



Effects of Leonardite and Mineral Fertilizer Applications on Plant Growth and Soil Quality of Garlic (*Allium sativum* L.)

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ABSTRACT

Turkey is one of the major garlic producing country in the world and the significant amount of Turkey's production has been made using a garlic variety called Taşköprü garlic (*Allium sativum* L.) in Kastamonu, Turkey. In order to improve the quality of garlic production, a field experiment was conducted to evaluate the effects of different doses of leonardite organic fertilizer, mineral fertilizer NPK and the mixture of both the leonardite and NPK fertilizers on the soil properties and mean performances of different characters and yield production of Taşköprü garlic. The treatments were: the plots without leonardite and NPK fertilizers (Control), (2) 80 N kg ha⁻¹ + 40 kg ha⁻¹ P₂O₅ + 100 kg ha⁻¹ K₂O (MF), (3) 2.6 ton ha⁻¹ leonardite (Leo₁), (4) 6.9 ton ha⁻¹ leonardite (Leo₂), (5) 9.7 ton ha⁻¹ leonardite (Leo₃), (6) Leo₁ + MF, (7) Leo₂ + MF and Leo₃ + MF. Most soil characteristics and the different characters and yield production of Taşköprü garlic statistically varied between the different fertilizer treatments. The plots with the Leo₃MF application showed the highest soil organic C, N, P and K concentrations, and the SOC_{stock} and TN_{stock}, while it had the highest bulb weight, length, equatorial diameter, weight of cloves, width of cloves, length of cloves as well as bulb yield per decare. Of the soil properties, the garlic yield was strongly positively correlated with the soil N concentration, indicating that the applications of leonardite with the different doses or the mixture of leonardite with the mineral fertilizer were resulting in higher soil N concentration and thus having the greatest effect on the garlic yields.

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Introduction

Garlic (*Allium sativum* L.) is one of the most important bulb vegetable crops and it is commonly used in the world as a spice or in medicine for a wide range of symptoms such as asthma, hypertension, bronchitis, cancer, circulatory weaknesses, colds, colitis, and coughing (Kaul, 1997). Garlic is also an important crop in Turkey and it has generally been cultivated for both domestic consumption and export. Turkey has 11.916 ha. garlic planting area and it is the fourteenth on the list in the world with 143.207 tonnes of production (FAO, 2018). Garlic is produced in almost all regions in Turkey, with exception of the northeast Turkey. Among all the regions, Kastamonu Province in the northwest Turkey has the highest production area, especially in Taşköprü town (nearly 26% of total production) with a Geographical Indication as "Taşköprü Garlic" in the region (Ibret, 2005). The cultivation area has continued to increase year by year in the Kastamonu Province. In 2012, the cultivated area of garlic in Taşköprü was 18.500 ha. with total production of

16,650 tons, while in 2016 this number increased to 2055 ha. with total production of 24024 tons (Çobanoğlu et al., 2016; Bayraklı and Gül, 2018). However, growing garlic in the newly reclaimed soils is, however, faced by various problems such as low amounts of available nutrients and poor organic matter content in the soil as well as poor hydrophobic, chemical and biological properties (Shafeek et al., 2015). Like other crops, the garlic plants also require appropriate proportions of nutrients and suitable environment. Although Taşköprü has an optimum climate for garlic production with a warm, humid spring (Anonymous, 2012), a number of studies on the productivity and nutrient content of the Taşköprü garlic have shown that the soils on which the Taşköprü garlic grows show nutrient deficiencies: nitrogen (67.5%), phosphorus (40%), Sulphur (82.5%), potassium (5%), zinc and manganese (97.5%), iron (7.5%) and organic matter (55%) (Taban et al., 2004; Akça et al., 2017). As emphasized by many authors (Henao and Baanante, 1999;

Tan et al., 2005), the rapid population growth and high demand for agricultural products generally result in using agricultural field intensely and finally it causes the reduction of organic matter and nutrients in soils, and so the reduction of the productivity and sustainability skills of agricultural land, which were productive before.

In order to increase the reduction in productivity of agricultural lands and to get a higher yield per unit area, one of the most common methods is to regain the lack of plant nutrients back into the soil with fertilizers. The most common way is to use some inorganic fertilizers. However, the use of inorganic fertilizers alone may cause problems for human health and the environment (Kumar et al., 2019). In order to reduce the negative effects of inorganic fertilizer, addition of organic fertilizers either alone or in addition to inorganic fertilizers has been increasing in the soil to regain the lost properties (Chen, 2006). One of these organic fertilizers is leonardite which is named in other countries as humat, organic humat, humalit or humus

(Akinremi et al., 2000). Leonardite consists of 30 to 80% humic acids and thus could be used as a soil amendment (Schnitzer, 1992; Akinremi et al., 2000; Erkoc, 2009; Sugier et al., 2013) Many studies have reported that application of humic substances can improve plant growth and increase crop production (Paksoy et al., 2010; Aisha et al., 2014; Shafeek et al., 2015). However, the effects of leonardite on soil properties and plant growth have received less attention (Ece et al., 2007; Halil et al., 2011; Sanli et al., 2013) and in our knowledge there is no information available about the interactions of both ground leonardite and the mineral fertilizers effects as soil amendments on plant growth, production and soil properties of garlic (*Allium sativum* L.) plantations. Therefore, this study aimed at determining the effects of different doses of leonardite either alone or in addition to inorganic NPK fertilizers on morphology, yield, nutrient content and soil quality of the Taşköprü garlic.

