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Reactions of Apple Tree and its Fruit to Compost Use in Central Anatolia, Turkey

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ABSRACT

Many soils in Turkish apple orchards are low in organic matter and nutrients, resulting in poor soil structure and Zn and Fe deficiencies in the fruit trees. Adding municipal waste compost, albeit with some heavy metal content, may improve soil structure and nutrient levels. This study investigated whether the use of municipal waste compost, with or without a chemical fertilizer, in an apple orchard in semi-arid Central Anatolia, Turkey, would improve soil fertility, yields and fruit quality without causing adverse heavy metal accumulations in the soil, leaves or fruit. In a 3-year period (2006-2008), three compost doses and three chemical fertilizer doses were applied annually as treatments in a randomized plots experimental design with five replicates; each plot contained 1 tree. Leaf and soil samples were collected each year at the end of July; soil was sampled from depths of 0-30 cm and 30-60 cm within the area of the tree canopy projections. Fruit was sampled at the end of September. The soil, leaf and fruit samples were analyzed for nutrients and heavy metals, and fruit yields and yield components were determined. Compost application increased electrical conductivity values and contents of organic matter, available nutrients, and heavy metals in the soil, as well as the contents of nutrients and heavy metals in the leaves and fruit; however, heavy metal contents of soil and plant were within safe limits. Moreover, compost use enhanced fruit yield and quality, and could reduce the need for chemical fertilizers by as much as 50%. Longer-term studies or monitoring are recommended in order to safeguard human health and the environment.

1. Introduction

Poor soil structural and micro-nutrients deficiencies are widespread in orchards in Turkey due to alkaline soils that have high clay and lime contents as well as low organic matter contents. This situation negatively affects the growth of fruit trees, which is detrimental to the yield and the quality of the fruit. The use of composts as a source of organic matter and nutrients is a potential solution to these problems.

Fruit trees generally grow better in deep permeable and well-drained clay-loam soils with a pH of 6.5-7.5, which are not saline and have high organic matter and low lime contents (Zengin et al 2008a;b). However, numerous studies carried out in Turkish orchards have generally reported that the soils were slightly alkaline to alkaline, high to very high in lime, poor to very poor in organic matter, and were impermeable due to poor structure and heavy textures (clay-loamy, silty-clay and clay). Such soils have been reported in the apple orchards in the Region of Central Anatolia (Türkoğlu et al 1974), the Provinces of Tokat and Amasya (Ateşalp & Işık 1978), the Districts of Korkuteli and Elmalı in Antalya (Sönmez & Kaplan 2000), around Van (Bozkurt et al 2000) and in Karaman Province (Zengin et al 2008a;b), in the cherry orchards of the Districts of Uluborlu and Senirkent in Isparta (Köseoğlu 1995), and in the peach orchards around Bursa (Katkat et al 1994). Such problems are not confined to Turkey since such soils have also been reported in other Mediterranean Basin countries, for example in the citrus orchards of Sicily (Canali et al 2002). No ideal orchard soils have micronutrient deficiencies, mainly of Fe and Zn, are common in Turkish orchards, depending on the general soil properties. In addition, there are problems in N, P, K, Ca, Mg and S uptake by the trees, depending on fertilizations

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and the soil properties. Consequently, these soil problems adversely affect the growth of the fruit, its yield and quality, in Turkish orchards. For example, chlorosis due to Fe deficiency alone was reported to reduce apple yields by up to 35% in the Central Anatolia Region about 35 years ago (Türkoğlu et al 1974). This problem has yet to be resolved by improving the soil, mostly by increasing organic matter and changing the soil chemistry.

The use of compost could be the solution for improving of many Turkish orchard soils that will in turn result in increased fruit quality and yield. Municipal solid organic waste is a source of suitable compost. This is because such composts, although varied, contain high levels of organic matter and both macro- and micro-nutrients. For example, contents of 40%-60% organic matter, 1%-2% N, 0.2%-0.4% P, 0.5%-1.2% K, 4%-10% Ca, 0.2%-0.6% Mg, 0.5%-2% S and Fe, 100-600 mg kg^{-1} Zn, 100-500 mg kg^{-1} Mn, 100-400 mg kg^{-1} Cu and 50-100 mg kg^{-1} B can be found (Zengin et al 2010). Treating organic solid waste as a resource avoids incurring the costs of disposing of it by burying it in city dumps or by burning it, while instead producing compost that has value to, and can be of use in, agriculture lands as a source of organic matter and nutrients (Stratton et al 1995). Composts obtained from municipal organic solid wastes and applied to agricultural soils have been shown to increase the growth, yield and quality of cultivated plants by positively affecting soil physical properties such as aggregation, the water-air balance and temperature (Movahedi Naeini & Cook, 2000). Soil chemical properties, such as the buffering capacity and the amount of available nutrients, were improved (Zinati et al 2004) and the microbial population and activity within the soil also benefitted (Montemurro et al 2005) from the use of this material.

Although using municipal organic waste has positive effects, there are also some disadvantages. An important factor limiting its use in agriculture is its heavy metal content. Composts produced from municipal organic solid wastes have been shown to contain total heavy metal of 0.5%-1% Al, 50-150 mg kg^{-1} Pb, 8 mg kg^{-1} As, 0.5-3 mg kg^{-1} Cd, 40-100 mg kg^{-1} Ni, 75-100 mg kg^{-1} Cr and 0.5-1.5 mg kg^{-1} Hg in dry matter (Zengin et al 2010). Limitations for the use of the compost not only depend on its heavy metal contents but also on the type and quality of the soil to which it is applied and the plant species that will be grown on it (Paris & Lucianer 1986). Use of these composts have generally increased the Zn, Cu and Pb contents in both the soil and the plants, but Cd, Ni and Cr also typically decreased but to a lesser degree (Businelli & Gigliotti 1994). The cumulative results of a research in Europe shows that the use of these composts resulted in heavy metal accumulations in the soil in the order: Zn > Cu > Pb = Cd > Ni > Cr (Petruzelli et al 1991). To avoid or reduce these problems, it is necessary to use organic materials that do not contain heavy metals when composting. When composts were produced from such materials, heavy metal accumulations were not observed in either the soil or the plants (Petruzelli et al 1991).

The purpose of this research was to determine and compare the effects of applying organic municipal compost, which did contain heavy metals, and chemical fertilizers commonly used by local farmers on some chemical properties of the soil, leaves and fruit in an apple orchard in Turkey. In addition, the study determined whether chemical fertilizer use could be decreased by the use of compost in the orchard as well as the most suitable compost dose for the apple trees. The study also investigated some heavy metal accumulations in the soil and the leaves and the fruit of the apple trees.

2. Materials and Methods

Field experiments were carried out in an apple (classic Starking Delicious) orchard that had been established for 28 years with a tree spacing of 8 m. The orchard was located in Karaman Province in Central Anatolia of Turkey. The study ran for three years in 2006, 2007 and 2008. Some basic properties of the soil samples collected from the orchard before applying the treatments are given in Table 1.

Table 1

Some physical and chemical properties of the orchard soil.

Soil parameters	0-30 cm	30-60 cm
pH (1:2.5 s:w)	7.95	8.03
EC (µS cm^{-1}; 1:5 s:w)	198	180
Organic matter (%)	2.6	1.1
Lime (%)	44	43
Clay (%)	26.8	28.8
Silt (%)	31.4	35.4
Sand (%)	41.8	35.8
Textural class	Loam	Loam

The experiments were established in a randomized plots experimental design with 5 replicates of each treatment; each plot was 8 x 8 m in area and had one tree. The treatments consisted of three compost (C) doses (C_0 = 0 kg $tree^{-1}$; C_1 = 10 kg $tree^{-1}$; C_2 = 30 kg $tree^{-1}$) and three chemical fertilizer (F) doses (F_0 = 0 g N + 0 g P_2O_5 + 0 g K_2O $tree^{-1}$; F_1 = 275 g N + 182.5 g P_2O_5 + 275 g K_2O $tree^{-1}$; F_2 = 550 g N + 365 g P_2O_5 + 550 g K_2O $tree^{-1}$). Note that the combination of C_0 and F_0 was designated as the control.

