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ORIGINAL ARTICLE

Effects of Sewage Sludge Amendment on Some Soil Properties, Growth, Yield and Nutrient Content of Raspberry (*Rubus idaeus* L.)

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Abstract This study was focused not only at the assessment of effects of different sewage sludge application rates on vegetative parameters and yield of raspberry (*Rubus ideaus* L.) but also heavy metal accumulation in the soil and raspberry leaves. A three-year field study was set up in a completely randomized block design with five sewage sludge application rates (0.0, 2.5, 5.0, 7.5 and 10.0 kg of dry matter per plant) and three replications. One-year-old, virus free 'Heritage' saplings were used for the experiment. The results of this study clearly indicated that the sewage sludge application is an effective mean for improvement of vegetative growth, yield, soil and plant chemical properties of raspberry in light textured soils. In addition to macro-element contents, sewage sludge application also caused significant changes in micro-element content of soils. No adverse effects of these increases were observed on plants throughout the experimental period. The most effective application rate was found as 7.5 kg per plant for this ecological condition. It can be concluded that when properly treated and applied to farmland sewage sludge is not only disposed economically but also improved vegetative growth and yield of raspberry.

Keywords Sewage sludge · Raspberry · Soil · Heavy metal · Vegetative growth · Yield

Auswirkungen von Klärschlamm als Zuschlagsstoff auf einzelne Bodeneigenschaften sowie Wachstum, Ertrag und Nährstoffgehalt bei Himbeeren (*Rubus idaeus* L.)

Schlüsselwörter Klärschlamm · Himbeere · Boden · Schwermetalle · Vegetatives Wachstum · Ertrag

Introduction

The *Rosaceae* is an economically important family of perennial fruit bearing crops such as *Prunus* sp. (stone fruits), *Pyrus* sp. (pear), *Fragaria* sp. (strawberry), *Malus* sp. (apple) and *Rubus* sp. (raspberry, blackberry). The red raspberry (*Rubus ideaus* L.) is a perennial woody shrub of temperate regions, and tolerant to many biotic and abiotic stresses, within *Rosaceae* species. Turkey is known as the ancestral home of raspberries (Kempler and Hall 2013). Despite its suitable ecological factors, raspberries are not widely grown in Turkey (Barut 2000). They mostly find in forest edges as native species. The production value of raspberry in Turkey is just 4,587 t in 2014 (TURCSTAT 2015). The main producing countries are Russia (143,000 t), Poland (121,040 t), United States (91,300 t), Serbia (68,458 t), and Mexico (30,411 t). These five countries, leading world raspberry producers, have 78.55% of the world total production of raspberry (FAOSTAT 2013).

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Table 1 Climatic parameters during the experimental period (2011–2013)

Months	Climatic parameters								
	Temperature (°C)			Relative Humidity (%)			Precipitation (mm)		
	2011	2012	2013	2011	2012	2013	2011	2012	2013
January	–8.4	–8.8	–9.5	81.2	83.6	83.0	23.4	6.7	28.7
February	–7.7	–14.6	–7.4	79.8	80.7	89.5	22.3	22.2	28.5
March	–1.5	–6.7	–0.8	75.0	78.2	75.9	17.1	8.4	30.9
April	5.6	7.2	7.2	72.1	66.7	64.4	147.7	37.2	36.3
May	9.6	11.4	11.6	69.5	68.0	63.5	105.2	73.0	36.3
June	14.6	15.7	15.0	63.4	58.1	57.2	55.3	7.0	32.3
July	19.6	19.0	19.4	53.3	52.3	50.4	26.6	19.8	25.1
August	19.4	20.0	19.5	48.2	49.6	45.7	21.8	22.8	7.8
September	13.9	15.0	13.6	53.8	48.4	49.8	7.5	11.0	13.6
October	6.7	9.4	6.0	62.0	68.6	59.6	23.1	41.7	16.8
November	–5.5	3.8	2.3	79.7	77.0	74.1	13.6	34.2	19.6
December	–11.4	–5.9	–13.4	82.5	86.3	78.6	9.2	29.4	8.3

Nowadays, there is an increasing demand for new plantation areas of raspberry in Turkey.

