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The Effects of Sewage Sludge Applications on the Yield, Growth, Nutrition and Heavy Metal Accumulation in Apple Trees Growing in Dry Conditions

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Abstract: The effects of various sewage sludge (biosolid) rates and a single dose barnyard manure application on the fruit yield, growth, nutrition and heavy metal accumulation of apple trees were investigated. The experiment was conducted using a completely randomized design with 4 replicates in dry conditions in Van, in the East Anatolia region of Turkey in 2000 and 2001. Sewage sludge was added to the soil at the rates of 0, 10, 20, 40 and 60 kg tree^{-1}. Barnyard manure was applied to the soil at a rate of 25 kg tree^{-1}. Two years' data showed that the addition of sewage sludge to calcareous soil significantly increased fruit yield, cumulative yield efficiency, shoot growth and leaf N, Mg, Fe, Mn and Zn concentrations at the end of the study. These increases were generally lower with barnyard manure applications. The sewage sludge and manure applications did not cause any significant increase in tree trunk girth and P, K, Ca, Ni, Cr and Cd concentrations in leaf samples. Leaf Fe, Mn and Zn concentrations increased at the highest sludge rate from 88.0 to 105.3, from 44.2 to 75.5 and from 9.2 to 10.4 mg kg^{-1}, respectively. The 2-year results of this study demonstrated that sewage sludge applied to apple trees did not cause toxicity in the leaves. However, long-term sewage sludge application may result in the accumulation of some heavy metals in the soil and their entry into plants in quantities above the maximum permitted concentrations.

Key Words: Sewage sludge, apple, nutrient, heavy metal, yield, growth

Kuru Koşullarda Arıtma Çamuru Uygulamalarının Elma Ağaçlarının Verim, Büyüme, Beslenme Statüsü ve Ağır Metal Birikimine Etkileri

Özet: Bu araştırmada elma ağaçlarında meyve verimine, gelişimine, beslenme durumuna ve ağır metal birikimine arıtma çamuru ve ahır gübresi uygulamalarının etkisi incelenmiştir. Araştırma tesadüf parselleri deneme desenine göre 4 tekrarlamalı olarak 2000 ve 2001 yıllarında Van kuru koşullarında yürütülmüştür. Arıtma çamuru 0, 10, 20, 40 ve 60 kg kg/ağaç, ahır gübresi 25 kg/ağaç düzeyinde deneme toprağına uygulanmıştır. İki yıllık araştırma sonuçlarına göre, kireçli toprağa arıtma çamuru ilavesi meyve verimi, kümulatif verim etkinliği, sürgün gelişimi ve elma yapraklarının N, Mg, Fe, Mn ve Zn konsantrasyonlarını önemli düzeyde artırmıştır. Bu artışlar genel olarak, ahır gübresi uygulamasında daha düşük bulunmuştur. Arıtma çamuru ve ahır gübresi uygulamaları ağaç gövde gelişimi ve yaprak P, K, Ca, Ni, Cr, Cd konsantrasyonlarında istatistiksel olarak önemli bir değişikliğe neden olmamıştır. En yüksek arıtma çamuru dozunda yaprak Fe, Mn ve Zn konsantrasyonları sırasıyla 88.0'dan 105.3'e, 44.2'den 75.5'e ve 9.2'den 10.4 mg kg^{-1} düzeylerine ulaşmıştır. Bu sonuçlar denenen arıtma çamuru dozlarının elma ağaçlarında toksite oluşturmadığını göstermektedir. Buna karşılık, uzun dönem arıtma çamuru kullanılması bazı ağır metallerin toprakta birikimine ve maksimum izin verilen sınırların üzerinde bitkilerde bulunmasına neden olabilir.

Anahtar Sözcükler: Arıtma çamuru, elma, ağır metal, besin elementi, verim, büyüme

Introduction

The application of sewage sludge (biosolid) to agricultural land has become a common practice over the past several decades. This practice is inexpensive, logical and easy to carry out. Since sewage sludge contains plant nutrients and organic matter, it may be used to supplement or replace commercial fertilizers for crop production.

