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Cadmium Contents of Oats (*Avena sativa* L.) in Official Variety, Organic Cultivation, and Nitrogen Fertilization Trials during 1997–1999

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The cadmium (Cd) contents of oats (*Avena sativa* L.) in Finland were examined over a 3 year period in three types of trials: official variety, organic vs conventional cultivation, and nitrogen fertilization trials. Large seasonal and regional variations were found in the Cd concentrations. In official variety trials, the mean Cd contents in 1997, 1998, and 1999 were 0.046, 0.029, and 0.052 mg kg^{-1} dry weight (dw), respectively, ranging from 0.008 to 0.120 mg kg^{-1} dw. The concentrations were generally well below the maximum permitted level of 0.100 mg kg^{-1} fresh weight. No significant differences were found between the organic and the conventional cultivation techniques. Nitrogen (N) fertilization increased the Cd contents of oats especially at high nitrogen rates (160 kg N $hectare^{-1}$ (ha)). Significant cultivar differences ($p < 0.001$) were determined in all trials. Cultivars Salo and Kolbu had consistently higher contents, and Belinda and Roope had lower Cd contents among the different growing conditions. Hence, it is possible to cultivate and develop oat cultivars less likely to accumulate Cd.

KEYWORDS: ***Avena sativa*; cadmium; oats; cereals; Finland; organic cultivation; nitrogen fertilization; cultivar differences; variety**

INTRODUCTION

Finland produces extensive amounts of oats and exports oats to many countries. A large market for oats has been developed for increasing human consumption of oats as a functionally healthy food. Oats are also high-quality feed for horses, hens, broilers, sheep, and milking cows. However, it is also important to determine the risk factors associated with intake of foods and feeds. Cadmium (Cd) is considered a risk factor in cereal crops for humans and animals due to its toxicity and accumulation in the body. Increasing concern has been shown over Cd contamination in soils and its impacts on health.

The Cd contents of cereals can be problematic for international trade if concentrations exceed the limit values. The main contamination sources are atmospheric deposition, use of animal manures, phosphorus fertilizers, or sewage sludges that may contain Cd as impurities (*1*, *2*). Cereals are the major sources of dietary Cd through their large consumption. In 1995, the calculated mean Cd intake in Finland was 10.8 μg d^{-1}, from which cereals contributed 60% (*3*).

Cd availability to plants is affected by factors such as total soil Cd, solubility of soil Cd, pH, soil type (clay, organic matter), soil fertility, use of fertilizers, and climatic conditions during the growing season, especially precipitation (*4*−*11*). Liming is usually assumed to reduce Cd concentrations in plants. However, Andersson and Siman (*5*) and He and Singh (*7*) reported that high soil pH enchances Cd uptake in oats; the reasons for this remain unclear. It is also well-documented that plant species differ in their ability to absorb Cd and transport it from roots to shoots (*12*−*16*). Fewer studies concerning cultivar differences are available.

Typical features of Finnish agricultural soils include their relatively strong natural acidity, low electrical conductivities, and $CaCO_3$ equivalents (*17*). The mean soil pH was 5.75 in 1987 and 5.76 in 1998. pH varies regionally, decreasing from south to north (*1*, *18*−*19*). The mean soluble Cd content in soils was 0.08 mg L^{-1} in 1998 (*19*). Cd contents of soils tend to be higher in southern Finland where clay soils predominate and where population densities and industrial activities are also higher (*1*, *18*, *19*). Abundant phosphorus fertilization has been practiced. During 1974−1987, AAAc (ammonium acetate acetic acid solution, pH 4.65) extractable P in Finnish agricultural soils increased about 14% and in coastal areas by as much as 50%. Meanwhile, AAAc ethylenediaminetetraacetic acid (EDTA) extractable Cd increased about 30%, averaging 0.079 mg L^{-1} in 1987. This was mainly because the P fertilizers had exceptionally high contents of Cd during 1975−1981. However,