Raspberries grow best in loam-textured soils that are high in organic matter, well drained, and slightly acidic (Ljones 1966). Therefore, addition of organic matter is essential for sustainable agriculture of raspberry. Sources of organic matter vary based upon their origin, composition, and application rate and expected or claimed mode of action. While conventional agriculture relies on targeted short-term solutions to solve nutritional problems, longer-term solutions can be viewed as the thread that links the physical, chemical and biological properties of soil. In order to achieve sustainable growth, long-term solutions should be taken into account at the systems level. Long-term solutions are based on the improvement of soil fertility and crop productivity and require the use of stabilized or mature organic matter amendments for low input agricultural systems.

The production of large quantities of organic waste all over the world poses major environmental and disposal problems (Edwards and Bater 1992), however when properly treated and applied to farmland these materials are not only disposed economically but also negative effects on the environment can be reduced (Aslantas et al. 2010; Angin et al. 2012). Utilization of organic wastes as organic matter amendment has great potential for improving soil fertility and crop productivity through improvement of the physical, chemical and biological properties of the soil as well as nutrient supply (Adediran et al. 2003). The nutrient values of organic wastes are promoted as a benefit and it can reduce the need for chemical fertilizers. In 2014, the total chemical fertilizer use in Turkey was approximately 11 mio. tons (TURCSTAT 2015). However, wastes can rarely be applied directly to the soil (Atiyeh et al. 2000). Notwithstanding some beneficial characteristics, these materials may have an adverse impact on the environment, human health, and the quality of agricultural products. Therefore, some forms of treatments should be done to make them suitable for land application.

Sewage sludge is a concentrated suspension of solids, largely composed of organic matter, usually rich in mineral nutrients. It also contains trace elements that are essential for plant growth (Anonymous 1996). There is increased pressure to apply the sewage sludge to agricultural land due to environmental concerns associated with the disposal of these materials in landfills and the high volumes produced. The positive effect of sewage sludge on soil and plant has been reported by several studies (Angin and Yaganoglu 2012; Angin et al. 2012; Antoniadis et al. 2015, 2010, 2013; Bai et al. 2013; Cellier et al. 2014; Kolodziej et al. 2015; Koutroubas et al. 2014; Sampaio et al. 2012; Saruhan et al. 2015). However, sewage sludge contains heavy metals and soluble salts, which can create phytotoxic effects to plants (Hargreaves et al. 2008). Therefore, particular concern should be given to their potential risk for the environment and human health.

Information on the fertilizing value of sewage sludge on perennial fruits is relatively scarce. Much research is needed to provide data for determining the effects of sewage sludge on soil and vegetative parameters of perennial fruits. In this way, realistic regulations can be created. Therefore, the present study was focused not only at the assessment of effects of different sewage sludge application rates on vegetative parameters and yield of raspberry but also heavy metal accumulation in the soil and raspberry leaves.

Materials and Methods

This study was conducted in the years 2011–2013 at the Department of Horticulture of the Atatürk University, in the

Table 2 Initial characteristics of soil and of sewage sludge used in the study

Parameter and unit (in relation to dry matter)	Soil	Sewage Sludge
Texture		–
Clay (%)	8.5	
Silt (%)	21.8	
Sand (%)	69.7	
pH	7.94[a]	6.23[b]
EC (mS cm^{-1})	0.55[a]	1.23[b]
Lime (%)	3.44%	1.23
Organic matter (%)	1.54%	43.54
CEC (meq 100 gr soil^{-1})	18.65	–
Total N (mg kg^{-1})	9.43	34,300
Total P (mg kg^{-1})	5.67	9400
K[c]	1.88	15,764
Na[c]	0.95	2455
Ca[c]	12.33	45,634
Mg[c]	2.12	15,644
Fe (mg kg^{-1})	1.45[d]	11,023[e]
Cu (mg kg^{-1})	1.34[d]	2344[e]
Mn (mg kg^{-1})	3.36[d]	3912[e]
Zn (mg kg^{-1})	1.33[d]	2983[e]
Ni (mg kg^{-1})	0.75[d]	257.65[e]
Pb (mg kg^{-1})	0.100[d]	1453[e]
Cd (mg kg^{-1})	0.22[d]	65.47[e]
Hg (mg kg^{-1})	0.002[d]	2.33[e]
Salmonella (25 g)	–	Not found
Helmint egg (g)	–	Not found

