



Investigation of the opportunities of using cover crops for weed control in corn (*Zea mays* L.) production

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Abstract Corn is a key agricultural crop with high grain yield, but effective weed control is essential for maximizing production. While herbicides and mechanical methods are common, herbicides can harm sustainable agriculture, necessitating alternative approaches. This study, conducted at the experimental field of the Agricultural Research and Treatment Centre of Erciyes University (Kayseri-Turkey) (ERUTAM), investigated the possibilities of using cover crops for weed control in grain corn cultivation. The experiment was established according to the split plot design in randomized blocks with four replications and consisted of a total of 7 characters, six of which were cover crop treatments and 1 control plot. Cover crops, including 100 kg ha⁻¹ *Vicia villosa* Roth, 20 kg ha⁻¹ *Secale cereale* L., 100 kg ha⁻¹ *Vicia pannonica*, 20 kg ha⁻¹ *Brassica rapa* var. *rapa* L., 20 kg ha⁻¹ *Lolium perenne* L., and 20 kg ha⁻¹ *Brassica oleracea* var. *acephala* L., were planted at regional densities on October 10, 2013, and October 15, 2014, and incorporated into the soil on May 5, 2014, and May 8, 2015, respectively. The studies showed that the highest dry biomass of cover crops was achieved in the plots with *V. villosa* (591.16 g m⁻²). The lowest weed dry biomass was recorded as 16.28 g m⁻² on day 28 and 27.72 g m⁻² on day 56 in the plots

where *V. villosa* was applied, after the cover crops were incorporated into the soil. After incorporating cover crops into the soil, *V. villosa* plots showed the greatest weed dry weight reductions (79.83% on day 28 and 88.93% on day 56) and the highest corn grain yield (7576 kg ha⁻¹). Thus, *V. villosa* should be included in integrated weed control programs for its ability to suppress weed germination and boost corn yield.

Keywords Sustainable agriculture · Agroecological management · Weed suppression · Living mulch

Introduction

Due to its nutritional content, corn is widely cultivated in many countries, as it plays a significant role in human and animal nutrition, benefits the soil through crop rotation, and serves as a source of raw materials for various industries (Altınok & Dikilitas, 2011). The corn plant is used to produce a variety of industrial products, primarily food-related items such as flour, oil, and starch. As a result, every part of the corn plant—such as the stalk, stem, leaves, and grain—holds significant economic value (Babaoglu, 2012).

While corn acreage in Turkey ranged from 680.000 to 690.000 ha between 2015 and 2020, it increased to 750.000 ha in 2021 compared to the previous period. Production, which was 6.5 million tons

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in 2020, increased to 6.75 million tons in 2021. It is expected that the cultivated area and production volume of corn will increase compared to the previous year (Tuik, 2022). Global corn production is 1.2 billion tons in 2021/22 and 1.3 billion tons in 2022/23 (USDA, 2022).

Weeds are one of the most important factors reducing corn production in Turkey as well as in other countries around the world (Dok et al., 2015; Isik et al., 2017). Weeds compete with crops for water, nutrients, and light needed for growth, and cause significant damage to many crops such as corn in the early stages of development because their growth rates are slow and their competitiveness is weak (Ozer et al., 2001). It is stated that the yield loss due to weeds in corn in the first stage of development is about 42% (Isik et al., 2006).

Intensive weed control is necessary to reduce the problems caused by weeds, which are a major problem in agricultural areas of Turkey and the world, to increase yield and quality. Weed control in corn is done with herbicides and mechanical control (Isik et al., 2017). However, these treatments also bring some problems. High herbicide and treatment costs, increased production costs due to the high labor involved in mechanical methods (Doğan et al., 2004), soil erosion due to tillage; environmental factors such as herbicide adherence to the soil and the buildup of resistance due to intensive spraying are just some of these problems. Therefore, new approaches are needed to reduce the weed problem in corn growing areas (Dok et al., 2015; Işik et al., 2015).

The use of cover crops in corn (*Zea mays* L.) production has been widely studied due to their potential benefits, such as improving soil health, weed management, and promoting sustainability in agriculture (Johnson et al., 2017; Smith et al., 2015). Several studies emphasize their advantages in corn-based systems while also addressing the challenges of their adoption (Clark et al., 2007; Teasdale et al., 2004).

Due to the development of the concepts of environmental protection and sustainability in agriculture and the fact that weed control in organic farming involves high costs for producers, alternative methods of weed control have come to the fore (Uygur & Uygur, 2010). One of these alternative methods is the use of cover crops. A cover crop is a plant that covers the soil surface in front of the crop and is mixed with the soil before the crop is planted (Isik et al., 2014).

Generally, cover crops are defined as covering the soil with annual or perennial short herbaceous plants, alone or mixed, in cultivated areas, year-round or during specific periods (Koloren, 2004).

Cover crops, especially legumes, are often integrated into agricultural cropping systems to improve soil quality and crop quality (Demir & Isık, 2019a, b). Cover crops are used to protect and improve soil quality, contribute to biodiversity, increase beneficial microorganisms in the soil, and suppress weeds due to their allelopathic properties (Blanco-Canqui et al., 2015). For instance, Dabney et al. (2001) emphasized that cover crops like rye (*Secale cereale*) and hairy vetch (*Vicia villosa*) can significantly reduce weed density and biomass through physical suppression and allelopathic effects. Similarly, Teasdale et al. (2007) demonstrated that cover crops effectively reduced early-season weed competition in corn systems, which could lead to improved yields and reduced reliance on chemical herbicides. Kaspar and Singer (2011) reported that leguminous cover crops such as clover (*Trifolium* spp.) and hairy vetch could fix atmospheric nitrogen, subsequently reducing the need for synthetic nitrogen fertilizers in corn production. Additionally, non-leguminous cover crops like rye have been shown to scavenge residual nitrogen, preventing nitrate leaching into water systems (Thorup-Kristensen et al., 2003).

Despite these benefits, the adoption of cover crops in corn systems is not without challenges. Timing of planting and termination, potential yield reductions, and additional costs associated with cover crop establishment are key concerns for farmers. Mirsky et al. (2012) pointed out that improper termination of cover crops can interfere with corn planting operations and may lead to nitrogen immobilization, negatively impacting corn growth. Furthermore, the choice of cover crop species must align with the specific goals of the farming operation, as some species may compete with the main crop for water and nutrients under certain conditions (Clark, 2007). Selection of appropriate cover crops is important for the use of cover crops in weed control (Adetunji et al., 2020).

