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Project Summary

Effects of Sewage Sludge on Corn Silage and Animal Products

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Studies were conducted to document the impact of sludge-fertilized corn on the food chain under controlled experimental conditions that eliminated any direct ingestion of sewage sludge. Specifically, the studies were to determine whether sludge-borne heavy metals that accumulate in corn are secreted into the milk of dairy goats or are accumulated in the organs and muscle of goats or market lambs consuming corn silage containing up to 5.26 mg cadmium (Cd)/kg.

Dry matter intake, milk production, and feed efficiency of dairy goats were not reduced by feeding a high-Cd corn silage continuously for 3 years — approximately half of their productive lives. Likewise, feed efficiency and daily gains of market lambs were not reduced by consuming high-Cd silage.

Cd and zinc (Zn) from corn silage were not secreted into the milk from lactating goats, even though some animals were receiving approximately 5 mg Cd and 100 mg Zn/day. In contrast, Cu concentrations were higher in milk from goats receiving the control feed.

The Cd concentrations in livers of both goats and lambs were always lower in animals receiving the control feed. These levels increased as the amount of silage Cd increased. Accumulations of Cd in animal kidneys were 5 to 10 times greater than those observed in livers, but they followed the same general patterns. Cd concentrations in animal heart and muscle were low and not affected by treatment. Zn, the only other element found to accumulate in silage as a result of treatment, did not increase in animal liver, heart, and muscle, but it increased slightly in lamb kidney as a result of feeding Zn-enriched silage. The concentrations of 16 other elements in the various animal tissues were not consistently affected when the animals were fed sludge-fertilized corn silage.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Use of municipal sewage sludges as a source of plant nutrients is of current interest because of environmental and economic concerns. Applications of sludge to soil at rates consistent with the nutrient requirements of a crop are believed to be most beneficial. Use of sludge as a crop fertilizer would not greatly affect the demand for fertilizer in the United States, since the total amount of sludge produced would supply only 1% to 2% of the annual nitrogen (N) required for crop production. But the impact of sludge additions to any given land area is significant where applications are feasible. Occurring along with the essential plant nutrients present in sludge are also nonessential elements or those potentially toxic to crops, animals, or humans.

Heavy metals are typically present in municipal sludges. Transfer of metals from sludge to soil and subsequently to plants that enter the food and feed chain present a significant health concern. Animals exposed to subclinical levels of heavy metals are not easily identified and may be slaughtered or used as a source of milk. Limited information is available concerning the effects of feeding sludge-fertilized crops to large ruminants, though varying degrees of metal accumulation in animal liver and kidneys have been shown. Most studies have involved direct ingestion of sewage sludge, either as a component of the ration or as an adherent to leaf surfaces of forages.

The purpose of the present studies was to document the impact of sludge-fertilized corn on the food chain under controlled experimental conditions that eliminated direct ingestion of sewage sludge. Specific objectives were to answer the following questions:

1. Does the feeding of sludge-fertilized corn silage affect the long-term performance of dairy goats and market lambs?
2. Are sludge-borne heavy metals that accumulate in corn secreted into the milk of dairy goats fed the silage for 3 consecutive years?
3. Does Cd accumulate in the organ and muscle tissues of the diary goats and market lambs that consumed corn silage containing high concentrations of Cd?

To accomplish these objectives, corn silage produced on sludge-amended soil was fed to dairy goats for 3 consecutive years and to a group of market lambs in each of the 3 years. Determination of the effects on human health of consuming food products from animals that were fed sludge fertilized corn silage was not included in this study.

Procedures

The soil was a well-drained, Typic Hapludoll, with a pH of 6.2. Waste-activated sewage sludge was applied initially at rates of 0, 30, 60, or 90 megagrams (Mg)/ha. Before the second and third croppings, sludge was applied at rates of 0, 15, 30, Or 45 Mg/ha (Table 1). These treatments are referred to as the control, low, medium, and high treatments, respectively. Though sludge metal concentrations varied from year to year (Table 1), Cd was the only metal that was atypically high.

Goats and lambs were fed silage *ad libitum.* Free choice trace mineral salt that contained <0.2 mg Cd, 2.4 mg chromium (Cr), 128 mg copper (Cu), and 125 mg Zn/kg was offered throughout the study. The corn silage composition data (Table 1) showed Cd and Zn as the only elements that increased consistently as a result of sludge applications. Cd levels in cornplant tissue showed the largest relative increases and reached a high of 5.26 mg/kg during the third year. These high Cd levels resulted in low Zn:Cd ratios and enhanced the potential for Cd absorption by the animals, since Zn may inhibit Cd absorption from the intestine of animals.