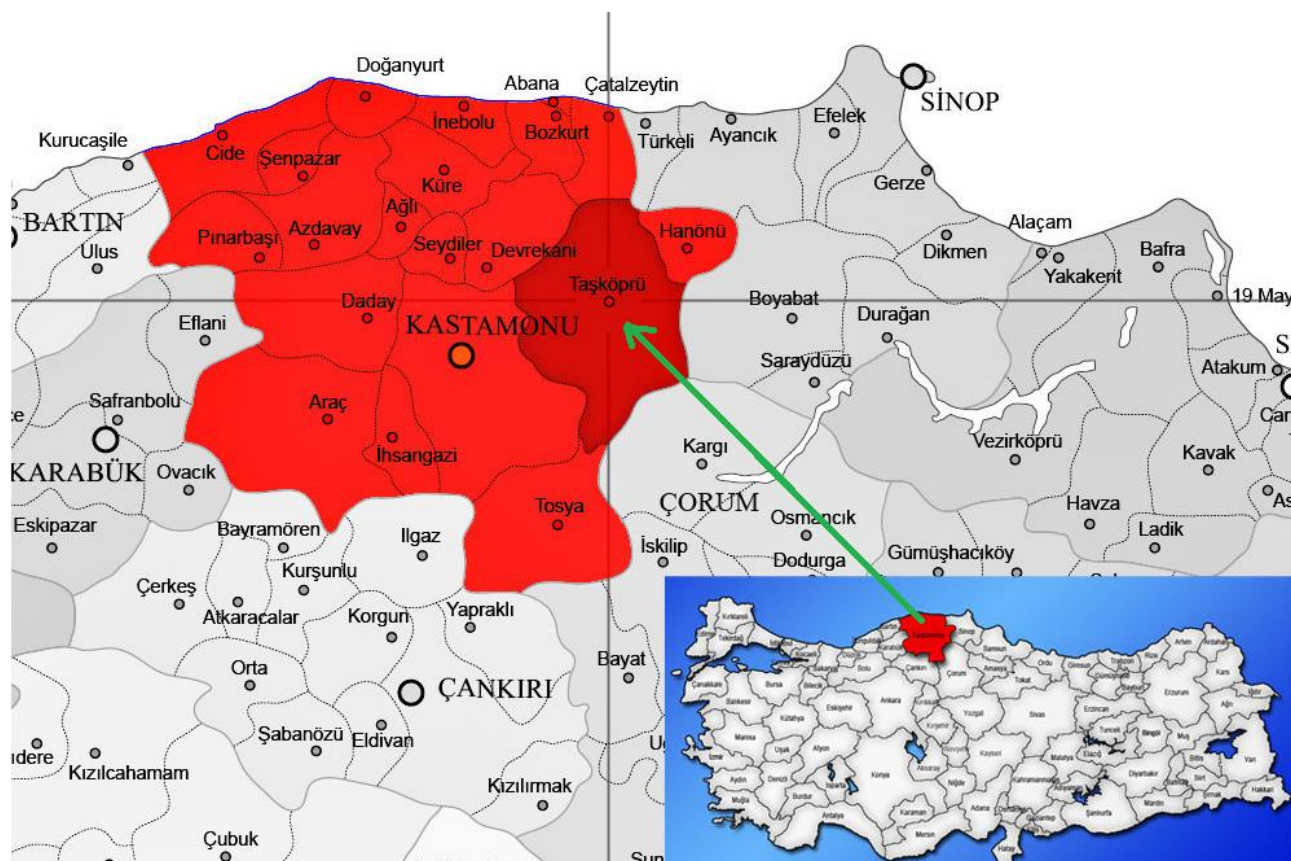


Figure 1. Location of the study area in Kastamonu, Turkey

Table 1. Treatments carried out on Taşköprü garlic (*Allium sativum* L.)

Treatment	Leonardite (ton ha ⁻¹)	N (kg ha ⁻¹)	K ₂ O (kg ha ⁻¹)	P ₂ O ₅ (kg ha ⁻¹)
Control	0	0	0	0
mineral Fertilizer (MF)	0	80	100	40
Leo ₁	2.8	0	0	0
Leo ₂	6.9	0	0	0
Leo ₃	9.7	0	0	0
Leo ₁ MF	2.8	80	100	40
Leo ₂ MF	6.9	80	100	40
Leo ₃ MF	9.7	80	100	40

Materials and Methods

Description of Study Site and Experimental Design

This study was carried out in Taşköprü, Kastamonu province, the northwest Turkey (41° 30' 35" N and 34° 12' 37" E) (Figure 1). Mean annual precipitation in Taşköprü is 652 mm, with the highest amounts in December (72 mm), and the lowest amount in July (35 mm). Mean annual temperature is 11.7°C, and average monthly temperature ranges from 20.8°C in July to 2.3°C in January.

The crop in this study was *Allium sativum* L., a species in the onion genus, *Allium*, commonly known in Turkey as Taşköprü garlic. The experimental design was a randomized split plot design with three replicates. The size of plot was 2.88 m² (1.6 × 1.8 m) and interrow spacing was 1 m. Plant (Taşköprü garlic) distances within the rows were 50 cm. The factors studied were ground leonardite and mineral fertilizer rates (NPK). Leonardite was ground and passed through a 2 mm mesh sieve and was applied at the rates of 2.8, 6.9 and 9.7 ton ha⁻¹ to the plots. The amounts of phosphate (P₂O₅), potash (K₂O) and urea used in the present study were based on the standard recommendation for the Taşköprü garlic in Kastamonu. The factors of experiment consisted of 8 treatments (Table 1). The application rates were (1) the plots without leonardite and NPK fertilizers (Control), (2) 80 N kg ha⁻¹ + 40 kg ha⁻¹ P₂O₅ + 100 kg ha⁻¹ K₂O (MF), (3) 2.6 tones ha⁻¹ leonardite (Leo₁), (4) 6.9 tones ha⁻¹ leonardite (Leo₂), (5) 9.7 tones ha⁻¹ leonardite (Leo₃), (6) Leo₁ + MF, (7) Leo₂ + MF and Leo₃ + MF. Total plots were 48 (3 replicates × 8 treatments × 2 study sites = 48 plots) (Figure 2a). The research area was irrigated twice with 7 days intervals.

