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These authors did report concentrations as high as 45 ppm for crops located near roadways. Marten and Hammond (5) found 12.5 ppm Pb in bromegrass (*Bromus inermis* L.) on soil of unspecified pH containing 680 ppm Pb.

None of the concentrations reported here are in the range of 120 to 150 ppm considered toxic for cattle and horses, but could possibly lead to subclinical symptoms (2).

It appears that raising the pH of acid Pb contaminated soils by liming, combined with a suitable choice of plant species and proper grazing management, could substantially reduce the entry of Pb into the food chain.

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Lead Uptake by Lettuce and Oats as Affected by Lime, Nitrogen, and Sources of Lead[1]

Matt K. John and C. Van Laerhoven[2]

ABSTRACT

Uptake of lead by lettuce (Lactuca sativa L.) and oats (Avena sativa L.) as a result of application of lime, nitrogen, and various sources of lead to the soil was studied in a growth chamber experiment. Soil application of lead increased the uptake of lead by lettuce to a greater degree than by oats. Application of lime repressed the uptake of added lead by both plants, while application of low levels of nitrogen reduced the uptake of lead by lettuce and oat roots only. Application of lead chloride lowered the amount of sulfur and phosphorus in plants, but levels of other elements studied were not affected by any lead treatment.

Additional Index Words: heavy metal, Lactuca sativa, Avena sativa.

The recognition of potential health hazards associated with lead entering the food cycle has brought attention to the levels of lead in soils and plants. Increased amounts of lead in plant and soil samples collected near highways, metal smelting plants, from orchards sprayed with lead arsenate as insecticide, and in industrial and urban areas have been reported (Cannon and Bowles, 1962; Chisholm and Bishop, 1967; Marten and Hammond, 1966; Motto et al., 1970; Page and Ganje, 1970; Purves, 1967; and, Warren and Delavault, 1962).

Previous studies presented conflicting information regarding the lead uptake by plants. Many workers (Keaton, 1937; Kloke and Riebartsch, 1964; MacLean et al., 1969; Marten and Hammond, 1966; and, Mitchell and Reith, 1966) indicated that lead was translocated to the aboveground plant portions in limited quantities even when grown on soil containing substantial amounts of lead. However, significant increases in lead content of top growth due to soil application of lead are reported by Jones and Hatch (1945) and by Warren and Delavault (1962). Motto et al. (1970) suggested that observed increases in lead content of plants were due mainly to accumulation of lead as particulate matter on the surface of plants.

The presence of lead in agricultural soils was reported previously (John, 1971). However, the influence of soil properties and agricultural practices such as lime and fertilizer application upon lead uptake by plants requires further study. This study attempts to provide more information concerning the absorption of lead by plants under various treatments of lead, lime, and nitrogen.

MATERIALS AND METHODS

The soil used in this study was the Ap horizon of Hjorth silty clay loam collected near Agassiz, British Columbia, Canada. The soil had a pH of 3.8 in 1*N* KCl, 17.4% oxidizable organic matter, 45.5 meq/100 g of cation exchange capacity, and was 14% base saturated.

Lead, lime, and nitrogen treatments, as described in Table 1, were applied by mixing appropriate amounts of $PbCl_2$, $PbCO_3$, $Pb(NO_3)_2$, NH_4NO_3, or $CaCO_3$ salt with the soil. The soil was brought to field capacity in 1-liter styrene cups and incubated in growth chambers at 25 ± 2C for 30 days.

Oat seedlings (*Avena sativa* L. cv. 'Fraser') were grown using a modified Stanford-DeMent type bioassay (Stanford and DeMent, 1957) in 400 g of quartz sand. Hoagland solution was used to maintain vigorous growth, and seedlings were thinned to 7 plants per pot. After 14 days, the bottom portion of the cup containing seedlings was removed, and seedlings were nested on top of treated soil. The trials were conducted in a controlled environment consisting of a 16-hour light, 8-hour darkness cycle, with a temperature of 25 ± 2C and relative humidity of 75 ± 5%. Light was provided by cool white fluorescent lamps. Nutrients were supplied through Hoagland solution without nitrogen.