The compost was produced by vertical silo method by the Kemerburgaz Organic Waste Compost Factory in Istanbul, which is one of a few compost producing organizations in Turkey. Relevant chemical properties of the compost are given in Table 2.

All of the phosphorus fertilizer was added with the compost on the dates presented in Table 3; as 500 g NPK 15.15.15 and 250 g TSP (Triple super phosphate; 43% P_2O_5) per tree in the F_1 treatment, and as 1000 g NPK

15.15.15 and 500 g TSP per tree in F_2. The remaining nitrogen and potassium fertilizers were applied at a later date as a top dressing of 306 g (F_1) and 612 g (F_2) of urea with 455 g (F_1) and 910 g (F_2) of KNO_3 (13% N, 44% K_2O) per tree (Table 3). Compost and chemical fertilizers were broadcast over the projected areas of the tree canopies and were then hoed in to incorporate them into the upper layer of the soil, to a depth of about 10-20 cm. The owner of the orchard carried out the routine orchard maintenance practices, such as pruning, cultivating, pesticide applications, irrigation, and harvesting during the study period.

Disturbed soil samples were collected from the 0-30 cm and 30-60 cm depths within the projected areas of the tree canopies on the dates given in Table 3. Soil analyses included: pH analysis using a pH-meter in a 1:2.5 soil:water solution; electrical conductivity (EC) using an EC-meter in a 1:5 soil:water solution (Jackson 1962); and organic matter by Smith & Weldon (1941). Available P by Olsen et al (1954), exchangeable cations (K, Ca, Mg and Na) by Bayraklı (1987), extractable Fe, Zn, Cu, Mn, Ni, Cd and Pb by Lindsay & Norvell (1978), and available B by Kacar (1986), were analyzed.

Table 2

Chemical analysis of the compost used in this study.

Parameters	Results	Parameters	Results
pH (1:5 s:w)	7.8 ± 0.1	Zn (mg kg^{-1})	405 ± 80
EC (mS cm^{-1})	7.7 ± 0.3	Mn (mg kg^{-1})	450 ± 167
Organic matter (%)	43 ± 3	Cl (H_2O soluble) (%)	0.51 ± 0.03
C (%)	23 ± 2	Cu (mg kg^{-1})	342 ± 128
C:N (%)	16 ± 1	B (mg kg^{-1})	64 ± 13
N (%)	1.44 ± 0.08	Al (%)	1.14 ± 0.36
P (%)	0.22 ± 0.05	Pb (mg kg^{-1})	93 ± 28
K (%)	0.93 ± 0.24	Ni (mg kg^{-1})	48 ± 11
Ca (%)	6.95 ± 0.39	Cd (mg kg^{-1})	0.90 ± 0.16
Mg (%)	0.40 ± 0.10	Cr (mg kg^{-1})	116 ± 22
S (%)	0.61 ± 0.14	Co (mg kg^{-1})	8.37 ± 1.47
Na (%)	0.44 ± 0.10	Hg (mg kg^{-1})	0.89 ± 0.31
Fe (%)	1.78 ± 0.50		

Table 3

Timetable of orchard operations.

Orchard operations	First year	Second year	Third year
Compost and basic fertilizers application	24.11.2005	21.11.2006	27.11.2007
Top fertilizing	07.04.2006	10.04.2007	11.04.2008
Soil and leaf sampling	01.08.2006	20.07.2007	22.07.2008
Fruit sampling	27.09.2006	21.09.2007	23.09.2008

Leaf sampling was conducted on the same day as the soil sampling (Table 3). The leaves found in the center of the annual shoots were collected with their stems and stored in paper bags in a cool box until they could be analyzed. Pre-treatment consisted of removing possible contaminants by washing the leaves thoroughly with tap water, followed by washing once with distilled water, then with 0.1 N HCl solution, two times with distilled water and once more with deionized distilled water. The leaves were dried in paper bags at 70 °C in an oven with air circulation until constant weight (48 hours). The dried samples were ground in a plant grinder plated with tungsten. The ground specimens were put in polyethylene pots and were again dried at 70 °C to constant weight.

A 0.3 g subsample of the pre-treated samples was digested with 5 ml HNO_3 at high temperature (210 °C) and pressure (200 PSI) in a microwave apparatus (CEM Marsx). The samples with their extracts were then transferred to 20 ml volumetric flasks and, when cool, the volume was made up with deionized distilled water. The 20-ml samples were filtered through blue line filter paper and the total P, K, Ca, Mg, S, Fe, Zn, Cu, Mn, B, Ni and Cr contents of the filtered extracts were determined by the ICP-AES (Soltanpour & Workman 1981). One blank and a certified reference material (1547 Peach Leaves, NIST, National Institute of Standards and Technology, Gaithersburg-USA) were included in the microwave set of samples to check the reliability of the leaf analyses.

The fruit yields per tree were determined at the harvest time at the end of September. Ten apples from each tree were collected for laboratory analysis of some fruit quality parameters, and nutrient and heavy metal contents. Macro- and micro-nutrients and heavy metals in the fruit samples were analyzed using the same procedures as those used for the leaf samples. Fruit yield per tree was determined by weighing the entire apple crop from each tree in the orchard. The sampled apples were weighed, the fruit diameters were measured with calipers, the dry matter contents of the fruit were determined with a refractometer, fruit pulp hardening was measured with a penetrometer with a smooth point and fruit peel hardening with a penetrometer with a conical point (Cemeroğlu 1992); mean values of each sample were obtained for all the parameters by averaging the values obtained for the ten apples in the sample.

Minitab and Mstat computer software were used in the statistical analysis of data obtained in this investigation (Düzgüneş et al 1983).

3. Results

The compost and chemical fertilizer applications in increasing doses over the three years of the study significantly affected (P < 0.01 or P < 0.05) the EC and the contents of organic matter, available macro- and micronutrients and heavy metals in the 0-30 cm and the 30-60 cm soil layers of the apple tree canopies. Based on the means of the measurements made in the three years, the EC and the contents of organic matter, available nutrients and heavy metals of the soil in the 0-30 cm layer were higher than those in the 30-60 cm layer (Figures 1 and 2). This probably results from the method of incorporating the compost and chemical fertilizer into the upper soil layer, where it has an immediate effect on these soil properties, whereas a longer time is required for these materials to reach or have an influence on the deeper layer. For the 30 kg of compost tree^{-1} (F_0C_2) treatment, the EC value of the soil increased by 19% in the upper layer and by 9% in the lower layer when compared with the control (F_0C_0). For the F_2C_2 treatment, these increases in the EC values of the soil were by 25% in the upper layer and by 11% in the lower layer. The highest EC value (222 µS cm^{-1}) was measured in the soil of the upper layer under the F_2C_2 treatment. The soil organic matter content increases also depended on the compost dose for both layers (Figure 1).

The available P, K, Ca and Mg contents of the soil in both layers increased significantly with the applications of compost and chemical fertilizer when compared with those of the control (F_0C_0). However, no statistically significant differences were observed between F_0C_1 and F_1C_0, or between F_0C_2 and F_2C_0, with respect to available K, Ca, Mg and S in either of the two soil layers (Figures 1 and 2). In addition, the available K, Ca and Mg contents in the soil receiving only compost (F_0C_1 and F_0C_2) were not significantly increased when compared with the control. However, the compost treatments alone did result in increases within both soil layers of available P and S contents when compared with the control. The lesser amount of compost (F_0C_1; 10 kg compost tree^{-1}) increased available P and S by 56% and 13% (0-30 cm) and by 70% and 7% (30-60 cm), respectively; while the greater amount of compost (F_0C_2; 30 kg compost tree^{-1}) resulted in increases that were 51% and 33% (0-30 cm), and 57% and 32% (30-60 cm) that of the control, respectively (Figures 1 and 2). These results may be an important indicator of when it would be possible to reduce the amount of chemical fertilizer while maintaining the necessary levels of P and S for plant uptake by applying the compost.

