Heavy metal uptake by barley and sunflower grown in abandoned animal lagoon soil

MADRID F. and KIRKHAM M.B.

Instituto de Recuros Naturales y Agrbiologia de Sevilla, Consejo Superior de Investigaciones Cientaficas (CSIC), Apartado de Correos 1052, 41080 Sevilla, Spain (FM), and Department of Agronomy, Kansas State University, Manhattan, KS 66506-5501, USA (MBK)

Abstract

Animal waste storage lagoons are used on farms and at concentrated animal operations. However, due to environmental regulations, lagoons in the USA are being closed. The soils at the bottom of lagoons are polluted by many contaminants, including heavy metals, and need to be remediated. Phytoremediation may be one method to restore them. The use of chelates, in conjunction with phytoremediation, is advocated for enhancing the clean-up of soil contaminated by heavy metals. No information is available concerning the efficacy of chelates applied to abandoned animal-waste lagoon soil for metal removal, and no work reports if chelate-solubilized heavy metals in the lagoon soil can pollute drainage water. Our objectives were to determine 1) if plants (barley, *Hordeum vulgare* L., and sunflower, *Helianthus annuus* L.) would grow in animal waste lagoon soil, and 2) the effect of the chelate, EDTA (ethylenediamine-tetraacetic acid), on uptake and movement of heavy metals in the lagoon soil.

Under greenhouse conditions, plants grew for 60 days in pots (16 cm diameter; 18.5 cm tall) with soil that came from a closed dairy feedlot lagoon. Control pots had no plants. Seventeen days before the end of the experiment, EDTA was added to half of the pots at a rate of 0.5 g per kg soil. The plants, especially sunflower, germinated poorly in the lagoon soil. Of 240 barley seeds planted, 45 germinated (19%); of 360 sunflower seeds planted, 7 germinated (2%). High penetration resistance of the lagoon soil appeared to be the cause of the poor growth. Barley grown with the chelating agent EDTA in the soil accumulated higher levels of Fe, Mn, Ni, and Pb than barley grown without EDTA. Even though there was a tendency for sunflower grown with EDTA to accumulate more heavy metals than sunflower grown without EDTA, differences between the two treatments were not significant. With or without EDTA, concentrations of Cd, Ni, and Pb were higher than normal in plants grown in the lagoon soil. This suggested that these toxic heavy metals are concentrated in the lagoon soil. Concentration of Cu in the leachate from the pots with EDTA was not elevated above drinking water standards, except in one instance (pots with no plants). Concentration of Fe in leachate from all pots with EDTA was elevated above drinking water standards. In general, pots without EDTA did not leach detectable amounts of Cu and Fe. The results showed that barley would be better choice for phytoremediation of the dairy lagoon soil than sunflower and that EDTA can solubilize Fe in lagoon soil and raise its concentration in leachate above drinking water standards.

Introduction

Animal-waste lagoons are large basins that are dug into soil to hold waste from livestock. During construction, the soil at the bottom of a lagoon is compacted from native soil or lined with clay that has been brought into the region. Consequently, they are called earthen-lined animal waste lagoons. Lagoons range in size from small ponds on family farms to large ones (e.g., 8 ha) run by corporations. While in use, the constituents of lagoons that could adversely affect the ground water are nitrate-nitrogen, ammonium-nitrogen, chloride, phosphorus, and heavy metals (Ham and DeSutter, 2000).

In September, 1999, Hurricane Floyd moved through North Carolina's swine-producing areas, and flooded hog lagoons. The state is now forcing operators to close animal-waste lagoons that pose water-pollution risks (American Society of Agronomy, 2000). Heavy rains may cause animal-waste lagoons to overflow, washing their contents into rivers (Mallin, 2000).

All lagoons at some point in time are closed, either because of environmental regulations or abandonment of animal operations. The uptake nitrogen by crops grown in animal-waste lagoon soil upon closure has been studied (Zhu, 2001; Liphadzi *et al.,* 2002). But apparently no work has been done to study uptake of heavy metals in abandoned animal waste lagoon soil and their movement to drainage water. The trace elements added to swine diets are Cu, Fe, I, Mn, Se, and Zn (Tokach *et al.,* 1997). Of these, Cu, Fe, Mn, and Zn are heavy metals, which have a density greater than 5.0 g mL^{-1}. Trace elements in beef diets contain the same trace elements plus Co, another heavy metal (Sindt *et al.,* 2001). These heavy metals at the bottom of animal waste lagoons contaminate the soil, and their uptake and movement after lagoon closure are unknown.

