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EFFECTS OF LEONARDITE APPLICATIONS ON YIELD AND SOME QUALITY PARAMETERS OF POTATOES (*Solanum tuberosum* L.)

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ABSTRACT

The present study was carried out at Suleyman Demirel University research farm in Isparta during 2008 and 2009 crop seasons to determine the effects of leonardite (54.5% organic matter) on yield and quality of potato. Four leonardite doses (0, 200, 400, 600 kg ha^{-1}) and four potato cultivars (Van Gogh, Milva, Lady Olympia, Agata) were used in the study. A total of seven traits (plant height, tuber number per plant, marketable tuber yield, total tuber yield, protein content, vitamin C content and specific gravity) were measured. Significant differences were detected between control and leonardite applications for all the traits studied. Statistically significant differences were not found between the leonardite doses for plant height and specific gravity. There was no significant difference between 400 and 600 kg ha^{-1} leornardite application for tuber number per plant, marketable tuber and total tuber yield, protein and vitamin C contents. Leonardite applications increased number of tubers per plant by 22%, marketable tuber yield by 38% and total tuber yield by 15% compared with the control. These results suggest that 400 kg ha^{-1} leonardite combination to the standard fertilization will be sufficient to obtain adequate yield and quality tubers in potatoes.

Keywords: Fertilization, leonardite, potato, yield

INTRODUCTION

Potato plants need significant amounts of fertilizers to produce marketable tubers and high yield. In order to provide necessary nutrients, both chemical and natural fertilizers are used in potato production. Intensive use of chemical fertilizers could cause environmental pollution (Ece et al., 2007). Therefore there is a growing interest to use natural alternatives of chemical fertilizers in agricultural production.

Leonardite is a concentrated form of humic and fulvic acids, and has appearance of coal but it does not reach the compactness of coal (Erkoç, 2009). Leonardite is rich in organic matter (50-75%) and its humic acid content could change between 30-80% (Akinremi et al., 2000). Humic acid and other humic compounds stimulate root and shoot development, increase both available plant nutrients and nutrient uptake from soil, enhance plants resistance to biotic and abiotic stress factors (Akinremi et al., 2000; Dursun et al., 2002; Serenella et al., 2002; Cimrin and Yilmaz, 2005; Ünlü et al., 2010). Effects of humic acid containing fertilizers on plant yield and nutrient uptake depend on humic acid source, concentration, application type, plant species and cultivars (Chen and Aviad, 1990).

Leonardite both provides nutrients and increases absorption of available nutrients in different soil types (Chen and Aviad, 1990). It also reduces soil pH around roots and helps converting unavailable nutrients to plant accessible forms (Vaughan and Donald, 1976). Leonardite could be used as a soil amendment because it releases nutrients slowly to soil thus preventing nutrient loss due to leaching and evaporation (Sibanda and Young, 1989). Humic acid and leonardite increase cation exchange capacity of soil and cell permeability of capillary roots, thus they serve to increase nutrient availability and act as plant growth promoters and stimulates plant development (O'Donnell, 1973; Malcolm and Vaughan, 1979). Humic substances increase water holding capacity of soil and provide plants the opportunity to develop better (Suganya and Sivasamy, 2006; Selim et al., 2009a; Hassanpanah and Khodadadi, 2009). In addition, it was stated that the coal-humic fertilizers activated the biochemical processes in plants (respiration, photosynthesis and chlorophyll content) and increased the quality and yield of potatoes.

Humic acid applications led to significant increase in soil organic matter content and improve plant growth and crop yield (Erik et al., 2000; Hartwigson and Evans, 2000; Hafez, 2003; El-Desuki, 2004). Mahmoud and Hafez

(2010) reported increased yield and quality of potato with increased level of humic acid application. Selim et al. (2011) reported beneficial effects of humic acid application on to plant growth parameters, tuber production and some biochemical indicators of potato crop. Both liquid and solid forms of humic acid applications are effective to increase yield of potato plants. Humic acid applications between 15 to 30 L ha^{-1} increased potato total yield by 2250 kg ha^{-1} and marketable tuber yield by 2750 kg ha^{-1} (Hopkins and Stark, 2003). Verlinden et al. (2009) reported potato tuber production increased 13% by foliar application and 17% by soil fertilization. Soil application of humic acid had a significant increase in plant growth characters, photosynthetic pigments, total and marketable yield and tuber root quality of sweet potato. In addition, humic acid application significantly increased chemical composition of tuber roots and reduced the weight loss and decay percentages (El Sayed Hameda et al., 2011).

