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Weed Management and Yield Outcomes in Strawberry (*Fragaria* x *ananassa* Duch.) Cultivation Using Various Mulching Materials

Enver ARTAN[1] | **Harun ALPTEKIN**[1] | **Ramazan GURBUZ**[1]*

[1] Iğdır University, Faculty of Agriculture, Department of Plant Protection, Iğdır, Türkiye

Correspondence
Ramazan GURBUZ,
E-mail: r_grbz@yahoo.com

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The first year of this study is based on Enver ARTAN's Master's thesis.

Abstract: Weeds are a major problem in the strawberry industry and are a major cause of yield loss and plant growth problems. Effective weed control can help support the healthy growth of strawberry plants, leading to higher yields and better quality. This study was conducted in the Patnos district of Ağrı province in 2022 and 2023 to examine the effects of different mulch materials on weed control and strawberry yield. Thirteen weed species from seven different families were identified in the experimental area. Compared to the control plots with weeds, all mulch materials resulted in lower weed dry weight, lower weed density, and higher strawberry yield. The most effective mulch materials for weed control were found to be wool felt and plastic mulch, while sawdust was observed to reduce weed pressure and increase strawberry yield. The highest strawberry yields in both years were achieved with sawdust (965.07 g and 1025.25 g). Correlation analysis revealed that weed density and dry weight negatively affected strawberry yield and plant growth parameters. However, in the mulched areas, weed density decreased, and strawberry yield increased compared to the control plots. These results indicate that mulch materials can be used as an effective method for sustainable weed management in strawberry cultivation.

Keywords: Chopped Paper, Felt, Mulching, Sawdust, Strawberry, Weed control

INTRODUCTION

The strawberry (*Fragaria* x *ananassa* Duch) is a healthy fruit, rich in bioactive compounds such as vitamin C, folate and phenolic compounds, and has a wide consumer base worldwide (Ağaoğlu and Gerçekçioğlu, 2013; Bayram et al., 2013; Giampieri et al., 2015). A range of health benefits, including anti-inflammatory, anti-cancer and anti-microbial protection, are provided by the antioxidants in strawberries (Basu et al., 2014; Nile and Park, 2014; Sarıdaş, 2021; Castellano-Hinojosa et al., 2022). Because of these qualities, strawberries have become a popular fruit in high demand worldwide, and production continues to increase every year (Hernández-Martínez et al., 2023). Global strawberry production has been rising every year, reaching 9,569,865 tons in 2022. The highest production of strawberries worldwide is in Asia (4,587,368.38 tons), followed by America with 2,343,808.3 tons. With a production of 728,112 tons, Turkey ranks as the third-largest strawberry producer after China and the United States (FAO, 2024). Strawberry production in Turkey has increased every year, from 155,000 tons in 2004 to 676,818 tons in 2023 (TUIK, 2024). Although global strawberry production has continually risen, there are factors that limit production and reduce its quality, one of which is weeds (Daugovish et al., 2008; Samtani et al., 2017; Hoove et al., 2021; Khan et al., 2021; Boyd et al., 2021). One of the most significant factors affecting strawberry productivity is weed control. Weeds compete with strawberry plants for resources such as nutrients, water, light, and space, which decreases yield, reduces harvest quality, and increases costs (Gilreath and Santos, 2005; Yu et al., 2018; Kapur and Şahiner, 2019).

Herbicides, which are frequently used to control weeds (Bo et al., 2017; Su, 2020), are often applied incorrectly and too frequently, negatively affecting human health (Jabłońska-Trypuć et al., 2019) and causing serious environmental and ecological problems (Sardana et al., 2017). Moreover, they can

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leave residues in products (McMurray et al., 1996). The declining availability and increasing cost of herbicides have led strawberry growers to seek non-chemical alternatives (Forcella et al., 2003). In this context, mulching has gained more attention as an environmentally friendly weed control method in strawberry production (Forcella et al., 2003; Gilreath and Santos, 2005; Yu et al., 2018; Kapur and Şahiner, 2019; Sharafati et al., 2021). Mulching provides an alternative approach to combat the negative consequences of chemical control and manage weed problems. It involves applying various cover materials to the soil surface to reduce weed populations, prevent moisture loss, and enhance yield (Forcella et al., 2003; Gilreath and Santos, 2005; Yu et al., 2018). When applied to the soil surface, mulches act as a barrier, blocking light (Iqbal et al., 2020) and physically preventing weed emergence from the soil (Ahmad et al., 2020). The use of mulches in strawberry cultivation can contribute to reduced water consumption and weed infestation (Pinto et al., 2022). Mulching is widely used in strawberry cultivation due to its positive effects on fruit quality and yield (Birkeland et al., 2002; Plekhanova and Petrova, 2002; Şener and Türemiş, 2017). Mulches play an important role in achieving sustainability in modern agricultural production systems. However, it is essential to choose the most suitable mulch type based on soil type, environmental conditions, crops, and the specific goals of mulching (Jabran, 2019). The aim of this study is to determine the effects of different mulch materials on strawberry yield and weed control while ensuring sustainability and reducing producer costs without harming the ecosystem.

MATERIALS and METHODS

This study was conducted in 2022 and 2023 at the Patnos District Directorate of Agriculture and Forestry in the Patnos, Ağrı Province (39°14'19" N, 42°50'32" E). Albion open-rooted Frigo strawberry variety was used in the study. The mulch materials used in the research included wool felt, plastic mulch (nylon), sawdust, and chopped paper (Table 1).