Different doses of the leonardite, the mineral fertilizer and the combinations of both were applied and mixed before sowing (ure 2b). The Taşköprü garlics were sown on the plots in March (ure 2c). The sown garlics started merging from the last week of June (ure 2d). The garlic plants were watered during the growing season (ure 2e). The garlic plants were harvested in August (ure 2f). Observations were recorded on 10 randomly selected plants from each plot (ure 2g) for yield parameters, weight of bulb (g), length of bulb (mm), equatorial diameter of bulb (mm), number of cloves per bulb, weight of cloves (g), width of cloves (mm), length of cloves (g), bulb yield (g per plot) and bulb yield (kg da⁻¹) after harvesting. Mean concentrations of nitrogen, phosphorus and potassium in garlic leaves were also determined from each plot.

Soil Sampling and Analysis

Prior to the commencement of the field experiment, mineral soil samples were taken from the depth of 20 cm using a soil core (diameter 5 cm). Bulk density was determined by weight loss after drying the undisturbed soil core. The soil samples were air-dried, crushed, and passed through a 2-mm sieve prior to analysis. The soil samples were then analysed for pH, soil texture, water holding capacity, soil organic matter, Kjeldahl-N, K and P. A glass calomel electrode was used to measure the soil pH in deionized H₂O. The soil texture was determined by the hydrometer method (Gülçur 1974). Percent soil organic matter was found using the wet digestion method (Kalra and Maynard, 1991). A factor of 0.58 was then used to convert soil organic matter to soil organic carbon. Concentration of

K was determined by flame emission spectrophotometer (FES) and P by continuous flow colorimetry using the molybdenum blue method (Allen, 1989). Standard procedures were also used to determine the selected chemical properties of leonardite. All analyses were carried out in triplicate.

After the harvest, mineral soils from the depth of 0-20 cm soil depth were also sampled and analysed for pH, texture, water holding capacity, organic matter, Kjeldahl-N, K and P as previously outlined.

Total soil organic carbon (SOC) and total nitrogen (TN) stocks were calculated as Mg ha⁻¹ by the following formula (Lee et al., 2009).

$$\text{SOC}_{\text{stock}} \text{ or } \text{TN}_{\text{stock}} = \text{SOC or TN} \times \text{BDi} \times \text{H} \times 10^4$$

Where;

SOC or TN = Is the quantity of the soil organic carbon,

BDi = Is the bulk density (Mg m⁻³)

H = Is the depth (m) of respective soil layers

10⁴ = Is a unit conversion factor.

Statistical Analysis

The data were analysed statistically by analysis of variance to detect the treatment effects. Means of the treatments was compared using Duncan's Multiple Range Test DMRT). All statistical analyses were conducted using IBM SPSS Statistics 20 for Windows (SPSS Inc, Chicago, IL, USA).

Results

Soil Characteristics of Experimental Plots Before and After Harvesting

The selected soil physico-chemical properties of the experimental plots and the leonardite before sowing are presented in Table 2. Regardless of the treatment, soil pH, soil texture, N, K and P were typical of Taşköprü soil (Taban et al., 2004). The soils in the experimental plots were slightly basic (7.60), with low organic carbon (1.09%) and sandy loam texture (Table 2). Mean nitrogen (%), phosphorus (mg kg⁻¹) and potassium (mg kg⁻¹) concentrations (mg kg⁻¹) were 0.108, 7.4 and 82 respectively. Mean soil moisture was 50%.

The pH (water), organic matter (OM) (%), N (%), P (%) and K (%) contents of leonardite were 6.70, 50.2, 1.12% 0.09 and 0.51 respectively and they were consistent with those reported in the literature (Yolcu, 2011).

At the end of the experiments after harvesting, the soil properties from the control, the leonardite (Leo₁, Leo₂ and Leo₃), the mineral fertilizer (MF) and the leonardite plus mineral fertilizer application plots (Leo₁MF, Leo₂MF and Leo₃MF) are presented in Table 3. All soil characteristics statistically showed a significant variation with the treatments (P<0.001). Compared to the control plots, soil pH showed a decrease with the fertilizer applications, while soil organic carbon (SOC), total nitrogen (TN), soil moisture, P and K had an increase (Table 3). In general, the soil sand and clay contents tended to increase with the fertilizer applications, whereas the silt content tended to decrease with the fertilizer applications.

