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Performance of Some Organic Mulch Materials for Weed Suppression, Soil Conditions and Yield in *Capsicum annuum* L. Cultivation

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Highlights:

- Organic Mulch Materials Effectively Controls Weeds and Increases Crop Yield in *Capsicum annuum* L. Cultivation
- Organic Mulches Enhances Soil Temperature, Moisture, and Crop Growth

Keywords:

- Mulching
- Weed,
- Chili pepper,
- Yield
- Soil properties

ABSTRACT:

The aim of this study was to investigate the effectiveness of different organic mulch materials and thicknesses in controlling weeds, improving soil temperature and moisture, and increasing crop yield in *Capsicum annuum* L. cultivation. The experiment was conducted in 2022, using three types of mulch materials (grass, chopped paper, wheat straw) and three different thicknesses (5 cm, 10 cm, 15 cm). A total of 22 weed species were identified in the experimental area, and statistical analysis revealed significant differences in all parameters between the mulch treatments and the control group. The use of organic mulch resulted in better weed control, with an increase in mulch thickness corresponding to greater suppression of annual weed species. The highest effect on weed dry weight was observed in the 15-cm paper mulch, which also produced the highest yield (3940.48 kg/da). The study also showed that soil temperature was lower and soil moisture was higher in all mulch treatments compared to the bare soil control group, with some fluctuations observed at times. Overall, the findings suggest that the use of organic mulch is crucial in arid and semi-arid regions for effective weed control, water conservation, improved water efficiency, reduced soil evaporation, and increased pepper yield.

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INTRODUCTION

Capsicum annuum L., commonly known as Capia pepper, is a highly valued and widely cultivated crop in the Solanaceae family due to its multiple uses as a spice, fresh or dried vegetable, and processed food ingredient. Capia pepper is also known for its high nutritional value, containing essential vitamins such as A, C, and E, carotenoids, phenols, flavonoids, and minerals such as potassium, sodium, calcium, iron, copper, and manganese. Moreover, Capia pepper seeds are rich in essential fatty acids and bioactive phytochemicals, making them a valuable food source (Bosland and Votava, 2000; Rodriguez-Burruezo et al., 2009; Hervert-Hernández et al., 2010; Mateos et al., 2013; Yılmaz et al., 2015). In this context, it is important to study the factors affecting Capia pepper cultivation, such as weed control and soil management practices, to optimize its growth, yield, and quality.

According to the Food and Agriculture Organization (FAO, 2023), the worldwide pepper cultivation area was 2,055,310 hectares, and the global pepper production was 36,286,644 tons in 2021. The Asian continent had the highest production rate of 67.9%, followed by America (11.5%), Europe (10.8%), and Africa (9.6%). China was the leading producer of pepper in the world in 2021, with a production amount of 16.7 million tons, followed by Türkiye, Indonesia, and Mexico. (FAO, 2023). In Türkiye, 763.977 peppers were planted in 2022, and 47.5% of them were Capia Pepper. The total pepper production was 3.018.775 tons, of which 49% was capia pepper. In Iğdır, in 2022, 1.777 decares of land were used to plant pepper, and 26.7% of them were capia pepper. The production of pepper in Iğdır was 3400 tons, and 48.9% of them were capia pepper (TÜİK, 2023).

Pepper is a significant crop worldwide and in Türkiye, serving as a crucial cultural plant and food source. Nevertheless, various factors can influence the yield and quality of pepper. Among these factors, weeds play a critical role in reducing the fruit yield and quality of pepper cultivation. Weeds have a detrimental effect on pepper plant growth and hinder fruit yield and quality. (Marques et al., 2017). Especially after planting, pepper seedlings are extremely low in competition with weeds due to their slow growth (Norsworthy et al., 2007). Yield losses have been reported to range from 43% to 97% depending on weed density (Patel et al., 2004; Darren et al., 2008). Many studies have reported that the pepper has low competitiveness with weeds (Darren et al., 2008; Coelho, 2013). Organic vegetable growers consider weed management to be the most important production issue as there are few effective weed control options for organic production (Beveridge and Naylor, 1999). Organic vegetablegrowers suffer significantly from weeds (Beveridge and Naylor, 1999). One of the most important challenges faced by pepper growers is weed management (Webster, 2010).

Chemical control methods have become the preferred choice for controlling weeds in agricultural areas due to their affordability, ease of application, and quick efficacy (Kitiş, 2011). Herbicides, which are used extensively to control weeds (Bo et al., 2017; Su, 2020), negatively affect human health due to their incorrect and frequent use (Jabłońska-Trypuć et al., 2019), cause serious environmental and ecological problems (Sardana et al., 2017). In addition, excessive use of herbicides causes weed resistance (Bo et al., 2017; Peterson et al., 2018).

Mulching offers an alternative approach to combat the negative consequences of chemical control and address weed problems. It involves spreading diverse cover materials on the soil surface to reduce weed populations, prevent moisture loss, and enhance crop yield (Nalayini, 2007; Kader et al., 2019). Mulches have the potential to suppress weed growth by creating shade (Rathore et al., 1998). When applied to the soil surface, mulches act as a barrier, obstructing light and inhibiting the germination of small-seeded weed species (Iqbal et al., 2020). They also physically impeed the emergence of weeds from the soil (Ahmad et al., 2020). Moreover, mulches safeguard plant seeds, promote soil fertility and productivity (Ghosh et al., 2015), and aid in moisture retention, reducing evaporation and soil water loss while regulating and balancing soil temperature (Jordan et al., 2010). Mulching also contributes positively to the preservation of water and soil (Kasirajan and Ngouajio, 2012). Consistent soil moisture levels reduce the energy expended by plants for water uptake, ultimately enhancing both yield and quality (Fan et al., 2017). By maintaining moisture in the root zone, mulching reduces the overall irrigation water requirement and increases the interval between irrigations (Schonbeck and Evanylo, 1998). Research indicates that organic mulches enhance production by lowering the soil temperature and evaporation rates (Sarkar et al., 2007) while promoting the formation of organic matter and soil nutrient cycling through decomposition (Nair and Ngouajio, 2012). In order to preserve soil and moisture/water, moderate temperatures, and improve soil health, the widespread use of mulching materials, especially in rainy conditions, is recommended to increase agricultural productivity (Bajorien et al., 2013). Global temperatures have risen due to rapid industrialization and urbanization, causing disruptions to agro-ecological systems worldwide. Consequently, environmentally friendly agricultural practices are essential for sustainable food production (Iqbal et al., 2020). Additionally, water scarcity has intensified due to climate change, population growth, and pollution of freshwater resources by pollutants such as heavy metals. The degradation of land resources has also become a pressing concern. Therefore, there is a need for cost-effective and accessible solutions. Mulches play a crucial role in achieving the sustainability objectives of modern agricultural systems. It is vital to select the most suitable mulch type, considering factors such as soil type, environmental conditions, specific targets, and the intended purpose of the mulch (Pramanik et al., 2015; Jabran, 2019).

Agriculture plays a crucial role in sustaining global food production, and its practices have a significant impact on the environment. One common technique used in farming is mulching, which involves covering the soil with a protective layer to conserve moisture, suppress weed growth, and enhance crop yield. While mulching has numerous benefits, there is growing concern about the negative environmental consequences associated with the use of traditional plastic mulch materials. For the reason described above, widely used plastic mulch materials cause damage to the environment because they break down, leave residue in the field after harvest and are not recyclable.

Non-plastic mulches are environmentally sustainable because, unlike plastic, they biodegrade quickly, preventing long-term damage. They leave no residue, preventing soil and water pollution. They are recyclable and enrich the soil, promoting healthier plants. Non-plastic options require fewer chemicals and support local economies by using local materials, reducing the carbon footprint.

MATERIALS AND METHODS

The study was conducted in Igdir University Agricultural Application and Research Center (TUAM) (39°55'45.6"N 44°05'42.3"E) in 2022, using the Barça F1 Capia pepper variety. To measure soil temperature and humidity values, a temperature and humidity logger with a temperature range of -30 to +60°C and a humidity range of 0% to 99% RH was employed.

