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RESEARCH

An Approach to Increasing Sustainability in Agricultural Systems: Evaluating the Effects of Different Cover Crops Yield Components in Maize (*Zea mays* L.)

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Abstract

The use of cover crops are increasing in maize (*Zea mays* L.) to improve soil quality and support sustainable production. This study evaluated the effects of different cover crop species on maize morphological traits and yield components under Central Anatolia conditions. Field trials were conducted during the 2013–2014 and 2014–2015 seasons at Erciyes University Agricultural Research and Application Center (Kayseri, Turkey). The experiment was arranged in a split-plot design with four replications. Six cover crop species (*Vicia villosa*, *Secale cereale*, *Vicia pannonica*, *Brassica rapa* var. *rapa*, *Lolium perenne*, and *Brassica oleracea* var. *acephala*) and a control plot were evaluated. Cover crops were sown in October and incorporated into the soil before maize planting in May. Plant height ranged from 141 to 236 cm in 2014 and 174–257 cm in 2015, with the highest values recorded in *V. villosa* (236–252 cm) and *V. pannonica* (257 cm) treatments. Stem diameter (15.3–25.3 mm) and corn size (length: 13.3–19.0 cm; diameter: 3.8–4.7 cm) were consistently greater in legume-based cover crops, particularly *V. villosa*. Grain cob ratio varied between 70% and 90%, reaching its maximum in *V. villosa* under two hoeing conditions. Corn yield ranged from 4634 to 8631 kg ha^{-1} with two hoeings and 3895–7059 kg ha^{-1} with one hoeing, with *V. villosa* producing the highest yield in both cases. The results indicate that *Vicia villosa* and *Vicia pannonica* are suitable and sustainable cover crop species for maize production under the semi-arid conditions of Central Anatolia.

Keywords Sustainable farming · Ecological cropping · Weed control · Soil cover crops · Green mulch

Introduction

Corn (*Zea mays* L.) is cultivated extensively across tropical, subtropical, and temperate climates both as a grain and forage crop (Grassini et al., 2011). Corn is supports industrial production through derivatives such as starch, glucose, and oil, contributing to economic sustainability (Süzer, 2017). In Turkey, the area for corn cultivation stayed between 680,000 and 690,000 hectares from 2015 to 2020. This area grew to approximately 750,000 hectares by 2021. Production rose from 6.5 million tons in 2020 to 6.75 million tons in 2021. These figures suggest that both cultivated area and output will likely keep increasing (TUIK, 2021). Globally, corn production was estimated at 1.2 billion tons for 2021/22 and grew to 1.3 billion tons in 2022/23 (USDA, 2022).

Weed interference limits crop productivity and quality agricultural systems (Abouziena & Haggag, 2016). Many annual and perennial weeds reduce corn yield by competieting for essential resources (Işık et al., 2006; Kale and Işık 2025). Herbicides are the main tool to suppress weeds in maize. Yet, relying mainly on on chemical herbicides creates health risks, leaves residues in soils, forters herbicide-resistant weeds, and degrades environment (Isık et al., 2015; Westwood et al., 2018).

To mitigate such challenges, many researchers advocate for sustainable production systems (Thierfelder et al., 2012). Alternative methods such as low-input agriculture, organic practices, intercropping, and cover crop combinations have

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gained popularity for their ecological compatibility and effectiveness in weed management (Finney & Kaye, 2017). These strategies are recognized for minimizing environmental harm while enhancing agricultural resilience (Finney & Kaye, 2017).

Moreover, rising herbicide costs and growing concerns about ecosystem health have prompted interest in non-chemical weed control techniques (Uygur & Uygur, 2010). One such eco-friendly practice uses cover crops to suppress weeds and promote sustainable crop production (Kolören, 2004). Typically, farmers sow cover crops prior to the main crop and are incorporated them into the soil before planting (Kale & Isık, 2025). These plants generally include low-growing, short-lived annual or perennial herbaceous species that are farmers plant alone or in mixtures to maintain soil cover during specific periods (Kolören, 2004).

Cover crops offer numerous agronomic and environmental advantages. They play a significant role in enhancing soil organic carbon levels and overall soil fertility (Demir and Isık, 2020). By shielding the soil surface, they reduce the risks of wind and water ınduced erosion and moderate fluctuations in soil temperature by limiting sunlight exposure (Demir and Isık, 2019). When legumes are employed as cover crops, improvements are often observed in both the chemical and physical properties of the soil. Moreover, cover crops compete effectively with weeds for essential resources such as water, light, and nutrients. They may also exert allelopathic effects, releasing biochemical substances that suppress weed seed germination and growth (Isık et al., 2009).

Cover crops in corn systems can mitigate early-season weed interference, potentially leading to higher yields and reduced reliance on herbicides (Teasdale et al., 2007). Legumes such as clover (*Trifolium* spp.) and hairy vetch can biologically fix atmospheric nitrogen, thereby reducing the need for synthetic fertilizers (Kaspar & Singer, 2011). On the other hand, non-leguminous species such as rye are efficient in absorbing residual soil nitrogen, helping to prevent nutrient leaching into groundwater (Thorup-Kristensen et al., 2003).

