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Research Article

The Effects of Organic Wastes on Soil and Cotton Quality with respect to the Risk of Boron and Heavy Metal Pollution

Müzeyyen Seçer,[1] Ömer Lütfü Elmaci,[1] and Şafak Ceylan[2]

[1]*Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Ege University, Bornova, 35100 İzmir, Turkey*
[2]*Ödemiş Vocational Training School of Ege University, Ödemiş, 35750 İzmir, Turkey*

Correspondence should be addressed to Ömer Lütfü Elmaci; oelmaci@hotmail.com

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The effects on soil and cotton quality of organic wastes from medicinal and aromatic plant factories were investigated with regard to the risks of boron and heavy metal pollution. Oily cumin, oregano, oilless oregano wastes, and mineral fertilizers were applied to cotton in two field experiments performed in the years 2003 and 2006. The Pb content of the soil differed significantly in the 2003 experiment and oregano wastes had significantly decreasing effect. Boron of soil to which oily cumin wastes had been applied reached a toxic limit value in 2006. Boron in soil adversely affected long fibres; B in leaves had a positive effect on the fineness of fibres in 2006. Soil Ni adversely affected plant height in 2006 and seed cotton yield in 2003. Leaf Ni had an adverse effect on fibre elasticity in 2006. Soil Co increased ginning out-turn and Cr decreased the fibre fineness of cotton in 2003.

1. Introduction

If production residues were used in agriculture, they would no longer be called wastes but would become economically valuable soil amendments by balancing soil organic matter and increasing yield. In particular, wastes of agroindustrial origin are expected to be high in organic matter and plant nutrients and low in toxic elements. These toxic elements can cause pollution in soil and ground water and have an inhibiting effect on the growth of plants. Levy and Taylor [1] reported inhibited seedling emergence with municipal solid waste and deformities in radish and cress seedlings with pulp mill solids. According to this author, both toxic constituents and nutrient imbalances could be held responsible for the growth inhibiting effects of these amendments. The stronger effect of pulp mill solids is largely nutritional, while the effect of municipal solid waste may be primarily toxicological. The application of all organic wastes to arable land must be regulated with regard to tolerable amounts of nutrients and heavy metals. Traulsen et al. [2] reported that 50 t ha^{-1} of biological waste compost induced no significant increase of the total content of nutrients and heavy metals in soil and plants. They suggest that the results of their study should be the basis for recommendations regarding the use of biological waste compost including the prevention of detrimental effects on plants, soil, and groundwater. According to Pala et al. [3], the wastes of vegetable and fruit processes should be investigated prior to their use as soil amendments for residues of fertilizers and pesticides used when they were being grown and for chemicals used in the cleaning process. Seçer et al. [4] investigated the pollution risk with boron and various heavy metals for soil and potato plants when agroindustrial wastes were used for plant nutrition.

The use of medicinal and aromatic plants is widespread in the world in many branches of industry. Turkey supplies 70% of the world's oregano. In the Aegean region, 81 oregano and 67 cumin processing factories are in operation [5]. If we consider that on average 12% of cumin processing and 40% of oregano processing generate wastes, the wastes of these factories will cause problems with respect to storage requirements. In our opinion it would be logical to evaluate these wastes for the nutrition of cotton, which is the dominant crop in this area. There are no studies in the literature on the effect on plant nutrition of wastes from medicinal and aromatic plant

Table 1: Chemical properties of composted wastes used in two field experiments.

Year	Composted wastes	pH	Total soluble salt (%)	Organic matter (%)	Milligram per kilogram					
					B	Pb	Ni	Cr	Co	Cd
2003	Oily cumin	7.4	1.9	79	11	7	5	3	3	0.4
	Oily oregano	7.2	3.1	85	15	13	35	20	7	0.7
	Oilless oregano	8.5	1.8	79	15	8	12	6	4	0.3
2006	Oily cumin	8.3	1.5	80	5.0	5	3	2	2	0.3
	Oily oregano	7.4	1.5	88	3.5	10	28	17	5	0.4

Values are an average of three samples.

Table 2: Physical and chemical properties of the two experimental soils (0–20 cm depth).

