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The effect of preceding forage crop application on maize (*Zea mays* L.) yield components in no-tillage farming conditions

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Abstract

Soil cultivation is an important practice in agriculture, which causes significant harm as well as benefits. Therefore, no-tillage farming has been widely practiced around the world. Preceding forage crop application is another important practice applied in plant production. The objective of this study was to investigate the effects of different preceding forage crop applications on some characteristics (plant height, ear height, ear length, ear diameter, kernel rows, grain number, ear grain yield, 1,000-grain weight) of maize under no-tillage farming conditions. Maize was used as the main plant in the study, and legumes (common vetch, narbon vetch, and forage pea) and cereal (barley, triticale, and annual ryegrass) forage plants were used as preceding forage crops. The results obtained over the 2-year trial indicated that legume species generally had a more favorable effect on maize yield components than cereal species. Among the legumes, vetch resulted in higher maize yield components than forage peas, while barley performed better than the other cereal species. These results showed that legumes are more advantageous as a preceding forage crop in no-tillage farming, and that vetch species from legumes and barley from cereals were more suitable as preceding forage crop species for maize cultivation.

Keywords: Cereals; Corn; Direct seeding; Legumes; Preceding crop; Soil tillage

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Introduction

Maize (also called corn) is a member of the Poaceae family and is one of the world's most important cereal crops, with major uses as human food, animal feed, and an industrial raw material[1,2]. Global production statistics identify maize as one of the leading cereal crops worldwide in terms of both production and harvested area[3–5].

Agricultural practices (irrigation, fertilization, spraying, weed control, etc.) have a direct impact on maize yield, as for all plants[6,7]. One of the main agricultural activities practised by farmers is tillage, and this is a widespread practice in modern agriculture. Although tillage is important for agricultural production, some negative conditions (deformation of soil structure, erosion, decrease in soil moisture and organic matter, and soil compaction) may arise when it is applied intensely[8–15]. Consequently, these conditions lead to a decline in soil productivity[16].

No-tillage or reduced-tillage farming is an important agricultural method that has been widely used and supported in recent years for the protection of both soil properties and the environment[17–20]. The benefits obtained from no-tillage farming may vary depending on the prevailing environmental and management conditions[21,22]. However, previous studies have reported that improvements in soil structure (bulk density, total porosity, aggregate size, and stability) have been observed in agricultural systems applied without cultivating the soil, and the biological activity of the soil, nutrient cycle, water-holding capacity, water infiltration, and water use efficiency of plants have been seen to increase[23,24]. As a result, an increase in productivity has been achieved[25,26].

Crop rotation is an important cultural management practice in agricultural production. Well-designed rotations can improve resource-use efficiency, soil fertility, and soil organic matter, and can help reduce pest and disease pressure[27–30]. In addition, nutrients contained in cover-crop residues can be recycled and subsequently become available to following crops as the residues decompose[31]. Crop rotation can also reduce erosion and improve water-use efficiency[32].

If crop rotation is not implemented carefully, it does more harm than good. Crop rotation, when not properly planned, can lead to imbalanced nutrient use in the soil, increased incidence of pests and diseases, and yield losses in certain crops. In particular, growing incompatible or poorly selected crops consecutively may result in adverse effects rather than providing the intended benefits of crop rotation. The selection of suitable plants in the areas where crop rotation will be applied is very important for profitable production[33]. The aim of this study was to determine the most suitable preceding forage crops for maize production in no-tillage agricultural conditions.

Materials and methods

Study site and climatic conditions

The trial was conducted in the research and application field on the campus of Akdeniz University, Antalya, Turkiye (36°54′ N, 30°38′ E) between November and September in 2015–2016 and 2016–2017. According to the climate data for the periods in which the experiments were carried out, the total amount of precipitation was lower than the long-term total of 829 mm, which is the long-term average (1930–2014) for Antalya; the total precipitation was 420.4 mm in 2015–2016 and 583.4 mm in 2016–2017. Average monthly temperature values were measured at 20.39 °C in

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2015–2016 and 19.82 °C in 2016–2017; these values were higher than the long-term average temperature of 18.9 °C (Table 1).