Phytoremediation is the use of green plants to remove pollutants from soil. The use of chelates, in conjunction with phytoremediation, is advocated for enhancing the clean-up of soil contaminated by heavy metals (Thayalakumaran *et al*., 2000; Lasat, 2002). Ethylenediamine-tetraacetic acid (EDTA) is the most commonly used chelating agent. Chelates increase solubility of heavy metals for plant uptake during phytoremediation (Brooks, 1998; Salt *et al*., 1998). The enhanced phytoextraction results in high metal concentration in plants (Deram *et al*., 2000). The contaminated plants then are ashed and placed in a confined disposal area. If the metals are valuable, they can be extracted from the ash and recycled (Anderson *et al*., 1998).

No information is available concerning the efficacy of chelates applied to abandoned animal-waste lagoon soil for metal removal, and no work reports if chelate-solubilized heavy metals in the lagoon soil can pollute drainage water. Our objectives were to determine 1) if plants (barley and sunflower) would grow in animal waste lagoon soil, and 2) the effect of the chelate, EDTA, on uptake and movement of heavy metals in the lagoon soil.

Materials and Methods

The experiment was carried out in a greenhouse located at Kansas State University in Manhattan, KS (39° 08' N 9637' W, 314 m above sea level). Dairy-feedlot lagoon soil from McPherson, a town in central Kansas, was used in the study. The lagoon was owned by a large feed company. It was constructed in 1987 and is the drainage basin for about 1000 animals (18 pens). The lagoon became dry due to a drought in Kansas, and the company took advantage of the drought to clean out the sludge in the lagoon. The sludge was placed on adjacent fields. On 6 Oct. 2000, when the bottom of the lagoon thus was exposed, the top 30 cm of lagoon soil was scraped off and mixed up and put in closed-top, plastic-lined trash cans and transported to Kansas State University. The gravimetric moisture content of the soil, when received, and determined on 10 Oct. 2000, was 16%. On 11 Oct., 18 black plastic pots, 16 cm in diameter and 18.5 cm tall, were filled with 2500 g each with the wet dairy lagoon soil. The soil was hard and broken up by hand before it was placed in the pots. The pots had drainage holes on the bottom. Each pot was placed in a larger pot without drainage holes. Drainage water was captured by placing a flask under the drainage holes of the interior pot. The flask sat inside the outer pot. This way, the soil at the bottom of the pot would not become anaerobic and free drainage could occur. The gravimetric moisture content in the pots on 11 Oct. was 8.5%. On 13 Oct., each pot got 700 mL water. On 17 Oct., seeds of barley (*Hordeum vulgare* L. 'Weskan') and sunflower (*Helianthus annuus* L. 'Hysun 354') were planted in 12 of the pots (6 pots with barley; 6 pots with sunflower). Twenty barley seeds were planted per pot and 30 sunflower seeds were planted per pot. Six pots had only the lagoon soil and no plants. On 30 Oct., because of poor germination, the pots were replanted with 20 barley seeds per barley pot and 30 sunflower seeds per sunflower pot. On 7 Nov., eight days after the second replanting, 45 out of 240 barley seeds planted had germinated, and 7 out of 360 sunflower seeds planted had germinated. A separate germination test was done in which the sunflower and barley seeds were placed in Petri dishes with 15 g of lagoon soil or 15 g of a common agricultural soil of the region (Haynie very fine sandy loam; coarse-silty, mixed, superactive, calcareous, mesic Mollic Udifluvents) plus 8 mL water per plate. Six seeds were in each plate. The germination test showed that the 96% of the barley seeds germinated in the Haynie soil and 92% germinated in the lagoon soil; 67% of the sunflower seeds germinated in the Haynie soil and 63% germinated in the lagoon soil. The poor germination in the pots, therefore, appeared to be due to the high mechanical resistance of the lagoon soil. The seeds that germinated in the germination study were transplanted into the pots on 8 Nov., so each pot had 10 plants. Some barley pots already had 10 or more plants and no plants were transplanted into those pots. The barley pots that had more than 10 plants per pot were thinned to 10 plants per pot on 23 Nov.