CEC cation exchange capacity

[a]Determined in 1:2.5 (soil:water) extract

[b]Determined in in 1:10 (soil:water) extract

[c]meq 100 g soil^{-1} for soil and mg kg^{-1} for sewage sludge

[d]Extractable concentrations

[e]Total concentrations

Research and Experimental Orchard, in Erzurum, Turkey (39°55′ *N*, 41°61′ E). The region is situated in a zone of semi arid climate. The mean annual minimum and maximum temperature, relative humidity, and total precipitation throughout the years of 1990–2014 is –2.4 and 12.7 °C, 66.4%, and 391.6 mm, respectively. Climatic parameters during the experimental period are given in Table 1. Soils of the experimental site are alluvial of hydromorphic origin. The territory of the experimental area has only a slight slope (<2%), so no runoff was noticed during the study.

The experiment was set up in a completely randomized block design with five sewage sludge application rates and with three replications. One-year-old, virus free ‘Heritage’ saplings were used for the experiment. They were planted at 1.5 m × 2.5 m in August 2011. A single plant served as replication. To get a more uniform plant growth, shoots were decapitated at 35 cm above the ground. Weeds were controlled around the plants by repeated hoeing. No pesticide was applied during the study. Sewage sludge (SS), obtained from the Ankara Metropolitan Municipality, was applied in August 2011, at the rates of 0.0 (control), 2.5, 5.0, 7.5, and 10.0 kg of dry matter per plant. No sewage sludge was employed after that date. Sewage sludge was applied during the plantation to the apparent root extension area (70 cm in diameter), to the depth of 20 cm. Initial soil properties and characteristics of sewage sludge are presented in Table 2.

Particle size distribution was determined using the Bouyoucos hydrometer method (Gee and Or 2002); pH and electrical conductivity measurements were carried out according to Thomas (1996) and Rhoades (1996). Lime content of the soils and sewage sludge was determined with the ‘Scheibler Calcimeter’ (Loeppert and Suarez 1996). Soil organic matter was determined using the Smith-Weldon method; loss on ignition method was used to determine organic matter content of sewage sludge (Nelson and Sommers 1996). Total nitrogen content of soils and sewage sludge were determined in Kjeldahl digests according to Bremner and Mulvaney (1982). Total phosphorus is measured photometrically as described by Olsen and Sommers (1982). Ammonium acetate buffered at pH 7 (Rhoades 1996) was used to determine exchangeable cations. Cation exchange capacity (CEC) was determined with a flame photometer using sodium acetate-ammonium acetate buffered at pH 7 (Sumner and Miller 1996). Trace element contents of soils were determined in the DTPA extracts, according to Lindsay and Norwell (1978), using a Perkin-Elmer inductively coupled plasma optical emission spectrometer (ICP-OES). Concentrations of K, Na, Ca, Mg, Fe, Cu, Mn, Zn, Ni, Pb, Cd and Hg in sewage sludge were determined on a Perkin-Elmer inductively coupled plasma optical emission spectrometer (ICP-OES) unit using USEPA 3051A method (USEPA 1997). *Salmonella* and helmint eggs were detected according to the methods proposed in APHA (1989).

Leaf samples, taken on July 30, 2013 were dried for 48 h at 65 ± 5 °C and ground to pass 1 mm. The mineral nutrient and heavy metal contents of leaves were determined using HNO_3-$HClO_4$ acid mixture digestion (AOAC 1990). K, Ca, Mg, Na, Fe, Cu, Mn, Zn, Ni, Pb, Cd, and Hg were determined in the extracts obtained, by a Perkin-Elmer inductively coupled plasma optical emission spectrometer (ICP-OES). Phosphorus was determined spectrophotometrically by the indophenol-blue method at 660 nm. The Kjeldahl method was used to determine N content of leaves (Bremner and Mulvaney 1982).