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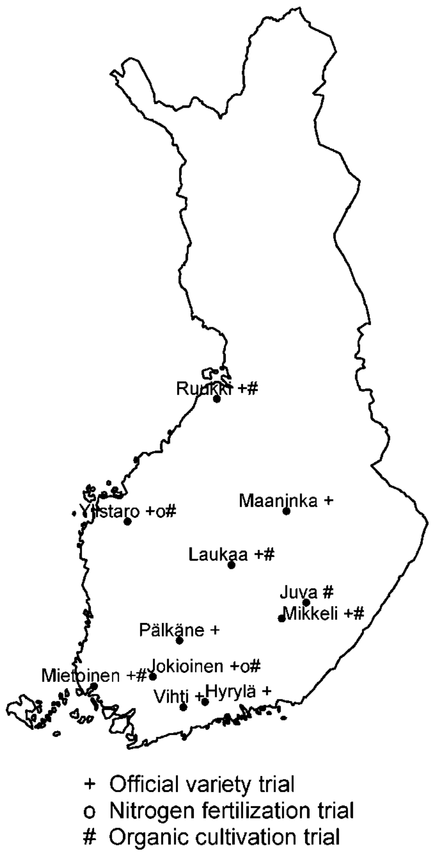

Figure 1. Locations of the trial sites in Finland.

domestic, very low Cd raw phosphates have been used in fertilizer production since 1986 (*1*). Since 1995, the use of P fertilizers has been limited to 15 kg ha^{-1} per year for environmental reasons (*20*). Thus, the Cd load from fertilizers has decreased markedly from levels observed during the 1970s and early 1980s and it was about 0.5 g ha^{-1} in 1987 (*1*).

The objectives of the present work were to examine the Cd contents and its variation in Finnish oats and thus assess the risk of appearance of high Cd oat products in the market. The purpose was also to obtain information on the effects of the cultivars and cultivation techniques on the Cd uptake in oats, which may aid in directing future plant breeding programs.

MATERIALS AND METHODS

Oat Samples. Oat (*A. sativa* L.) samples were collected in 1997−1999 from official variety and two types of agronomy trials (organic cultivation and nitrogen fertilization trials) conducted by the Agrifood Research Finland. The total number of samples analyzed was 141, 150, and 125 in 1997, 1998, and 1999, respectively.

The official variety trials were managed according to standard protocol in 8−10 locations throughout Finland (**Figure 1**). More detailed information on the trials is published elsewhere (*21*). Soil pH, soil types, precipitation, and effective temperature sums in 1997−1999 are presented in **Table 1**. Soil fertility analyses were also performed every year. The varieties studied were Leila, Salo, Veli, Kolbu, Roope, and Belinda. Kolbu and Roope have yellow husks, and the other varieties have white husks. Roope and Veli are Finnish, Leila and Kolbu are Norwegian, and Belinda and Salo are Swedish cultivars.

Organic cultivation trials were conducted as two types of trials: comparison of organic and conventional cultivation (six locations) and organic cultivation variety trials (seven locations). All trials were performed at the same field location. Conventional and organic cultivation were compared with two oat cultivars (Veli and Puhti) grown in organic and conventional farming systems at six locations (**Figure 1**). In organic cultivation variety trials, six additional cultivars were also studied as follows: Aarre, Katri, Kolbu, Leila, Roope, and Yty. Leila and Kolbu are Norwegian cultivars, and Veli, Puhti, Aarre, Katri, Roope, and Yty are Finnish cultivars. The conventional and organic farming system trials were carried out on the same field: conventional in the middle and organic on both sides; a 6 year rotation of crops was used. In organic cultivation, the preceding crop was clover to improve the nitrogen status of the soil, and in conventional systems, cereal crops preceded the trial. Organic and conventional cultivation trials were held on the main plots, and cultivars were held on subplots with 3−4 replications. In all experimental fields, organic cultivation was initiated during the early 1990s. Precipitation and effective temperature sums at different locations are presented in **Table 1**.