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The beneficial effects of using sludge on agriculture have been proven by numerous researchers. It has been shown that sewage sludge application improves the physical, chemical and biological properties of soil (Aggelides and Londra, 2000; Benitez et al., 2001; Selivanovskaya et al., 2001; White et al., 1997). Nutrients contained in sludge increase plant biomass and yield (Brofas et al., 2000; Cogger et al., 2001; Snyman et al., 1998). Reed et al. (1991) reported that sludge and nitrogen fertilizer applications as the source of applied N did not affect the grain and silage yield of corn, indicating that the fertilizer value of sludge was comparable to that of commercial fertilizers. Pedreno et al. (1996) found that tomato yield was clearly favored by sewage sludge fertilization and no that difference was observed from other organic fertilizer treatments.

Sewage sludge has been applied to apple trees by various researchers. Solov and Khamyakov (1989) reported that an application of up to 300 t ha^{-1} sewage sludge resulted in high biomass production in apple trees. Awad et al. (1995) stated that sewage sludge application significantly increased the growth of apple seedlings. The Pb and Ni contents of fruits and leaves were slightly increased and Hg and Cd remained almost unaffected. Pinamonti et al. (1997) tested sewage sludge compost in 14 apple orchards. The resulting data demonstrated that sewage sludge compost did not cause any significant increase in heavy metal levels in plants. Researchers found that sewage sludge can be used to fertilize the soil with no danger in the short/medium term either to the environment or to crops.

Sewage sludge application may lead to the accumulation of a number of potentially harmful components such as heavy metals in soil and crops. The presence of heavy metals in the applied sludge can result in phytotoxic effects, soil and water contamination and accumulation of heavy metal in food supplies (Keller et al., 2002; Yingming and Corey, 1993).

In Turkey, the application of sewage sludge to vegetable and fruit production has been limited by Ministry of the Environment regulations. After the analysis of sewage sludge and soil, permission to apply them must be obtained from the relevant officials (Resmi Gazete, 2001).

Accumulation and availability to plants of heavy metals in agricultural soils largely depend on the composition of the sludge, rate of sludge application, soil properties and crop species and cultivar. Increased Zn and Cu concentrations have often been observed in soil and plants with sludge applications (Barbarick et al., 1998; Nyamangara and Mzezewa, 1999; Reed et al., 1991) while only very slight variations in Cr, Pb, Ni, Cd, Hg and B concentrations have generally been registered (Barbarick et al., 1998; Selivanovskaya et al., 2001; Snyman et al., 1998).

In the long - term, the use of sewage sludge can also cause a significant accumulation of heavy metals in soil and plants. Sloan et al. (1997) stated that 15 years after sludge applications the relative bioavailability of sludge applied with heavy metals was Cd > Zn > Ni > Cu > Cr > Pb.

The solubility or bioavailability of heavy metals from sewage sludge is based on soil pH, lime content, soil cation change capacity and soil organic material. Liming is a common practice in agriculture to maintain optimal soil pH and has also been used to reduce the solubility of heavy metals. Research has been performed on the effect of lime addition to reduce heavy metal solubility (Basta and Sloan, 1999; Fang and Wong, 1999; Krebs et al., 1998; Little et al., 1991). Peles et al. (1998) found that Zn, Cu, Cd and Pb concentrations in various field plant species were significantly lower in plants collected from limed compared to unlimed sludge treated plots.

Agricultural land in Turkey, especially East Anatolia region soils, is generally rich in lime, and is low in organic matter and available P, Fe and Zn concentrations, and soil pH is alkaline. The mobility of heavy metals depends on soil pH and lime content; therefore, the physical and chemical properties of soil in the region can be improved by using sewage sludge which has sufficient organic matter, available P and micronutrients.

The apple is the most widely produced fruit in Van, with 4,553 t produced. Although there are a few intensively managed apple orchards in Van, fertilizers and other agricultural inputs are not sufficiently applied in most apple orchards. Apple yield per tree is below the Turkish average at approximately 30 kg (DİE, 2003).

