

Short-Term Effects of Legume Green Manures on Soil Chemical Properties in a Calcareous Mediterranean Soil

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Abstract

Green manuring is widely used to develop soil fertility, yet its short-term influence on soil properties in calcareous Mediterranean soils is not fully understood. This study investigated the short-term effects of four legume green manure species—chickpea (*Cicer arietinum* L.), faba bean (*Vicia faba* L.), forage pea (*Pisum sativum* L.), and vetch (*Vicia sativa* L.)—on selected soil chemical properties under field conditions. The experiment was conducted according to a randomized complete block design. After plant development was complete, all above-ground and below-ground biomass was incorporated into the soil. Soil sampling was performed after approximately six months of decomposition. Soil pH, total salt, organic matter, total N, available P and K, and selected microelements were analyzed. No statistically significant differences were found among legume species in any of the measured soil chemical parameters ($p>0.05$). Soil pH ranged from 7.34 to 7.41, and total salt remained at 0.010% in all treatments. Organic matter (1.56–1.72%) and total N (0.083–0.093%) showed only small numerical differences. Although available P and K concentrations showed slight differences among treatments, these differences were not statistically significant. No significant changes were observed in the concentrations of DTPA-extractable Fe, Cu, Zn, and Mn. Although no statistically significant differences were found among the four legume species in the short term, no decrease in soil chemical parameters was observed during a single growing season. Values after incorporation into the soil remained within similar ranges to those measured before application.

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1. Introduction

Green manuring is an agroecological practice used to improve soil fertility, conserve soil organic matter, and support nutrient cycling during fallow periods (Dutta et al., 2022). In these systems, particularly when legume crops are used, fresh biomass is mixed into the soil as an organic input and affects soil chemical properties during decomposition and mineralization processes (Stein et al., 2023). The magnitude and timing of these effects are determined by soil characteristics, climatic conditions, and the duration of green manure application (Bolan et al., 2023). Mediterranean agricultural soils generally have high calcium carbonate (CaCO_3), pH values ranging from neutral to slightly alkaline, and low organic matter. The high CaCO_3 content provides strong buffering and limits short-term changes in soil pH and nutrient availability after organic fertilizer applications, especially under calcareous conditions (Durán et al., 2024). In contrast, changes in soil organic matter, total organic C, and total N are largely determined by plant residue inputs, decomposition processes, and time scale. P fixation, microelement precipitation, and slow organic matter turnover in these soils often limit short-term soil chemical responses following green manure application (Bolan et al., 2023). Therefore, evaluating the effects of green manure in calcareous soils is important for understanding realistic short-term outcomes in the Mediterranean soil environment. Legume species used as green manure show wide variations in growth habit, biomass production, plant residue quality, and nutrient composition. These differences, together, regulate their decomposition processes and nutrient release after being incorporated into the soil (Allito et al., 2021; de Freitas et al., 2023). Chickpea (*Cicer arietinum* L.), faba bean (*Vicia faba* L.), forage pea (*Pisum sativum* L.), and vetch (*Vicia sativa* L.) are representative widely grown annual legumes in Mediterranean agroecosystems. These species represent different plant architectures and biomass distribution patterns with varying above-ground biomass levels from low to high. They are cultivated in regional crop patterns either

for grain production or as green manure crops (Yeremko et al., 2025). They were selected because they exhibit significant differences in biomass production and crop residue characteristics specific to Mediterranean rotations. This allows for direct comparison of short-term and species-specific soil responses under similar field conditions. Although legume green manures are widely used, most current studies focus on long-term or perennial applications where cumulative effects on soil chemical properties become more pronounced. Previous studies have shown that short-term changes in soil chemical properties are generally limited in calcareous soils. However, studies directly comparing different legume species in the same calcareous field environment over a single growing season are limited; this is particularly true for Mediterranean agroecosystems (Hansen et al., 2021). Testing whether short-term responses are truly limited and whether differences exist between species under the same soil conditions is essential for demonstrating the practical significance of single-season applications. Therefore, this study aimed to evaluate the short-term effects of four legume green manure species on selected soil chemical properties under field conditions in a calcareous Mediterranean soil. It was hypothesized that (i) soil chemical properties might show limited short-term responses after a single green manure application due to the high CaCO_3 -derived buffering capacity affecting pH and nutrient availability, and (ii) despite numerical differences in biomass production and plant residue characteristics, differences between legume species might not lead to statistically significant changes within a growing season.