The effectiveness of cover crops varies significantly based on regional climatic and soil conditions. For instance, studies conducted in temperate regions have shown consistent benefits in terms of soil conservation and weed suppression, while results from tropical and arid regions are less conclusive

(Blanco-Canqui et al., 2015). This variability underscores the need for location-specific research to optimize cover crop management practices in corn systems. Additionally, there is a lack of comprehensive studies addressing the long-term effects of cover crops on the stability and profitability of corn yield. Sarrantonio and Gallandt (2003) emphasized the importance of multi-year studies to evaluate cumulative benefits and potential trade-offs.

Cover crops provide an effective control method that can reduce the use of chemical herbicides, but different cover crop species vary in their effects on weed suppression and corn growth. For these reason, the primary objective of this study is to investigate the potential use of cover crops in weed management for corn (*Zea mays* L.) production. Therefore, the aims of this study can be summarized in 4 items. These are: 1. To determine the potential of different cover crops to suppress weed density and biomass in corn cultivation; 2. To examine the effects of cover crop applications on corn yield; 3. To explore the feasibility of using cover crops as an alternative or complementary method to chemical herbicides in weed management 4. To compare different cover crop species in terms of their effectiveness in weed suppression and compatibility with corn production.

Material and method

Field trials and year

The research was conducted in 2014–2015 at Yıldırım Beyazıt Farm, which is part of the Agricultural Research and Treatment Centre of Erciyes University (ERUTAM) Kayseri. Kayseri is located in the Central Anatolian region of Turkey and has a continental climate with hot and dry summers and rainy and cold winters. The average altitude of the field trials is 1094 m and lies between 34° 56' and 36° 59' east longitude and 37° 45' and 38° 18' north latitude.

Soil and climatic properties of the experimental areas

Some physical and chemical properties of the soil in the area where the studies were conducted are listed in Table 1. When the soil properties are examined, clay and silt ratio is low at both depths. The soil has a sandy-loam structure and moderate organic

Table 1 Soil properties of the field trials

Soil properties	Dept., cm	
	0–30	30–60
Clay (%)	12.58	9.18
Silt (%)	5.11	9.55
Sand (%)	82.31	81.27
Texture	sandy-loam	sandy-loam
pH	7.48	7.60
OM (%)	1.09	1.14
CaCO ₃ (%)	0.24	0.29
K ₂ O (kg/ha)	1184.20	842.34
P ₂ O ₅ (kg/ ha)	110.41	12.58

matter. pH shows slightly alkaline values at both depths (Table 1). The research area has a temperate climate, and data for the years of the study and the long-term average (2014–2015) are shown in Table 2. The average annual precipitation for many years is 391.1 mm, the average annual relative humidity is 63.8%, and the average annual temperature is 10.7 °C.

The analysis of the soil samples taken in the experimental area was carried out in the laboratories of Erciyes University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition.

Experimental material

The corn variety Prestige (FAO: 550 medium-early maturity group) of May-Agro Seed Industry and Trade Joint Stock Company was used in the study. Hairy vetch (*Vicia villosa* Roth.), rye (*Secale cereale* L.), Hungarian vetch (*Vicia pannonica* Crantz.), turnip (*Brassica rapa* var. *rapa* L.), perennial ryegrass (*Lolium perenne* L.), and kale (*Brassica oleracea* var. *acephala*) were used as cover crops.

Field trials

The study was laid out in randomized blocks according to the split-plot design with four replicates. In the experiment, plot sizes were set at 5×2.8 m. The trial consisted of 7 characters, six of which were cover crop applications. A weedy control plot and a control plot with hand hoe without weeds were also established. Cover crops were sown in the main plots and hoeing was done twice in the subplots (1 hoe after 56 days and 2 hoes on the 28th and 56th day

Table 2 Average values of monthly climate data for the years in which the experiment was conducted (Anonymous, 2015)

Month	Monthly Total Precipitation (mm)			Monthly Average Temperature (°C)			Monthly Average Relative Humidity (%)		
	2014	2015	L.T	2014	2015	L.T	2014	2015	L.T
January	31.6	33.7	33.3	2.0	1.6	−1.7	75.1	75.3	73.1
February	17.6	36.5	34.1	4.7	0.1	0.1	65.0	72.6	70.7
March	88.9	42.7	43.0	8.1	5.0	5.1	64.0	70.1	67.2
April	2.9	52.4	53.9	14.1	10.8	10.7	60.0	60.4	64.5
Mays	39.7	52.4	51.7	16.7	15.1	15.1	60.5	58.6	62.0
June	52.9	40.9	39.4	19.7	19.2	19.2	54.3	60.2	56.8
July	0.0	10	10.1	25.2	22.7	22.6	48.5	48.5	53.6
August	47.4	5.9	6.1	25.1	22.2	22.0	48.5	51.0	54.2
September	85.4	13.7	14.6	18.8	17.4	17.2	57.3	51.9	56.6
October	54.4	28.4	30.9	11.7	11.6	11.5	68.2	68.1	64.1
November	33.6	33.2	34.5	5.2	5.1	5.0	70.4	63.0	69.5
December	39.5	38.8	39.5	4.7	0.4	0.5	78.9	69.0	73.3

LT Long Term

after sowing). A distance of 1 m was left between plots and 2.5 m between blocks. The first year of the experiment, on October 10, 2013, and in the second year, on October 15, 2014, cover crops were planted at the appropriate planting density for regional conditions. 100 kg ha^{−1} hairy vetch (*Vicia villosa* Roth.), 20 kg ha^{−1} rye (*Secale cereale* L.), 100 kg ha^{−1} Hungarian vetch (*Vicia pannonica* Crantz.), 20 kg ha^{−1} turnip (*Brassica rapa* var. *rapa* L.), 20 kg ha^{−1} grass (*Lolium perenne* L.), and 20 kg ha^{−1} kale (*Brassica oleracea* var. *acephala*) were grown.

Throughout the study, the growth of the cover crop was regularly monitored. Cover crops and weeds samples in each plot were taken separately. The process was carried out by taking samples from four different points in each plot, within a 0.5×0.5 m area, and just above the soil surface. Cover crops and weeds were separated and weighed. Following the determination of fresh weight, the plants were placed in a drying oven at 70 °C for 48 h, after which their dry weights were calculated. Cover crops were mixed into the soil on May 5, 2014, in the first year of the experiment and on May 8, 2015, in the second year.