The objective of the present study was to investigate the effects of sewage sludge application on the plant growth, nutrient and heavy metal concentrations of apple trees grown in calcareous soil. In addition, the effect of added sewage sludge was compared to that of barnyard manure and a metal-free control.

Materials and Methods

The experiment was conducted on an apple orchard in Van-Turkey, 1716 m above sea level, during 2000 and 2001. The average annual rainfall and temperature during the 2-year experimental period were 234.6 mm and 355.2 mm and 10.3 °C and 10.9 °C, respectively.

The sludge used in this experiment was obtained from the sewage sludge treatment plant of Yüzüncü Yıl University. Aerobically stabilized sewage was dried in holding pools. The experiment was conducted on 10-year-old trees belonging to the cultivar Starking Delicious. Intervals between plants in the apple orchard were 5 x 5 m. The properties of the research area soil can be summarized as: texture, clay loam; $CaCO_3$, 12.2%; total salt, 0.050%; available P, 15.3 mg kg^{-1}; exchangeable K, 573 mg kg^{-1}; exchangeable Ca, 4220 mg kg^{-1}; exchangeable Mg, 322 mg kg^{-1}; DTPA-extractable Fe, Mn, Zn and Cu, 2.7, 6.6, 0.68, 0.73 mg kg^{-1}, respectively. Details of the physicochemical properties of the soil, sewage sludge and barnyard manure used in this experiment are listed in Table 1.

In the soil of the experiment area, texture was determined using the hydrometer method (Bouyoucos, 1965). Soil pH was determined in a 1:2.5 soil water suspension (Jackson, 1958). Organic matter was analyzed colorimetrically using the modified Walkley Black method (Houba et al., 1989). Calcium carbonate was measured with a calcimeter. Available P was determined by the molybdenum blue method in a sodium bicarbonate extract (Olsen et al. 1954). Total N was analyzed by the Kjeldahl method. Fe, Mn, Zn and Cu were extracted using a solution (pH 7.3) containing 0.005 M diethylenetriaminepentaacetic acid (DTPA), 0.1 M triethanolamin (TEA) and 0.01 $CaCl_2$ with a 2 h shaking time (Lindasy and Norvell, 1978). The concentrations of these elements in the extracts were determined by atomic absorption spectrophotometer.

Table 1. Selected physicochemical properties of sewage sludge and barnyard manure.

Properties	Soil	Sewage sludge	Barnyard manure
pH (1:2.5 water)	8.56	6.11	
Organic matter, %	1.55	47,3	55.0
Dry matter, %		95.1	96.4
Total N, %	0.041	2.82	1.50
Total P, %	0.034	0.76	0.34
Total K, %	3.01	0.44	1.10
Total Ca, %	3.00	5.69	5.73
Total Mg, %	2.12	2.32	1.63
Total Fe, %	2.32	1.50	0.065
Total Mn, mg kg^{-1}	503	270	236
Total Zn, mg kg^{-1}	39	1807	69
Total Cu, mg kg^{-1}	24	271	38
Total Ni, mg kg^{-1}	29	64	56
Total Cd, mg kg^{-1}	0.26	2.1	0.41
Total Cr, mg kg^{-1}	51	99.4	34

In the experiment 5 sewage sludge treatments including a control and 1 barnyard manure application were replicated 4 times in a completely randomized design on a total of 24 trees. Sewage sludge was applied at rates of 0, 10, 20, 40 and 60 kg $tree^{-1}$ (equal to approximately 0, 12.5, 25.0, 50.0 and 75.0 Mg sludge ha^{-1}) after being air-dried. Barnyard manure was applied at a rate of 25 kg tree $^{-1}$ (equal to approximately 47.0 Mg manure ha-1). Sewage sludge and barnyard manure applications were performed in autumn in both years. Sewage sludge and manure were added to and mixed with the soil of the tree crown area at a depth of 0.20 m.

Tree girth and length and diameter of shoot were measured at the end of the vegetative growth season. The lengths and diameters of 10 shoots per tree were measured with a ruler and a compass. Tree girth measurements were done annually with tape measure. Trunk cross-sectional areas were calculated from girth measurements. Cumulative yield efficiency was then determined by using the trunk cross-sectional areas.