Table 1. *Mulch materials used in the study and their general characteristics.*

Used Materials	General Features	Application Amounts
Chopped Paper	Paper cut vertically into 1 cm sized pieces	1500 kg/da
Sawdust	Pine tree sawdust	2500 kg/da
Wool Felt	Wool felt (1-year-old Morkaraman sheep wool) 5 mm thick	-
Plastic Mulch (Nylon)	100 µm ultraviolet light-resistant plastic mulch (nylon) 400 µm	

Soil samples were taken from a depth of 0-30 cm before planting to represent the experimental field. The soil texture class of the experimental field is Clay-Loam, with the following characteristics: calcium carbonate ($CaCO_3$) content of 5.5%, total salt 2 mmhos/cm, pH value of 7.52, available phosphorus (P_2O_5) value of 0.8 kg da^$^{-1}$, available potassium (K_2O) value of 9.27 kg da^$^{-1}$, and organic matter content of 1.50%.

Strawberry Planting, Care, and Setup of the Experiment

In the study, strawberry seedlings were planted on 25.05.2022 at a spacing of 30 cm between rows and 32 cm between plants along raised beds. The seedlings were planted manually, with two-thirds of the seedling underground and one-third above ground. After planting, a drip irrigation system was installed, and the first irrigation was carried out immediately. Subsequently, irrigation was performed weekly, considering rainfall and the plant's water requirements. The field was divided into plots before the application of mulch materials. In the study, each plot had an area of 6.36 m² (1.2 m x 5.3 m), and 0.5 m wide strips were left between the plots and blocks. The total area of the experimental field was

343 m², and 25 seedlings were planted in each plot. For the partitioning, stakes were fixed to the ground, and strings were used inside the strips. The experiment was set up as a randomized block design with 4 replications and 6 treatments (chopped paper, sawdust, wool felt, plastic mulch, with weeds, and without weeds), resulting in a total of 24 plots. Mulch materials were applied on 30.05.2022 in the first year and 20.05.2023 in the second year. Care was taken not to cover the seedlings with mulch while covering the spaces between the rows and the rows themselves.

Determining the Weed Species and Their Density in the Experimental Field

In both years of the study, before applying the mulch materials to the plots, the weed species and their densities in the experimental field were determined. For this purpose, a 1 m² frame was randomly placed in the field, and the weed species and their counts within the frame were recorded. This allowed for the identification of the weed species present and the density of each species. Weed densities were calculated based on the arithmetic mean of the observations. The density (plants/m²) of each weed species was calculated by dividing the total number of plants in the observed area by the number of observations made (Odum, 1971).

Density (plants/m²) = B/m

B = Total number of individuals in the sample

m = Total number of samples

Additionally, the density of weed species was ranked according to the scale provided by Üstüner and Güncan (2002), as shown in

Table 2. *Density Scale*

Classification	Density Level	Density (plants/m²)
A	High Density	10+
B	Dense	1 - 10
C	Medium Density	0.1 - 1
Ç	Low Density	0.01 - 0.1
D	Rare	Less than 0.01

Effect of Mulching on Weed Growth

In order to determine the effect of mulching materials on weed emergence, weed densities in m² were counted every 30 days. A total of three counts were made on the following dates: 25.06.2022, 25.07.2022, and 25.08.2022. Weed densities in the plots were evaluated by considering the total m² of weed density. Additionally, in weed-free (hoeing) plots, hoeing was done along with weed emergence. To determine the weed density in all applications, 1x1 m frames were used. The density values for each counting date were calculated using the density formula of Odum (1971) mentioned above. The total weed count to be determined was divided by the total area counted to calculate the densities of the applications.

Effect of Mulching on Weed Dry Weights

Before the final strawberry harvest, weeds present in a 1 m² area in each plot were cut from the soil surface and placed in paper bags, then transported to the Department of Plant Protection Herbology Laboratory at Iğdır University. In the laboratory, the samples were dried at 70°C for 72 hours in an oven. After drying, the dry weights of the weeds were measured individually, and numerical data were recorded. In this way, the dry weights of weeds in each 1 m² area in each plot were determined.

Additionally, the percentage effects of mulching treatments on weed dry weights were determined in comparison with the weed-infested control plots.

Effect of Mulching on Strawberry Yield Components and Yield

Strawberry harvesting occurred in the first year from 04.07.2022 to 04.09.2022, and in the second year from 05.06.2023 to 05.09.2023. The harvested strawberry fruits were transported to the Herbology Laboratory at the Iğdır University Şehit Bülent Yurtseven Campus, Faculty of Agriculture. To determine the effects of different mulching materials on yield factors and yield, the following parameters were evaluated: plant height (cm), fruit length (mm), fruit width (mm), soluble dry matter (SÇKM %) content, fruit weight (g), yield per plant (kg), and total yield (kg/da). Fruit and fruit factors were compared in mulched plots with weed-infested control and weed-free (hoeing) control plots. The obtained values were compared between mulched plots and the weed-infested and weed-free control plots.

Data Analysis

The weed densities, weed dry weights, and strawberry yield components were evaluated based on the results of three separate counts. The data were subjected to one-way analysis of variance. Means were compared using Duncan's multiple comparison test ($p<0.05$) (SPSS 20). In addition, various statistical analyses were performed to associate the study's findings. After data transformation/normalization, correlation analysis (JASP) was used to determine the strength and weakness of relationships between variables, cluster analysis using a heatmap (SRplot) was done to visualize data density and identify similar groups. Hierarchical clustering analysis (SRplot) was performed to group applications based on similarities, and network graph analysis (PAST software) was used to determine and visualize relationships between variables. Principal component analysis (PAST Software) was also performed to reduce multivariate data to a smaller dimensional area and identify key variables.

RESULTS and DISCUSSION

Weed Species and Densities in the Trial Area

In the trial area, 13 weed species from 7 different families were identified in 2022, while in 2023, 10 weed species from 6 families were identified. The families, scientific names, common names, and life cycles of the weed species identified in the trial area are presented in Table 3.