The nitrogen fertilization trial employed 5 N rates as calcium ammonium nitrate (0, 40, 80, 120, and 160 kg N ha^{-1}) with four oat cultivars (Aarre, Katri, Kolbu, and Salo) at two locations (Jokioinen and Ylistaro) during 1997−1999. N fertilization was done before sowing. The experimental design was split plot with four replications. Rates of N uptake were determined in main plots and oat cultivars in subplots.

Sample Pretreatment. After harvest, the grains were immediately dried with warm air in a flatbed grain dryer to a moisture content below 14%. Yields were sorted with a 1.5 mm sieve to remove shrunken grains and impurities. A representative grain sample was taken with a grain sample divider. For quality measurements, grain samples were further sorted with a 2.0 mm sieve and hulled with a laboratory hulling machine BT 459 using air pressure. Broken groats were discarded. Oat groats were milled with a falling number hammer mill using a 1.0 mm sieve. The samples were stored in plastic containers in a freezer until analysis.

Analytical Methods. Dry weight (dw) was determined by oven-drying (135 ± 2 °C) 2 g of oat sample for 2 h. Cd was determined with the electrothermal atomic absorption (ETAAS) method described previously (*22*). The method was accredited in 1995. A total of 1−2 g of oat samples were digested in concentrated nitric acid (p.a. Baker) and diluted to 50 mL with MILLI-Q purified water. Cd concentrations were measured with ETAAS, using a Varian SpectrAA 400 atomic absorption spectrometer with Zeeman effect background correction. Ammonium phosphate ($(NH_4)H_2PO_4$) was used as the matrix modifier and method of additions for calibration. The accuracy of the analytical method was tested by determining certified reference materials in every batch of samples. The Cd concentrations in ARC/CL wheat flour reference were 0.041 ± 0.003 mg kg^{-1} dw ($n = 26$) and in NBS 1568a rice flour 0.021 ± 0.003 mg kg^{-1} dw ($n = 12$), certified values being 0.039 ± 0.004 and 0.0225 ± 0.004 mg kg^{-1} dw, respectively.

Statistical Methods. The data from different trials were analyzed in four separate parts. In the first part, the differences between the varieties (data from variety trials) were analyzed, using mixed linear models. In the model year, location and trial were analyzed as the random factor and varieties were analyzed as the fixed factor (*23*). In the second part, differences between six additional cultivars in organic cultivation were analyzed as in part 1. In the third part, the main effects of farming systems (organic and conventional), cultivars (Veli and Puhti), and their interactions were determined by analyses of variance according to the split plot design. In the analyses, the farming system (as the main plot factor) and cultivar (as the split plot factor) were analyzed as the fixed and location (as block factor) and year as the random factor. In the fourth part, the main effects of N fertilization, cultivars, and their interactions were determined by analyses of variance according to the split plot design. In the analyses, the N fertilization (the main plot factor) and cultivars (subplot factor) were analyzed as the fixed effects factor and replications and year and location were analyzed as random effects. In general, when multiple comparison procedures were needed in all parts, Tukey's HSD method or *t*-type contrast examination with 95% confidence intervals was used.

Before performing analysis of variance, assumptions of group variances were checked in Box-Cox diagnostic plots. In addition, the normality assumption of errors was assessed with stem-and-leaf display and normal probability plot. All analyses were performed by means of the SAS statistical package. The MIXED, UNIVARIATE, and GPLOT procedures were used.

