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Original Article

Effect of Vermicompost on Chemical and Biological Properties of an Alkaline Soil with High Lime Content during Celery (*Apium graveolens* L. var. *dulce* Mill.) Production

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Abstract

The aim of this study was to investigate impact of vermicompost on chemical and biological properties of an alkaline soil with high lime content in the presence of plant under the open field conditions in semiarid Mediterranean region of Turkey. The study also included farmyard manure and chemical fertilizers for comparison and was conducted in two consecutive growth seasons in the same plots to observe any cumulative effect. Plots were amended with fertilizers in different rates and celery (*Apium graveolens* L. var. *dulce* Mill.) was grown as the test plant. In general, vermicompost appeared to be more effective to increase organic matter, N, P, and Ca compared to farmyard manure. Soil alkaline phosphatase and β-glucosidase activities, especially in the second growth season, were significantly elevated by the vermicompost application. Urease activity, however, appeared not to be influenced by the type of organic fertilizer. A slight but statistically significant difference was detected between organic amendments in terms of number of aerobic mesophilic bacteria with vermicompost giving the lower values. Results showed that, in general, vermicompost significantly alters chemical and biological properties of the alkaline soil with high lime content during celery production under field conditions compared to farmyard manure and that it has a high potential to be used as an alternative to conventional organic fertilizers in agricultural production in the Mediterranean region of Turkey.

Keywords: bacterial enumeration, calcareous soil, cumulative effect, soil enzyme activity, organic farming

Introduction

It is highly recommended to use organic fertilizers in agricultural production to supply soils with plant nutrients and improve soil chemical, physical, and biological properties (Brady and Weil, 2001). Conventional fertilizers such as farmyard manure and compost are widely used for these purposes (Ferreras *et al*., 2006; Herencia *et al*., 2007). However, in recent years, vermicompost has been emerged as an alternative to conventional organic fertilizers due to its additional benefits. Vermicompost, which is the product of nonthermophilic biodegradation of organic material through the joint action of earthworms and microorganisms, contains plant growth promoting compounds and exhibits disease suppression properties in addition to being nutrient source and soil conditioner (Logsdon, 1994; Ersahin *et al*., 2009). Some problems, such as nutrient loss, nutrient toxicity, and salinity that may be associated with organic amendments under certain conditions could also be avoided by vermicompost application due to more gradual release of nutrients from vermicompost to the soil environment (Kale *et al*., 1987; Nethra *et al*., 1999; Lazcano *et al*., 2008).

Vermicompost has been the subject of several studies related to its utilization in agriculture. The main objectives in majority of these studies have been its disease suppression properties (Ersahin *et al*., 2009; Somasekhara *et al*., 2011; Singh *et al*., 2012; Carr and Nelson, 2014) and its effect on plant growth and yield (Arancon *et al*., 2003; Sallaku *et al*., 2009; Kalantari *et al*., 2011). There are also some studies focusing on the relationship between vermicompost and soil biological and chemical properties under various soil conditions (Arancon *et al*., 2006; Gopinath *et al*., 2011; Tejada and Benitez, 2011; Doan *et al*., 2013; Lazcano *et al*., 2013; Doan *et al*., 2014). However, most of these studies employed soils with neutral or acidic reactions. Therefore, in terms of soil biological and chemical

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parameters, how vermicompost performs in alkaline soils with high lime content is open to speculation due to lack of information. Moreover, in general, such studies involve short-term experimentation and soil sampling in limited frequency. As we noted in a previous study (Uz and Tavali, 2014), in order to assess cumulative effect of vermicompost and true nature of relationships, experiments should be repeated in the same blocks in consecutive growth seasons with presence of plants under the open field conditions. In such studies, more frequent soil sampling should be employed to monitor microbial changes in detail after application of vermicompost. This is especially important for Turkish Mediterranean region whose soils are typically in alkaline character with high lime content. Even though there are some studies investigating potential of vermicompost for plant growth and yield in the region (Tavali *et al*., 2013; Kucukyumuk *et al*., 2014), to our knowledge, there is no detailed study focusing on the effect of vermicompost on biological and chemical properties of soil in this region.

Therefore, the aim of this study was to investigate effect of vermicompost on some chemical and biological properties of alkaline soil with high lime content during celery production in two consecutive growth periods under the open field conditions in the semiarid Mediterranean region of Turkey.

Materials and Methods

Study area, organic and biological materials

This study was conducted as a field experiment in training and application land of Faculty of Agriculture at Akdeniz University located on Antalya, Turkey (Fig. 1A). Vermicompost used in the study was produced mainly from farmyard manure and provided by a local company, and farmyard manure was obtained from the dairy farm belonging to the Faculty of Agriculture. Celery (*Apium graveolens* L. var. *dulce* Mill) was used as the test plant.

Experimental design and data collection

The study conducted under field conditions with randomized factorial block design with four replicates and contained 56 plots and 30 plants in each plot (Fig. 1B). The experiment was repeated in two consecutive growth seasons (Fall-2011 and Spring-2012) in the same plots and each season lasted approximately 100-120 days after transplantation. The study included two organic materials (vermicompost [V] and farmyard manure [FM]) applied in five different doses and three combinations. Also, a treatment with chemical fertilizers corresponding to amount of nutrients taken up by celery plants from soil (180 kg ha^{-1} N, 100 kg ha^{-1} P_2O_5, and 180 kg ha^{-1} K_2O) was included (Vural *et al*., 2000). Application rates and treatments are given in Table 1. Prior to the experiment, physical, chemical and biological properties of test soil and organic fertilizers were determined (Table 2). Also, at the end of the experiment in each growth season (Fall and Spring) soil samples from each block were collected and analyzed for pH, electrical conductivity (EC), organic matter content, total N, available P, exchangeable K, Ca, and Mg contents. In order to assess the effect of organic materials on soil biological properties, soil samples were collected in regular intervals (0, 1st, 2nd, 3th, 4th, 6th, 10th, 13th, and 18th week) from plots receiving organic fertilizers in the rates of 0, 20 and 40 t ha^{-1} (C, FM20, V20, FM40, V40) and blocks treated with chemical fertilizers (CF) and analyzed for biological parameters. Biological parameters measured included urease, alkaline phosphatase and β-glucosidase activities, and total number of aerobic mesophilic bacteria in soil. Soil pH and EC were also monitored.

