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Cadmium contamination in agriculture and zootechnology

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Introduction

Fortunately, acute Cd toxicity caused by food consumption is rare, but chronic exposure to significant Cd levels in food (and specially in plant materials) may be more frequent. It could significantly increase the accumulation of this heavy metal in certain body organs of man or animals (kidney, liver, etc.).

For populations not exposed to Cd from fall out or to professional contamination, the main source of Cd body burden is also from food. The Food and Drug Administration reported an average daily ingestion of 39 µg/day for 15-20-year old males in the USA[44].

Drinking water and ambient air contribute relatively little to the daily intake. Cigarette smoking is another risk for Cd intake by inhalation. Occurrence of Cd in the food chain and in tobacco is certainly the main source for human or animal contamination.

The concentration of Cd in foods is controlled by its level in the soil, its availability for plants, and by the physical and chemical properties of the growing substrate.

Some agricultural practices, as phosphatic fertilizers, sewage sludge disposal, town-refuse composts applications etc., may increase Cd accumulation in soil and lead to heavy metal transfer to crops and to the food chain.

1. *Cd additions to the soil through environmental pollution and agricultural practices*

The concentration of Cd in most soils is in the range of 0.5-1.0 mg/kg, although concentrations above 20 mg/kg occur naturally in some mining areas. Following Davies and Roberts[11] we may consider that concentrations of Cd, in agricultural soil, in excess of 2.4 mg/kg are anomalously high. Raised concentrations of Cd in soil may be found naturally or as a result of pollution from mining or smelting (e.g. in the Meuse Valley[14,15,45]) or from moving sources (principally automobiles).

The dispersal of metal rich waste around mine and smelting plants has led to high concentrations of Cd in top soils at various localities (e.g. La Calamine, Plombières, Engis, in Belgium). Atmospheric fall-out raise levels of Cd in industrial and urban areas, even in rural areas. Secondary metal refining activities, waste incineration, tyre and oils residues from vehicles, also dissipate Cd into the environment[12].

Agricultural soils are mainly contamined by phosphatic fertilizers and sludge disposal. The Cd content of rock phosphate is variable and depends on its geographical origin[70]. In a Belgian survey of 31 common phosphatic fertilizers Beaufays and Nangniot[6] found Cd concentrations ranging from 0.1 to 80.8 mg/kg. In glasshouses, where intensive cultures of vegetables are performed, an excess of phosphatic fertilizers presents an important hazard of Cd pollution, especially when leafy vegetables (lettuce, spinach etc.) are grown. Andersson[3] calculated that if the Cd concentration in phosphatic fertilizers exceeds 8 mg/kg, Cd levels in top soil may be increased.

The use of Cd-containing agricultural sprays (plant protection chemicals containing Cd are rare) or soil amendments is limited to phosphatic fertilizers or micro nutrients solutions.

In flooded rice culture, as practiced in the Po Valley, the irrigation water is the most important vector of the heavy metals Cd, Cu and Cr. The maximum yearly

Table 1. Total trace elements contents of composted town refuse (ppm dry matter). After Gray and Biddlestone[21] and Delcarte et al.[13]

Sample	Pb	Cu	Cd	Ni	Zn	Fe	Mn	B	Cr
(Gray-Biddlestone)[21]	1630	610	7.5	–	1350	–	–	174	–
Roma, Italy[13]	57	130	0.8	6	365	2430	29	–	19
Switzerland[13]	396	483	7.1	41	1875	3500	100	–	65
Belgian (common)[13]	595	251	5.2	87	1363	24548	856	–	69
Belgian (arrosol)[13]	360	318	5.1	25	846	1615	39	–	8

increase in the Cd concentration of the top 20 cm of soil, as a percentage of the actual concentration, would be 6%[7].

Another important source for Cd contamination of soils and crops are the sewage sludges used as fertilizers (cf. chapter written by Davies on cadmium in sludges used as fertilizers).

The composting of town refuse, in order to produce a material which would be of value as a soil conditioner or manure, becomes a new recycling process for organic waste. The nutrient content of such composts is low, but they contain considerable amounts of trace elements as shown in table 1.

Farmyard manures from animals receiving dietary supplements is not known as a possible source for Cd transfer to soils.

Prediction of increases in Cd concentrations in agricultural soils due to high inflows by atmospheric fallout, intensive culture practices, combined with low outflows by leaching and crop removal is important in assessing future Cd load and availability to the animals and to the human populations.

Some authors have attempted to simulate the progressive enrichment of Cd in soils, with a predicted average retention time for Cd in the ploughing layer (25 cm depth) in the range 5–50 years[57,64,68]. The cadmium balance on normal agricultural soil indicates a much longer retention, and actually inflows are much greater than outflows (see fig. 1)[28].