Information on the general properties and application rates of the mulch materials, montly meteorological data from the long-term average (LTP), spanning the years 2022 and 1941-2022, and the soil properties of the research area are presented in Table 1-3, respectively.

Table 1. General properties and application rates of mulch materials

Code	Used Materials	General Features	Application Quantitiesd
CP - 5 cm	Clipping paper 5 cm	1 cm vertically cut sheets of paper	1.000 kg/da
CP - 10 cm	Clipping paper 10 cm	-	2.000 kg/da
CP - 15 cm	Clipping paper 15 cm	-	3.000 kg/da
CTG - 5 cm	Clipping grass wastes 5 cm	*Lolium perenne* 25% *Festuca arundinacea* 45% *Poa pratensis* 10% *Festuca rubra rubra* 20% mixed mown grass wastes	1.750 kg/da
CTG - 10 cm	Clipping grass wastes 10 cm	-	3.500 kg/da
CTG - 15 cm	Clipping grass wastes 15 cm	-	5.250 kg/da
WS - 5 cm	Straw 5 cm	Wheat straw	1.500 kg/da
WS - 10 cm	Straw 10 cm	-	3.000 kg/da
WS - 15 cm	Straw 15 cm	-	4.500 kg/da

Table 1. General properties and application rates of mulch materials

Table 2. The weather conditions of the region

	Temperature (°C)		Precipitation (mm)		Humidity (%)	
Months	**2022**	**LTP (1941-2022)**	**2022**	**LTP (1941-2022)**	**2022**	**LTP (1941-2022)**
March	5.1	6.2	17.7	22.1	54.8	52.2
April	15.7	13	24.7	33.8	44.1	49.9
May	17.1	17.7	50.5	46.5	53.8	51.5
June	24.5	22.1	22.3	32	47.5	47.3
July	27.7	25.9	1.4	13.7	37.5	45.3
August	27.9	25.3	2.3	9.7	42.3	47.1
September	23.1	20.4	5.1	11.5	41.9	46.2
October	15.4	13.1	12	26.3	49.6	48.53

(MS, 2023): LTP: Long-term period

Table 3. Soil characteristics of the experimental area

Soil properties	Units	Trial area
Profile depth	cm	0-30
Texture	-	Clay- Loamy
Phosphorus (P_2O_5)	kg da^{-1}	0.8
Lime ($CaCo_3$)	%	11.32
Potassium (K_2O)	kg da^{-1}	9.28
PH	-	7.9
Total salt	mmhos/cm	2
Organic matter	%	1.8

Experimental Setup and Plants Care

The pepper seedlings were planted using a row spacing of 50x80 cm on April 29, 2022. The seedlings were placed in the soil with 2/3 of their height below the ground and 1/3 above the ground. Prior to planting, NPK fertilizer at a rate of 30 kg/da was mixed into the soil. Following the planting of the seedlings, a drip irrigation system was established, and the first irrigation took place immediately after planting. Subsequent irrigation was carried out once a week, taking into consideration both rainfall levels and the water requirements of the plants.

The experiment was set up according to randomized block trial design, consisting of 4 replications and 11 characteristics in a total of 44 parcels. Each character was assigned a plot size of 6.75 m^2 (4.5 × 1.5 m), with a distance of 0.5 m between the plots and 1 m between the blocks. The overall trial area covered 419.25 m^2. To demarcate the plots, laths were fixed to the ground and ropes were used for the strips.

Straw, grass and chopped paper applications were compared, with weedy and unweedy control. The mulch materials were lie down to soil at 5, 10, and 15 cm thickness. The mulch materials were laid on June 10, 2022, ensuring that the pepper seedlings were not covered during this process.

Determination of weed species and densities in the experimental area

The primary objective of the study was to determine the weed species and their densities in the trial area before applying mulch. For this aim, a 1 m² wooden frame was placed in the trial area, and weeds were counted within the frame which were randomly thrown. This process allowed to the identification of weed species present in the trial area as well as the density of each species. The density of weeds was calculated using the arithmetic mean. To calculate weed densities, the total number of plants observed per m² in the surveys was divided by the number of surveys conducted. Subsequently, the densities of each weed species were determined according to the methodology described by Odum (1971).

The density of weeds (plants/m²) was calculated using the formula B/m, where "B" represents the total number of individual plants observed in the samples, and "m" represents the total number of square meters surveyed. Additionally, the density of weed species in the trial area was evaluated using a scale (Üstüner and Güncan, 2002) (Table 4).

Table 4. Scale used for weed density

Scale	Density Level	Density (plants/m^2)
A	High dense	10+
B	Dense	1–10
C	Middle dense	0.1–1
Ç	Low dense	0.01–0.1
D	Rare	Less than 0.01

Effects of mulching on weed species

As mulch materials, straw, grass and paper were applied at 5, 10, and 15 cm thickness to determine the effect on weed emergence. After the mulch materials were applied, weed densities in square meters were counted twice a month. A total of 7 counts were done during the study period on June 30, July 17, July 30, August 15, August 30, September 15, and September 30, 2022. Weed densities were assessed both for the entire parcels and for individual weed species. Specifically, weeds that only emerged in the parcels with mulch materials were separately counted based on their species. The densities of weeds per square meter were then evaluated for each plot after considering the different weed species. The weed species *Sorghum halepense*, *Convolvulus arvensis* and *Xanthium strumarium* were evaluated individually due to their consistent emergence in the plots where the mulch materials were applied. Other weed species were assessed collectively when their emergence was not uniform. Additionally, hoeing was conducted in plots where weed emergence was observed to maintain weed-free conditions.

To assess the weed density in all treatments, 1 m^2 frames will be employed. The density values for each survey date will be calculated using the density formula established by Odum (1971). This involves dividing the total number of weeds observed by the total area covered during the counting process to determine the densities in each treatment.

Effect of mulching on weed dry weight

Prior to the final pepper harvest, the weeds present in all plots will be individually removed from the soil surface, collected in paper bags, and transported to the Herbology Laboratory. Once in the laboratory, the weed samples will be placed in an oven and subjected to a temperature of 70 °C for 24 hours to achieve complete dryness. Subsequently, the dried weed samples will be weighed individually, and the corresponding numerical data will be recorded. This process will allow for the determination of weed dry weights in each plot. Furthermore, the percentage effects of the other plots, compared to the weed control plots, on the weed dry weights will be assessed to evaluate their impact.

Effect of mulching on soil temperature and moisture

Data loggers were utilized to monitor temperature and humidity during the operation period from August 9th to August 10th, 2022. These data loggers were placed at a depth of 5 cm into the soil within the 10 cm thick bare ground plots, which served as the control. The measurements commenced at 00:00 on August 9th, 2022, and data were recorded every hour throughout the duration of the operation.

The Effect of mulching on pepper yield components and yield

During the study, the pepper harvest took place between July 28th, 2022, and October 1st, 2022. Considering the market conditions at the time of harvest, the harvested pepper fruits were transported to the Herbology Laboratory located at the Şehit Bülent Yurtseven campus of the Faculty of Agriculture at Iğdır University. Various parameters were determined for the pepper fruits collected from each plot, including plant height (in centimeters), number of fruits per plant, fruit weight (in grams), yield per plant (in kilograms), and overall yield (in kilograms per hectare). These values were then compared to the weedy and weedy-free (hoeing-hand weeding) control plots, in the mulched plots.

Statistical analysis

The experimental design employed in this study followed a factorial model within a completely randomized block design. The treatments consisted of herbicide application or no herbicide application, as well as weed-free or weedy checks. To ensure sufficient statistical effects, four replications were conducted, with each replication consisting of ten plants. The obtained data were subjected to one-way variance analysis, and mean comparisons were performed using Duncan's multiple range test with a significance level of $p < 0.05$, using SPSS 22 software. To further analyze and interpret the results, several statistical techniques were employed. Firstly, the data underwent transformation or normalization as required. Subsequently, correlation analysis was conducted using JASP software to examine the relationships between variables. Heat map clustering using SR plot software was employed to visually represent the clustering patterns of the data. Principal component analysis (PCA) was performed using PAST software to identify key components explaining the variation in the dataset. Lastly, network plot analysis, also using PAST software, was employed to investigate complex relationships among the variables.