On 29 Nov. 2000, the disodium dihydrate salt of EDTA ($C_{10}H_{14}N_2O_8Na_2 \cdot 2H_2O$; molecular weight 372.2) was added at a rate of 0.5 g EDTA salt per kg dry soil to half of the pots. This is the recommended rate for use in chelate-facilitated phytoremediation (Robinson *et al*., 1999). Because each pot had 2500 g lagoon soil, 1.25 grams EDTA salt were added per pot. On an area basis, this was 6.25 mg cm^{-2}. The salt was dissolved in water, and 75 mL of the EDTA solution were added to each pot with EDTA to give the 0.5 g EDTA salt kg^{-1} soil rate.

Before EDTA was added, water was not added each day to the pots. It was added to maintain adequate moisture for crop growth. After EDTA addition, 180 mL were added daily to each pot. The leachate of the previous day was collected before a new irrigation. The leachate was collected until the last day of the experiment, 16 Dec. (60 days after the first planting and 17 days after the addition of EDTA).

Plant height was measured on 4, 8, 11, and 14 Dec. (5, 9, 12, and 15 days after EDTA was added). Fresh weight of the plants was measured on 16 Dec., the day of harvest, and on 19 Dec. dry weight was measured, after drying at 70 °C for 48 h. The lagoon soil at the beginning of the experiment, leachate, and plants and soil at harvest were analyzed using standard methods (Madrid *et al*., 2002). Leachate was analyzed for Cu and Fe. Plants were analyzed for amounts of four essential heavy metals (Cu, Fe, Mn, and Zn) and three non-essential heavy metals (Cd, Ni, and Pb). Soil was analyzed for extractable amounts of Cu, Fe, Mn, and Zn, as well as pH and soluble salts. Metals in the plants and soil were determined by using ICP-ES (inductively coupled plasma-atomic emission spectroscopy) (Fison Instruments, now owned by Thermo Optek Corp., Franklin, Massachusetts, USA). Detection limits in mg kg^{-1} for the ICP-ES were Cd, 0.05; Cu, 0.01; Fe, 1.00; Mn, 0.60; Ni, 0.10; Pb, 0.10, and Zn, 0.05. Copper and Fe in the leachate were determined by using a flame atomic absorption spectrometer (Perkin Elmer Model No. 3110). It had a detection limit of 0.01 g mL^{-1} for Cu and 1 g $mL^{-1}$for Fe.

On 17 Nov., 18 Nov., and 21 Dec. (6 da after harvest), penetration resistance of the soil in all 18 pots was measured with a pocket penetrometer (Model No. 77114, Forestry Suppliers, Inc., Jackson, Mississippi, USA). Penetration resistance of 1500 g of the Haynie soil watered to pot capacity (0.30 m^3 m^{-3}) on 17 Nov. was measured on the same dates for comparison.

The experiment was a completely random one with 6 treatments (barley with and without EDTA; sunflower with and without EDTA; pots with no plants, but with and without EDTA) and 3 replications per pot.

Results and Discussion

Lagoon soil

The lagoon soil had a pH of 8.0; 36% sand, 39% silt, and 25% clay; and an organic matter content of 0.4%. Extractable amounts of P (Bray-1 test), Ca, K, Mg, and Na were 14, 1276, 441, 575, and 170 mg kg^{-1}, respectively, and Cl^- was 133 mg kg^{-1}. Ammonium-N and nitrate-N in the lagoon soil were 97.0 and 0.9 mg kg^{-1}, respectively. Extractable amounts of Cu, Fe, and Mn were 1.9, 35, and 57 mg kg^{-1}, respectively, and extractable Zn was below detection limits (less than 0.05 mg kg^{-1}). The lagoon soil had a CEC of 13.3 cmol kg^{-1} and an electrical conductivity (soluble salts) of 1.318 dS m^{-1}. Total N in the lagoon soil was 400 mg $kg^{-1}$and total carbon was 1420 mg kg^{-1}.

Normal ranges for these analyses in mineral soils are given by Liphadzi *et al*., (2002). Calcium, K, Mg, Cl, and NH_4 were above normal levels. Under non-polluted conditions, Ca in soil ranges from 168 to 407 mg kg^{-1}; K ranges from 66 to 341 mg kg^{-1}; Mg ranges from 28 to 64 mg kg^{-1}; Cl^- ranges from 7 to 50 mg kg^{-1}; and NH_4-N ranges from 2.5 to 20 mg kg^{-1}.