After sampling, the cover crops were incorporated into the soil. 1 week after the cover crops were mixed into the soil (1st year 12 May 2014, 2nd year 15 May 2015), 4 rows of corn were sown in each plot at 70×25 cm spacing using a Cansa Tarım C900-4 series pneumatic corn seeder and 30 kg ha^{−1} of corn. Irrigation was done once a week with the drip irrigation system. Corn harvest was done on 20

October 2014 in the first year of the experiment and on 16 October 2015 in the second year. Diammonium phosphate (DAP) 250 kg ha^{−1} and 500 kg ha^{−1} 33% ammonium nitrate fertilizer were used in the study.

To determine the effect of six different cover crop applications on weed density, weed species and densities were also determined in the experimental area after corn planting. Densities were evaluated as plants m^{−2} (Odum, 1971). Weed counts were made after the cover crops were mixed into the soil on the 7th, 14th, 28th, and 56th days. Weed counts in the plots were done by counting the weeds that had invaded the frame, using 0.5×0.5 m frames from 4 different parts of the plot. Following the determination of fresh weight, the plants were placed in a drying oven at 70 °C for 48 h, after which their dry weights were calculated. The effects of cover crops on weed density and weed biomass were studied by comparing the obtained results with the control plots.

Density (Abundans)=T.Y. /n (T.D.: Total density of each species in the counted areas (plant); a: Total area counted (m²)). Identification of weeds in plots was made using Davis's Flora of Turkey (Davis, 1965–1989).

Statistical analysis

The effects of cover crops on weed density and weed biomass were evaluated by comparing the results with those from the control plots. Data analysis was performed using the Statistical Analysis

Software (SAS) program (SAS Institute, 2022). The treatment means were compared using the LSD test at a 0.05 significance level. Additionally, one-way analysis of variance (ANOVA) was conducted to analyze the differences between treatment means. Since the application year interaction was found to be significant, the results are presented separately on a yearly basis.

Canonical Discriminant Analysis (CDA) was used to determine how cover crop and weed groups differed based on biomass and density data. The analysis was conducted to identify the variables contributing to the separation between groups and to establish the importance ranking of these variables.

Results

Determination of biomass formed by cover crops and its effect on weeds

Dry weight of cover crops before mixing into soil (g m^{-2})

The dry weights formed by the cover crops were determined. As a result of the analysis of variance applied to these dry weight values of cover crops (Table 3), the difference between treatments was significant ($p \leq 0.01$), the interaction between treatments years was not significant. The values for the first year, the second year and the average values of the cover crops dry weights are presented in Table 4. According to the data, the highest dry weight (591.16 g m^{-2}) was obtained in the plot where *V. villosa* was grown, while there was no statistical difference between *V. villosa* and *S. cereale* plots. The lowest cover crop dry weight (134.24 g m^{-2}) was recorded in the plot where *B. rapa var. rapa* L. was grown.

Table 3 The result of the variance analysis of the cover crops dry weights before mixing into the soil

Source	DF	Sum of Squares	F Ratio	Prob > F
Year	1	56.00	0.0187	0.8915
Recurrence[Year]	6	32977.18	1.8382	0.1024
Application	5	109593.06	7.3306	< 0.0001**
Application*Year	5	34837.56	2.3302	0.0501

** $p \leq 0.01$

Table 4 Year x treatment and average values of dry weight of cover crops before mixing into soil

Treatments	Dry weight of cover crop (g m^{-2})		
	2014	2015	Mean
1. <i>L. perenne</i>	276.52 bc	263.00 bc	269.72 BC
2. <i>S. cereale</i>	416.60 abc	327.00 bc	371.80 AC
3. <i>B. rapa var. rapa</i>	265.20 bc	90.00 c	134.24 C
4. <i>V. villosa</i>	470.32 a	712.00 a	591.16 A
5. <i>B. oleracea</i>	183.52 bc	84.10 c	177.60 C
6. <i>V. pannonica</i>	454.52 ac	548.00 ab	501.32 AB
Mean	344.44	337.48	
Significance level x Year			NS
Treatments	**	**	**
Treatment x Year	NS	NS	

** $p \leq 0.01$: Significant at 1% NS: Not significant

Weed dry weight before cover crops mixed into the soil (g m^{-2})

The 1st and 2nd year values and the average values of weed dry weight formed in the cover crop plots are shown in Table 6 and variance analysis result in Table 5. Statistical analysis showed that although the difference between treatments was significant ($p \leq 0.05$), the interaction between treatments and years was not significant. According to the data, the highest weed dry weight (51.84 g m^{-2}) was obtained from *B. rapa var. rapa* L. plots, while the lowest weed dry weight before planting was obtained from the plots with *S. cereale*, *V. villosa* and *V. pannonica* treatments (Table 6).

Effects of the weed biomass after mixing the cover crops into the soil

Corn was planted after the cover crops were mixed into the soil. No weed emergence was observed during counts on the 7th and 14th day after cover crops

Table 5 The effect of cover crops on weed dry weight before mixing into the soil the variance analysis result

Source	DF	Sum of Squares	F Ratio	Prob > F
Year	1	85.2789	1.5366	0.2204
Recurrence[Year]	6	896.2273	2.6914	0.0231
Application	5	3092.4840	11.1441	< 0.0001**
Application*Year	5	439.2872	1.5830	0.1802

** $p \leq 0.01$ **Table 6** Year x treatment and average values of weed dry weight before covering plants are mixed into the soil

Treatments	Weed dry weight (g m ⁻²)		
	2014	2015	Mean
1. <i>L. perenne</i>	3.48 c	12.00 c	7.72 BC
2. <i>S. cereale</i>	0.00 c	0.00 c	0.00 C
3. <i>B. oleracea</i>	31.48 ac	24.00 bc	27.72 B
4. <i>V. villosa</i>	0.00 c	0.00 c	0.00 C
5. <i>B. rapa</i> var. <i>rapa</i>	44.60 a	57.00 a	51.84 A
6. <i>V. pannonica</i>	0.00 c	0.00 c	0.00 C
Mean	26.52	31.00	
Significance level x Year			NS
Treatments	*	*	**
Treatment x Year			NS

** $p \leq 0.01$, * $p \leq 0.05$: Significant at 1% NS: Not significant

were mixed into the soil. Weed dry weights were recorded on the 28th and 56th day after cover crops were mixed into the soil.

When the data of the 28th day after the cover crops were mixed into the soil were examined, the variance analysis result is shown in Table 7 and the average values of the decrease in weed dry weight and weed dry weight in the plots on the 28th day after mixing the cover crops into the soil are shown in Table 8. According to the results of the analysis, application, year and application – year interaction was found to be significant. According to the statistical analysis, the interaction between the treatments ($p \leq 0.01$) and the year of treatment was significant ($p \leq 0.05$). Since the application year interaction was found to be significant, the results are presented separately on a yearly basis.