RESULTS AND DISCUSSION

Weeds Detected in the Trial Area

A total of 22 weed species from 9 different families were identified in the trial area. These species included one parasite, one narrow-leaved, and seven broad-leaved weeds. Among the 22 weed species, the families with the highest number of species were Poaceae (5 species), Amaranthaceae (5 species), and Brassicaceae (4 species) (Table 5). Previous studies by Pamukoğlu (2011) reported a total of 20 weed species from 15 families, including 1 parasitic, 2 monocotyledons, and 12 dicotyledons. The families with the highest number of weed species were Poaceae, Asteraceae, and Amaranthaceae. We also detected weed species such as *X. strumarium, S. halepense, C. arvensis, Seteria* spp., *A. retroflexus,* and *C. album,* which were similar to those found in the trial area. Similarly, the highest number of weed species was recorded in Capsicum annuum cultivation; 22 weed species from 16 families, mainly Poaceae, Asteraceae, Amaranthaceae and Solanaceae (Argün-Yıldız, 2019). Furthermore, Sırrı and Özaslan (2020) identified a total of 52 weed species belonging to 20 different families in their study conducted in vegetable production areas of Siirt province. Among these families, 2 were monocotyledons and 18 were dicotyledons. Notably, the families with the highest diversity of weed species were Poaceae (10 species), Asteraceae (8 species) and Fabaceae (6 species). The weed species identified in their research included *S. halepense, S. viridis, C. dactylon, A. retroflexus, X. strumarium, H. europaeum, C. arvensis, A. pseudalhagi* and *P. oleracea*. Interestingly, the weed species found in their study showed similarities to those previously documented. Similarly, the study by Torun (2022) identified 18 weed species belonging to 12 different families. The families with the highest number of weed species were Poaceae (4 species), Fabaceae (3 species) and Amaranthaceae (2 species). The weed species *S. viridis, A. retroflexus, H. europaeum, C. arvensis* and *P. oleracea* found in our study are similar to the weed species found in our study.

Table 5. Some systematic features and densities (number/m^2) of weeds

Family	Scientific Name	Common Name	Life Cycle	Density (adet/m^2)	Density scale
Narrow-leaved					
Poaceae	*Sorghum halepense* (L.) Pers.	Johnson grass	P	12.25	A
	Phragmites sp.	Common reed	P	1	B
	Setaria viridis L.	Green foxtail	A	0.6	C
	Setaria verticillata (L.) P.B.	Bristly foxtail	A	0.75	C
	Cynodon dactylon (L.) Pers.	Bermuda grass	P	1.5	B
Broad-leaved					
Amaranthaceae	*Amaranthus retroflexus* L.	Redroot pigweed	A	0.5	C
	Amaranthus blitoides S. Watson	Prostrate pigweed	A	0.1	C
	Atriplex nitens Schkuhr.	Saltbush	P	0.5	C
	Chenopodium album L.	Common lambsquarters	A	2.25	B
	Suaeda altissima (L.) PALL	Seablite	A	0.5	C
Asteraceae	*Cirsium arvense* (L.) Scop.	Canada thistle	P	0.5	C
	Xanthium strumarium L.	Common cocklebur	A	1.75	B
Boraginaceae	*Heliotropium europaeum* L.	Common heliotrope	A	0.05	Ç
Brassicaceae	*Sinapis arvensis* L.	Wild mustard	A	0.15	C
	Descurainia sophia (L.) Webb. Ex Prant.	Flixweed	A	0.15	C
	Cardaria draba (L.) Desv.	Hoary cress	P	0.05	Ç
	Myagrum perfoliatum L.	Musk weed	A	0.2	C
Convolvulaceae	*Convolvulus arvensis* L.	Field bindweed	P	1.3	B
Fabaceae	*Alhagi pseudalhagi* (BIEB.) DESV.	Camel-thorn	P	0.15	C
Portulacaceae	*Portulaca oleracea* L.	Common purslane	A	0.1	C
	Polygonum aviculare L.	Common knotgrass	A	0.05	Ç
Parasite					
Cuscutaceae	*Cuscuta* spp.	Dodder	Parasite	0.1	C

Life Cycle—A: Annual, P: Perennial; A = High density = >10.00 m^2, B = Intensive = 1.00–10.00 m^2, C = Medium = 0.10–1.00 m^2, Ç= Low density = 0.01-0.10 m^2

Among the weed species identified in the experimental area, the five species with the highest density were as follows: *S. halepense* (12.25 number/m^2), *C. album* (2.25 number/m^2), *X. strumarium* (1.75 number/m^2), *C. dactylon* (1.5 number/m^2), and *C. arvensis* (1.3 number/m^2). Furthermore, based on the weed species detected in our study, there was one species with high density (H: 10+ number/m^2), five species with dense density (H: 1-10 numbers/m^2), thirteen species with medium density (H: 0.1-1 number/m^2), and three species with low density (H: 0.01-0.1 number/m^2) (Table 6).

In another studies conducted in chili pepper fields located in Southeast Anatolia region of Türkiye, the dense weed species were *C. rotundus* (16.88 number/m^2), *X. strumarium* (9.36 number/m^2), *S. halepense* (8.64 number/m^2), and *C. arvensis* (5.48 number/m^2) in Kahramanmaraş province (Pamukoğlu, 2011), whereas, *P. oleracea* (9.6 number/m^2), *S. nigrum* (3.2 number/m^2), and *S. halepense* (1.6 number/m^2) in Siirt province (Sırri and Özaslan, 2020). On the other hand, the highest dense species in vegetable areas in Mediterranean region were reported as *A. retroflexus* (1.01 number/m^2), *E. colonum* (0.34 number/m^2), and *E. indica* (0.13 number/m^2) (Torun, 2022). The clear parallelism is evident when comparing the weed species and their densities detected in the aforementioned studies with the results of our own study. Nevertheless, the differences in weed species found in different studies can be attributed to regional differences, as certain regions tend to show differences in both weed species and densities (Güncan and Karaca, 2018).

Effect of mulching on weed species and population

Significant differences ($p < 0.01$) were observed in all the conducted counts to assess the impact of mulch materials on weeds (Table 6). The influence of different mulch materials and thicknesses on weed populations in pepper cultivation varied depending on the specific mulch materials and thicknesses employed. In general, it was found that increasing the thickness of the mulch layer had a more pronounced effect on weed populations. Within the recorded measurements, the plots with a 15 cm mulch thickness incorporating paper and straw materials had the lowest weed density at the initial assessment with a count of 0.25 plants/m². Throughout all subsequent measurements, the plots with 15 cm of paper mulch had consistently lower weed densities, ranging from 2.00 to 4.00 plants/m² (Table 6).

Table 6. Number of weeds

Applications	1. assessment	2. assessment	3. assessment	4. assessment	5. assessment	6. assessment	7. assessment
CTG - 5 cm	6.00 b	15.00 b	18.00 b	22.00 b	22.75 b	22.75 b	22.75 b
CTG - 10 cm	4.00 b	10.00 cd	14.00 c	14.25 de	15.75 d	16.00 d	16.00 d
CTG - 15 cm	1.50 c	5.00 ef	8.00 e	9.00 f	10.00 f	10.50 f	10.50 f
CP - 5 cm	5.00 b	9.00 d	14.00 c	16.00 d	18.00 cd	18.25 c	18.25 c
CP - 10 cm	1.00 c	6.00 e	7.00 ef	7.50 fg	8.25 fg	8.50 f	8.50 f
CP - 15 cm	0.25 c	2.00 gh	2.00 g	2.68 h	3.62 h	4.00 g	4.00 g
WS - 5 cm	5.00 b	12.00 c	17.00 b	19.00 c	19.75 c	21.00 b	21.00 b
WS - 10 cm	1.50 c	7.25 de	11.00 d	12.00 e	13.00 e	13.25 e	13.25 e
WS - 15 cm	0.25 c	3.00 fg	5.00 f	5.25 g	6.00 gh	6.00 g	6.00 g
Weed-free	0.00 c	0.00 h	0.00 g	0.00 j	0.00 j	0.00 h	0.00 h
Weedy	9.00 a	24.00 a	38.00 a	47.00 a	54.50 a	58.00 a	58.00 ±a
Mean	3.04	8.47	12.18	14.06	15.60	16.20	16.20
F	15.141	54.094	151.609	229.377	252.831	432.574	432.574
p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R^2	0.821	0.943	0.979	0.986	0.987	0.992	0.992

Each evaluation was compared within itself. The differences between the means with the same letter are not significant at the 0.05 level.