2. Material and Methods

2.1. Study area, experimental design, and crop management

The field study was conducted in Manavgat, Antalya (Turkey) ($36^\circ 48' 30''$ N, $31^\circ 23' 18''$ E), a coastal area located approximately 25 m above sea level. The land was left fallow for four years without any crop cultivation or chemical inputs. Before planting, soil samples

were taken from two different depths (0–30 and 30–60 cm) to determine the initial soil conditions, and then the land was prepared by plowing using conventional tillage methods. Before establishing the experimental plots, the basic physico-chemical properties of the experimental area were determined, and the results are presented in Table 1. The soil had a clay loam texture at both depths. It showed no salinity, and pH values ranged from 7.49 to 7.75. The lime (CaCO_3) content was above 45% throughout the soil profile, indicating that

the soil is significantly calcareous. Organic matter content ranged from 0.70% to 1.11%, while total N varied between 0.05% and 0.06% at different depths. Available macro- (P, K, Ca, and Mg) and microelement levels (Fe, Cu, Zn, Mn, B, Mo, Co, and extractable S), are presented in Table 1 to characterize the initial soil conditions prior to green manure application. Overall, these values describe the baseline status of the experimental site before green manure application.

Table 1. Baseline physicochemical properties of the experimental soil before green manure application.

Parameter	Unit	0–30 cm	30–60 cm
(A) Physicochemical properties			
Texture	–	Clay loam	Clay loam
Field capacity	%	58.89	55.37
pH	–	7.49	7.75
Total soluble salt	%	0.01	0.01
Lime (CaCO_3)	%	45.92	45.30
Organic matter	%	1.11	0.70
Total N	%	0.06	0.05
Available Ca	mg kg ⁻¹	4893.90	4612.50
Available Mg	mg kg ⁻¹	168.80	187.00
Available P (P_2O_5)	kg da ⁻¹	1.46	0.56
Available K (K_2O)	kg da ⁻¹	25.56	21.12
(B) Micronutrient concentrations			
Fe (DTPA-extractable)	mg kg ⁻¹	8.30	6.90
Cu (DTPA-extractable)	mg kg ⁻¹	1.80	1.08
Zn (DTPA-extractable)	mg kg ⁻¹	0.25	0.15
Mn (DTPA-extractable)	mg kg ⁻¹	8.24	6.80
Extractable S	mg kg ⁻¹	11.35	11.35
Available B	mg kg ⁻¹	0.34	0.30
Available Mo	ppb	17.70	12.84
Available Co	mg kg ⁻¹	9.12	8.80

Table 2. Long-term average meteorological characteristics of the Mediterranean region (Antalya)

Parameter	Value
Mean annual air temperature (°C)	18.9
Mean annual maximum temperature (°C)	24.2
Mean annual minimum temperature (°C)	13.9
Mean daily sunshine duration (h)	8.1
Total annual precipitation (mm)	1031.8
Mean annual number of rainy days (days)	73.0

Meteorological data, covering the experimental period from December 2022 to October 2023 were obtained from the Turkish State Meteorological Service (Anonymous, 2024). Long-term average climatic conditions of the region, based on Antalya meteorological records, are presented in Table 2. The region has a typical Mediterranean climate, with mild, rainy winters and hot, dry summers. The experiment was arranged in a randomized complete block design with four legume species used as green manure, chickpea (*Cicer arietinum* L.), faba bean (*Vicia faba* L.), forage

pea (*Pisum sativum* L.), and vetch (*Vicia sativa* L.), and three replications. Each species was randomly assigned within each block, resulting in 12 plots in total. Plot size was 5×2 m, with 1 m spacing between blocks and 0.5 m spacing between adjacent plots within a block. Sowing was carried out on 6 December 2022 using certified seeds obtained from a local seed producer. The experimental factor consisted solely of plant species (green manure type). A general view of the experimental field and plot layout is presented in Figure 1.



Figure 1. General view of the experimental field showing the plot layout during the establishment of the legume green manure experiment

No irrigation was applied during the experiment, as sowing was carried out in the winter season and crop water requirements were met by natural precipitation. No mineral or organic fertilizers were applied throughout the experimental period.