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Table 1—Influence of lead, lime, and nitrogen treatments on yield and lead content of lettuce and oats.

Treatment		Yield, g dry weight/pot			Lead content, ppm in dry matter			Transport index in oats, %*
		Lettuce leaves	Oat tops	Oat roots	Lettuce leaves	Oat tops	Oat roots	
				Effect of Lead Treatments†				
0 ppm Pb	-	0.76 a	5.87 a	0.78 a	50.0 a	4.4 a	20.3 a	62.0
1000 ppm Pb	$PbCl_2$	0.49 c	6.08 a	0.87 a	138.9 c	37.1 c	59.1 b	81.4
1000 ppm Pb	$PbCO_3$	0.63 b	5.91 a	0.79 a	126.0 b	28.6 b	59.2 b	78.3
1000 ppm Pb	$Pb(NO_3)_2$	0.57 bc	6.00 a	0.80 a	140.6 c	35.7 c	58.6 b	82.1
				Effect of Lime Treatments‡				
No lime	-	0.12 a	6.15 b	0.86 a	173.7 b	40.1 b	58.8 b	83.0
1 g/100 g	$CaCO_3$	1.10 b	5.78 a	0.76 a	54.0 a	12.8 a	39.7 a	71.1
				Effect of Nitrogen Treatments§				
0 ppm N	-	0.69 b	5.72 a	0.78 a	115.1 b	28.7 a	55.6 b	79.1
50 ppm N	NH_4NO_3	0.69 b	6.06 a	0.86 a	101.6 a	24.0 a	50.4 b	77.1
500 ppm N	NH_4NO_3	0.45 a	6.11 a	0.79 a	124.9 c	26.6 a	42.0 a	83.1

* Transport index = (mg of lead in oat tops per pot/mg of lead in oat tops and roots per pot) x 100.
† Means for three nitrogen treatments at two lime treatment rates replicated three times.
‡ Means for three nitrogen treatments at four lead treatment rates replicated three times.
§ Means for four lead treatments at two lime treatment rates replicated three times. Means within a plant part and treatment effect section, followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

After growing on treated soil for a 21-day period, oat tops and roots in the quartz layer were harvested. The dry weight yield of each portion was recorded.

Similar techniques were used in growing lettuce (*Lactuca sativa* L. cv. 'Salad Bowl') on the same soil for a 30-day period, except that roots were not harvested.

Oven-dry plant samples were digested in 3:1 nitric-perchloric acid mixture, and elemental determinations performed via atomic absorption spectrophotometry, except that phorphorus was determined colorimetrically with ascorbic acid (John, 1970a), sulfur was determined by the turbidimetric method (Tabatabai and Bremner, 1970), and nitrogen determined by the method described by Bremner (1965). The computer methods of acquisition, reduction, and statistical analysis of the data were employed as previously described (John, M. K. 1970. Computerized acquisition and interpretation of soils data. Agron. Abstr. p. 138).

RESULTS

Yield—Lead application reduced the lettuce yield significantly, whereas yields of oat top growth and roots were not affected (Table 1). Lime had a significant effect upon yields of lettuce and oat shoots, but had no effect on yield of roots. Nitrogen treatments did not affect yield of oats but the high rate of application reduced the lettuce yield significantly.

Lead Content—Soil application of lead affected the lead content of all plant parts studied (Table 1). The plant species and plant parts differed greatly in their lead content, lead content in lettuce being much higher than in oat parts. Although no differences between sources of lead were observed with regard to the content of oat roots, lead content of the above-ground portions of both lettuce and oats was significantly less when the source was $PbCO_3$ rather than $PbCl_2$ or $Pb(NO_3)_2$. The increased transport index when lead was added shows that the movement into the above-ground portion of oat plants was enhanced.