Table 7 Effects of cover crops on weed dry weight on the 28th day after mixing into the soil the variance analysis result

Source	DF	Sum of Squares	F Ratio	Prob > F
Year	1	767.8359	30.9275	< 0.0001**
Recurrence[Year]	6	557.9271	3.7454	0.0020
Application	7	2445.8932	14.0740	< 0.0001**
Application*Year	7	1521.3932	8.7543	< 0.0001**

** $p \leq 0.01$ **Table 8** Average values of the dry weight of the 28th day and decrease in weed dry weight after compared to the control (%) the cover crops were mixed into the soil

Treatments	28th day weeds dry weight (g m ⁻²) /Decrease by control (%)						
	2014		2015		Mean		
1. <i>L. perenne</i>	39.00 ab	54.47	54.00 abc	28.95	46.50 B	42.47	
2. <i>S. cereale</i>	23.00 de	73.19	55.00 abc	27.63	39.00 C	51.78	
3. <i>B. oleracea</i>	25.64 bc	70.15	61.00 ab	19.74	43.32 BC	46.43	
4. <i>V. villosa</i>	12.60 efg	85.26	19.96 fg	73.74	16.28 DE	79.83	
5. <i>B. rapa</i> var. <i>rapa</i>	21.32 abc	75.06	84.00 ab	10.53	52.66 B	34.79	
6. <i>V. pannonica</i>	21.28 def	75.11	24.08 ef	68.32	22.68 D	73.64	
7. Weedy	85.64 a	0.00	76.00 a	0.00	80.82 A	0.00	
Mean	32.56		53.40				
Significance level x Year	**		**		**		
Treatments	**		**		**		
Treatment x Year	*		*		*		

* $p \leq 0.05$: Significant at the 5% level ** $p \leq 0.01$: Significant at the 1% level

In the first year of the experiment, the highest weed dry biomass value (85.64 g m^{-2}) was measured in the weedy plots on the 28th day after corn sowing. There was no statistically significant difference between *L. perenne* and *B. rapa* var. *rapa* applications and the weedy control in terms of effect on weed dry weight. In the second year of the experiment, the highest weed dry biomass value (76.00 g m^{-2}) was measured in the weedy plots on the 28th day after corn sowing. There was no statistically significant difference between *L. perenne*, *S. cereale*, *B. oleracea*, *B. rapa* var. *rapa* applications and the weedy control in terms of effect on weed dry weight. It was found that *V. villosa*, *V. pannonica* and *S. cereale* were the most competitive cover crops with weeds. It was found that *B. rapa* var. *rapa*, and *B. oleracea* did not prevent weed emergence and development as much as the other species. The weed dry biomass of the cover crops plots was compared to the control plots, and the reduction compared to the weed control plots was expressed as a percentage. According to the results, on the 28th day after the cover crops were mixed into the soil, the highest decrease in weed dry biomass was obtained in the plots with *V. villosa*,

79.83%, while the lowest decrease was obtained in the plots with *B. rapa* var. *rapa*, 34.79% (Table 8).

When the data of the 56th day after the cover crops were mixed into the soil were examined, the variance analysis result is shown in Table 9 and the average values of the decrease in weed dry weight and weed dry weight in the plots on the 28th day after mixing the cover crops into the soil are shown in Table 10. According to the statistical analysis, difference between applications and the interaction between treatments and year was significant ($p \leq 0.01$). Since the application year interaction was found to be significant, the results are presented separately on a yearly basis.

In the first year of the experiment, the highest weed dry biomass value (378.0 g m^{-2}) was measured in the weedy plots on the 56th day after corn sowing. There was no statistically significant difference between *L. perenne*, *S. cereale*, *B. oleracea*, *B. rapa* var. *rapa* and the weedy control in terms of effect on weed dry weight. In the second year of the experiment, the highest weed dry biomass value (123.0 g m^{-2}) was measured in the weedy plots on the 56th day after corn sowing. There was no statistically significant difference between *B. oleracea*,

Table 9 Effects of cover crops on weed dry weight on the 56th day after mixing into the soil the variance analysis result

** $p \leq 0.01$

Source	DF	Sum of Squares	F Ratio	Prob > F
Year	1	33810.016	97.6788	<0.0001**
Recurrence[Year]	6	3341.094	1.6088	0.1686
Application	7	19141.609	7.9001	<0.0001**
Application*Year	7	9460.859	3.9047	0.0023**

Table 10 Average values of the dry weight of the 56th day and decrease in weed dry weight after compared to the control (%) the cover crops were mixed into the soil

* $p < 0.05$, ** $p \leq 0.01$: %1 at significance

Treatments	56th day weeds dry weight (g m^{-2}) /Decrease by control (%)					
	2014		2015		Mean	
1. <i>L. perenne</i>	279.0 a-d	26.19	68.00 bc	44.72	173.48 B	30.74
2. <i>S. cereale</i>	288.0 abc	23.81	54.00 bc	56.10	171.00 B	31.73
3. <i>B. oleracea</i>	296.0 ab	21.69	90.00 ab	26.83	193.0 AB	22.95
4. <i>V. villosa</i>	22.92 ef	93.94	32.52 d	73.56	27.72 C	88.93
5. <i>B. rapa</i> var. <i>rapa</i>	283.0 a-d	25.13	85.0 abc	30.89	184.0 AB	26.54
6. <i>V. pannonica</i>	26.68 ef	92.94	39.08 d	68.23	32.88 B	86.87
7. Weedy	378.0 a	0.00	123.0 a	0.00	250.48 A	0.00
Mean	224.8		70.20			
Significance level x Year	**		**		**	
Treatments	**		**		**	
Treatment x Year	**		*		*	

Table 11 Weeds in the cover crops and their density in the experimental area

Familia	Scientific Name	Density(plant m ⁻²)
Brassicaceae	<i>Sysbrium officinale</i>	2.2
Papaveraceae	<i>Fumaria officinalis</i>	2.9
Asteraceae	<i>Lactuca serriola</i>	4.5
Asteraceae	<i>Sonchus oleraceus</i>	1.5
Poaceae	<i>Poa annua</i>	6
Brassicaceae	<i>Sinapis arvensis</i>	2.1
Polygonaceae	<i>Polygonum cognatum</i>	1.5

Table 12 Weeds and their density after cover crops terminations in the experimental area

Familia	Scientific Name	Density(plant m ⁻²)
Amaranthaceae	<i>Amaranthus retroflexus</i>	13.218
Zygophyllaceae	<i>Tribulus terrestris</i>	3.4
Chenopodiaceae	<i>Salsola ruthenica</i>	2.4
Chenopodiaceae	<i>Chenopodium album</i>	10.04
Asteraceae	<i>Lactuca serriola</i>	2.4

applications and the weedy control in terms of effect on weed dry weight. The reductions in weed dry biomass due to cover crops compared to the control plots were determined as %. Accordingly, on the 56th day after cover crop incorporation into the soil, the highest decrease in weed dry weight was obtained with 88.93% in the plots with *V. villosa* treatment, while the lowest decrease was obtained in the plots with 26.54% treatment of *B. rapa* var. *rapa* (Table 10).

