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The residual effects of vermicompost, leonardite and farmyard manure on soil properties

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Abstract

The use of organic amendments on agricultural lands enhances soil nutrient concentrations and properties during mineralization processes. In this study, residual effects of vermicompost (VC), leonardite (L) and farmyard manure (FYM) and their doses (0, 20, 40, and 60 t ha^{-1} in dry weight) on soil properties were investigated. For this purpose, different doses of three organic amendments were mixed into the soil and after 90 days, tomato seedlings were planted in pots. At the end of the 10-week plant growth period, the experiment was terminated and then soil samples were taken and analyzed to determine the residual effects of organic amendments and their increasing doses. The results showed that residual effects of organic amendments and their doses significantly increased soil organic matter (SOM), total nitrogen (N), available phosphorus (P), exchangeable potassium (K), available iron (Fe) and available zinc (Zn), and especially at 60 t ha^{-1} application dose. Soil exchangeable calcium (Ca), available manganese (Mn) and available copper (Cu) were not changed by the applications. Soil reaction (pH) was decreased with residual effects of amendments and their doses compared to control, while soil electrical conductivity was increased due to mineralization. Residual effects of VC and FYM were more effective on soil properties than leonardite. Results showed that organic amendments could take advantage of the short-term benefits of nutrients supplied from manure application to improve soil quality and reduce fertilizer input cost.

Introduction

Soils of Türkiye have very low organic matter contents due to semi-arid and arid climatic conditions (Demirtaş et al., 2013). Soil organic matter influences a wide range of physical, chemical and biological attributes and processes, including the formation and stabilization of soil aggregates, nutrient cycling, water retention, pH buffering and cation exchange capacity (Marschner, 2002). In order to improve soil properties and increase the amount of crop production, organic fertilizers should be applied to agricultural production areas. In addition, the increase in natural gas, electricity and oil prices as side effects of the recent economic crisis has led to an increase in the cost of inorganic fertilizers. The increase in chemical fertilizer prices encourages producers to use organic fertilizers (Nazlı et al., 2016).

Among organic fertilizers, farmyard manure is the best known in Türkiye. However, it is difficult to find farmyard manure in sufficient quantity and maturity at the required time due to the decline in animal husbandry for various reasons and the use of animal waste for energy production. This situation has led to the widespread use of compost, vermicompost, leonardite, liquid and solid humic acids, biochar and poultry manure (Öktüren Asri et al., 2024). Actually, about 62 million tons of crop plant residues and plant biomass is formed annually in Türkiye, nearly 90% of which is lignocellulosic waste and is rich in organic carbon and other plant nutrients (Ünlü et al., 2023). Vermicomposting is a very important method for the utilization of these wastes. Vermicompost is produced by the composting of various organic materials (stalk, straw, fruit and vegetable wastes, sawdust etc.) by specific species of earthworms and their associated microbiota during the decomposition of organic matter (Demir, 2024). Vermicompost was reported to improve soil fertility through improving soil organic matter content (Öktüren Asri et al., 2024), macro and micronutrient elements (Zhang et al., 2020; Demir, 2024), porosity and structure (Demir, 2024).

Leonardite, one of the organic materials, is a product of atmospheric oxidation of lignite. It is rich in organic matter (50-75%) and humic acid (HA) content (30%-80%). HA contains active functional groups (e.g. quinonyl, carboxyls and phenolic hydroxyl), thereby, it has the capability to engage with metal ions, oxides, hydroxides and minerals (Abdullah et al., 2024). Due to humic acid (HA) content, positive effects of leonardite on aggregate stability, water holding capacity, organic matter content, nutrient elements concentration and enzyme activity of soil were reported by Sesveren and Taş (2022), Alagöz et al. (2006), and Wang et al. (2013).