Year	pH	Percentage (%)						Texture	Milligram per kilogram					
		Total soluble salt	$CaCO_3$	Organic matter	Sand	Silt	Clay		B	Pb	Ni	Cr	Co	Cd
2003	7.0	<0.03	0.52	1.30	75.94	20.64	3.42	Loamy sand	0.23	9	31	28	12	0.36
2006	7.1	<0.03	0.81	0.80	83.00	13.00	4.00	Loamy sand	0.32	5	29	26	11	Trace

factories. These organic wastes were chosen for this study because the medicinal and aromatic plants are collected from different areas which could be polluted with heavy metals and in the industry different machines are used while these wastes are generated. Field experiments were undertaken with cotton plants to understand whether these wastes were free of boron and heavy metal toxicity and whether they had any effect on soil and plants.

2. Materials and Methods

Two field experiments were conducted in 2003 and 2006 with cotton plants using composted wastes from medicinal and aromatic plant factories in the Ödemiş district of İzmir province in Turkey, which has a high cotton growing potential. Three samples were taken from each waste type and from the field soil for chemical analysis (Tables 1 and 2). The pH, total soluble salt, and organic matter [6] contents of the wastes (oily cumin, oily oregano, and oilless oregano) were determined. For the field soil, the pH, total soluble salt, $CaCO_3$ [7], and organic matter [8] contents were determined. In addition, the texture of the soil was determined according to Gee and Hortage [9] (Table 2). For the determination of B content, extraction with hot water was performed on the soil and on the wastes after digestion of the samples at 500°C. The boron content of the extracts was measured using a 1 : 1 dianthrimid indicator with colorimeter [10, 11]. For determination of heavy metals, the wastes were ashed by digesting at 500°C and dissolving in 1 : 10 1 N HCl [12], and soil was extracted with 3 parts HCl + 1 part HNO_3 [13]. The contents of total Pb, Ni, Cr, Co, and Cd in the extracts were determined using atomic absorption spectrometry.

The experiments were conducted using randomized block design with three blocks and five plots (four plots for the year 2006) ($2.8\,m \times 3\,m = 8.4\,m^2$) per block. Oily cumin and oregano and oilless oregano wastes, additionally, for comparing mineral fertilizer and control were applied to the plots. Oilless oregano wastes could not be obtained for the experiment in 2006. According to their humidity, pH, and C/N value, three wastes were composted separately using H_2O, $CaCO_3$ and N in the form NH_4NO_3 and to increase microorganism population farmyard manure were added and allowed for composting for 45 days. The composted wastes ($40\,t\,ha^{-1}$) were incorporated into the soil at a depth of 15–20 cm before planting. Mineral fertilizers were applied at doses of $120\,kg\,N\,ha^{-1}$, $60\,kg\,P_2O_5\,ha^{-1}$, and $90\,kg\,K_2O\,ha^{-1}$ as is the tradition in the region. Half of N and the whole of P and K were given as 15 : 15 : 15 and in the form of K_2SO_4 (%50 K_2O) at planting, and the second part of the N was given before the first irrigation as NH_4NO_3 (%26 N). *Gossypium hirsutum* L. (var. Nazilli 84) was planted in each plot in 4 rows with 0.7 m between rows on 6 May 2003 for the first experiment and on 14 May 2006 for the second experiment.

Although some difficulties were observed at the beginning at seedling emergence in the plots with applied wastes, better growing performance was obtained on these plants with irrigation (see Table 5). The height of the plants of the 2006 experiment was noticeably shorter when compared with 2003 experiment. The reason for this outcome is the climatic conditions that the number of sunny days which temperature exceeded 30°C in May, June, and July in 2006 was much less when compared with the same period of 2003.

Leaf samples were taken at the beginning of flowering (10 July 2003 and 20 July 2006) and fibre samples were taken at harvest (30 September 2003 and 4 October 2006). Leaf B and heavy metal content were determined as described above.

Seed cotton weight was obtained as the mean value of 5 seed cotton weights of each of 10 plants per plot. Ginning fibre out-turn (%) was determined according to the following equation:

$$\text{Ginning fibre out-turn (\%)} = \frac{\text{Fibre content (g)}}{\text{Seed cotton weight (g)}} \times 100. \quad (1)$$

Table 3: Chemical properties of the treated soils (0–20 cm) at harvest in the two experiments.

