*Original Research*

# The Use of Sewage Sludge as an Organic Matter Source in Apple Trees

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*Received: 11 June 2009*
*Accepted: 17 November 2009*

### Abstract

The objective of this experiment was to evaluate the effects of different doses of sludge on fruit yield, growth, nutrition and heavy metal accumulation of apple trees on a calcareous soil 1999-2003. Sewage sludge was added to the soil at rates of 0, 10, 20, 40 and 60 kg tree$^{-1}$. Manure was applied to the soil at a rate of 25 kg tree$^{-1}$. According to four-years data, cumulative application of sewage sludge to apple trees significantly increased fruit yield, trunk cross-sectional area, shoot growth and leaf N, Mg, Fe, Mn, Zn and Cu contents at the end of the study. Leaf Ni slightly increased with sludge addition in 2003 only. The four-year results of this study indicated that repeated sewage sludge application to apple trees did not cause toxicity in leaves and fruits. However, long-term sewage sludge application may result in the accumulation of Zn, Cu and Ni in the soil and plant.

**Keywords:** biosolid, fruit trees, heavy metal, fertilization

## Introduction

Fruit yield and its nutritional value are important considerations for apple producers. Optimum levels of soil organic matter have long been considered a necessity for agricultural crops and affect the physical, chemical and biological properties of the agricultural soils. In Turkey, the lack of soil organic matter is one of the major reasons for the low fertility and is critical for 90% of its agricultural land [1].

Apple growing has a special place among fruit production in the Van region and Turkey. Based on the number of trees and fruit production, the apple is the most important crop in Van, Turkey [2]. One of the major reasons for lower fertility in apple growing is the insufficient organic matter of the agriculture soils. Municipal sewage sludge (biosolid) can be used effectively as an organic fertilizer on agricultural soils. The high content of organic matter and the presence of nutrients of sewage sludge are a guarantee of agronomic advantages; at the same time, the use of sewage sludge makes the reuse of organic wastes possible and has numerous advantages.

Insufficient organic matter of agriculture soil is an especially serious problem in Mediterranean climate zones, including Turkey, where high temperatures during the summer promote high annual mineralization of organic matter [3]. Agricultural lands of Turkey, especially the Eastern Anatolian region soils, are generally rich in lime, with their low organic matter content. Therefore, these soils favor the application of sewage sludge as an organic amendment and nutrient supply to these soils with a relatively small risk of pollution [4, 5]. An increase in soil organic matter and nutrient availability after sewage sludge application has been observed by many researchers [6, 7].

The use of sewage sludge improves soil structure by enhancing aggregate stability, which results in improved water-holding capacity, aeration and reduction of erosion [8, 9]. Similarly, many papers have been published on the beneficial effects of sewage sludge amendment on the yield

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of various crops [10, 11]. At the same time, sewage sludge serves as a reservoir for nutrients such as N, P, K and Ca, as well as micronutrients like Fe, Mn, Zn and Cu, and can help stabilize soil pH [12].

Horticultural crop yields, including apple, have also been improved with sewage sludge application [13, 14]. Pinamonti et al. [15] tested sewage sludge compost in 14 different Malus domestica orchards. The resulting data demonstrated that sewage sludge could be used to fertilize the soil with no danger in the short/medium term either to the environment or to crops. Neilsen et al. [16] conducted a field experiment to assess the effects of municipal biosolid surface application on the nutrition of apple trees in the 8-year-period. Biosolid application often raised leaf Zn, Cu and Mn concentration but increases were modest, with concentrations of Zn insufficient to change standard commercial recommendations for annual dormant Zn applications.

The presence of organic and inorganic contaminants in sewage sludge may, however, constitute a danger to the environment. Heavy metal content is one of the major factors limiting the application of sewage sludge to agricultural lands. Heavy metals may be toxic to both plants and animals, including humans at high concentrations [17]. Crop uptake is one of the major routes of exposure of the food chain to heavy metals in sludge. Uptake varies with crop type, heavy metal, cumulative application rate, soil chemistry and sludge chemistry. Over the long term, the use of sewage sludge can also cause a significant accumulation of Zn, Cu, Ni, Cr and Cd in soil and plants [18].