The application of organic amendments to soil is known to provide macro and microelements to soil through mineralization. However, information on the time and speed of mineralization process is scarce. There are studies on the effects of organic matter added to the soil before crop cultivation on soil properties, but studies on the effects of organic materials after crop cultivation are very limited. Thus, the objective of this study was to evaluate the residual effects of different doses of farmyard manure, leonardite and vermicompost on soil properties after tomato harvest.

Materials and Methods

The study was carried out in a pot experiment in the greenhouse of Akdeniz University Faculty of Agriculture, Antalya-Türkiye. The pots were filled with a Alfisol soil. Some properties of soil and organic amendments were given in Table 1 and Table 2.

Table 1. Some properties of soil used in the study

Measured Parameters	Values
Total N, %	0.10
Available P, mg kg^{-1}	39
Extractable K, mg kg^{-1}	120
Extractable Ca, mg kg^{-1}	6600
Extractable Mg, mg kg^{-1}	658
DTPA- Extractable Fe, mg kg^{-1}	6.7
DTPA- Extractable Cu, mg kg^{-1}	2.2
DTPA- Extractable Mn, mg kg^{-1}	11.7
DTPA- Extractable Zn, mg kg^{-1}	0.90
pH (1:2.5 distilled water)	7.40
EC (1:2.5 distilled water), dS m^{-1}	0.274
Lime (%)	26.4
Organic Matter (%)	1.25
Bulk density (g cm^{-3})	1.18
Field capacity (%)	34.0
Wilting point (%)	22.0
Texture	Clay Loam (CL)

In the experiment performed in 3 L pots based on the randomized block experimental design as 4 replications. Leonardite (L), vermicompost (VC) and farmyard manure (FYM) were mixed in four different (0, 20, 40, and 60 tons ha^{-1} in dry weight) doses with soil. After 90th day, tomato seedlings were planted to pots. No inorganic fertilizer was applied to the organic fertilizer plots throughout the life of the plant. At the end of the 10-week growing period, the experiment was ended and then soil samples were taken and analyzed for determining residual effects of organic amendments and their increasing doses.

Analytical methods

Soil analysis methods: Soil samples were taken and analyzed after air drying and passing through a 2 mm sieve. The pH and EC were measured in a 1:2.5 (w/v) soil to water ratio (Jackson, 1967). Total carbonates were determined using the Scheibler calcimeter (Kacar, 2016). Soil texture was determined based on the hydrometer method (Bouyoucos, 1955) and the organic matter was determined based on the modified Walkey-Black method (Black, 1965). Total nitrogen was determined based on the modified Kjeldahl method (Kacar, 2016). Available phosphorus was extracted with 0.5 M $NaHCO_3$ and determined based on the molybdate colorimetric method (Shimadzu UV 1800) (Olsen and Sommers, 1982). Extractable K, Ca, and Mg was extracted with 1 N ammonium acetate (NH_4OAc) and determined via ICP-OES (PerkinElmer Avio 2000) (Kacar, 2016). Available Fe, Zn, Mn, and Cu in the soil was extracted with Diethylene Triamine Pentaacetic Acid (DTPA) (Lindsay and Norwell, 1978), and determined with the ICP-OES device (PerkinElmer Avio 2000).

Table 2. Some properties of organic amendments used in the study

Measured Parameters	Leonardite (L)	Vermicompost (VC)	Farmyard Manure (FYM)
pH (1:5 distilled water)	6.20	7.46	6.50
EC (1:5 distilled water), dS m^{-1}	5.20	6.53	6.70
Organic Matter, %	49.0	52	55.0
Organic C, %	27.0	28	27.5
Organic C/total N	9.64	10.76	9.48
Total N, %	2.80	2.60	2.90
Total P, mg kg^{-1}	2500	3701	1300
Total K, mg kg^{-1}	4100	5905	18800
Total Ca, mg kg^{-1}	13270	5378	82300
Total Mg, mg kg^{-1}	701	1193	2000
Total Fe, mg kg^{-1}	69	34.8	6897
Total Zn, mg kg^{-1}	1.41	7.57	114
Total Mn, mg kg^{-1}	1.22	3.53	259
Total Cu, mg kg^{-1}	0.19	2.20	31.9