There has been increasing interest in the use of cover crops within corn (*Zea mays* L.) production systems due to their contributions to soil health, weed management, and ecological sustainability (Smith et al., 2015). While numerous studies have confirmed the benefits of integrating cover crops into corn-based cropping systems, researchers have also acknowledged various logistical and agronomic challenges that limit widespread adoption (Clark et al., 2007; Carrera et al., 2004).

The timing of cover crrop planting heavily influences their performance. Plant early in autumn to maximize biomass before winter dormancy, which boosts competitiveness against weeds and improves soil parameters (Mirsky et al., 2012). Legumes like *Vicia villosa* fix more nitrogen fixation and sshow better agronomic potential when sown before soil temperature drop (Finney et al., 2016). Delayed planting, and cover crops fail to strongs roots or enough biomass, limiting their benefits. Identifiy optimal sowing window for each regionto maximize effectiveness.

Regional climate and soil conditions greatly influence the success and functionality of cover crops. However, results in arid and tropical regions vary and largely depend on local conditions (Blanco-Canqui et al., 2015). Location-specific studies are needed to optimize cover cropping strategies under different environmental and agronomic conditions. The long-term effects of cover crops on maize productivity are still unclear. Their impact on farm profitability also remains insufficiently studied. Long-term field experiments are necessary to assess the benefits and limitations of cover crops in maize systems (Sarrantonio & Gallandt, 2003).

Despite the widely acknowledged advantages, the precise impact of cover crops on yield components is not fully established (Abdalla et al., 2019). This study was conducted to evaluate the influence of different cover crop species on key agronomic parameters in corn, including plant height, stem diameter, first cob height, cob diameter and length, grain moisture content, grain-to-cob ratio, and overall yield. The aim was to identify the most effective cover crop species for improving productivity in sustainable maize production systems.

Material and Method

Field Trials and Year

This study was carried out during the 2014 winter and summer growing seasons, and the 2015 winter and summer growing seasons, at the Yıldırım Beyazıt Farm, affiliated with the Agricultural Research and Application Center (ERUTAM) of Erciyes University. The experimental site is situated at an elevation of approximately 1094 meters and is located between the coordinates 34°56'–36°59' E longitude and 37°45'–38°18' N latitude.

Soil and Climatic Properties of the Field Trials

Soil analyses for the experimental site were conducted at the Soil Science and Plant Nutrition Laboratory of the Faculty of Agriculture, Erciyes University. The soils in the trial area are classified as loamy in texture, slightly alkaline in pH, free from salinity, and contain a moderate level of organic matter (Table 1). The experimental site is located in Kayseri province, which is known for its continental climate

Table 1 Soil properties of the field trials

Soil properties	0–30 Dept., cm	30–60 Dept., cm
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
Organic Matter (%)	1.09	1.14
$CaCO_3$ (%)	0.24	0.29
K_2O (kg ha^{-1})	1184.20	842.34
P_2O_5 (kg ha^{-1})	110.41	12.58

features. Specifically, the study location has a temperate climate. Climatic parameters for the study years and the long-term averages (2014–2015) are summarized in Fig. 1 (Anonymous, 2015). Based on long-term records, the region receives an average of 321 mm of precipitation annually, with an average annual temperature of 10.7 °C and relative humidity of 63.8%.

Experimental Material

In this study, the corn hybrid 'Prestige' (FAO 550, medium-early maturity group), supplied by May-Agro Seed Industry and Trade Inc., was selected as the main crop. The cover crop species included 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*).

Field Trials

The experiment was conducted using a split-plot design arranged in a randomized complete block with four replications. Each plot measured 5 × 2.8 m. The main plot factor consisted of seven treatments including six cover crop species and one weedy control treatment. Cover crops were randomly assigned to main plots. The subplots factor consisted of two hoeing regimes: a single hoeing 56 days after sowing or two hoeings at 28 and 28th and 56th days aftersowing. Buffer zones of 1 m between plots and 2.5 m between blocks were maintained to prevent treatment interference.

Sowing of cover crops took place on October 10, 2013, in the first season and on October 15, 2014, in the second season, using locally recommended seeding rates: 100 kg ha^{-1} for *Vicia villosa* Roth., 20 kg ha^{-1} for *Secale cereale* L., 100 kg ha^{-1} for *Vicia pannonica* Crantz., 20 kg ha^{-1} for *Brassica rapa* var. *rapa* L., 20 kg ha^{-1} for *Lolium perenne* L., and 20 kg ha^{-1} for *Brassica oleracea* var. *acephala*. These crops were incorporated into the soil on May 5, 2014, and May 8, 2015, for the respective growing seasons. The soil incorporation process was carried out by working the cover crops to a depth of 15–20 cm using a disc harrow while the green mass was still mature.

