to maximum temperatures exceeding 29.44°C and on 10.24% of the days due to average temperatures above 29.44°C. Peppers were exposed to heat stress on 93.7% of the days due to maximum temperatures above 23.89°C and 47.24% of the days based on average temperatures above 23.89°C. Cold stress affected both crops on 40.94% of the days when minimum temperatures fell below 18.33°C.

In my study, I observed not only days of high temperatures but also days without measurable precipitation. I recorded precipitation data during the outdoor field study period (Fig. 3). High temperatures with no precipitation indicate dry weather periods, which may have affected plant growth. Several days saw maximum temperatures exceeding 30°C with no recorded precipitation, signaling possible drought conditions. The total precipitation observed during the outdoor field study period was 265.12 mm. Out of the 127 days, 91 were dry, while 36 days recorded measurable rainfall. The highest recorded daily precipitation was 35.81 mm, while the lowest was 0 mm. The bar chart (Fig.3) shows daily rainfall, with noticeable peaks in June and July, the months with the highest levels of precipitation. These rainfall levels could have affected crop growth and water availability. Accounting for these weather patterns, it provided valuable insights into the weather trends, temperature variations, and potential impacts on the growth season of 2023.

Results

The results for the tomato data (Table 1) show the soil cover types, including the weight (kg) and total number of fruits harvested for each observation. The soil cover types data analyzed six observations of weight (kg) and number of fruits across the four soil cover types: Control, Hemp Hurd, Straw Mulch, and Plastic Fabric. Each soil cover type is represented by six observations, with both the total weight (kg) and the total number of fruits harvested. These observations were part of a series of tomato observation harvests, numbered 1 through 6.

The average total weight, average total number, and specimen to yield ratio for each soil cover treatment (Table 2). The average total weight observed in the Hemp Hurd treatment showed the highest average weight (12.19 kg), followed closely by Straw Mulch (11.96 kg), Plastic Fabric (10.18 kg), and control (8.93 kg). Hemp Hurd had the highest average total number (74 fruits), followed by Straw Mulch (67.33 fruits), Plastic Fabric (65.33 fruits), and Control (61.33 fruits). Control had the highest specimen to yield ratio (6.87). Hemp Hurd, Straw Mulch, and Plastic Fabric had ratios of 6.07, 5.63, and 6.42, respectively.

The tomato weight for each soil cover type across six observations, and the total sum of weights for each treatment (Table 3) presents Control had a total weight of 53.55 kg, with individual observations ranging from 1.79 kg to 16.3 kg. Hemp Hurd had the highest total weight of 73.13 kg, with weights ranging from 3.77 kg to 18.69 kg. Straw Mulch treatment had a total weight of 71.73 kg, with individual observations ranging between 2.74 kg to 17.45 kg. Plastic Fabric resulted in a total weight of 61.08 kg, with individual weights ranging from 4.48 kg to 17.93 kg.

The cumulative tomato weight (kg) for each soil cover type (Fig. 4) showing the total weight of tomatoes after each observation. Control shows a steady increase in cumulative weight, with a total sum of 53.33 kg by the final observation. Hemp Hurd exhibits the highest cumulative weight, reaching a total of 73.13 kg at the end. Straw Mulch also shows a progressive increase in weight, reaching a total of 71.73 kg at the end. Plastic Fabric had a moderate increase in cumulative weight, with a final total of 61.08 kg.

The total number of fruits harvested for each soil type across six observations, along with the total sum of fruit numbers harvested (Table 4). Control had a total number of fruits with 368 harvested in the growing season, with individual counts ranging from 18 to 96 total fruits. Hemp Hurd had a total number of fruits of 444, with individual counts ranging from 24 to 109 fruits harvested. Straw Mulch had a total number of fruits of 404, with individual counts ranging from 19 to 94 fruits harvested. Plastic Fabric resulted in a total number of fruits of 392, with individual counts ranging from 26 to 122 fruits harvested.

The cumulative tomato number of fruits for each soil cover type (Figure 5) reflects the total number collected after each observation. Control shows a steady increase in the cumulative fruit numbers, with a total of 368 fruits by the final observation. Hemp Hurd exhibits the highest cumulative fruit numbers, reaching a total of 444 fruits by the end of six harvests. Straw shows a progressive increase in cumulative number of fruits, reaching 404 fruits harvested by Observation 6. Plastic Fabric also shows a steady increase, culminating in a total of 392 fruits harvested.

A statistical summary of tomato weight (Table 5) by soil cover type, including key descriptive statistics such as mean, median, standard deviation, and the range of weights. As well as a statistical summary of tomato total number of fruits harvested (Table 6) by soil cover type, providing an overview of the distribution and spread of total number of fruits harvested for each soil cover type. The tomato weight statistics are presented as a boxplot comparison of tomato weight across the four soil cover types (Figure 6). A boxplot to compare the tomato total number of fruits harvested across the four soil cover types (Figure 7) is used to highlight the distribution, median, and variability of the number of fruits for each treatment.

The results of tomato weight ANOVA test (Table 7) present the tomato weight summary statistics and the results of the ANOVA test, which shows there were no significant differences in tomato weight across the soil cover types (p-value = 0.72). Based on this ANOVA result, the F-statistic for between groups of 0.45 is smaller than the critical F-value of 3.09. The p-value of 0.72 is greater than the significance threshold of 0.05, suggesting there is no statistically significant difference in tomato weight between the different soil cover types. Therefore, we fail to reject the null hypothesis and conclude the soil cover type does not have a significant effect on tomato weight in my study.