Among the weed species identified in the experimental field, 2 are narrow-leaved and 11 are broad-leaved. Additionally, of the identified weeds, 9 are annual species, 3 are perennial, and 1 is both an annual and perennial species. The most prevalent weed species include *Convolvulus arvensis* and *Chenopodium album*. *Convolvulus arvensis* showed high density (B) in both years, with a density of 5.5 plants/m² in 2022 and 5.00 plants/m² in 2023. *Chenopodium album* also had high density (B) with 3.00 plants/m² in 2022 and 2.50 plants/m² in 2023 (Table 3). Similar weed species were also found in a previous survey conducted in the region in various crops (Gürbüz et al., 2018; Savcı and Gürbüz, 2023). This shows that these weed species are adapted to the local climate and are common in similar climatic conditions. The weed species identified in the experimental field show both similarities and differences when compared to species reported in different studies. For example, Elmore (1991) highlighted the prevalence of species like *Poa annua and Chenopodium album*, which aligns with the findings in the experimental field. In a study by Boz et al. (2002), weeds such as *Portulaca oleracea, Cyperus rotundus, Amaranthus retroflexus*, and *Polygonum aviculare* were identified, which supports the findings in the experimental field. Giannapolitis (2021) noted that *Echonocloa crus-galli, Setaria* spp., *Chenopodium album*, *Amaranthus* spp., and *Cyperus rotundus* are prevalent in strawberry fields. Furthermore, the study by Gradila et al. (2023) also identified weed species such as *Chenopodium album*, *Polygonum aviculare*, and *Convolvulus arvensis* in strawberry planting areas, which show similarities to the species found in the experimental field. In conclusion, the weed species identified in the experimental field largely overlap with those reported in the literature.

Table 3. *Weed Species Identified in the Trial Area, Their Families, Scientific Names, Common Names, and Life Cycles*

Family	Latin Name	Common Name	LC	2022 year		2023 year	
				Y.(plants/m²)	**DC**	**Y.**(plants/m²)	**DC**
Monocots							
Poaceae	*Poa annua* L.	Annual Bluegrass	A	0,50	C	-	-
Cyperaceae	*Cyperus rotundus* L.	Purple Nutsedge	P	2,50	B	2,00	B
Dicots							
Amaranthaceae	*Chenopodium album* L.	Fat Hen	A	3,00	B	2,50	B
	Amaranthus albus L.	Tumble Pigweed	A	2,50	B	2,75	B
	Amaranthus retroflexus L.	Redroot Pigweed	A	0.75	C	0,25	C
Convolvulaceae	*Convolvulus arvensis* L.	Field Bindweed	P	5.5	B	5,00	B
Portulacaceae	*Portulaca oleracea* L.	Common Purslane	A	0,5	C	0,5	C
	Polygonum aviculare L.	Prostrate Knotweed	A	0,25	C	-	-
Asteraceae	*Anthemis arvensis* L.	Corn Chamomile	A	0,1	C	-	-
	Lactua sarriola L.	Prickly Lettuce	P-A	1,5	B	1,00	B
	Crepis foetida L.	Stinking Hawksbeard	A	0,5	C	0,75	C
	Achillea millefolium L.	Common Yarrow	A	0,5	C	0,25	C
Euphorbiaceae	*Euphorbia cyparissias* L. (EPHCY)	Cypress Spurge	P	0,5	C	0,5	C

*: A; Annual, P; Perennial, A = High density = 10.00 plants/m², B = Dense = 1.00-10.00 plants/m², C = Moderate density = 0.10-1.00 plants/m², LC = Life Cycle, D = Density, DC = Density Class

Effect of Mulching on Weed Density

It was determined that there were differences in weed density between the three surveys conducted at specific intervals, and these differences varied according to the mulching materials. Statistically significant differences ($p<0.01$) in weed density were observed between the mulching materials in both years and at each survey time. The average values of the effect of mulching on weed density in strawberry and the resulting groups are shown in Table 4.

In all three assessments, the highest weed densities were determined in the weedy control plots. In the final survey, the weed density in these plots was 21.50 weeds/m² in 2022, and 24.00 weeds/m² in 2023. Among the mulching materials, the highest weed densities were observed in the shredded paper plots, with 4.75 weeds/m² in 2022 and 6.5 weeds/m² in 2023. It was observed that there was very little weed emergence in the plastic mulch and wool felt plots. Overall, all mulching materials resulted in lower weed densities compared to the weedy control plots. Mulching has emerged as an effective method for weed control in strawberry cultivation. Pinto et al. (2022) stated that mulching inhibits the growth of weeds and significantly reduces weed infestation. Similar studies by Yu et al. (2018), Kapur and Şahiner (2019), and Sharafati et al. (2021) also emphasized that mulching is an effective method for weed control in strawberry fields. Mulch covers the soil surface, preventing weeds from receiving sunlight, thus limiting their growth and enabling their control. Sharafati et al. (2021) demonstrated that polyethylene mulch was more effective in weed control compared to non-mulched treatments. Similarly, Gradila et al. (2023) noted that mulching effectively controlled weeds. In general, your study concludes that weed density is lower in mulched plots compared to the control plots, aligning with other research in the literature and demonstrating the effectiveness of mulching methods in weed management. In this regard, the success of the mulching material in weed control varies depending on the different materials used.