The extractable concentrations of the four heavy metals were within normal ranges observed in non-contaminated soils. Zinc probably was within a normal range, but could not be detected using the equipment available. The range of extractable Zn in non-polluted soils ranges from 0.01 to 200 mg kg^{-1} (Kirkham, 1979). The extractable amounts of Cu in soils normally range from 0.002 to 180 mg $kg^{-1}$and for Mn, 15 to 1250 mg kg^{-1}. Soils need at least 2.5 mg kg^{-1}Fe in solution for plants to survive, but toxic upper limits for extractable Fe in soil are not known (Liphadzi *et al.,* 2002). The lagoon soil was not saline and had a low salinity ranking (soluble salts less than 2 dS m^{-1}).

Plant survival and penetration resistance

As noted, sunflower germinated especially poorly in the lagoon soil. At harvest, only 5 of the six sunflower pots had living plants in them (Pots 2, 5, 8, 11, and 14), and the numbers of plants per pot at harvest were 4, 6, 3, 2, and 5, respectively. No plants survived in Pot 6. Germination was probably poor for the sunflower because of the high strength of the lagoon soil.

On 17 Nov., pots without plants had a penetration resistance of 0.84±0.12 kg cm^{-2} (mean and standard deviation; n = 6). The pots with barley had a penetration resistance of 1.50±0.71 kg cm^{-2}. The pots with sunflower had a penetration resistance of 1.67±0.71 kg cm^{-2}. The Haynie soil had a penetration resistance of 0.50 kg cm^{-2}, and the dry lagoon soil had a penetration resistance of greater than 4.5 kg cm^{-2} (off scale of the penetrometer). On 18 Nov., the penetration resistances for pots with no plants, with barley, and with sunflower were 1.02±0.08, 2.04±1.12, and 2.05±0.91 kg cm^{-2}, respectively. One day after being watered to pot capacity, the Haynie soil had a penetration resistance of 0.75 kg cm^{-2}, and the dry lagoon soil had a penetration resistance of greater than 4.5 kg cm^{-2}. On 21 Dec. 2000, six days after the last watering and five days after harvest, all pots with lagoon soil had a penetration resistance greater than 4.5 kg cm^{-2}, and the Haynie soil (6 da after watering) had a penetration resistance of 2.25 kg cm^{-2}. The results showed that the mechanical resistance of the lagoon soil was high compared to an agricultural soil, and that plants growing in the lagoon tended to increase the penetration resistance of the soil.

Growth

The fresh weights per pot at harvest of barley without and with the EDTA (10 plants per pot) (± standard deviation; n = 3) were 10.4±6.1 and 2.4±0.6; for sunflower without and with EDTA, the fresh weights per pot were 6.9±0.3 and 4.1±2.8. The dry weights per pot at harvest of barley without and with EDTA were 1.49±0.97 and 0.58±0.16; for sunflower without and with EDTA, the dry weights per pot were 0.71±0.21 and 0.54±0.47.

Plant height increased little after EDTA was added, and the plants with EDTA were shorter than the plants without EDTA (Table 1).

Table 1 Height of barley and sunflower grown in dairy waste lagoon soil treated with the chelate, EDTA. The seeds were planted two times, on 17 Oct. 2000 and 30 Oct. 2000, because of poor germination. Mean and standard deviation are given (n = 9)

Days after first	planting Days after EDTA addition	Height (cm)	
		No EDTA	With EDTA
	Barley		
48	5	26.9±4.2	23.3±1.9
52	9	27.8±4.0	23.0±1.7
55	12	27.4±3.8	22.3±1.7
58	15	27.2±3.6	21.6±1.9
	Sunflower		
48	5	10.1±4.4	8.3±4.9
52	9	10.7±4.4	9.0±5.3
55	12	11.8±4.3	9.3±5.6
58	15	12.4±3.7	10.8±4.8

Metals in plants

Barley grown in soil with EDTA had a higher concentration of all seven heavy metals than barley grown in soil without EDTA (Table 2). Differences were significant (standard deviations did not overlap) for Fe, Mn, Ni, and Pb. Normal concentration ranges of the essential heavy metals Cu, Fe, Mn, and Zn in plants are 4 to 40, 25 to 300, 25 to 300, and 10 to 100 mg kg^{-1}, respectively (Beeson, 1941; Chapman, 1973). With EDTA, barley accumulated more Cu, Fe, and Mn than normally occurs in plants. The maximum amounts of Cd, Ni, and Pb that occur in plants under non-polluted conditions are 0.20, 1.0, and 5.0 mg kg^{-1}, respectively (Kirkham, 1977). With and without EDTA, barley had abnormal amounts of Cd and Ni, and with EDTA it had elevated levels of Pb. Even though the lagoon soil was not analyzed for Cd, Ni, and Pb, the barley-uptake results suggest that the lagoon soil was elevated in these toxic heavy metals.