The ANOVA results for tomato total number (Table 8) provides the summary statistics and ANOVA result for tomato fruit number across the different soil cover types. The results show there were no significant differences in fruit number between the soil cover types (p-value =

0.93). The tomato total number of fruits ANOVA test result had an F-statistic for between groups of 0.15, which is smaller than the critical F-value of 3.09. The p-value of 0.93 is greater than the significance threshold of 0.05, suggesting there is no statistically significant difference in tomato fruit number between the soil cover types. Therefore, we fail to reject the null hypothesis and conclude the soil cover type does not significantly affect the number of tomatoes in my study.

The pepper data weight (kg) and total number with observation harvest (Table 9). The pepper type California Wonder statistical summary (Table 10) presents a statistical summary for weight (kg) and total number. The pepper type Outsider statistical summary of weight (kg) and number of fruits harvested (Table 11). I created boxplot to illustrate the weight comparison between the two pepper types (Fig. 8). The comparison of two pepper varieties between the number of fruits harvested (Fig. 9) is shown through a boxplot as well.

The Welch Two-Sample T-test result, the mean difference in weight between the two pepper types of California Wonder and Outsider (Table 12) was found to be 4.89 kg and 6.99 kg, respectively. The test yielded a t-statistic of -0.29 with a degree of freedom of 2.88 and a p-value of 0.79, which is greater than the significance level of 0.05. This suggests there is no statistically significant difference in weight between the two peppers.

The mean difference in number of fruits for the two pepper types of California Wonder and Outsider (Table 13) was 30 and 34, respectively. For pepper comparison of fruit number, the Welch Two-Sample t-test produced a t-statistic of -0.11 with degree of freedom of 3.4 and a p-value of 0.92. The calculated p-value is greater than the significance level of 0.05, suggesting there is no significant difference in the number of fruits between the two pepper types.

For the pepper weight, the 95% confidence interval for the difference means was -25.27, 21.05, indicating the true different difference in mean may lie within this range. Similarly, for the pepper number of fruits, the confidence interval for the difference was -112.01, 104.01. Based on the result of the Welch Two-Sample T-test, we fail to reject the null hypothesis as there is no evidence to support a significant difference between the two pepper types in terms of total weight and total number in my study.

Discussion

My study includes limitations and uncertainties which must be noted. Including in the study limits are contained within a large area may result in inconsistent results. This study was found to be affected by weeds and pests. Human errors may also include incorrect watering and weeding. The changes in environmental conditions and amount of hand-applied water have a high likelihood of impacting yield outcomes.

This study is based on a small garden scale. The guidance when starting a garden plot is to start small and grow when needed. Starting on a manageable scale will develop an understanding of the growth of garden crop types, time constraint, water availability, postharvest considerations. Through water retention in the soil profile, there is a decreased need for water input in fruit production. This positively impacts the increase of sustainable practice used through water use efficiency. With recent droughts in western Kansas, the reduced need for water input is beneficial for the agroeconomic system.

I observed Florida 91 tomato total weight and total number to have higher averages increase in the use of mulch treatments compared to the control. The peak production for the control group was in the second harvest. Hemp hurd had a mentionable high performance between harvest three and four. While straw and plastic soil coverage material had a peak in the fourth harvest.

Bare soil maintains relatively stable average weights across the rows and harvests. Hemp hurd treatments across all rows exhibited the highest average weights, suggesting a potentially positive impact on tomato growth compared to other soil covers. Straw mulch shows a significant fluctuation in average weight across different harvests, indicating potentially variability in its effectiveness. Plastic mulch demonstrates consistent average weights with moderate variability, possibly indicating stable performance.

From the specimen to yield ratio, Control had the highest specimen to yield ratio, 6.87, indicating the control treatment requires more numbers of fruit compared to having soil cover, making it less efficient in terms of fruit number production relative to yield. Hemp Hurd has the highest weight average, 12.19 kg, but not the lowest specimen to yield ratio, suggesting hemp hurd yields well, without needing to have as many fruits produced compared to the other soil covers. Straw Mulch has the lowest ratio, 5.63. In terms of maximizing efficiency, straw mulch was the best soil cover type based on these results. In terms of maximizing yield, hemp hurd is the highest yielding option.

This comparison, with potential weather influence, pests, and environmental conditions on the harvest data. The potential influences in this study demonstrate the effectiveness of mulch as the plants survived extreme harsh conditions of drought, heat stress, water scarcity, and pests (El-Beltagi et al., 2022; Kumar et al., 2012). To reduce the negative impact of these factors on plant growth, projecting a surface barrier from the stressful conditions is less damaging to the plants through a sustainable way to protect the plants (Massimi et al., 2023).

The results of my study indicated an observational improvement in tomato growth with hemp hurd, showing consistently strong performance throughout the growing season, with higher tomato weights. Hemp hurd consistently produced the highest average weights, particularly peaking between harvests three and four. It also demonstrated a relatively high total weight across all harvests compared to the other soil cover types. The data suggested a potentially positive impact on tomato growth compared to the control group. In harvest three, hemp hurd showed an increase in average weight compared to the other soil cover types, with variations potentially influenced by weather or other environmental conditions. Overall, my results illustrated consistent performance by hemp hurd, suggesting it could have a positive impact on tomato growth in northeastern Kansas.