Year	Treatments	pH	% Total soluble salt	% $CaCO_3$	% Organic matter	Available B ($mg\,kg^{-1}$)	Total ($mg\,kg^{-1}$) Pb	Ni	Cr	Co	Cd
2003	Control	7.1	<0.03	0.57	1.77	0.25	9.7^{a}	35	33	13	0.37
	Mineral fertilizer	6.8	<0.03	0.47	1.30	0.22	7.3^{ab}	27	29	11	0.30
	Oily cumin wastes	7.2	<0.03	0.50	1.83	0.27	6.7^{ab}	27	35	11	0.33
	Oily oregano wastes	7.3	<0.03	0.50	1.57	0.27	5.3^{b}	36	35	13	0.43
	Oilless oregano wastes	7.3	<0.03	0.57	2.20	0.31	4.3^{b}	34	32	13	0.30
	Minimum	6.8	<0.03	0.47	1.30	0.22	4.3	27	29	11	0.30
	Maximum	7.3	<0.03	0.57	2.20	0.31	9.7	35	35	13	0.43
	LSD	n.s.	n.s.	n.s.	n.s.	n.s.	3.37*	n.s.	n.s.	n.s.	n.s.
2006	Control	7.2^{a}	<0.03	1.0	0.50^{b}	0.19	3.8	31	28	12	Trace
	Mineral fertilizer	6.8^{b}	<0.03	1.0	0.60^{b}	0.37	3.7	30	28	10	Trace
	Oily cumin wastes	7.3^{a}	<0.03	1.2	1.10^{ab}	0.56	3.5	29	27	9	Trace
	Oily oregano wastes	7.2^{a}	<0.03	0.9	1.40^{a}	0.19	4.2	31	28	9	
	Minimum	6.8	<0.03	0.9	0.50	0.19	3.5	29	27	9	
	Maximum	7.3	<0.03	1.2	1.40	0.56	4.2	31	28	12	
	LSD	0.23**	n.s.	n.s.	0.61**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Values are an average of three replicates; n.s.: nonsignificant; LSD: least significant difference method. Means for treatments followed by the same letter are not significantly different, $^{*}p < 0.05$, $^{**}p < 0.01$.

Various quality parameters such as length, fineness, and elasticity of fibre were obtained using HVI (High Volume Instrument) 900-A equipment.

After harvest, soil samples were taken from each plot at a depth of 0–20 cm and changes in chemical properties were determined.

The data was analysed by one-factor randomized block design, and variance analysis was applied. Statistical analyses were made using the Tarist 4.01 DOS [14] package. Mean values were separated according to the least significant difference method at $p \leq 0.01$. Microsoft Excel 2010 was used for the correlation and regression analyses of the properties of soil, leaves, and fibres.

3. Results and Discussion

All of the wastes used showed lower heavy metal values than the accepted limit values (Pb: 150, Ni: 50, Cr: 100–150, Co: 25, and Cd: 1.5–3.0 $mg\,kg^{-1}$) [15] for a compost (Table 1). Both of the experimental soils were neutral and had no salinity problem, were low in $CaCO_3$ and organic matter contents, and were loamy sand in texture. The soils showed no pollution with respect to B, Pb, Ni, Cr, Co, or Cd content (Table 2) according to the values given as follows: B: 1; Pb, Ni, Cr: 100; Co: 50; Cd: 3 $mg\,kg^{-1}$ soil [16].

The pH, total salt, $CaCO_3$, and organic matter contents of soils taken from the treated plots after harvest are given in Table 3. Because of the climatic conditions different applications affected soil reactions significantly ($p < 0.01$) only in the 2006 experiment. No significant effects of the applications on the total soluble salt content of soil could be observed. The lack of change in total soluble salt value of controls and waste-application treatments indicated that these kinds of wastes carried no risk with respect to salinity. No significant differences in $CaCO_3$ percentages were observed between the applications. In the 2006 experiment, the organic matter content of the soils was affected significantly from oily oregano and cumin wastes. Bahtiyar [17] pointed out that organic wastes of various origins had recently been used as a soil amendment to increase or regulate the organic matter content of soil.