Leaf area was measured with a CI-202 portable leaf area meter (CID Bio-Science, WA, USA) in fall of 2013. Shoot number (primocane), shoot length, and shoot thickness were determined for all plants in the fall of 2013. Since all of the fruits do not ripen at the same time, the harvest

Table 3 Effects of sewage sludge application on soil chemical properties

SS[a]	pH	EC mS cm^{-1}	Lime %	OM %	*N* mg kg^{-1}	*P* mg kg^{-1}	K	Na	Ca	Mg	CEC	Fe	Cu	Mn	Zn	Ni	Pb	Cd	Hg
							meq 100 gr soil^{-1}					mg kg^{-1}							
Control	7.85^{a}	0.63^{e}	3.39^{a}	1.48^{c}	7.70^{e}	6.14^{e}	1.90^{b}	0.92^{d}	12.37^{c}	2.20^{a}	18.23^{c}	1.69^{d}	1.40^{d}	3.73^{c}	1.44^{c}	0.74^{e}	0.122^{d}	0.33^{c}	0.007^{c}
2.5	7.83^{a}	0.81^{d}	3.33^{ab}	1.53^{b}	8.26^{d}	6.45^{d}	1.93^{b}	0.96^{c}	12.53^{b}	2.19^{a}	18.71^{ab}	1.77^{c}	1.49^{c}	3.85^{b}	1.51^{bc}	0.78^{d}	0.128^{d}	0.36^{bc}	0.008^{c}
5.0	7.76^{b}	0.93^{c}	3.38^{a}	1.56^{b}	9.17^{c}	7.18^{c}	1.98^{a}	1.00^{b}	12.65^{ab}	2.23^{a}	18.73^{ab}	1.93^{b}	1.51^{c}	3.92^{b}	1.54^{b}	0.84^{c}	0.147^{c}	0.37^{b}	0.010^{b}
7.5	7.73^{c}	1.02^{b}	3.27^{b}	1.65^{a}	11.2^{b}	7.73^{b}	1.90^{b}	1.09^{a}	12.69^{a}	2.06^{b}	18.66^{b}	1.93^{b}	1.74^{b}	4.04^{a}	1.62^{a}	0.92^{b}	0.155^{b}	0.42^{a}	0.011^{b}
10.0	7.70^{d}	1.16^{a}	3.25^{b}	1.67^{a}	12.43^{a}	8.20^{a}	1.93^{b}	1.10^{a}	12.39^{c}	1.94^{c}	18.81^{a}	2.09^{a}	1.91^{a}	4.09^{a}	1.65^{a}	0.98^{a}	0.163^{a}	0.42^{a}	0.013^{a}

EC electrical conductivity, *OM* organic matter, *CEC* cation exchange capacity, values followed by the same letter are not significantly different ($p \leq 0.05$)

[a] Application rates of sewage sludge (Control (0), 2.5, 5.0, 7.5 and 10.0 kg of dry matter per plant)

Table 4 Amount of trace elements incorporated into the soil by sewage sludge application (kg ha^{-1})[a]

Application rate (kg per plant)	Fe	Cu	Mn	Zn	Ni	Pb	Cd	Hg
2.5	73.50	15.63	26.08	19.89	1.72	9.69	0.44	0.02
5.0	146.99	31.26	52.17	39.78	3.44	19.38	0.87	0.03
7.5	220.49	46.89	78.25	59.67	5.15	29.06	1.31	0.05
10.0	293.98	62.51	104.33	79.56	6.87	38.75	1.75	0.06
Critical soil concentration[b]	–	144–360	–	240–720	48–144	48–720	2.4–12	1.2–12
USEPA (1995)	–	1500	–	2800	420	300	39	17

[a] Amount of elements incorporated into the soil were calculated considering 2667 plants per hectare (1.5 m × 2.5 m spacing)

[b] Critical soil concentration (kg ha^{-1}) is calculated from maximum allowable concentration (mg kg^{-1}) (Kabata-Pendias 2011) for a bulk density of 1200 kg m^{-3} and a depth of 0.20 m.