My study provides insights into the growth and productivity of California Wonder and Outsider pepper varieties under outdoor growing conditions (El-Beltagi et al., 2022; Kumar et al., 2012). While no statistically significant differences were found between the two in terms of weight and number of fruits, Outsider had higher average number of fruits than California Wonder. The study also examined the effect of mulch, specifically the role of hemp hurd in enhancing soil moisture retention, which may influence growth and yield under conditions of heat waves and low precipitation. These findings may have implications for future planting practices and field management, particularly regarding hemp hurd's ability to retain water, reduce watering requirements, and protect the soil (Visković et al., 2023).

Throughout my study, a notable observation was the reduced weed growth with covered soil compared to bare soil. Additionally, differences between the mulch materials became evident in the hemp hurd trials showing a decreased need for weed control. The reduced need for weed control labor in the hemp hurd mulch trials suggests potential for further studies (Visković et al., 2023). My results showed no significant difference between the mulch and control groups, however; despite the lack of statistical evidence, there was a notable indication hemp hurd supported tomato growth. As evidenced by hemp hurds consistently strong performance throughout the growing season and higher average tomato weights.

As mulch improves water retention, increases water use efficiency in production, the use of soil cover is beneficial for the agroeconomic system. Emphasizing environmental constraints of plastic soil cover, organic mulch is suggested for soil cover material (El-Beltagi et al., 2022). Organic mulch is recommended for crop production within drought-prone climates (Ren et al., 2016).

The hemp mulch type was observed to keep weed growth at a minimum with observances compared to the other trials within this study. From this study, I suggest there is a need for further studies towards understanding the benefits of hemp hurd. Specific areas for concern are the materials water retention abilities and the additional nutrients provided by the hemp hurd is suggested to be studied as well (Visković et al., 2023).

As my study is based on a small garden scale, I am suggesting further research in larger production scale in future studies.

By aiming agricultural techniques through environmental, economic, and social challenges; we can enhance food security and reduce barriers to availability of sufficient and safe food production.

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Tables

Table 1. Soil cover types with corresponding observations of total weight (kg) and total number across six collection harvests (1 to 6) of the Florida 91 tomato variety. C (Control): Bare soil, without any over. HH (Hemp Hurd): Hemp hurd applied as the soil cover. S (Straw Mulch): Wheat straw mulch used as the soil cover. PF (Plastic Fabric): Plastic fabric used as the soil cover. 1 to 6: These represent tomato collection harvest observations numbered sequentially (from 1st to 6th observation).

Soil Cover Type	Observation	Weight (kg)	Fruit Number
C	1	7.23	46
C	2	16.3	96
C	3	9.56	63
C	4	10.1	82
C	5	8.57	63
C	6	1.79	18
HH	1	5.39	33
HH	2	11.2	68
HH	3	18.61	109
HH	4	18.69	109
HH	5	15.47	101
HH	6	3.77	24
S	1	5.89	32
S	2	15.56	93
S	3	15.33	78
S	4	14.76	88
S	5	17.45	94
S	6	2.74	19
PF	1	4.59	26
PF	2	9.9	56
PF	3	13.28	84
PF	4	17.93	122
PF	5	10.9	72
PF	6	4.48	32

Table 2. Tomato summary of the average total weight (kg), average total fruit number, and specimen to yield ratio for each soil cover type. The table represents the data for the four treatments: Control, Hemp Hurd, Straw Mulch, and Plastic Fabric.

Soil Cover Type	Average Weight (kg)	Average Fruit Number	Specimen to Yield Ratio
Control	8.93	61.33	6.87
Hemp Hurd	12.19	74	6.07
Straw Mulch	11.96	67.33	5.63
Plastic Fabric	10.18	65.33	6.42

Table 3. The tomato total weight (kg) for each soil cover type (Control, Hemp Hurd, Straw Mulch, and Plastic Fabric) across six observations. The data show the total weight of tomatoes collected under each treatment during the specified observations (1 through 6). The Total Sum column represents the cumulative weight (kg) for each soil cover type across all observations.

Soil Cover Type	1	2	3	4	5	6	Total Sum
Control	7.23	16.3	9.56	10.1	8.57	1.79	53.55
Hemp Hurd	5.39	11.2	18.61	18.69	15.47	3.77	73.13
Straw Mulch	5.89	15.56	15.33	14.76	17.45	2.74	71.73
Plastic Fabric	4.59	9.9	13.28	17.93	10.9	4.48	61.08

Table 4. Tomato total number for each soil cover type (Control, Hemp Hurd, Straw Mulch, and Plastic Fabric) across six observations. The total number is the pooled number of fruits (e.g., the number of tomatoes) from each replication harvest. The Total Sum column represents the total number of fruits harvested across all six observations for each soil cover type.

Soil Cover Type	1	2	3	4	5	6	Total Sum
Control	46	96	63	82	63	18	368
Hemp Hurd	33	68	109	109	101	24	444
Straw Mulch	32	93	78	88	94	19	404
Plastic Fabric	26	56	84	122	72	32	392

Table 5. The statistical properties of tomato total weight (kg) for each soil cover type. The table includes the minimum, 1st quartile (Q1), median, mean, 3rd quartile (Q3), maximum, standard deviation, and the range of weights.