How to reduce the availability of heavy metals is a major concern in land application of sewage sludge. Acidity, as measured by pH, is the primary soil parameter affecting heavy metal uptake by crops: heavy metal uptake increases with increasing acidity. However, the addition of lime may significantly reduce the solubility and bioavailability of heavy metals from sewage sludge. Thus, an increase in pH may also prevent the risks of soil and plant contamination by heavy metals [19]. Agricultural land in Turkey, especially Eastern Anatolia region soils (including that of Van Province), is generally rich in lime and soil pH ranges between 7.5-8.5. Therefore, the physical and chemical properties of soil in the region can be improved by using sewage sludge.

The data of the previous study on apple trees conducted by our research team [20] were used in this research and thus the 4-year cumulative effect of municipal sewage sludge was investigated. The purpose of this study was to determine the effects of sewage sludge applications on the growth and fruit yield of apple trees grown in calcareous soils of East Anatolia in Turkey. In addition, the availability of nutrients and heavy metals from added sewage sludge is compared to that of manure and a metal-free control.

## Materials and Methods

The experiment was conducted on an apple orchard in Van 1,716 m above sea level during 1999-2003. Rainfall and mean temperature in the area is around 380 mm and 8.8ºC.

Table 1. Mean analytical characteristics of soil, sewage sludge and manure used in the experiment (dry weight basis).

| Characteristic | Soil | Sewage sludge | Permitted values for sewage sludge | Manure |
|---|---|---|---|---|
| Texture | Clay loam | - | - | - |
| $CaCO_3$, % | 12.1 | - | - | - |
| EC mS $cm^{-1}$ | 0.873 | 3.87 | - | 3.61 |
| pH ($H_2O$) | 8.50 | 6.09 | - | 6.42 |
| Organic Matter, % | 1.40 | 45.9 | - | 54.6 |
| Total N, % | 0.054 | 2.48 | - | 1.43 |
| Total P, % | - | 0.75 | - | 0.31 |
| Total K, % | - | 0.43 | - | 1.32 |
| Olsen P, mg $kg^{-1}$ | 12.2 | - | - | - |
| Extractable K, mg $kg^{-1}$ | 590 | - | - | - |
| DTPA-Fe, mg $kg^{-1}$ | 3.0 | - | - | - |
| DTPA-Mn, mg $kg^{-1}$ | 9.4 | - | - | - |
| DTPA-Zn, mg $kg^{-1}$ | 0.65 | - | - | - |
| DTPA-Cu, mg $kg^{-1}$ | 0.90 | - | - | - |
| Total Fe, % | 2.57 | 1.42 | - | 0.077 |
| Total Mn, mg $kg^{-1}$ | 530 | 380 | - | 290 |
| Total Zn, mg $kg^{-1}$ | 46 | 1,500 | 4,000 | 67 |
| Total Cu, mg $kg^{-1}$ | 25 | 240 | 1,750 | 33 |
| Total Cd, mg $kg^{-1}$ | 0.21 | 1.80 | 40 | 0.44 |
| Total Cr, mg $kg^{-1}$ | 66 | 90 | 1,200 | 32 |
| Total Ni, mg $kg^{-1}$ | 42 | 80 | 400 | 45 |

The average annual rainfall and temperature during the 4-year experimental period (2000-03) were 235 mm, 355 mm, 416 mm, 430 mm and 10.3ºC, 10.9ºC, 9.6ºC and 10.5ºC, respectively.

The sludge (of human origin) used in this experiment was obtained from the sewage sludge treatment plant of Yüzüncü Yıl University. Aerobically stabilized sewage sludge was dried in holding pools. The experiment was conducted on 10-year-old trees belonging to the cultivar Starking Delicious. Rootstocks were apple seedlings. The interval between plants in the apple orchard were 5 × 5 m. As a mean of 4-years, the physicochemical properties of soil, sewage sludge and manure used in this experiment are listed in Table 1.

In the soil of the experiment area, texture was determined using the hydrometer method. Soil pH was determined in a 1:2.5 soil-water suspension. Organic matter was analyzed colorimetrically using the modified Walkley Black method. Calcium carbonate was measured with a calcimeter.