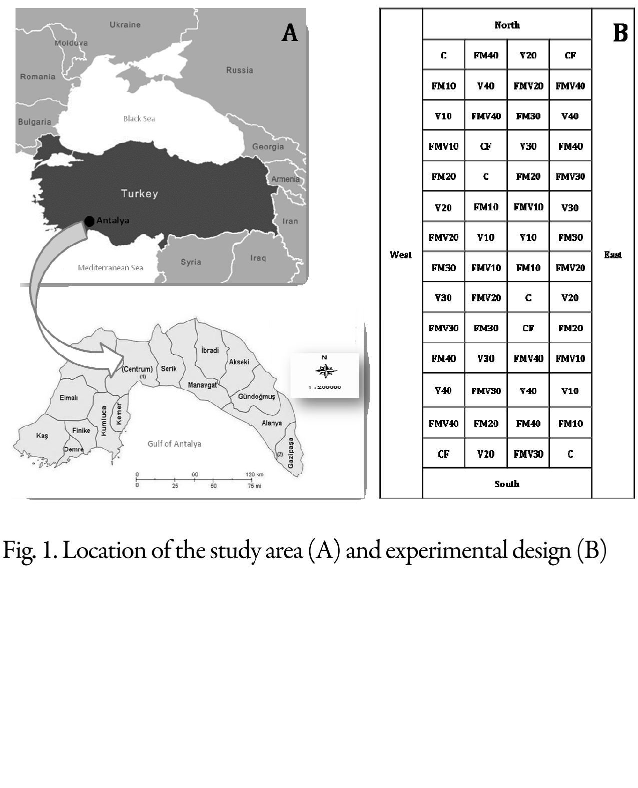

Fig. 1. Location of the study area (A) and experimental design (B)

Methods

Soil texture was determined by using Bouyoucos hydrometer method (Bouyoucos, 1951). Soil pH and EC were measured in 1:2.5 soil-water mixture (Jackson, 1970; Rhoades, 1982). Soil lime content was analyzed according to Caglar (1949). Soil organic matter content was measured by using modified Walkley-Black method (Nelson and Sommers, 1982) and total N by modified Kjheldahl method (Bremner and Mulvaney, 1982). Analysis of available phosphorus content of soil samples was done as described by Olsen and Sommers (1982). Exchangeable K, Ca, and Mg contents were determined by ammonium acetate method (Kacar, 1994) and available Fe, Mn, Zn, and Cu by DTPA method (Lindsay and Norvell, 1978) using ICP-OES (PE Optima 7000DV). Values of pH, EC, organic matter and total N contents of organic materials were determined with the same methods used for soil samples. For total P, K, Ca, Mg, Fe, Zn, Mn, and Cu contents of the organic fertilizers, samples were wet-digested (4:1 HNO3:HClO4) and measured with ICP-OES (Soltanpour and Workman, 1981). Soil enzyme activities were measured as described by Tabatabai

Table 1. Application rates and treatments used in the study

Application rate	Treatment
0 t ha^{-1}	Control (C)
10 t ha^{-1}	100% Farmyard Manure (FM10)
	100% Vermicompost (V10)
	50% Farmyard Manure + 50% Vermicompost (FMV10)
20 t ha^{-1}	100% Farmyard Manure (FM20)
	100% Vermicompost (V20)
	50% Farmyard Manure + 50% Vermicompost (FMV20)
30 t ha^{-1}	100% Farmyard Manure (FM30)
	100% Vermicompost (V30)
	50% Farmyard Manure + 50% Vermicompost (FMV30)
40 t ha^{-1}	100% Farmyard Manure (FM40)
	100% Vermicompost (V40)
	50% Farmyard Manure + 50% Vermicompost (FMV40)
Chemical Fertilizer	N-P-K: 15-15-15 (CF)

Table 2. Physical, chemical and biological properties of soil and organic materials used in the study

Parameters	Soil	Parameters	Vermicompost	Farmyard manure
Texture	Clay	Texture	-	-
pH (1:2.5 water)	7.90	pH (1:2.5 water)	7.73	7.98
EC (1:2.5 soil:water) µS cm^{-1}	265	EC (1:2.5 soil:water) µS cm^{-1}	1558	4325
Lime (%)	6.25	Lime (%)	-	-
Organic matter (%)	1.51	Organic matter (%)	51.23	65.98
Total N (%)	0.09	Total N (%)	1.88	1.51
C/N	9/1	C/N	15/1	25/1
Available P (mg kg^{-1})	9.23	Total P (%)	1.98	0.83
Exchangeable K (mg kg^{-1})	254	Total K (%)	0.85	2.39
Exchangeable Ca (mg kg^{-1})	4081	Total Ca (%)	2.28	2.79
Exchangeable Mg (mg kg^{-1})	151	Total Mg (%)	0.91	0.69
Available Fe (mg kg^{-1})	2.6	Total Fe (%)	0.14	0.05
Available Mn (mg kg^{-1})	4.95	Total Mn (%)	0.04	0.006
Available Zn (mg kg^{-1})	0.6	Total Zn (%)	0.01	0.05
Available Cu (mg kg^{-1})	0.11	Total Cu (%)	0.005	0.006
Urease (µg NH_4^+-N g^{-1} dw h^{-1})	12.86	Urease (µg NH_4^+-N g^{-1} dw h^{-1})	119.52	146.96
Alkaline phosphatase (µg PNP g^{-1} dw h^{-1})	28.91	Alkaline phosphatase (µg PNP g^{-1} dw h^{-1})	277.76	198.26
β-glucosidase (µg PNG g^{-1} dw h^{-1})	6.98	β-glucosidase (µg PNG g^{-1} dw h^{-1})	87.92	92.66
Number of aerobic mesophilic bacteria (cfu g^{-1} dw)	1.0×10^6	Number of aerobic mesophilic bacteria (cfu g^{-1} dw)	1.7×10^7	1.8×10^7

(1994). Total number of aerobic mesophilic bacteria was determined by using dilution plate count method and expressed as cfu g^{-1} dry weight soil (Parkinson *et al.*, 1971).