Table 4. *Means and groupings of the effect of mulching on weed growth in strawberry*

Treatments	**1st. assessment**			**2nd. assessment**			**3rd. assessment**		
	2022 Year	**2023 year**	**Mean**	**2022 Year**	**2023 year**	**Mean**	**2022 Year**	**2023 year**	**Mean**
WS	1,50b	0,5b	1,00b	3,25b	4,00b	3,63b	4,00b	4,25b	4,13b
SP	2,25b	1,25b	1,75b	3,75b	4,50b	4,13b	4,75b	6,5b	5,63b
Weedy	4,00a	6,00a	5,00a	5,50a	12,5a	9,00a	21,50a	24a	22,75a
Weed-free	0c	0c	0,00c	0,00c	0c	0,00c	0,00c	0c	0,00c
PMN	0c	0c	0,00c	0,25c	0,25c	0,25c	0,50c	0,25c	0,38c
WF	0c	0c	0,00c	0,25c	c	0,13c	0,25c	0,00c	0,13c
Mean	1,62	1,29	1,46	2,33	3,58	2,96	5,33	5,92	5,63
F	32,46	47,82	20,45	26,85	14,42	37,65	43,79	39,68	52,75
P	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
R^2	0,90	0,92	0,88	0,88	0,91	0,92	0,92	0,88	0,89

WS; Wood Shavings, SP; Shredded Paper, PMN; Plastic Mulch (Nylon), WF; Wool Felt
Differences between means indicated by the same letter are not significant at the 0.05 level.

Effect of Mulching on Weed Dry Biomass Weights in Strawberries

When evaluating the effects of different mulching materials on weed dry biomass weights in strawberries, statistically significant differences (p<0.01) were found between mulching materials at the 1% level in both years. The average values for weed dry weights in strawberries for the mulching materials are shown in Table 5.

Table 5. *Effect of mulching on weed dry biomass weights(g) in strawberries*

Treatments	**2022 year**		**2023 year**		**Means**	
	Weed Dry Weights (g)	**Effect (%)**	**Weed Dry Weights (g)**	**Effect (%)**	**Weed Dry Weights (g)**	**Effect (%)**
WS	46,50b	75,65	58,00c	75,63	52,25	75,64
SP	31,00c	83,77	74,25b	68,80	52,62	76,29
Weedy	191,00a	0,00	238,00a	0,00	214,5	0,00
Weed-free	0,00d	100,00	0,00d	100,00	0,00	100,00
PMN	3,25d	98,30	2,25d	99,05	2,75	98,68
WF	2,00d	98,95	0,00d	100,00	1,00	99,48
Mean	47,29b		62,08bc			
F	114,660		178,126			
P	0,000**		0,000**			
R^2	0,970		0,898			

** p<0,01, WS; Wood Shavings, SP; Shredded Paper, PMN; Plastic Mulch (Nylon), WF; Wool Felt
Differences between means indicated by the same letter are not significant at the 0.05 level.

In the study, the highest dry weight (2022 = 46.50 g, 2023 = 58.00 g) and the lowest percentage effect (2022 = 75.65%, 2023 = 75.63%) among the mulching materials were determined in the "Coarse

Sawdust" treatment. The lowest weed dry weights and highest effect rates were observed in the "Wool Felt" treatment, which achieved 2.00 g of dry weight and 98.95% effect in 2022, and 0.00 g of dry weight with 100% effect in 2023. In both years, all mulching materials resulted in lower weed dry weights compared to the weed control plots. The findings of this study are consistent with other studies in the literature regarding the contribution of mulching practices to weed control. Grassbaugh et al. (2004) and Hammermeister (2016) reported that different mulching materials (e.g., tree bark, black polyethylene, newspaper, wheat straw) significantly suppressed weed emergence. Similarly, in our study, plastic mulch and wool felt were observed to significantly reduce weed density. Studies by Ateş and Uygur (2013) and Bozhüyük et al. (2022) also emphasized that mulching materials (e.g., polyethylene, straw) are effective in controlling weed emergence. Alptekin and Gürbüz (2022) and Tülek et al. (2022) found that the lowest weed dry weights were generally obtained from plots mulched with paper and straw. In our study, particularly in shredded paper plots, low weed density was observed, while the highest density values were recorded in the weed control plots. In this context, our findings are consistent with the current literature on weed control; however, it is evident that some mulching materials show varying effects under different environmental conditions or across years. These differences may be related to factors such as mulching material thickness, climatic conditions, and the type of crop.

Effect of Mulching Materials on Strawberry Yield and Yield Components

When evaluating the effects of different mulching materials on strawberry yield and yield components, statistical differences were observed in all parameters except for the percentage of water soluble dry matter content (TSSC) (%) in both years. The effects of mulching materials on strawberry yield and yield components are shown in Table 6.

In trials with different mulch applications, differences in plant height, fruit length, fruit width (diameter), SEDM (Standard Emergence Dry Matter), fruit weight, and total yield were observed. The highest total yield was obtained with the "Coarse Sawdust" treatment in both years (2022 = 965.07 g, 2023 = 1025.25 g). The lowest total yield in the study was recorded in the weed control plots, with 580.53 g in 2022 and 630.1 g in 2023. In general, coarse sawdust and wool felt yielded high and similar results. Plastic mulch (nylon) and shredded paper mulches showed similar performance in average yield and other parameters. The impact of different mulch materials on yield and quality parameters in our study showed both similarities and some differences compared to other studies in the literature. Specifically, the findings that coarse sawdust and wool felt were effective in weed control and provided high yields are consistent with the results reported by Pinto et al. (2022) and Forcella et al. (2003). These studies also reported that different mulch types reduced weed density and had positive effects on strawberry plants. However, in our study, the weed control plots showed lower yields, which aligns with the findings of Sharafati et al. (2021) and Saeed et al. (2020), which indicated that mulching applications contribute to weed control. On the other hand, the coarse sawdust, wool felt, and shredded paper mulches used in our study provided higher yields compared to plastic mulches. While Gupta and Acharya (1993) and Geçer et al. (2018) mentioned that plastic mulches can provide high yields, differences might occur depending on climate conditions and the strawberry variety used. For instance, Johnson and Fennimore (2005) found that biomass and yield varied by mulch type, and plastic mulches sometimes provided higher yields in strawberries. However, in our study, organic mulches such as shredded paper were found to significantly contribute to yield. Our findings support those of Özkaplan (2010) and Ullah et al. (2021), who found that mulching increases yield. These results suggest that different mulch types in strawberry cultivation may perform differently depending on climate, variety, and mulch material. In this context, organic mulches may positively impact yield, and mulch preferences may vary based on climate conditions and strawberry varieties.