Subsequently, corn sowing was carried out one week after incorporation (May 12, 2014, and May 15, 2015) using a Cansa Tarım C900-4 series pneumatic seeder at a spacing of 70 × 25 cm and a seeding rate of 30 kg ha^{-1}. Drip irrigation was applied weekly throughout the growing period. Fertilization included diammonium phosphate (DAP, 250 kg ha^{-1}), which was applied to the rows using a band application method before maize planting. Ammonium nitrate (500 kg ha^{-1}, 33% N) was applied to the soil surface by broadcasting and then lightly covered with soil. Weekly drip irrigation was applied.

At physiological maturity, corn plants were harvested to assess grain yield. Morphological measurements were taken from five randomly selected plants per replicate to determine yield-related traits.

Plant height (cm) was determined by measuring from the soil surface to the highest point of five sampled plants. Plant diameter (mm) was recorded by measuring the section between the stem nodes (knuckles). The height of the first cob (cm) was measured as the distance from the soil surface to the node where the first cob attaches to the stem. Cob diameter (cm) was measured at the mid-point of the cob using a caliper, while cob length (cm) was measured from the point where the cob stem connects to the cob tip.

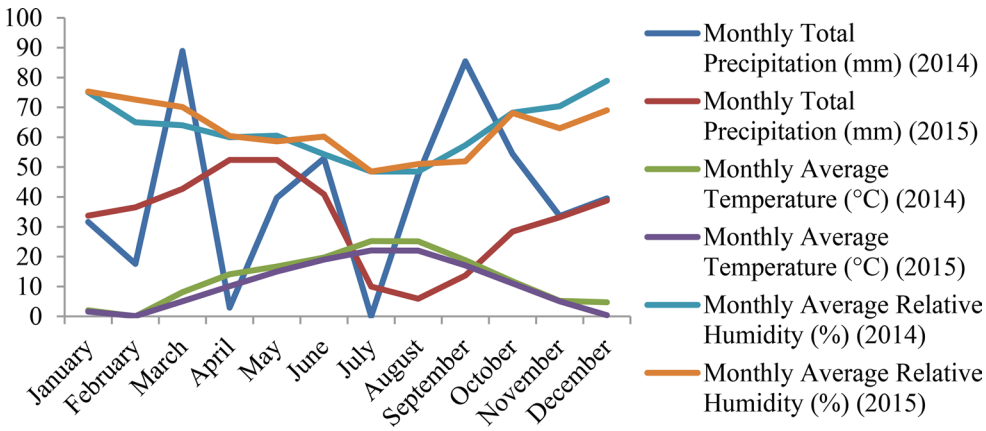


Fig. 1 Average values of monthly climate data for the years in which the experiment was conducted

Table 2 Weed species and density detected in the trial area

Familia	Scientific Name	Density (plant/m^{-2})
Amaranthaceae	*Amaranthus retroflexus* L.	13.2
Chenopodiaceae	*Chenepodium album* L.	10
Poaceae	*Poa annua* L.	6
Asteraceae	*Lactuca serriola* L.	4.5
Zygophyllaceae	*Tribulus terrestris* L.	3.4
Papaveraceae	*Fumaria officinalis* L.	2.9
Asteraceae	*Artemisia absinthium* L.	2.5
Boraginaceae	*Symphytum officinale* L.	2.2
Brassicaceae	*Sinapis arvensis* L.	2.1
Polygonaceae	*Polygonum cognatum* Meissn.	1.5
Asteraceae	*Sonchus oleraceus* L.	1.5

Cobs were then separated from their grains and weighed; cob weights were calculated accordingly. The grain-to-cob ratio (%) was determined based on these measurements (Anonymous, 2018).

After accounting for border effects in each plot, grain yield (kg ha^{-1}) was obtained by threshing the cobs to separate grains, which were then weighed (Anonymous, 2018).

Statistical Analysis

The experiment was established according to a split-plot arrangement within a randomized complete block design with four replications. Cover crop species were placed in the main plots, whereas hoeing treatments were assigned to the sub-plots. The collected data were subjected to ANOVA using the SAS statistical software package (SAS Institute, 1999). Significant differences among treatment means were determined using the LSD test. Since the application x year interaction was found to be insignificant in terms of grain-cob ratio and corn yield, annual averages are given. In other data, since the application x year interaction was significant, the data are given separately on a yearly basis.

Result

A total of 13 weed species belonging to 9 families were determined during the years of the experiment in the experimental field where the cover crop application was carried out. Weeds detected in the experimental area are given in Table 2. The highest density was observed in *Amaranthus retroflexus* L. (13.2 plants m^{-2}), followed by *Chenopodium album* L. (10 plants m^{-2}) and *Poa annua* L. (6 plants m^{-2}). In contrast, some species, such as *Sonchus oleraceus* L. and *Polygonum cognatum* Meissn., were found at lower densities.

In terms of family distribution, Asteraceae is the most represented family with three species. Overall, the results indicate that *Amaranthus retroflexus* and *Chenopodium album* are particularly dominant species in the experimental area and occupy an important place in the weed flora.