New leonardite mines have been discovered and started to the production of this organic material in Turkey. The aim of the present study was to evaluate the effects of leonardite fertilization on yield and some quality parameters of potatoes grown in Isparta province.

MATERIALS AND METHODS

Study was conducted at the research farms of Suleyman Demirel University, Isparta (37º 45' N, 30º 33' E, altitude 1035 m), during 2008 and 2009 crop seasons. Soil type of the experimental area was loam with a pH of 8.2. Nutrient content of the experimental area was determined for the entire location and it was divided two parts and each part was used to grow potatoes during first and second year of the study separately. Leonardite doses used at the research were determined after soil chemical analysis to supplement nutrient content of the soil. Total nitrogen content of the entire location was 0.21% (macro Kjelhdal method), extractable phosphorus and potassium contents were 18.5 mg kg^{-1} (Olsen method) and 166 mg kg^{-1}, respectively. Organic matter content of soil was 1.3% (Walcley-Black method). Total precipitation between April and September was 127 mm and 178 mm for the first and second years of the experiment, respectively and for the same period the long term average rain fall was 188 mm. Average daily temperature for the same period was 19.7 °C and 18.6 °C, for 2008 and 2009 crop seasons, respectively. Long term average daily temperature between April and September was 18.3 °C.

The experiment was established as factorial design with two factors in a randomized complete block design with three replications. Four doses of leonardite (0, 200, 400, 600 kg ha^{-1}) and four potato cultivars (Agata, very early; Milva mid-early; Van Gogh, mid-late; Lady Olympia, late) were used. Commercial leonardite was purchased from Mineral Tarım (Fethiye, Muğla) and potato tubers were purchased from the Potato Producers Organization (Sandıklı, Afyon). Some chemical and physical properties of leonardite used in the study were given in Table 1.

Table 1. Some physical and chemical properties of leonardite used in the study.

Organic matter (%)	**Humic + Fulvic acids (%)**	**N (%)**	**P (mg kg^{-1})**	**K (mg kg^{-1})**	**pH**	**Humidity (%)**	**Heavy metal content**
54.5	50.5	1.79	24	135	6.80	16	Below threshold values

Tubers were planted at the first week of May at each growing season and leonardite was broadcast at appropriate doses during the planting. Each plot was 6 m in length and consisted of 4 rows. Planting space between rows were 70 cm and tubers were planted 30 cm apart within rows. Nitrogen (200 kg ha^{-1}) and phosphorus (100 kg ha^{-1}) fertilization were uniformly applied as ammonium sulphate and diamonium phosphate to plots during planting (Karadoğan, 1994).

Weed control was done with hand two to three times depending on weed density. Irrigation was performed with drip irrigation system when available soil moisture dropped below 50% in soil. During the blooming period, plant height was recorded from 20 plants from middle two rows of each plot. Tubers were harvested at the second half of September for each growing year.

Plant height and number of tubers per plant were determined from middle row of each plot on 20 plants. Rest of the plants within the same two rows were harvested with a machine to determine marketable tuber yield (>45 mm) and total tuber yield.

Protein contents of tubers were determined using macro Kjehldal method (Kaçar and İnal, 2008). Vitamin C content was determined according to AOAC (1975) method and results were expressed as mg 100 g fresh weight (fw)$^{-1}$. In order to calculate specific gravity, approximately 5 kg of tubers were weighted both in air and in water, and specific gravity was calculated according to following formula (Esendal, 1990): weight of tubers in air / (weight in air) – (weight in water).

Data was subjected to the analysis of variance (ANOVA) procedure with SAS statistical program (SAS, 1998). Means were separated using Duncan’s multiple range tests at the 0.05 significance level.

RESULTS

According to ANOVA results, cultivar (C) and dose (D) effects were significant for all examined traits at 1% level of significance (Table 2). No statistically significant interactions were detected between Y x D and Y x D x C interactions. Y x C interaction was important for marketable tuber yield (1% level) and total tuber yield (5% level). C x D interaction was important for marketable tuber yield (1% level) and protein content (5% level).

