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Cadmium concentration in vegetable crops grown in a sandy soil as affected by Cd levels in fertilizer and soil pH

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Abstract

Field trials were conducted over a three-year period with chinese cabbage (*Brassica pekinensis* Rupr.) and carrots (*Daucus carota* L.) grown in a sandy soil with pH adjusted to 5.5 and 6.5. The NPK fertilizers containing 1, 30, 90, and 400 mg Cd kg^{-1} P were applied at the rate of 0.07, 2.1, 6.3 and 28 g Cd ha^{-1} yr^{-1}. The amounts of Cd added through phosphate rock also ranged between 0.1 and 28 g ha^{-1} yr^{-1}. The increased Cd application rates through NPK fertilizers increased the Cd concentration in both vegetables but the differences among treatments were not found to be significant. The Cd uptake by both crops was significantly ($p<0.01$) higher at pH 5.5 than at pH 6.5. Chinese cabbage exhibited lower Cd concentration than carrots. Carrot leaves contained higher Cd than its roots. Cadmium removals by chinese cabbage and carrot were about 0.7 and 1.3 g ha^{-1} yr^{-1}, respectively. At pH 5.5, Cd concentrations in the two crops, based on a three-year average, were 23 and 46% higher than at pH 6.5. Cadmium uptake by chinese cabbage from different sources of phosphate rock was affected to a very limited extent. Cadmium concentration generally increased over the years. Cadmium extracted by ammonium nitrate after harvest of the crops was closely related with soil pH and Cd concentration in the plants.

Introduction

Cadmium, a potentially hazardous heavy metal, is often present in varying amounts in soils and waters used for vegetable production. From the health point of view, Cd in fresh vegetables is considered as a risk element. There is yet no critical Cd-levels in vegetables in the EU. But the Nordic Food Industries Committee has proposed the maximum tolerable limit of Cd in vegetable crops to 0.1 mg Cd kg^{-1} fresh weight. Cadmium in the terrestrial environment is introduced through anthropogenic pathways such as sewage sludge application (Sposito *et al.*, 1982), application of commercial fertilizers (Bærug and Singh, 1990; He and Singh 1993a; Mortvedt, 1987) and through weathering of soil minerals. Investigations with cadmium-containing mineral fertilizers have given contrasting results with regards to Cd concentration of different crops. Andersson and Hahlin (1981) and He and Singh (1994a) reported increasing Cd concentration in grain crops with increase in the Cd content of commercial fertilizers applied, while Dam Kofoed and Søndergård (1983) found no such effects at normal fertilizer application rates. Jaakola (1979) reported increased Cd uptake by vegetable crops with increasing application rates of Cd-containing mineral fertilizer.

Besides Cd addition to soils from mineral fertilizers, small amounts can also be added through atmospheric deposition (Jones, 1990; Steinnes, 1991). Danish (Dam Kofoed and Søndergård, 1983), Swedish (Witter *et al.*, 1990) and Norwegian (Singh, 1994) investigators conclude that the Cd concentration in the soil increases as a result of fertilizer application and atmospheric deposition. In Southern Norway, annual atmospheric deposition of about 1.5 g Cd ha^{-1} has been reported (SFT, 1993), which increases towards the southern most parts of the country (Allen and Steinnes, 1980). Investigating the plant uptake of Cd from the soil and atmosphere in Norway Singh *et al.* (1991) found that approximately 20% of the Cd uptake by carrots was due to atmospheric deposition.

Among plant species the Cd concentration is generally higher in leafy plant species such as spinach and in root crops like carrots as compared to grain crops. Guttormsen (1990) found higher concentration of Cd in vegetables earlier in the growing season than at harvest.

The study was planned to investigate the effects of Cd contained in mineral fertilizers or phosphate rock on Cd uptake by Chinese cabbage and carrots grown in a sandy soil adjusted to two pH levels.