Cover Crops Effect on Plant Height of Corn (cm)

In 2014, cover crop affected plant height under both hoeing regimes. Under the two-hoe treatment (28th and 56th days), plant height ranged from 144 to 236 cm. The highest plant heightest values were observed with *V. villosa* (236 cm), followed by *V. pannonica* (186 cm) and *S. cereale* (179 cm), while the lowest height occurred in the control (144 cm). Similarly, under the one-hoe regime, plant height ranged from 141 to 236 cm. The highest value was again observed with *V. villosa* (236 cm), followed by *Vicia pannonica* (173 cm). The control treatment showed the lowest plant height (141 cm). In 2015, differences among treatments were observed for plant height and plant diameter. Under the two-hoe regime, plant height ranged from 189 to 257 m. The tallest plants were recorded in *V. pannonica* (257 cm), followed by *V. villosa* (252 cm), while the shortest plants occurred in the control plots (189 cm). Under the one-hoe treatment, similar trends were observed. *Vicia villosa* (246 cm) and *V. pannonica* (243 cm) produced taller plants than the control (174 cm) (Fig. 2).

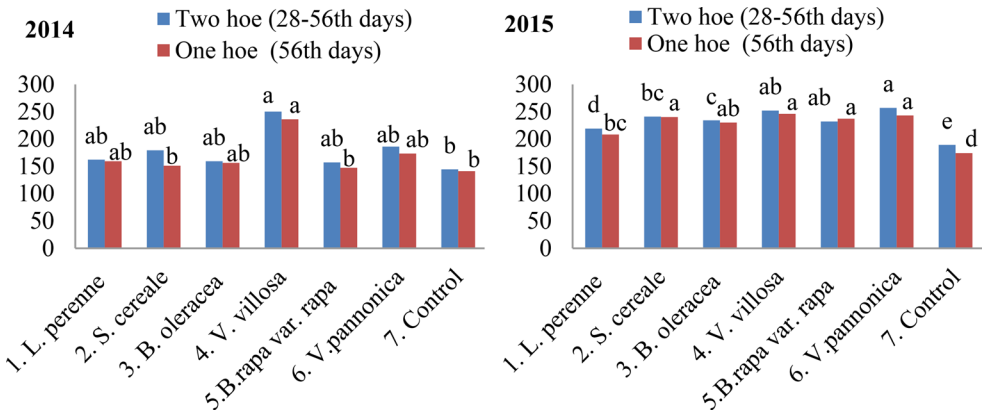


Fig. 2 Effects of cover crop and hand hoe treatments on plant height (cm)

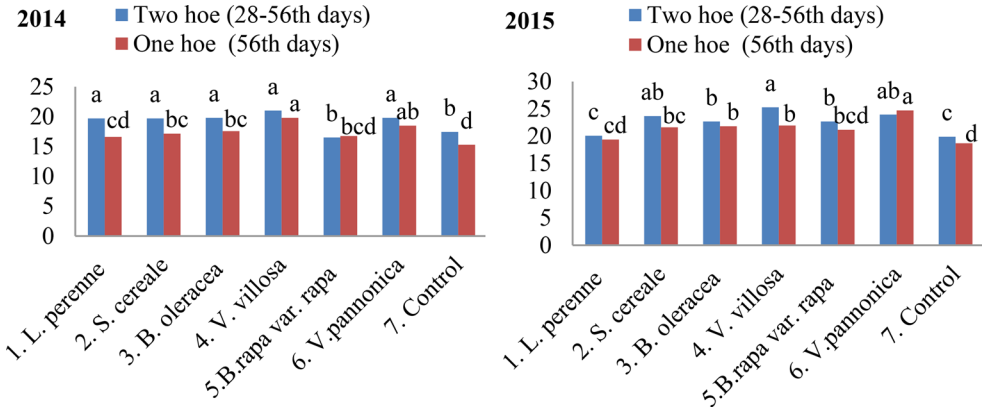


Fig. 3 Effects of cover crop and hand hoe treatments on plant diameter (mm)

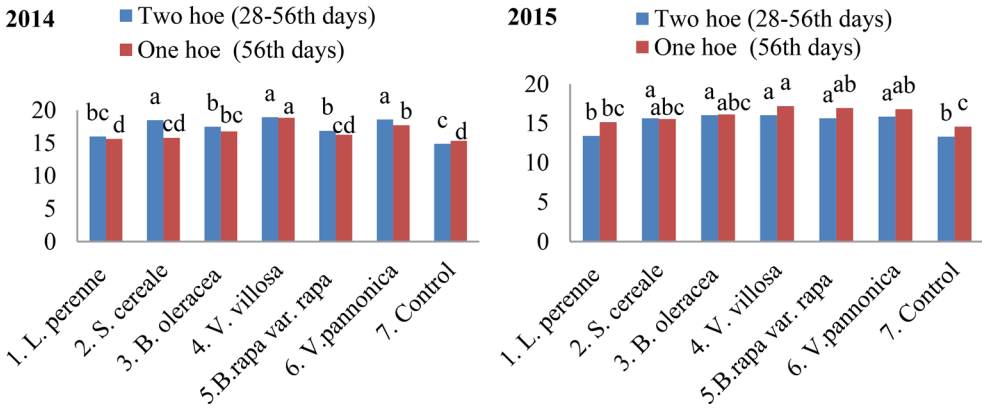


Fig. 4 Effects of cover crop and hand hoe treatments on cob length (cm)