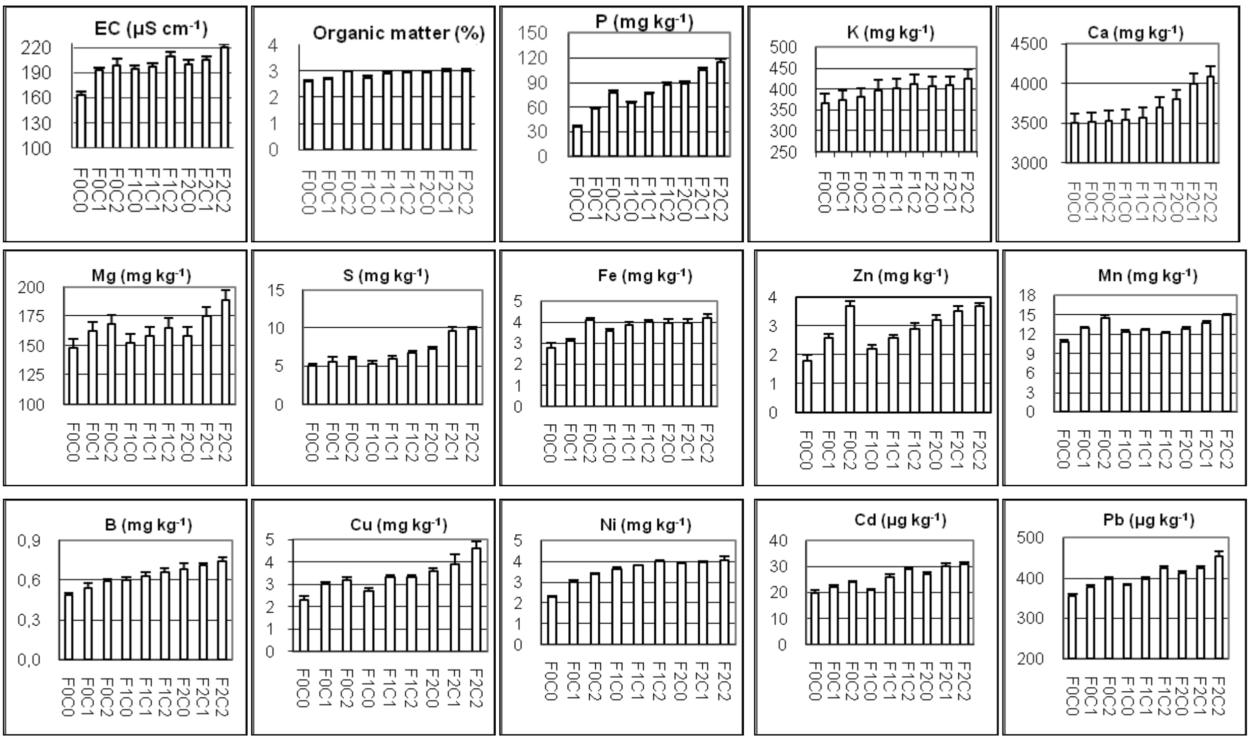

Figure 1

Effects of different doses of the municipal compost (C_0, C_1, C_2) and of chemical fertilizers (F_0, F_1, F_2) on the 3-year-mean values of electrical conductivity (EC) and of the contents of organic matter, available macro- and micro-nutrients and heavy metals in the 0-30 cm soil layer.

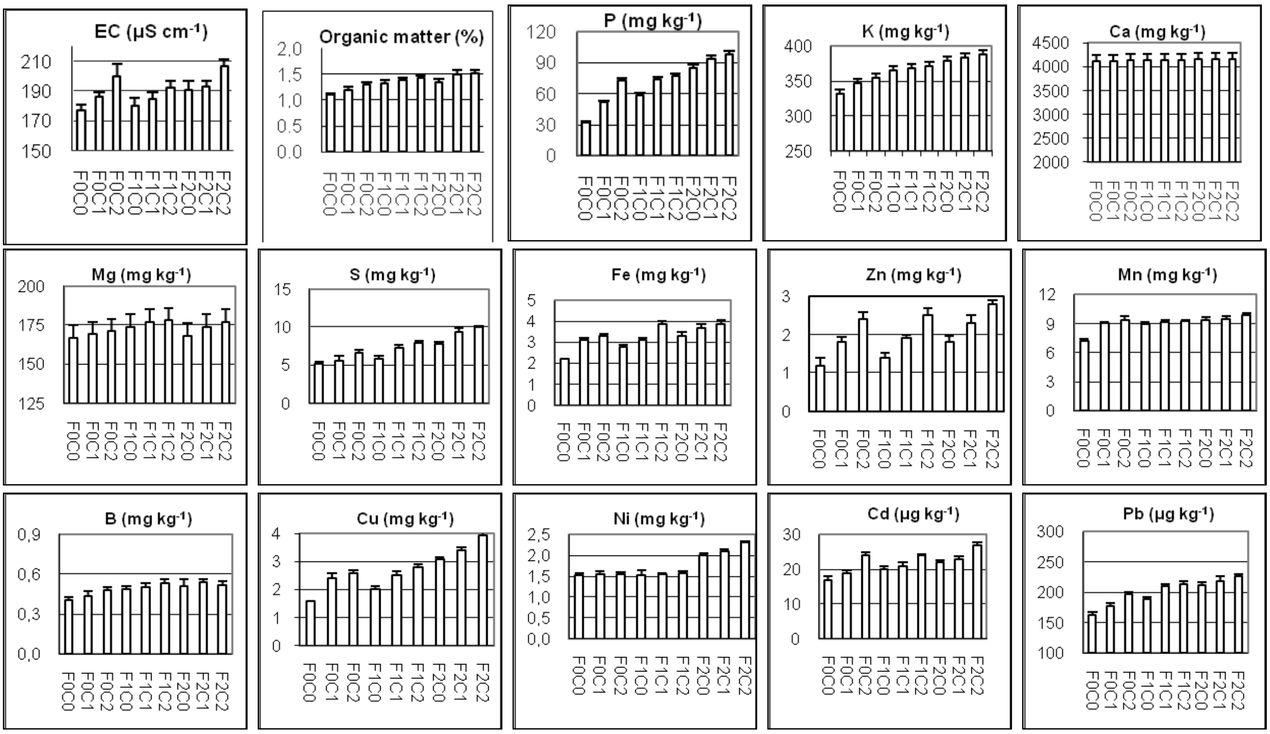

Figure 2

Effects of different doses of the municipal compost (C_0, C_1, C_2) and of chemical fertilizers (F_0, F_1, F_2) on the 3-year-mean values of electrical conductivity (EC) and of the contents of organic matter, available macro- and micro-nutrients and heavy metals in the 30-60 cm soil layer.