Statistic	Control	Hemp Hurd	Straw Mulch	Plastic Fabric
Minimum	1.79	3.77	2.74	4.48
1st Quartile (Q1)	7.57	6.84	8.12	5.92
Median	9.07	13.34	15.05	10.4
Mean	8.93	12.19	11.96	10.18
3rd Quartile (Q3)	9.97	17.83	15.5	12.69
Max	16.3	18.69	17.45	17.93
Standard Deviation	4.69	6.52	6.07	5.18
Range	1.79-16.3	3.77-18.69	2.74-17.45	4.48-17.93

Table 6. The statistical summary of tomato total number of fruits harvested for each soil cover type. The table includes the minimum number of fruits collected in one harvest, 1st quartile (Q1), median, mean, 3rd quartile (Q3), maximum number of fruits collected in one harvest, standard deviation, and the range of fruit number from the harvests.

Statistic	Control	Hemp Hurd	Straw Mulch	Plastic Fabric
Minimum	18	24	19	26
1st Quartile (Q1)	50.25	41.75	43.5	28
Median	63	84.5	83	64
Mean	61.33	74	67.33	65.33
3rd Quartile (Q3)	77.25	107	91.75	81
Max	96	109	94	122
Standard Deviation	27.38	38.46	33.15	35.64
Range	18-96	24-109	19-94	26-122

Table 7. The summary statistics and the ANOVA results for tomato total weight across the four soil cover types: Control (C), Hemp Hurd (HH), Straw Mulch (S), and Plastic Fabric (PF). The summary statistics table shows the soil cover types observation count, sum of tomato weights, the average weight and the variance for each soil cover type. The results of the ANOVA test for tomato weight shows the sum of squares, degrees of freedom, mean square, F-statistic, and p-value for each source of variation.

SUMMARY

Soil Cover	Count	Sum	Average	Variance
Control	6	53.55	8.93	22.02
Hemp Hurd	6	73.13	12.12	42.47
Straw	6	71.78	11.96	36.94
Plastic	6	61.08	10.18	26.8

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	43.1	3	14.4	0.45	0.72	3.09
Within Groups	641.1	20	32.1	NA	NA	NA
Total	684.2	23	46.5	NA	NA	NA

Table 8. The summary statistics and ANOVA results for tomato total number across the four soil cover types: Control (C), Hemp Hurd (HH), Straw Mulch (S), and Plastic Fabric (PF). The summary statistics table shows the soil cover observation count, the sum of tomato total number, the average number of fruits, and the variance for each soil cover type. The results of the ANOVA test for tomato number of fruits show the sum of squares, degrees of freedom, mean square, F-statistic, and p-value for each source of variation.

SUMMARY

Soil Cover	Count	Sum	Average	Variance
Control	6	368	62.33	749.47
Hemp Hurd	6	444	74	1479.2
Straw	6	404	67.33	1099.07
Plastic	6	392	65.33	1269.87

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	504	3	168	0.15	0.93	3.09
Within Groups	22988	20	1149	NA	NA	NA
Total	23492	23	1317	NA	NA	NA

Table 9. Pepper data of two pepper types observed, California Wonder (C.W.) and Outsider (O) with the three harvest observations of total weight (kg) and total number of fruits harvested.

Pepper Type	Observation	Weight (kg)	Fruit Number
C.W.	1	10.99	68
C.W.	2	2.56	19
C.W.	3	1.11	3
O	1	19.79	95
O	2	1.10	6
O	3	0.09	1

Table 10. The statistical properties of pepper type California Wonder (C.W.) total weight (kg) and total number of fruits harvested. The table includes the minimum, 1st quartile, median, mean, 3rd quartile, maximum, and the standard deviation.

Statistic	Weight (kg)	Number of Fruit
Minimum	1.11	3
1st Quartile (Q1)	1.84	11
Median	2.56	19
Mean	4.89	30
3rd Quartile (Q3)	6.78	43.5
Max	10.99	68
Standard Deviation	5.34	33.87

Table 11. The statistical properties of pepper type Outsider (O) total weight (kg) and total number of fruits harvested. The table includes the minimum, 1st quartile (Q1), median, mean, 3rd quartile (Q3), maximum, and the standard deviation.

Statistic	Weight (kg)	Number of Fruit
Minimum	0.09	1
1st Quartile (Q1)	0.59	3.5
Median	1.10	6
Mean	6.99	34
3rd Quartile (Q3)	10.45	50.5
Max	19.79	95
Standard Deviation	11.09	52.89

Table 12. Welch Two-Sample t-test result for pepper total weight comparison, California Wonder (C.W.) versus Outsider (O).

T-statistic	-0.29
Degrees of Freedom	2.88
P-value	0.79
Confidence Interval	-25.27, 21.05
C.W. Mean Weight (kg)	4.89
O Mean Weight (kg)	6.99

Table 13. Welch Two-Sample t-test result for the comparison of total number of fruits harvested, California Wonder (C.W.) versus Outsider (O).

T-statistic	-0.11
Degrees of Freedom	3.40
P-value	0.92
Confidence Interval	-112.01, 104.01
C.W. Mean Fruit Number	30
O Mean Fruit Number	34

Figures

Figure 1. Map of Willow Lake Student Farm, Manhattan, Kansas (39.25N, 96.57W), showing the study area with plots designed for tomatoes and peppers. The map highlights the layout of the rows, mulch types, plant spacing, number of plants per row (four), spacer plants, and treatment locations within each row. Modified data from Google Earth (Google, 2023).