The boron content of soils after harvest varied between 0.22 and 0.31 in 2003 and between 0.19 and 0.56 $mg\,kg^{-1}$ in 2006 (Table 3). The differences between the treatments were not significant. For the 2006 experiment only the boron content of soil to which oily cumin wastes had been applied (0.56 $mg\,kg^{-1}$) was at the toxic limit value given by Güneş et al. as 0.5 $mg\,kg^{-1}$ [18]. Figure 1 demonstrates a positive significant relationship ($p < 0.01$) between boron and the organic matter content of soils in the 2003 experiment. The same relationship was also obtained by Tamcı [19] in East Mediterranean soils and by Seçer et al. [4] in Aegean soils.

The boron content of soil had a significant negative effect ($p < 0.05$) on the percentage of long fibres in the 2006 experiment as seen in Figure 2.

In the 2003 experiment, the total Pb, Ni, Cr, Co, and Cd contents of soils varied between 4.3 and 9.7, 27 and 35, 29 and 35, 11 and 13, and 0.30 and 0.43 $mg\,kg^{-1}$, respectively, after harvest (Table 3). Only the Pb content of treated soils varied significantly, and the oregano wastes significantly decreased the Pb content of soils. This result indicates that Pb has a high affinity for organic matter. Antoniadis et al. [20] pointed out that organic matter added with sludge had a key role in metal availability so that metal transfer coefficients decreased significantly with organic matter increase.

In 2006 especially, Pb values of soils were lower than in 2003 and no statistical differences could be observed between

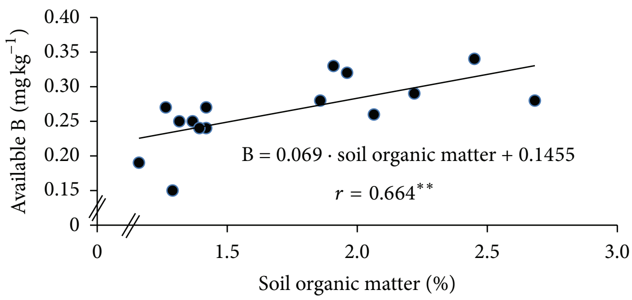

FIGURE 1: Relationship between organic matter and available B content of soil in the 2003 experiment ($^{**}p < 0.01$).

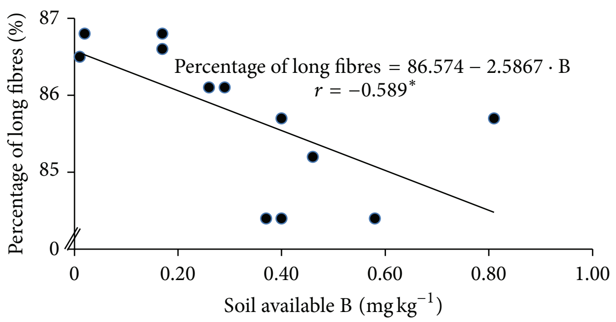

FIGURE 2: Effect of boron content of soil on percentage of long fibre in the 2006 experiment ($^{*}p < 0.05$).

the treatments. Compared with the toxic limit values given by Hasselbach [21] of 100 mg kg^{-1} for Pb and Cr, 50 mg kg^{-1} for Co, and 3 mg kg^{-1} for Cd, there was no pollution risk in soils treated with wastes with respect to these heavy metals in either of the experiments. Antoniadis et al. [20] reported 210 and 234 mg kg^{-1} total Ni content in 50 Mg ha^{-1} plots to which sewage sludge had been applied in the years 1996 and 1999, respectively.

No increase in boron and heavy metal contents of soils in the treatments compared with the beginning of the experiments can be explained by the organic origin of the wastes used. Similarly, in a study by Akrivos et al. [22], heavy metal content in no soil and plant tissues samples increased significantly as a result of sludge amendment. According to Tsadila et al. [23], trace element concentration increased multifold in the top 10 cm due to sludge application.

Negative correlations were observed between the Ni content of soil and plant height ($p < 0.01$) in 2006 (Figure 3) and seed cotton yield ($p < 0.05$) (Figure 4) in 2003. Akrivos et al. [22] observed low plant productivity with one of the soil types studied and this was attributed to the high concentration of Ni in the soil and low nutrient content of the soil.

In the 2003 experiment, ginning out-turn (%) was found to be negatively correlated ($p < 0.05$) with soil Co (Figure 5) while fibre fineness was positively affected by the Cr content of the soil ($p < 0.05$) (Figure 6).