Organic amendments analysis methods: The organic matter (OM) contents of leonardite, vermicompost and farmyard manure were determined in a combustion oven (550 °C) (Black, 1965). EC and pH were determined by using a portable EC and pH meter in 1:5 (w/v) organic material to water ratio (Jackson, 1967). Total N content was determined by Kjeldahl method. Total P, K, Ca, Mg, Fe, Zn, Mn, and Cu in the same solution were determined in the wet-digested samples via ICP-OES (Kacar and Inal, 2010).

Statistical methods

The statistical analysis was made according to the principles set by Yurtsever (1984). All data were analyzed using the JMP Statistical package program developed by SAS (SAS Institute, Cary, North Carolina, USA). Means were compared by analysis of variance (ANOVA) and the LSD test at the $p \leq .05$ significance level.

Results and Discussion

Residual effects of organic amendment applications, doses and interaction between organic amendments and their doses on soil reaction (pH) were found to be statistically significant (p<0.001) (Table 3). Initial soil pH (1:2, 5) was 7.40, after the applications soil pH was changed between 7.31 and 7.46 (Figure 1). Organic amendments and their increasing doses caused to decrease soil pH compared to control. Ateş and Namlı (2021) disclosed that decomposition process of organic materials changed to soil pH due to accelerating the release of organic acids and CO_2. Zhao et al. (2017) explained that the application of vermicompost resulted in decreased soil pH because the high ability of vermicompost to promote crop system development and absorb more mineral ions while simultaneously producing hydrogen ions. Soil pH is an important soil property that can limit the effects of plant nutrition practices on crop yield and quality. Soils of Türkiye have high lime and pH level (92.64% of the Turkish soils reaction higher than 6.5) due to parent material and climatic conditions (Kacar and Inal, 2010). Thus, organic amendment applications and their effects of soil pH is important for Türkiye's soils.

Residual effects of organic amendments, doses and interaction between organic amendments and their doses on soil electrical conductivity (EC) were found to be statistically significant (p<0.001) (Table 3). Initial soil EC was 0.27 dS m^{-1}. After applications, the lowest EC value (0.20 dS m^{-1}) was obtained from 0 t ha^{-1} doses of control pots and the highest value (0.70 dS m^{-1}) was determined by 60 t ha^{-1} of leonardite application (Figure 1). The residual effects of organic amendment doses increased to soil EC by 53.5%-64.9% (Table 2). Öktüren Asri et al. (2024) reported that soil EC increase with farmyard manure, vermicompost, spent mushroom compost and chicken manure by 12%-33%. Obour et al. (2017) explained that the relatively greater EC values with higher manure application rates may be attributed to higher residual K, Ca and inorganic N concentrations resulting from greater rates of manure application.

One important ecological service that organic matter management offers is the storage of carbon in soil organic matter. By raising the organic carbon content of soil and encouraging the synthesis of stable organic carbon molecules, organic sources aid in the sequestration of carbon (Boostani et al., 2020). Residual effects of organic amendment applications (p<0.01) and their doses on soil organic matter (SOM) were found to be statistically significant (p<0.001) (Table 3). The residual effects of organic amendment doses increased to soil organic matter (SOM) by 19%-45% (Figure 1) compared to control. 60 t ha^{-1} (1.61%) application dose was the most prominent application dose. Although the organic matter contents of organic materials were close (Table 2), leonardite (1.28%) and vermicompost (1.24%) were particularly effective and created the highest SOM, followed by farmyard manure (1.13%) (OA means in Figure 1). Öktüren Asri et al. (2024) reported that SOM increased by 13%–16% with organic amendments (vermicompost, farmyard manure, chicken manure, spent mushroom compost), these positive effective continued in the following year and resulted in increases of 14%-24%, compared with the control. Dinakaran et al. (2024) found that soil organic matter was more accumulated with vermicompost compared to farmyard manure, and SOM increased by 23%, 19% and 25% ratio compared to control with 15, 30, and 60 t ha^{-1} vermicompost doses.