In the first countinf, the highest weed density was observed in the plots laid out 5 cm grass mulch (6 number/m^2). Subsequent counts consistently showed that the highest weed densities were obtained in the plots applicated 5 cm grass mulch. Furthermore, throughout all the countings, the weed control plots consistently exhibited the highest weed density, falling into a single statistical group. The weed density in these plots was 9 number/m^2 in the first counting, but it increased to 58 number/m^2 in the last counting (Table 6).

Weed densities generally increased between counts and varied depending on the weed control methods (Ateş, 2007). The highest weed densities were observed in the weed control plots (129 number/m^2 and 172.25 number/m^2 at first and second year). Similar to our result, Jodaugiene et al. (2006) stated that increasing the mulch thickness resulted in better weed control, with greater effects observed on annual weed emergence compared to perennial weeds. These findings align with our study. In general, the level of weed control is influenced by the amount of mulch biomass (Teasdale and Mohler, 2000). Çağlar (2022) reported the lowest weed density in plots with a 15 cm thick paper mulch (3.00 numbers/m^2), while the highest weed density among the mulch materials was observed in plots with a 5 cm thick grass mulch (29.00 numbers/m^2). Increasing the thickness of the mulch materials generally led to better weed control. Kaya (2011) indicated that a mulch thickness of 10 cm was most effective and that the impact of the treatments on annual weed emergence was greater than that on perennial weeds. In our study, increasing the mulch thickness resulted in a decrease in weed density, which is consistent with the aforementioned research findings.

It is determined that the effects of mulch materials on weed species varied in the study. Specifically, *S. halepense*, *C. arvensis*, and *X. strumarium* were primarily evaluated due to their homogeneous emergence in the mulch materials. Additionally, other weed species were observed in the plots mulch materials laid out, but when their emergence was not homogeneous, they were evaluated as a whole in terms of weed species seen in the trial area (Figure 1).

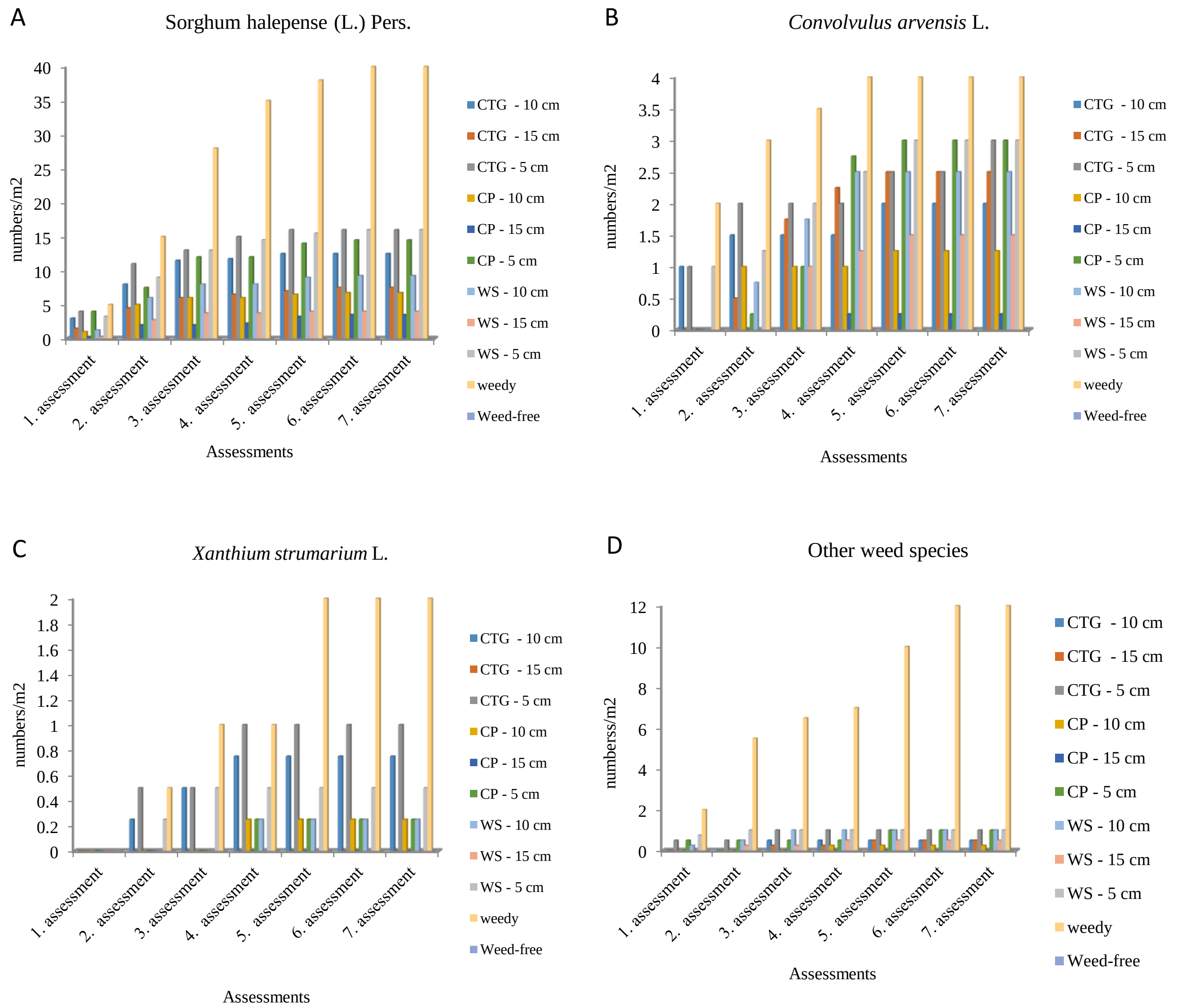


Figure 1. Effect of mulching on *S. halepense* (A), *C. arvensis* (B), *X. strumarium* (C), other weed species (D)

In the final counting, the lowest density of *S. halepense* was observed in the Paper 15 plots (3.5 number/m^2), while the highest density was found in the Grass 5 and Hay 5 plots (16 number/m^2) (Figure 1A). For *C. arvensis*, the lowest density was determined in the Paper 15 plots (0.25 number/m^2), whereas the highest density was observed in the Grass 5 plots (3.5 number/m^2) in the last count (Figure 1B). In the initial count, *X. strumarium* did not emerge in any of the mulched plots. However, in the final counting, the highest density of *X. strumarium* was recorded in the Grass 5 plots

(1.00 number/m^2). It was also noted that *X. strumarium* did not emerge in three plots within the mulched area (Figure 1C). In the last count, the highest density of other weed species, which were collectively evaluated in the countings conducted in the study, was observed in the Grass 5, Straw 5, Paper 5, and Straw 10 plots (1.00 numbers/m^2). Interestingly, no other weed species emerged in the Paper 15 plots at all. Throughout all the counts, the weed control plots consistently exhibited the highest weed densities (Figure 1D). Kaya (2011) reported the emergence of *A. myosuroides*, *Amaranthus* spp., *C. album*, *C. arvense*, *C. juncea*, *C. arvensis*, *M. chamomilla*, *S. arvensis*, *S. nigrum*, *S. oleraceus*, *S. halepense*, *S. media*, and *X. strumarium* weed species in the mulch-laid plots. These findings align with the emergence of *S.halepense*, *X. strumarium*, and *C. arvensis* weed species observed in our study. Furthermore, the total weed densities recorded in the mulch plots were 4.77numbers/m^2 for straw, 3.88 numbers/m^2 for barley, 3.77 numbers/m^2 for vetch, 0.77 numbers/m^2 for clover, and 2.22 numbers/m^2 for canola. Jodaugiene et al. (2006) stated that increasing mulch thickness improved weed control and had a greater impact on annual weed emergence compared to perennial weeds. A continuous increase in weed densities between the first and last counts was also determined in another study (Çağlar, 2022) and the emergence of *S. halepense*, *C. arvensis*, and *X. strumarium* were recorded in the plots with mulch materials laid out. These findings were consistent with the increasing weed densities observed in our study, and *S. halepense* was the most prevalent weed species throughout the countings. Furthermore, the highest weed density was consistently found in the weed control plots. These results align with the findings of the aforementioned studies, demonstrating similarities with our study.