Table 4 shows the boron and heavy metal contents of cotton leaves. Compared with the finding of Bergmann [24],

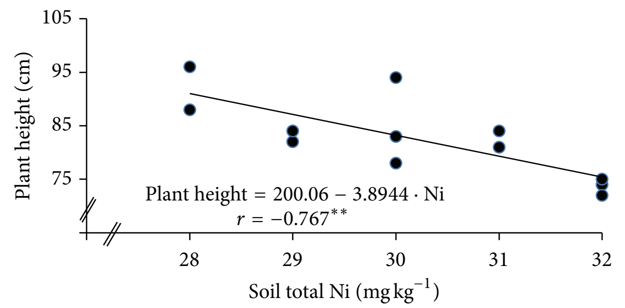

FIGURE 3: Regression curve between Ni content of soil and plant height in the 2006 experiment ($^{**}p < 0.01$).

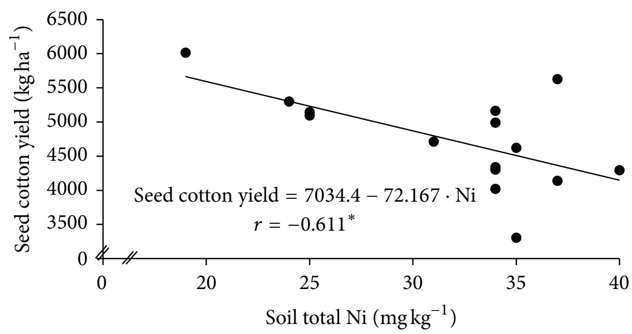

FIGURE 4: Relationship between Ni content of soil and seed cotton yield in the 2003 experiment ($^{*}p < 0.05$).

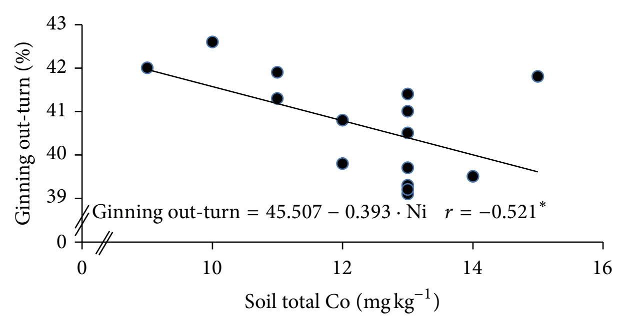

FIGURE 5: Relationship between Co content of soil and ginning out-turn (%) in the 2003 experiment ($^{*}p < 0.05$).

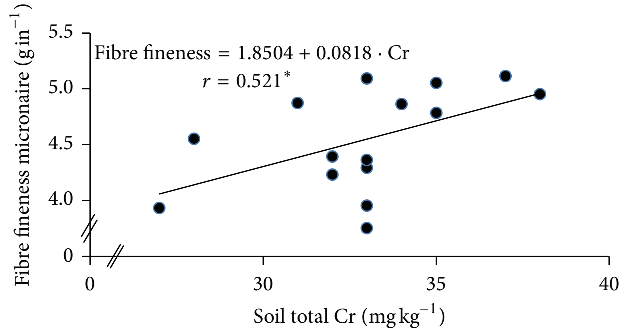

FIGURE 6: Relationship between Cr content of soil and fibre fineness (micronaire) in the 2003 experiment ($^{*}p < 0.05$).

Table 4: The effect of treatments on the boron and heavy metal content of cotton leaves (dry weight basis) in the two experiments.

Year	Treatments	mg kg^{-1}					
		B	Pb	Ni	Cr	Co	Cd
2003	Control	13	3.1	1.9	0.1	1.9	0.30
	Mineral fertilizer	16	5.4	2.3	0.4	2.0	0.20
	Oily cumin wastes	18	4.1	1.8	0.5	2.1	0.20
	Oily oregano wastes	18	5.1	1.5	0.3	1.9	0.20
	Oilless oregano wastes	17	5.6	1.7	0.4	2.3	0.20
	Minimum	13	3.1	1.5	0.1	1.9	0.20
	Maximum	18	5.6	2.3	0.5	2.3	0.30
	LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
2006	Control	15	4.3	1.9	0.16	1.4	0.14
	Mineral fertilizer	16	3.9	2.4	0.06	1.1	0.20
	Oily cumin wastes	17	4.3	2.0	0.22	1.5	0.23
	Oily oregano wastes	15	3.4	1.6	0.16	0.9	0.15
	Minimum	15	3.4	1.6	0.06	0.9	0.14
	Maximum	17	4.3	2.4	0.22	1.5	0.23
	LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Values are an average of three replicates. LSD: least significant difference method; n.s.: nonsignificant.