Table 2. Results of Analyses Variance (ANOVA) for the traits measured in the study.

Source of variation	Df	Plant height (cm)	Tuber number per plant	Marketable tuber yield (t ha^{-1})	Total Tuber yield (t ha^{-1})	Protein content (%)	Vitamin C content (mg 100 g fw^{-1})	Specific gravity (g/cm^3)
Year (Y)	1	**	**	**	**	ns	ns	ns
Blok (Year)	4	ns	*	*	**	ns	*	**
Cultivar (C)	3	**	**	**	**	**	**	**
Y x C	3	ns	ns	**	*	ns	ns	ns
Doses (D)	3	**	**	**	**	**	**	**
Y x D	3	ns	ns	ns	ns	ns	ns	ns
C x D	9	ns	ns	**	ns	*	ns	ns
Y x C x D	9	ns	ns	ns	ns	ns	ns	ns
Error	60							
CV		4.8	11.1	10.1	7.7	3.3	8.3	0.3

df, degrees of freedom ; ns, non significant; * $P<0.05$; ** $P<0.01$

Plant Height

Leonardite applications increased plant height significantly compared to the control (70.7 cm). Statistically significant differences were not observed between leonardite doses (73.8-74.4 cm) used in the study. Plant height of cultivar Van Gogh was found to be lower than the other 3 cultivars used in the study (Table 3).

Tuber number per plant

The lowest number of tubers per plant was recorded (5.3 tubers) in control. The highest number of tubers per plant was obtained from 600 kg ha^{-1} leonardite application (6.5 tubers), but no statistically significant differences were detected between 400 and 600 kg ha^{-1} leonardite applications (Table 3). Among the tested cultivars, Milva had the highest number of tubers per plant (7.7 tubers) and Agata had the lowest number of tubers per plant (4.4 tubers).

Marketable tuber yield

The lowest marketable tuber yield was found in the control (17.5 t ha^{-1}) and marketable tuber yield increased with increased leonardite doses (Table 3). The yield increase between the control and 200 kg ha^{-1} leonardite application was 18%. Compared to the control, marketable tuber yield increased by 31% and 38% for 400 and 600 kg ha^{-1} leonardite applications, respectively. But a statistically significant difference was not found between these two doses for marketable tuber yield (Table 3). Differences were observed for marketable tuber yield between the cultivars. Marketable tuber yield of cultivars Van Gogh, Milva and Lady Olympia was over 20 t ha^{-1} whereas yield of Agata was 12.2 t ha^{-1}(Table 3). There were no statistically significant differences between 400 and 600 kg ha^{-1} leonardite applications for marketable tuber yield in Van Gogh, Milva and Lady Olympia. Marketable tuber yield increased by 4.6 t ha^{-1}, 7.7 t ha^{-1} and 9.1 t ha^{-1} for Van Gogh, Milva and Lady Olympia at 400 kg ha^{-1} leonardite doses compared with the control, but marketable tuber yield did not increase significantly for Agata among the control and leonardite doses.

Total tuber yield

Leonardite applications increased tuber yield and yield increase associated with increased leonardite doses. Average tuber yield was 29.2 t ha^{-1} in control plots where only standard fertilization was practiced whereas tuber yields of 200, 400 and 600 kg ha^{-1} leonardite applications were 31.5, 33.2 and 33.5 t ha^{-1}; respectively. While 400 and 600 kg ha^{-1} leonardite doses gave the highest total tuber yield, there was no statistical difference between these two doses (Table 3). The highest tuber yields were obtained from Milva (37.0 t ha^{-1}) and Lady Olmpia (36.5 t ha^{-1}) followed by Van Gogh (32.7 t ha^{-1}) and Agata (21.3 t ha^{-1}).

Protein content

Leonardite applications increased protein content of all cultivars compared with control. The highest increase was observed for 400 (2.08%) and 600 kg ha^{-1} (2.12%) leonardite applications, but difference detected between these doses was not significant (Table 4). The highest amount of protein was found in Lady Olympia (2.08%) and Van Gogh (2.07%). With increased leonardite doses protein content usually increased in tested cultivars except in Van Gogh, in which protein content did not increased after 200 kg ha^{-1} leonardite application (Table 4).