Effects of cover crops on weed density (plant m⁻²)

Weed densities of cover crops before and after mixing into the soil were determined. The effects of six different cover crop treatments on weed density were determined based on the species in each plot. For each observation date, the weed density values were calculated. The total number of individuals counted for each weed species was divided by the total sampled area, and the resulting weed density values are presented in Tables 11 and 12. In the survey to determine the weed species in the experimental plot, a total of 11 weed species were detected in the first year before cover crop termination and a total of 5 weed

species were detected in the second year during the pre cover crop termination count. In the first year of the experiment, the most weed species were found in the plots of *B. rapa* var. *rapa* before termination (80 plants m⁻²) and the least weed species were found in the plots of *V. villosa* and *V. pannonica* with an average of 1 plant m⁻².

The canonical discriminant analysis (CDA) conducted in this study effectively illustrates the differentiation among treatments in terms of weed species composition and density prior to mixing cover crops into the soil. The results show that the first canonical axis accounts for 75% of the variance, while the second axis explains 68%, indicating a substantial portion of the variation in weed species correlation is captured by these two axes. The distinct grouping of *B. oleracea* and *B. rapa* var. *rapa* suggests that these cover crops are associated with unique weed species or significantly different weed densities compared to other treatments. This separation highlights the potential influence of these specific cover crops on weed population dynamics. For example, the clustering of *B. oleracea* with high weed densities in the first year and *B. rapa* var. *rapa* with higher weed densities in the second year may indicate their reduced ability to suppress certain weed species compared to other cover crops. Conversely, the overlap of groups like *V. villosa*, *V. Pannonica* and *S. cereale* in the analysis reflects their similar and effective weed suppression capabilities, as evidenced by their low weed densities (average of 1 plant m⁻²). This suggests that these cover crops may exert comparable competitive effects on weed populations. In summary, the CDA provides a clear visual and statistical differentiation of the weed suppression efficacy of various cover crops (*V. villosa*, *V. pannonica* and *S. cereale*), emphasizing the superior weed management potential of certain cover crop species (*B. rapa* var. *rapa*, *B. oleracea*) while identifying those that may require additional management strategies (Fig. 1).

On the 28th day after the cover crops were mixed into the soil, Canonical Discriminant Analysis (CDA) conducted in the study to determine the effect of cover crops on weeds revealed differences between the treatments in terms of weed species. The analysis showed that 73% of the weed correlation between treatments was explained by the first canonical axis, while 54% was explained by the second canonical axis. These results provide a strong statistical

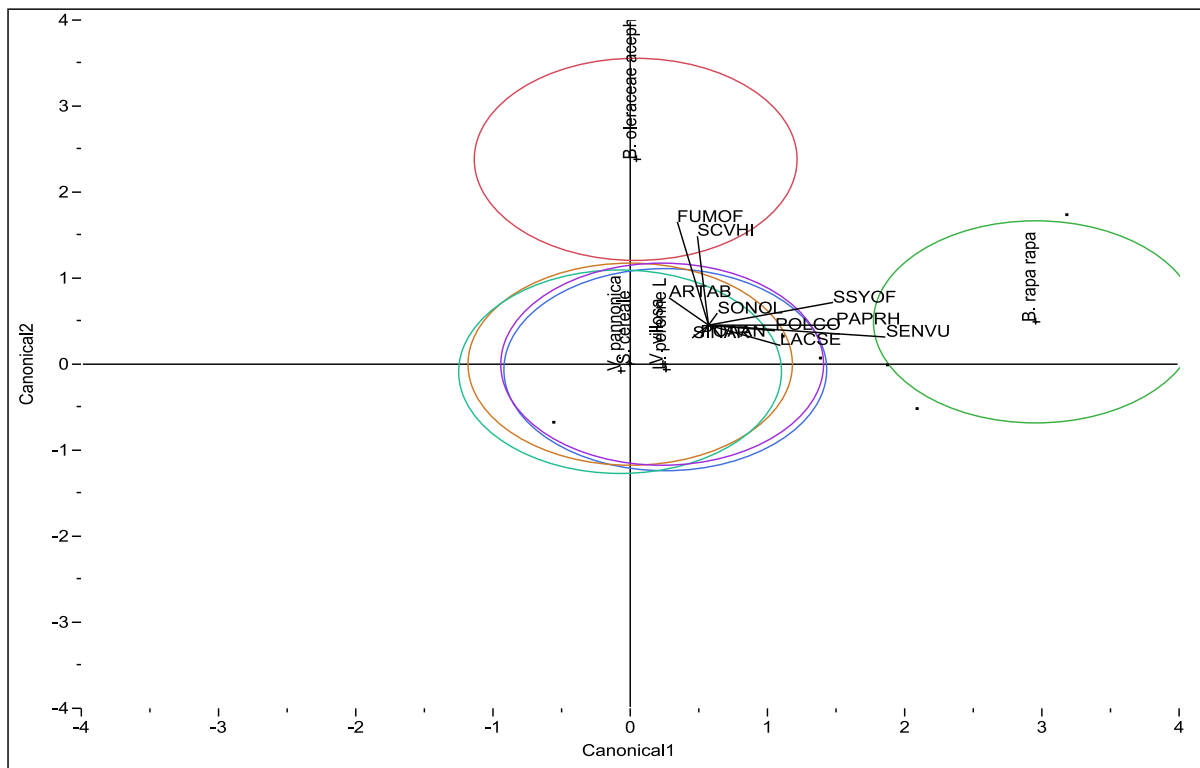


Fig. 1 Cononical discriminant analysis graph of weed species in cover crops

foundation for evaluating the impact of cover crops on weed species.