Statistical analysis

In order to determine similarities and differences among treatments, data obtained from the study were subjected to statistical analysis including ANOVA for soil chemical parameters and repeated measure ANOVA (rANOVA) for biological parameters, pH and EC. Duncan multiple range test and Pearson correlation tests were also performed. All statistical analysis was done by using SPSS package program (SPSS, 2008).

Results and Discussion

Organic matter

Organic matter contents of soil samples from treatments at the end of the growth seasons are given in Table 3. In both growth seasons, soil organic matter content was significantly affected by organic amendments compared to the control ($p<0.001$). In the first season, the lowest and highest organic matter content values were obtained with the control and FMV40 treatments, respectively. In the second season, lowest and highest values were with the control and FMV20 treatments, respectively. Organic fertilizers increased the soil organic matter content depending on application rates compared to the control. Moreover, vermicompost was found to increase organic matter more than farmyard manure applied in the same doses (except for FM40 and V40 in the first season and FM20 and V20 in the second season). There also appeared to be a difference between seasons and the second season showed higher organic matter content.

It was reported that applications of organic materials in increasing rates result in elevated soil organic matter content (Ferreras *et al.*, 2006; Ouda and Mahadeen, 2008). Therefore, observing similar results in our study is not surprising. The difference between the first and the second season in terms of organic matter content in soil can be explained by the difference in weather conditions affecting degradation processes. Due to cooler weather in the first season, it is possible that activity of microorganisms was limited and, therefore, some of organic compounds added with fertilizers might have remained unchanged at the end of the season. In the second season, however, with warmer weather, remaining and newly added organic compounds might have been decomposed in faster rate elevating soil organic matter content. The data suggest that vermicompost is more effective than farmyard manure to increase soil organic matter content even though farmyard manure used in the study has higher organic matter (Table 2). This is rather interesting because our previous study conducted with a similar soil under laboratory conditions without plants showed no significant difference between these two materials in terms of soil organic matter content (Uz and Tavali, 2014). Cheng *et al.* (2003) reported that decomposition rate in soils with plant is significantly higher than that in soils with no plants. Therefore, it is possible to suggest that, under field condition, presence of plants enhances effect of vermicompost on organic matter content. As a result, vermicompost may be considered as a better alternative than farmyard manure under field conditions in terms of improving organic matter in this soil. Indeed, several researchers support this conclusion (Kale *et al.*, 1987; Nethra *et al.*, 1999; Azarmi *et al.*, 2008; Lazcano *et al.*, 2008).

Total N, available P and exchangeable K

Total N, available P and exchangeable K contents of soils at the end of the growth seasons are shown in Table 3. In general, significant increases in these nutrients were observed with increasing application doses ($p<0.001$). Total N contents of treatment soils in the first season ranged from 0.13% to 0.18% and were found to be highly close to each other even though differences among treatments are significant. In the second season, however,

Table 3. Effect of treatments on soil chemical properties at the end of growth seasons

Treatment	Organic matter (%)		Total N (%)		Available P (mg kg^{-1})		Exchangeable K (mg kg^{-1})		Exchangeable Ca (mg kg^{-1})		Exchangeable Mg (mg kg^{-1})	
	Growth Season											
	I	II	I	II	I	II	I	II	I	II	I	II
C	2.13j[1]	1.84g	0.13c	0.12c	31.9h	52.0g	174b	247f	3328b	3460c	210c	260f
FM10	2.24ı	2.34f	0.15b	0.13c	41.7h	56.2f	176b	338e	3282b	3338d	216c	267f
V10	2.33h	3.26d	0.13c	0.16c	52.6g	64.3e	205b	351e	3328b	3570b	217c	297d
FMV10	2.35h	2.54f	0.14c	0.13c	33.5h	65.3e	228b	366e	3638a	3762b	235b	284e
FM20	2.43g	3.41d	0.13c	0.13c	67.5f	62.0e	177b	468d	2900c	3260e	196d	258f
V20	2.54e	3.70c	0.15b	0.21b	52.9g	120a	210b	586b	3234b	3454c	222c	357b
FMV20	2.53e	4.09a	0.16b	0.20b	82.8e	82.2d	205b	560b	3186c	3656b	216c	342b
FM30	2.45f	3.16d	0.17a	0.18b	62.6f	74.6d	235a	584b	3172c	3504b	212c	310c
V30	2.77d	3.12d	0.15b	0.23a	95.4c	104b	249a	510c	3388b	3678b	240a	333b
FMV30	2.85c	3.85b	0.18a	0.18b	105.b	79.7d	234a	534c	3188c	3600b	223c	330b
FM40	3.08a	2.94e	0.17a	0.23a	69.8f	68.5e	260a	611b	3336b	3438c	226c	322c
V40	3.01b	3.65c	0.18a	0.23a	113.1a	113a	215b	592b	3192c	3472c	225c	337b
FMV40	3.08a	3.53d	0.17a	0.24a	113.4a	93.1c	246a	734a	3064c	3814a	216c	360a
CF	2.95b	1.98f	0.13c	0.19b	85.6d	60.3f	225b	391e	3030c	3824a	206d	255f
LSD %5	***[2]	***	***	***	***	***	***	***	*[3]	***	*	***

[1]Means in the same column followed by the same letter are not significantly different.
[2]***p<0.001.
[3]* p<0.05.

the differences among treatments are more prominent (p<0.001). Total N contents of soils varied between 0.12% and 0.24% and appeared to be higher than those of the first season. Based on the values from blocks receiving vermicompost and farmyard manure in the same doses (except for FM40 and V40) vermicompost increased total N more effectively than farmyard manure. Application of fertilizers also significantly affected available P contents of soils (p<0.001) in both growth seasons. Available P values ranged between 31.9 ppm and 113.4 ppm in the first season and 52.2 ppm and 120.3 ppm in the second season. Similar to total N, vermicompost was observed to increase available P concentration more than farmyard manure applied in the same doses. In addition, available P in some of the treatment soils, especially the treatments receiving chemical fertilizer (CF) and combination of farmyard manure and vermicompost (FMV), decreased or remained unchanged in the second season compared to the first season. Effect of amendments on soil exchangeable K contents in both growth seasons was found to be statistically significant compared to the control (p<0.001). In the first season, vermicompost applied in the rate of 10 and 20 t ha^{-1} (V10 and V20) appeared to elevate soil exchangeable K content while no significant change was observed with farmyard manure applied in the same rates. When the application rate was increased to 30 and 40 t ha^{-1} (V30 and V40), however, vermicompost resulted in similar or lower K values than did farmyard manure. In the second season, exchangeable K contents of all treatment soils increased compared to the first season and the differences among treatments in this season were found to be significant (p<0.001). Except for FM20 and V20 treatments, vermicompost amendments gave similar or slightly but significantly lower K values compared to the farmyard manure amendments.