Table 1. Precipitation, Effective Temperature Sum, Soil pH, Soil Type, and Mean Cd Content (mg kg^{-1} dw) of Oat in Official Variety Trials during 1997–1999 at Different Trials Locations[a]

location	year	precipitation May–Aug (mm)	effective temp sum	soil pH	soil type	mean Cd content (mg kg^{-1} dw)
Jokioinen	1997	302	1217	6.3	sandy clay	0.036
	1998	318	1011	5.8	clay	0.028
	1999	146	1184	5.7	sandy clay	0.050
Mietoinen 1	1997	232	1285	5.3	clay	0.067
	1998	245	1036	5.9	sandy clay	0.044
	1999	92	1236	5.8	sandy clay	0.064
Mietoinen 2	1999	92	1236	6.3	clay	0.092
Hyrylä	1997	NA	NA	6.3	sandy clay loam	0.052
	1998	NA	NA	6.0	coarse silt	0.024
Pälkäne	1997	253	1250	5.7	fine silt	0.041
	1998	339	1043	6.0	fine silt	0.029
	1999	141	1231	5.9	fine silt	0.081
Mikkeli/Juva	1997	115	1150	6.9	fine sand	0.035
	1998	337	976	6.0	fine sand	0.016
	1999	243	1133	6.0	fine sand	0.018
Maaninka	1997	177	1153	5.8	coarse silt	0.044
	1998	340	938	6.1	coarse silt	0.027
	1999	183	1134	5.5	coarse silt	0.062
Laukaa	1997	182	1146	6.0	coarse silt	0.081
	1998	345	916	6.0	coarse silt	0.067
	1999	175	1112	6.0	coarse silt	0.081
Ylistaro 1	1997	155	1143	6.0	sandy clay loam	0.024
	1998	372	937	6.2	silty clay	0.018
	1999	120	1062	6.1	silty clay	0.027
Ylistaro 2	1997	155	1143	5.3	mold	0.038
	1998	372	937	5.7	mold	0.019
	1999	120	1062	5.5	mold	0.023
Ruukki 1	1998	439	850	5.9	coarse silt	0.019
	1999	182	952	5.4	coarse silt	0.021
Ruukki 2	1999	182	952	5.4	mold	0.026
Vihti	1998	389	997	5.9	coarse silt	0.018
	1999	132	1173	6.2	clay	0.074

[a] NA, not available.