Soil physical and chemical properties

The experimental area soil (0–30 cm) contained a low level of organic matter (1.3%) (Walkley & Black[34]), medium total nitrogen (N) (0.089%) (Kjeldahl method), low absorbable phosphorus (P) (5 mg·kg^{-1}) (Olsen et al.[35]), and low potassium (K) (0.296 meq·100 g^{-1}) (A. Asetat-ICP) content. The soil texture was clay-loam (clay: 40%, silt: 35%, sand: 25%) (Bouyoucos[36]), and slightly salty (2.7 dS·m^{-1}) (saturation extract), high in lime (27%) (Scheibler calcimeter), and strongly alkaline (pH 8.6) (Jackson[37]). The experiment was conducted in the same field in both years.

Experimental design and plant materials

The study was conducted in a randomized complete block design (RCBD) with three replicates. Maize (*Zea mays* L.) was used as the main material. Legume plants (common vetch [*Vicia sativa* L.], narbon vetch [*Vicia narbonensis* L.], and forage pea [*Pisum arvense* L.]) and cereal plants (barley [*Hordeum vulgare* L.], triticale [*x Triticosecale* Wittmack], and annual ryegrass [*Lolium multiflorum* Lam.]) were used as the cover crop material.

Preceding crop establishment and management

When sowing the preceding forage crop material (legumes and cereals), conventional soil tillage practices were applied. At sowing, elemental N was applied at rates of 50 kg·ha^{-1} to legumes and 100 kg·ha^{-1} to cereals, while both groups received 100 kg·ha^{-1} P_2O_5. The lower N rate applied to legumes reflected their capacity to obtain part of their N requirement through biological N_2 fixation. With the exception of annual ryegrass, all the other preceding forage crops were sown on the same date (November). As annual ryegrass is a multi-cut plant, it was planted 2 weeks before the other preceding forage crops. In this way, it was ensured that the second cutting time of annual ryegrass would be the same as for the other preceding forage crops. Weeds were removed manually, and no herbicide was applied. At the time of cutting for green herbage, the preceding forage crop plots were cut with a sickle 5 cm above the ground surface, and after harvest, the aboveground biomass was removed from the experimental area, while the roots and crop residues remained in the soil.

Table 1. Temperature and total precipitation values for the study area in Antalya Province.

	Temperature (°C)			Total precipitation (mm)		
	2015–2016	2016–2017	Long term (1930–2014)	2015–2016	2016–2017	Long term (1930–2014)
November	18.4	17.5	15.4	116.9	99.2	77.8
December	13.2	11.2	11.6	0.4	76.3	182.5
January	10.6	10.2	10.2	79.4	132.8	245.7
February	14.6	12.5	11.1	66.7	4.4	133.2
March	15.3	15.0	13.7	57.2	166.9	48.2
April	19.1	17.7	16.4	14.4	54.0	55.8
May	20.4	21.3	21.0	28.2	42.2	49.8
June	26.9	26.3	25.9	24.3	3.4	4.2
July	29.9	30.4	28.9	0.6	0.4	3.0
August	29.5	29.0	28.8	0.0	1.6	1.8
September	26.4	26.9	25.1	32.3	2.2	27.0
Average	20.39	19.82	18.9	420.4	583.4	829.0

Maize establishment and crop management

Maize was planted directly into the stubble without any tillage in the plots where the preceding forage crops were harvested, using a hand hoe to simulate direct seeding with a no-till planter. In addition, plots without a preceding forage crop were included as the control group. Maize seeds were sown on the 3rd of May in the first year and the 5th of May in the second year. Row spacing was 70 cm, and rows were opened using a pickaxe to imitate a direct seed drill. Seeds were sown with 3–5 cm intra-row spacing and thinned to 20 cm intra-row spacing after emergence.