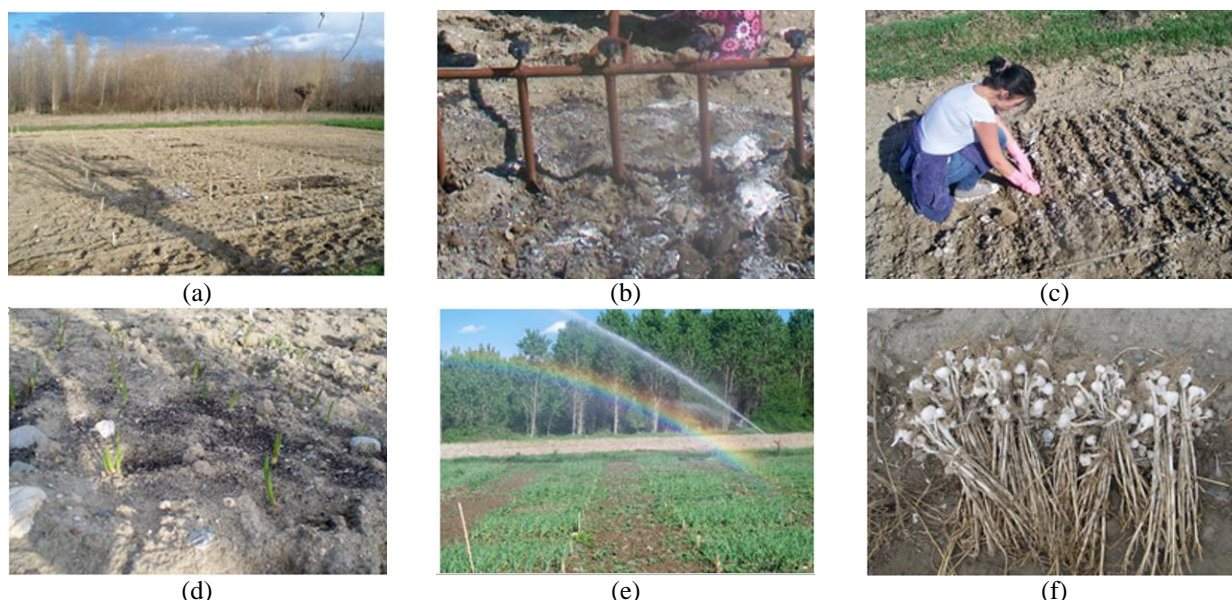


Figure 2. The experimental was carried out in the field, (a) the experimental plots, (b) mixing the fertilizers in the plots, (c) sowing the garlics in the plots, (d) emerging garlic plants, (e) watering the plots, (f) harvesting garlic plants

As seen in Table 3, the addition of leonardite + mineral fertilizers to the soil nearly reduced the soil pH 1.6 unit. The plots with higher doses ($9.7 \text{ tones ha}^{-1}$) Leo_3MF application had the highest soil organic carbon and nitrogen (3.10% and 0.78% respectively) compared to the control which had the lowest contents (1.17% and 0.23% respectively). The application of only mineral fertilizers or the different dose leonardites increased the SOC nearly 2-fold and 2.5-fold respectively, while the applications of both mineral fertilizers and the different leonardite doses increased the SOC 3-fold. On the other hand, the application of only mineral fertilizers did not significantly vary soil N content, while the different dose leonardites increased the soil N 2.5-fold. However, the applications of both mineral fertilizers and the different leonardite doses increased the soil N 3.5-fold.

The application of only mineral fertilizers did not significantly vary the $\text{SOC}_{\text{stock}}$ and TN_{stock} (Table 3) in the soils, however, the applications of the different leonardite doses or the mixture of different leonardite doses and the mineral fertilizers significantly varied the $\text{SOC}_{\text{stock}}$ and TN_{stock} . The $\text{SOC}_{\text{stock}}$ and TN_{stock} from the plots with Leo_3MF application were highest (78.8 Mg ha^{-1} and 19.9 Mg ha^{-1} respectively), compared to the control plots (29.6 Mg ha^{-1} and 5.8 Mg ha^{-1} respectively). The application of different dose leonardites increased the $\text{SOC}_{\text{stock}}$ and TN_{stock} nearly 2-fold and 2.4-fold respectively, while the applications of both mineral fertilizers and the different leonardite doses increased the $\text{SOC}_{\text{stock}}$ and TN_{stock} 2.7-fold and 3.5-fold.

Similar to the SOC and TN contents, P and K concentrations were also highest in the soil from the Leo_3MF application plots (14.9 mg kg^{-1} and 286 mg kg^{-1} respectively), and the lowest for the control plots (9.3 mg kg^{-1} and 107 mg kg^{-1} respectively). The application of only mineral fertilizers did not significantly vary P concentration, while the different dose leonardites increased the P concentration 1.3-fold. However, the applications of both mineral fertilizers and the different leonardite doses increased the P concentration 1.6 fold. The K concentration increased 1.25 fold with the application of mineral fertilizers, 2.12 fold with the different leonardite doses, and 2.67 fold with the applications of both mineral fertilizers and the different leonardite doses.

Table 2. Selected physical and chemical properties of experimental site and leonardite before sowing

Soil physico-chemical properties	Values
pH (H_2O)	7.60
Soil Organic Carbon (%)	1.09
N (%)	0.108
P (mg kg^{-1})	7.4
K (mg kg^{-1})	82
Sand (%)	75
Silt (%)	8
Clay (%)	17
Soil moisture (%)	50
Fertilizer (Leonardite)	
pH	6.70
Organic matter (%)	50.2
N (%)	1.12
P (%)	0.09
K (%)	0.51

The applications of mineral fertilizer, the different leonardite doses or both to the soils seemed to vary the sand content (3% to 6%), and clay content, (1% to 4%), whereas it increased the silt content (5% to 8%). The soil moisture content also increased 11% to 40% more with the applications of mineral fertilizer, the different leonardite doses or both (Table 3).