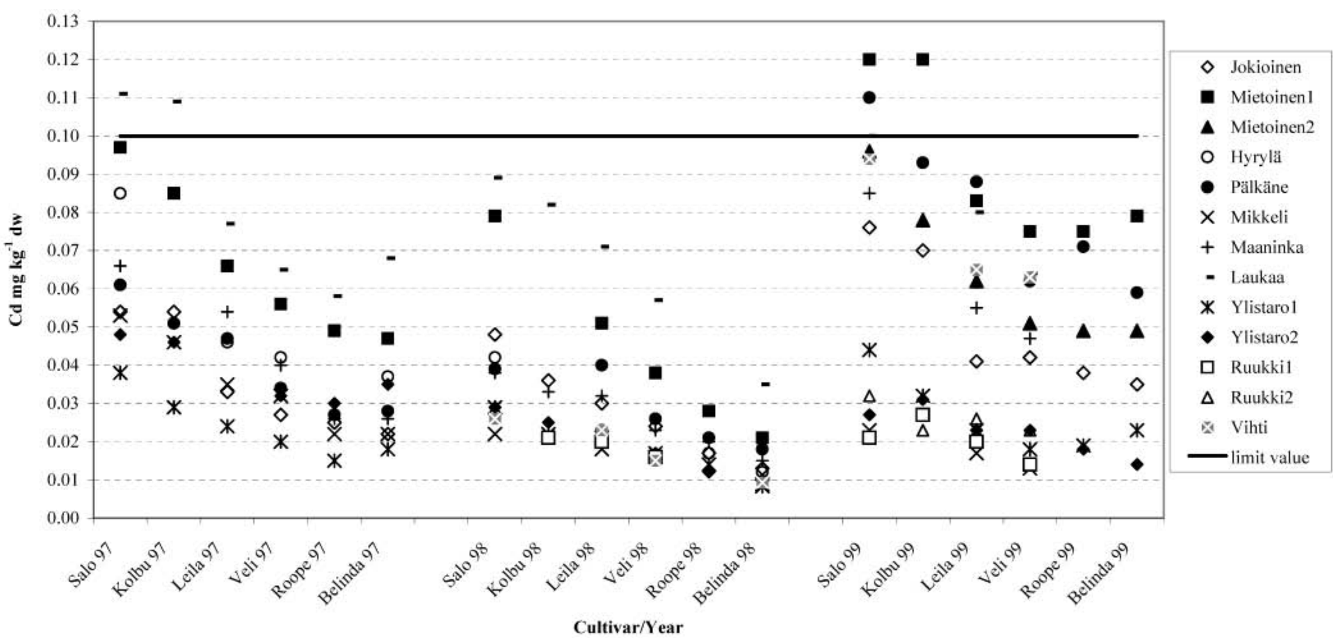

Figure 2. Cd contents of six oat cultivars across all sites of official variety trials during 1997–1999.

RESULTS AND DISCUSSION

Official Variety Trials. The Cd contents of oat groats during official variety trials varied considerably between the trial locations, the years, and the cultivars (**Figure 2**). Finnish authorities have set a maximum Cd content of 0.100 mg kg^{-1} fresh weight for cereals (about 0.110 mg kg^{-1} dw), which is also the maximum level in the EU. The results in this study were generally well below the critical value, even if presented on a dw basis. The mean Cd contents in 1997, 1998, and 1999 were 0.046, 0.029, and 0.052 mg kg^{-1} dw, respectively, ranging from 0.008 to 0.120 mg kg^{-1} dw (**Table 2**). The Cd concentrations of oats were similar to those observed in previous studies from Finland (*24*−*27*) and various other countries (*28*−*33*). The mean Cd concentrations of oat grain found in Finland have

Table 2. Cd Contents (mg kg^{-1} dw) of Different Oat Cultivars in Official Variety, Organic Cultivation, and Nitrogen Fertilization Trials during 1997–1999[a]

	year			all			
cultivar	1997	1998	1999	*n*	original[b]	Log(*x*)[b]	SEM
			official variety trials				
n	52	55	56				
range	0.015–0.110	0.008–0.089	0.013–0.120				
Salo	0.068	0.044	0.069	31	0.060[a]		0.005
Kolbu	0.059	0.036	0.059	22	0.053[a]		0.006
Leila	0.046	0.032	0.049	32	0.043[b]		0.005
Veli	0.039	0.025	0.041	32	0.035[c]		0.005
Roope	0.032	0.019	0.045	21	0.029[c]		0.006
Belinda	0.034	0.015	0.043	25	0.027[c]		0.006
all	0.046	0.029	0.052	163	0.041		
			organic cultivation variety trials				
n	46	45					
range	0.007–0.074	0.003–0.050					
Kolbu	0.030	0.020		12	0.026	0.00308[a]	0.00020
Leila	0.024	0.020		12	0.022	0.00295[ab]	0.00020
Katri	0.025	0.015		11	0.021	0.00283[b]	0.00020
Veli	0.022	0.016		12	0.019	0.00280[bc]	0.00020
Yty	0.024	0.019		10	0.018	0.00273[bc]	0.00020
Aarre	0.020	0.015		10	0.017	0.00268[c]	0.00020
Puhti	0.020	0.014		12	0.017	0.00264[c]	0.00020
Roope	0.018	0.012		12	0.015	0.00257[c]	0.00020
all	0.023	0.016		91	0.020		
			nitrogen fertilization trials				
Salo				40	0.051	0.00386[a]	0.00018
Kolbu				40	0.044	0.00372[b]	0.00018
Katri				40	0.036	0.00342[c]	0.00018
Aarre				40	0.027	0.00324[d]	0.00018

[a] Number of trials (*n*), range of values, means of values, means of values after log transformation (Log (*x*)), and standard error of means (SEM). [b] Within columns, means followed by the same letter are not significantly different at $p < 0.05$. Statistical analyses in organic cultivation and nitrogen fertilization trials are based on log-transformed values.

varied between 0.019 and 0.041 mg kg^{-1} (*24*−*27*); in Sweden, 0.031−0.042 mg kg^{-1} (*28*, *35*); The Netherlands, 0.09 mg kg^{-1} dw (*29*); and Poland, 0.086−0.108 mg kg^{-1} (*31*). However, direct comparison with this study is not possible, because in many of the studies whole grains instead of hulled grains were analyzed. The fertilization levels at research stations also tend to be higher than generally occur in Finland, which may lead to slight misinterpretation of the Cd situation among normal farming situations.