The experimental fruit was harvested on 3 October 2000 and 24 September 2001. The crop from each tree was weighed. Leaf samples were collected from the middle of the terminal shoots in late July. Approximately 40 leaves were collected from each tree. All samples were oven dried at 65 °C and ground in a stainless steel mill. Leaf samples were digested in a nitric-perchloric acid mixture. K, Ca, Mg, Fe, Mn, Zn, Cu, Ni, Cd and Cr contents in the extracts were determined using atomic absorbtion spectrophotometry. P was determined by vanado molybdate. The N content of leaf samples digested in concentrate sulfuric acid was determined by the Kjeldahl method (Kacar, 1984; İbrikçi et al., 1994).

Dry matter of sewage sludge and barnyard manure was determined at 105 °C for 24 h (Kocasoy, 1994). Total heavy metals in the soil, sludge and manure were determined by digestion in boiling aqua regia (Khan and Frankland, 1983).

Statistical analysis was performed by using the analysis of variance procedure for each harvest year. The means were compared using Duncan's multiple range test (Düzgüneş et al., 1987).

Results

Yield, Trunk Girth and Shoot Growth

Table 2 shows the changes in fruit yield, trunk girth increments and shoot growth with sludge application in both years. Sewage sludge addition significantly increased fruit yield in comparison to control and barnyard manure treated trees in both years. The highest fruit yield (17.16 kg tree^{-1}) was obtained with the highest sludge rate (60 kg tree^{-1}) in the second year.

Cumulative yield efficiency of apple trees treated with sewage sludge was significantly ($P < 0.05$) higher than that of the control and manure applied trees. The treatment of 60 kg sludge per tree exhibited a 105% increase in cumulative yield efficiency (Table 2).

Trunk girth increment rose from 2.89 to 3.86 cm due to sewage sludge effect. However, the effect of sludge applications on the increase in trunk girth was not statistically significant.

Sludge applications significantly increased shoot growth. At the end of the first year, sewage sludge application to apple trees increased the length and diameter of shoots more than the control and manure applications. Shoot length and diameter increased from 13.6 to 22.7 cm and from 0.29 to 0.36 cm with the highest sewage sludge application rate, respectively. This increase was lower with the barnyard manure application (Table 2). The addition of sludge also caused significant increases in shoot length in the second year of the study, but differences in shoot diameter were not statistically significant.

Nutrient and Heavy Metal Concentrations

The effect of sludge and barnyard manure applications on leaf N, P, K, Ca and Mg concentrations in apple trees are shown in Table 3. N, P, K and Ca contents of leaves were not influenced by sludge application to the soil at the end of the first year. The N concentration ranged from 2.08% to 2.44% with increasing sludge rates. However, this increase was not statistically significant. The application of 60 kg tree^{-1} of sewage sludge significantly increased the leaf Mg concentrations with respect to the control (Table 3).

At the end of the second year, sludge applications caused significant increases in leaf N and Mg concentrations. Manure application significantly increased leaf N concentrations with respect to the control. N and Mg concentrations increased from 2.01% to 2.60% and from 0.33% to 0.47% with the highest sewage sludge application rate, respectively. Sludge and manure applications did not significantly affect P, K and Ca concentrations in apple leaves.

Table 2. The effects of sewage sludge and manure applications on the fruit yield, cumulative yield efficiency shoot growth and trunk girth increment in apple trees in the study.

Sludge treatments kg tree^{-1}	2000 Yield kg tree^{-1}	2000 Shoot length cm	2000 Shoot diameter mm	2001 Yield kg tree^{-1}	2001 Cumulative yield efficiency kg/cm^2	2001 Shoot length cm	2001 Shoot diameter mm	2001 Girth increment cm
0	4.08 c	13.6 c	0.29 c	5.44 b	0.20 b	16.3 c	0.35	2.89
10	10.10 a	19.5 abc	0.31 bc	12.73 ab	0.30 ab	22.7 abc	0.34	2.92
20	6.20 bc	24.1 a	0.33 abc	6.64 b	0.25 b	27.4 ab	0.37	3.49
40	5.83 bc	25.6 a	0.34 ab	8.16 b	0.29 ab	26.0 ab	0.38	3.08
60	7.95 ab	22.7 ab	0.36 a	17.16 a	0.41 a	28.5 a	0.37	3.86
Manure treatment								
25	3.90 c	16.7 bc	0.31 bc	5.22 b	0.21 b	18.6 bc	0.36	3.20
F value	2.84*	4.62**	3.11*	2.98*	2.91*	3.14*	ns	ns