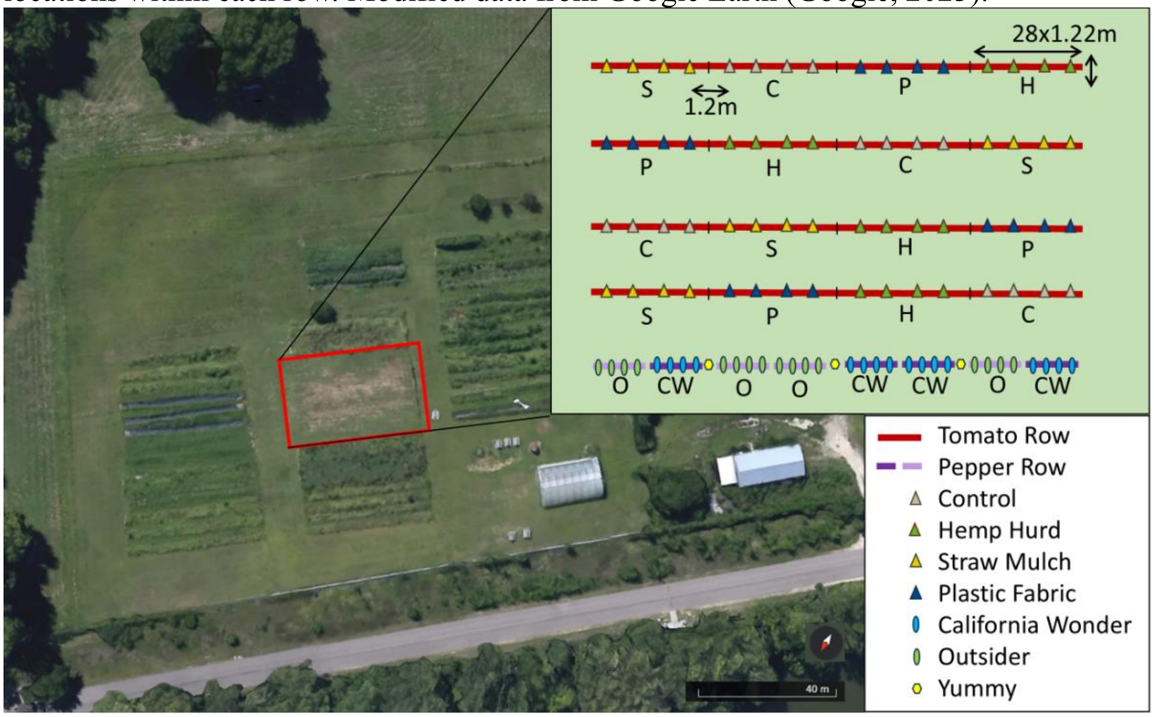

Figure 2. Manhattan, Kansas daily temperature (°C) from May 15, 2023, to September 18, 2023. The plot shows the variation in temperature over the course of the growth season, highlighting daily fluctuations.

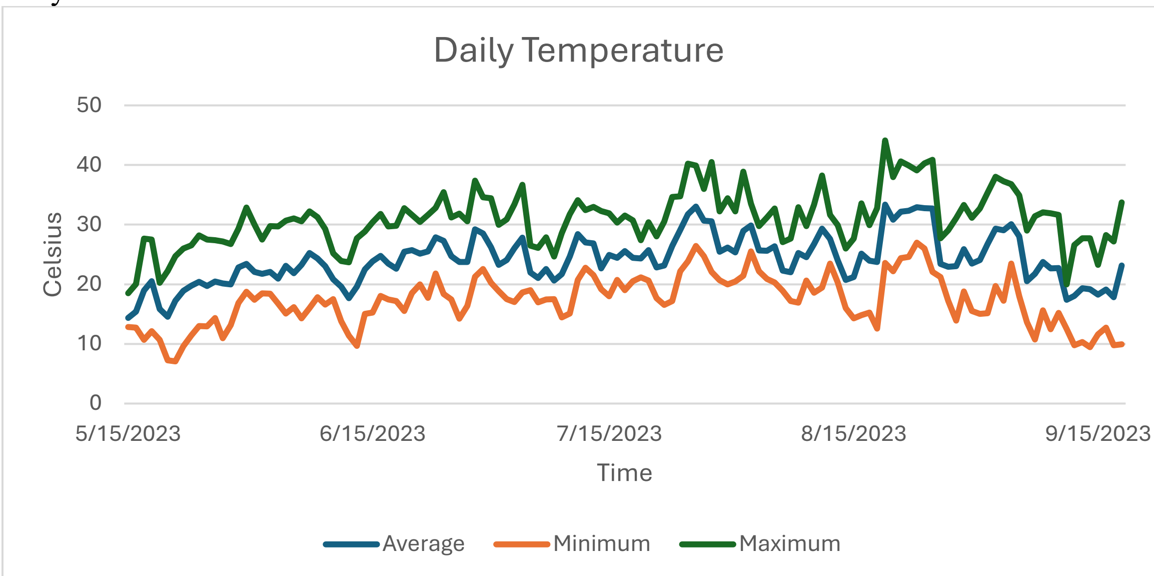

Figure 3. The precipitation data from May 15, 2023, to September 15, 2023, for daily precipitation (mm), with the height of each bar representing the amount of daily rainfall.