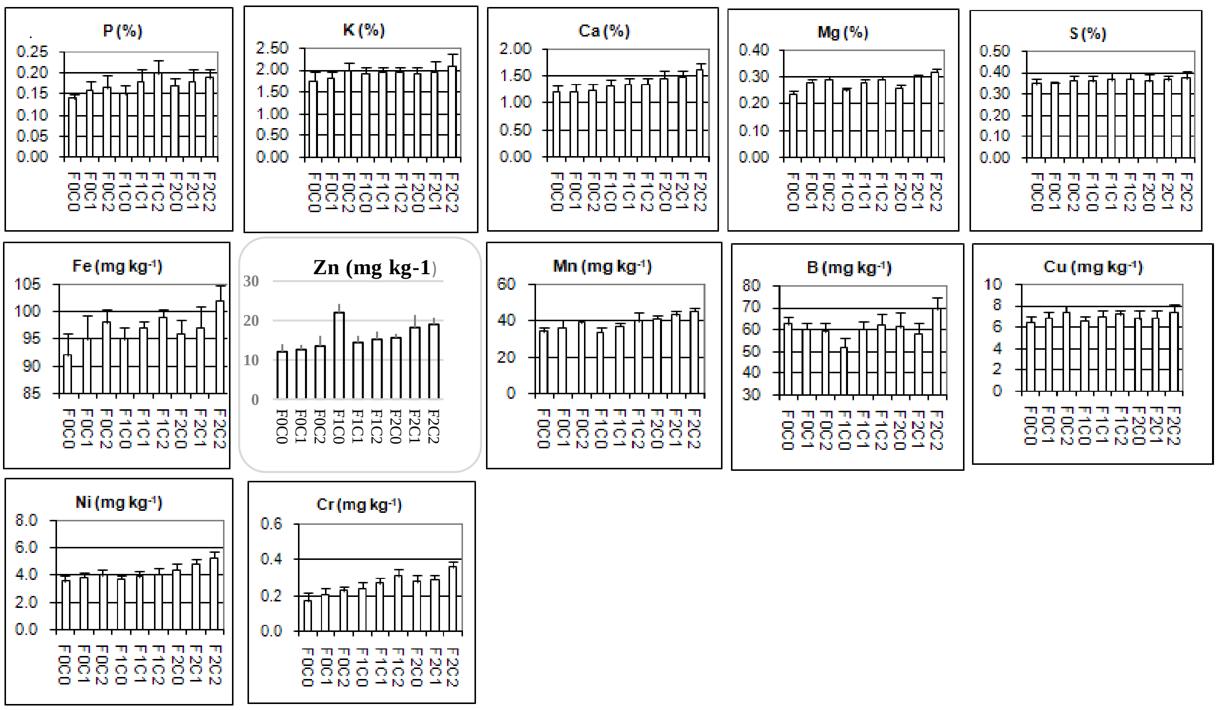

Figure 3

Effects of different doses of the municipal compost (C_0, C_1, C_2) and of chemical fertilizers (F_0, F_1, F_2) on the 3-year-mean contents of total macro- and micro-nutrients and heavy metals of apple leaves.

Increases in the available Fe, Zn, Mn, Cu and B contents in both soil layers were directly related to the amounts of compost (F_0C_1 and F_0C_2) applied (Figures 1 and 2). In general, for all treatments the contents of these elements in the soil was higher in the upper layer than in the lower layer. There were also statistically significant increases in the contents of Ni, Cd and Pb, which are dangerous with respect to human health, for compost and chemical fertilizer applications over the three years when compared with the control. Even the chemical fertilizers applied in the absence of compost resulted in significant increases. However, none of the treatments resulted in accumulations of these elements in the soil that would constitute soil contamination or a health hazard. Allowed concentrations of total Cd, Ni and Pb are 3 mg kg^{-1}, 75 mg kg^{-1} and 300 mg kg^{-1} for pH > 6 agricultural soils, respectively (Kabata-Pendias & Pendias 1992).

The effects of compost and chemical fertilization on all the total contents of the macro- and micro-nutrients, and of the heavy metal contents, of the leaves sampled in the third year were statistically significant ($P < 0.01$ or $P < 0.05$) with the exception of the K, Mg, Cu and B contents (Figure 3). Compared with the control, some nutrient (P, K, Ca, Mg, S, Fe, Zn, Cu, Mn and B) and heavy metal (Ni and Cr) contents of the apple leaves increased at rates that depended on the compost (F_0C_1, F_0C_2) amounts. These increases were even higher when the compost was used with a chemical fertilizer. The levels of heavy metal accumulations in the leaves due to the compost were not dangerous in either the third year of the experiment or in the first or second years. Maximum allowed limits in leaf for Ni and Cr are 5 and 14 mg kg^{-1} respectively (Kabata-Pendias & Pendias 1992).

Correlation analyses generally found positive and significant correlations between the amount of a given element in the soil and its content in the leaves (Table 4 and 5). This indicates that compost applied into the soil would be an important beneficial source of nutrients for the apple trees. However, it also suggests caution as the amount of heavy metal found in the leaves is also directly related to their soil content. Zn and B notably exhibited a poor relationship between the soil and leaf contents.

The effect of the compost and chemical fertilizer applications on the mean fruit weight, fruit diameter, peel and pulp hardening and dry matter contents were all statistically significant ($P < 0.01$), but the effect on fruit yield was not. Although there was no significant difference among the fruit yields for the various treatments, the highest apple yield (132.2 kg $tree^{-1}$) was achieved in the F_0C_1 treatment, while the lowest yield (77.0 kg $tree^{-1}$) occurred in the F_2C_2. The effect of compost on increasing the fruit yield was greater than that of the chemical fertilizers. Similarly, the effect of the compost on the mean fruit weight, diameter and pulp hardening was greater than that of the chemical fertilizers. Increasing the compost dose increased the mean fruit weight and diameter. The effect of the chemical fertilizers on peel hardening and dry matter content was also greater (Table 6).

Table 4

Correlation coefficients (r) between electrical conductivity (EC) or contents of organic matter (OM), available nutrients, or heavy metals in the 0-30 cm soil layer and the contents of some elements in the leaves.

Soil	Content in leaves									
property	P	K	Ca	Mg	S	Fe	Cu	Mn	Zn	B	Ni
EC	0.552**	0.451*	0.545**	0.409*	0.635**	0.530**	0.412**	0.483**	0.174	-0.049	0.466**
OM	0.412**	0.331*	0.564**	0.397**	0.428**	0.437**	0.347*	0.458**	0.044	0.008	0.629**
P	0.487**	0.376**	0.694**	0.440**	0.546**	0.551**	0.354*	0.602**	0.192	0.002	0.733**
K	0.516**	0.447**	0.682**	0.382**	0.585**	0.554**	0.377*	0.498**	0.306*	-0.043	0.586**
Ca	0.280	0.299*	0.593**	0.380**	0.392**	0.392**	0.210	0.561**	0.171	0.065	0.763**
Mg	0.439**	0.454**	0.448**	0.406**	0.397**	0.558**	0.394**	0.522**	0.095	0.008	0.580**
S	0.445**	0.408**	0.666**	0.462**	0.521**	0.541**	0.348**	0.601**	0.175	0.077	0.754**
Fe	0.437**	0.487**	0.594**	0.416**	0.552**	0.518**	0.397**	0.549**	0.260	-0.004	0.587**
Cu	0.434**	0.421**	0.623**	0.505**	0.516**	0.537**	0.311	0.613**	0.171	0.016	0.728**
Mn	0.465**	0.359*	0.382**	0.381**	0.421**	0.583**	0.435**	0.341*	0.024	-0.056	0.359*
Zn	0.382**	0.346*	0.501**	0.377*	0.438**	0.536**	0.371*	0.483**	0.061	0.034	0.630**
B	0.378*	0.452**	0.568**	0.225	0.584**	0.480**	0.261	0.535**	0.206	-0.107	0.650**
Ni	0.491**	0.432**	0.606**	0.429**	0.557**	0.477**	0.414**	0.486**	0.219	-0.049	0.517**
Cd	0.493**	0.330*	0.637**	0.445**	0.527**	0.574**	0.308*	0.578**	0.216	0.051	0.706**
Pb	0.525**	0.427**	0.619**	0.433**	0.564**	0.591**	0.420**	0.516**	0.227	0.011	0.610**

**: > 0.381; *: > 0.294

Table 5

Correlation coefficients (r) between electrical conductivity (EC) or contents of organic matter (OM), available nutrients, or heavy metals in the 30-60 cm soil layer and the contents of the some elements in the leaves.