Table 2. The effects of different sewage sludge and manure applications on the fruit yield and trunk cross-sectional area increment.

| sludge treatment kg tree$^{-1}$ | fruit yield, kg tree$^{-1}$ | | | | Cumulative | | trunk cross-sectional area increment, cm$^2$ | | | cumulative increment, cm$^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | yield, kg tree$^{-1}$ | yield efficiency, kg cm$^{-2}$ | 2001 | 2002 | 2003 | |
| 0 | 4.1 c | 5.4 b | 15.6 b | 19.7 b | 44.8 b | 0.79 b | 7.29 | 4.28 b | 5.60 | 17.2 b |
| 10 | 10.1 a | 12.7ab | 39.2 a | 65.4 a | 127.5 a | 1.50 a | 7.76 | 10.0 a | 9.57 | 27.4 a |
| 20 | 6.2 bc | 6.6 b | 30.3 a | 64.3 a | 107.4 a | 1.38 a | 10.4 | 8.60 a | 8.55 | 27.5 a |
| 40 | 5.8 bc | 8.2 b | 32.4 a | 59.5 a | 105.9 a | 1.59 a | 7.95 | 9.56 a | 8.38 | 25.9 a |
| 60 | 8.0 ab | 17.2 a | 40.1 a | 60.7 a | 125.9 a | 1.55 a | 11.3 | 11.3 a | 7.27 | 29.9 a |
| manure 25 | 3.9 c | 5.2 b | 17.9 b | 28.6 b | 55.6 b | 0.93 b | 8.72 | 9.74 a | 6.74 | 25.2 a |
| prob. level | * | * | *** | *** | *** | ** | ns | * | ns | ** |

* $P<0.05$, ** $P<0.01$ and *** $P<0.001$. ns - not significant. Means followed by the same letter are not statistically different (Duncan test, $P<0.05$).

Available P was determined by the molybdenum blue method in a sodium bicarbonate extract. Extractable K was determined in 1 N ammonium acetate extract. Total N was analyzed by the Kjeldahl method. DTPA (diethylenetriaminepentaacetic acid)-extractable Fe, Mn, Zn and Cu were extracted using a solution (pH = 7.3) containing 0.005 M DTPA, 0.1 M TEA (triethanolamine) and 0.01 M $CaCl_2$ with a 2 h shaking time. The concentrations of these elements in the extracts were determined by the atomic absorption spectrophotometer.

In the experiment 5 sewage sludge treatments including a control and a manure application were replicated 4 times in a completely randomized design on a total of 24 trees. That is, there were four trees per treatment. A tree was accepted as a plot. 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$^{-1}$). Sewage sludge and manure applications were performed in autumn in all years. Sludge and manure were added to and mixed with the soil of the tree crown area at a depth of 0.20 m.

Length and diameter of shoots were measured at the end of the vegetative growth season. The length and diameters of 10 shoots per tree were measured with a ruler and compass. Trunk cross-sectional area was calculated from trunk diameter measurements made at 0.30 m height. Trunk diameter measurements were done annually with compass. Cumulative yield efficiency was then determined using the trunk cross-sectional areas.

The experimental fruit was generally harvested on late September or early October. 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 65ºC 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 an atomic absorption spectrophotometer. P was determined by vanado molybdate. The N content of leaf samples digested in concentrated sulfuric acid was determined by the Kjeldahl method [21, 22]. Total heavy metals in the soil, sludge and manure were determined by digestion in boiling aqua regia [23].

Statistical analysis was performed using the analysis of variance procedure for each harvest year. The means were compared using Duncan's multiple range test [24].

## Results

### Yield, Trunk and Shoot Growth

We compared the sewage sludge and manure applications in this experiment with respect to yield, growth, nutrient and heavy metal contents of apple trees. Organic matter contents of Turkish and district soils are generally low [1, 25]. In fruit growing, to increase organic matter of the soil, manure is added to the garden soil (if there is sufficient manure).