2.2. Soil sampling and chemical analysis

Soil samples were collected before plot establishment and sowing to determine baseline soil conditions. Sampling was performed at two depths (0–30 and 30–60 cm). For each depth, a composite sample representing the experimental area was

prepared and submitted for laboratory analyses. This pre-establishment sampling was conducted to characterize the general soil conditions of the experimental field prior to green manure application. The pre-establishment sampling was conducted only once prior to plot establishment and is described here solely for site characterization; the post-decomposition sampling represents a separate and independent sampling event used for statistical analyses. Baseline soil data were used only to characterize the experimental site and were not considered in the statistical analysis. After harvest (29 April 2023), the

above- and belowground biomass of each legume species was returned to its own plot to minimize nitrogen losses, and no plant residues were left on the soil surface. Plant material was manually mixed into the surface soil within the effective root zone (approximately 0–30 cm) to obtain uniform distribution within each plot. Soil samples were collected on 18 October 2023 following a decomposition period of about 6 months to evaluate treatment effects. This second sampling was used as the main soil dataset for statistical analyses. Samples were taken from the 0–30 cm soil layer directly affected by green manure incorporation. Due to the small plot size (5×2 m), sampling was performed using a single-point approach from the center of the plot to minimize edge effects. Within-plot spatial variability was minimized through uniform biomass incorporation and standardized tillage prior to sampling. Experimental variability was controlled through the randomized complete block design and replications. During the sampling process, necessary precautions were taken to prevent contamination, especially for microelement analyses. In the laboratory, soil samples were air-dried in the shade, lightly crushed, and passed through a 2 mm sieve prior to analysis. The prepared samples were stored in sealed containers until chemical analyses were performed. Soil pH and total soluble salts were measured potentiometrically in soil-water suspensions according to standard soil analysis procedures. Soil organic matter was determined by the Walkley–Black wet digestion method (Walkley and Black, 1934), and total N by the Kjeldahl digestion method (Bremner, 1965). Available P was determined by the Olsen sodium bicarbonate extraction method (Olsen, 1954) and expressed as P_2O_5 . Exchangeable K was extracted with neutral ammonium acetate and expressed as K_2O . Exchangeable Ca and Mg were extracted with ammonium acetate and quantitatively determined by inductively coupled plasma-optical emission spectrometry (ICP-OES). Available microelements (Fe, Cu, Zn, and Mn) were determined by the DTPA extraction method according to Lindsay and Norvell (1978). This method reflects the plant-

available fractions in neutral and alkaline soils. Extractable S was measured by turbidimetric method. In alkaline and calcareous soils, S uptake is generally limited and its vertical distribution depends on water movement and soil profile characteristics. Therefore, initial values obtained from composite samples were interpreted as field-level indicators rather than depth-specific differences. Available B, Mo, and Co concentrations were determined by ICP-OES according to standard laboratory procedures. Soil texture was determined by the Bouyoucos hydrometer method (Bouyoucos, 1962), and field capacity was measured according to established physical soil analysis procedures. Initial physico-chemical and microelement properties determined for the characterization of the area before green manure application are presented in Table 1.

2.3. Statistical analysis

Statistical analyses were conducted using SPSS software. Soil data collected after green manure decomposition were analyzed by analysis of variance (ANOVA) under a randomized complete block design, with plant species treated as a fixed factor and block as a random factor. Statistical significance was assessed at the 0.05 probability level. When no significant treatment effects were detected, results were reported accordingly without applying multiple comparison tests. Baseline soil data collected prior to plot establishment were used solely for descriptive characterization of the experimental site and were not included in the statistical analysis.

3. Result and Discussion

Soil chemical properties measured after the decomposition of the four legume green manure species are presented in Table 3. No statistically significant differences were detected among legume species for any of the evaluated soil chemical parameters ($p > 0.05$). However, numerical differences between treatments, especially when considered in conjunction with initial soil properties and known process control mechanisms in calcareous soils, can provide contextual information about short-term soil responses

and species-specific trends under field conditions (Brownrigg et al., 2022; Xue et al., 2025). The main finding of this study is that consistently statistically significant short-term

changes in soil chemical properties were not observed following a single green manure application across all legume species.

Table 3. Soil chemical properties measured after the decomposition of four legume green manure species under field conditions. Values are given as mean $\pm$ standard deviation ($n = 3$)