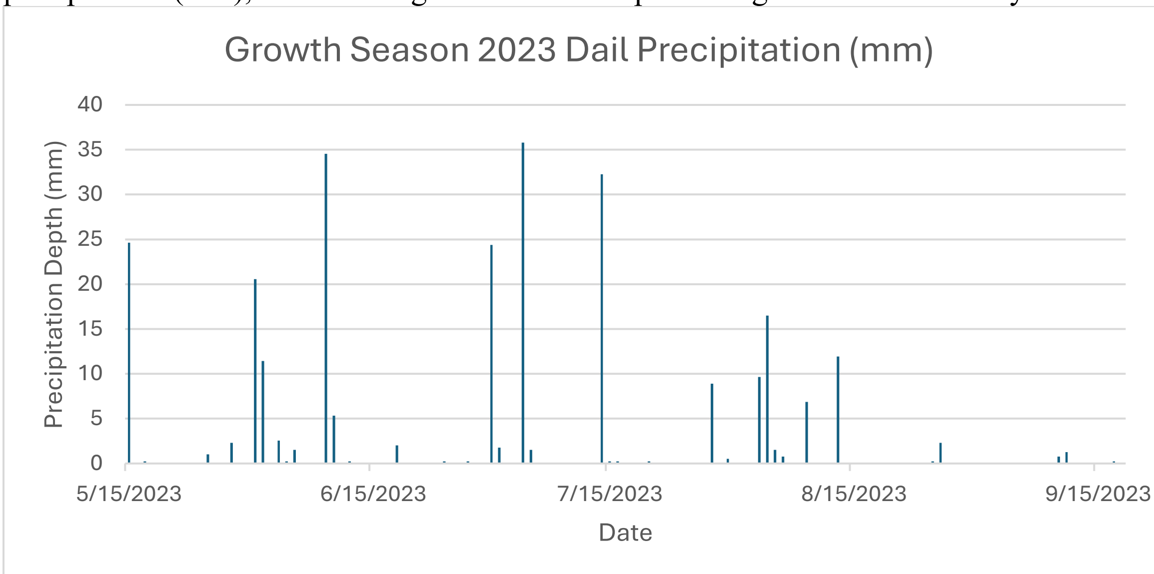

Figure 4. Cumulative tomato total weight (kg) across the six harvest observations for each of the four soil cover types: Control (C), Hemp Hurd (HH), Straw Mulch (S), and Plastic Fabric (PF), showing the sum of tomato weight after each harvest.

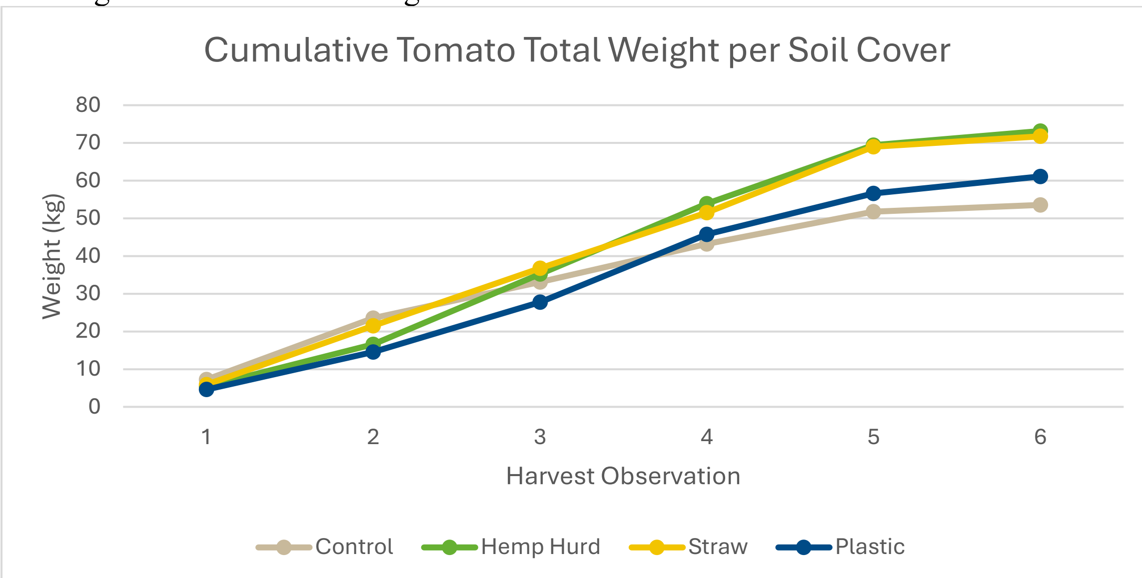

Figure 5. The cumulative total number of fruits across the six harvest observations for each soil cover type: Control (C), Hemp Hurd (HH), Straw Mulch (S), and Plastic Fabric (PF). The cumulative count is obtained by summing the number of fruits harvested after each observation, from Observation 1 to Observation 6.