A regular survey of soil pollution by Cd must be initiated where important fall out occurs and when high doses of phosphatic fertilizers or sludge applications are repeated. This survey will include chemical soil analysis, permitting to characterize the enrichment, but a real diagnosis should be based on determination of the mobile fraction of Cd and on plant analysis. Indeed, only the mobile part of Cd is available to plants, and this fraction depends on pH, organic matter content, redox-potential, precipitation with phosphates, carbonates, competition with other heavy metals, etc.

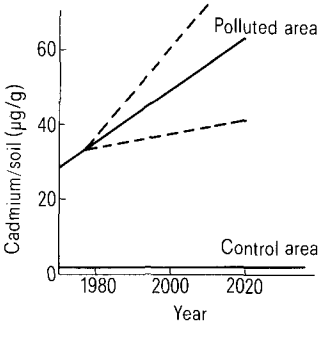

Figure 1. Evolution of Cd accumulation in soil of 2 different areas: polluted or not. The dotted lines are representative of the dispersion due to standard deviation[28].

2. *Cadmium in plants*

2.1 *Distribution within plants*

Cadmium is a non-essential element for both plants and animals, so there are no lower critical concentrations below which deficiency of the element would occur. Upper critical concentrations mark the beginning of phytotoxicity.

All plants contain detectable concentrations of Cd. In general, the background concentration analyzed in crops grown on soils not subjected to any known outside source of Cd pollution, seems to be in the range 0.1–1.0 mg Cd/kg dry matter. In experimental results, Cd concentrations found in plant tissue are expressed on a dry-weight basis. However, for convenience, wet weight is frequently used as the basis for Cd concentrations in dietary studies. Page et al.[55] have reviewed and summarized the concentrations of Cd in various leafy, legume and root vegetables, fruits and various grains grown on non-polluted soils. Generally, the variation of Cd concentrations among the various plant parts analyzed is decreasing in the order roots > leaves > fruiting parts > seeds = storage organs. Differences in Cd concentration between these organs become accentuated as exposure to Cd increases.

The concentration of Cd in foods or fodder grown in soils are related to the properties of the soil on which they are grown, to the Cd concentrations in the soil, to different absorption characteristics of species and cultivars, the nature of the edible part, the age of the plant, and some environmental factors.

2.2 *Uptake of Cd*

There are 2 possible pathways for disposed Cd to enter into the plant tissues: the intake of soil's Cd by the roots and the foliar absorption of Cd present in deposited dust.

In the Meuse Valley investigations were carried out in order to identify and measure separately the transfer of Cd from soils to the roots and from air to the leaves (aerial deposition).

A crossed culture pattern was designed to distinguish the two routes of plant contamination; lettuce and italian rye grass were used as indicators of the intake (table 2).

Table 2. Experimental scheme of crossed cultures pattern[28]

	Crops grown on Cd polluted site Bulk contamination of crops (pattern 1)	
Without atmospheric Cd source Crops grown on polluted soil in clean air area (pattern 2)		*Without soil Cd source* Crops grown on non-Cd polluted soil, exposed in an industrial area (pattern 3)
Physiological contamination by soil-plant transfer		Contact contamination by aerial deposition on leaves
	Crops grown as reference on soil in a non-polluted area (pattern 4)	

In the 3 exposed patterns (1, 2 and 3), there is a regular enrichment in Cd, during the growth period. Contamination kinetics of plants growing in polluted soil is characteristic of root absorption with a peak during the first weeks of exposure and a decrease later (pattern 2). This decrease does not appear when plants are cultivated on polluted soil in presence of aerial fall out (pattern 1).

Crops grown according to the 3rd pattern allow the detection of the actual air pollution and to follow quantitatively the progressive Cd contamination of plant tissues, as shown in figure 2. In this figure it can be seen how crops growing slowly and submitted to aerial deposition (measured by Owen gauges and analyzed for their Cd content) might be contaminated during the vegetation period[28].

Comparison between the two pathways were also made using a radioactive tracer (^{109}Cd). Foliar uptake and translocation of ^{109}Cd is limited to a few percent of the disposed quantity[23,26]. Root absorption remains the major pathway for Cd enrichment in plant tissues as shown by pot trials, greenhouse's experiments or open field observations.