Parameter	Chickpea	Faba bean	Forage pea	Vetch	p-value
pH	7.34 $\pm$ 0.15	7.41 $\pm$ 0.16	7.37 $\pm$ 0.20	7.34 $\pm$ 0.07	0.950
Total salt (%)	0.010 $\pm$ 0.000	0.010 $\pm$ 0.000	0.010 $\pm$ 0.000	0.010 $\pm$ 0.000	ns
Organic matter (%)	1.56 $\pm$ 0.27	1.72 $\pm$ 0.27	1.72 $\pm$ 0.27	1.65 $\pm$ 0.27	0.862
Total N (%)	0.093 $\pm$ 0.005	0.083 $\pm$ 0.005	0.090 $\pm$ 0.005	0.090 $\pm$ 0.005	0.556
Available P (P_2O_5) (kg da ⁻¹)	4.657 $\pm$ 0.769	2.637 $\pm$ 0.769	2.973 $\pm$ 0.769	2.747 $\pm$ 0.769	0.304
Available K (K_2O) (kg da ⁻¹)	54.770 $\pm$ 8.177	41.410 $\pm$ 8.177	41.480 $\pm$ 8.177	42.300 $\pm$ 8.177	0.618
Fe (mg kg ⁻¹)	8.073 $\pm$ 0.221	7.387 $\pm$ 0.221	7.687 $\pm$ 0.221	7.707 $\pm$ 0.221	0.280
Cu (mg kg ⁻¹)	0.973 $\pm$ 0.026	0.900 $\pm$ 0.026	0.933 $\pm$ 0.026	0.947 $\pm$ 0.026	0.342
Zn (mg kg ⁻¹)	0.497 $\pm$ 0.067	0.403 $\pm$ 0.067	0.483 $\pm$ 0.067	0.470 $\pm$ 0.067	0.767
Mn (mg kg ⁻¹)	16.880 $\pm$ 0.791	15.387 $\pm$ 0.791	14.867 $\pm$ 0.791	13.953 $\pm$ 0.791	0.167

ns denotes non-significant differences at $p > 0.05$. For total soluble salt, statistical testing was not applicable due to zero variance among treatments

Soil pH remained stable between treatments (7.34–7.41; Table 3). Although mean pH values were slightly higher in fava beans and forage peas compared to chickpeas and vetch, these differences were small and not statistically significant. This weak pH response is typical for carbonate-rich soils. High $CaCO_3$ content provides strong buffering and limits short-term pH changes after incorporating organic residues into the soil (Bolan et al., 2023; Dvořáčková et al., 2022; Zhu et al., 2024). Total soluble salt content showed negligible variation between treatments. Total salt remained at approximately 0.010% (Table 3). Accordingly, under the current conditions, a single incorporating cycle was insufficient to alter soil salinity, consistent with findings from similar Mediterranean environments (Quintana-Estera et al., 2025). Soil organic matter showed little variation between treatments (1.56–1.72%; Table 3). Although mean values were slightly higher in fava beans and forage peas compared to chickpeas and vetch, these differences were not statistically significant and remained within the limits of baseline variability. This limited short-term variation is consistent with calcareous soils with low baseline organic matter levels; in such soils, it takes time for organic inputs to decompose and stabilize into measurable soil

organic matter pools (Bolan et al., 2023; Hijbeek et al., 2017). Total N showed only minor differences between treatments (0.083–0.093%; Table 3). This indicates that there is no measurable short-term change after a single green manure application. Similar results have been reported in the literature. Soil organic matter and total N generally increase after repeated inputs and/or longer evaluation periods. This situation is particularly pronounced in carbonate-rich soils because the stabilization process is slow (Bolan et al., 2023; Hansen et al., 2021; Hijbeek et al., 2017; Stein et al., 2023). Biomass was incorporated into the soil after full plant development, and generative structures were also included to maximize residue input. However, the short assessment period likely limited the detection of differences beyond natural within-plot variability. These short-term responses are consistent with current knowledge regarding the decomposition of plant residues in soil. Following incorporation, plant residues are gradually broken down by soil microorganisms. Easily decomposable components dissolve rapidly, while residual carbon is transferred slowly to more stable soil organic matter pools (Lavalley et al., 2020; Midwood et al., 2021; Rocci et al., 2021). In the early stages of decomposition, residual

nutrients and carbon are partially incorporated into active microbial processes and transient soil organic fractions. This can limit their immediate detection in total soil measurements. Therefore, measurable changes in total soil organic matter or total nitrogen usually require repeated residual inputs or longer stabilization periods (Lavalley et al., 2020). Furthermore, the quality and biomass input of the biomass significantly influence the decomposition dynamics. This is due to differences in the carbon/nitrogen ratio, structural composition, and biochemical properties of plant tissues (Cotrufo et al., 2013; Lavalley et al., 2020; Sokol et al., 2019). These properties determine how and when residues are transformed in the soil, nutrient release, and stabilization processes (Lavalley et al., 2020; Sokol et al., 2019). However, under field conditions and short assessment periods, species-specific effects may be limited. These effects may fall within the limits of normal soil variability and may not be clearly evident in total soil measurements (Oldfield et al., 2022; Poeplau and Don, 2015). Importantly, the mechanisms underlying these patterns differ among parameters. Carbonate buffering mainly accounts for pH stability, whereas the limited short-term responses of soil organic matter and total nitrogen are more closely linked to time scale and residue decomposition and stabilization processes rather than buffering alone (Bolan et al., 2023; Carvalho et al., 2023; Stoner et al., 2023). No statistically significant differences were observed in available P and K among legume species (Table 3). Mean values of available P and K were numerically higher under chickpea, but these differences remained within overall plot variability. In calcareous soils, P availability is often affected by reactions with Ca compounds, and short-term organic inputs may not be sufficient to significantly alter extractable P pools (Brownrigg et al., 2022; Penn et al., 2019). Exchangeable K is similarly affected by soil mineralogy and clay content; this may limit short-term changes that may occur after a single residue application (Ahlersmeyer et al., 2025; Firmano et al., 2020). Microelement responses remained