Materials and Methods

A field experiment was conducted at the Norwegian Agricultural Research Station, Landvik, near Grimstad during 1990-92 on a sandy soil. The soil at the start of the experiment has a pH value of 6.0, loss on ignition of about 3.0%, and a P-AL value (Ammonium lactate method, Egner *et al.*, 1960) of 300 mg kg^{-1}. The soil was adjusted to pH 5.5 by using sulphuric acid and to pH 6.5 by using lime as per requirement. The experiment was laid out in a factorial design with two pH levels in the main plots and four rates of Cd in the sub plots with 3 replications. The plot size was 13 m^2. The crops grown were chinese cabbage and carrot. The NPK feztilizezs containing 1, 30, 90, and 400 mg Cd kg^{-1} P were applied at the rate of 70 kg P ha^{-1}. The Cd containing fertilizers were manufactured by the Norsk Hydro using phosphate rocks of different Cd concentrations. The amounts of Cd added through the fertilizers containing 1, 30, 90, and 400 mg Cd kg^{-1} P worked out to be 0.07 (70 kg P $\times$ 1 mg Cd kg^{-1} P= 70 mg Cd and the same way for other rates), 2.1, 6.3 and 28 g ha^{-1}. The rates of fertilization of N, P and K were 200, 70 and 200 kg ha^{-1} in Chinese cabbage and 160, 70 and 140 kg ha^{-1} in carrots. The amounts of N and K, in addition to those added through the Cd-containing NPK, were supplemented with calcium nitrate and potassium sulphate, respectively. The amounts of Cd added through the fertilizers were the same in all the three years under investigation. The crops weze irrigated several times during the growth period. In addition to the experiment mentioned above, another experiment was conducted using phosphate rocks of different sources containing varying amounts of Cd. The experiment was laid out in a complete randomized design with 4 replications. Only pH level of 5.5 was used for this study. Type of phosphate rocks used along with their Cd contents are presented in Table 3. The rest of the procedure used for this experiment was the same as described above. The crops were harvested at maturity by taking about 1 kg fresh weight sample from 10 plants selected randomly from each plot. Plant samples were dried at about 80°C, ground and homogenized by thorough mixing. The dried samples were ashed at 450°, the ashes dissolved in concentrated HNO_3 and filtered. The filtrate was analyzed for Cd using graphite furnace atomic absorption spectrophotometer. The results are expressed on oven dry basis. After the harvest of crops in 1991 (year 2 in subsequent text and tables), soil samples from each treatment were collected. The soil samples were dried and passed through a 2-mm sieve. The soils were analyzed for pH(1:2.5 soil to solution ratio) and for Cd by extracting them with 1 *N* NH_4NO_3 solution (Symeonides and McRae, 1977). Cadmium in the filtrate was analyzed by graphite furnace atomic absorption spectrophotometer. The data obtained were subjected to variance and regression analyses using Norwegian version of MSTAT program.

Results and Discussion

The concentration of Cd in carrots tended to increase with increasing rate of Cd levels in fertilizers (Table 1) and the increase was more pronounced in carrot leaves. The concentration differences among treatments were not found to be significant. In Chinese cabbage this type of increase was not visible. Irrespective of the vegetable crop grown, the Cd concentration consistently and significantly increased with decreased pH (Table 1). The effect of soil pH was consistent over the years. The effect of soil pH in regulating the availability of metals and particularly Cd is well documented, (Bærug and Singh, 1990; He and Singh, 1993b; Kuo *et al.*, 1985; Mc Bride *et al.*, 1982). Cadmium uptake generally decreases with increasing soil pH but the relationship may not always be so straightforward as found in this study. The concentration may decrease or increase depending on the type of crops and soils used (He and Singh, 1994a).

The Cd concentration was higher in carrots than in Chinese cabbage in all the years and the carrot leaves contained higher Cd than its roots (Table 2). These

Table 1. Effect of Cd levels in the fertilizer applied on Cd concentration in Chinese cabbage and carrot (mean values of three years)

pH	Application rate in fertilizer (g ha^{-1} year^{-1}) 0.07	2.1	6.3	28	Mean
	Cd concentration (mg kg^{-1} DM)				
Chinese cabbage					
6.5	0.30	0.31	0.29	0.25	0.30
5.5	0.40	0.39	0.27	0.40	0.37
Mean	0.37	0.35	0.28	0.33	
Carrot root					
6.5	0.38	0.38	0.32	0.49	0.39
5.5	0.58	0.56	0.53	0.60	0.57
Mean	0.48	0.47	0.43	0.55	
Carrot leaves					
6.5	0.71	0.98	0.87	0.90	0.87
5.5	0.86	0.82	1.08	1.04	0.95
Mean	0.79	0.90	0.98	0.97	

LSD pH: 0.08 ($p < 0.01$);
Application rate: NS;
Interaction pH × rate: NS.