Table 6. *Effects of mulching materials on strawberry yield(kg/da) and yield components*

Treatments	Plant Height (cm)	Fruit Length (mm)	Fruit Diameter (mm)	SDMC (%)	Fruit Weight (g)	Yield (kg/da)
WS	21,75a	34,58a	30,28a	13,12a	16,08a	965,07a
SP	22,10a	33,45a	28,93a	11,25a	12,70abc	762,27abc
Weedy	15,85b	19,18b	16,88b	10,75a	9,68d	580,53d
Weed-free	25,15a	32,17a	28,05a	12,75a	13,01abc	780,45abc
PMN	22,95a	32,50a	28,24a	12,37a	11,81bc	708,75bc
WF	23,90a	34,97a	30,05a	13,12a	14,96ab	897,87ab
Mean	21,95a	31,14	27,07	11,89	13,04	782,49
F	8,805	12,097	9,778	2,645	3,887	3,887
P	0,000**	0,000**	0,000**	0,058	0,015*	0,015*
R^2	0,710	0,771	0,731	0,424	0,519	0,871
WA	24,25a	35,25a	29,32a	12,20a	17,20a	1025,25a
SP	25,40a	34,18a	27,50a	11,75a	14,05ab	901,35bc
Weedy	17,35b	21,74b	17,24b	11,15a	10,30d	630,1d
Weed-free	25,05a	33,32a	29,40a	12,15a	13,95abc	895,55bc
PMN	24,25a	32,72a	28,10a	12,95a	12,10bc	823,4c
WF	25,60a	34,27a	29,25a	13,00a	14,08ab	945,72ab
Mean	23,65	31,91	26,80	12,20	13,61	870,23
F	15,058	10,465	22,872	1,964	8,469	5,354
P	0,000**	0,000**	0,000**	0,075	0,008**	0,022*
R^2	0,805	0,75	0,845	0,384	0,705	0,755
WA	23,00a	34,91a	29,80a	12,66a	16,64a	995,16a
SP	23,75a	33,81a	28,215a	11,50a	13,37ab	831,81bc
Weedy	16,60b	20,46b	17,06b	10,95a	9,99d	605,31d
Weed-free	25,10a	32,74a	28,725a	12,45a	13,48ab	838,00bc
PMN	23,60a	32,61a	28,17a	12,66a	11,95bc	766,07c
WF	24,75a	34,62a	29,65a	13,06a	14,52ab	921,79ab
Mean	22,8	31,525	26,93	12,04	13,325	826,36
F	10,548	2,58	5,785	3,241	10,236	6,453
P	0,000**	0,000**	0,000**	0,06	0,021*	0,02*
R^2	0,75	0,8	0,762	0,412	0,75	0,895

** p<0,01, *p<0,5 WS; Wood Shavings, SP; Shredded Paper, PMN; Plastic Mulch (Nylon), WF; Wool Felt, SDMC; soluble dry matter content Differences between means indicated by the same letter are not significant at the 0.05 level.

Multivariate Analysis of Parameters and Applications

In addition to one-way analysis of variance, the mean values obtained were subjected to a series of statistical analyses, including correlation, heatmap clustering, network graph analysis, hierarchical clustering, and principal component analysis to visualize the relationships between parameters. Since weed dry weight and density are critical issues in both agricultural and non-agricultural areas, their relationships with other parameters were examined. In this context, correlation coefficients, heatmap clustering, network graph analysis, hierarchical clustering, and principal component analysis were performed.

The correlation analysis results show that there is a strong positive relationship between weed dry weight and weed density (r = 0.998, p < .001). However, both weed dry weight and density showed negative relationships with strawberry yield and yield components. The strongest negative relationship with weed dry weight was found with plant height (r = -0.977, p < 0.001), and the weakest negative relationship was with fruit weight (r = -0.582, p = 0.225). Similarly, with weed density, the strongest negative relationship was with plant height (r = -0.977, p < 0.001), and the weakest negative relationship was with fruit weight (r = -0.630, p = 0.180). These results show that increasing weed biomass and density exert pressure on plant parameters, and as weed dry weight and density increase, a significant reduction in plant growth occurs. On the other hand, positive relationships were observed between plant parameters. The strongest positive relationship was between yield and fruit weight (r = 0.987, p < 0.001), and the weakest positive relationship was between fruit weight and plant height (r = 0.650, p = 0.162). These relationships are visualized in Figure 1 and Figure 2.