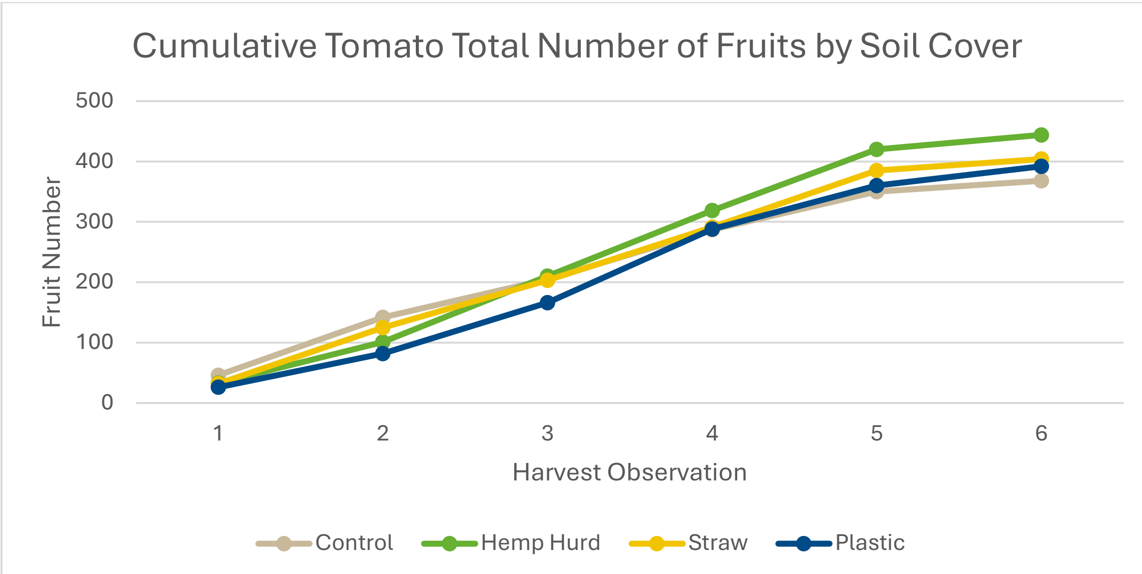

Figure 6. Boxplot comparison of tomato weight (kg), across the four soil cover types: Control (C), Hemp Hurd (HH), Straw Mulch (S), and Plastic Fabric (PF), illustrating the distribution, median, and range of tomato weight per treatment.

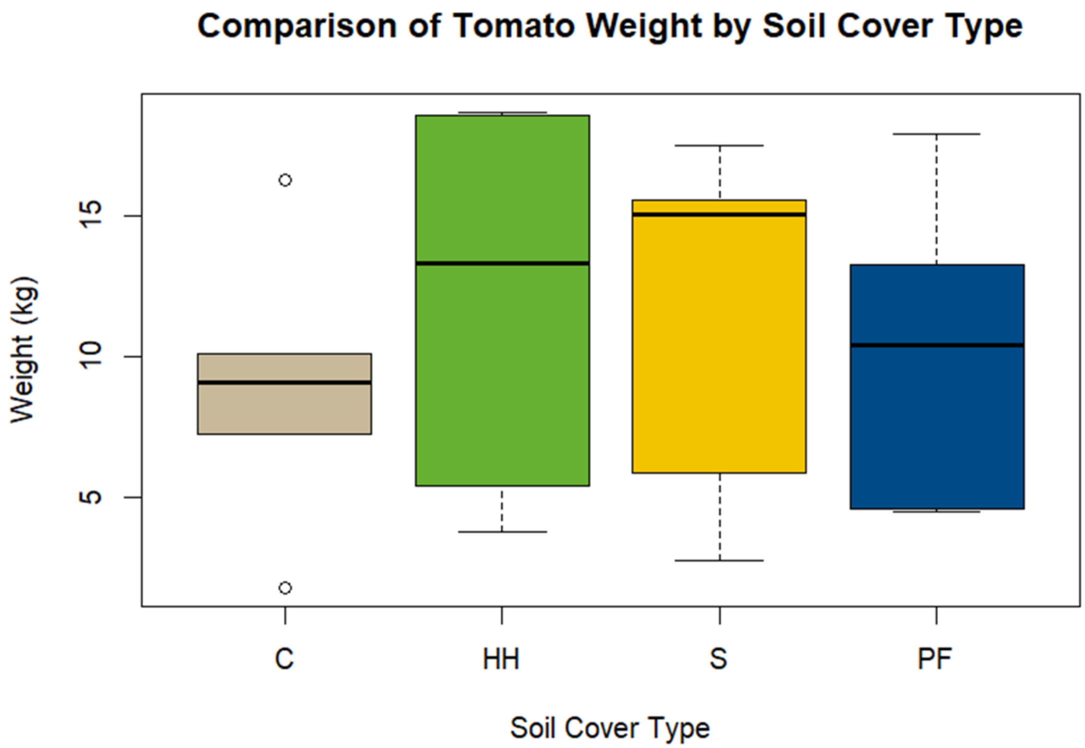

Figure 7. Boxplot comparison of tomato number of fruits harvested across the four soil cover types: Control (S), Hemp Hurd (HH), Straw Mulch (S), and Plastic Fabric (PF), illustrating the distribution and spread of number of fruits.