When organic materials are applied to soils to improve organic matter status, they also supply soils with nutrients including N, P and K (Tiwari *et al*., 2004; Zakir *et al*., 2012). Our data are in agreement with this fact. Vermicompost that we used had higher total N and available P than those of farmyard manure. This may explain higher total N and available P values in soils treated with vermicompost compared to the soils with farmyard manure. On the other hand, these findings contradict some previous reports suggesting that especially phosphorus in vermicompost is released more gradually in available form in soil (Kale *et al*., 1987; Doube and Brown, 1998; Nethra *et al*., 1999; Lazcano *et al*., 2008). Our previous study showing similar total N and available P contents in soils with vermicompost and farmyard manure supported these reports (Uz and Tavali, 2014). Based on our current data, it appears that this remark does not always apply. Some factors including weather conditions, soil type, presence of plants and plant type may influence rate of nutrient release from vermicompost. K content of farmyard manure used in our study was almost three times higher than that of vermicompost (Table 2). As a result, soils receiving farmyard manure especially in high doses showed higher level of exchangeable K compared to the soils with vermicompost applied in the same doses. The difference between K concentrations of vermicompost and farmyard manure is rather interesting because, in general, K concentration ranges between 0.8 and 1.2% in farmyard manure and 1.4 and 2.0% in vermicompost (Agarwal, 1999). On the other hand, in our previous study (Uz and Tavalı, 2014), vermicompost and farmyard manure obtained from the same company and dairy farm showed a similarly significant difference in K concentration. Therefore, even though vermicompost used in the present study is produced from farmyard manure, nutrient composition and quality of the source material and vermicomposting conditions may greatly affect nutrient content of the vermicompost. Similary, nutrient content of farmyard manure may be influenced by cattle feeding practices and cattle dung maturation conditions. There are several reports in scientific literature indicating that farmyard manure and vermicompost enrich soils in terms of major plant nutrients (Patil and Sheelavantar, 2006; Gopinath *et al*., 2009; Pant *et al*., 2011; Doan *et al*., 2014; Sharma and Banik, 2014). Our findings are in agreement with these reports but also suggest that vermicompost may be considered as a better alternative than farmyard manure, especially in terms of N and P addition, in alkaline soils of Mediterranean region of Turkey.

Exchangeable Ca, Mg

Exchangeable Ca and Mg contents of soils at the end of the growth seasons are provided in Table 3. Effect of treatments on exchangeable Ca content of soils was found to be significant in the first and second growth seasons (p<0.05 and p<0.001, respectively). In the first season, application of organic materials (except for AGV10) resulted in similar or lower Ca concentrations in soil compared to the control. In the second season, in general, exchangeable Ca concentrations exhibited an increasing trend according to the application doses and were higher than their counterparts were in the first season in all treatments. In both growth seasons, soils receiving vermicompost gave higher Ca values than did soils with farmyard manure in the same doses (except for FM40 and V40). Soil exchangeable Mg content was significantly affected by treatments in the first and second growth seasons ($p<0.05$ and $p<0.001$, respectively). Unlike exchangeable Ca, Mg values in soils treated with fertilizers were generally above the control value (except for AG20 and CF) in the first season. In this season, the treatments with vermicompost showed similar or slightly higher Mg values compared to the farmyard manure treatments. In the second season, however, difference between vermicompost and farmyard manure treatments was more prominent. Mg values in all treatments were higher than those of the first season and effect of application in increasing rate was more apparent.

It is known that organic amendments improve soil cation exchange capacity (CEC) through humus formation and increase concentrations of nutrients such as Ca and Mg as a result of decomposition (Jenkinson, 1990; Johnston, 1997). Storage and availability of these cations in soil is closely related to CEC. Therefore, an increase in exchangeable Ca and Mg contents in soils with organic fertilizers are expected. However, in the first season, similar or lower Ca values in soils with fertilizers compared to the control and significant but small differences in Mg contents among treatments may indicate effect of some other factors. Indeed, elevated Ca and Mg values in the second season in all treatments including the control and CF, which did not receive organic materials, provide evidence that weather conditions may be the other factor. It is possible that activity of microorganisms and also perhaps activity of plant roots were limited in the first season, which was the period from October to December, due to low air temperature and rainfall. When the weather conditions became more favorable in the second season, which was the period from February to April, microorganisms may have become more active producing organic acids and CO_2 from organic materials and root exudates and, in turn, lowering pH of surrounding soil environment that leads to solubilization of Ca and Mg from carbonates which are present in high level in the test soil. Nevertheless, vermicompost appeared to be more effective to increase exchangeable Ca and Mg contents of soils when the vermicompost and farmyard manure applied in the same doses are compared with each other. This result is in agreement with the observation previously reported (Azarmi *et al.*, 2008).

Electrical Conductivity (EC) and pH

Changes that occurred in pH in blocks receiving vermicompost and farmyard manure at the rates of 40 t ha^{-1} during the first and second growth seasons are given in Fig. 2. In the first and second seasons, soil pH values of all treatments followed similar trend in the first three-four weeks. After the third and fourth week, however, pH values of soils receiving organic materials (FM and V) began to decrease and remained lower than the control and CF treatments during the remainder of the growth periods. Farmyard manure appeared to decrease soil pH more than vermicompost and difference among treatments was found to be statistically significant ($p<0.001$) (Table 4). Effect of treatment × time interaction on soil pH was also significant ($p<0.001$ and $p<0.05$ for the first and second seasons, respectively).