Soil	Content in leaves										
property	P	K	Ca	Mg	S	Fe	Cu	Mn	Zn	B	Ni
EC	0.332*	0.382**	0.492**	0.491**	0.341*	0.365**	0.499**	0.392*	-0.007	0.066	0.555**
OM	0.427**	0.424**	0.519**	0.200	0.481**	0.577**	0.263	0.442**	0.215	-0.035	0.523**
P	0.499**	0.446**	0.657**	0.424**	0.581**	0.522**	0.361*	0.599**	0.199	0.024	0.708**
K	0.387**	0.376*	0.630**	0.390**	0.439**	0.592**	0.336*	0.417**	0.276	-0.026	0.570**
Ca	0.162	0.349*	0.385**	0.229	0.198	0.190	0.169	0.385**	0.149	0.021	0.459**
Mg	0.127	0.271	0.217	-0.042	0.265	-0.088	-0.013	0.210	0.071	-0.199	0.082
S	0.429**	0.420**	0.649**	0.454**	0.523**	0.520**	0.357*	0.604**	0.190	0.097	0.732**
Fe	0.558**	0.440**	0.572**	0.449**	0.584**	0.501**	0.396**	0.553**	0.141	0.042	0.575**
Cu	0.445**	0.390**	0.642**	0.449**	0.522**	0.479**	0.302*	0.608**	0.098	0.010	0.754**
Mn	0.509**	0.427**	0.615**	0.410**	0.575**	0.513**	0.379*	0.536**	0.203	-0.052	0.592**
Zn	0.542**	0.418**	0.479**	0.430**	0.473**	0.596**	0.479**	0.470**	0.040	0.011	0.550**
B	0.467**	0.246	0.400**	0.272	0.458**	0.231	0.152	0.479**	0.179	-0.076	0.458**
Ni	0.439**	0.409**	0.658**	0.437**	0.531**	0.518**	0.360*	0.593**	0.141	0.042	0.722**
Cd	0.568**	0.397**	0.608**	0.411**	0.647**	0.519**	0.373*	0.494**	0.124	0.004	0.707**
Pb	0.519**	0.440**	0.674**	0.448**	0.585**	0.552**	0.363*	0.586**	0.241	0.006	0.640**

**: > 0.381; *: > 0.294

Table 6

Effects of different doses of the municipal compost (C_0, C_1, C_2) and of chemical fertilizers (F_0, F_1, F_2) on the 3-year-mean values of fruit (apple) yield and yield components.

Fertilizer –compost mixture	Fruit yield (kg tree^{-1})	Fruit weight (g)	Fruit diameter (mm)	Peel hardening (kg cm^{-2})	Pulp hardening (kg cm^{-2})	Dry matter (%)
C_0	105.8	157.4 bc	70.4 bcd	4.20 abc	5.18 cd	14.28 e
F_0 C_1	132.2	150.7 bc	70.3 cd	3.98 e	5.40 ab	15.06 d
C_2	79.8	175.6 a	72.1 ab	3.82 f	5.02 d	14.98 d
C_0	105.8	152.8 bc	67.2 e	4.08 cde	5.10 d	16.24 c
F_1 C_1	100.2	159.2 bc	72.0 abc	4.24 ab	5.34 bc	15.28 d
C_2	103.2	108.7 e	69.8 d	4.04 de	5.56 a	16.76 bc
C_0	87.8	128.2 d	72.5 a	4.26 ab	5.40 ab	15.34 d
F_2 C_1	94.4	146.4 c	69.5 d	4.32 a	5.50 ab	17.12 ab
C_2	77.0	163.2 ab	73.1 a	4.16 bcd	5.10 d	17.68 a
Min.	*77.0*	*108.7*	*67.2*	*3.82*	*5.02*	*14.28*
Max.	*132.2*	*175.6*	*73.1*	*4.32*	*5.56*	*17.68*
LSD[a], $P < 0.05$	*ns*	*14.53*	*1.779*	*0.148*	*0.176*	*0.593*

[a] LSD, least squares difference values for P < 0.05.

3-year-mean values within a column followed by the same lowercase letters are not statistically different at P <0.05

The effects of increasing the doses of the compost and fertilizer on all of the macro- and micro-nutrients and heavy metal contents of the fruit were statistically significant ($P < 0.01$) with the exception of those of Ca, Mn and Cr (Figure 4). The effects of fertilizer and fertilizer with compost on the micro-nutrient contents, except on Mn and B, were greater than compost's. Compost use did not significantly increase the heavy metal contents of the fruit and, in some cases, they even decreased (e.g. Cd, Ni, and Al).

Correlation analyses generally showed that significant positive correlations ($P < 0.01$ or $P < 0.05$) existed between the soil properties and the mean fruit diameter or dry matter content, and that significant negative correlations existed between the soil properties and fruit yield, mean weight, or peel hardening (Tables 7 and 8). Significant positive correlations ($P < 0.01$ or $P < 0.05$) were also found between the soil properties and total K, Mg, S, Fe, Cu, Zn, Cr, Al and Co contents of the fruit, while significant negative correlations occurred between the soil properties and Zn, B and Pb contents of the fruit (Tables 9 and 10).

Figure 4
Effects of different doses of the municipal compost (C_0, C_1, C_2) and of chemical fertilizers (F_0, F_1, F_2) on the 3-year-mean contents of total macro- and micro-nutrients and heavy metals in apples.

Table 7
Correlation coefficients (r) between electrical conductivity (EC) or contents of organic matter (OM), available nutrients, or heavy metals in the 0-30 cm soil layer and fruit (apple) yields or yield components.

Soil property	Fruit yield and yield components					
	Yield	Mean weight	Mean diameter	Peel hardening	Pulp hardening	Dry matter
EC	-0.235	-0.194	0.252	-0.059	0.086	0.670**
OM	-0.340*	-0.012	0.401**	0.015	0.021	0.503**
P	-0.329*	-0.166	0.301*	0.222	0.211	0.775**
K	-0.265	-0.288*	0.174	0.161	0.154	0.781**
Ca	-0.270	-0.131	0.263	0.448**	0.169	0.700**
Mg	-0.254	0.092	0.298*	-0.072	-0.001	0.664**
S	-0.286*	-0.147	0.322*	0.345*	0.206	0.755**
Fe	-0.303*	-0.072	0.263	-0.003	0.027	0.633**
Cu	-0.263	0.004	0.288*	0.220	0.113	0.790**
Mn	-0.198	0.187	0.350*	-0.367*	-0.117	0.492**
Zn	-0.310*	0.070	0.421**	0.002	0.079	0.550**
B	-0.232	-0.150	0.284*	0.329*	0.092	0.687**
Ni	-0.238	-0.219	0.205	-0.046	0.147	0.659**
Cd	-0.296*	-0.136	0.248	0.334*	0.262	0.771**
Pb	-0.255	-0.218	0.298*	0.006	0.153	0.755**

**: > 0.381; *: > 0.294

Table 8

Correlation coefficients (r) between electrical conductivity (EC) or contents of organic matter (OM), available nutrients, or heavy metals in the 30-60 cm soil layer and fruit (apple) yield or yield components.