limited in the short term. DTPA-extractable Fe, Cu, Zn, and Mn did not differ significantly among treatments (Table 3), and species-dependent variation remained low. Mean Cu, Zn, and Mn values ranged narrowly between treatments, consistent with stable soil organic matter and the typical chemical behavior observed in calcareous soils. Initial microelement concentrations are presented in Table 1 to provide site-specific context for these short-term observations. While calcareous soils are generally associated with decreased microelement solubility under neutral to alkaline pH conditions (Vélez-Bermúdez et al., 2023), the DTPA-extractable Fe concentrations observed in this study reflect the chelating fraction, not the total Fe content. These values appear to be largely related to soil mineralogical composition and parent material properties, which generally control extractable microelement pools in calcareous soils. This interpretation is consistent with the strong influence of mineralogy and parent material on extractable micronutrient pools (Dhaliwal et al., 2021; Jalali et al., 2022), particularly under carbonate-rich conditions where short-term residue effects may be limited. Following decomposition, soil values remained within the initial soil variability range. The absence of statistically significant changes in the short term suggests that the initial soil conditions in the experimental area limit rapid chemical responses within a growing season. These conditions include high lime content, pH ranging from neutral to slightly alkaline, and low organic matter levels (Scavo et al., 2022; Zhu et al., 2024). Under such conditions, short-term application of legume green manure may function primarily as a soil-protective practice rather than directly providing chemical improvement (Garba et al., 2022). The stability of pH, salinity, and extractable nutrient levels, and the absence of a measurable decrease in organic matter and nitrogen, may be considered a significant outcome in calcareous Mediterranean agroecosystems (López-Vicente et al., 2021; Scavo et al., 2022). These findings highlight the importance of time scale in evaluating the effects of green manure in carbonate-rich soils (Ma et al., 2021; Xue et al.,

2025; Yan and Arthur, 2025). While short-term chemical responses are limited, legume-based green manure applications, when implemented as a sustainable and perennial management strategy, can contribute to the preservation of long-term soil fertility (Aydi Ben Abdallah et al., 2024; Xu et al., 2021); this highlights the need for longer-term assessments.

4. Conclusion and Recommendations

The findings show that a single application cycle of legume-based green manure does not lead to statistically significant short-term changes in soil chemical properties under calcareous Mediterranean soil environment. This is consistent with the high buffering capacity of calcareous soils, which limits rapid chemical changes, particularly soil pH, in the short time periods following the incorporation of plant residues into the soil. The absence of statistically significant differences in the short term should not be interpreted as the green manure application being ineffective. The results demonstrate that soil chemical properties can be maintained, at least on a single growing season scale. The lack of significant changes or decreases in pH, salinity, and extractable nutrient levels allows short-term stability in calcareous Mediterranean agroecosystems to be considered a meaningful finding. This study suggests that, in the context of a single application and a short evaluation period, legume-based green manuring may be associated with maintaining the existing soil chemical status rather than producing large-scale chemical improvements. However, repeated applications or longer monitoring periods may be required for more significant changes to emerge. Additional field trials involving perennial and repeated green manure applications are needed to more clearly demonstrate the cumulative effects in calcareous soils. Such studies will allow for a more detailed assessment of potential changes in soil organic matter stabilization, nitrogen dynamics, and nutrient availability. In addition to routine chemical analyses, the inclusion of biological indicators such as carbon and

nitrogen fractions and microbial activity will contribute to a more mechanistic interpretation of the observed processes. Comparing soils with varying carbonate content and management history will help understand under what conditions legume-based green manuring shows more significant effects.

Declaration of Author Contributions

The author declares that she conducted all stages of the study, including study design, data collection, analysis, interpretation, and manuscript preparation, and approved the final version of the manuscript.

Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

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Ethical Committee Approval

This study did not involve human or animal subjects; therefore, ethical approval was not required.

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