Residual effects of organic amendments, application level and their interaction on soil total nitrogen (TN) concentration were found to be statistically significant (p<0.001) (Table 3). The lowest total N (0.106%) was obtained from all of control pots

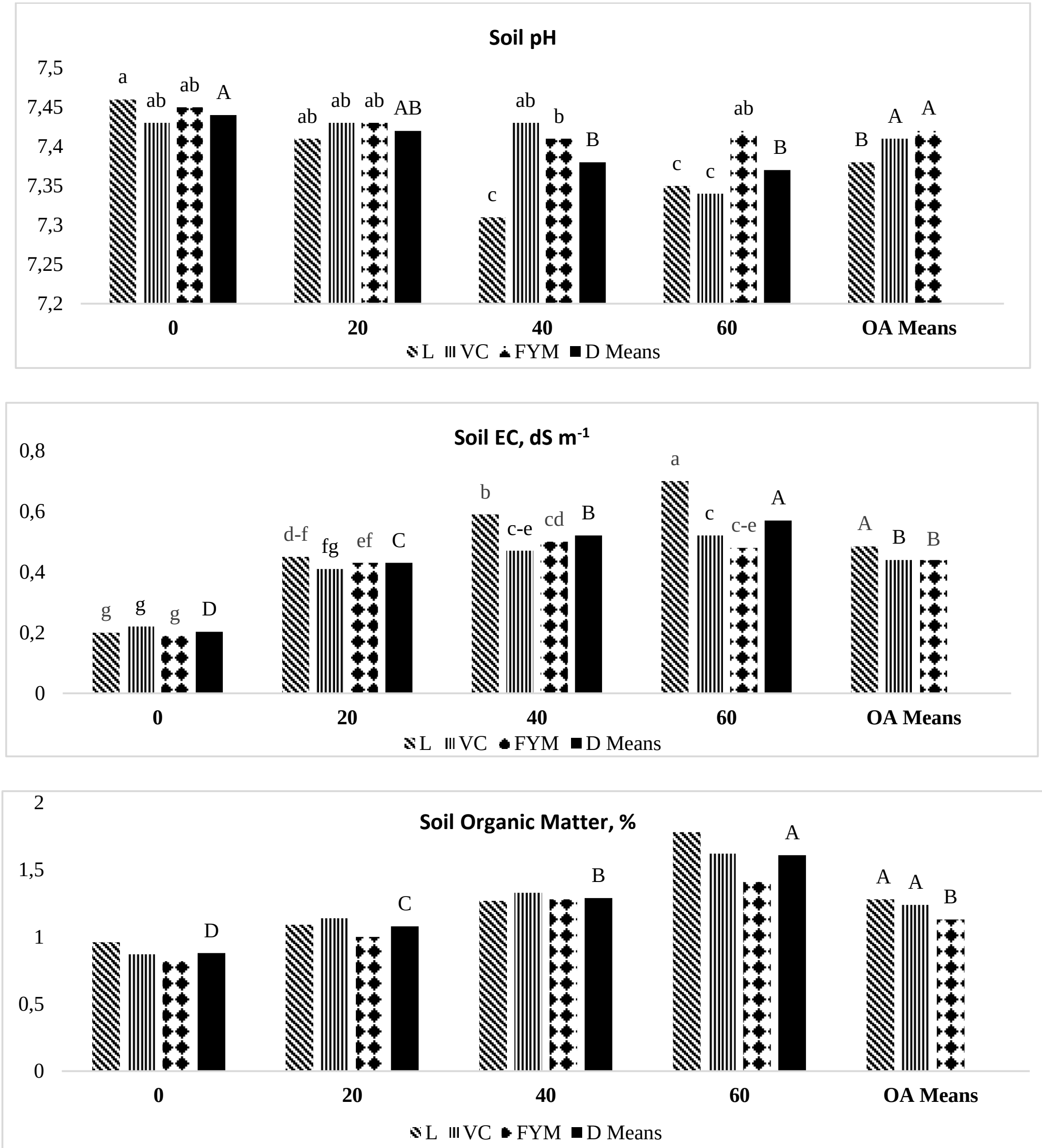

Figure 1. Residual effects of organic amendments on soil pH, EC and organic matter content