The effects of sewage sludge and manure applications on the yield and trunk cross-sectional area increments are presented in Table 2. Apple yields increased with an increase in sewage sludge amendments in relation to control and manure-treated trees in all years. The increase in the cumulative yield and yield efficiency of apple trees fertilized with sewage sludge was significantly higher than those trees growing by fertilized manure. Cumulative yield efficiency of apple trees increased significantly from 0.79 to 1.59 kg cm$^{-2}$ at 40 kg tree$^{-1}$ sludge rate in relation to the control, 4 years after the initial application.

Sewage sludge applications resulted in a slight increase in trunk cross-sectional area in relation to the control. However, there was a noticeable and statistically significant increase in the cumulative increment. Cumulative trunk cross sectional increment rose significantly from 17.2 to 29.9 cm$^2$ at the highest sewage sludge dose (Table 2).

Table 3. The effects of different sewage sludge and manure applications on the shoot growth of apple trees in 2000 and 2003.

| Sludge treatment, kg tree$^{-1}$ | Shoot Diameter (cm) | | | | Shoot length (cm) | | | | Cumulative shoot length, cm |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | 2000 | 2001 | 2002 | 2003 | |
| 0 | 0.29 c | 0.35 | 0.32 c | 0.31 c | 13.6 c | 16.3 c | 18.0 c | 17.3 c | 65.2 c |
| 10 | 0.31 bc | 0.34 | 0.39 b | 0.31 c | 19.5 abc | 22.7 abc | 29.5 b | 22.6 b | 94.3 b |
| 20 | 0.33 abc | 0.37 | 0.42 ab | 0.34 b | 24.1 a | 27.4 ab | 34.4 ab | 30.9 a | 116.8 a |
| 40 | 0.34 ab | 0.38 | 0.45 a | 0.37 a | 25.6 a | 26.0 a | 36.8 ab | 34.8 a | 123.2 a |
| 60 | 0.36 a | 0.37 | 0.47 a | 0.37 a | 22.7 ab | 28.5 a | 40.5 a | 34.0 a | 125.7 a |
| manure 25 | 0.31 bc | 0.36 | 0.43 ab | 0.35 ab | 16.7 bc | 18.6 bc | 35.5 ab | 33.3 a | 104.1 ab |
| prob. level | * | ns | *** | *** | ** | * | ** | *** | *** |

* $P<0.05$, ** $P<0.01$ and *** $P<0.001$. ns - not significant. Means followed by the same letter are not statistically different (Duncan test, $P<0.05$).

Table 4. The effects of different sewage sludge and manure applications on the nitrogen and phosphorus contents (%) of apple leaves and fruits in 2000-03.

| Sludge treatment, kg tree$^{-1}$ | Leaf N | | | | Fruit N | Leaf P | | | | Fruit P |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | 2003 | 2000 | 2001 | 2002 | 2003 | 2003 |
| 0 | 2.08 | 2.01 c | 1.96 c | 1.98 b | 0.27 | 0.21 | 0.22 | 0.21 | 0.22 | 0.052 |
| 10 | 2.20 | 2.20 bc | 2.27 b | 2.33 a | 0.27 | 0.19 | 0.22 | 0.22 | 0.25 | 0.047 |
| 20 | 2.36 | 2.22 bc | 2.39 b | 2.43 a | 0.28 | 0.18 | 0.21 | 0.22 | 0.26 | 0.057 |
| 40 | 2.24 | 2.59 a | 2.45 ab | 2.48 a | 0.27 | 0.18 | 0.21 | 0.21 | 0.23 | 0.049 |
| 60 | 2.44 | 2.60 a | 2.62 a | 2.54 a | 0.30 | 0.18 | 0.21 | 0.21 | 0.25 | 0.048 |
| manure 25 | 2.35 | 2.36 ab | 2.27 b | 2.27 a | 0.27 | 0.20 | 0.20 | 0.22 | 0.24 | 0.050 |
| prob. level | ns | ** | *** | ** | ns | ns | ns | ns | ns | ns |

** $P<0.01$ and *** $P<0.001$. ns - not significant. Means followed by the same letter are not statistically different (Duncan test, $P<0.05$).