Half of the N and the full dose of P and K at the rate of 100 kg·ha^{-1} were applied at the time of sowing with 15-15-15 fertilizer. When the plants were 30–40 cm tall, the other half of the N was applied at 100 kg·ha^{-1} with 33% ammonium nitrate fertilizer. The fertilizer rates were calculated based on elemental N, P, and K contents. The same fertilization program was applied uniformly to all maize plots, regardless of the preceding crop treatment. During the trial, irrigation was applied as necessary, and weeds were removed manually without the use of herbicides. No other process (hoeing, throat filling, etc) was applied.

Measurements and data collection

When the maize ears reached harvest maturity, one border row at each plot edge and the first 25 cm of each row were excluded from the measurements. The height of 10 plants randomly selected from the plants in the plot was measured and recorded in cm. Then, ear height (cm) was determined in 10 randomly selected plants. All of the ears in the plot were harvested by hand, and 10 of the harvested ears were selected; ear length (cm), ear diameter (cm), kernel rows (ear^{-1}), and grain number (row^{-1}) values were determined.

Four 1,000-seed technical subsamples were randomly taken from each plot and weighed in the laboratory. The mean of the four subsamples was calculated and recorded as the 1,000-grain weight (g) for that plot; the plot mean, rather than the individual subsamples, was used as the experimental unit in the statistical analysis.

Statistical analysis

The data were analyzed using SAS 9.1 statistical software (SAS Institute Inc., USA). Because the experiment was conducted over 2 consecutive years at the same site, a combined analysis of variance was performed with year, preceding-crop treatment, and the year × treatment interaction included in the model. The statistical model was $Yijk = \mu + Yi + Bj(i) + Tk + (YT)ik + \varepsilon ijk$, where Yi is the effect of year, Bj(i) is the effect of block nested within year, Tk is the effect of preceding-crop treatment, and (YT)ik is the year × treatment interaction. Year and year × treatment effects were tested before pooling the data across years. Neither the year effect nor the year × treatment interaction was significant ($p > 0.05$) for the evaluated traits; therefore, 2-year means are presented. When treatment effects were significant, means were separated using Duncan's multiple range test at $p < 0.05$.

Results and discussion

Comparisons of the plant groups (legumes vs cereals)

The combined analysis showed that neither year nor the year × treatment interaction significantly affected the evaluated traits ($p > 0.05$); therefore, the results are presented as means across the two

experimental years. As seen in Table 2, when preceding forage-crop applications were evaluated on a group basis, they had statistically significant effects on several of the examined characteristics. In general, legumes used as preceding forage crops produced more favorable values than cereals and the control group.

The highest plant height (261 cm) was obtained from legume applications, while the lowest plant height (238 cm) was determined in cereal applications. The first ear height varied between 105 and 112 cm, with no statistical difference determined between the applications. The highest values for ear length (17.22 cm) and ear diameter (4.43 cm) were obtained in legume applications and the control group, and the lowest ear length (14.24 cm) and ear diameter (4.28 cm) values were determined among the cereal applications. Similarly, the greatest number of kernel rows (16) was obtained from the legume application, and the results were determined to be similar for the cereal and control groups. The number of grains reached the highest value at 31 in legume applications, 28 grains were determined in the control group application, and 25 grains in the cereal application. The ear grain yield was determined to be highest in legume applications at 129.28 g, and the lowest yield was determined in cereal applications at 90.61 g. When the 1,000-grain weight values, which are one of the most important characteristics examined for seed yield in plants, were examined, the highest value was determined to be 285.2 g in the control group and 264.6 g in the legume application. The lowest 1,000-grain weight value of 235.5 g was found in the cereal applications.