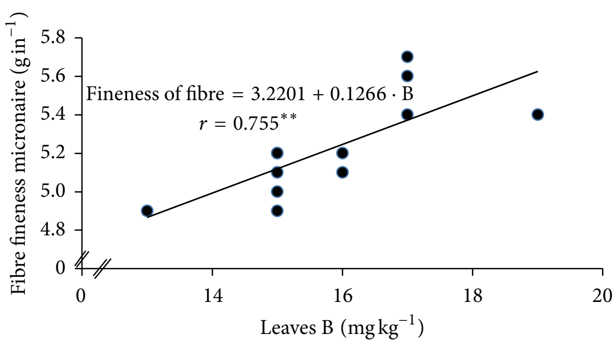

Figure 7: Regression curve between B content of leaves and fineness of fibre (micronaire) in the 2006 experiment ($^{**}p < 0.01$).

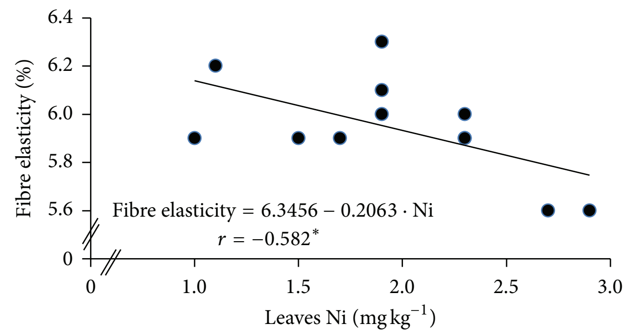

Figure 8: Regression curve between Ni content of leaves and fibre elasticity in the 2006 experiment ($^{*}p < 0.05$).

who gives 20–80 mg kg^{-1} B as sufficient, and Bennett William [25], who gives 10–20 mg kg^{-1} B as critical, the boron values of experimental leaves were insufficient, with 13–18 mg kg^{-1} in 2003 and 15–17 mg kg^{-1} in 2006. Dell and Huang [26] extensively reviewed physiological responses to B deficiency in higher plants in the whole plant and at the organ level. Impacts of B mobility on B uptake by plants are thoroughly discussed by Brown and Shelp [27]. Figure 7 demonstrates a significant positive ($p < 0.05$) relationship between B content of leaves and the fineness of fibre found in the 2006 experiment.

According to Dell and Huang [26], there is a great diversity among species of effects of low B on reproductive growth and within the same species between sites and seasons. Boron in plant cell walls was discussed in detail by Matoh [28] and the particular importance of B interactions with cell wall components, membranes, enzymes, sugars, and polyols was discussed by Power and Woods [29]. According to Hu et al. [30], species with a high pectin content would have a higher tissue-B requirement.

Table 4 indicates the Pb, Ni, Cr, Co, and Cd contents of leaves for the experimental year 2003 as being between 3.1 and 5.6, 1.5 and 2.3, 0.1 and 0.5, 1.9 and 2.3, and 0.2 and 0.3 mg kg^{-1}, respectively. Nearly all the values of the heavy metals of leaves found in the 2006 experiment had not differed too much from the experimental year 2003. The generally accepted level of Co in the dry matter of plants is 5 mg kg^{-1} [31]; the normal Cd level is between 0.2 and 0.3 mg kg^{-1} [24], and that of Pb is between 10 and 35 mg kg^{-1} [32]. According to Kabata-Pendias and Pendias [31], the normal Cr content of plants is between 0.1 and 0.5 mg kg^{-1}, and the critical value is 2 mg kg^{-1}. Antoniadis et al. [20] reported 3.88, 3.17, 2.73, and 2.98 mg kg^{-1} nickel in cotton leaves in the years 1996, 1997, 1998, and 1999, respectively.