Table 2 Concentrations at harvest of heavy metals in shoots of barley and sunflower grown in dairy waste lagoon soil treated with the chelate, EDTA. The seeds were planted two times, on 17 Oct. 2000 and 30 Oct. 2000, because of poor germination. Harvest was 60 days after the first planting. Mean and standard deviation are given (n = 3)

	Barley (mg kg^{-1})		Sunflower (mg kg^{-1})	
	No EDTA	With EDTA	No EDTA	With EDTA
Cd	1.5±1.6	2.1±1.2	1.93±1.30	0.65±0.07
Cu	18.7±11.4	47.6±19.7	20.2±4.8	20.7±2.7
Fe	97.4±16.3	588.3±90.5	238.0±147.9	356.8±36.0
Mn	198.2±41.9	928.6±244.7	395.0±118.5	452.8±94.0
Ni	2.8±3.0	15.5±6.7	4.5±2.8	5.4±2.4
Pb	4.6±6.3	28.0±11.4	2.1±3.1	5±3.0
Zn	13.4±3.4	18.7±5.8	32.4±12.4	26.5±8.1

Because sunflower grew so poorly, its root system probably did not penetrate the pots enough to pick up solubilized metals after the EDTA was added. No significant differences occurred in metal concentrations of sunflower grown with EDTA compared to sunflower grown without EDTA. As with barley, both with and without EDTA, sunflower had elevated levels of Cd and Ni. Lead was not unusually high in sunflower with or without EDTA. The sunflower-uptake results suggest that the lagoon soil had abnormal concentrations of the toxic heavy metals, Cd and Ni.

Soluble salts, pH, and metals in soil

At harvest, the soluble salts were low (less than 2 dS m^{-1}), as they were in the original analyses of the lagoon soil before the experiment, indicating that the poor germination of the seeds was not due to saline soil (Table 3). The pH at the end of the experiment was just about the same as it was at the beginning of the experiment (about 8.0). These results suggested little microbial activity was taking place in the lagoon soil, such as nitrification or microbial production of carbon dioxide, which lower the pH.

The extractable concentrations of the heavy metals in the soil with EDTA were slightly higher than those without EDTA, but differences were not significant. The extractable amounts of heavy metals (Cu, Fe, Mn, and Zn) fell within normal ranges observed in soils.

Table 3 Extractable concentrations at harvest of heavy metals in dairy waste lagoon soil treated with the chelate, EDTA, and growing either barley or sunflower. Lagoon soil in pots with no plants also was treated with EDTA. Controls received no EDTA. The seeds were planted two times, on 17 Oct. 2000 and 30 Oct. 2000, because of poor germination. Harvest was 60 days after the first planting. Soluble salts and pH of the lagoon soil at harvest also are shown. Mean and standard deviation are given (n = 3)

	No plants		Barley		Sunflower	
	No EDTA	With EDTA	No EDTA	With EDTA	No EDTA	With EDTA
			mg kg^{-1}			
Cu	1.7±0.2	2.0±0.3	2.0±0.2	2.2±0.2	1.9±0.1	2.2±0.1
Fe	29.4±3.5	36.1±5.4	36.2±1.9	40.1±2.8	35.8±4.5	44.5±5.5
Mn	51.0±7.6	57.2±5.6	43.6±11.5	57.7±2.2	46.6±4.7	52.2±2.2
Zn	0.4±0	0.5±0.1	0.5±0.1	0.6±0.1	0.5±0	0.6±0.1
			dS m^{-1}			
			Sol.			
Salt	1.59±0.27	1.53±0.10	1.33±0.08	1.60±0.09	1.16±0.17	1.36±0.12
			pH units			
pH7	7±0.17	9±0.1	7.9±0.1	7.9±0.1	8.0±0.1	8.0±0.1

Drainage water (leachate)

Amount of drainage water collected will be presented only for the last day, 16 Dec. (17 days after EDTA addition). Pots without plants and with no EDTA drained 146.0±1.8 mL (mean and standard deviation; n = 3). Pots without plants and with EDTA drained 149.7±11.1 mL. Barley pots without and with EDTA drained 126.2±3.8 and 142.2±2.1 mL, respectively. Sunflower pots without and with EDTA drained 128.7±7.1 and 142.1±15.0 mL, respectively. Thus, EDTA had no effect on drainage from pots without plants. But when plants were present, the EDTA must have killed the roots, because more water drained in the presence of EDTA than with no EDTA. Amount of drainage from pots with plants and EDTA was similar to that from pots with no plants.