Vitamin C content

Leonardite applications increased Vitamin C content. Average vitamin C content was 16.3 mg 100 g fw^{-1} in control whereas average vitamin C content was 17.5, 18.6 and 19.1 mg 100 g fw^{-1} in 200, 400 and 600 kg ha^{-1} leonardite applications, respectively. There was no significant difference between 400 and 600 kg ha^{-1} leonardite application for vitamin C content (Table 4). Among the tested cultivars, Agata (20.2 mg 100 g fw^{-1}) and Van Gogh (13.7 mg 100 g fw^{-1}) had the highest and the lowest vitamin C concentrations; respectively.

Table 3. Effects of different doses of leonardite applications on plant height, tuber number, marketable tuber yield and total tuber yield of potato cultivars.

	2008-2009					**2009-2010**					**2-year average**				
	Leonardite Doses (kg ha^{-1})														
Cultivars	0	200	400	600	Mean	0	200	400	600	Mean	0	200	400	600	Mean
	Plant Height (cm)														
Van Gogh	68.3	70.0	70.2	71.7	70.1	70.5	72.7	73.5	71.7	72.1	69.4	71.3	71.9	71.7	71.1b
Milva	69.6	75.0	75.1	75.1	73.7	72.3	77.3	77.8	77.8	76.3	71.0	76.2	76.5	76.5	75.0a
Lady Olympia	67.5	73.6	71.9	75.3	72.1	72.0	75.7	77.6	76.1	75.4	69.8	74.6	74.8	75.7	73.7a
Agata	71.7	71.6	74.2	73.3	72.7	73.9	74.2	73.5	74.1	73.9	72.8	72.9	73.8	73.7	73.3a
Mean	69.3	72.5	72.9	73.9	**72.1**	72.0	75.0	75.6	74.9	**74.4**	70.7b	73.8a	74.2a	74.4a	
	Tuber Number Per Plant (number plant $^{-1}$)														
Van Gogh	4.9	6.1	6.1	6.5	5.9	5.4	5.5	6.3	6.5	5.9	5.1	5.8	6.2	6.5	5.9b
Milva	6.4	7.2	7.7	7.9	7.3	7.6	7.8	8.3	8.6	8.1	7.0	7.5	8.0	8.3	7.7a
Lady Olympia	5.1	5.7	6.3	6.4	5.9	5.4	6.7	6.9	6.9	6.5	5.3	6.2	6.6	6.6	6.2b
Agata	3.7	4.3	4.3	4.1	4.1	3.7	5.1	5.0	5.1	4.7	3.7	4.7	4.6	4.6	4.4c
Mean	5.0	5.8	6.1	6.2	**5.9**	5.5	6.3	6.6	6.8	**6.3**	5.3c	6.1b	6.4ab	6.5a	
	Marketable Tuber Yield (t ha^{-1})														
Van Gogh	18.3	21.6	22.3	23.6	21.5	20.4	23.2	25.3	26.4	23.8	19.4	22.4	23.8	25.0	22.6c
Milva	17.2	22.9	25.8	26.7	23.2	23.7	28.3	30.4	31.9	28.6	20.4	25.6	28.1	29.3	25.9a
Lady Olympia	16.1	20.9	25.0	25.2	21.8	21.7	24.0	31.0	32.6	27.3	18.9	22.5	28.0	28.9	24.6b
Agata	11.1	12.4	12.7	13.4	12.4	11.6	11.8	11.8	13.1	12.1	11.8	12.1	12.3	13.2	12.2d
Mean	15.7	19.5	21.4	22.2	**19.7**	19.4	21.8	24.6	26.0	**23.0**	17.5c	20.6b	23.0a	24.1a	
Lsd $_{cultivar\ x\ dose\ :\ 2.49}$ Lsd $_{year\ x\ cultivar\ :\ 1.76}$															
	Total Tuber Yield (t ha^{-1})														
Van Gogh	29.1	32.0	32.6	33.4	31.8	32.5	32.7	34.5	35.0	33.7	30.8	32.3	33.6	34.2	32.7b
Milva	30.3	36.2	38.2	38.5	35.8	35.5	37.6	39.6	39.5	38.1	33.0	36.9	38.9	39.0	37.0a
Lady Olympia	32.6	35.0	36.2	36.2	35.0	33.2	36.3	41.6	41.2	38.1	32.9	35.7	38.9	38.7	36.5a
Agata	20.5	2.17	22.2	22.7	21.8	20.3	20.4	20.9	21.5	20.8	20.4	21.1	21.6	22.1	21.3c
Mean	28.1	31.2	32.3	32.7	**31.1**	30.4	31.8	34.2	34.3	**32.7**	29.2c	31.5b	33.2a	33.5a	
Lsd $_{year\ x\ cultivar\ :\ 1.99}$															