Effect of mulching on weed dry weight

Statistically, there were no significant differences in the effects of various mulch materials with different thicknesses on weed dry weights in Chili pepper (F=60.232 and $p < 0.01$). The study revealed that weed dry weights varied depending on the type and thickness of the mulch materials (Table 7).

Table 7. Weed dry weights

Applications	Weed dry weights (g/m^2)	Rate (%)
CTG - 5 cm	202.63bc	63.89
CTG - 10 cm	180.70bcd	67.8
CTG - 15 cm	139.40de	75.16
CP - 5 cm	230.30b	58.96
CP - 10 cm	89.00e	84.14
CP - 15 cm	54.50ef	90.28
WS - 5 cm	224.68b	59.96
WS - 10 cm	162.56cd	71.03
WS - 15 cm	60.00ef	89.3
Weed-free	0.00f	100
weedy	561.25a	0
Mean	173.18	
F	60.232	
p-value	0.00	
R^2	0.948	

The differences between the means with the same letter are not significant at the 0.05 level.

The lowest weed dry weight was observed in the paper 15 (54 g/m^2) and straw 15 (60 g/m^2) plots among the different mulch materials. Conversely, the highest weed dry weights were recorded in the paper 5 plots (230.30 g/m^2). The weed control plots exhibited the highest weed dry weight, reaching 561.25 g/m^2 (Table 7). Similar findings were reported by Çağlar (2022), the lowest dry weight (42 g/m^2) in 15 cm thick paper plots and the highest dry weight in 5 cm grass plots (210.3 g/m^2). Grassbaugh et al. (2004) and Gurbuz et al. (2021) also demonstrated the effectiveness of mulch materials in controlling weeds, with dry weights ranging from 72.50 g/m^2 to 525.00 g/m^2. Tülek (2021) found the lowest weed dry weight in paper plots (22 g/m^2) and the highest in weed control plots (247.5 g/m^2). Similarly, Alptekin and Gürbüz (2022) reported weed dry weights of 67.63 g/m^2 and 45.12 g/m^2 in their paper plots for the first and second years, respectively. The findings of Usanmaz Bozhüyük et al. (2022) align with the results obtained in our study. Regarding the rate of weed dry weight, the highest rate was observed in the paper 15 plots (90.28%), while the lowest rate was found in the paper 5 plots (58.96%) (Table 8). Ates and Uygur (2013) and Hammermeister (2016) have also highlighted that mulch application can provide partial or complete control of weeds. It is indicated by our data that weeds were predominantly suppressed. Additionally, a percentage effect on weed dry weight of 76.26% in the first year and 81.82% in the second year for their paper plots was reported by Alptekin and Gürbüz (2022).

The effect of mulching on pepper yield ond yield components

To assess the impact of various mulch materials and thicknesses on pepper yield and yield components; plant height, number of fruits per plant, fruit weight, fruit length, fruit diameter, yield, and yield per plant, were evaluated. The results revealed that all of these parameters were significantly influenced by the mulch applications ($p < 0.05$) (Table 8).

Table 8. Pepper yield and yield components

Applica-tions	Plant height (cm)	Fruit number (number/ plant)	Fruit weight (gr)	Fruit length (cm)	Fruit diameter (cm)	Yield per plant (kg/ plant)	Grain yield (kg/da)
CTG - 5 cm	85.75 cde	41.50 de	27 a	9.50 d	3.41 d	1.13 de	2.843.14 de
CTG - 10 cm	100.75 b	44.19 bcd	27a	9.10 de	3.80 cd	1.21 cde	3.032.66 cde
CTG - 15 cm	112.25 a	46.75 bc	30a	13.80 a	4.50 b	1.41 b	3.534.61 b
CP - 5 cm	80.25 de	37.20 f	29a	12.40 b	3.97 c	1.09 e	2.739.12 e
CP - 10 cm	91.75 bcd	48.00 ab	28a	10.82 c	3.80 cd	1.35 bc	3.393.68 bc
CP - 15 cm	93.00 bc	51.15 a	31a	14.20 a	5.40 a	1.57 a	3.940.48 a
WS - 5 cm	78.50 e	39.25 ef	27a	8.70 e	3.80 cd	1.08 e	2.709.72 e
WS - 10 cm	92.50 bcd	40.95 def	29a	12.50 b	4.30 bc	1.20 de	3.000.00 de
WS - 15 cm	100.00 b	43.15 cde	29a	12.80 b	4.80 b	1.25 cd	3.138.63 cd
Weed-free	88.50 bcde	39.43 ef	29a	11.20 c	4.60 b	1.16 de	2.900.99 de
weedy	52.00 f	23.89 g	21b	5.37 ±	2.80 e	0.64 f	1.246.41 f
Mean	88.65	41.40	0.028	10.94	4.10	1.19	2.952.67
F	16.113	31.912	4.264	100.594	16.949	23.214	30.961
p-value	0.000	0.000	0.001	0.000	0.000	0.000	0.000
R^2	0.830	0.906	0.564	0.968	0.837	0.876	0.904

The differences between the means with the same letter are not significant at the 0.05 level.

The average pepper plant height ranged from 52 to 112. 25 cm, and the highest height observed in the 15-cm grass plots (Table 8). Pepper plant height was ranged from 29.38 to 51.62 cm in a similar research (Ateş, 2007). The tallest pepper plant measured 78.45 cm, while the shortest plant was 61.15 cm inThe Old Brahmaputra Floodplain (Ashrafuzzaman et al. (2011).

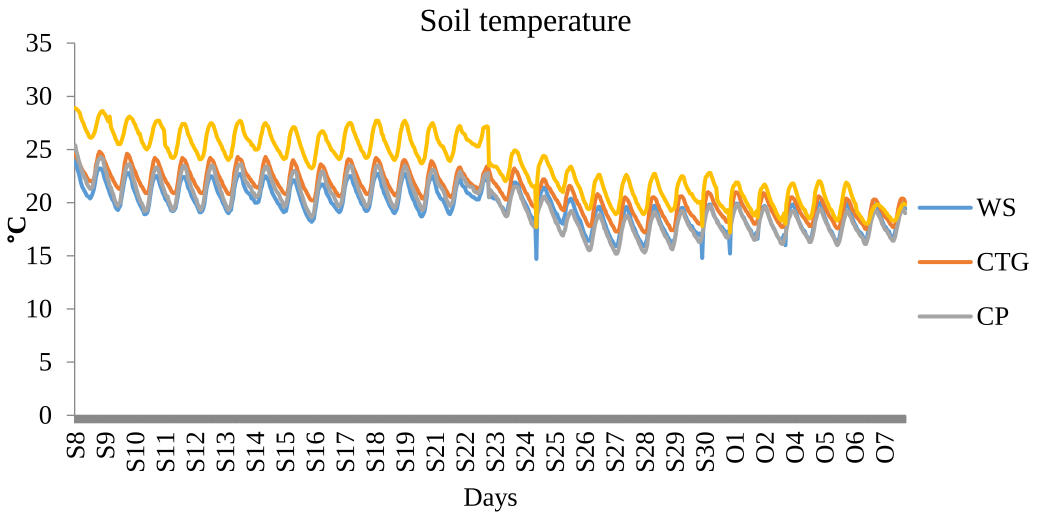
The highest fruit number was recorded in the Paper 15-cm plots with an average of 51.15. The highest pepper fruit weight was obtained in the paper 15-cm (0.31 g) and grass 15-cm (0.30 g) plots. Pepper fruit length varied from 5.37 cm to 14.20 cm, with the highest lengths observed in the paper

15-cm plots (Table 8). Azder et al. (2020) reported the largest fruit length was 14.12 cm and the the narrowest was 11.63 cm in the first year. In the second year, the largest fruit length measured 16.78 cm, while the narrowest was 14.08 cm. Regarding fruit diameter, the averages ranged from 2.80 cm to 5.40 cm, with the highest diameter recorded in the 15-cm paper plots. In a study by Azder et al. (2020), fruit width ranged from 3.99 cm to 4.99 cm in the first year and from 4.37 cm to 5.24 cm in the second year. For pepper yield per plant, the highest values were obtained in the paper 15-cm plots with an average of 1.57 kg per plant and grass 15-cm plots with an average of 1.41 kg per plant (Table 8).