Lowercase letters indicate a significant difference in the interaction between organic amendments and their doses. Uppercase letters indicate a significant difference between the organic amendments (OA Means). Uppercase letters indicate a significant difference between the doses (D Means)

Table 3. Results of analysis of variance (*p* values) for soil properties treated with organic amendments

Soil Parameters	Organic Amendments (OA)	Dose of Organic Amendments (D)	OA*D
pH	0.0033**	<,0001***	<,0001***
EC	<,0001***	<,0001***	<,0001***
SOM	0.0292**	<,0001***	0.360ns
Total N	<,0001***	<,0001***	0.0004***
Available P	<,0001***	<,0001***	<,0001***
Exchangeable K	<,0001***	<,0001***	<,0001***
Exchangeable Ca	0.0037ns	0.3299ns	0.6825ns
Exchangeable Mg	0.3974ns	<,0001***	0.1634ns
Available Fe	<,0001***	<,0001***	<,0001***
Available Zn	<,0001***	<,0001***	<,0001***
Available Mn	0.9071ns	0.8214ns	0.6544ns
Available Cu	0.4102ns	0.5257ns	0.0584ns

* Significant at the α= 0.05 probability level.
** Significant at the α= 0.01 probability level.
*** Significant at the α= 0.001 probability level.
ns = non-significant.

in 0 t ha^{-1} dose, while the highest values was determined in 60 t ha^{-1} VC (0.140%) and FYM (0.144%) (Figure 2). The organic amendment doses increased the soil TN by 10%-22%, compared with the control. High organic amendment application rates are expected to increase soil N mineralization and actively enhance organic N mineralization (i.e. protein and amino acids), which might be due to high organic N addition (Ma et al., 2018). Mineralization of organic N rates is influenced by a number of factors, especially the quantity and the microbial susceptibility of existing carbonaceous compounds which act as a source of energy (Zhao et al., 2017). Farmyard manure (0.126%) and vermicompost (0.122%) were found more effective on N compared to leonardite (0.117%) in this study (OA means in Figure 2). Öktüren Asri et al. (2024), reported that soil total nitrogen was increased by 7.7% - 20% with organic amendments at the end of the first growing season and this positive effect continued in the following year and caused increases of 12% - 25%. In this study, C/N rate of leonardite, vermicompost and farmyard manure were 9.64, 10.76 and 9.48, respectively (Table 2). According to Chen et al. (2018), a lower soil C/N ratio causes microorganisms more limited by C than by N, especially when this ratio is lower than 13-15. In this regard, N excess may easily occur with N deposition in ecosystems with low soil C/N, and C limitation accompanied by a C/N stoichiometric imbalance is also more likely to control the response of soil N mineralization to N deposition (Song et al., 2022).

Residual effects of organic amendments, application level and their interaction on soil available phosphorus (av-P) concentration were found to be statistically significant ($p<0.001$) (Table 3). After the applications, the lowest av-P concentration (24.0 mg kg^{-1}) was obtained from 0 t ha^{-1} leonardite and the highest value (56.3 mg kg^{-1}) was determined by 40 t ha^{-1} farmyard manure (Figure 2). While doses of organic amendments caused to enhance soil av-P concentration by 26.5%-39.9% compared to the control, residual effects of organic amendments increased av-P concentration by 36.4%-40.2% and the most effective material was FYM. Sheoran et al. (2024) reported that the application of 15 t of FYM ha^{-1} resulted in a considerable increase av-P by 9.7%–12.1%.