Means followed by the same letters in rows and columns are not significantly different at $P < 0.05$ level

Specific gravity

Leonardite applications increased the specific gravity compared to control plots, but there was no statistically significant differences observed between different leonardite doses for specific gravity (Table 4). However significant differences were detected between potato cultivars for their specific gravity. The highest specific gravity was observed in Lady Olympia (1.091 g cm$^{3\ -1}$) followed by Van Gogh (1.089 g cm$^{3\ -1}$), Milva (1.080 g cm$^{3\ -1}$) and Agata (1.078 g cm$^{3\ -1}$).

DISCUSSION

Even though plant height is not an important agronomic or quality parameter for potato it could be used to have an idea about vegetative growth and plant development, thus an estimate of yield (Maity and Chatterjee, 1977). Statistically significant differences were not detected between 200, 400 and 600 kg ha^{-1} leonardite doses for plant height, but leonardite applications significantly increased plant height compared with control. Increased plant height may result from increased soil fertility and available plant nutrient elements due to leonardite applications. Good plant development due to increased soil moisture content and nutrient availability increases stolon number and length per tuber (Mahmoud and Hafez, 2010). Similar results were reported by Erik et al. (2000) and Sajid et al. (2012) for onion who reported that humic acid applications led to significant increase in soil organic matter, thus improving plant growth, neck and plant height and crop production.

Leonardite applications increased number of tubers reported in the present study. Leonardite applications also increased both total tuber yield and marketable tuber yield as compared with control, and the best results for yield increase were obtained from 400 and 600 kg ha^{-1} (Table 3). As was mentioned before humic acid increase soil fertility, soil moisture and provides essential nutrients for better growth of plants and hence increase yield of the crops.

Table 4. Protein and vitamin C contents and specific gravity of leonardite applied potato cultivars.

	2008-2009					2009-2010					2-year average				
	Leonardite Doses (kg ha^{-1})														
Cultivars	0	200	400	600	Mean	0	200	400	600	Mean	0	200	400	600	Mean
	Protein Content (%)														
Van Gogh	1.89	2.01	2.14	2.16	2.05	1.90	2.03	2.21	2.20	2.09	1.90	2.02	2.18	2.18	2.07a
Milva	1.86	1.89	1.97	2.04	1.94	1.92	1.94	2.00	2.10	1.99	1.89	1.92	1.99	2.07	1.97c
Lady Olympia	2.00	2.03	2.10	2.14	2.07	1.97	2.10	2.14	2.15	2.09	1.99	2.07	2.12	2.15	2.08a
Agata	1.96	2.03	2.05	2.06	2.03	1.99	2.00	2.03	2.08	2.02	1.97	2.02	2.04	2.07	2.02b
Mean	1.93	1.99	2.07	2.10	**2.02**	1.95	2.02	2.10	2.14	**2.05**	1.94c	2.00b	2.08a	2.12a	
Lsd $_{cultivar\ x\ dose\ :\ 0.108}$															
	Vitamin C Content (mg100g fw^{-1})														
Van Gogh	13.3	13.5	13.8	15.8	14.1	12.9	13.0	13.3	13.9	13.3	13.1	13.3	13.5	14.8	13.7d
Milva	15.5	16.1	19.6	20.4	17.9	16.1	17.8	18.9	20.2	18.2	15.8	16.9	19.3	20.3	18.1c
Lady Olympia	18.2	18.7	20.5	19.4	19.2	18.0	19.5	20.0	20.8	19.6	18.1	19.1	20.3	20.1	19.4b
Agata	18.0	20.9	20.4	20.8	20.0	18.2	20.3	22.0	21.3	20.5	18.1	20.6	21.2	21.1	20.2a
Mean	16.2	17.3	18.6	19.1	**17.8**	16.3	17.7	18.6	19.1	**17.9**	16.3c	17.5b	18.6a	19.1a	
	Specific Gravity (g cm$^{3\ -1}$)														
Van Gogh	1.086	1.087	1.093	1.091	1.089	1.085	1.087	1.091	1.090	1.088	1.085	1.087	1.092	1.090	1.089b
Milva	1.077	1.082	1.081	1.080	1.080	1.079	1.081	1.081	1.082	1.081	1.078	1.081	1.081	1.081	1.080c
Lady Olympia	1.087	1.089	1.091	1.092	1.090	1.092	1.092	1.093	1.094	1.093	1.089	1.091	1.092	1.093	1.091a
Agata	1.077	1.078	1.078	1.077	1.078	1.076	1.078	1.078	1.078	1.078	1.077	1.078	1.078	1.078	1.078d
Mean	1.081	1.084	1.086	1.085	**1.084**	1.083	1.085	1.086	1.087	**1.085**	1.082b	1.084a	1.085a	1.085a	