Effect of Lime and Lead Treatment—The interaction of lime and lead treatments significantly affected the lead content of both lettuce and oat tops but did not affect the oat root content (Table 2). Addition of 1,000 ppm lead resulted in an almost four-fold increase in the lead content of lettuce grown on unlimed soil, whereas only small increases were found when the soil was limed. Similarly, lead in oat tops increased from 3.2 ppm to 57.4 ppm as the result of application of 1,000 ppm lead, as $PbCl_2$, to unlimed soil, whereas the corresponding increase for limed soil was only from 5.6 ppm to 16.8 ppm lead.

Interaction of Lead and Nitrogen Treatment—In lettuce leaves, nitrogen application in the absence of lead application caused a decrease in lead content (Table 3). However, when lead was added, lead content of all plant parts varied significantly depending upon the source of lead and rate of nitrogen applied.

Interaction of Lime and Nitrogen—When no lime was applied, nitrogen treatments gave significantly different

Table 2—The effect of lead and lime treatments on the lead content of lettuce and oats.

Plant material	Lime treatment	Lead, ppm in dry matter			
		No Pb	$PbCl_2$	$PbCO_3$	$Pb(NO_3)_2$
Lettuce leaves	0	57.3 b*	223.6 d	197.9 c	216.1 d
	Lime	42.6 a	54.3 ab	54.1 ab	65.0 b
Oat tops	0	3.2 a	57.4 d	45.3 c	54.4 cd
	Lime	5.6 a	16.8 b	11.8 ab	17.0 b
Oat roots[ns]†	0	19.3	73.2	74.4	68.6
	Lime	21.2	44.9	44.1	48.7

* Means for three nitrogen treatments replicated three times. Means within the same plant part followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.
† Nonsignificant interaction of lead and lime at 5% level, from analysis of variance.

Table 3—The effect of lead and nitrogen treatments on the lead content of lettuce and oats.

Plant material	Nitrogen treatment	Lead, ppm in dry matter			
		No Pb	Pb Cl_2	$PbCO_3$	$Pb(NO_3)_2$
Lettuce leaves	0 ppm N	67.5 c*	161.9 g	102.1 d	128.7 ef
	50 ppm N	33.4 a	117.9 h	124.0 eh	131.0 ef
	500 ppm N	49.0 b	137.1 f	151.8 g	161.8 g
Oat tops	0 ppm N	4.7 a	49.5 e	24.8 c	35.6 bd
	50 ppm N	4.3 a	32.9 bcd	27.3 cd	31.6 bc
	500 ppm N	4.1 a	28.9 cd	33.6 bd	39.9 b
Oat roots	0 ppm N	20.4 a	75.1 e	58.7 cde	68.3 de
	50 ppm N	20.4 a	64.6 de	56.1 cd	60.3 cd
	500 ppm N	20.0 a	37.6 b	63.0 cde	47.3 bc

* Means for two rates of lime replicated three times. Within a plant part, means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

Table 4—The effect of lime and nitrogen treatments on the lead content of lettuce and oats.

Plant material	Lime treatment	Pb, ppm in dry matter		
		0 ppm N	50 ppm N	500 ppm N
Lettuce leaves	0	179.3 c*	151.0 d	190.9 e
	Lime	50.9 a	52.1 ab	59.0 b
Oat tops[ns]†	0	44.9	36.1	39.1
	Lime	12.4	11.9	14.1
Oat roots	0	73.2 c	57.3 b	46.1 a
	Lime	38.0 a	43.4 a	37.8 a

* Means for four lead treatments replicated three times. Means within a plant part do not differ significantly at the 5% level, when followed by the same letter, according to Duncan's Multiple Range Test.
† No significant interaction of lime and nitrogen found at 5% level, from analysis of variance.

Table 5—Effect of lead treatment on the elemental composition of lettuce and oats and on the soil pH.