Residual effects of organic amendments, application level and their interaction on soil exchangeable potassium (ex-K) concentration were found to be statistically significant ($p<0.001$) (Table 3). Soil ex-K were increased by 27%-39% residual effects of organic amendments and 23%-48% their ascending doses (Figure 2). In this study soil had 34.88% clay, 35.28% silty and 29.84% sand, with clay loam texture. Soil clay content may be resulted in increasing soil ex-K concentration. Rai et al. (2014) explained that organic amendments increase soil ex-K by reducing K fixation and release due to the interaction of organic matter with clay, in addition to direct addition of K to the av-K pool of soils. Yadav et al. (2019) reported that FYM (15 t ha^{-1}) significantly increased soil ex-K concentration by 37% over inorganic fertilizer application. Najafi Ghiri (2014) reported that the mean increase in cumulative K release with vermicompost application was 88% compared to the control.

The residual effects of organic amendments were found to be not effective on soil exchangeable calcium (ex-Ca) concentration (Table 3). The residual effects of organic amendments were found to be not effective on soil exchangeable magnesium (Mg) concentration. But

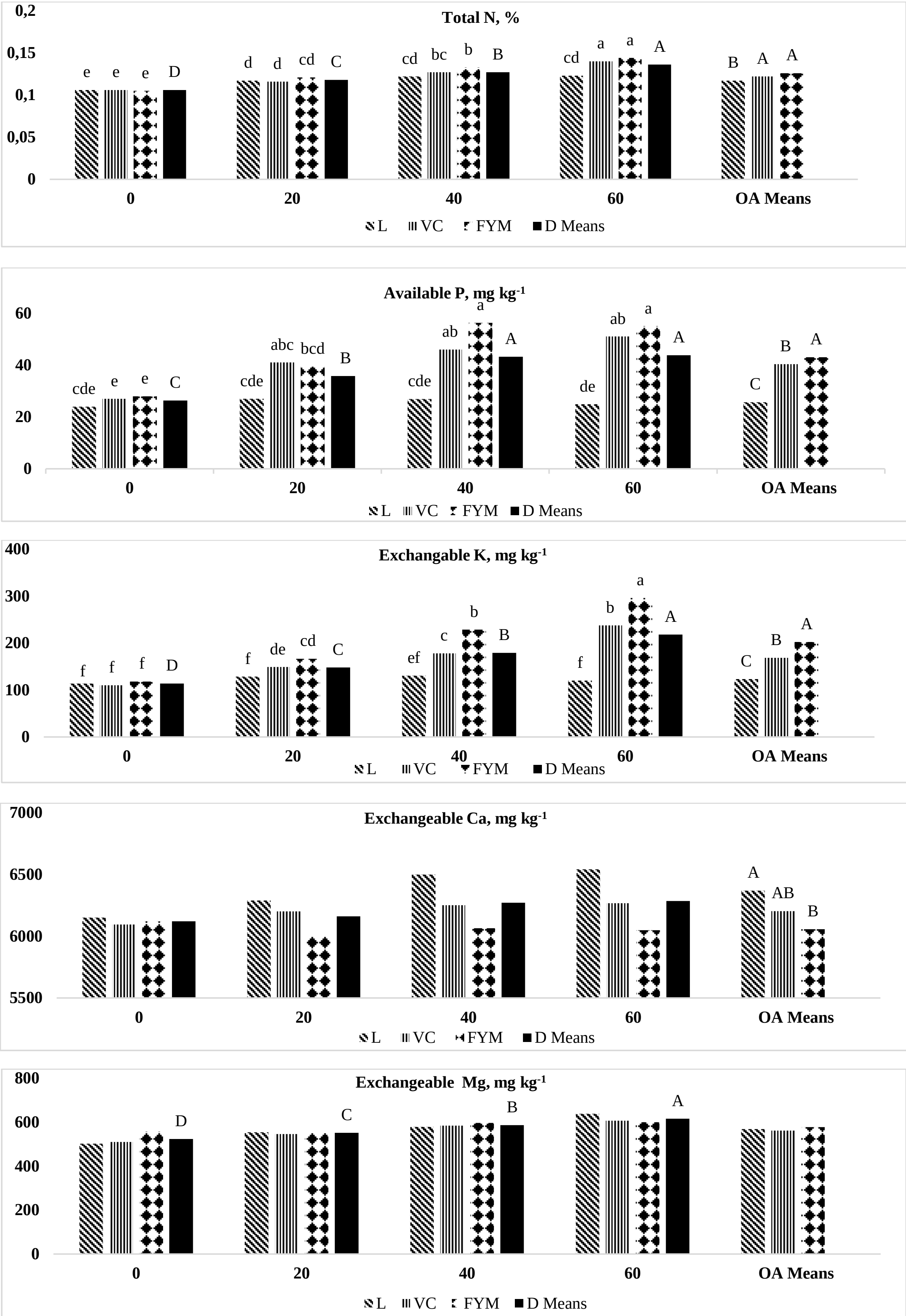

Figure 2. Residual effects of organic amendments on soil macro elements concentration

Lowercase letters indicate a significant difference in the interaction between organic amendments and their doses. Uppercase letters indicate a significant difference between the organic amendments (OA Means). Uppercase letters indicate a significant difference between the doses (D Means).