Soil	Fruit yield and yield components					
property	Yield	Mean weight	Mean diameter	Peel hardening	Pulp hardening	Dry matter
EC	-0.315*	0.076	0.364*	-0.238	-0.049	0.376*
OM	-0.229	-0.118	0.075	0.150	0.185	0.715**
P	-0.273	-0.177	0.304*	0.185	0.190	0.723**
K	-0.318*	-0.203	0.233	0.253	0.155	0.707**
Ca	-0.179	-0.053	0.144	-0.050	-0.051	0.354*
Mg	-0.071	-.0107	-0.162	0.064	0.249	0.226
S	-0.319*	-0.142	0.339*	0.314	0.176	0.747**
Fe	-0.179	-0.313*	0.200	0.070	0.294*	0.721**
Cu	-0.298*	-0.104	0.342*	0.225	0.228	0.710**
Mn	-0.227	-0.129	0.272	-0.004	0.198	0.663**
Zn	-0.255	-0.009	0.379**	-0.268	-0.004	0.592**
B	-0.052	-0.243	-0.084	0.171	0.397**	0.517**
Ni	-0.330*	-0.181	0.340*	0.280	0.191	0.678**
Cd	-0.265	-0.128	0.317*	-0.016	0.114	0.712**
Pb	-0.226	-0.264	0.200	0.169	0.282	0.771**

**: > 0.381; *: > 0.294

Table 9

Correlation coefficients (r) between electrical conductivity (EC), or contents of organic matter (OM), available nutrients, or heavy metals in the 0-30 cm soil layer and the content of those elements in apples.

Soil	Content in apples							
property	P	K	Ca	Mg	S	Fe	Cu	Mn
EC	-0.049	0.278	0.068	0.334*	0.263	0.569**	0.243	0.243
OM	-0.152	0.259	0.115	0.387**	0.422**	0.497**	0.317*	0.021
P	-0.029	0.498**	0.025	0.473**	0.548**	0.619**	0.224	0.220
K	0.122	0.393**	-0.089	0.331*	0.324*	0.662**	0.133	0.175
Ca	0.088	0.684**	-0.033	0.518**	0.565**	0.483**	0.194	0.228
Mg	0.005	0.519**	0.155	0.696**	0.643**	0.552**	0.452**	0.266
S	0.042	0.561**	0.035	0.468**	0.576**	0.598**	0.272	0.257
Fe	-0.027	0.160	0.040	0.373**	0.375**	0.544**	0.197	0.072
Cu	0.098	0.627**	0.103	0.561**	0.590**	0.510**	0.202	0.270
Mn	-0.093	0.283	0.162	0.570**	0.341*	0.422**	0.323*	0.243
Zn	-0.263	0.304*	0.122	0.559**	0.565**	0.460**	0.339*	0.152
B	0.120	0.452**	0.084	0.347*	0.416**	0.509**	0.217	0.121
Ni	-0.083	0.248	-0.040	0.326*	0.272	0.617**	0.156	0.124
Cd	0.041	0.550**	0.033	0.492**	0.614**	0.630**	0.308*	0.284*
Pb	-0.005	0.516**	-0.051	0.470**	0.327*	0.668**	0.244	0.211
	Zn	B	Ni	Cd	Pb	Cr	Al	Co
EC	0.181	-0.113	0.256	0.096	0.007	0.223	0.024	0.140
OM	-0.161	-0.276	0.128	-0.133	-0.204	0.076	0.203	0.173
P	-0.169	-0.122	0.106	0.041	0.162	0.056	0.240	0.265
K	0.073	-0.141	0.248	0.157	0.109	0.041	0.127	0.278
Ca	-0.423**	-0.041	-0.049	0.000	0.297*	0.005	0.298*	0.359**
Mg	-0.146	0.148	0.129	0.194	-0.341*	0.259	0.340*	0.201
S	-0.218	-0.108	0.100	0.137	0.118	0.075	0.306*	0.324*
Fe	0.076	-0.286*	0.149	0.008	0.091	0.086	0.035	0.065
Cu	-0.195	0.011	0.003	0.155	0.040	0.130	0.198	0.236
Mn	0.116	0.043	0.113	0.058	-0.332*	0.291*	0.053	0.024
Zn	-0.167	-0.208	0.038	-0.184	0.109	0.138	0.133	0.085
B	-0.093	-0.129	0.125	0.050	0.210	0.080	0.145	0.273
Ni	0.097	-0.222	0.265	-0.056	0.157	0.061	0.049	0.191
Cd	-0.193	0.010	0.146	0.191	0.016	0.145	0.376*	0.362*
Pb	-0.012	-0.049	0.234	0.033	0.073	0.132	0.176	0.343*

**: > 0.381; *: > 0.294

Table 10

Correlation coefficients (r) between available nutrients or heavy metal contents in the 30-60 cm soil layer and their contents in the apples.

Soil property	Content in apples							
	P	K	Ca	Mg	S	Fe	Cu	Mn
P	-0.057	0.385**	0.033	0.391**	0.468**	0.583**	0.190	0.171
K	0.173	0.481**	-0.202	0.421**	0.367*	0.503**	0.127	0.149
Ca	-0.042	0.301*	0.100	0.395**	0.270	0.272	0.276*	0.125
Mg	0.118	0.030	-0.173	-0.134	-0.058	0.251	-0.114	0.036
S	0.005	0.520**	0.068	0.463**	0.590**	0.596**	0.263	0.213
Fe	-0.153	0.445**	0.051	0.372*	0.422**	0.700**	0.336*	0.257
Cu	-0.072	0.558**	0.056	0.518**	0.585**	0.538**	0.251	0.271
Mn	-0.089	0.268	0.053	0.361*	0.367*	0.482**	0.085	0.219
Zn	-0.178	0.358*	0.071	0.557**	0.409**	0.624**	0.436**	0.173
B	0.044	-0.198	0.057	0.059	0.329*	0.453**	-0.051	0.097
Ni	-0.046	0.495**	0.038	0.445**	0.486**	0.569**	0.203	0.200
Cd	-0.050	0.373*	0.011	0.441**	0.448**	0.678**	0.348*	0.148
Pb	-0.050	0.383**	0.049	0.372*	0.470**	0.620**	0.184	0.255
	Zn	B	Ni	Cd	Pb	Cr	Al	Co
P	-0.064	-0.218	0.136	0.002	0.204	0.086	0.145	0.185
K	-0.095	-0.070	0.119	0.127	0.157	0.063	0.113	0.259
Ca	-0.235	-0.056	-0.111	-0.151	0.165	0.174	0.070	0.035
Mg	0.179	0.039	0.179	0.173	-0.015	0.087	0.075	0.073
S	-0.238	-0.140	0.088	0.096	0.147	0.022	0.300*	0.315
Fe	-0.014	-0.040	0.308*	0.082	0.019	0.157	0.314*	0.373*
Cu	-0.228	-0.093	0.044	-0.020	0.177	0.124	0.250	0.271
Mn	0.114	-0.171	0.118	-0.060	0.144	0.139	-0.034	0.034
Zn	-0.031	-0.045	0.235	-0.012	-0.149	0.177	0.240	0.259
B	0.066	0.002	0.274	0.084	0.120	-0.002	0.236	0.170
Ni	-0.198	-0.200	0.072	-0.021	0.264	0.025	0.203	0.257
Cd	-0.064	-0.124	0.239	0.058	0.036	0.112	0.284	0.305*
Pb	0.035	-0.134	0.203	0.108	0.102	0.134	0.191	0.215