According to the CDA diagram, the *Brassica oleracea* and *Brassica rapa rapa* formed a distinct group in terms of weed density. In summary, the CDA shows that different cover crops have distinct visual and statistical effects on weed suppression some species, such as *V. villosa* and *V. pannonica*, are effective in controlling weeds, while others, such as *B. oleracea*, may require additional management strategies (Fig. 2).

Based on the results observed on the 56th day after cover crop termination, the Canonical Discriminant Analysis (CDA) can provide insights into the relationships between the cover crops and the weed species counts. The analysis will likely reveal distinct patterns between the various treatment groups, as the weed density varied significantly between the weed control plots and the cover crop treatments.

From the data, in both the first and second years, the weed control plots exhibited the highest weed density, with 115.7 plants m^{-2} in the first year and

90.5 plants m^{-2} in the second year. On the other hand, *V. villosa* and *V. pannonica* plots showed the lowest weed density, with only 1 plant m^{-2} on the 56th day in both years. These results suggest that these two cover crops were particularly effective in suppressing weed growth compared to the control plots.

In the CDA context, the differences in weed density between the cover crop treatments and control plots should be clearly distinguishable on the canonical axes. The weed control plots are likely to be placed farther away from the other treatments, reflecting higher weed density, while the plots with *V. villosa* and *V. pannonica* will be grouped together with low weed density, showing their effective role in suppressing weeds.

Overall, the CDA will highlight the significant influence of cover crops like *V. villosa* and *V. pannonica* on weed suppression, confirming that these species are more effective at reducing weed populations compared to the control plots. Additionally, the CDA will emphasize the statistical significance of the

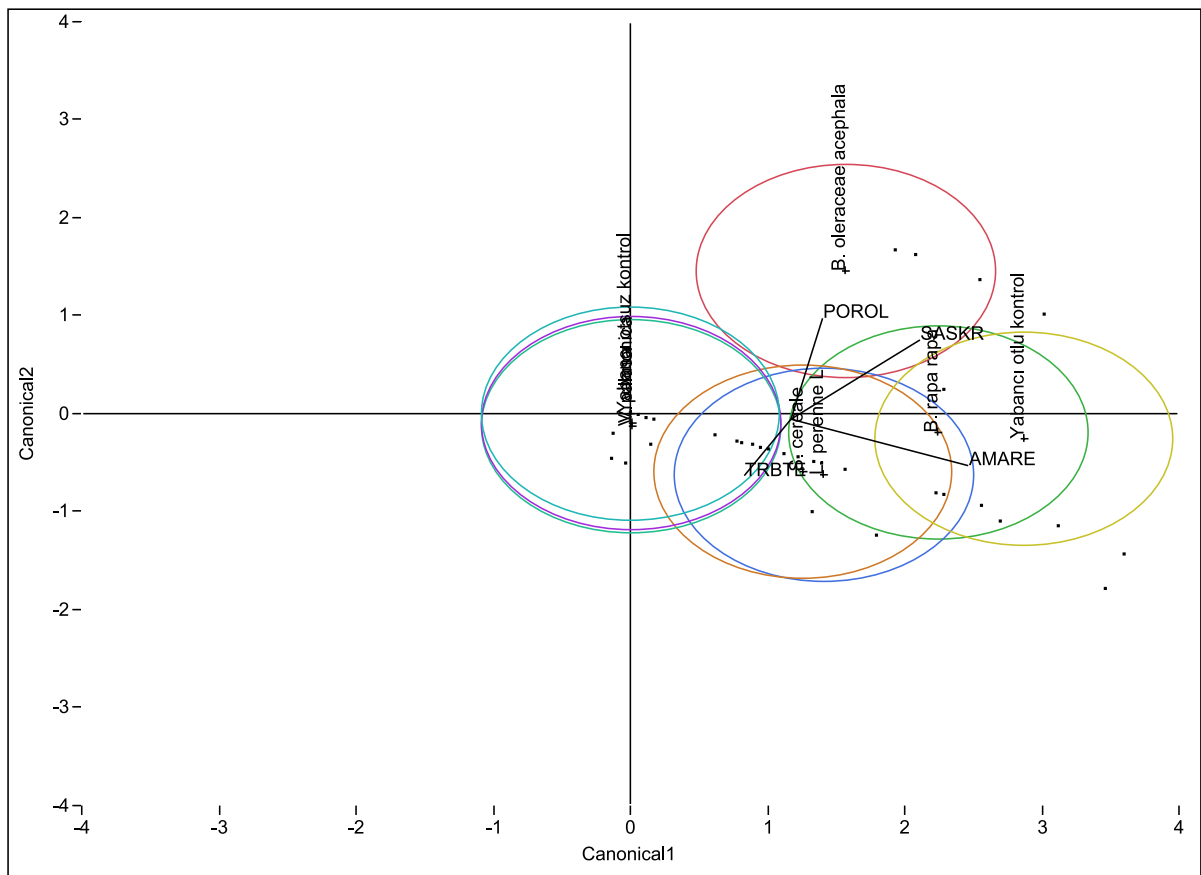


Fig. 2 Cononical discriminant analysis graph of weed species according to cover crops on the 28th day after the cover crops were mixed into the soil

differences in weed density between the treatments, supporting the visual findings from the data (Fig. 3).

Effect of cover crops on corn yield (kg ha^{-1})

The variance analysis result is shown in Table 13, and the hand hoe weeding—treatment interaction and average values for the effect of cover crops on corn yield are shown in Table 14. According to the variance analysis results, the application $\times$ year interaction was found to be insignificant, so the average data is presented in the table. Cover crop treatment, hand hoe interaction were statistically significant ($p \leq 0.05$), and the results were grouped according to the LSD multiple comparison test.

Since the application $\times$ hoe interaction was found to be statistically significant, the results are presented separately for 1 hoe (56th) and 2

hoe (28th and 56th days). According to the application results, the highest yield (8149 kg ha^{-1}) was obtained from *V. pannonica* application in the plots where 2 hoeings were made (28th and 56th days), and the highest yield (7058 kg ha^{-1}) was obtained from *V. pannonica* application in the plots where 1 hoeing (56th day) was made. It was determined that the grain yield increased in the plots where hoeing + *V. villosa* was applied on the 56th day after planting compared to the hoeing + *V. pannonica* application on the 28th and 56th days. There is no statistical difference between *V. pannonica*, *S. cereale* and *V. villosa* applications in the parcels where 1 hoe (56th day) is applied. In the parcels where 2 hoeing (28th and 56th days) was applied, there is no statistical difference between *V. pannonica* and *V. villosa* applications (Table 14).