The variation in the Cd contents of oats between the trial locations and the cultivation years was large. It can be seen that all of the samples near or exceeding the maximum permitted value occurred in the dry, warm growing seasons of 1997 and 1999, in cultivars Salo and Kolbu and in southern or central Finland (**Figure 2**). The soluble Cd content at the cultivation zone in the trial locations has been monitored during 1992 and 1997 (34). In 1997, the mean soluble Cd contents varied between 0.03 and 0.15 mg L^{-1}. The lowest Cd concentrations were found from the northern trial locations, Ylistaro and Ruukki (0.03 mg L^{-1}), and highest from the southern and central locations, Pälkäne (0.15 mg L^{-1}) and Mietoinen (0.11 mg L^{-1}). The southern parts of the country also receive a three times higher deposition of Cd (0.3 g ha^{-1}, 1997−1999) as compared with northern Finland (*2*). These partly explain the higher Cd contents observed in southern trial locations. The soil type, pH, and environmental conditions are probably also important factors affecting the Cd contents of oats but could not be statistically tested as variables that were not independent.

In Ylistaro (1997−1999), Ruukki (1999), and Mietoinen (1999), official variety trials were performed in two soil types (**Table 1**). In Ylistaro (1997−1998) and Ruukki, mold soils resulted in slightly higher Cd contents of oats than clay or coarse silt soils, the differences varying between 5 and 30%. However, in Ylistaro (1999), oats grown on mold soils had 19% lower Cd concentrations than clay soil. In Mietoinen (1999), Cd contents were 30% higher in clay soil than in sandy clay. The highest mean Cd concentrations were found in Laukaa (coarse silt, pH 6.0).

The cool, rainy growing season in 1998 resulted in lower Cd contents than the dry, warm seasons of 1997 and 1999 (**Table 1**); the reason behind this observation is not clear. In dry growing seasons, the biomass of the oat plant stays smaller than normal and the Cd may be more concentrated in the tissues. Plant root systems also may become smaller in waterlogged soils, and thus, Cd uptake may be less. This result is in contrast with Eriksson's (*4*) studies, which showed that in high precipitation areas in Sweden, the Cd contents of oats tend to be higher than in low precipitation parts of the country. According to our results, the risk of higher Cd contents in oats in Finland appears to grow during dry and warm growing seasons. However, further studies are needed.

The cultivar significantly affected ($p < 0.001$) the Cd contents of oats in official variety trials. Despite the annual and regional variations in Cd contents of oats, the same relative pattern exists between the cultivars, also indicating the presence of genetic variations. The Cd contents of cultivars Salo and Kolbu were significantly higher ($p < 0.001$) than in the other cultivars studied (**Table 2**). The mean Cd content in cultivar Salo was 0.060 mg kg^{-1} dw. This was twice as much as in the lowest Cd cultivar Belinda. Veli and Roope also take up less Cd than Salo and Kolbu. The sensitivity of Salo and Kolbu to accumulated Cd is also seen in N fertilization and organic cultivation trials (**Table 2**). Eriksson (*35*) also found differences