Legume species can obtain atmospheric N_2 through symbiotic biological nitrogen fixation, and legume-derived N can contribute to soil N supply and to the N nutrition of subsequent crops[38–40]. This biological N input can reduce dependence on mineral N fertilizer in appropriately managed rotations.

Legume root systems can also influence soil structure and nutrient acquisition. Deep-rooted legumes may explore subsoil resources and contribute belowground carbon and N inputs, although the magnitude of these effects depends on species and environmental conditions[41–43]. These root-mediated processes may be particularly relevant in reduced- and no-tillage systems[44].

Another potential advantage of legumes is the belowground residue remaining after harvest. Legume residues generally have lower C/N ratios than cereal residues and can therefore decompose and release N more rapidly under suitable soil conditions[45,46]. In many studies, legumes grown as preceding crops have provided benefits to the following crop[47–50].

Also, the higher 1,000-grain weight recorded in the treatment control group may also be associated with greater availability of soil water and nutrients during maize growth. Preceding forage crops (particularly non-legumes) may use part of the available soil water and nutrients before termination, which could reduce their availability to the following maize crop[51,52]. However, as soil water and N dynamics were not directly measured in this study, these factors should be considered possible explanations rather than confirmed causes of the observed differences.

Comparisons of legumes

As can be seen in Table 3, legume plants used as preceding forage crops showed statistically significant effects on the examined characteristics of ear length, the grain number in the row, grain yield on the ear, and 1,000-grain weight.

The highest plant height value was 267 cm in the common vetch application, and the lowest value of 258 cm was in the narbon vetch application. However, the difference between the values was not found to be statistically significant. Similar results were observed in the first ear height, with values ranging from 115 (forage pea) to 105 cm (narbon vetch), and no statistically significant difference was determined. Different leguminous plants have been shown to have significant effects on ear length. In this study, the highest value for ear length was observed to be 18.50 cm in the narbon vetch application, followed by 18.33 and 17.20 cm in the common vetch and control group, respectively, and all three values were statistically classified within the same group. The lowest ear length of 14.83 cm was recorded in the forage pea application.

The different legume preceding forage crop applications had no statistically significant effect on ear diameter and kernel rows. Ear diameter values varied between 4.36 and 4.48 cm, and kernel rows in the ear varied between 15 and 16 pieces. Grain number per row

Table 2. The effects of different plant groups used as preceding forage crops on maize yield characteristics (2-year average).

	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Kernel rows (ear^{-1})	Grain number (row^{-1})	Ear grain yield (g)	1,000-grain weight (g)
Legumes	261a	109	17.22a	4.43a	16a	31a	129.3a	264.6b
Cereals	238b	105	14.24b	4.28b	15ab	25b	90.6b	235.5c
Control	251ab	112	17.20a	4.38ab	15b	28ab	120.4a	285.2a
F	9.65**	ns	5.51*	7.41**	4.02*	4.58*	15.20**	211.34**
LSD	15.00	7.51	2.30	0.11	0.82	5.01	20.28	5.26

Means followed by different letters within the same column are significantly different at the 0.05 (*) and 0.01 (**) probability levels. ns: not significant; LSD: least significant difference.

Table 3. The effects of different forage legume crops used as preceding forage crops on maize yield characteristics (2-year average).

	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Kernel rows (ear^{-1})	Grain number (row^{-1})	Ear grain yield (g)	1,000-grain weight (g)
Common vetch	267	107	18.33a	4.36	15	35a	143a	266b
Narbon vetch	258	105	18.50a	4.48	16	32a	136a	266b
Forage pea	259	115	14.83b	4.45	16	25b	109b	261b
Control	251	112	17.20a	4.38	15	28ab	120ab	285a
F	ns	ns	13.64**	ns	ns	4.44*	4.26*	22.30**
LSD	15.68	10.04	1.41	0.12	1.06	5.83	22.37	6.70

Means followed by different letters within the same column are significantly different at the 0.05 (*) and 0.01 (**) probability levels. ns: not significant; LSD: least significant difference.