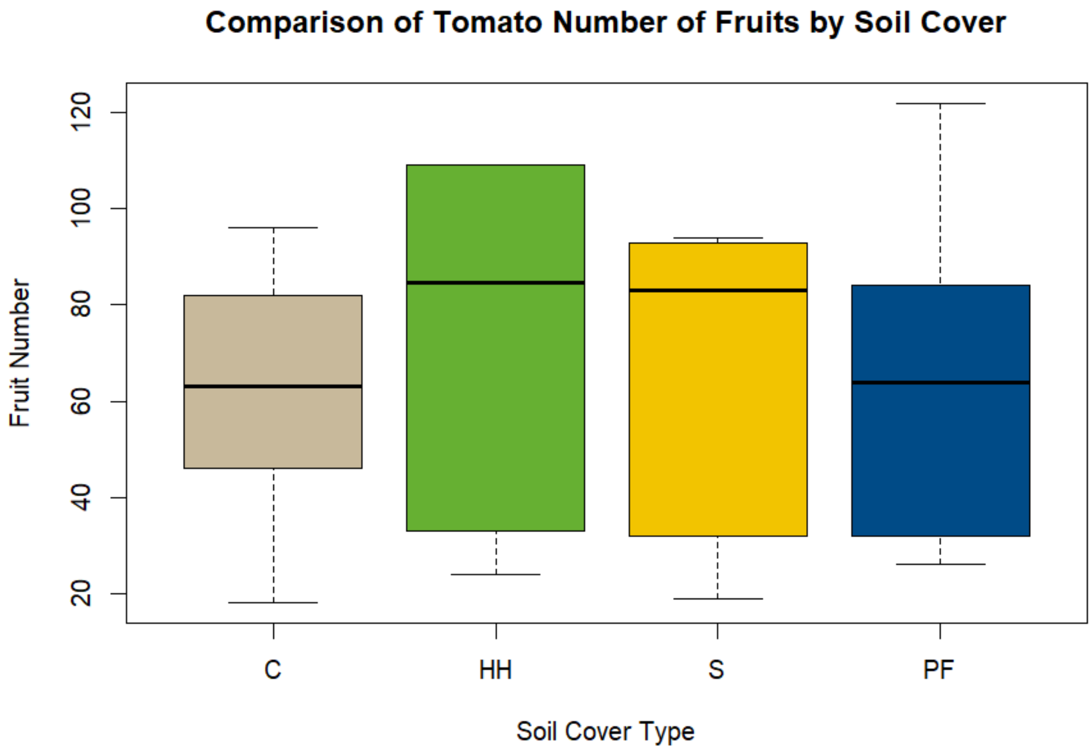

Figure 8. Boxplot comparison of pepper weight (kg) between pepper types, illustrating the distribution, median, and range of weight per pepper type.

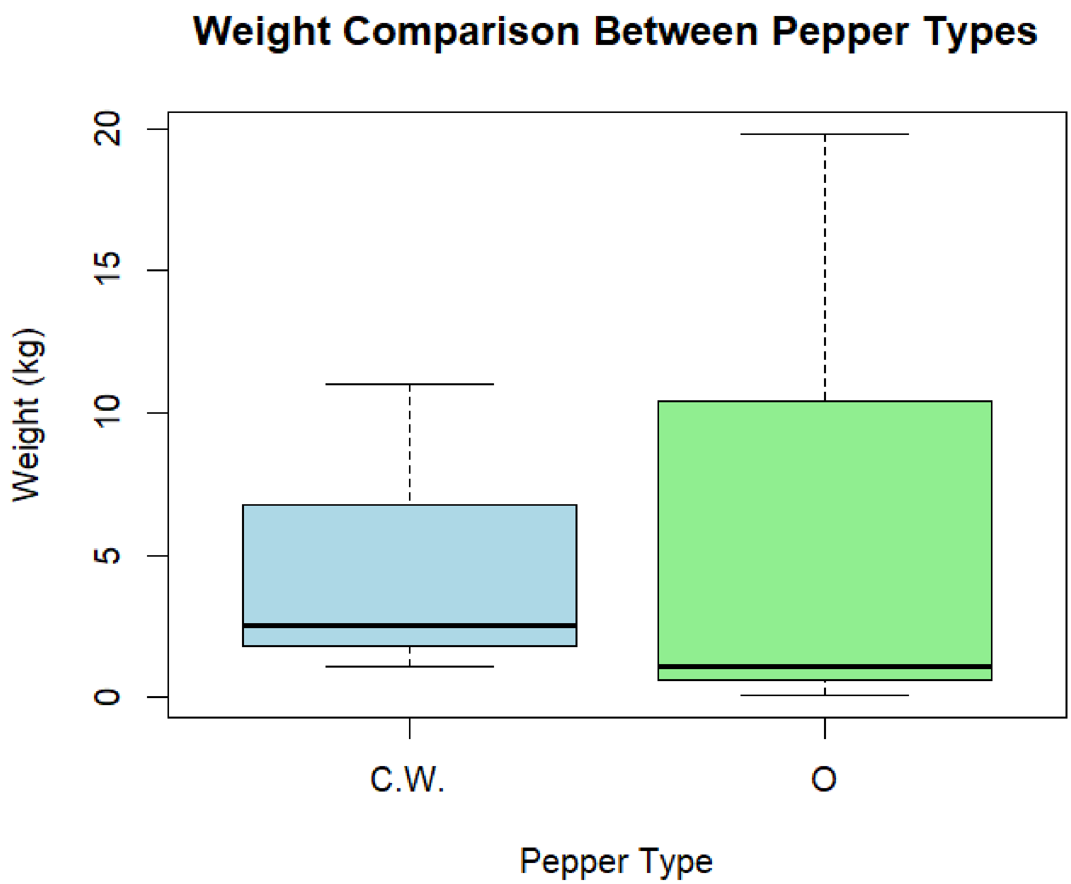

Figure 9. Boxplot comparison of pepper types; California Wonder (C.W.) and Outsider (O), on the number of fruits harvested, visualizing the distribution of data through median, interquartile range (IQR), and range of data.