Table 3. Comparison of the Cd Contents (mg kg^{-1} dw) of Hulled Grains and Whole Grains of Single Oat Samples[a]

cultivar	location	Cd content (mg kg^{-1} dw) oat groat	oat grain	difference	%
Salo	Mietoinen	0.079	0.068	0.011	16
Salo	Jokioinen	0.048	0.040	0.008	20
Kolbu	Jokioinen	0.036	0.031	0.005	16
Salo	Hyrylä	0.042	0.037	0.005	14
Salo	Vihti	0.026	0.022	0.004	18
Salo	Pälkäne	0.040	0.038	0.002	5
Salo	Mikkeli	0.022	0.019	0.003	16
Salo	Maaninka	0.038	0.032	0.006	19
Kolbu	Maaninka	0.033	0.029	0.004	14
Salo	Laukaa	0.089	0.075	0.014	19
Kolbu	Laukaa	0.082	0.062	0.020	32
Salo	Ylistaro	0.029	0.024	0.005	21
Kolbu	Ylistaro	0.022	0.019	0.003	16
Salo	Ylistaro	0.029	0.026	0.003	12
Kolbu	Ylistaro	0.025	0.024	0.001	4
Kolbu	Ruukki	0.021	0.019	0.002	11
mean		0.041	0.035	0.006	16

[a] Differences in these measurements (oat groat – oat grain) and percentage values of differences as compared with oat grain measurements. Samples were collected from official variety trails in 1998, cultivars Salo and Kolbu.

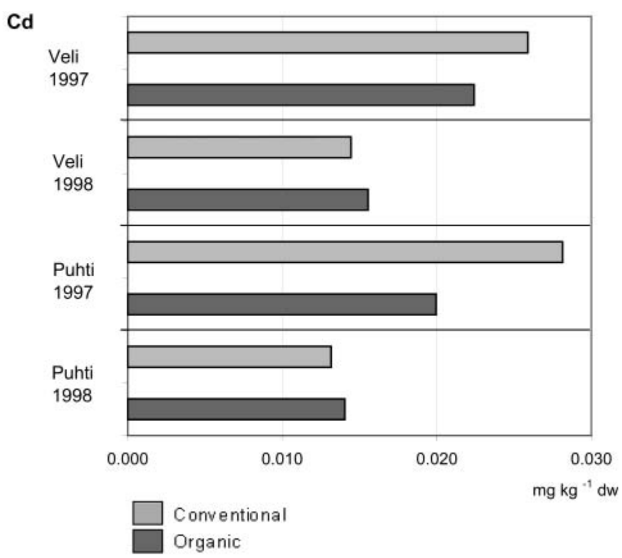

Figure 3. Cd contents of oats in organic cultivation trials during 1997–1998.

Table 4. Main Effect of Nitrogen Fertilization on Cd Content (mg kg^{-1} dw) of Oats[a]

nitrogen fertilization (kg N ha^{-1})	Cd content (mg kg^{-1} dw) mean	Log(x)[b]	SEM
0	0.0369	0.00352[a]	0.00018
40	0.0366	0.00349[a]	0.00018
80	0.0378	0.00352[a]	0.00018
120	0.0401	0.00358[a]	0.00018
160	0.0466	0.00376[b]	0.00018

[a] Means of nitrogen levels, means after log transformation (Log (x)), and SEM. [b] Within columns, means followed by the same are not significantly different at $p < 0.05$. Statistical analyses are based on log-transformed values.