Pepper yield ranged from 1,246.41 kg/ha to 3,940.48 kg/ha. The highest yield was observed in the paper 15-cm (3,940.48 kg/ha) and straw 15-cm (3,534.61 kg/ha) plots. Weed control plots gave the lowest yield and yield components (Table 8). Ateş (2007) reported the highest pepper yield of 1,842.50 kg/ha in polyethylene plots in the first year, and 1,858.13 kg/ha in straw plots in the second year. The lowest pepper yield was observed in the weed control plots in both years (first year: 1,151.88 kg/ha, second year: 1,170.31 kg/ha). In another study, the highest pepper yield was reported as 3,300 kg/ha, while the lowest was 1,600 kg/ha (Argün Yıldız, 2019). Azder et al. (2020) reported pepper yields ranging from 1,991 kg/ha to 3,391 kg/ha in the first year and from 2,074 kg/ha to 4,292 kg/ha in the second year. The pepper yield was 2,820 kg/ha in the first year and 3,148 kg/ha in the second year. In a different study, the lowest pepper yield was determined as 1,346 kg/ha, and the highest as 2,133 kg/ha (Ashrafuzzaman et al., 2011).

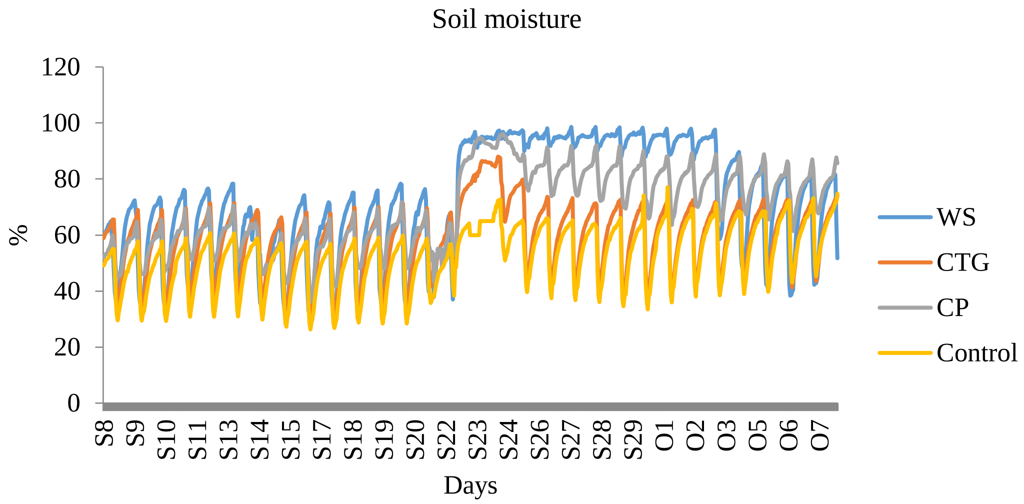
Effect of mulching on soil temperature and moisture

All mulch materials resulted in lower soil temperatures compared to the bare ground (control) plots. Grass exhibited the highest temperature readings, while straw generally had the lowest temperature values. At certain times, temperature reductions of 7.2°C with straw, 6.5°C with paper, and 5.3°C with grass were observed compared to the bare ground (Figure 2). Similar findings were reported by Jia et al. (2020) who observed soil temperature reductions of 2.04°C–3.52°C at a depth of 5 cm using mulch materials. Rafi and Kazemi (2021) found that one type of mulch material reduced soil temperature by 1.6°C, while the other type did not cause any significant change. According to Yusef et al. (2020a), soil temperature can vary depending on soil type, with loamy soil being around 6°C cooler than bare soil and sandy soil being approximately 3.5°C cooler. Chang et al. (2020) reported a soil temperature reduction of 0.8°C–1.4°C with straw mulch. Ramakrishna (2006) observed soil temperatures as low as 6°C at a depth of 5 cm. However, it is important to note that soil temperature reductions due to mulch materials can vary depending on factors such as the type and thickness of the mulch, soil structure, and climate (Yin et al., 2016; Xianchen et al., 2020; Alptekin and Gürbüz, 2022; Busari et al., 2023; Yin et al., 2023). Compared to the bare ground, higher moisture levels were observed in all mulch materials. Among the different mulch materials, straw exhibited the highest moisture values. Moisture levels were occasionally 60% higher in straw, 44.24% higher in paper, and 22.6% higher in grass compared to the bare ground (Figure 3). Similar findings were reported by McMillen (2013), who observed that mulch materials retained more moisture than bare ground, preventing up to 40% water loss at a soil depth of 5 cm. Additionally, greater mulch thickness was associated with higher moisture content. Yusef et al. (2020b) found that mulch materials had 20-25% higher moisture content compared to bare ground. Burg et al. (2022) determined that straw had the highest soil moisture levels among the mulch materials. Mulching has been shown to increase soil moisture and reduce moisture loss (Yin et al., 2016; Saglam et al., 2017; Bavougian and Read, 2018; Jia et al., 2020; Alptekin and Gürbüz, 2022; Yin et al., 2023; Busari et al., 2023). The extent of moisture loss can vary depending on factors such as the type of mulch material, thickness of the mulch layer, climatic conditions, and soil properties.



S: September, O: October, 8-9-10…30-1-2-3..8: Days

Figure 2. Effect of mulching on soil temperature



S: September, O: October, 8-9-10…30-1-2-3..8: Days

Figure 3. Effect of mulching on soil moisture

Multivariate analysis of parameters and applications

In addition to a one-way analysis of variance, various statistical analyses were employed to investigate the relationships, magnitudes, and correlations of the estimated parameters linked to the independent treatments. The utilization of multivariate statistical tools has been widely recognized in the literature for effectively presenting essential study parameters, especially when dealing with numerous dependent and independent variables. Given the pivotal roles that weed density and biomass play in both agricultural and non-agricultural contexts, correlations with other variables were explored. In this context, the correlation coefficients between the variables were initially assessed. Negative correlations between weed density and weed dry weight (-0.809 to -0.926) and all agronomic characteristics of pepper were revealed by our multivariate statistical analysis (Figure 2-3). As anticipated, a positive correlation with weed dry weight (r=0.991***, p<0.001) was exhibited by weed density. However, negative correlations were observed between weed density and the following parameters: pepper yield (r=0.887***, p<0.001), plant height (r=-0.809**, p=0.003), number of fruits per plant (r=-0.839**, p=0.001), fruit weight (r=-0.926***, p<0.001), fruit length (r=-0.815**, p=0.002), fruit diameter (r=-0.829**, p=0.002), and yield per plant (r=-0.857***, p<0.001). Similarly, negative correlations with pepper yield and yield components were exhibited by weed dry weight. When considering the overall analysis of the variables, significant and directionally consistent coefficients were consistently observed (as depicted in Figure 4 and Figure 5).