**: > 0.381; *: > 0.294

4. Discussion

The statistically significant increases in the EC and contents of organic matter, macro- and micro-nutrients and heavy metals in the soils resulted from the compost and chemical fertilizer treatments. In addition to the compost, chemical fertilizers also played a part in increasing parameters that could become detrimental to the fruit trees, human health or the environment. However, these increased values did not exceed safe or permissible levels. By judicially using the compost and/or chemical fertilizers at appropriate doses, the increases in EC values can be maintained at levels below 4 mS cm^{-1}, which is the maximum value considered to be appropriate for growing plants (Brady & Weil 1996). The increases in EC values result from the soluble salts in the chemical fertilizers while the compost also contains soluble components (Brady & Weil 1996), which lead to higher EC values than those found in unfertilized agriculture soils. The EC values (7.7-8.3 mS cm^{-1}; Table 2) determined for the compost used in the orchard experiments were actually higher than the desirable range suggested by Brady and Weil (1996) for composts (3.69-7.49 mS cm^{-1}). Even so, after 3 years of applying the compost and chemical fertilizers, the EC value in the soil had not changed greatly over the study period (Figure 5). The increases in EC values of the soil in both layers were higher for the C_2 than for the C_1 treatments. Similarly, the EC value for the F_2 dose was generally higher than that of either the F_0 or the F_1 doses (Figure 5). At the end of the 3 years, when compared with the control, the C_2 treatment resulted in increased EC values of the soil in the upper (0-30 cm) and lower (30-60 cm) layers of 24% and 10%, respectively. The corresponding increases in the second year were 17% and 14% for the upper and lower layers, respectively, and in the first year they were 17% and 12%. Clearly, these EC values increased from the first year to the third year. These results concerning the effects of the compost on soil salinity were similar to those of other studies (He et al 1995; Hicklenton et al 2001; Walter et al 2006). Long-term management should monitor soil salinity and adjust the doses of the compost and fertilizers to appropriate levels.

The organic matter contents in both soil layers were increased significantly by the compost applications and were affected by the dose amount. The organic matter content increased by 13% in the upper layer and by about 14% in the lower layer for the dose of 30 kg of compost per tree (C_2) during the 3 years. The organic matter content values increased by 7.2% and 10.8% in the second year, and by 11.5% and 16.7% in the first year in the upper and lower layers, respectively. In addition, the magnitude of the increases of the organic matter depended on the application year (Figure 6). Some scientists (Demir & Çimrin 2011; Çolpan et al 2013) have stated that the potential improvement of soil fertility in cases such as that of the study orchard, which had low levels of organic matter, is an important management objective. Addition of organic compost can meet that objective. Delschen and Necker (1995) reported that compost applications increased soil organic matter contents by between 0.02% and 0.08%. In similar studies it was determined that important soil organic matter content increases were achieved through the use of compost (Aran 1986; Aichberger et al 1987; Percucci 1990; Shirajipour et al 1992; Öztürk et al 2012).

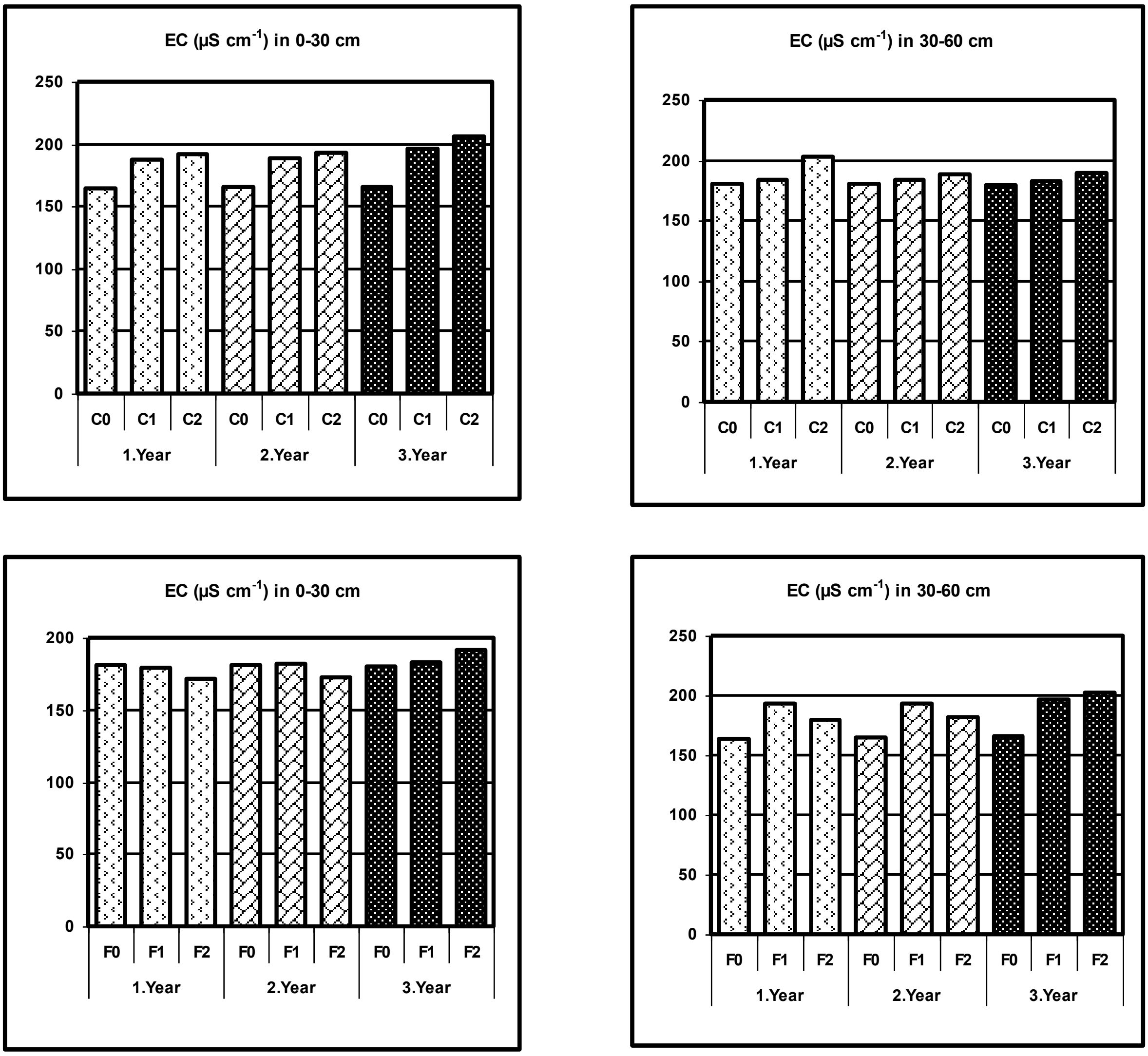

Figure 5

Annual effects of the municipal compost and chemical fertilizers on EC values for the 0-30 and 30-60 cm soil layers during a 3-year study.

The macro- and micro-nutrients of the studied soil were increased significantly through the use of the compost. In the study period of 3 years, available Fe increased by 36.7%-55.5% and Zn by 72.0%-100.0% in the upper soil layer. Similarly, other studies (Chattopadhyay et al 1986; Murillo et al 1997; Warman 2001; Zheljazkov & Warman 2004) have found that available nutrients in the soil were notably increased through the application of organic composts. Therefore, the use of the municipal organic compost benefitted the orchard soil by increasing the contents of organic matter and nutrients. This study further indicated that the use of the compost could decrease the amount of chemical fertilizers used in the orchard. Certainly that, heavy metal accumulation in the treated soil must be followed yearly.