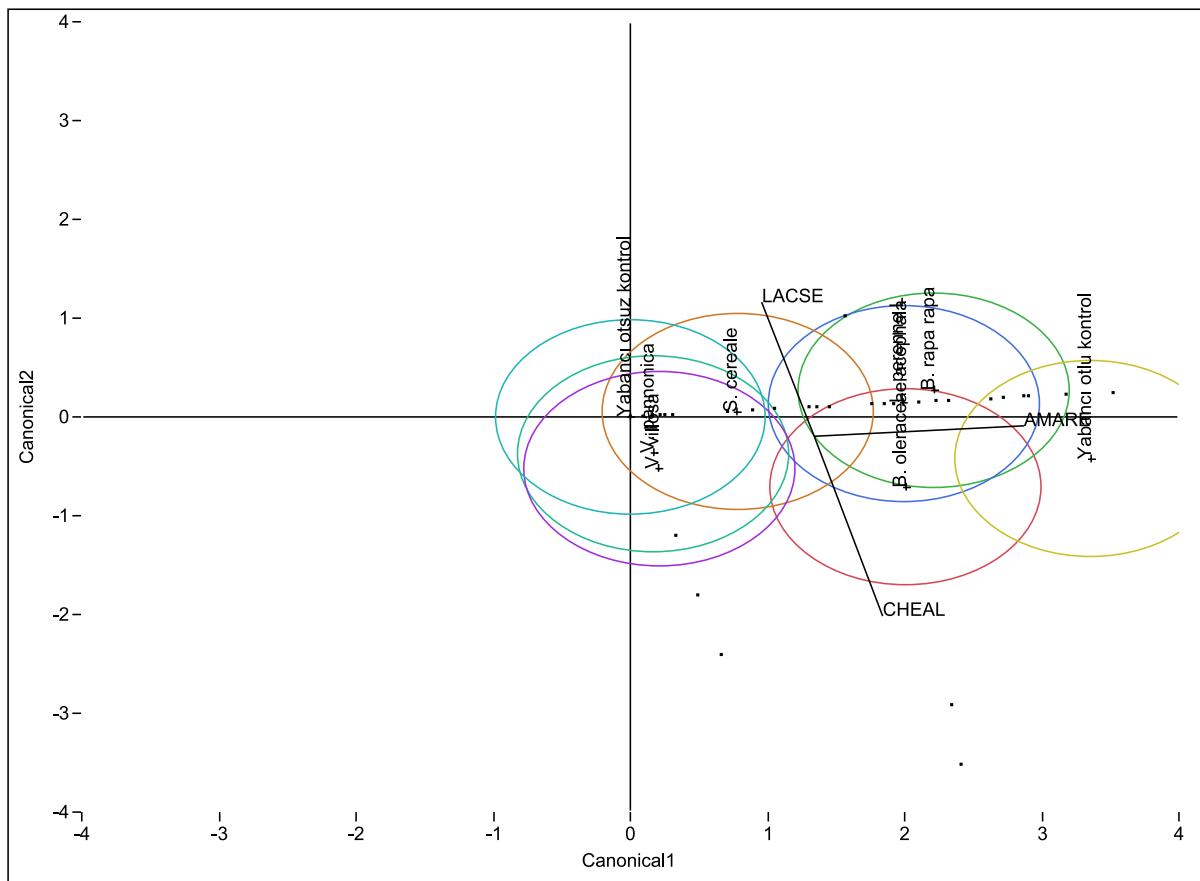


Fig. 3 Cononical discriminant analysis graph of weed species compared to cover crops on the 56th day after the cover crops were mixed into the soil

Table 13 Effect of cover crops on corn yield the variance analysis result

Source	DF	Sum of Squares	F Ratio	Prob > F
Year	1	297780.14	5.0349	0.0302
Recurrence[Year]	6	940826.63	2.6513	0.0285
Application	7	542418.86	1.3102	0.2694
Application*Year	7	564145.44	1.3627	0.2463

Discussion

The findings highlight the variability in weed suppression capabilities and biomass production among cover crop species, as well as the significance of integrating cover crops with hoeing practices for optimal yield outcomes.

Table 14 Average values of the effect of cover crops on corn yield kg ha⁻¹

Treatments	Hoe		Meanly
	28-56th Hoe	56th Hoe	
1. <i>L. perenne</i>	5765 cde	4544 de	5154 CD
2. <i>S. cereale</i>	6048 a-e	5790 b-e	5919 A-D
3. <i>B. oleracea</i>	6232 bcd	5170 cde	5701 BCD
4. <i>V. villosa</i>	8094 ab	7058 a	7576 A
5. <i>B. rapa var. rapa</i>	6993 bc	5458 cde	6225 ABC
6. <i>V. pannonica</i>	8149 a	6353 ab	7251 AB
7. Weedy	4634 e	3894 e	4264 D
Mean	6559	5466	
Treatment	*	*	*
Treatment X Hoe	*	*	*

* $p \leq 0.05$: Significant at the 5% level

According to the results of this study, a total of 13 weed species belonging to 8 families were determined during the years of the experiment in the experimental field where the cover crop application was carried out. These species are *Symphytum officinale*, *Fumaria officinalis*, *Lactuca serriola*, *Sonchus oleraceus*, *Poa annua*, *Sinapia arvensis*, *Polygonum cognatum*, *Artemisia absinthium*, *Amaranthus retroflexus*, *Tribulus terrestris*, *Salsola rutenica*, *Chenopodium album*. The results of the experiment show that the weed species intensively occurring in Kayseri province of Turkey are similar to the studies of Esitmez and Isik (2016); Akca and Isik (2016).

The dry biomass production data indicate that *Vicia villosa* produced the highest biomass, which was statistically similar to *Secale cereale*. In contrast, *Brassica rapa* var. *rapa* yielded the lowest dry biomass. These findings align with recent studies demonstrating that legumes and cereals, such as hairy vetch and cereal rye, typically achieve greater biomass compared to brassica species like turnip (St Aime et al., 2020). The high biomass of *V. villosa* and *S. cereale* likely contributed to their effective weed suppression, as higher biomass can result in greater soil coverage and competition for resources (Hartwig & Ammon, 2002). In a study investigating the effects of cover crop treatment on the control of weeds that are a problem in kiwifruit growing areas, the highest dry weight value was found when *V. villosa* and *Hordeum vulgare* were applied, confirming this study (Gundogan & Koloren, 2022).