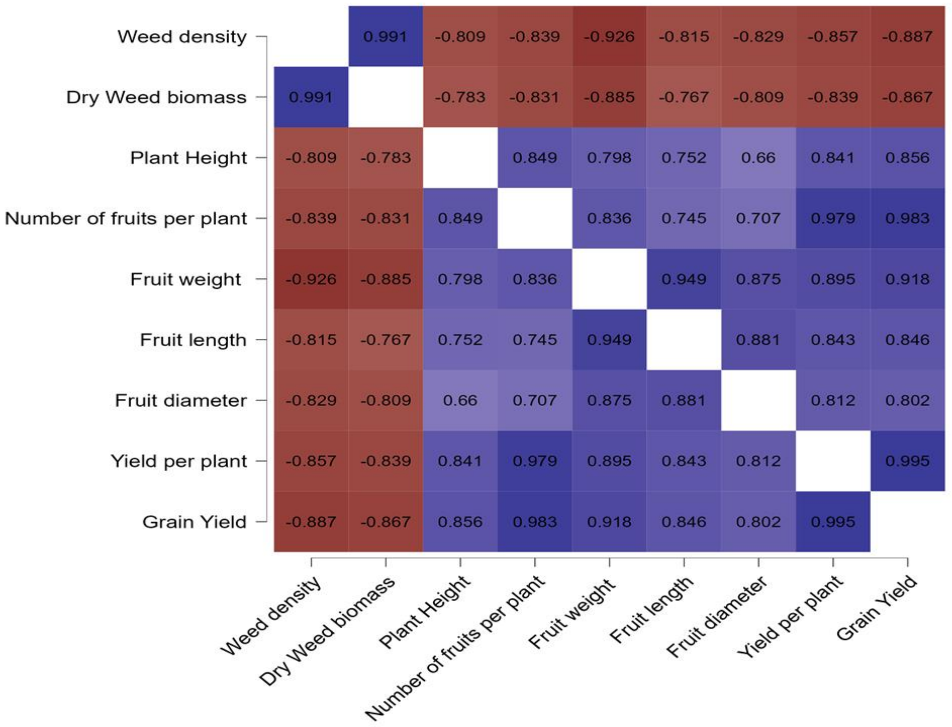


Figure 4. Correlation analysis of predicted parameters

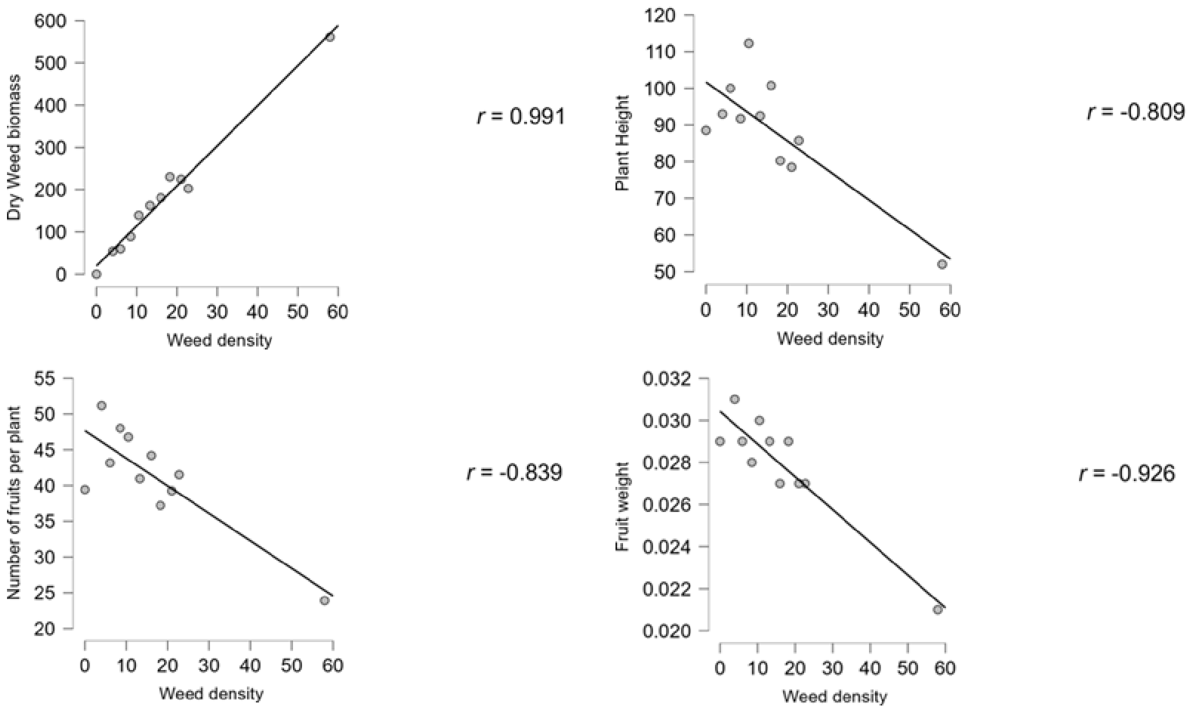


Figure 5. Weed density and other parameter correlations

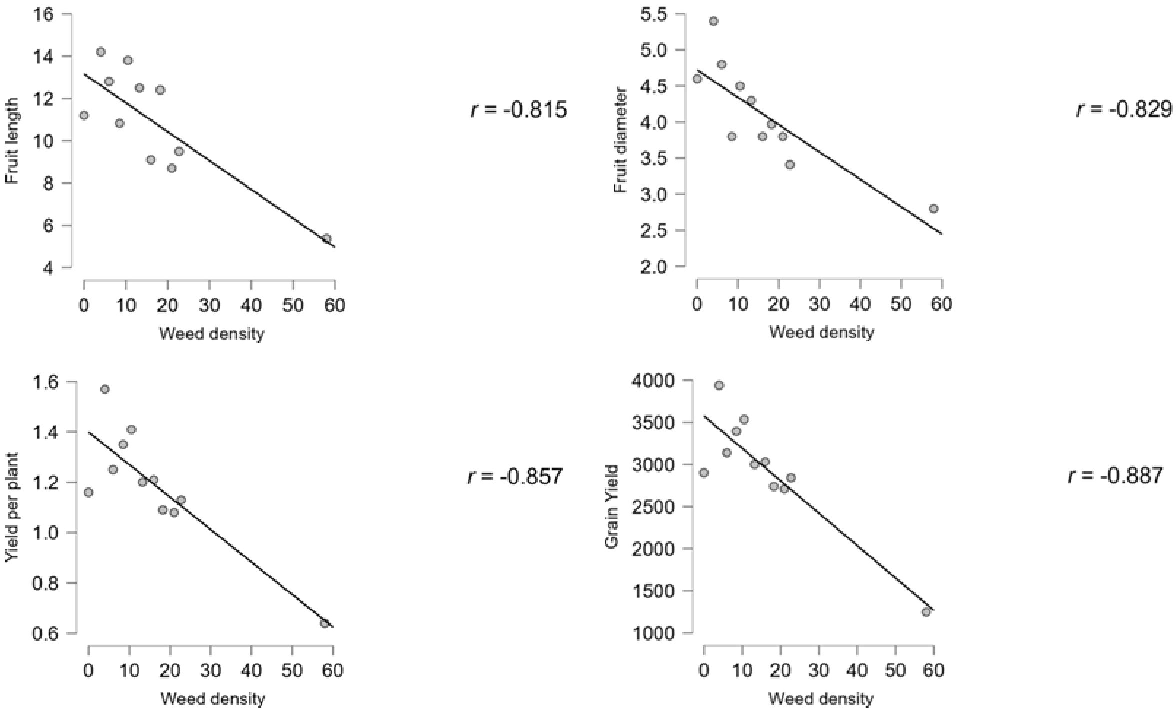


Figure 5. Weed density and other parameter correlations

Therefore, advanced analyses such as heat map clustering, principal component analysis and network plot analysis were performed using the means of the variables. Through heatmap clustering, we were able to clearly distinguish the dependent and independent variables by dividing them into two primary clusters. The range of colors in the heatmap (+4 to -4; red to blue) indicated the corresponding values obtained (refer to Figure 6). Within these clusters, the weed control plots were grouped together, exhibiting the highest weed density and weed dry weight. These findings are based on our comprehensive field research and a wealth of available reports. The study was designed to explore practical management strategies that could effectively mitigate the impact of weeds on plants. The results derived from the heatmap clustering demonstrate the effectiveness of all the mulch materials utilized in the study in weed control, although their effectiveness varied.