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values were affected by the different applications, and statistically significant differences were determined. The highest grain number per row value was determined in the application of common vetch with 35 pieces, and the lowest value was obtained from the application of forage pea with 25 pieces. A similar situation was also recorded for the grain yield per ear values; the highest ear grain yield was determined to be 143 g in the common vetch application, and the lowest yield was 109 g in the forage pea application.

When the effects of different legume preceding forage crop applications on 1,000-grain weight were examined, there were seen to be statistically significant differences. The greatest 1,000-grain weight was 285 g from the control group application. In the applications of common vetch, narbon vetch, and forage pea, the 1,000-grain weight was calculated as 266, 266, and 261 g, respectively.

Nitrogen is one of the most important elements affecting the yield and quality of plants. Therefore, one of the most important properties sought in plants to be used as preceding forage crops in crop rotations is that they will add N to the soil in which they grow. Legume plants fix N to the soil in which they are grown, leaving a soil with high N content for the plants which will be subsequently grown. However, the rates of nitrogen fixation vary among legume plants. Kebede[53] reported that the amount of N fixed to the soil (107–131 kg·ha^{-1}) in areas planted with common vetch is higher than that of pea plants (36.6–125.3 kg·ha^{-1}).

The results of this study showed that when the values related to the maize grain properties (grain number in row and ear grain yield) were examined, better results were obtained from vetch species compared to forage pea. This difference may be related to the amount of N fixed by the species. In this regard, Enrico et al.[54] reported that vetch generally has a greater potential to contribute N to the succeeding crop than field pea, mainly due to its higher biological nitrogen fixation and more positive N balance. Pál & Zsombik[55] determined that the nutrient forms attached to the soil by common vetch and produced during the decomposition of plant residues are more beneficial for the subsequent growing of oats than fertilizer applied as top-dressing in spring.

Another result obtained from this study was that the 1,000-grain weight was higher in the control group than in the other applications. The weight value is related to the number of grains per ear, so especially when compared to vetch species, the maize ear grain yields decreased in the control group application; competition decreased because the number of grains decreased and the existing grains became heavier, thereby increasing the 1,000-grain weight value. In studies by Alnuaimi et al.[56] and Zaitsev et al.[57] there was a negative correlation reported between the number of grains on the ear and the 1,000-grain weight value.

Comparisons of cereals

When the cereal preceding forage crop applications were examined, it was determined that the applications had statistically significant effects on plant height, first ear height, number of grains in the row, ear grain yield, and 1,000-grain weight (Table 4).

In general, it was determined that the control group application had more favorable effects on the properties examined. The highest value of plant height was determined in the application control group at 251 cm, and the lowest value in the annual grass application at 226 cm. Similarly, for the first ear height, the highest value was determined in the application control group at 112 cm, and the lowest value was determined in the annual grass application at 100 cm. None of the applications created significant statistical effects on the features of ear length (14.50–17.20 cm), ear diameter (4.24–4.38 cm), and number of ear rows (15 pieces). When the values of the number of grains in the row were examined, the application control group gave the highest value with 28 pieces, and the annual grass application gave the lowest value with 24 pieces. The control group application had favorable effects on the ear grain yield, and the highest yield obtained was 120 g. The lowest ear grain yields were determined in annual grass at 84 and triticale at 86 g. The control group application weight gave the highest value of 1,000-grain weight at 285 g, and the lowest value was determined in the annual grass application at 232 g.

The values recorded for the control treatment were generally higher than those obtained when cereals were used as preceding forage crops. Unlike legumes, cereals do not fix atmospheric N_2 and depend on soil N for growth. Cereal cover crops can take up substantial mineral N before termination and, after termination, high-C/N residues can temporarily immobilize N, thereby reducing short-term N availability to a following maize crop[58–60]. The magnitude of this effect depends on cover-crop biomass, termination timing, residue quality, soil conditions, and N management.