The Characters and Yields of Taşköprü Garlic with the Different Treatments

The effects of mineral fertilizer, the different leonardite doses and both applications on the different characters and yield of Taşköprü garlic are shown in Table 4. All type of applications significantly ($P < 0.001$) varied the characteristics and the yields of Taşköprü garlic. However, the application of both the different leonardite doses and the mineral fertilizers together clearly showed the highest values compared to the control and the other treatments (Table 4). For example, compared to the control plots ($25.3 \pm 4.69 \text{ g}$) the bulb weight gradually increased with the applications of mineral fertilizer ($27.8 \pm 3.00 \text{ g}$) and the

different dose leonardite (ranged from 30.8±3.80 g to 35.7±4.33 g), and it had the highest values with the mixture of both mineral fertilizers and the different leonardite dose applications (ranged from 36.0±2.42 g to 41.8±2.65 g). Similar variations in the bulb length (mm), equatorial diameter (mm), weight of cloves (g), width of cloves (mm) and length of cloves (g) were also found with the different fertilizer treatments (Table 4). As seen for all the other garlic characters, the plots with highest doses (9.7 tones ha⁻¹) Leo₃MF application had the highest bulb yield (g per plot) and bulb yield (kg da⁻¹) (3867±25.0 g per plot and 1343±86.9 kg da⁻¹ respectively) compared to the control (2167±39.5 g per plot and 753±130.7 kg da⁻¹ respectively), the mineral fertilizer (2487±28.5 g per plot and 864±99.0 kg da⁻¹ respectively) and the different dose leonardites (mean 3052 g per plot and 1060 kg da⁻¹).

Percent N, P and K in the garlic leaves after harvesting also showed significant variations with the applications of mineral fertilizers, the leonardite and the mixtures of both (Table 5). Mean nitrogen, phosphorus and potassium concentrations in the leaves of garlic were 1.3-, 1.2- and 1.4-fold higher in the soils with the mineral fertilizer

respectively, 1.4, 1.5 and 1.7 fold with the different dose leonardites respectively, and 1.4, 1.8 and 2.4 fold with the mixture of both the mineral fertilizer and the different dose leonardites respectively compared to the control plots. The ratio of N:P in the garlic leaves did not vary between the different fertilizer treatments. However, the ratio of N:K in the garlic leaves showed the highest ratio from the control plots (2.39), whereas it showed the lowest ratio from the Leo₃MF application plots (1.68).

To estimate the degree of relationship between the soil properties and the garlic yields, a correlation matrix was created using the soil properties and yield data from all different fertilizer treatments (Table 6). Of the soil properties, the garlic yield was strongly positively correlated with the soil N concentration (r=0.891), the soil K concentration (r=0.878) and the soil organic carbon (r=0.827). This indicates that among the soil properties measured, the higher soil N concentrations due to the applications of the leonardite alone or the mixture of leonardite with the mineral fertilizer were having the greatest effect on the garlic yields as shown in Figure 3.

Table 3. Soil physical and chemical properties of experimental sites after harvesting

Soil properties	Treatments							
	Cont.	MF	Leo ₁	Leo ₂	Leo ₃	Leo ₁ MF	Leo ₂ MF	Leo ₃ MF
pH (H ₂ O)	7.75 ^d ±0.36	7.21 ^c ±0.05	6.21 ^{ab} ±0.06	6.18 ^{ab} ±0.04	6.31 ^b ±0.10	6.14 ^a ±0.05	6.15 ^a ±0.04	6.19 ^{ab} ±0.02
C (%)	1.17 ^a ±0.13	1.88 ^b ±0.48	1.98 ^{bc} ±0.16	2.20 ^{cd} ±0.23	2.42 ^{de} ±0.27	2.42 ^{de} ±0.19	2.52 ^e ±0.14	3.10 ^f ±0.13
N (%)	0.23 ^a ±0.02	0.26 ^a ±0.01	0.44 ^b ±0.01	0.48 ^b ±0.03	0.55 ^c ±0.03	0.64 ^c ±0.01	0.77 ^d ±0.02	0.78 ^d ±0.03
SOC _{stock}	29.6 ^a ±3.29	37.6 ^a ±8.65	50.3 ^b ±4.07	55.9 ^{cd} ±5.73	61.5 ^c ±6.86	61.5 ^{cd} ±4.85	64.0 ^d ±3.46	78.8 ^e ±3.29
TN _{stock}	5.75 ^a ±0.39	6.72 ^a ±0.47	11.1 ^b ±0.64	12.2 ^b ±0.38	13.9 ^b ±0.62	16.3 ^c ±0.61	16.6 ^c ±0.47	19.9 ^d ±0.41
P (mg kg ⁻¹)	9.3 ^a ±9.3	10.5 ^{ab} ±1.43	11.1 ^b ±0.50	11.4 ^{bc} ±0.81	11.8 ^{bc} ±1.35	12.3 ^{cd} ±0.39	13.4 ^d ±1.83	14.9 ^e ±1.59
K (mg kg ⁻¹)	107 ^a ±15.1	133 ^b ±27.4	177 ^c ±4.15	185 ^c ±11.6	227 ^d ±22.7	235 ^{de} ±9.42	246 ^e ±4.48	286 ^f ±19.9
Sand (%)	70 ^a ±1.8	76 ^c ±1.1	76 ^c ±1.2	73 ^b ±1.5	73 ^b ±1.3	73 ^b ±1.1	75 ^c ±2.2	75 ^c ±0.7
Silt (%)	16 ^d ±0.72	10 ^b ±0.70	9 ^b ±0.69	11 ^c ±0.65	9 ^b ±1.04	11 ^c ±0.83	8 ^a ±1.38	10 ^b ±0.84
Clay (%)	14 ^a ±2	14 ^{ab} ±1.3	15 ^{ab} ±1.5	16 ^{bc} ±1.7	18 ^c ±0.9	16 ^{ab} ±0.7	17 ^{bc} ±3.3	15 ^{ab} ±1.3
Soil moisture (%)	54 ^a ±3.92	72 ^{cd} ±1.98	60 ^b ±3.62	62 ^b ±2.14	71 ^c ±9.55	71 ^c ±2.07	76 ^d ±2.78	76 ^d ±3.27

Means with different alphabets in line indicate significant difference between treatments by Duncan's test at P<0.001, n=8.