Angelova et al. [33] compared cotton with flax and hemp plants with respect to heavy metal accumulation and indicated that in cotton the accumulation of heavy metals was in the following order: leaves > seed > roots > stem. This researcher determined high heavy metal contents in cotton leaves (Pb: 29.6 mg kg^{-1}, Cd: 0.6 mg kg^{-1}) which were at a distance of 0.5 km from the pollution source, and much smaller concentrations of heavy metals (Pb: 2.6 mg kg^{-1}, Cd: 0.20 mg kg^{-1}) were obtained in cotton leaves which were 15 km away from the pollution source. According to these statements, the Pb and Cd values of our experimental cotton leaves indicate the absence of pollution from any source. In sunflowers, the dry mass and the height of plants were reduced in the presence of a high concentration of Pb in the leaf area [34].

Of the heavy metals in leaves, only Ni content showed a negative correlation with fibre elasticity ($p < 0.05$) in the 2006 experiment, as can be seen in Figure 8. Antoniadis et al. [20] demonstrated a significant correlation between cotton yield and the Ni content of leaves with the lowest r value ($r = 0.545$ at $p < 0.05$).

Singh and Rao [35] found that higher concentrations of Ni (>10 μg mL^{-1}) inhibited nodulation, nitrogenase activity, and plant growth but that Ni at 1 μg mL^{-1} had a beneficial effect with enhanced bacterial population, plant growth,

Table 5: Yield and quality parameters of cotton of the experiments from 2003 and 2006.

Year	Treatments	Plant height (cm)	Seed cotton yield (kg ha^{-1})	Ginning out-turn (%)	Percentage of long fibre (%)	Fineness of fibre micronaire (g in^{-1})	Fibre elasticity (%)
2003	Control	105^{b}	4474^{bc}	39.5^{c}	84.13	4.50	4.90
	Mineral fertilizer	117^{ab}	5049^{ab}	41.3^{ab}	84.37	4.53	5.23
	Oily cumin wastes	120^{a}	5575^{a}	42.1^{a}	84.23	4.57	5.17
	Oily oregano wastes	120^{a}	4689^{abc}	41.0^{b}	84.57	5.03	5.47
	Oilless oregano wastes	111^{ab}	3885^{c}	39.3^{c}	84.23	4.20	4.77
	Minimum	105	3885	39.3	84.13	4.20	4.77
	Maximum	120	5575	42.1	84.57	5.03	5.47
	LSD	13.912^{*}	1061.6^{**}	0.932^{**}	n.s.	n.s.	n.s.
2006	Control	78	2270	—	86	5.1	6.1
	Mineral fertilizer	79	2333	—	85	5.2	5.8
	Oily cumin wastes	86	2263	—	85	5.5	5.8
	Oily oregano wastes	86	2110	—	87	5.1	6.1
	Minimum	78	2110	—	85	5.1	5.8
	Maximum	86	2333	—	87	5.5	6.1
	LSD	n.s.	n.s.	—	n.s.	n.s.	n.s.

Values are an average of three replicates; n.s.: nonsignificant; LSD: least significant difference method. Means for treatments followed by the same letter are not significantly different, $^{*}p < 0.05$, $^{**}p < 0.01$.

and fixation. These authors reported that, to increase the productivity of pulse crops that are dependent on biologically fixed N, Ni should be used as an additional micronutrient. According to Gerendás et al. [36], Ni is required by higher plants for urease activity, and Co does not replace Ni in this respect.

Only the yield and fibre quality parameters of cotton, which showed significant correlations with the boron and heavy metal of soils and leaves, have been summarized in Table 5. The oily cumin wastes, which had generally lower heavy metal contents (see Table 1), had a pronounced effect on most of the yield parameters, especially by the 2003 experiment.

4. Conclusion

The organic matter content of the soil increased significantly with oily oregano and cumin wastes in the 2006 experiment. No pollution risk was observed in soil with respect to total Pb, Ni, Cr, Co, and Cd content. Oregano wastes decreased the Pb content of the soil significantly in 2003 experiment. Boron and heavy metals affected percentage of long fibres, fineness of fibres, seed cotton yield, fibre elasticity, and ginning out-turn differently. Oily cumin wastes which had generally a lower heavy metal content had a pronounced effect on most of the yield parameters, especially in the 2003 experiment. These kinds of organic wastes can be recommended to use to grow cotton without any risk from the aspect of boron and heavy metal pollution.

Competing Interests

The authors declare that they have no competing interests.

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