Table 5 Effects of sewage sludge application on mineral element concentration in raspberry leaves

SS[a]	*N* (%)	*P* (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)	Ni (ppm)	Pb (ppm)	Cd (ppm)	Hg (ppm)
Control	2.31^{e}	2924^{c}	17818^{d}	6581^{d}	4326^{d}	578^{d}	253^{c}	10.18^{c}	31.51^{c}	35.47^{ab}	3.41^{d}	0.41^{d}	1.44^{e}	0.002^{c}
2.5	2.44^{d}	3267^{b}	18296^{c}	6847^{c}	4541^{c}	625^{cd}	263^{c}	12.59^{b}	35.04^{bc}	35.97^{ab}	3.92^{c}	0.45^{cd}	1.59^{d}	0.002^{bc}
5.0	2.60^{c}	3518^{a}	19300^{b}	7445^{b}	4861^{b}	670^{c}	293^{b}	13.29^{b}	36.86^{ab}	37.68^{a}	4.41^{b}	0.49^{bc}	1.66^{c}	0.003^{bc}
7.5	2.76^{b}	3641^{a}	20154^{a}	7892^{a}	4610^{c}	757^{b}	313^{a}	15.12^{a}	41.09^{a}	34.27^{b}	4.55^{b}	0.52^{ab}	1.74^{b}	0.004^{b}
10.0	2.88^{a}	3597^{a}	18642^{c}	7341^{b}	5019^{a}	834^{a}	287^{b}	15.52^{a}	37.70^{ab}	37.71^{a}	5.41^{a}	0.55^{a}	1.92^{a}	0.006^{a}

[a] Application rates of sewage sludge (Control (0), 2.5, 5.0, 7.5 and 10.0 kg of dry matter per plant); values followed by the same letter are not significantly different ($p \leq 0.05$)

was done a number of times at frequent intervals in 2012 and 2013.

Analysis of variance (ANOVA) was performed using the SPSS Statistical Package v. 20.0 (IBM Corp., Armonk, NY, USA) with GLM. Duncan's HSD test was used for testing mean differences. Mean differences were considered significant if $p \leq 0.05$.

Results and Discussion

Effects of sewage sludge application on soil properties are presented in Table 3. In all application rates tested, sewage sludge application induced significant changes in soil chemical properties. Sewage sludge significantly decreased soil pH. This decrease could be related to pH value of sewage sludge (Table 2) and organic acids produced during the mineralization process (Veeresh et al. 2003; Angin et al. 2012). Sewage sludge application increased electrical conductivity (EC) of soils significantly. However, in all application rates tested soil salinity did not exceeded the critical value (<2 dS m^{-1}) (Abrol et al. 1988). Addition of sewage sludge to soil is expected to increase lime content of soil due to its composition. Whereas, sewage sludge application decreased lime content of soils significantly. Organic matter addition to soil considerably influences microbial oxidation to CO_2 (Kolář et al. 2007). When free CO_2 comes in contact with $CaCO_3$ with irrigation $Ca(HCO_3)_2$ forms and