Cover Crops Effect on Plant Diameter of Corn (mm)

Plant diameter was also significantly affected by cover crop treatments in 2014. Under two hoe treatment, stem diameter ranged from 16.6 to 21.1 mm. The hihhest values were obtained with *V.villosa* (21.1 mm), fallowed by other treatments, while the lowes values were recorded in the control (17.4 mm). Similarly, under the one-hoe treatment, plant diameter ranged from 15.3 to 19.8 mm, the highest diameter values were again obtained from *V. villosa* (19.8 mm), and the lowest in the control treatment. In 2015, plant diameter values were generally higher compared to 2014. Under two hoe treatment, stem diameter ranged from 19.9 to 25.3 mm, with the highest value recorded in *V. villosa* (25.3 mm) and the lowest in the control (19.9 mm). Under the one-hoe treatment, plant diameter ranged from 18.7 to 24. 7 mm. The highest value was obtanined with *V. pannonica* (24.7 mm), while the lowest values was again recorded in the control plots (18.7 mm). Taken together, the 2015 results indicate that leguminous cover crops, particularly *V. villosa* and *V. pannonica*, substantially enhanced vegetative growth parameters, with stronger treatment effects observed compared to 2014 (Fig. 3).

Cover Crops Effect on Cob Length (cm)

Cob length varied among cover crop treatments regimes, and the response differed depending on hoeing intensity. Under the two-hoe treatment (28th and 56th days), cob length ranged from 15 to 19 cm. The longest cobs were obtained from *Vicia villosa* (19 cm) and *V. pannonica* (18.7 cm), followed by *S. cereale* (18.6 cm), while the shortest cob length was recorded in the control (15 cm). Under the one-hoe regime, cob length varied between 15.4 and 18.9 cm, with *V. villosa* again producing the longest cobs (18.9 cm), whereas the control and *L. perenne* resulted in shorter values. In the second evaluation, under the two-hoe regime, cob length ranged from 13.3 to 16.1 cm. The highest values were observed in *S. cereale*, *B. oleracea*, *V. villosa*, and *Vicia pannonica* (15.7–16.1 cm), while the lowest value occurred in the control (13.3 cm). Under the one-hoe treatment, cob length ranged from 14.6 to 17.2 cm, with *V. villosa* producing the longest cobs (17.2 cm), and the control together with *L. perenne* again showing lower values (Fig. 4).

Cover Crops Effect on Cob Diameter (cm)

In 2014 cob diameter varied among cover crop treatments and hoeing practices. Under two hoeings, cob diameter

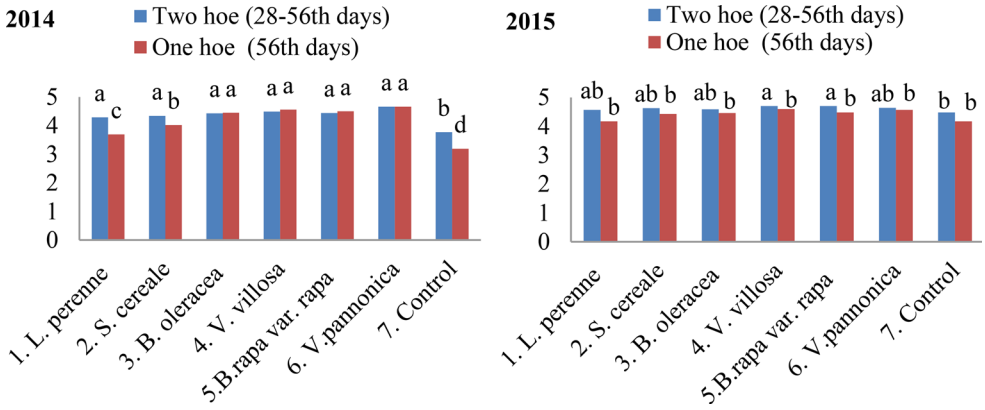


Fig. 5 Effects of cover crop and hand hoe treatments on cob diameter (cm)