Table 2. Effect of soil pH on Cd concentration in Chinese cabbage and carrots in different years (mean values of different rates of Cd application). Values in brackets are in μg kg^{-1} fresh weight

pH	Year 1	Year 2 (mg Cd kg^{-1} DM)	Year 3	Mean
Chinese cabbage				
6.5	0.16	0.47	0.25	0.30
	(8)	(20)	(10)	(13)
5.5	0.20	0.61	0.29	0.37
	(10)	(30)	(14)	(18)
Mean	0.18	0.54	0.27	0.33
	(9)	(25)	(12)	(15)
Carrot root				
6.5	0.24	0.56	0.37	0.39
	(20)	(56)	(37)	(37)
5.5	0.36	0.72	0.62	0.57
	(28)	(68)	(59)	(52)
Mean	0.30	0.64	0.50	0.48
	(24)	(62)	(48)	(45)
Carrot leaves				
6.5	0.38	1.00	1.21	0.86
	(38)	(156)	(190)	(128)
5.5	0.49	1.35	1.01	0.95
	(49)	(228)	(171)	(149)
Mean	0.44	1.18	1.11	0.91
	(43)	(192)	(180)	(138)

LSD Year: 0.13(15) (p<0.01);
Crop: 0.10(15) (p<0.01);
Interaction year × crop: NS.

observations have similarity to those reported from other investigations from Norway (Guttormsen, 1990; He and Singh, 1994a; Singh *et al.* 1991) or elsewhere (Jakkola,1979). It should be noted that the amounts of Cd added through fertilizers except the last treatment were so small as compared to the Cd already present in the soil (300 g ha^{-1}) in 0–20 cm soil depth (Guttormsen, 1990) that only a minor contribution to the total uptake of Cd from the fertilizer applied may be expected. The relative contribution of soil Cd and fertilizer Cd at different levels of soil and fertilizer Cd towards the Cd uptake by plants was described in some previous studies (Eriksson 1989; He and Singh, 1993c). They reported that soil properties such as organic matter and clay content may control the Cd uptake by plants.

Cadmium concentration in both crops tended to increase in the succeeding years (Table 2) but it was invariably highest in the second year of the investigation. The differences in Cd concentration among the years were significant. Although it is difficult to give precise reason for the lower Cd concentration in year 3 as compared to year 2, climatic variations between year 3 and year 2 may to some extent be responsible for this variation. During the months of maximum

Table 3. Effect of phoshate rock containing different levels of Cd on Cd concentration in Chinese cabbage in different years. (Mean values on dry matter (DM) and fresh weight basis (FW))

	Cd added (g ha^{-1} yr^{-1} 0.1	28	6	0.1	15
	Sources of rock phosphate Kola	Taiba	Israel	Granges	Bou
	(mg Cd kg^{-1} DM)				
Year 1	0. 31	0.31	0.30	0.29	0.29
Year 2	0.54	0.51	0.50	0.44	0.49
Year 3	0.20	0.22	0.17	0.19	0.24
Mean (DM)	0.35	0.35	0.32	0.30	0.34
Mean FW	0.024	0.028	0.023	0.022	0.025

LSD Year: 0.05(p<0.001);
Phosphate rock: 0.03(p<0.05); Interaction: NS.

growth was year 3 drier with higher average temperature than year 2 (Av. rainfall and temperature during June were 9 mm and 17° in year 3 and 184 mm and 11° in year 2). These results may imply that the yearly application of Cd through fertilizer had resulted in an accumulation in this sandy soil which was then reflected back in the increased concentration in the vegetable crops. These results resemble those reported previously by other investigators (Bærug and Singh, 1990; Dam Kofoed and Søndergård, 1983; Witter *et al.*, 1990). Dam Kofoed and Søndergård (1983) reported that in an 80 years old experiment, the Cd concentration in the soil increased at a rate of 0.25% per year and the corresponding increase in Sweden was found to be 0.4% (Witter *et al.*, 1990). An accumulation of Cd in soils as a result of long-term fertilization has also been reported from Norway (Singh 1994). In the present study the soil used was a sandy which has limited capacity to adsorb Cd and therefore the Cd added in the succeeding years remained in a relatively available form and was taken up by the plants. Christensen (1984) found that the Cd added to the soil was adsorbed rapidly and strongly in the heavy textured soils but in the sandy soil adsorption was weak and to a greater extent reversible. Based on the total uptake by the crops over the years it was found that the Chinese cabbage removed about 0.7 g Cd ha^{-1} and the corresponding value for carrot was 1.3. These values are similar to those reported by Witter *et al.* (1990) for potatoes. In southern Norway a yearly atmospheric deposition of Cd is estimated to be 1.5 g ha^{-1} (SFT, 1993). This may suggest that the Cd added through atmosphere and fertilizers far exceeds the amount removed by the vegetable crops and thus a net accumulation in the soil may be expected.

Cadmium concentration in the Chinese cabbage was affected only to a limited extent by Cd applied through phosphate rock form different sources (Table 3). From Table 3 it can be seen that the Cd concentration in the Chinese cabbage was increased when an equivalent amount of Cd at the same pH level was added through a NPK fertilizer (Table 1) manufactured from the same phosphate rock. This shows that the availability of Cd in the fertilizer was improved somewhat during the manufacturing process because Cd in phosphate rock is strongly bound in the apatite structure and is more recalcitrant than that in NPK fertilizers (He and Singh, 1994a).