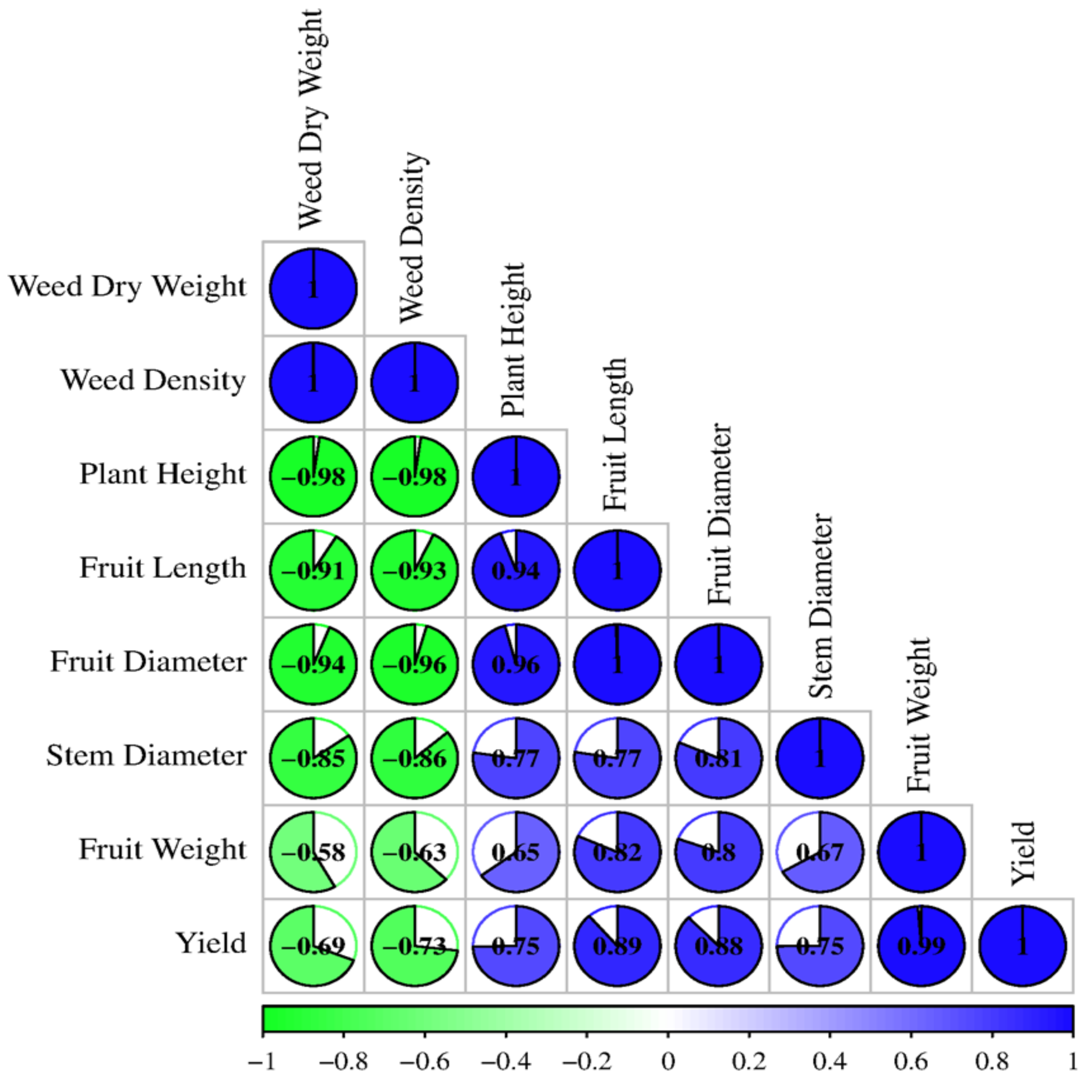

Figure 1. *Correlation analysis of estimated parameters*

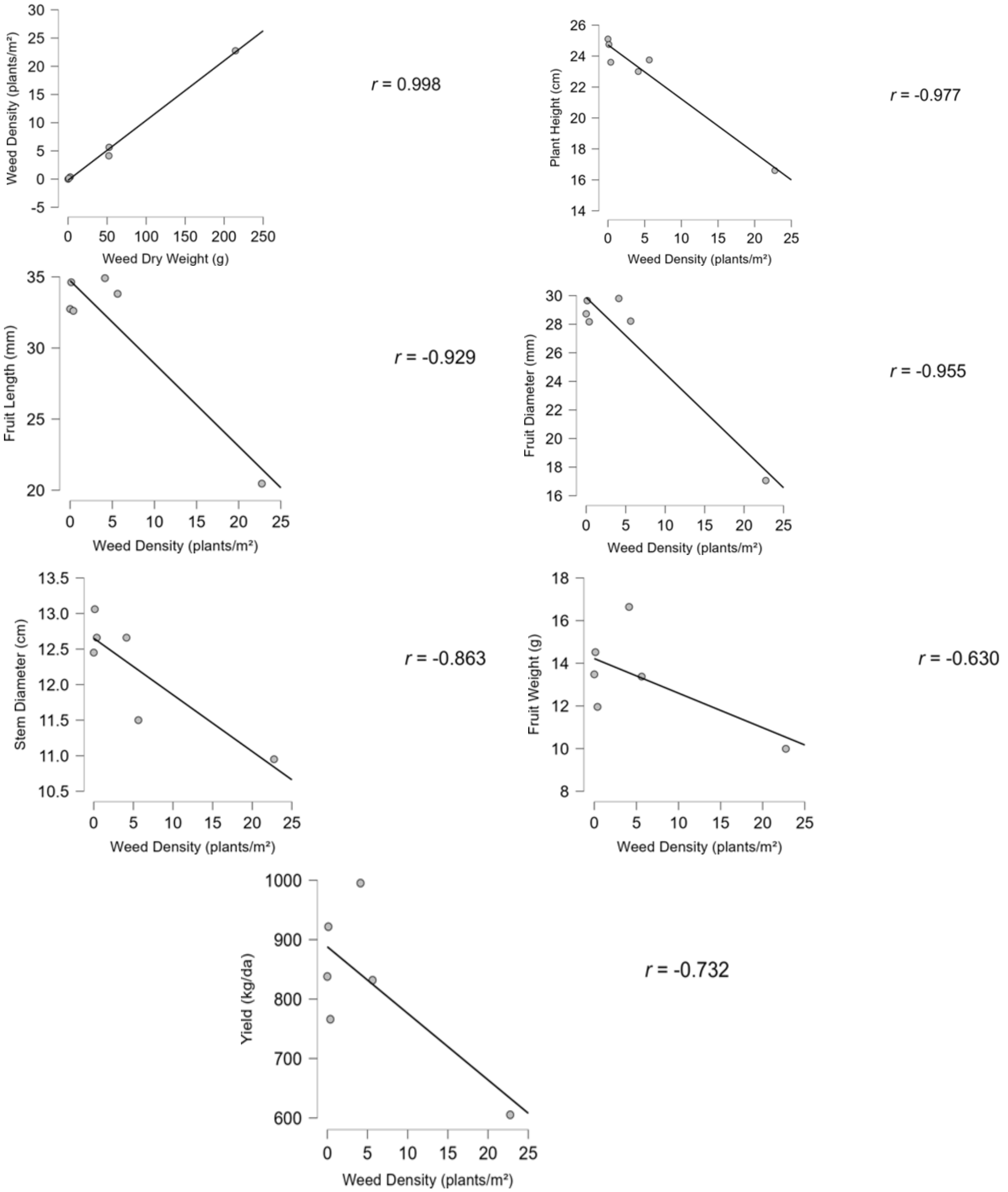

Figure 2. *Correlation between weed density and other parameters*

The heatmap clustering analysis clearly distinguishes two main clusters with a color gradient ranging from red (+2) to blue (-2), highlighting the relationships between dependent and independent variables. One of the clusters consists of the weed-free control plot. The results of this clustering reveal that despite the variations in the mulch materials used in the study, they have all proven effective in controlling weeds.

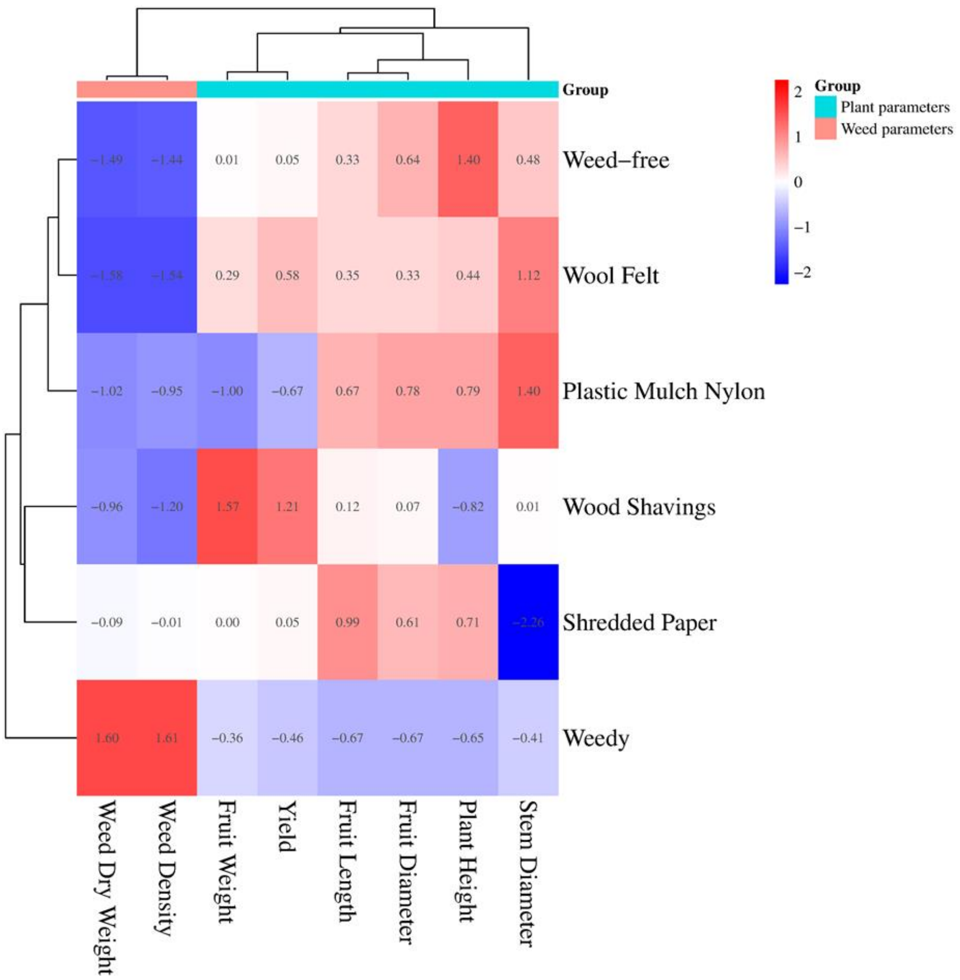

Figure 3. *Heatmap of parameters corresponding to treatments.*

A hierarchical clustering analysis was performed to evaluate strawberry yield, yield components, weed dry weight, and density, as well as to identify similarities between different treatments. In addition to hierarchical clustering, a network graph analysis was conducted to detect relationships between treatments. While hierarchical clustering provides a general classification, the network graph analysis makes the classification more meaningful by indicating the strength of the relationships between clusters, allowing for a more detailed analysis. Using both methods together provides a more comprehensive approach to examining and evaluating the relationships between different treatments. As a result of the hierarchical clustering, the treatments were grouped into two main categories. In the first group, the weed-infested control was placed alone, while in the second group, the wood chip mulch was isolated. In the network graph analysis, the thickness of the lines indicates the strength of the relationships. Thicker lines represent stronger relationships, while thinner or lighter lines indicate weaker relationships. Consistent with the heatmap clustering, a clear separation emerged. In this analysis, the weed-infested control group did not show any relationships with other treatments. The remaining treatments, however, exhibited varying degrees of association with each other. The main findings from these analyses suggest that different treatments had varying degrees of impact on strawberry yield and yield components, with weed control playing a significant role.