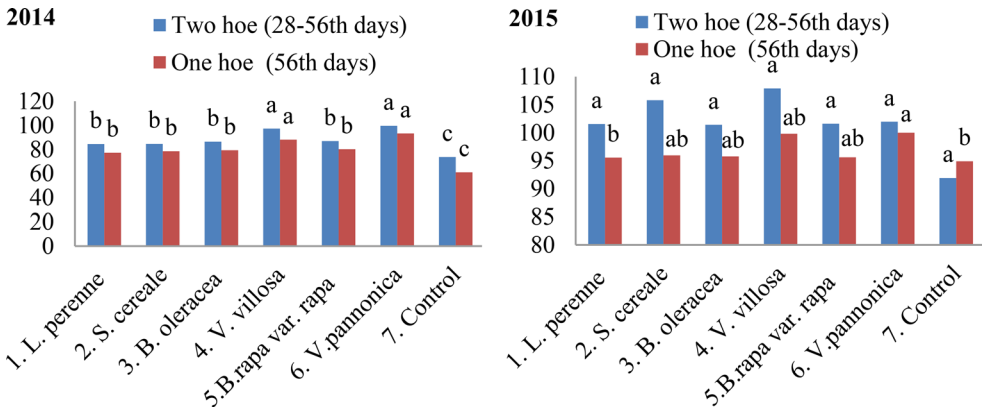


Fig. 6 Effects of cover crop and hand hoe treatments on first cob height (cm)

ranged from 37.7 to 4.7 cm. The largest cob diameter was observed in *V.pannonica* (4.7 cm), followed by *V. villosa* (4.5 cm). The lowest diameter was recorded in the control treatment (3.8 cm). Under two hoeings, cob diameter ranged from 4.5 to 4.7 cm, and *V.villosa* produced the largest cob diameter (4.7 cm). The lowest diameter values were consistently observed in the control treatment. Taken together, the 2015 results confirm that leguminous cover crops, especially *V. villosa*, consistently improved cob size parameters under both hoeing regimes, whereas the control treatment resulted in significantly reduced cob length and diameter (Fig. 5).

Cover Crops Effect on First Cob Height (cm)

In 2014, under the two-hoe treatment (28th and 56th days), first cob height ranged from 73.8 to 99.5 cm. The highest first cob height was recorded in *V. pannonica* (99.5 cm) and *V. villosa* (97.3 cm). These treatments were followed by *B.oleracea* and *B. rapa* var. *rapa*, while the lowest value was observed in the control treatment (73.8 cm). Similarly, under the one-hoe regime, first cob height varied between 61 and 93.2 cm. The maximum height was obtained from *V. pannonica* (93.2 cm) and *V. villosa* (88.2 cm). The lowest first cob height was again recorded in the control plots (61 cm). In 2015, under the two-hoe treatment, first cob height ranged from 92 to 108 cm. The highest values were recorded in *V. villosa* (108 cm), *S. cereale* (105.9 cm), and *V.pannonica* (102 cm). The lowest first cob height was again observed in the control treatment (92 cm). Under the one-hoe regime, first cob height varied between 95 and 100 cm. *V. pannonica* (100 cm) and *V.villosa* (99.9 cm) produced the highest first cob heights, whereas the control treatment resulted in significantly lower values (95 cm) (Fig. 6).

Cover Crops Effect on Grain Cob Ratio (%)

In 2014, under the two-hoe treatment (28th and 56th days), grain cob ratio ranged from 74.7 to 98.9%. The highest value was recorded in *V. villosa* (98.9%), followed by *V.pannonica* (81.6%). The remaining treatments, including *B. rapa* var. *rapa*, B. oleracea, *S. cereale*, and *L. perenne*, showed similar and relatively lower values, while the lowest value was observed in the control treatment (74.7%). Under the one-hoe regime, grain cob ratio varied between 67.9 and 77.9%. The highest value was obtained from *V.villosa* (77.9%), followed closely by *V. pannonica* (77.5%) and *B. oleracea* (76.4%). The lowest grain cob ratio was recorded in the control plots (67.9%). In 2015, under the two-hoe treatment, grain cob ratio ranged from 72.9 to 81.6%. The highest value was obtained from *V. villosa* (81.6%), followed by *V. pannonica* (80.7%) and *B. rapa* var. *rapa* (81.2%).

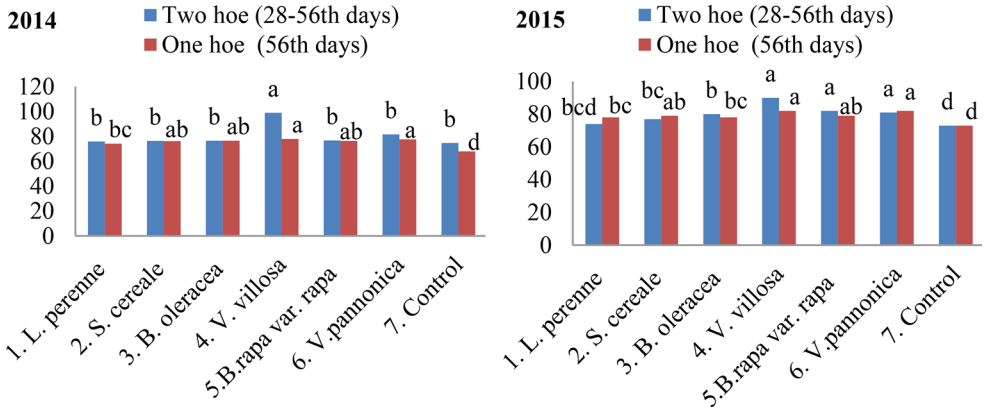


Fig. 7 Effects of cover crop and hand hoeing treatments on grain cob ratio(%)