Table 4. Mean performance of different characters and yield of Taşköprü garlic with the different treatments

Treatment	Weight of bulb (g)	Length of bulb (mm)	Equatorial diameter (mm)	Number of cloves/bulb	
Cont.	25.3 ^a ±4.69	37.8 ^a ±3.48	39.2 ^a ±3.58	13.0 ^a ±2.69	
MF	27.8 ^b ±3.00	40.1 ^b ±3.53	42.8 ^b ±3.35	13.9 ^a ±1.50	
Leo ₁	30.8 ^c ±3.80	43.0 ^c ±2.81	45.3 ^c ±3.22	15.7 ^b ±1.67	
Leo ₂	32.4 ^c ±3.93	44.5 ^{cd} ±1.99	46.2 ^{cd} ±2.80	17.1 ^c ±2.01	
Leo ₃	35.7 ^d ±4.33	45.1 ^d ±3.68	46.9 ^{cd} ±3.54	18.7 ^d ±2.05	
Leo ₁ MF	36.0 ^d ±2.42	46.2 ^d ±2.95	46.4 ^{cd} ±2.70	19.3 ^d ±1.66	
Leo ₂ MF	39.0 ^e ±1.51	48.3 ^e ±3.25	47.7 ^d ±1.48	20.5 ^e ±1.24	
Leo ₃ MF	41.8 ^f ±2.65	49.1 ^e ±2.18	49.5 ^e ±2.64	21.0 ^e ±1.41	
Treatment	Weight of cloves (g)	Width of cloves (mm)	Length of cloves (mm)	Bulb yield/plant per plot (g)	Bulb yield (kg da ⁻¹)
Cont.	2.08 ^a ±0.76	8.77 ^a ±2.66	23.4 ^a ±2.71	2167 ^a ±39.5	753 ^a ±130.7
MF	2.36 ^b ±0.24	9.82 ^b ±1.23	27.8 ^b ±3.25	2487 ^b ±28.5	864 ^b ±99.0
Leo ₁	2.77 ^c ±0.54	16.0 ^{bc} ±2.52	29.1 ^{bc} ±6.28	2860 ^c ±35.0	993 ^c ±122
Leo ₂	2.95 ^{cd} ±0.56	18.3 ^{cd} ±2.36	30.5 ^{cd} ±3.28	2993 ^c ±37.9	1039 ^c ±132
Leo ₃	3.07 ^{cde} ±0.48	19.8 ^{cd} ±1.95	31.9 ^{de} ±3.38	3304 ^d ±39.9	1147 ^d ±139
Leo ₁ MF	3.14 ^{de} ±0.46	20.4 ^d ±1.82	32.5 ^{de} ±3.17	3334 ^d ±23.2	1157 ^d ±80.4
Leo ₂ MF	3.30 ^e ±0.30	21.0 ^d ±1.37	33.3 ^e ±2.33	3612 ^e ±15.9	1254 ^e ±55.1
Leo ₃ MF	3.59 ^f ±0.30	22.3 ^d ±2.35	34.1 ^e ±2.30	3867 ^f ±25.0	1343 ^f ±86.9

Means with different alphabets in column indicate significant difference between treatments by Duncan's test at P < 0.001, n=23.

Table 5. Percent N, P and K in garlic leaves after harvesting

Treatment	N (%)	P /%	K (%)	N:P	N:K
Cont.	5.12 ^a ±1.21	0.60 ^a ±0.13	2.14 ^a ±0.11	8.53	2.39
MF	6.26 ^b ±0.59	0.72 ^b ±0.14	3.02 ^b ±0.16	8.69	2.07
Leo ₁	6.76 ^b ±1.32	0.78 ^{bc} ±0.11	2.89 ^b ±0.32	8.66	2.34
Leo ₂	7.23 ^{cb} ±1.02	0.82 ^c ±0.12	3.23 ^b ±0.09	8.82	2.24
Leo ₃	7.59 ^c ±0.99	0.89 ^c ±0.09	3.89 ^{cd} ±0.22	8.53	1.95
Leo ₁ MF	7.90 ^{cd} ±1.11	0.91 ^{cd} ±0.08	4.21 ^d ±0.11	8.68	1.88
Leo ₂ MF	8.16 ^d ±0.89	0.94 ^d ±0.11	4.56 ^d ±0.07	8.68	1.79
Leo ₃ MF	8.44 ^d ±1.23	0.99 ^d ±0.13	5.03 ^e ±0.21	8.52	1.68

Means with different alphabets in column indicate significant difference between the treatments by Duncan's test at P<0.05, n=5.

Table 6. Pearson correlation coefficients between the garlic yields and the soil properties

Variables	Garlic Yields	pH	SOC	P	K	Sand	Silt	Clay	Soil moisture	N
Garlic Yields	-									
pH	-0.711**	-								
SOC	0.827**	-0.724**	-							
P	0.700**	-0.524**	0.729**	-						
K	0.878**	-0.777**	0.886**	0.765**	-					
Sand	0.323**	-0.435**	0.388**	0.278*	0.314*	-				
Silt	-0.545**	0.679**	0.616**	-0.388**	-0.531**	0.622**	-			
Clay	0.264*	-0.316	0.277*	0.125	0.262*	-0.386**	-0.472**	-		
Moisture	0.631**	-0.431**	0.714**	0.494**	0.628**	0.406**	-0.594**	0.246*	-	
N	0.891**	-0.784**	0.817**	0.749**	0.933**	0.300*	-0.539**	0.277*	0.608**	-

*Correlation is significant at the 0.05 level (two-tailed), **Correlation is significant at the 0.01 level (two-tailed).