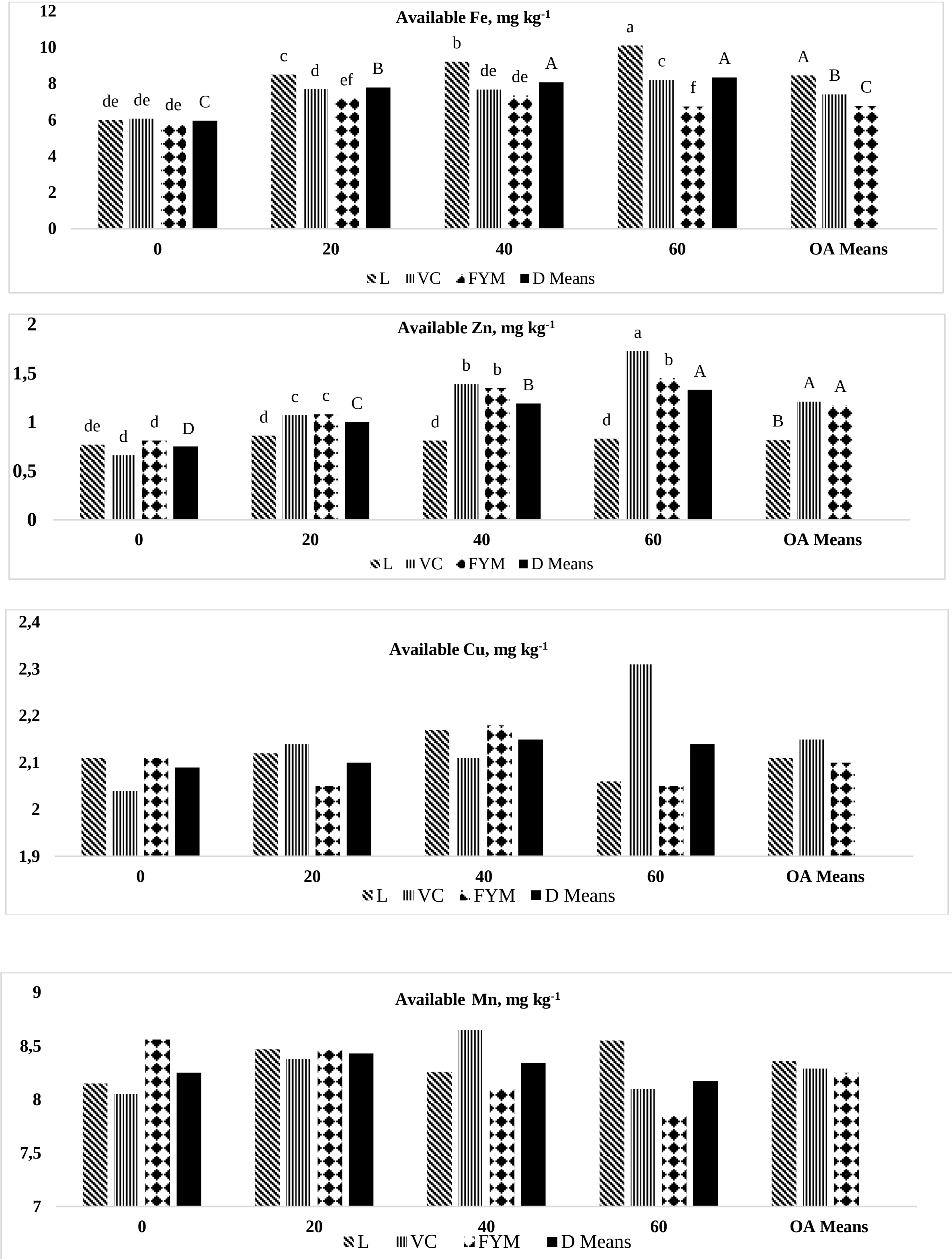

Figure 3. Residual effects of organic amendments on soil micro elements concentration

Lowercase letters indicate a significant difference in the interaction between organic amendments and their doses. Uppercase letters indicate a significant difference between the organic amendments (OA Means). Uppercase letters indicate a significant difference between the doses (D Means).

the increasing doses caused to soil ex-Mg concentration by 5%-15%. The highest ex-Mg concentration was obtained from 60 t ha^{-1} dose of organic amendments (Figure 2). Demir (2019) found that vermicompost application increased soil ex-Ca and ex-Mg concentrations. Agbede et al. (2013) found that application of organic fertilizers tended to improve soil pH, organic C, total N, and exchangeable K, Ca and Mg more than chemical fertilizers.

Residual effects of organic amendments, application level and their interaction on soil available iron (av-Fe) concentration were found to be statistically significant (p<0.001) (Table 3). The lowest av-Fe concentration (5.80 mg kg^{-1}) was obtained from 0 t ha^{-1} farmyard manure, while the highest value (10.12 mg kg^{-1}) was attained by 60 t ha^{-1} leonardite (Figure 3). Available Fe concentrations of soil were increased by 24%-29% residual effects of organic amendments and 9%-20% their ascending doses. Nuzzo et al. (2018) reported that more than 95% of the total plant-available Fe in the soil solution may be represented by organic Fe pool. An important Fe source in soil is represented by the insoluble Fe complexes with humic substances (HS). Iron complexation by humic substances is attributed to the oxygen-containing functional groups (carboxylic, phenolic and carbonyl). Thus, it is thought that humic substances and functional groups content of organic materials resulted in an increase in av-Fe concentration of soil in this study.

Conclusions

The aim of this study was to determine the residual effects of vermicompost, leonardite, farmyard manure and their increasing doses on soil properties. Residual effects of organic amendments were increased electrical conductivity, organic matter, total N, available P, exchangeable K, available Fe and Zn concentrations of the soil. Among application doses, 60 t ha^{-1} dose was more effective for nutrient release. These results indicated that these treatments had compensated more than the nutrient removal of tomato seedlings for 10^{th} weeks as evidenced from significant increase in available elements in soil. Based on the results, it is concluded that growers can take advantage of the long-term benefits of nutrients supplied from single or repeated organic amendments application to improve soil quality and reduce N, P and K fertilizer input cost.

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Author Contribution

S.S.: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Resources, Validation, Writing – review & editing. **F.Ö.A.:** Formal analysis, Investigation, Statistical analysis, Visualization, Software, Writing-original draft, Writing –review & editing.

Conflict of Interest

No potential conflict of interest was reported by the authors.

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