Sludge applications significantly increased shoot diameter and lengths in all years. However, the effect of sludge applications on the increase in shoot diameter was not statistically significant in 2001 only. At the end of four years, sewage sludge application to apple trees increased cumulative shoot length more than the control, and even more than that of manure applications. Cumulative shoot length increased from 65.2 cm to 125.7 cm with the highest sewage sludge rate, in relation to the control. The increases on shoot growth were more marked particularly in 2002 and 2003 with sludge applications (Table 3).

## Leaf and Fruit Nutrient and Heavy Metal Contents

Sewage sludge and manure applications to apple trees lead to significant increases in leaf N content at 2001, 2002 and 2003 (Table 4). These increases were lower generally with the manure application. In contrast, the effect of sludge applications on the increase in leaf N in the first year of the study and fruit N contents were not statistically significant. Leaf N content increased from 1.96% to 2.62% by 60 kg tree$^{-1}$ of sewage sludge application in 2002.

The applications of sewage sludge and manure lead to no significant variation of the P content in apple leaves and fruits.

The contents of K and Ca in apple leaf were unaffected by the application of sewage sludge and manure in all years. There was, however, a noticeable and statistically significant increase in fruit Ca content with respect to control.

Sludge applications caused significant increases in leaf and fruit Mg contents in all years. Leaf and fruit Mg contents increased from 0.39% to 0.72% and from 0.20% to 0.29% with the highest sewage sludge application rate, respectively, in 2003 (Table 5).

In 2001 and 2003, sludge applications significantly increased leaf Fe content in relation to the control. But sludge and manure applications did not affect leaf Fe contents in 2000 and 2002.

Table 5. The effects of different sewage sludge and manure applications on the magnesium (%) and iron contents (mg kg$^{-1}$) of apple leaves and fruits in 2000-03.

| sludge treatment, kg tree$^{-1}$ | Leaf Mg | | | | Fruit Mg | Leaf Fe | | | | Fruit Fe |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | 2003 | 2000 | 2001 | 2002 | 2003 | 2003 |
| 0 | 0.36 b | 0.33 b | 0.46 b | 0.39 d | 0.20 c | 91 | 88 b | 117 | 133 c | 13.8 |
| 10 | 0.39 b | 0.36 b | 0.50 b | 0.43 cd | 0.21 c | 89 | 102 a | 126 | 138 bc | 13.9 |
| 20 | 0.38 b | 0.36 b | 0.54 b | 0.49 c | 0.24 bc | 85 | 105 a | 129 | 158 a | 13.3 |
| 40 | 0.42ab | 0.44 a | 0.58 b | 0.62 b | 0.33 a | 84 | 110 a | 125 | 152 ab | 12.9 |
| 60 | 0.47 a | 0.47 a | 0.74 a | 0.72 a | 0.29 ab | 89 | 105 a | 125 | 155 a | 12.6 |
| manure 25 | 0.37 b | 0.35 b | 0.53 b | 0.49 c | 0.23 bc | 89 | 95 ab | 117 | 158 a | 13.1 |
| prob. level | * | *** | *** | *** | ** | ns | * | ns | ** | ns |

* $P<0.05$, ** $P<0.01$ and *** $P<0.001$. ns - not significant. Means followed by the same letter are not statistically different (Duncan test, $P<0.05$).

Table 6. The effects of different sewage sludge and manure applications on the manganese and zinc contents (mg kg$^{-1}$) of apple leaves and fruits in 2000-03.

| sludge treatment, kg tree$^{-1}$ | Leaf Mn | | | | Fruit Mn | Leaf Zn | | | | Fruit Zn |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | 2003 | 2000 | 2001 | 2002 | 2003 | 2003 |
| 0 | 44 b | 44 b | 50 c | 52 b | 2.52 | 9.4 b | 9.2 b | 7.3 c | 8.8 c | 1.58 |
| 10 | 55 ab | 48 b | 62 ab | 60 b | 2.52 | 9.6 b | 9.3 b | 12.2 a | 11.8 b | 1.60 |
| 20 | 57 ab | 60 ab | 58 bc | 56 b | 2.46 | 9.5 b | 9.3 b | 12.3 a | 13.5 ab | 1.39 |
| 40 | 57 ab | 74 a | 65 ab | 67 ab | 2.70 | 9.7 b | 9.5 ab | 11.9 a | 13.8 ab | 1.45 |
| 60 | 64 a | 76 a | 72 a | 78 a | 2.61 | 10.9 a | 10.4 a | 12.5 a | 16.1 a | 1.44 |
| manure 25 | 66 a | 70 a | 64 ab | 66 ab | 2.58 | 9.2 b | 9.3 b | 9.0 b | 11.7 b | 1.43 |
| Prob. level | * | *** | ** | * | ns | * | * | *** | *** | ns |