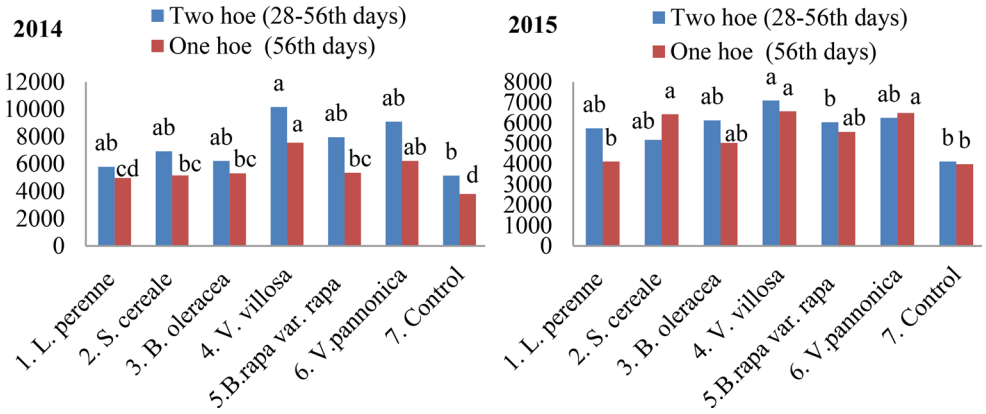


Fig. 8 Mean values showing the impact of cover crops on corn yield (kg ha⁻¹)

Lower values were observed in *B.oleracea*, *S. cereale*, and *L. perenne*, while the lowest value was recorded in the control treatment (72.9%). Under the one-hoe regime, grain cob ratio varied between 72.9 and 81.6%. The highest values were recorded in *V. villosa* (81.6%) and *V. pannonica* (81.1%), whereas the lowest value was again observed in the control plots (72.9%) (Fig. 7).

Effect of Cover Crops on Corn Yield (kg ha^{-1})

In 2014, under the two-hoe treatment (28th and 56th days), corn yield ranged from 5151.0 to 10168.4 kg ha⁻¹. The highest yield was obtained from *V.villosa* (10168.4 kg ha⁻¹), followed by *V. pannonica* (9092.5 kg ha⁻¹) and *B.rapa* var. *rapa* (7954.6 kg ha⁻¹). Lower yields were recorded in *S.cereale*, *B. oleracea*, and *L. perenne*, while the lowest yield was observed in the control treatment (5151.0 kg ha⁻¹). Under the one-hoe regime, corn yield varied between 3803.3 and 7551.1 kg ha⁻¹. The highest yield was again obtained from *V. villosa* (7551.1 kg ha⁻¹), followed by *V. pannonica* (6216.6 kg ha⁻¹). The lowest yield was recorded in the control plots (3803.3 kg ha⁻¹). In 2015, under the two-hoe treatment, corn yield ranged from 4117.4 to 7095.5 kg ha⁻¹. The highest yield was obtained from *V. villosa* (7095.5 kg ha⁻¹), followed by *V. pannonica* (6248.4 kg ha⁻¹), *B. oleracea* (6130.1 kg ha⁻¹), and *B.rapa* var. *rapa* (6031.3 kg ha⁻¹). The lowest yield was again observed in the control treatment (4117.4 kg ha⁻¹). Under the one-hoe regime, corn yield varied between 3986.6 and 6566.6 kg ha⁻¹. The highest yields were recorded in *V. villosa* (6566.6 kg ha⁻¹) and *V. pannonica* (6491.3 kg ha⁻¹), while the lowest yield was obtained from the control plots (3986.6 kg ha⁻¹) (Fig. 8).

Discussion

During the experimental period, a total of 13 weed species belonging to 8 different families were identified in the plots where cover crops were applied. The recorded species included *S.officinale*, *F. officinalis*, *L. serriola*, *S. oleraceus*, *P. annua*, *S. arvensis*, *P. cognatum*, *A. absinthium*, *A. retroflexus*, *T. terrestris*, *S. ruthenica and C. album*. The weed flora observed in the experimental area was largely consistent with previous reports on the dominant weed species in the Kayseri region of Türkiye (Esitmez & Isık, 2016; Akca & Isık, 2016; Kale & Isık, 2025).

This research investigated the effects of different cover crop species on important morphological characteristics and yield parameters of corn, including plant height, stem thickness, first cob height, cob length, cob diameter. These findings add to the evidence supporting cover crops as a

sustainable tool for weed management as well as improving corn yield.