Table 1. *Sludge Application Rates and Cd, Cu, and Zn Concentrations in Sewage Sludge and Corn Silage*

Item	*Treatment*				*Average Standard Deviation Within Treatments*
	Control	*Low*	*Medium*	*High*	
Sewage sludge applied (metric tons/ha)[a]					
Year 1	*0*	*30*	*60*	*90*	
Year 2	*0*	*15*	*30*	*45*	
Year 3	*0*	*15*	*30*	*45*	
Cd content of sewage sludge (mg/kg)[a]					
Year 1	–	*156*	*161*	*156*	*14*
Year 2	–	*186*[b]	*133*	*137*	*7*
Year 3	–	*108*	*105*	*112*	*5*
Cu content of sewage sludge (mg/kg)[a]					
Year 1	–	*703*	*712*	*717*	*34*
Year 2	–	*640*[c]	*629*	*730*	*53*
Year 3	–	*711*	*699*	*653*	*40*
Zn content of sewage sludge (mg/kg)[a]					
Year 1	–	*1700*	*1590*	*1675*	*136*
Year 2	–	*2065*[b]	*2580*	*2680*	*123*
Year 3	–	*1625*	*1570*	*1605*	*63*
Cd content of corn silage (mg/kg)[a]					
Year 1	*<0.02*[d]	*0.71*	*1.27*	*1.73*[b]	*0.29*
Year 2	*<0.02*[d]	*1.84*	*2.68*	*4.25*[b]	*0.77*
Year 3	*<0.06*[d]	*1.39*	*2.73*	*5.26*[b]	*0.70*
Cu content of corn silage (mg/kg)[a]					
Year 1	*3.6*[d]	*3.9*	*4.4*	*4.4*[c]	*0.36*
Year 2	*3.5*	*3.7*	*3.8*	*3.6*	*0.54*
Year 3	*4.2*[e]	*4.1*	*4.8*	*5.3*[b]	*0.44*
Zn content of corn silage (mg/kg)[a]					
Year 1	*31*[d]	*40*	*50*	*60*[b]	*6.1*
Year 2	*44*[e]	*52*	*67*	*113*[b]	*32.0*
Year 3	*35*[d]	*74*	*75*	*107*[b]	*14.6*

[a] *70 C Weight basis.*
[b] *Linear effect within sludge levels is significant (P<0.01).*
[c] *Linear effect within sludge levels is significant (P<0.05).*
[d] *Control versus all sludge levels is significant (P<0.01).*
[e] *Control versus all sludge levels is significant (P<0.05).*

Milk samples collected during each lactation, blood samples taken annually, and animal organ tissues collected at necropsy were analyzed for Al, As, B, Ca, Cd, Cr, Cu, Fe, Hg, K, Mg, Mn, Na, Ni, P, Pb, Se, and Zn.

Results

Animal Performance

Goat performance was measured by dry matter intakes and did not differ among treatments in any of the 3 years (the study period constituted about half of their productive lives). Intake ranged from 0.84 to 1.67 kg and was generally lower the first year. Daily milk production and feed efficiency did not differ substantially among the control, the medium, and the high sludge treatments.

Though the effect was significant only in the second year, lambs fed sludge-fertilized corn silage tended to average higher daily gains (0.19 kg) than lambs fed control silage. Daily feed intakes and efficiencies of lambs were not significantly affected by treatment, except in the first year, when feed efficiencies of lambs fed sludge-fertilized corn silage were slightly higher than for lambs on control silage.

Milk Composition

Cd, the major trace metal that was bioaccumulated in the corn silage, was not transferred to milk from lactating goats (Table 2), even though animals on the high treatment consumed silage that contained more than 5 mg Cd/kg (approximately 5.0 mg Cd/day). The Cd concentration in milk from goats fed the highest level of dietary Cd was only 0.009 mg/kg (approximately 0.001 mg/L on a fluid basis). This figure is considerably lower than some of those reported in the literature.

Table 2. *Concentrations of Cd, Cu, and Zn in Milk Collected from Goats Fed Corn Silage Grown on Sludge-Amended Soil*

Metal	Year	Treatment (mg/kg)[a]				Average Standard Deviation Within Treatments
		Control	Low	Medium	High	
Cd	1	<0.005	<0.005	<0.004	<0.003	–
	2	0.013	0.011	<0.009	<0.009	–
	3	0.011	0.017	0.012	0.009[b]	–
Cu	1	0.42	0.32	0.29	0.28	0.40
	2	0.79	0.63	0.58	0.53	0.52
	3	0.64[c]	0.43	0.26	0.29	0.42
Zn	1	35.1	37.2	33.8	30.8[d]	5.61
	2	34.1	40.8	34.5	32.8[d]	7.13
	3	39.4	40.1	34.6	36.9	12.86

[a]70 C Weight basis.
[b]Linear effect within sludge levels is significant (P<0.05).
[c]Control versus all sludge levels is significant (P<0.01).
[d]Linear effect within sludge levels is significant (P<0.01).