Material	Element or determination	Units	Lead treatment to soil			
			No Pb	$PbCl_2$	$PbCO_3$	$Pb(NO_3)_2$
Soil	pH in 1*N* KCl		4.49 a	4.52 b	4.57 a	4.54 b
Lettuce leaves	Pb	ppm	50.0 a	158.9 a	126.0 b	140.6 a
	S	%	0.272 b	0.248 a	0.266 a	0.327 a
	P	%	0.189 b	0.166 a	0.203 a	0.189 b
Oat tops	Pb	ppm	4.4 a	37.1 a	28.6 b	35.7 a
	S	%	0.261 b	0.198 a	0.260 b	0.269 b
	P	%	0.149	0.146	0.145	0.139
	N	%	1.43	1.49	1.45	1.61
	Ca	%	0.488	0.515	0.462	0.508
	Mg	%	0.205	0.194	0.187	0.197
	Na	%	0.015	0.019	0.018	0.020
	K	%	1.84	2.00	1.85	1.91
	Zn	ppm	16.9	14.8	13.1	14.9
	Mn	ppm	109.3 a	114.0 a	119.5 ab	125.8 b
	Fe	ppm	36.6	40.2	34.4	37.7
	Cu	ppm	11.5	10.6	11.1	12.5
	Al	ppm	10.0 a	16.8 a	13.5 b	15.4 bc
Oat roots	Pb	ppm	20.3 a	59.1 b	59.2 b	56.6 b
	S	%	0.091 b	0.057 ac	0.100 b	0.085 bc
	P	%	0.142	0.128	0.150	0.133
	Ca	%	0.512	0.487	0.475	0.496
	Mg	%	0.218	0.190	0.194	0.188
	Na	%	0.054	0.049	0.051	0.051
	Zn	ppm	33.6	32.2	34.8	30.4

* Means for three nitrogen treatments at two lime treatment rates replicated three times are expressed as units in dry matter. Means, within a horizontal row of means, are significantly different at the 5% level according to Duncan's Multiple Range Test if they are followed by different letters.

levels of lead in lettuce leaves and oat roots, without affecting lead content of oat tops (Table 4). The low level of nitrogen application reduced the lead content of lettuce and oat roots. The high level of nitrogen treatment further reduced lead content of oat roots, but the opposite effect on content of lettuce was observed.

Effect of Soil pH on Lead Content—The average soil pH measured in KCl increased from 3.8 to 5.2 due to liming. The lead treatments also affected soil pH significantly (Table 5). The correlations of soil pH with lead content of plant portions harvested from the 72 pots in the experiment ($r = -0.72$ for lettuce; $r = -0.57$ for oat tops; and $r = -0.31$ for oat roots) were all significant at the 1% level.

Effect of Lead Treatment on Elemental Composition of Plants—Lettuce leaves were analyzed for phosphorus and sulfur only, and the levels of both elements were found to be significantly lower when soil was treated with $PbCl_2$ (Table 5). Similar results were observed with regard to sulfur in both oat plant portions. The aluminum content of oat tops increased when lead was applied, whereas manganese content increased when $Pb(NO_3)_2$ was added to the soil. Other elements analyzed were not affected significantly by lead treatment.

DISCUSSION

The greater susceptibility of lettuce than oats to lead accumulation emphasizes the importance of selecting lead-tolerant crops when cultivating lead contaminated soils. The accumulation of lead in plants due to addition of lead to soil is in agreement with the findings of previous workers (Jones and Hatch, 1945; MacLean et al., 1969). The higher levels of lead in roots than in tops seems to indicate that translocation of lead is of a restricted nature. Liming reduced the lead uptake by above-ground plant portions to a much greater degree than by oat roots. MacLean et al. (1969) suggested that repression of the solubility of lead by addition of lime reduced the lead uptake by oat and alfalfa plants. However, the present study indicates that while lead carbonate is insoluble in water, its availability to plants was not much lower than the other water soluble forms of lead used. Therefore, formation of lead carbonate as a result of liming cannot be considered a sole factor affecting lead availability. It is also postulated that liming may restrict the translocation of lead from roots to above-ground portions.

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