The highest plant height and stem thickness were recorded in plots with *V. villosa.* The lowest values appeared in plots with weedy control. There was no difference in plant height between *V. villosa* and *V. pannonica.* Similarly, stem diameter showed no statistical difference between weedy plots and those with *Lolium perenne*, *Brassica oleracea*, and *B.rapa* var. *rapa*. Employing two hand hoeings (on days 28 and 56) enhanced both plant height and stem thickness compared to a single hoeing (on day 56). This positive effect is likely due to the *V. villosa* nitrogen-fixing ability andand weed suppression capacity. Previous research also supports this finding. Leguminous cover crops reduce weed pressure (Teasdale & Mohler, 2000). In addition, they improve soil conditions and root development (Snapp et al., 2005).These crops also conserve soil moisture (Wortman et al., 2012), and promote stronger stem growth (Clark, 2007). The nitrogen added by *V. villosa* improves corn development. Increased nitrogen uptake and improved plant traits have been reported under suitable management practices (Rosolem et al., 2004; Kaplan et al., 2016), Additionally, increasing planting density has been shown to enhance plant height and first cob height, as well as cob length and diameter (Özata, 2013). These results indicate that cover crops positively influence not only yield but also the structural development of corn. In both years, the application of *V. pannonica* and *V. villosa* resulted in the highest first cob height under both one and two hoeing conditions. These legume species are known to increase soil nitrogen content through biological nitrogen fixation, promoting the vegetative development of maize and enhancing soil structure (Snapp et al., 2005). Previous studies have also reported that legume cover crops positively impact plant height and cob formation in corn (Teasdale, 1996; Liebman & Dyck, 1993). Increased plant height and internode length lead to more cob formation, resulting in higher first cob height.

The generally higher first ear height observed in double hoeing compared to single hoeing can be explained by the more effective reduction of weed competition. Weeds competing with maize during early growth reduce light, water, and nutrient availability, thereby negatively affecting plant height and yield components (Page et al., 2012). Likewise, mechanical weed control has been shown to improve plant growth and ear characteristics (Khan et al., 1998). Furthermore, improved weed control and resource availability (Teasdale & Mohler, 2000), better soil moisture retention (Wortman et al., 2012), and increased nitrogen supply (Kaplan et al., 2016) also contribute to the positive impact on cob height.

The results of this study demonstrate that the combined use of cover crops and mechanical weed control significantly influences maize growth, yield components, and overall productivity. In general, leguminous cover crops, particularly *Vicia villosa* and *Vicia pannonica*, showed superior performance across most parameters, indicating their suitability for sustainable maize production systems.

Improved vegetative growth under these treatments can be explained by better resource availability and reduced weed competition. Cover crops contribute to improved soil conditions and suppress weeds, allowing maize plants to utilize light, water, and nutrients more efficiently (Snapp et al., 2005; Wortman et al., 2012). The higher plant height and stem thickness observed under double hoeing further highlight the importance of effective weed control in enhancing crop growth.

Higher first cob height in legume treatments reflects improved plant development, whereas lower values in control plots indicate the negative effects of weed competition and suboptimal soil conditions. More effective weed suppression under double hoeing likely reduced early-stage competition, contributing to better plant structure (Page et al., 2012; Khan et al., 1998).

Cob length and diameter were also positively affected by both cover crop species and hoeing intensity. The superior performance of *Vicia villosa* and *Vicia pannonica* suggests that favorable soil conditions and reduced competition support reproductive development and grain formation. In contrast, lower values in control and non-legume treatments may be associated with limited nutrient availability and higher weed pressure (Teasdale, 1996; Hartwig & Ammon, 2002).

Grain/cob ratio results further indicate that cover crops improve the efficiency of assimilate partitioning. Higher ratios observed in legume-based systems suggest more effective grain filling, while lower ratios in control treatments reflect limitations caused by competition and resource constraints. Increased ratios under more intensive hoeing also emphasize the role of weed management in improving resource use efficiency (Khan et al., 1998).

Maize grain yield was strongly influenced by the combination of cover crop species and weed control practices. Although differences among some treatments were not always pronounced, consistently higher yields obtained from *Vicia villosa* and *Vicia pannonica* indicate that these species create favorable growth conditions. The higher yields under double hoeing confirm the importance of timely and repeated weed control in minimizing competition during critical growth stages. In contrast, lower yields in control plots demonstrate the limitations of systems without cover crops and adequate weed management.

These findings are consistent with previous studies reporting positive effects of cover crops on crop performance in different agricultural systems (Liebman and Davis

2000; Mennan et al. 2009a, b; Işık et al., 2009; Demir & Işık, 2019). Similar results have also been observed in orchard systems, where *Vicia villosa* improved productivity under diverse conditions (Demir and Işık 2020b; Macit et al. 2020; Macit and Işık, 2023).

Overall, the findings indicate that integrating suitable cover crop species with effective mechanical weed control improves maize growth and productivity while supporting more sustainable crop management practices.

Conclusion

This study demonstrates that integrating cover crops with mechanical weed control is an effective and sustainable approach to improving maize performance. Leguminous cover crops, particularly *V. villosa* and *V.pannonica*, enhance crop productivity by supporting soil fertility and suppressing weeds. Their use, combined with timely hoeing, can reduce reliance on herbicides and external nitrogen inputs. Overall, these findings support the adoption of cover crops as a practical strategy for sustainable maize production and improved soil health.

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Data Availability The data supporting the findings of this study can be provided upon reasonable request.

Declarations

Competing Interests The authors declare no competing interests.

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