When averaged across all sludge treatments, the Zn concentrations in milk from control goats did not differ from those of goats fed sludge-fertilized corn silage. But Zn in milk decreased as amounts of applied sludge increased within sludge treatments (Table 2), in spite of the fact that Zn concentrations in the silage ratio increased with increasing sludge applications.

Control goats had higher Cu concentrations in milk in each year, but they were significant only in the third year, as the amount of sludge used as fertilizer increased. Possibly the increased levels of Cd and Zn in the corn silage from sludge-fertilized soil caused Cu to be less readily absorbed by the goats.

The concentrations of the other measured elements in milk were unaffected by treatment. The elemental content of colostrum was usually higher than that of regular milk, but it was unaffected by treatment.

Blood Composition

The elemental composition of goat and lamb blood was essentially unaffected by feeding sludge-fertilized corn silage. The significance of no Cd increase in blood is that blood Cd levels are determined by current exposure and that exposure is apparently not high enough to affect blood concentrations.

Organ Composition

Goats

Selected metal concentrations in tissues collected from goats at necropsy are listed in Table 3. After 3 years, goats fed corn silage that received control, low, medium, and high sludge rates had consumed approximately <40, 1,300, 2,200, and 3,900 mg Cd, respectively. Cd (the element that accumulated in the corn silage most dramatically) was present at 0.26, 1.72, 2.10, and 2.94 mg/kg in goat livers for the control, low, medium, and high sludge treatments, respectively. These levels tended to increase as amount of sludge applied increased. Kidney Cd concentrations were approximately 10 times those observed in liver, ranging from 3 to 22 mg/kg for animals on control and high treatments, respectively. Kidney Cd levels for control animals were significantly lower than those in kidneys of animals fed sludge-fertilized corn silage, and they increased linearly with increasing sludge applications. Cd levels in heart and muscle were minimal and averaged 0.08 and 0.07 mg/kg, respectively.

Zn concentrations in liver and heart did not differ significantly among treatments. Kidney Zn ranged from 76.6 to 91.8 mg/kg with control animals having less Zn than animals fed sludge-fertilized corn silage. Cu concentrations in livers and kidneys were significantly lower (approximately 2 mg/kg) in animals receiving sludge-fertilized corn silage treatments than in animals fed control silage. The reason for this result may have been that the elevated Cd and Zn levels in the sludge-fertilized corn silage caused Cu to be less readily absorbed by the goats.

None of the other measured elements had accumulated in the goat tissues as a result of fertilizing corn with sewage sludge.

Lambs

Concentrations of selected metals in lamb tissues are presented in Table 4. For each year, livers and kidneys from control animals had a lower concentration of Cd than those of animals fed sludge-fertilized corn silage. The latter lambs showed linear increases in the amounts of Cd in liver and kidney with increasing sludge applications. Cd concentrations in heart and muscle were low and unaffected by sludge treatments.

Zn concentrations in liver, heart, and muscle were not significantly affected by sludge treatments. Kidneys from control animals tended to contain less Zn than those of animals fed sludge-fertilized corn silage. The lack of a major dose-related increase in kidney Zn may be a result of high dietary Cu (trace mineral salt) and Cd (corn silage) interacting to reduce the absorption of Zn.

Although significant only in the second year, Cu levels in kidneys from control lambs were lower than those from lambs fed sludge-fertilized corn silage. Elemental concentrations of Al, B, Ca, Fe, K, Mg, Mn, Na, Ni, P, and Pb in liver, kidney, heart, and muscle were not consistently affected by sludge treatment.

Histological examinations of lamb liver and kidney tissues showed no observable morphological differences among sludge treatments.

Table 3. *Concentrations of Cd, Cu, and Zn in the Liver and Kidney of Goats Following 3 Years of Feeding with Corn Silage Grown on Slude-Amended Soil*

Organ and Metal	Treatment (mg/kg)[a]				Average Standard Deviation Within Treatments
	Control	Low	Medium	High	
Liver:					
Cd	0.26[b]	1.72	2.10	2.94	1.41
Cu	16.6[b]	8.6	10.3	10.7	4.33
Zn	90.3	91.2	85.9	88.8	22.4
Kidney:					
Cd	3.1[b]	10.8	24.8	22.4[c]	8.1
Cu	15.8[b]	13.5	14.9	13.5	1.2
Zn	76.6[b]	82.7	90.4	91.8	7.7

[a]70 C Weight basis.
[b]Control versus all sludge levels is significant (P<0.01).
[c]Linear effect within sludge levels is significant (P<0.05).