Means followed by the same letters in rows and columns are not significantly different at $P < 0.05$ level

Mahmoud and Hafez (2010) reported that the vegetative growth parameters, yield, tuber size, weight, quality and nutritive value of potato tubers were significantly increased with increased levels of humic acid applications. Hopkins and Stark (2003) showed humic acid applications increased total and marketable yield of potato crop. It was also reported that humic acid application increased tuber yield, number of tubers and marketable tuber yield compared to standard fertilization as was observed in our study (Ezzat et al., 2009; Mahmoud and Hafez, 2010; Selim et al., 2009b). Seyedbagheri (2010) found increased leonardite doses significantly increased marketable tuber yield from 11.4% to 22.3%. Yield increase resulting from use of humic substances were also reported for other crops such as; cucumber (El-Shabrawy et al., 2010), maize (Ayuso et al., 1996), wheat (Delfine et al., 2005) and cabbage (Syabryai et al., 1965).

Protein content is an important quality parameter and depends on the amount of assimilated N by the plants (Selim et al., 2009a). Leonardite used in the study contained 1.8% N (Table 1). Leonardite also serves to increase available N, P and other plant nutrients, such as K; in the soil which in turn could be taken up by plants (David et al., 1994). The lowest rates for protein and vitamin C contents were found in control (Table 4). For both traits, the best results were obtained from 400 and 600 kg ha^{-1} leonardite applications. It was also noted that cultivars differed from each other for protein and vitamin C contents; such as, while Van Gogh had the highest level of protein, the same cultivar had the lowest level of vitamin C content (Table 4). Differences observed among cultivars for protein and Vitamin C contents may depend on genetic background of the cultivars. Potassium fertilization and humic acid applications affect concentration of vitamin C and amount of antioxidative compounds in solanaceous crops (Ünlü et al., 2010; Wuzhong, 2002).

Specific gravity depends on dry matter content of tubers affected by starch accumulation and could be used as a quality trait (Hassanpanah et al., 2011). Even though fertilization is necessary for high yield, it prolongs necessary time for tuber maturity and excessive fertilization could cause tubers to accumulate excess water. Water accumulation reduces dry matter content of tubers and in turn specific gravity and quality of tubers (Herman et al., 1960). In the present study, specific gravity was higher in tubers harvested from leonardite applied plots than the tubers harvested from control. Similarly, it was reported that N containing organic fertilizers increase dry matter contents of potato (Jarvan and Edesi, 2009) and maize kernels (Ouggiotti et al., 2004).

Based on the research findings and related discussion cited in this study it was concluded that leonardite applications increase number of tubers per plant (22%), marketable tuber yield (38%) and total tuber yield (15%). In addition, leonardite applications improve protein and vitamin C contents, and specific gravity of tubers which are important quality traits for both industrial and fresh market consumption. Differences between 400 and 600 kg ha^{-1} leonardite doses were insignificant for marketable and total tuber yield, protein and vitamin C contents, and specific gravity suggesting that 400 kg ha^{-1} leonardite application to standard fertilization would be sufficient to obtain good yield with high quality tubers.

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