Even though EC values of soils fluctuated during the both growth seasons depending on time and treatment, organic and chemical amendments generally showed increasing trend compared to the control (Fig. 3). In the first season, the highest EC value was recorded with CF treatment and overall difference among treatments was significant based on calculated mean values ($p<0.001$) (Table 4). In the second season, the highest values were observed with FM20, FM40, and V40 treatments in the first week of the experiment. Later in the growth season, however, CF treatment increased the soil EC more than did other treatments. Based on calculated mean values, overall difference among treatments was significant also in the second season ($p<0.001$). Effect of treatment × time interaction was found to be significant in both growth seasons ($p<0.001$).

Plant growth, availability of nutrients, and microbial activity in soil are greatly influenced by soil pH. For many agriculturally important plants including celery, optimum soil pH value ranges from 6 to 7 (Hartel, 2005). In the present study, vermicompost and farmyard manure decreased the soil pH to optimum levels even though test soil has alkaline pH and high lime content, and organic fertilizers initially have alkaline reaction (Table 2). Previously published studies also indicate that organic amendments can lower soil pH (Khaleel *et al.*, 1981; Atiyeh *et al.*, 2001). The relatively lower pH in soils treated with organic fertilizers can be attributed to organic acids produced through degradation of organic compounds added with organic fertilizers and CO_2 originated from higher root and microbial activity leading to H_2CO_3 formation (Brady and Weil, 2001). It is known that organic and chemical fertilizers elevate soil EC and our study

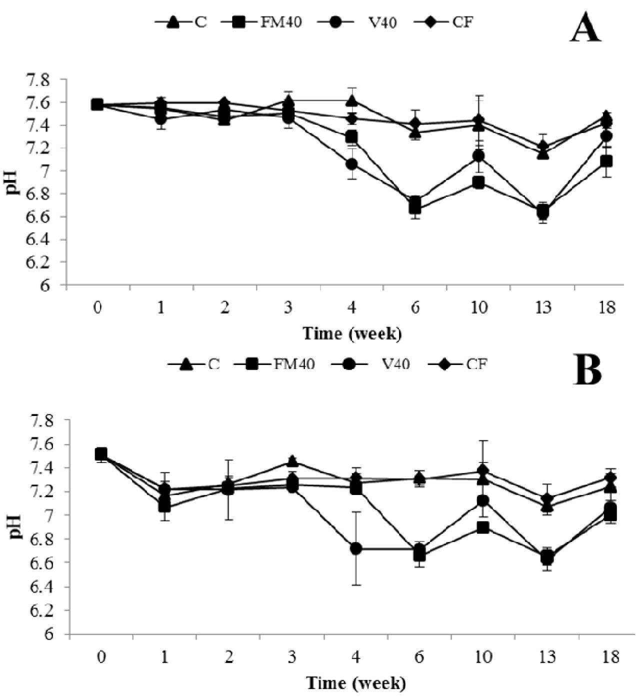

Fig. 2. Changes in pH in soils during the first (A) and second (B) growth season with farmyard manure (FM40) and vermicompost (V40) applied at the rate of 40 t ha^{-1}, chemical fertilizer (CF), and control (C) treatments. Error bars represent standard errors based on four replicates.

Table 4. Effect of treatments on pH, EC, enzyme activity and number of bacteria in soil during growth seasons

Treatment	pH		EC (μS cm^{-1})		Urease (μg NH_4^+-N g^{-1} dw h^{-1})		Alkaline phosphatase (μg PNP g^{-1} dw h^{-1})		β-glucosidase (μg PNG g^{-1} dw h^{-1})		Number of bacteria (10^6 cfu g^{-1} dw)	
	Growth Season											
	I	II	I	II	I	II	I	II	I	II	I	II
C	7.46 a[1]	7.28 a	252.98 d	227.58 d	28.67 b	30.29 c	25.71 b	25.94 d	8.69 c	9.59 c	0.90 c	1.86 d
FM20	7.20 c	7.09 b	303.52 cd	333.04 bc	53.13 a	53.21 b	38.00 a	41.89 c	11.73 a	15.04 b	2.29 a	2.99 bc
V20	7.30 b	7.20 a	325.72 cd	303.51 c	53.95 a	55.69 b	34.14 a	47.33 bc	10.94 ab	16.07 b	1.54 b	2.62 c
FM40	7.18 c	7.05 b	475.73 b	368.75 bc	54.87 a	60.78 a	38.82 a	50.36 b	12.27 a	16.39 ab	2.07 a	3.82 a
V40	7.20 c	7.04 b	366.30 c	384.84 b	56.44 a	61.40 a	34.65 a	61.13 a	12.33 a	17.94 a	1.98 ab	3.38 ab
CF	7.47 a	7.30 a	574.35 a	458.81 a	31.54 b	32.17 c	27.43 b	29.37 d	9.34 bc	10.67 c	1.01 c	2.02 d
ANOVA (LSD 5%)												
Time	42.22^{***2}	17.01^{***}	7.00^{***}	11.75^{***}	378.35^{***}	160.41^{***}	38.39^{***}	19.14^{***}	76.15^{***}	50.23^{***}	9.08^{***}	9.99^{***}
Treatment	16.75^{***}	10.10^{***}	16.29^{***}	16.72^{***}	259.75^{***}	217.31^{***}	7.10^{***}	33.24^{***}	9.73^{***}	45.01^{***}	10.14^{***}	17.67^{***}
Time × Treatment	2.60^{***}	1.63^{*}	3.04^{***}	2.73^{***}	25.87^{***}	12.23^{***}	2.97^{***}	2.84^{***}	5.30^{***}	3.72^{***}	1.89^{**3}	1.52^{*4}

[1]Means in the same column followed by the same letter are not significantly different.
[2] $^{***}p<0.001$.
[3] $^{**}p<0.01$.
[4] $^{*}p<0.05$.