* $P < 0.05$; ** $P < 0.01$; ns: not significant; different letters indicate means significantly different (Duncan's multiple range test)

Table 3. The effects of sewage sludge and manure applications on leaf N, P, K, Ca and Mg concentrations in apple trees in 2000 and 2001.

Sludge treatments kg tree^{-1}	2000					2001				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
0	2.08	0.21	4.72	1.59	0.36 b	2.01 c	0.22	4.47	1.86	0.33 b
10	2.20	0.19	4.66	1.72	0.39 b	2.20 bc	0.22	4.68	2.00	0.36 b
20	2.36	0.18	4.64	1.57	0.38 b	2.22 bc	0.21	4.78	1.94	0.36 b
40	2.24	0.18	4.68	1.54	0.42 ab	2.59 a	0.21	4.58	2.00	0.44 a
60	2.44	0.18	4.61	1.82	0.47 a	2.60 a	0.21	4.47	2.10	0.47 a
Manure treatment										
25	2.35	0.20	4.73	1.56	0.37 b	2.36 ab	0.20	4.42	1.86	0.35 b
F value	ns	ns	ns	ns	2.80*	5.01**	ns	ns	ns	15.1***

* P < 0.05; ** P < 0.01; *** P < 0.001; ns: not significant; different letters indicate means significantly different (Duncan's multiple range test)

The effects of sewage sludge and barnyard manure applications on the leaf Fe, Mn, Zn and Cu concentrations in apple trees are presented in Table 4. Sewage sludge dosages caused significant increases in leaf Mn and Zn concentrations in the first year. Sludge applications did not statistically affect Fe and Cu.

Following the second year of application of the sewage sludge there was a significant increase in concentrations of Fe, Mn and Zn in the leaves. Sludge application did not change leaf Cu concentrations. Barnyard manure applications significantly increased leaf Mn concentrations in both years. Leaf Fe, Zn and Cu concentrations in apple trees treated with barnyard manure did not change.

Sewage sludge and barnyard manure applications did not significantly change leaf Ni, Cd and Cr concentrations in apple trees when compared with the control in both years (Table 5).

Diccussion

The sewage sludge used in this study was suitable for agricultural purposes in terms of the investigated heavy metal contents (Wallace and Wallace, 1994)

Fruit yield and cumulative yield efficiency of apple trees significantly increased with sludge addition in this study. This result may be attributed to the high organic matter and macro and micronutrient concentrations of

Table 4. The effects of sewage sludge and manure applications on leaf Fe, Mn, Zn and Cu concentrations in apple trees in 2000 and 2001.

Sludge treatments kg tree^{-1}	2000				2001			
	Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu
0	90.6	44.0 b	9.4 b	8.6	88.0 b	44.2 b	9.2 b	8.2
10	89.4	54.6 ab	9.6 b	8.8	102.4 a	47.5 b	9.3 b	8.6
20	85.2	56.6 ab	9.5 b	9.0	105.3 a	59.5 ab	9.3 b	7.9
40	84.3	57.1 ab	9.7 b	8.9	110.1 a	73.6 a	9.5 ab	7.4
60	88.5	64.2 a	10.9 a	8.8	105.3 a	75.5 a	10.4 a	8.3
Manure treatment								
25	88.6	65.7 a	9.2 b	8.5	95.1 ab	70.4 a	9.3 b	7.3
	ns	3.12*	3.54*	ns	3.06*	7.1***	3.07*	ns

* P < 0.05; *** P < 0.001; ns: not significant; different letters indicate means significantly different (Duncan's multiple range test)

Table 5. The effects of sewage sludge and manure applications on leaf Ni, Cd, Cr concentrations in apple trees in 2000 and 2001.