In addition, the biomass of cereals contains a higher C/N ratio compared to legumes. Dannehl et al.[61] reported that while the C/N ratio of barley straw was 81.5, the C/N ratio of peas was 50.5. The C/N ratio is one of the main factors affecting the N release of organic materials[62]. Plant residues with high C/N content are very difficult to decompose in the soil[63], and it takes time for the organic and inorganic materials they contain to mix into the soil. Therefore, the use of nutrients by plants grown after cereals is prevented, and plant development is negatively affected.

The lowest values for all examined traits were obtained when annual ryegrass was used as the preceding forage crop. One possible explanation is the relatively long growth period and high resource capture of ryegrass before termination. Longer or later-terminated grass cover crops can accumulate more biomass and N, which may temporarily reduce soil mineral N availability to the following crop[64,65]. Because soil water and nutrient uptake by the preceding crops were not directly measured in the present study, this explanation should be regarded as a plausible mechanism rather than a demonstrated cause.

Another reason for the low values obtained for the properties examined in the annual ryegrass application is thought to be the

Table 4. The effects of different cereal crops used as preceding forage crops on maize yield characteristics (2-year average).

	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Kernel rows (ear^{-1})	Grain number (row^{-1})	Ear grain yield (g)	1,000-grain weight (g)
Annual ryegrass	226b	100b	14.50	4.24	15	24c	84c	232d
Triticale	241ab	106ab	14.67	4.35	15	25bc	86c	236c
Barley	248a	108ab	15.67	4.27	15	27ab	102b	239b
Control	251a	112a	17.20	4.38	15	28a	120a	285a
F	3.66*	3.56*	ns	ns	ns	4.54*	15.20**	414.14**
LSD	20.17	9.11	3.01	0.19	1.24	3.09	13.12	3.58

Means followed by different letters within the same column are significantly different at the 0.05 (*) and 0.01 (**) probability levels. ns: not significant; LSD: least significant difference.

chemical composition of root residues. Ponce et al.[66] isolated substances such as flavonoids, benzoic acids, and cinnamic acids from the stem and root of the annual ryegrass plant. Bezuidenhout et al.[67] reported that a high rate of allelochemicals (phenolic acids and benzoxazolin-2[3H]-one) was detected in the root residues of the annual ryegrass plant, and because of these chemicals, primarily germination and ultimately yields of the main plant were negatively affected.

Conclusions

No-tillage farming is an important component of sustainable agriculture. In this study, the effects of preceding forage crops on selected maize yield components under no-tillage conditions were investigated. Overall, legumes were generally more advantageous than cereals as preceding forage crops. Among the legumes, vetch species produced more favorable results than forage pea, while barley performed better than annual ryegrass and triticale among the cereals. The control treatment nevertheless produced higher values for some parameters, indicating that preceding crops can also impose short-term competition for water or nutrients. Because two crops can be harvested from the same land within the annual cropping cycle, the agronomic value of the system should ultimately be assessed together with total seasonal production and economic returns. A limitation of the present study is that the experiment was conducted at a single site over two consecutive years; consequently, the findings should be interpreted within the soil and climatic conditions of this environment. Multi-location and longer-term experiments across contrasting Mediterranean environments are needed to test the stability and broader applicability of the observed responses.

Ethical statements

During the revision of this manuscript, the author used ChatGPT (OpenAI) solely to assist with English language editing and to improve the clarity and readability of the text. The scientific content, experimental design, data collection, statistical analyses, interpretation of the results, and conclusions were developed independently by the author. All AI-assisted revisions were critically reviewed and verified by the author, who takes full responsibility for the content of the manuscript.

Author contributions

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

Data availability

The data supporting the findings of this study are available from the corresponding author upon request.

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Conflict of interest

The authors declare that they have no conflict of interest.

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