Ammonium nitrate-extractable Cd in the soil increased with decreased pH and a highly significant correlation (r = 0.0883*** and 0.954*** in the soil grown with cabbage and carrots, respectively) was

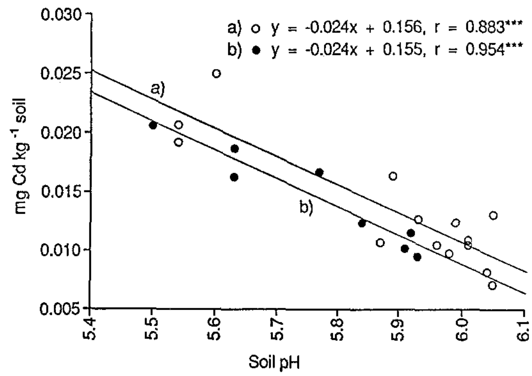

Fig. 1. The relationship between soil pH and NH_4NO_3 - extractable Cd in the soil (year 2 data). a: Chinese cabbage (for no. of obs. see text under methods) b: carrots.

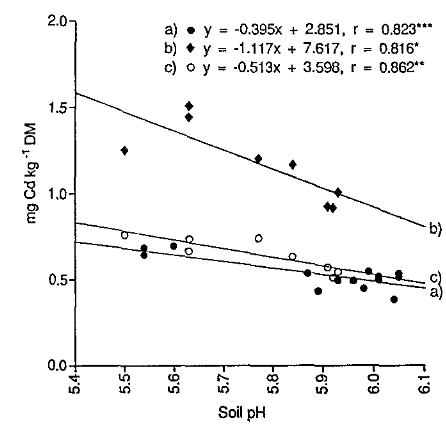

Fig. 2. The Cd concentration in different vegetable crops in relation to soil pH (year 2 data). a: Chinese cabbage (for no. of obs. see text under methods) b: carrot leaves c: carrot roots.

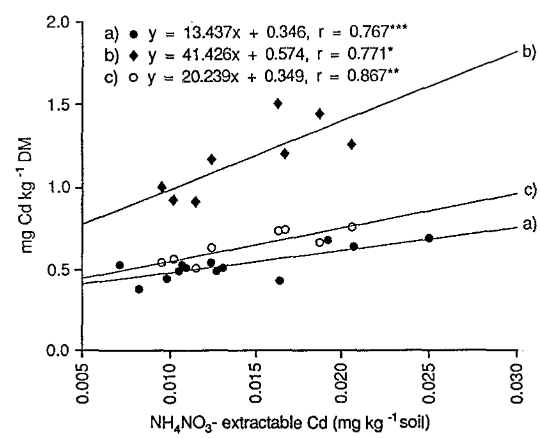

Fig. 3. The relationship between NH_4NO_3 - extractable Cd in the soil and the Cd concentration (year 2 data) in vegetable crops. a: Chinese cabbage (for no. of obs. see text under methods) b: carrot leaves c: carrot roots.

obtained between these parameters (Fig.1). For cabbage, soil samples from the phosphate rock experiment (6 sample, data for one local product tested along with phosphate rock are not presented) were also analyzed and are presented in Figures 1 to 3. This made the number of observations 14 for cabbage and 8 for carrots. Soil pH affects the extractability of Cd in soils owing to the increase in Cd adsorption or the decrease in solubility of Cd-minerals such as $CdCO_3$ and $Cd_3(PO_4)_2$ when increasing soil pH (Christensen, 1989). This relationship compares well with the results reported by He and Singh (1994b) where they showed a good relationship between the NH_4NO_3 -extractable Cd and soil pH along with other soil properties such as Mn-oxides, fine sand and clay content. A good relationship between soil pH and the Cd concentration (year 2 data only) in the plant was observed and the correlation values ranging from 0.82 to 0.86 were obtained in different crops or plant parts (Fig.2). The effect of soil pH on Cd uptake by plants is discussed above. Cadmium concentration in both crops was found to increase with increasing concentration of the NH_4NO_3 -extractable Cd in the soil and showed a significant correlation (Fig.3). Similar observations were also made by other investigators (Alloway and Morgan, 1986; Kuo *et al.*, 1985). Alloway and Morgan (1986) reported that Cd extracted by 0.05 $CaCl_2$ and 1 M NH_4NO_3 from 40 contaminated soils and 5 uncontaminated soils were highly correlated with the Cd concentration in carrots, cabbage, lettuce and radish.

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