Toxic level for Zn: 100-400 mg kg$^{-1}$.
* $P<0.05$, ** $P<0.01$ and *** $P<0.001$. ns - not significant. Means followed by the same letter are not statistically different (Duncan test, $P<0.05$).

The effects of sewage sludge and manure applications on the leaf and fruit Mn and Zn contents in apple trees are presented in Table 6. Sludge applications caused significant increases in leaf Mn and Zn contents in all experiment years. Moreover, for leaf Zn, the percentage difference in relation to the control was greater in 2002 and 2003 than that of 2000 and 2001. For example, the treatment of 60 kg sludge per tree showed a 71% and 83% increase in leaf Zn content in comparison to control in 2002 and 2003. The addition of manure also caused significant increases in leaf Zn contents in relation to the control in the third and fourth years of the study. In contrast, sludge and manure doses had no significant effect in the fruit Mn and Zn content.

Leaf Cu content was not influenced by sludge application to the soil in the 2000 and 2001. The use of sewage sludge, however, significantly increased the Cu content both in 2002 and 2003 (Table 7). Manure application leads to no significant variation of the Cu content in apple leaves and fruits.

Generally, sewage sludge addition did not increase Ni contents of leaves and fruit in comparison to control and manure-treated trees. However, the treatment of 40 kg sludge per tree resulted in a significant increase in leaf Ni in 2003 only. The applications of sewage sludge and manure did not significantly change Cd and Cr contents in the leaves and fruits in comparison to control in all years.

## Discussion

The investigated heavy metal contents of sewage sludge used in this study were always under limits established under Turkish law, applied to alkaline soils. Zinc was the element with the highest proportion with respect to the limit indicated by law as dangerous, but was only 38% of the total recommendation, followed by nickel (20%) and copper (14%). The other elements were always under 8% of the total limit [26].

Table 7. The effects of different sewage sludge and manure applications on the copper and nickel contents (mg $kg^{-1}$) of apple leaves and fruits in 2000-03.

| Sludge treatment, kg $tree^{-1}$ | Leaf Cu | | | | Fruit Cu | Leaf Ni | | | | Fruit Ni |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | 2003 | 2000 | 2001 | 2002 | 2003 | 2003 |
| 0 | 8.6 | 8.2 | 7.5 b | 6.8 c | 1.00 | 2.80 | 2.58 | 1.89 | 2.08 b | 0.38 |
| 10 | 8.8 | 8.6 | 7.8 b | 6.3 c | 0.96 | 2.80 | 2.63 | 1.78 | 2.06 b | 0.37 |
| 20 | 9.0 | 7.9 | 8.6 ab | 7.4 bc | 1.13 | 2.60 | 2.68 | 1.83 | 2.12 b | 0.35 |
| 40 | 8.9 | 7.4 | 8.4 ab | 8.3 ab | 1.04 | 2.70 | 2.60 | 2.14 | 2.96 a | 0.36 |
| 60 | 8.8 | 8.3 | 9.1 a | 8.7 a | 0.94 | 2.73 | 2.58 | 2.26 | 2.31 ab | 0.35 |
| manure 25 | 8.5 | 7.3 | 7.6 b | 7.1 c | 0.95 | 2.80 | 2.54 | 1.85 | 1.91 b | 0.37 |
| prob. level | ns | ns | * | ** | ns | ns | ns | ns | * | ns |

Toxic levels for Cu and Ni: 20-100 and 10-100 mg $kg^{-1}$, respectively.
* $P<0.05$ and ** $P<0.01$ and. ns - not significant. Means followed by the same letter are not statistically different (Duncan test, $P<0.05$).