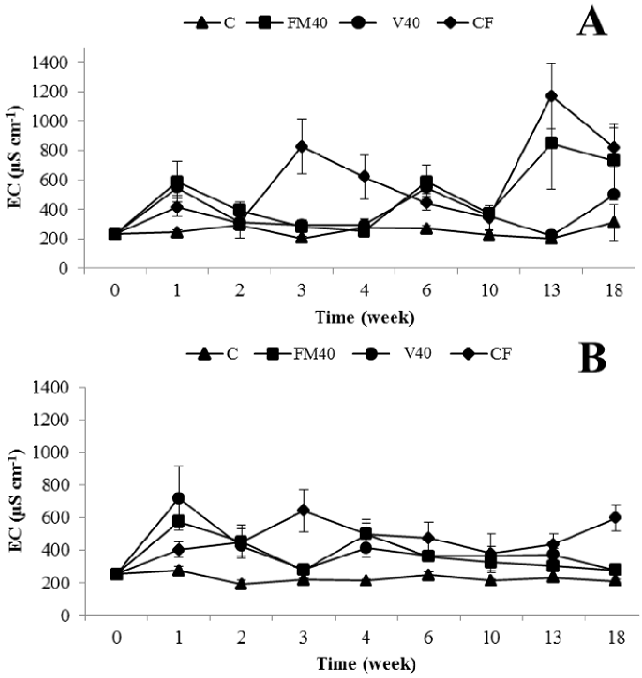

Fig. 3. Changes in EC in soils during the first (A) and second (B) growth season with farmyard manure (FM40) and vermicompost (V40) applied at the rate of 40 t ha^{-1}, chemical fertilizer (CF), and control (C) treatments. Error bars represent standard errors based on four replicates.

showed an increase in EC with farmyard manure and vermicompost applied in increasing doses. However, overall evaluation indicated that EC values of soils treated with organic fertilizers were below the EC value of soil with chemical fertilizer. This is possibly due to the fact that, unlike chemical fertilizers, organic fertilizers release nutrients more gradually as a result of degradation process and their chelate effect (Gerke *et al.*, 1999; Sharma and Banik, 2014). EC values of vermicompost-treated soils (except for V4 in the second season) were generally similar to or slightly below those of soils with farmyard manure applied in the same doses. This finding is supported by the reports pointing out the advantage of vermicompost over other organic fertilizers due to more gradual release of nutrients from vermicompost than from any other organic fertilizer to the soil environment (Kale *et al.*, 1987; Nethra *et al.*, 1999; Lazcano *et al.*, 2008). With exception of one or two sampling points, EC of soils with vermicompost and farmyard manure followed similar trend during both growth seasons. EC values obtained in the current study were not in a level to cause any salinity problem. Several researchers pointed out that organic fertilizers do not cause salinity when applied in moderate levels (Sutton, 1994; Garg *et al.*, 2009).

Urease activity

In the first growth season, urease activity showed increasing trend in all treatments during the first four weeks. During this time, organic and chemical amendments exhibited significantly higher urease activity than the control. After the fourth week, however, the activity in the control and chemical fertilizer treatments became similar and stable while the activity in organic amendments continued to rise (Fig. 4). Overall difference between organic amendments and the control and chemical fertilizers was found to be statistically significant ($p<0.001$) and urease activity appeared to be significantly affected by the treatment × time interaction ($p<0.001$) (Table 4). However, there was no significant difference between vermicompost and farmyard manure in all application doses based on calculated mean values. Almost the similar trend in urease activity was observed in the second growth season (Fig. 4). Overall difference among treatments and effect of the treatment × time interaction was significant ($p<0.001$) while no significant difference was found between organic materials applied in the same doses (Table 4).

Due to its involvement in nitrogen cycle, urease is considered to be one of the important enzymes that are used as indicators to monitor soil fertility. Its activity is known to be increased with stimulation of microorganisms in soil (Bremner and Mulvaney, 1982; Dick and Tabatabai, 1993; Bandick and Dick, 1999). In the present study, vermicompost and farmyard manure applications elevated soil urease activity compared to the chemical fertilizer and the control treatments. This result is consistent with findings of previous studies (Gopinath *et al.*, 2009; Sharma and Banik, 2014) and can be attributed to the addition of nutrients in organic forms, including nitrogenous compounds, to soil through organic materials leading to higher microbial number and activity. However, urease activity in soils treated with vermicompost and

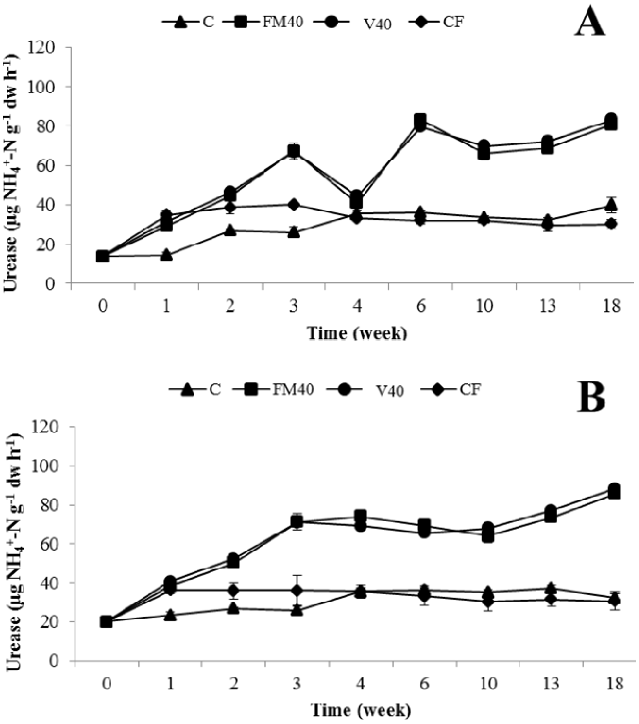

Fig. 4. Changes in urease activity in soils during the first (A) and second (B) growth season with farmyard manure (FM40) and vermicompost (V40) applied at the rate of 40 t ha^{-1}, chemical fertilizer (CF), and control (C) treatments. Error bars represent standard errors based on four replicates.