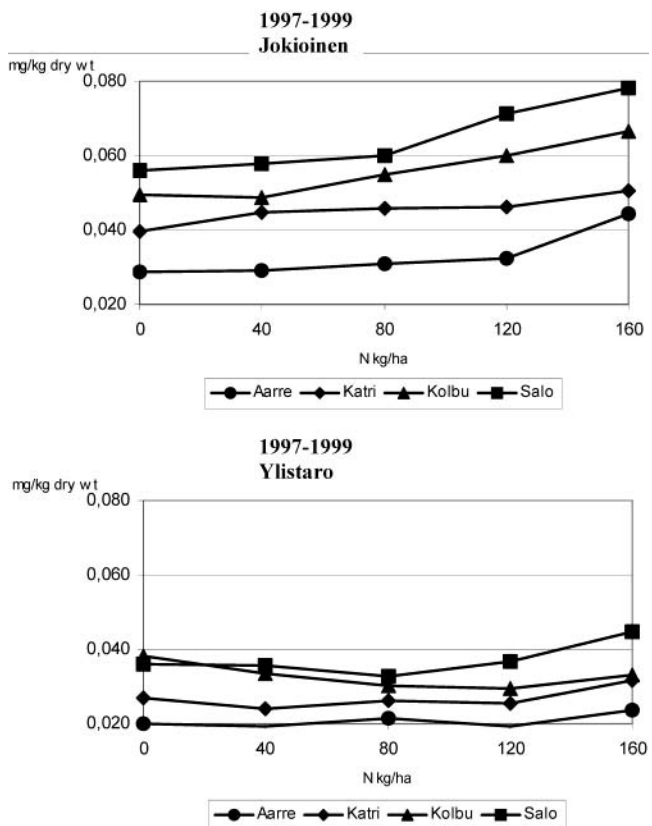

Figure 4. Mean Cd contents of oats in nitrogen fertilization trials during 1997–1999 at two sites (Jokioinen and Ylistaro).

among Cd contents of oat cultivars. These differences permit development of cultivars with lower tendency to accumulate Cd.

The effect of hulling on the Cd content was tested by analyzing both groats and whole grains of the same sample. The groats resulted in about 16% higher Cd contents than whole grains (**Table 3**). This means that the husks do not contain as much Cd as groats and that it is not possible to reduce the Cd content of oats by hulling.

Organic Cultivation Trials. The mean Cd values in organic cultivation were 0.023 and 0.016 mg kg^{-1} dw in 1997 and 1998. Clear cultivar differences ($p < 0.001$) were found (main effect of cultivar). Kolbu had significantly higher Cd contents than other cultivars except Leila (**Table 2**). The lowest Cd contents were in Aarre, Puhti, and Roope. Generally, organic cultivation trials resulted in lower Cd contents than official variety trials. However, because the locations and also many cultivars differed in organic and official variety trials, results cannot be compared directly.

Organic and conventional cultivation were compared on the same field with cultivars Veli and Puhti (**Figure 3**). No significant differences were found between organic and conventional cultivation techniques ($p = 0.32$, confidence interval -5.9 to 2.1) or between the cultivars ($p = 0.19$, confidence interval -2.1 to 0.4). Hence, when organic and conventional farming systems were studied on the same field, no difference in Cd contents could be found. Thus, the cultivation technique employed appears to not affect Cd contents in oats.

Nitrogen Fertilization Trials. Nitrogen fertilization increased the Cd contents of oats ($p < 0.001$, main effect of N fertilization). At lower N levels (0−80 kg N ha^{-1}), only a minor increasing effect was observed at Jokioinen, and in Ylistaro, the Cd concentrations even decreased slightly. The increment in Cd contents was significant at the high, 160 kg N ha^{-1}, N levels (**Table 4**). However, the trends are mostly ascending, especially in Jokioinen where Cd contents were also higher than in Ylistaro (**Figure 4**). In Ylistaro, the effect was not as clear; the soils at Ylistaro are naturally high in N, so the effect of added N may be not be as clear as in poorer soils (*36*). All of the cultivars differed significantly ($p < 0.001$, main effect of cultivars) in their ability to absorb Cd: Salo had the highest and Aarre the lowest Cd contents. Environmental regulations restrict the use of N fertilizers to 90 kg ha^{-1} per year (*20*). Thus, the effect of high N levels on the Cd contents of oats is not a problem on Finnish farms; a more important consideration is the selection of cultivars.

In the experiments, the Cd contents of the N fertilizer itself were low. High N applications cause acidification and increased ionic strengths that can enhance the solubility of Cd in the soil (*37*−*39*). However, the effect of N fertilization on pH may be of short duration. High salt contents can also increase desorption of Cd exchangeable sites in soil colloids, the effect being stronger in sandy soils as compared with clay soils. In present study, clay soil types predominated.

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