Sludge treatments kg tree^{-1}	2000			2001		
	Ni	Cd	Cr	Ni	Cd	Cr
0	2.8	0.16	0.36	2.6	0.17	0.41
10	2.8	0.17	0.36	2.6	0.15	0.42
20	2.6	0.17	0.36	2.7	0.15	0.39
40	2.7	0.15	0.36	2.6	0.17	0.38
60	2.7	0.17	0.40	2.6	0.15	0.39
Manure treatment						
25	2.8	0.16	0.40	2.5	0.15	0.41
F value	ns	ns	ns	ns	ns	ns

ns: not significant

applied sewage sludge. Sewage sludge applications increased yield in various plant species (Keller et al., 2002; Pedreno et al., 1996; Selivanovskaya et al. 2001). Solov and Khomyakov (1989) stated that the application of sewage sludge resulted in fairly high biomass production in young apple trees. Awad et al. (1995) found that the growth of apple seedlings was significantly increased by the application of dried sewage sludge .

Cumulative yield efficiency values in our study (0.20-0.41 kg/cm^2) were compatible with the values in the literature (Warmund, 2001; Chun et al., 2002). Chun et al. (2002) reported that cumulative yield efficiency values (0.12-0.76 kg/cm^2)in apples were not changed by the application of N + K fertilizers. However, we obtained less fruit yield than we expected compared to long-term apple yield capacity in Van. The low fruit yield of the apple trees included in our study may be due to the low rainfall during and before the experiment years. Moreover, irrigation could not be performed during the experiment.

Sewage sludge applications increased tree trunk girth, but this increase was not statistically significant. Rigueiro-Rodriguez et al. (2000) stated that the increase in the height and diameter of trunks growing in plots fertilized with sewage sludge was significantly higher than that of trees growing in control and inorganically fertilized plots. Sewage sludge and wastewater applications increased the shoot growth, as reported by Vasseur et al. (1998).

Sewage sludge application to apple trees increased leaf N and Mg contents, but did not increase P, K and Ca contents at the end of our study. The lack of any increase in leaf P concentrations could be attributed to the low P content of the sludge and to the low available P level in the soil because of the high pH and lime content of the experimental soil.

The treatments did not affect leaf K and Ca concentrations, probably because the experimental soil K and Ca contents were already high. Menelik et al. (1991) stated that sewage sludge increased the N, P and Mg concentrations of wheat grain.

At the end of the experiment, leaf Fe, Mn and Zn concentrations increased with sludge addition. Cu, Ni, Cr and Cd concentrations did not change significantly with treatment. While the N, P, Mg, Fe, Mn and Cu contents of apple leaves were sufficient, K and Ca contents were rich, but the Zn content was insufficient when we compared these values with predetermined limit values (Jones et al., 1991). This may be due to the fact that the soil in this apple orchard was rich in K and Ca but poor in Zn. Anaç et al. (1993) applied the sludge obtained from an oil processing plant to an olive grove at different rates. Researchers stated that sludge application resulted in no heavy metal toxicity and could be used after narrowing the C/N ratio. The results of some researches indicated that the Zn, Cu, Cd and Cr concentrations of plant tissues increased with sludge application (Frost et al., 2000; Pinamonti et al., 1997). However, in the present study metal concentrations were in the normal range and did not reach the phytotoxic levels reported by Lopez-Mosquera et al. (2000). This can be explained by the low heavy metal concentrations in the sludge and the high pH and lime content of the experimental soil. Peles et al. (1998) found that heavy metal concentrations (Cu, Zn, Cd and Pb) were significantly lower in plants collected from limed soils compared to unlimed soils treated with sludge.

Although the sewage sludge used in this study is suitable for agricultural use (Resmi Gazete, 2001), if it is applied in high amounts to soil over long periods, Zn and other heavy metals can reach a dangerous level for public health. Although the soil in Turkey and the Van region are generally calcareous and have a pH value above 7.0 and this is an advantage for preventing against the toxic effects of heavy metals, the heavy metal contents of soil and plants to which sewage sludge is applied have to be controlled.

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