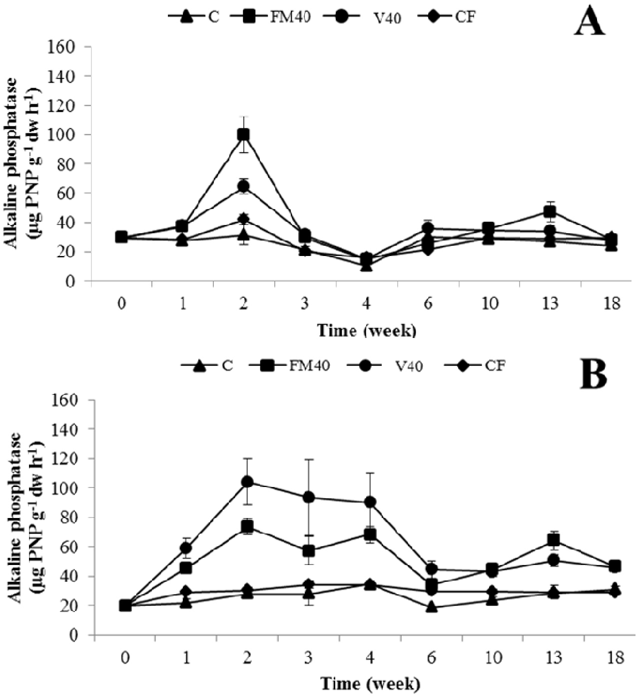

Fig. 5. Changes in alkaline phosphatase activity in soils during the first (A) and second (B) growth season with farmyard manure (FM40) and vermicompost (V40) applied at the rate of 40 t ha^{-1}, chemical fertilizer (CF), and control (C) treatments. Error bars represent standard errors based on four replicates.

farmyard manure followed similar trend during the both growth seasons and no significant difference was observed between these organic materials applied in the same doses. In their study, Sajjad et al. (2002) found that soil urease activity maintain a certain stable level and may not depend on type of organic material due to its complexation with humus compounds in soil, and stabilization and protection of the enzyme by organic matter. Similar urease activities observed between organic fertilizers in our study may be attributed to this fact. On the other hand, Albiach *et al*., (2000) stated that soil urease activity is associated with urea and urea-like compounds found in organic fertilizers. It is also possible that the vermicompost and farmyard manure used in the present study include similar amount of urea and urea-like compounds.

Alkaline phosphatase activity

In the first growth season, alkaline phosphatase activity of soils amended with vermicompost and farmyard manure was higher than those with chemical fertilizer and the control during the first three-four weeks (Fig. 5). Farmyard manure appeared to increase the enzyme activity more compared to vermicompost (only in the second week). After the fourth week, however, the enzyme activity in organic treatments dropped to a level similar to chemical fertilizer and control treatments and generally remained stable. Overall difference among treatments was significant ($p<0.001$) (Table 4). Treatment × time interaction was also statistically significant ($p<0.001$). On the other hand, no significant difference was found between vermicompost and farmyard manure in all application doses. In the second growth season, from the beginning of the experiment, organic material-amended soils had higher alkaline phosphatase activity compared to chemical fertilizers and control treatments (Fig. 5) and remained higher during this growth season. Based on calculated mean values, vermicompost and farmyard manure resulted in significantly higher alkaline phosphatase activity compared to chemical fertilizer and the control ($p<0.001$) (Table 4). Difference between vermicompost and farmyard manure treatments was also significant and vermicompost increased the enzyme activity more effectively than farmyard manure applied in the same doses (Fig. 5, Table 4). Effect of treatment × time interaction was also found to be significant ($p<0.001$).

It is known that soil alkaline phosphatase activity is stimulated by phosphorus bound to organic compound supplied with organic fertilizers (Kanchikerimath and Singh, 2001). Therefore, it is not surprising to observe relatively higher phosphatase activity in vermicompost and farmyard manure treatments compared to chemical fertilizer and control treatments. This observation is also in agreement with previous studies reporting that organic fertilizers including vermicompost increase this enzyme's activity in soil (Saha *et al*., 2008; Doan *et al*., 2013). Significantly higher soil phosphatase activity with vermicompost than with farmyard manure in the second growth season, but not in the first growth season, indicates that, in more favorable weather conditions, vermicompost has higher potential to stimulate indigenous organisms to produce this enzyme in the test soil.

β-Glucosidase activity

In the first growth season, overall difference between treatments was found to be significant ($p<0.001$) (Table 4). However, with one exception, there was no significant difference between organic fertilizers and also application doses. Effect of treatment × time interaction was significant ($p<0.001$). Soil β-glucosidase activity in all treatments fluctuated but generally followed similar trend during this season. In the second growth season, however, difference among treatments was more apparent ($p<0.001$) (Table 4 and Fig. 6). Based on calculated mean values, overall difference between vermicompost and farmyard manure was not significant when applied at the rate of 20 t ha^{-1} (V20 and FM20) but was significant when the application dose was increased to 40 t ha^{-1} (V40 and FM40) (Table 4). However, when the sampling points were evaluated individually vermicompost appeared to increase soil β-glucosidase activity more effectively especially during the period between the second and sixth week (Fig. 6) and effect of treatment × time interaction was found to be significant in this season ($p<0.001$).

Activity of β-glucosidase can be used to assess carbon turnover that has an impact on soil fertility due to the fact that it involves in degradation of cellulose, an important process producing glucose which is one of the main energy sources for soil organisms. Several scientists indicated that addition of organic fertilizers increases soil β-glucosidase activity depending on their composition of carbon compounds (Albiach *et al*., 2000; Laic *et al*., 2002; Srivastava *et al*., 2012). Indeed, in the present study, vermicompost and farmyard manure treatments showed higher enzyme activity compared to the other treatments and these results are in consistent with previous reports. Higher β-glucosidase activity in soils with vermicompost than with farmyard manure in the second growth season suggests that, under favorable conditions for soil microorganisms, vermicompost has greater potential to stimulate organisms capable of secretion of β-glucosidase. This can be attributed to the fact that vermicompost contain carbon compounds with relatively simple structure, such as cellobiose and glucose, as indicated previously (Parthasarathi and Ranganathan, 2000; Gopinath *et al*., 2008).

Number of total aerobic mesophilic bacteria

Aerobic mesophilic bacterial numbers in treatment soils are given in Fig. 7. Based on the calculated mean values, in both growth seasons, application of organic fertilizers resulted in higher bacterial number than did chemical fertilizer and control ($p<0.001$). In addition, farmyard manure appeared to yield slightly but significantly higher bacterial number in soil compared to vermicompost applied in the same doses ($p<0.001$) (Table 4). Effect of treatment × time interaction was also significant in both growth season ($p<0.01$ and $p<0.05$, respectively).