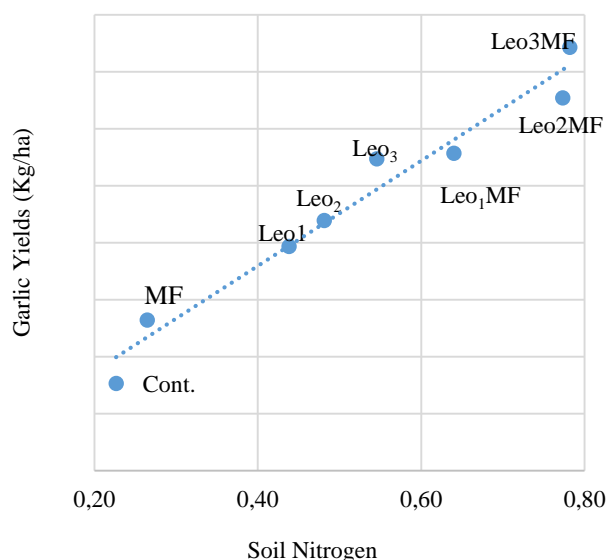


Figure 3. The garlic yields (Kg/ha) versus the soil N contents from the control, the applications of the mineral fertilizer, the different dose leonardites and the mixture of both the leonardite and the mineral fertilizer.

Discussion

Soil Characteristics of the Experimental Plots

It was clearly seen from the results of this study that the application of the different leonardite doses and mineral fertilizers (NPK fertilizer) alone positively influenced soil fertility (chemically and physically) of the Taşköprü garlic. On the other hand, the application of leonardite with the mineral fertilizer together had a significant positive effect

on the soil pH, soil moisture, soil organic C and total N contents, P and K concentrations as well as the SOC_{stock} and TN_{stock} compared to the control and the other applications alone (Table 3). It seems from the literature that there has been a few report on the application of leonardite for soil and crop yield improvement. However, there are several reports on pure humic acid application on crop yield. In those reports, many researchers have stated that using humic substances produced from leonardite as soil amendments can be useful substitutes for mineral fertilization in agriculture (Pascual et al., 1997; Hernandez et al., 2014). Significant impacts of humic substances on soil structure and plant growth are also reported in the literatures (El-Razek et al., 2012; Ihsanullah and Bakhshwain, 2013). They have explained that humic acids can directly affect physical, chemical and biological conditions of soil and also indirectly improve metabolic activity in plant growth (Kumar et al., 2013).

Some researchers have reported that the humic acids produced from leonardite reduce soil pH around roots and help converting unavailable nutrients to plant accessible forms (Vaughan and Donald, 1976; Chen and Aviad, 1990; Ali and Mindari, 2016). In our study, the soil pH was initially slightly basic (7.60). After the experiments, it was found that the use of mineral fertilizer slightly decreased the soil pH by 0.55 unit in comparison to the control (7.75). There was no statistically significant difference among the different leonardite doses either alone or with the mineral fertilizers for the soil pH, but it was seen that the use of leonardite either alone or with the mineral fertilizers significantly decreased soil pH by 1.44 – 1.61 units compared with the control soil (Table 3). Similar to the our results, soil pH decrease with the use of both mineral

fertilizers and humic substance was shown by Karcauskiene et al. (2019). In their study, soil pH of the fertilized soil was by 0.31–0.41 units lower than the control (unfertilized) soil. On the other hand, they noted that mineral fertilizers initially resulted in the fastest soil acidification, while they noted soil pH decrease after 3 years' time. Compared to their study, in our study, we found annually much higher soil pH decrease with the use of leonardite either alone or with the mineral fertilizers, and only slightly decrease with the mineral fertilizers. This pH range appeared to favor nutrient uptake by Taşköprü garlic since the ideal soil reaction for garlic cultivation is desired to be between 6-7 (Akça et al., 2017).

Without any doubt, the most important component of a fertile soil is available water. The stored water in the top soil provides an environment for nutrients required by soil organisms and plant roots. Many researchers have shown that the most important ability of the humic substances is to keep the water in the soil and to provide plants the opportunity to develop better (Suganya and Sivasamy, 2006; Selim et al., 2009; Hassanpanah and Khodadadi, 2009; Olk et al., 2018). Similar to their findings, we also found that percent soil moisture increased 11% to 40% with the application of leonardite alone or with the mineral fertilizer together (Table 3).

In our study, there was a significant effect of leonardite either alone or with the mineral fertilizers on the SOC and TN in the soil of Taşköprü garlic (Table 3). The SOC contents in the fertilized treatments varied from 1.88% (with mineral fertilizer) to 3.10% (Leo₃MF) compared to the control soil (1.17%), while the TN contents varied from 0.26% (with mineral fertilizer) to 0.78% (Leo₃MF) compared to the control soil (0.23%). Other studies have also shown that the use of leonardite as soil amendments with the other organic or inorganic fertilizers can improve soil nitrogen and organic carbon much better (Galloway et al., 2004; Hobbie 2008; Jiang et al., 2010; Powlson et al., 2012). Moreno et al. (2017) found that the use of leonardite mixed with zeolite increased the level of inorganic N forms (nitrate and ammonium) in soil. Akinremi et al. (2000) found an increase in N content of canola with increasing leonardite applications. An increase in soil organic C content due to the leonardite applications was also reported in other studies (Leita et al., 1999; Soler-Rovira et al., 2010; Ondoño et al., 2016; Moreno et al., 2017), and this in turn enhanced soil organic C stocks (Smith, 2004; Diacono and Montemurro, 2010; Bhattacharya et al., 2016). The data in this present study also supported the previous findings, with improving the soil organic C stocks due to the application of leonardite either alone or with the mineral fertilizers (Table 3). The application of different dose leonardites stored nearly 2 times more SOC in the soil, while the applications of both mineral fertilizers and the different leonardite doses stored 2.7 times more SOC in the soil than the control soil. In addition, our results also showed that the application of different leonardites doses stored 2.4 times more TN in the soil, while the applications of both mineral fertilizers and the different dose leonardites stored 3.5 times more TN in the soil than the control soil.