The study found that heavy metal accumulations occurred in the upper soil layer during the three years of the study. In the first, second and third year, Ni contents increased by 57.8%, 61.6% and 79.0%; Cd by 11.8%, 15.0% and 16.3%; and Pb by 17.7%, 20.4% and 20.1%, respectively. However, the increases in the heavy metal contents of the soils by use of three yearly did not reach levels that would endanger human health. Accumulations also occurred in the lower layer. However, while Ni increases were less in the lower than in the upper layer, those of both Cd and Pb were greater in the lower soil layer. These results suggest that Cd and Pb were more susceptible to leaching than Ni, i.e., that Ni tended to be adsorbed on the soil surfaces in the upper soil layer to a greater degree than Cd or Pb. This in turn suggests that Cd and Pb might eventually pose more of an immediate risk to ground water than Ni. Other similar studies found that Cr, Pb, Ni, Cd, Hg and B contents in the soil and plant did not change significantly due to compost use (Barbarick et al 1998; Selivanovskaya et al 2001; Snyman et al 1998), but Barbarick et al (1998) and others found that Zn and Cu accumulations occurred (Reed et al 1991; Nyamangara & Mzezewa 1999). In contrast, a longer-term study by Sloan et al (1997) determined that biosolids containing heavy metals applied for 15 years resulted in significant heavy metal accumulations in the soil and a relative bioavailability (determined by levels in Romaine lettuce grown in the soil) of Cd >> Zn ≥ Ni > Cu >> Cr > Pb. Clearly, the findings of these studies suggest that the composition of the composts will affect the long-term heavy metal accumulation in the soil and that this in turn, as well as the form of the heavy metal, will affect the levels in the plants.

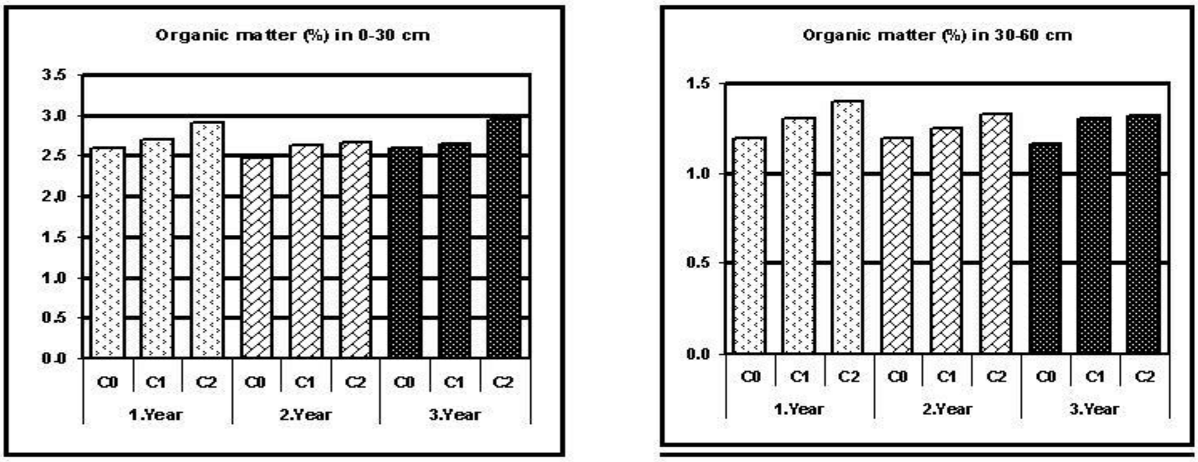

Figure 6

Annual effects of three doses of municipal compost (C_0, C_1, C_2: 0, 10, 30 kg compost tree^{-1}) on organic matter content in the 0-30 and 30-60 cm soil layers during a 3-year study.

During the three years of this study, not only were heavy metal accumulations in the soil and leaf due to the use of the municipal compost below levels considered to be dangerous for human health but amounts found in the apples were also safe. For example, it has been determined that the maximum permitted levels of total Pb and Cd in fresh fruits are 100 and 50 µg kg^{-1}, respectively (Anonymous 2008). These heavy metal contents in the apples from the trees where compost was applied were about 1%-3% of the amounts allowed (Figure 4). In addition, the total Cr and Ni contents in the apples did not consistently increase, and notably Ni contents actually decreased during the study period (Figure 7). The heavy metal contents in the soil were often poorly correlated with the fruit contents although they were better correlated with the leaf contents (Tables 4, 5, 9 and 10); Pinamonti et al (1999) noted the same phenomenon with vine plant tissues and grapes. This suggests that high levels of heavy metals in the soil do not necessarily result in apples, or other fruit, that are dangerous for human consumption.

Macro- and micro-nutrients in leaves were increased by the compost applications and these increases were related to the application dose. Both available Fe and Zn contents in the soil and total Fe and Zn in the leaves for the 30 kg of compost tree^{-1} treatment increased significantly. Consequently, no symptoms of Fe or Zn deficiencies were observed in the trees receiving this treatment. In contrast, Fe and Zn deficiencies are widespread in more than 70% of apple orchards around Karaman (Zengin et al 2008a;b). Similarly, other studies (Chattopadhyay et al 1986; Murillo et al 1997; Warman 2001; Zheljazkov & Warman 2004) have found significant increases in available nutrient contents in soil receiving applications of composts.

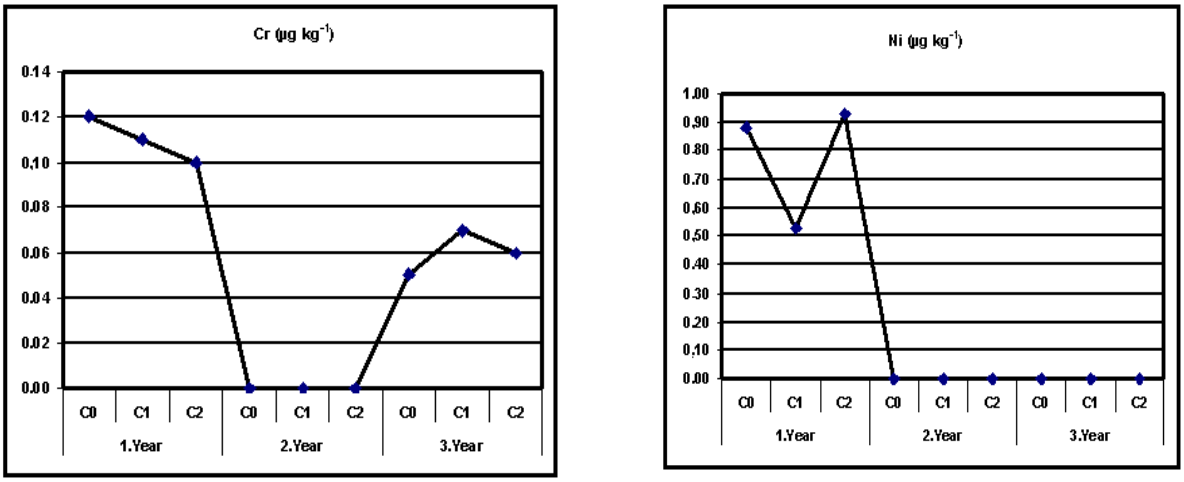

Figure 7

Annual effects of three doses of municipal compost (C_0, C_1, C_2: 0, 10, 30 kg compost tree^{-1}) on total Cr and Ni contents in apples during a 3-year study.

Compost did not have a statistically significant effect on apple yield but the highest yields, generally, were obtained by the F_1 (275 g N + 182.5 g P_2O_5 + 275 g K_2O tree^{-1}) dose applied with either the 10 or 30 kg of compost tree^{-1} dose. It can be concluded that compost is a good source of nutrients and organic matter for orchard soils and, as noted previously, using it can substantially reduce the amount of chemical fertilizer needed. Furthermore, the use of compost has demonstrable positive effects on the quality of the apples such as increasing the mean weight and diameter, while removing Fe and Zn deficiencies commonly found in Turkish orchards.

Although the presented study determined that the compost application over a 3 year period had not caused any heavy metal accumulations to dangerous levels for human health, a longer-term study of continuous use of this compost might not give the same results. Therefore, to obtain certain and more reliable results, this kind of study carried out in orchards with different soils should continue for at least 15-20 year periods. Based on the soil properties, optimum durations for heavy metal accumulation should be determined by these long-term studies. Furthermore, the potential for leaching the heavy metals into the ground water should be monitored.

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