It is considered that fodder beet and black cabbage had difficulties to adapt to the climatic conditions of the Kayseri region where the experiment was conducted, so they could not show sufficient production and development. The highest weed dry weight (51.84 g m^{-2}) in the cover crop was obtained from *B. rapa* var. *rapa*, while the lowest weed dry weight before cover crop termination was obtained from the plots with *S. cereale*, *V. villosa* and *V. pannonica*.

As a result of the study, the highest weed dry weight value (80.72 g m^{-2}) was recorded on the 28th day after cover crop termination in the weedy control plots and the lowest dry weight value (16.28 g m^{-2}) was recorded in the *V. villosa* applied plots. According to the results of the experiment, the highest dry weight value of weeds (250.48 g m^{-2}) was recorded in the weedy control plots on the 56th day after cover crop termination and the lowest weed dry weight was recorded in the

treatment of *V. villosa* (27.72 g m^{-2}). According to the results of Mennan et al (2009) on the treatment of winter cover crops in organic tomato under Samsun conditions, it was found that *V. villosa* was the most effective cover crop species in suppressing weeds. Similarly Isik et al (2014) found the lowest weed dry weight in *V. villosa* applications in hazelnut orchards.

The weed suppression capabilities of the cover crops varied significantly. *V. villosa*, *V. pannonica*, and *S. cereale* were the most effective in reducing weed dry biomass. On the 28th day after cover crop incorporation, *V. villosa* plots showed a remarkable weed biomass reduction of 79.83%, while the lowest reduction (34.79%) was observed in *B. rapa* var. *rapa* plots. Similarly, on the 56th day, *V. villosa* achieved the highest weed suppression (88.93%), whereas *B. rapa* var. *rapa* had the lowest suppression (26.54%).

Recent studies have highlighted the efficacy of legumes and cereals in suppressing weeds due to their rapid canopy establishment and allelopathic properties (Finney et al., 2016). For example, cereal rye suppresses weeds through multiple mechanisms, including allelopathy, while legume cover crops contribute to sustainable weed management practices (Blesh, 2018; Finney et al., 2016). These findings emphasize the potential of incorporating these cover crops into cropping systems to enhance weed suppression and promote sustainable agriculture. Conversely, the relatively poor weed suppression by *B. rapa* var. *rapa* and *B. oleracea* may be attributed to their lower biomass production and limited competitive ability, as suggested by Brennan and Smith (2005). These consequences are supported by former research. Previously, lacy phacelia cover crop was stated to suppress *Echinochloa crus-galli*, *C. album*, and *Portulaca oleracea* L. in maize plantings (Dhima et al., 2009). Campiglia et al (2010), in a study on tomato, found that *V. villosa* reduced weed density by 79%. Similarly, Işık et al. (2009) in their study on weed suppression with cover crops in organic bell pepper production found that *V. villosa* was the most effective cover crop and weed density was reduced by 73% after 28 days and 70% after 56 days reported a reduction in rate.

The outcomes of this research emphasized that cover crops can be effective in reducing the weed dry weight, and invasion in corn production. Cover crop reduce the weeds growth and production of seed by competing with weeds for nutrients, light and water (Moonen & Barberi, 2004; Tursun et al., 2018). Cover crops cause decreases in weed density

and biomass due to the physical barrier they create, reduction of light permeability, increase in soil moisture and changes in soil temperature, and allelochemical substances (Jabran et al., 2015; Tursun et al., 2018). The hairy vetch suppressive effects on weeds have been well-reported former studies, and this could suppress the weeds by further than 60% (Isik et al., 2009; Campiglia et al., 2010).

Cover crops efficacy against weeds has been described in the prior works. For instance, in the fallow systems *Melilotus officinalis* (L.) Pall. in place of a cover crop could decrease weed biomass by 95% and may perhaps also suppress the weeds after residues of this cover crop were mixed in the soil (Blackshaw et al., 2001). Even though, this much high weed suppression was not seen in our investigation, we can recommend that cover crop can overwhelm weeds, mainly in the corn fields. Legume cover crops possibly will also improve nutrients in soil lengthways with suppressing weeds, and this might play an significant role in preserving the soil and sustaining the agronomic practices (Sainju et al., 2002).

The integration of cover crops with hoeing treatments significantly influenced corn yield. In plots where two hoeing treatments were applied (28th and 56th days), the highest grain yield was obtained with *V. pannonica* application. In single hoeing plots (56th day), *V. pannonica* again produced the highest yield. These results underscore the synergistic effect of combining mechanical weed control with competitive cover crops (Liebman & Davis, 2000). Although there was no statistical difference between *V. villosa*, *V. pannonica*, and *S. cereale* in one-hoeing treatments, *V. villosa* showed a slight advantage in two-hoeing treatments. This finding is consistent with earlier studies that suggest legumes like *V. villosa* not only suppress weeds but also enhance soil fertility through nitrogen fixation, indirectly benefiting subsequent crop yields (Tonitto et al., 2006). Mennan et al., 2009, As a result of the study conducted to determine the effects of summer and winter greening on weed suppression in Samsun region, *V. villosa* vincreased the yield of lettuce and black cabbage by two times, Işık et al., 2009, in their study on bell bell pepper showed that the yield of bell bell pepper increased by *V. villosa* was higher than the plots. Demir and Işık found that the highest yield of persimmons in 2019 was obtained by applying *V. villosa*.

In a study conducted by Işık et al. (2018), it was found that tree growth and apple yield in organic apple orchards were higher when cover crops were applied than in weedy control plots. In this case, it was considered that the treatment of cover crops had an effect on increasing the yield elements and that *V. villosa* gave better results than other crops under these crops. In another study by Demir and Işık (2019a, b), evaluating the effect of cover crops on kiwifruit yield, the lowest yield was obtained from weedy plots, while the highest yield was obtained from *T. meneghinianum* plots. Furthermore, the study demonstrates the potential of integrating cover crops with mechanical weed control to optimize resource use and minimize reliance on chemical herbicides. This approach aligns with the principles of sustainable agriculture, promoting environmental health and long-term productivity (Altieri, 1999).

As a result, it has been found that cover crop treatments can be an alternative to using herbicides and it has been found that cover crops such as *V. villosa*, *S. cereale*, *V. pannonica* can be used in integrated weed control systems. It should be included in the control systems as studies have shown that the use of cover crops promotes crop development and reduces farmer labor. *V. villosa*, *S. cereale*, *V. pannonica* should be included in control programmes as they significantly reduce weed seed germination by covering the soil surface and preventing moisture loss from the soil. Cover crops, which are very important for weed suppression but do not compete with the crop for growth factors such as water, light and oxygen, should be expanded.

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Declarations

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