It is well documented previously that humic substances can be a reservoir for nitrogen and phosphorus (Qian et al., 2015). The results of this study also indicated that the sandy loam soil of Taşköprü garlic treated with the leonardite alone

or with the mineral fertilizers accumulated 2.5-3.5 times more nitrogen, 1.3 - 1.6 times more P and 2.1 - 2.7 times more K than traditionally mineral fertilized soil. A good correlation between the addition of leonardite and an increase in soil organic matter and P was also shown by a number of authors (Duplessis and Mackenzie, 1983; Turgay et al., 2004; Ece et al., 2007). It is well known that P is very important for plant development and growth. The root development can be inhibited by lower phosphates. Wang et al. (2007) reported that humic acids application in an alkaline soils solubilized phosphorus from phosphates and this slowly contributed to the soil's available phosphorus budget. For soil K content, Duplessis and Mackenzie (1983) reported an increase in soil K level with the leonardite, while Ece et al. (2004) showed a decrease in soil K level with the leonardite application. They attributed this decrease to K uptake by plants during the growing time. Sanli et al. (2013) have also stated that leonardite can increase available nitrogen, potassium and phosphorus availability in soil, which could be in turn taken up by plants.

The Characters and Yields of Taşköprü Garlic with the Different treatments

The results of this study have indicated that the application of the different leonardite doses alone or with the mineral fertilizers can significantly improve some characters of bulbs (weight, length and equatorial diameter), cloves (number, weight and width) and yields of Taşköprü garlic (Table 4). According to the report by Turkish Agriculture Engineering Chamber, in 2018, the average yield per dry garlic was 798 kg da⁻¹ (average 882 kg da⁻¹ in Turkey) (ZMO, 2020). In this present study, the application of leonardite either alone or with the mineral fertilizers improved the dry garlic yields of Taşköprü garlic ranged from 993 kg da⁻¹ to 1343 kg da⁻¹ (Table 4). The improvements of all those characters and yields of Taşköprü garlic could be attributed to (1) the positive effects of leonardite on the physical and chemical properties of soil (Ali and Mindari, 2016; Karcauskiene et al., 2019), (2) high available water holding and high adsorption capacities (Suganya and Sivasamy, 2006; Selim et al., 2009), and (3) improvement of nutrient use efficiency by increasing the availability and uptake of macro and micro plant minerals (Akinremi et al., 2000; Qian et al., 2016). A better plant growth due to optimal nutrient availability and soil moisture has been reported by many authors (Mahmoud and Hafez, 2010). A significant increase in soil organic matter and plant growth of onion due to humic acid applications was reported by Erik et al. (2000) and Sajid et al. (2012). A study by Akinremi et al. (2000) showed for canola that leonardite application facilitated nutrient uptake. They also reported that the dry matter of canola increased linearly with the leonardite application at the rates 10, 20, 60 and 200 g to 3 kg of the soil. Yield increase with the leonardite or humic substances application were also found for cucumber, maize, wheat, cabbage and potato (El-Shabrawy et al., 2010; Ayuso et al., 1996; Delfine et al., 2005; Syabryai et al., 1965; Hopkins and Stark, 2003 respectively). Saha et al. (2014) concluded that the combine application of humic acid and manure considerably influenced rice grain yield. Seyedbagheri (2010) found that tuber yield significantly increased from 11.4% to 22.3% with increasing leonardite doses. In our

study, yield increase of Taşköprü garlic ranged from 38% to 78% due to the application of leonardite either alone or with the mineral fertilizers compared to the control, while this increase was only 14% using the mineral fertilizers alone (Table 4).

In this study, all fertilizer treatments also provided higher nitrogen, phosphorus and potassium concentrations in garlic. However, it was noted that the garlic concentration of nitrogen, phosphorus and potassium increased as the level of leonardite applications either alone or with the mineral fertilizers increased (Table 5). The similar results were noted by Yolcu et al. (2011) for ryegrass and by Akinremi et al. (2000) for canola. On the other hand, several other studies also reported that leonardite, humic substances produced from it or other organic fertilizers such as manure or zeolite increased nutrients in many crops (Akinremi et al., 2000; Butler and Muir, 2006; Gevrek et al., 2009). On the contrary, some studies reported that manure application decreased Mg in oat plants, while K and Ca decreased in corn shoots with zeolite application (Ahmed et al., 2010). In addition, studies with manure application showed no effect on the K, Mg and Ca content of cereals and common vetch (Yolcu, 2008; Yolcu et al., 2010). These differences were probably due to the plant species or/and to the various soil and climatic conditions of the experimentation sites.

Conclusions

In conclusion, the results of the present study suggest that the alternative fertilization treatments with the different leonardite doses either alone or with the mineral fertilizers have a significant individual effect on the soil properties, vegetative growth and yield of Taşköprü garlic in comparison to only conventional fertilization of NPK fertilizer.

The pioneer results have indicated that the application of leonardite with the mineral fertilizer can provide sufficient nutrients to the garlic and improve soil quality. Especially, the use of leonardite in Taşköprü garlic on sandy soils could be beneficial. When all the data are considered, the results indicate that leonardite could be used as soil conditioner material in soils with lower organic matter and nutrients in order to increase the quality and yield of Taşköprü garlic. Further studies are also needed to assess the interaction between leonardite and different soil properties. And the effects of humic and fulvic acids produced from leonardite on the performances of different characters and yield production of Taşköprü garlic should be also studied in future.

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