Leachate from pots without EDTA had concentrations of Cu and Fe that were usually below detection limits (Table 4). Concentration of Cu and Fe in leachate from pots with EDTA was always above detection limits. Drinking water limits for Cu and Fe are 1.0 and 0.3 g mL^{-1}, respectively (Public Health Service, 1962). Six days after EDTA was added, the pots with no plants had a concentration of Cu in the leachate that exceeded drinking water standards (1.11 g mL^{-1}). On other dates, the standard was not exceeded. On all dates, Fe in the leachate from pots with EDTA exceeded drinking water standards.

Table 4 Concentration of Cu and Fe in leachate from pots with dairy waste lagoon soil treated with the chelate, EDTA, and growing either barley or sunflower. Lagoon soil in pots with no plants also was treated with EDTA. Controls received no EDTA. The seeds were planted two times, on 17 Oct. 2000 and 30 Oct. 2000, because of poor germination. EDTA was added on 29 Nov. 2000, 43 days after the first planting. Harvest was 16 Dec. 2000, 60 days after the first planting. Days after EDTA addition (DOE) are shown. Mean and standard deviation are given (n = 3). Only one sample was analyzed per day to determine leachate concentration from pots with no EDTA

DOE	No plants		Barley		Sunflower	
	No EDTA	With EDTA	No EDTA	With EDTA	No EDTA	With EDTA
			Copper (g mL^{-1})			
2	0[†]	0.94±1.08	0	0.26±0.06	0	0.38±0.14
6	0.01	1.11±1.30	0.01	0.38±0.07	0.01	0.28±0.24
7-8	0	0.69±0.59	0	0.38±0.10	0	0.36±0.29
10	0	0.32±0.13	0	0.43±0.13	0	0.22±0.21
11	0.01	0.12±0.06	0.01	0.19±0.03	0.01	0.16±0.19
15	0.02	0.17±0.19	0.02	0.18±0.05	0.02	0.09±0.08
			Iron (g mL^{-1})			
2	0[‡]	14±11	0	6±4	0	16±5
6	0	11±10	0	7±1	0	11±5
7-8	0	7±3	0	6±2	0	14±7
10	1	4±1	1	7±2	1	12±2
11	2	7±5	2	5±2	2	12±5
15	?					

[†] Detection limit for Cu was less than 0.01 g mL^{-1}
[‡] Detection limit for Fe was less than 1 g mL^{-1}
[?] Not analyzed

The concentrations of Fe in the leachate were higher in the leachate from the pots with sunflower compared to the pots with barley. This is probably because the sunflower grew poorly in the lagoon soil. The Fe concentration in leachate from sunflower pots was usually higher than the Fe concentration in leachate from pots with no plants. This suggested that the sunflower created preferential flow paths through which the leachate went that were not present in the soil without sunflower. The results showed that if EDTA is added to soil to solubilize metals for plant uptake during phytoremediation, the drainage water may be polluted with the metals, if plants do not take them up.

Conclusions

Barley and sunflower were grown in soil from the bottom of a closed dairy lagoon to see if plants would grow in the polluted soil, and, if so, if they would take up heavy metals solubilized by EDTA in the lagoon soil. The plants, especially sunflower, germinated poorly in the lagoon soil. Of 240 barley seeds planted, 45 germinated (19%); of 360 sunflower seeds planted, 7 germinated (2%). High penetration resistance of the lagoon soil appeared to be the cause of the poor growth. Barley grown with the chelating agent EDTA in the soil accumulated higher levels of Fe, Mn, Ni, and Pb than barley grown without EDTA. Even though there was a tendency for sunflower grown with EDTA to accumulate more heavy metals than sunflower grown without EDTA, differences between the two treatments were not significant. With or without EDTA, concentrations of Cd, Ni, and Pb were higher than normal in plants grown in the lagoon soil. This suggested that these toxic heavy elements are concentrated in the lagoon soil. Concentration of Cu in the leachate from the pots with EDTA was not elevated above drinking water standards, except in one instance (pots with no plants). Concentration of Fe in leachate from all pots with EDTA was elevated above drinking water standards. In general, pots without EDTA did not leach detectable amounts of Cu and Fe. The results showed that barley would be better choice for phytoremediation of dairy lagoon soil than sunflower and that EDTA can solubilize Fe in lagoon soil and raise its concentration in leachate above drinking water standards.

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