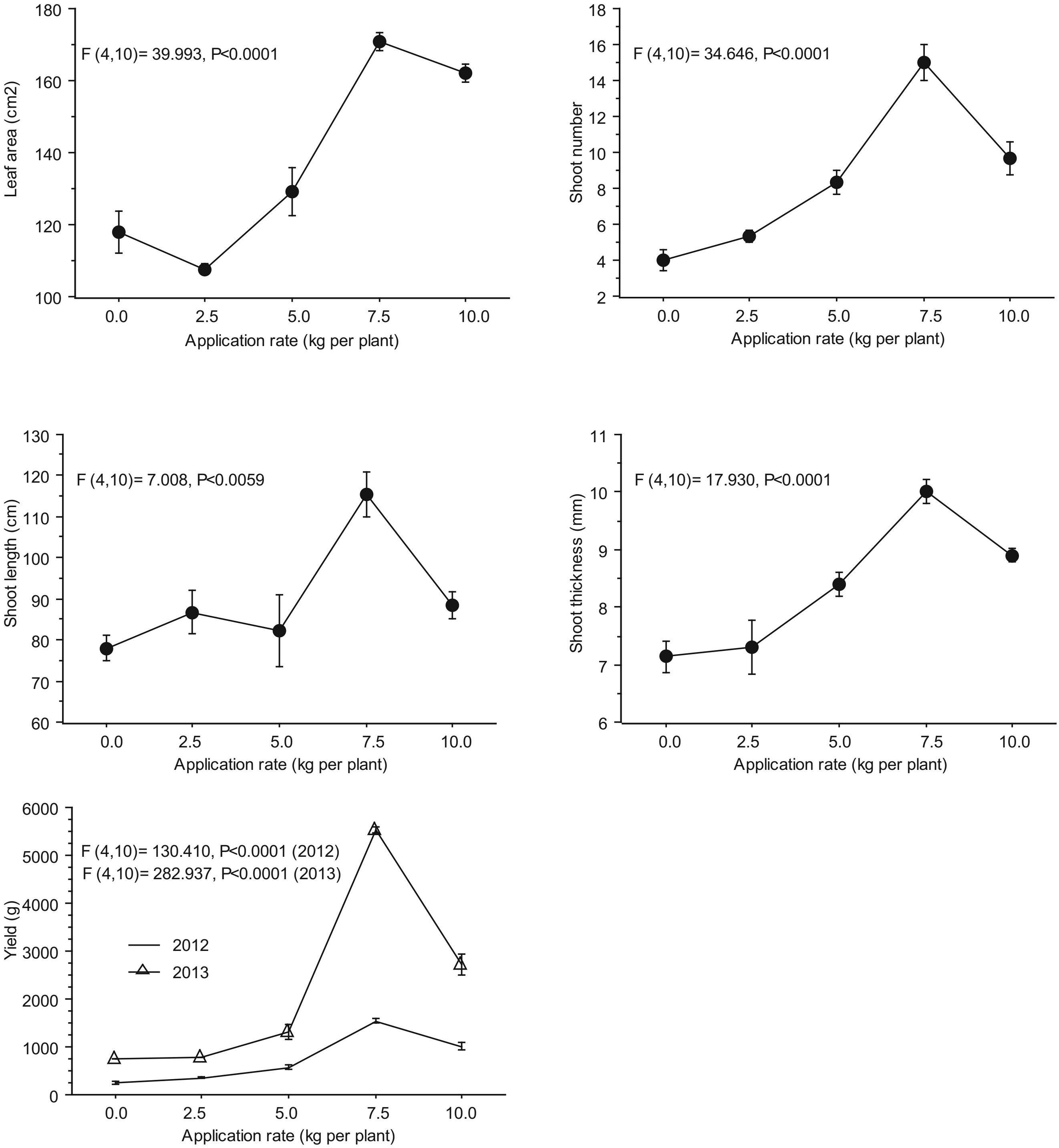

Fig. 1 Effects of sewage sludge application on vegetative parameters and yield of raspberry

it can be leached easily. Decrease in pH could also favor this leaching (McLean 1982). Organic matter, nitrogen and phosphorus contents of soil increased with increasing sewage sludge application rates (Table 3). Whereas the organic matter content of control was 1.48%, it increased to 1.53%, 1.56%, 1.65% and 1.67% with 2.5, 5.0, 7.5 and 10.0 kg of dry matter per plant application rates, respectively. These increases could be related to composition of sewage sludge (Table 2). Similar results were reported by Angin et al. (2012), Cellier et al. (2014), and Antoniadis et al. (2015). Cation exchange capacity (CEC) of soils increased with increasing sewage sludge application rates and was the highest at the rate of 10.0 kg per plant (Table 3). This tendency could be related to the high macro-element content of sewage sludge itself and to an increase of the adsorption surface due to organic matter content of sewage sludge (Table 2). Except Mg, macro-element contents of soils were increased with the increasing sewage sludge application rates (Table 3). While statistically significant increases were observed in macro-element contents of soils, these increases are not in comparable level for K and Ca. When compared with control the highest application rate of sewage sludge increased K, Na, and Ca content in the rates of 1.6, 20.0 and 0.2%, respectively. Increase in Na content is due to Na content of sewage sludge itself, which is relatively high. This finding is also closely related with electrical conductivity of soils. Increase in sewage sludge application rates increased Na, thus EC. Effects of sewage sludge application on Mg was not stable, there was no clear trend between the amount applied and the extent of response. In addition to macro-element contents, sewage sludge application also caused significant changes in micro-element content of soils. Increase in the application rate of sewage sludge increased micro-element content of soils, apparently due to its composition. No adverse effects of these increases were observed on plants throughout the experimental period.