Our data showed that the cumulative applications of sludge over a 4-year period had a significant impact on fruit yield and yield efficiency of apple trees at the end of the experiment period. Long-term sludge application improves physical and chemical properties of soils and plant growth due to the addition of organic matter [11]. Similarly, Garcia et al. [27] has also demonstrated that the annual addition of organic amendments, such as sewage sludge, improved fertility of degraded soils of Mediterranean climate zones due to positive effects on various soil properties. The positive effect of repeated sewage sludge applications on the cumulative trunk cross-sectional area increment and shoot growth during four consecutive years was particularly striking. In the case of sludge treatment, mineralization of added organic matter released enough nutrients to enhance growth of plants in the following year [3]. The increase in the fruit yield, trunk and shoot growth of apple trees growing with sewage sludge was generally higher than those trees growing by manure. The increase in trunk increment and shoot growth can be attributed to the high organic matter and macro and micro nutrient content of applied sewage sludge [28, 29]. According to Awad et al. [30] apple seedlings were significantly stimulated by the application of dried sewage sludge. Chun et al. [31] reported that yield efficiency values of apple trees were not affected by the application of nitrogen and potassium fertilizers.

With respect to leaf nutrient contents, cumulative sewage sludge application increased leaf N, Mg, Fe, Mn, Zn and Cu contents of apple trees. However, there was no generally significant increase in fruit nutrients contents following sewage sludge amendment. The increase on fruit nutrient content was observed only for Ca and Mg, with an increase in sludge amendment rate. This indicates that the application of sewage sludge provided a good source of nutrients for plant growth without toxicity [32]. Furthermore, regular annual applications of sludge have a cumulative effect on residual N and other nutrients [3]. One of the important soil characteristics of Eastern Anatolia, Turkey, is the low levels of organic matter, N, P, Fe and Zn [1, 25]. Generally, in all experiment years, the level of N, Fe and Zn improved with sewage sludge addition.

At the end of the experiment period, leaf and fruit Ni, Cd and Cr contents did not change significantly with sludge addition except for leaf Ni in 2003. Cumulative sewage sludge application increased leaf Fe, Mn, Zn Cu and Ni contents with the increases of Zn being especially significant. However, the existence of a notable translocation of these metals from the vegetative to reproductive organs has not been observed. Although Zn and Cu seemed to be the most mobile elements [6, 7], in our work their values were always fairly lower than the upper critical amounts established for apple [33]. Leaf Zn content increased from 8.8 mg $kg^{-1}$ to 16.1 mg $kg^{-1}$ in 2003. That is, even in the highest sludge application, the leaf Zn level was at the deficiency point.

In the other experiment conducted with the same soil conditions, soil pH of topsoil decreased from 8.6 to 7.8 with sewage sludge addition. Total N, available P, extractable Fe, Mn, Cu, Ni and Zn concentrations of soil significantly increased. But sewage sludge applications did not increase soil Cd and Cr concentrations [4].

The alkaline pH and high lime of experiment soil could have led to strong adsorption of these heavy metals, decreasing their solubilization, leaching and availability to plant and favoring their accumulation in cultivated sites as reported by others [3, 34]. This shows that sewage sludge could be used without causing toxicity in plants in order to prevent the micronutrient deficiency in apple growing. On the other hand, some authors reported that sludge application to soil increased Zn, Cu, Ni and Cd contents of plant tissue [35, 36].

## Conclusions

The results of this study indicate that cumulative sewage sludge application produced an increase of fruit yield and growth on apple trees. Sludge application also caused significant increases in leaf N, Mg, Fe, Mn, Zn and Cu contents.

These increases were generally lower with manure in all experiment years. Repeated application of sewage sludge did not lead to any variation in the leaf and fruit contents of the Ni, Cd and Cr, with the exception of leaf Ni in 2003. Moreover, no symptoms of the phytotoxicity by metals were observed in the experiment. Continued sewage sludge use in the soils of Eastern Anatolia Region, Turkey, may be an attractive option without risk, due to the high pH and lime content of the region soils and lower plant uptake of heavy metal. Sewage sludge, therefore, can be considered as a suitable alternative to manures for fruit growing. However, there was a significant increase of leaf Zn, Cu and Ni contents that should be taken into consideration if long-term applications of sludge are proposed.

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