Organic compounds supplied by organic materials are the major source of nutrients for soil microorganisms. Therefore, soil microorganisms are considered one of the major factors determining soil fertility through their involvement, especially, in transformation of nutrients that is important for plants. In the present study, farmyard manure applications appeared to give higher aerobic mesophilic bacterial number than did vermicompost even though the difference was less than 10-fold. This result contradicts a previous study conducted in a similar soil with no plants under greenhouse conditions in the same region (Uz and Tavali, 2014). One of the possible explanations is that, farmyard manure contains microorganisms that are more adaptive and supports indigenous microorganisms that respond better under the field conditions with the presence of test plant. Since the farmyard manure and vermicompost have similar bacterial

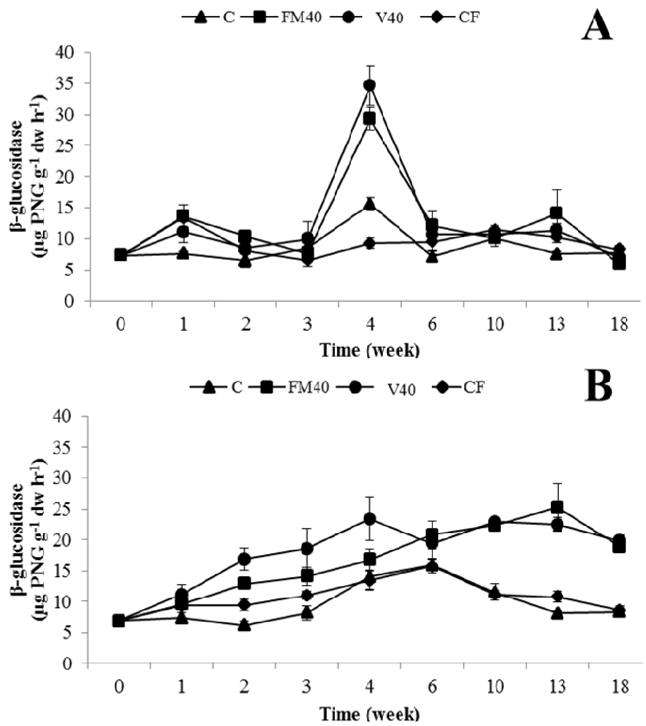

Fig. 6. Changes in β-glucosidase activity in soils during the first (A) and second (B) growth season with farmyard manure (FM40) and vermicompost (V40) applied at the rate of 40 t ha^{-1}, chemical fertilizer (CF), and control (C) treatments. Error bars represent standard errors based on four replicates.

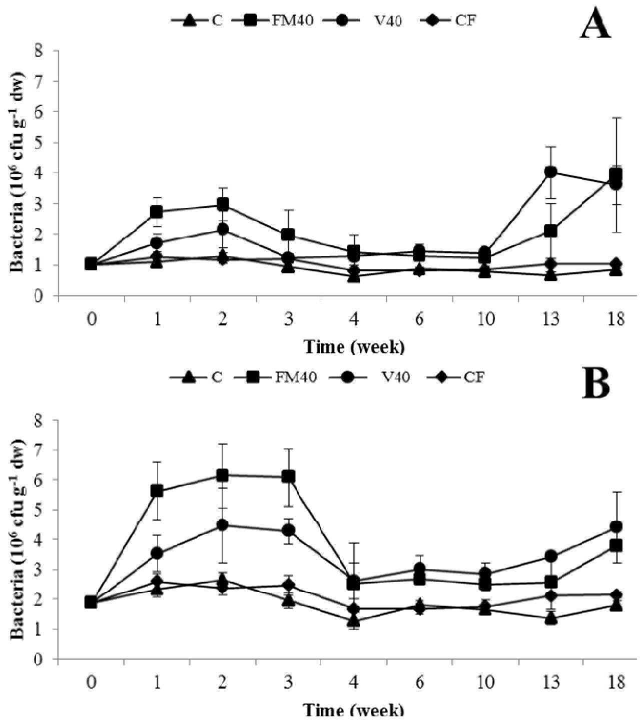

Fig. 7. Changes in number of aerobic mesophilic bacteria in soils during the first (A) and second (B) growth season with farmyard manure (FM40) and vermicompost (V40) applied at the rate of 40 t ha^{-1}, chemical fertilizer (CF), and control (C) treatments. Error bars represent standard errors based on four replicates.

numbers (Table 2), the difference may be attributed to type of bacteria present in the farmyard manure and farmyard manure's effect on soil microbial diversity. On the other hand, this does not necessarily mean that vermicompost is less effective on soil microbial activity and diversity. Several scientists reported greater microbial activity and diversity in vermicompost and soils amended with vermicompost (Kannan *et al.*, 2005; Aira *et al.*, 2008; Sebastian *et al.*, 2009; Doan *et al.*, 2013). In the present study, higher alkaline phosphatase and β-glucosidase activities in vermicompost-treated soils are also indicatives of vermicompost's influence on microbial activity. Therefore, an alternative and perhaps the most likely explanation is that some of the bacterial species in soils treated with vermicompost could not grow in the growth media used in the enumeration procedure leading to underestimation of bacterial populations. This result indicate that, in order to understand vermicompost's effect on microbial dynamics of soil, more detailed studies targeting specific microbial groups should be conducted.

Conclusion

The aim of this study was to investigate effect of vermicompost on some chemical and biological properties of alkaline soil with high lime content during celery production in two consecutive growth periods under the open field conditions in the semiarid Mediterranean region of Turkey. The result showed that vermicompost significantly affects chemical and biological properties of alkaline soil with high lime content during celery production under field conditions. In general, organic matter, total N, available P, and exchangeable Ca contents of soil were higher with vermicompost than with farmyard manure. Especially in the second growth season, when weather conditions are more favorable, vermicompost has higher potential to stimulate microorganism involved in carbon and phosphorus cycles. This may also be an evidence for its cumulative effect on soil microorganisms. However, compared to farmyard manure, vermicompost appeared to support slightly lower bacterial number in this soil. Clearly, vermicompost has a high potential to be used as an organic fertilizer during celery production in agricultural systems in the Mediterranean region of Turkey, whose soils are typically in alkaline character and have high lime content. However, in order to assess its full potential and its long-term effects in the region, further studies are required with other plants and various production practices.

Acknowledgments

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