Sewage sludge application increased the content of trace elements in the soil. However, increase in the content of these elements in the soil did not exceed the critical values reported by Kabata-Pendias (2011) and USEPA (1995) regulations. Amount of trace elements incorporated into the soil by sewage sludge application were much lower than critical values (Table 4).

In addition to soil chemical properties, sewage sludge application also caused significant changes in chemical properties of raspberry leaves (Table 5). Sewage sludge application significantly increased macro- and micro-element contents of leaves at all application rates, due to their increase in soil. The highest values were reached with the application of 7.5 and 10.0 kg per plant. Considering the ranges for nutrient levels in raspberry leaves, sewage sludge application healed nutrient content in all application rates (Anonymous 2015). There was clear trend between the amount applied and the extent of the response not only to chemical composition of leaves but also plant growth parameters.

The effects of sewage sludge application on vegetative growth and yield are presented in Fig. 1. In all application rates tested, sewage sludge induced significant changes in leaf area, shoot number (primocanes), shoot length, and shoot thickness. The highest values were obtained with the application of 7.5 kg per plant. Rate above this dose not only had negatively affected vegetative growth, but were also considered to increase costs associated with transportation and labor. Compared to the control, the application of sewage sludge at this rate increased the leaf area by 44.7%, shoot number by 275%, shoot length by 47.9%, and shoot thickness by 40.3%. Increase in vegetative growth can be due to mineralization of organic matter, which released enough nutritional elements to enhance plant growth (Angin and Yaganoglu 2012). Reduced effects of higher application rate on vegetative parameters might be due to the amount of salt, and metals incorporated into the soil by sewage sludge application, which could have affected the fertilizing capacity. Similar results were reported by Ribeiro et al. (1997) for pelargonium, Perez-Murcia et al. (2006) for broccoli, and Aslantas et al. (2013) for sour cherry. Increase in vegetative growth significantly increased yield of raspberry (Fig. 1). It increased yield quantity under all application rates. The increase in yield showed a parabolic curve. The highest values were obtained with the application of 7.5 kg per plant. Compared to control, sewage sludge increased yield in the rate of 39.8%, 119.1%, 501.2%, and 292.8% for 2012 and 3.4%, 73.3%, 636.9%, and 262.4% for 2013 for the application rates of 2.5, 5.0, 7.5 and 10.0 kg per plant, respectively. These data are in accord with the studied vegetative growth parameters. Crandall and Daubeny (1990), have stated that there is a strong correlation between vegetative growth parameters and yield of raspberry.

Conclusion

The results of this study clearly indicated that the sewage sludge application is an effective mean for improvement of vegetative growth, yield, soil and plant chemical properties of raspberry in light textured soils. The most effective application rate was found as 7.5 kg per plant. However, this situation depends on ecophysiological conditions and species. In order to minimize negative effects of sewage sludge to soil and plant, characteristics of sewage sludge should be taken into account, amount of heavy metals and soluble salts in particular. This study demonstrated that when properly treated and applied to farmland sewage sludge is not only disposed economically but also improved vegetative growth and yield of raspberry. Further studies should be conducted on the fertilizing value of sewage sludge on perennial fruits. It must be also assessed – for how many years does sewage sludge sustains its effect on vegetative growth and yield.

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