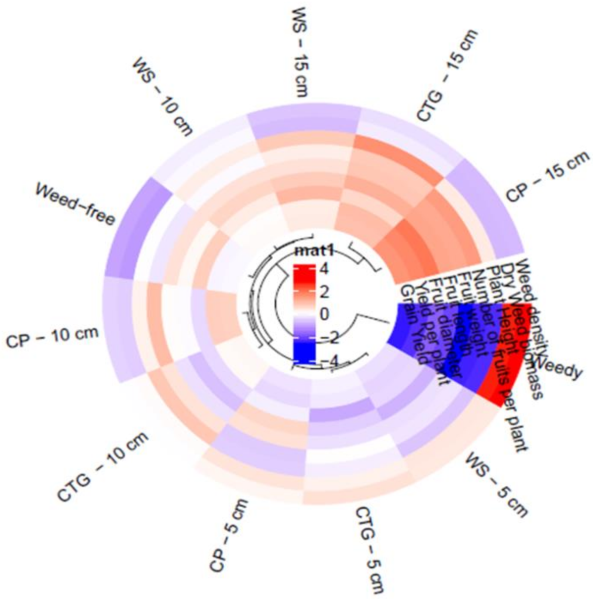


Figure 6. Heatmap of parameters corresponding to applications

To enhance the comprehension of the influence of various trials/treatments on pepper plants, a network graph analysis was performed. This analysis aimed to explore the relationships among treatments based on their effects on agronomic characteristics, weed density, and weed dry weight (refer to Figure 7). The nodes in the graph represent the treatments, while the lines connecting them reflect the strength of the relationships. Thicker and more solid lines indicate stronger connections, while thinner and more open lines represent weaker associations. The results of the network graph analysis were in line with the findings from the heatmap clustering, clearly distinguishing distinct patterns. As expected, there were varying degrees of interconnectedness among the other treatments. However, the weed control group did not exhibit any relationships with the other treatments. To further assess the similarity between treatment groups and determine the extent of their resemblance, similarity indexes were used in conjunction with the nodal points.

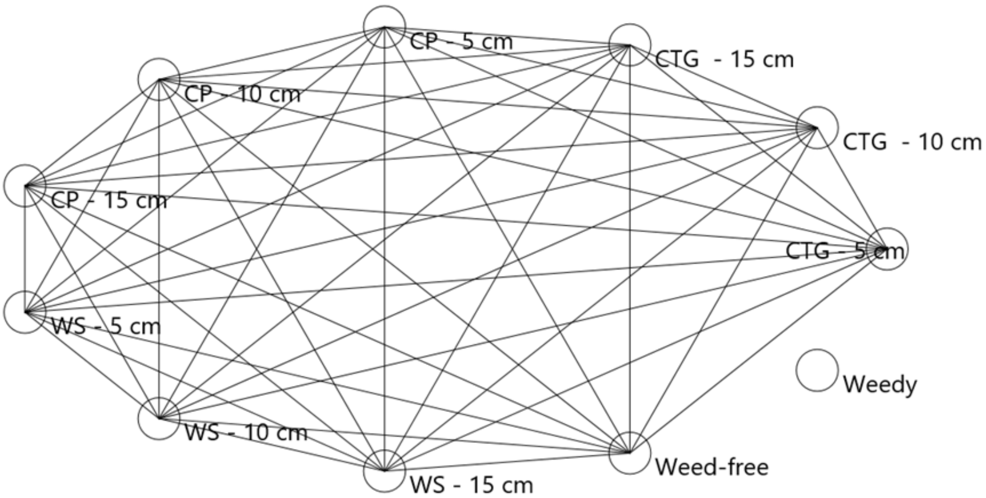


Figure 7. Network graph analysis of applications

The distribution of agronomic characteristics, weed density, and weed dry weight of pepper was visualized using a biplot pair (refer to Figure 8) to explain the variation observed. The first two components, PC1 (86.73%) and PC2 (5.63%), accounted for a total of 92.30% of the original data's variability. This high variance highlights the successful application of principal component analysis in assessing the response of predicted parameters to different treatments.

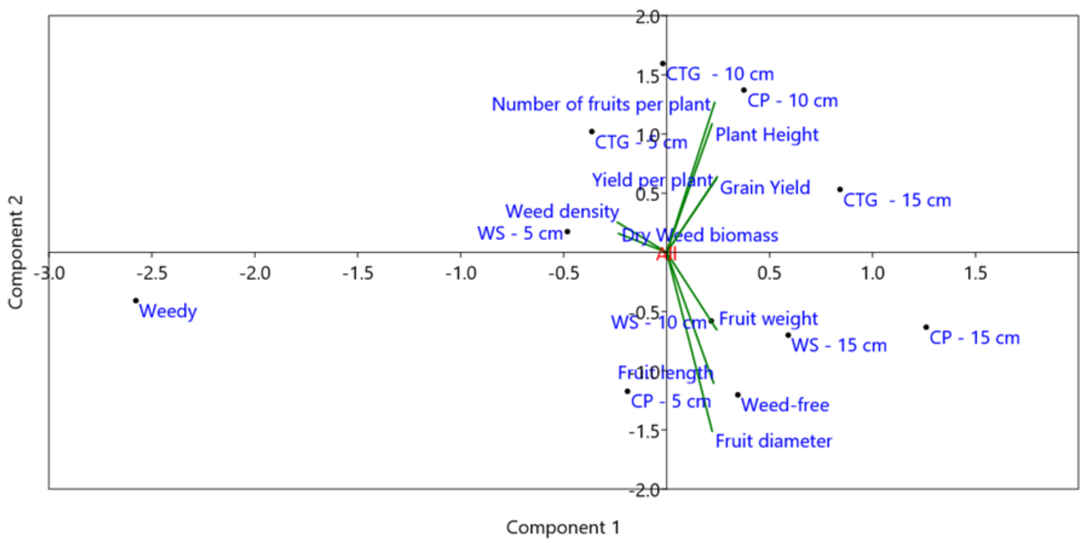


Figure 8. Principal component analysis of parameters and applications

The first component (PC1) displayed negative relationships with the CTG-5 cm group (score of -0.36), CTG-10 cm group (score of -0.018), CP-5 cm group (score of -0.19), WS-5 cm group (score of -0.48), and the weed control plots group (score of -2.57). On the other hand, the remaining applications exhibited positive associations. Additionally, there was a negative correlation between "weed density" (score of -0.32) and "weed dry weight" (score of -0.33), while the other agronomic parameters showed positive correlations.

CONCLUSION

The objective of this research was to assess the impact of various mulch materials with different thicknesses on weed control, soil temperature and moisture, as well as pepper yield in pepper cultivation. The study revealed that the effectiveness of mulch materials varied depending on the type and thickness of the mulch. Annual weeds were more effectively controlled than perennial weeds by the specific mulch materials used. Increasing the thickness of the mulch resulted in lower weed density and weed dry weight. The greatest reduction in weed dry weight was observed in plots with 15-cm paper mulch (90.28%). Similarly, the highest pepper yield was obtained in plots with 15-cm paper mulch (3.940.48 kg/da). Conversely, the weed control plots exhibited the lowest pepper yield and yield components. The study also found that all mulch materials led to lower soil temperature and higher soil moisture compared to the control (bare ground). Consequently, thicker mulch layers resulted in improved weed control and increased pepper yield. Utilizing mulch materials in pepper cultivation is crucial for effective weed management and higher crop productivity. Determining the most suitable mulch material and thickness is essential, with organic-based mulch materials being particularly recommended in arid and semi-arid regions. In the selection of mulch materials, priority should be given to accessibility and affordability, with preference given to materials that are available in the local area.

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Conflict of Interest

The article authors declare that there is no conflict of interest between them.

Author’s Contributions

The authors declare that they have contributed equally to the article.

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