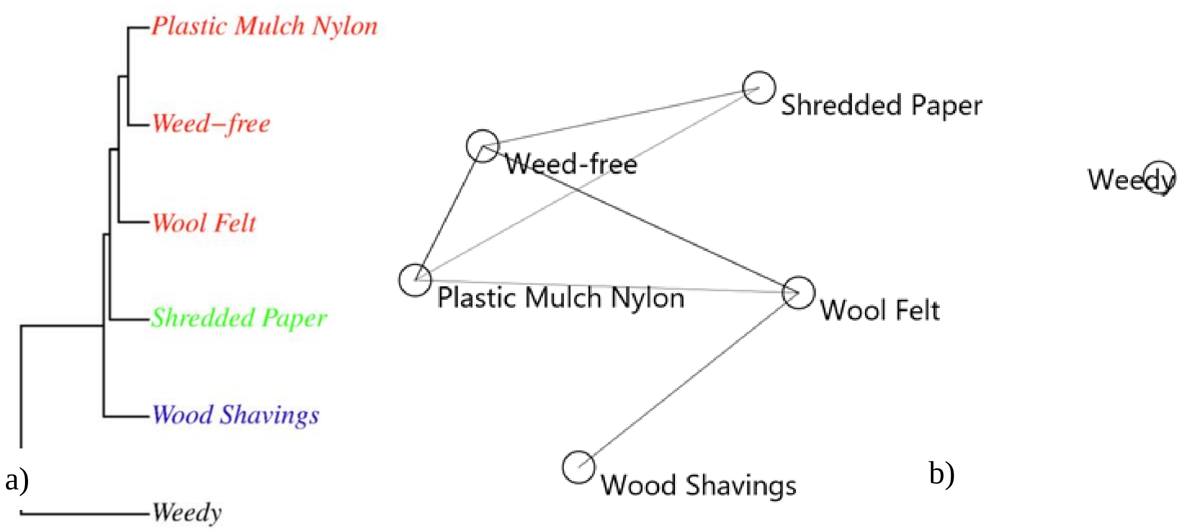

Figure 4. *Treatments: a) Hierarchical clustering analysis and b) Network graph analysis.*

To better understand the effects of different mulch treatments on strawberry yield and other yield components, and to assess the combined effects of variables to determine which factors have the greatest impact on yield, Principal Component Analysis (PCA) was performed. To explain the variation rate, quinoa's agronomic characteristics and weed dry weight were plotted on a biplot (Figure 5). The first two components (PC1: 86.13% and PC2: 9.71%) explained 95.84% of the total variability in the original data. This high variance explained demonstrates that PCA can be successfully used to evaluate the effects of treatments on the predicted parameters. The first component (PC1) showed a negative relationship with the weed control treatment (-1.97 points), while being positively associated with other treatments. This component also had a negative relationship with weed dry weight (-0.35 points) and weed density (-0.36 points), while other parameters were positively correlated (Figure 5).

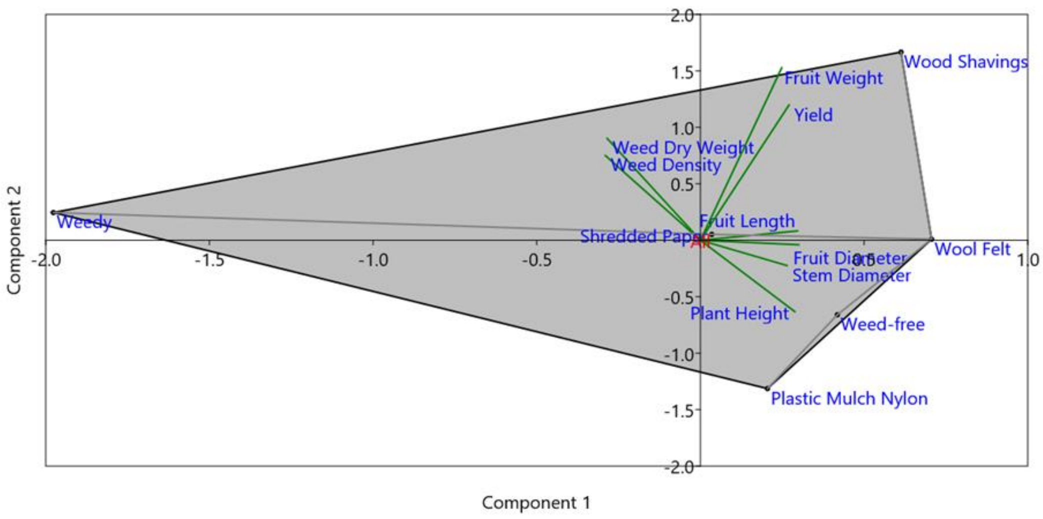

Figure 5. *Principal Component Analysis of parameters and treatments.*

The correlation of the average values of the variables, along with advanced analyses such as heatmap clustering, hierarchical clustering, network graph analysis, and principal component analysis, supports the variance analysis and can be considered highly effective in clustering the findings and reducing the dimensionality of the variables considered in the analysis. Overall, the effects and relationships between the treatments and parameters have been clearly outlined.

CONCLUSION

Acccording to the results of the study, the most effective mulch material for weed control was "Wool Felt and Mulch (Nylon)," which resulted in the lowest weed dry weight and the highest effectiveness rates in both years. The mulch materials also had positive effects on strawberry yield, with the highest total yield values obtained from coarse sawdust. On the other hand, the yield in weed-infested control plots remained at the lowest levels, indicating that weeds negatively affect strawberry yield and growth parameters. Correlation analyses revealed negative relationships between weed dry weight and density with strawberry yield and yield components. These findings suggest that the increasing density of weeds suppresses the growth and development of strawberry plants. As a result, mulch applications for weed control in strawberry cultivation emerge as an effective method. Wool felt and coarse sawdust were identified as the most suitable mulch materials for providing high effectiveness and yield increase. Based on the findings of this study, using these mulch types in areas with high weed density is beneficial for protecting strawberry plants from weed competition and enhancing yield. The long-term effects of mulch use, in combination with integrated weed management strategies, should be investigated, and sustainable solutions could be developed.

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AUTHOR CONTRIBUTIONS

The authors contributed equally to this study.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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