Table 4. *Concentrations of Cd, Cu, and Zn in the Liver and Kidney of Lambs Fed Corn Silage Grown on Sludge-Amended Soil*

Organ and Metal	Year	Treatment (mg/kg)[a] Control	Low	Medium	High	Average Standard Deviation Within Treatments
Liver:						
Cd	1	0.56[b]	8.82	1.06	1.31	0.53
	2	0.29[c]	1.97	3.56	5.29[d]	1.32
	3	0.52[c]	1.13	2.52	3.58[d]	1.29
Cu	1	185	196	215	210	111
	2	53	64	89	66	50
	3	164	163	168	128	50
Zn	1	102	110	103	98	14
	2	79	89	85	84	21
	3	105	105	118	114	15
Kidney:						
Cd	1	1.57	1.38	1.90	3.11[d]	0.97
	2	2.09[c]	5.07	10.89	18.94[d]	4.03
	3	0.78[c]	2.70	7.31	10.19[c]	3.72
Cu	1	15.3[c]	16.9	15.4	16.8[c]	2.31
	2	16.0[c]	16.9	17.8	18.0	1.21
	3	19.4	20.5	19.5	19.6	1.66
Zn	1	109	103	109	113	14
	2	103[c]	110	124	126	7
	3	100[b]	103	111	113	11

[a] 70 C Weight basis.
[b] Control versus all sludge levels is significant ($P<0.05$).
[c] Control versus all sludge levels is significant ($P<0.01$).
[d] Linear effect within sludge levels is significant ($P<0.01$).

Conclusions

Total dry matter intake, daily milk production, and feed efficiency of dairy goats were not reduced by feeding a high-Cd corn silage continuously for 3 years — approximately half of their productive lives. Similarly, daily gains and feed efficiencies of market lambs were not affected by treatment.

Cd from corn silage was not secreted into the milk from lactating goats, even though some animals were receiving approximately 5 mg Cd/day. Zn concentrations in milk from control animals did not differ from those of goats fed sludge-fertilized corn silage, but Cu concentrations were higher in milk from the control goats. The bioavailability of Cu may have been limited by the elevated levels of Cd and Zn in silage from sludge treatments.

The elemental concentrations of 15 other metals and minerals in milk were not affected by treatment. The composition of goat and lamb blood was not affected by treatment, except that Cu was higher in the blood of control goats.

The Cd concentrations in livers of both goats and lambs were always lower in control animals, and they increased with increasing sludge applications. This result was particularly true for lambs, where Cd concentrations as high as 5.29 mg/kg were found. Accumulations of Cd in animal kidneys were 5 to 10 times greater than those observed in livers, but they followed the same general patterns. Cd concentrations in animal heart and muscle were low and not affected by treatment.

Zn, the only other element found to accumulate in silage as a result of treatment, did not increase in animal liver, heart, and muscle as a result of feeding Zn-enriched silage. Small but significant increases in Zn content were observed in lamb kidneys for animals fed sludge-fertilized corn silage.

Cu concentrations in goat and lamb kidneys and goat livers were lower for animals fed sludge-fertilized silage than for control animals. The concentrations of 15 other elements in the various animal tissues were not consistently affected by sludge fertilization of corn silage.

Thus corn silage produced on soil amended at moderate to high rates with sewage sludge containing high levels of bioaccumulated Cd can be fed to dairy goats and market lambs without impairing their performance. Trace metals (particularly Cd) taken up by the corn and ingested by the animals did not accumulate in milk or muscle tissue — foods consumed directly by humans. Cd did accumulate in the kidneys of goats and lambs, reaching concentrations of 25 mg Cd/kg in goat kidney when corn silage containing as much as 5.26 mg Cd/kg of silage (an ingestion rate of approximately 5 mg Cd/day) was consumed continuously for 3 years. Though Zn is taken up by corn to a smaller extent than Cd, it did accumulate in lamb kidneys, but not in goat kidneys or livers of either species. Histological examinations of lamb livers and kidneys showed no observable morphological differences as a result of consuming Cd-enriched silage.

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The complete report, entitled "Effects of Sewage Sludge on Corn Silage and Animal Products," (Order No. PB 84-168 756; Cost: $10.00, subject to change) will be available only from:
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