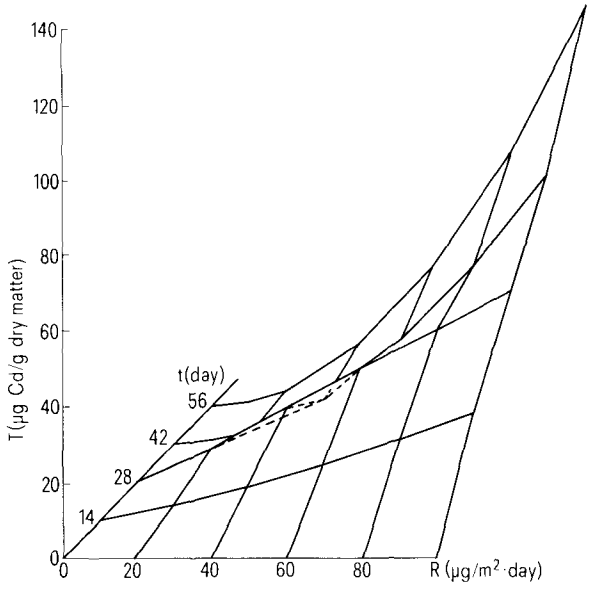

Figure 2. Relation between Cd content in plant tissues (T) and atmospheric fall out (R) (µg Cd/m^2/day) and term of exposure (t)[28].

The soluble inorganic salts are much more readily available to plant roots than Cd originating from organic material (sludge, town refuse compost etc.). Extreme caution is essential in extrapolating from results with inorganic salts under controlled conditions to what might happen in living soils, with an important organic matter content, and a wild microflora, under natural environmental conditions. Physiological experiments are performed with inorganic and usually soluble salts of Cd (e.g. $CdCl_2$, $CdSO_4$). The trials use various substrata (water, sand, natural or artificial soils) and are justified for examining the physiological effects of Cd within plant tissue (phytotoxicity) and how the Cd enters and accumulates in the tissue.

2.3 *Plant uptake of Cd from soil*

Chemically, Cd may be dissolved in the soil solution, adsorbed into organic or inorganic colloidal surfaces, occluded into soil minerals, precipitated with other compounds in soils, and incorporated into biological structures. As long as Cd remains tightly bound to solid soil constituent and that the available contents (i.e. soluble forms) remain low, there will be little effects on the environment. When soil conditions change in such a way that Cd goes into solution, the raised Cd content of soils imposes a direct environmental hazard. The increasing availability (or mobility) of Cd in soils may have adverse effects on plant growth. In addition, there may be a leaching down to groundwater or to surface water, and hence reach man and animals through the drinking water.

The mobility of Cd in a soil, and the hazards associated to its availability for plants growing on that soil depends on:

- chemical form of the Cd in that soil, plants may take up some Cd by direct contact between roots and solid soil constituents (in order for root uptake to occur, soluble forms must exist adjacent to the root membrane for some finite periods),
- pH of the soil,
- occurrence of other elements, notably competing heavy metals (Zn) and of complexing ligands, and adsorption sites associated with the solid phase,
- amount of available Cd in the soil,
- environmental conditions (soil temperature and moisture contents, and other factors which affect microbial activity),
- plant species[23].

Field and greenhouse experiments have shown that Cd concentrations and pH of the soil are the two main factors influencing uptake of Cd by food crops. Although oxidation reduction potential is important on Cd absorption by roots, it is a relatively unimportant factor in food production as most food crops, except for rice, will not grow under reducing soil conditions.

Numerous authors have described the extent to which Cd is accumulated by plants in relation to soil pH (a review is given by Page et al.[55]). If other soil conditions remain unchanged the plant tissue Cd concentration would decrease as the pH of the soil increases.

One of the most effective means of minimizing the

absorption of Cd by plants grown on acid soils is to increase their pH by liming. Bingham et al.[9] reported that liming soil from pH 5.2 to pH 6.7 reduced the Cd content of wheat grain by about 50% and also reduced Cd concentrations in lettuce and swiss chard[8].

Organic matter has been thought to play a role in the binding of Cd in soil through both chelation and adsorption mechanisms. It seems that chelation is much less important than adsorption, so that the ability of organic matter to immobilize Cd is largely due to its CEC (cation-exchange capacity)[33]. As result, the complexing of Cd with organic matter affects its uptake by plants[40] which decreases mainly because of the CEC of the organic matter.

The synergistic and antagonistic effects of other trace metals in the soil substrate on the absorption of Cd by plants has been examined by a number of investigators. For example, abundant available zinc in soil might depress plant uptake of Cd[1]. However, the effect of Zn depended upon the Cd concentration in the soil. At low Cd levels (1 ppm), increasing levels of Zn reduced the concentration of Cd in lettuce leaves, but at higher Cd levels the added Zn either shows no effect or increases the Cd concentration.

The interactive effects of Cd, Zn, Cu and Ni were studied by Mitchell et al.[50]. Increasing concentrations of both Cu and Ni in soil consistently reduced concentrations of Cd in the leaves of lettuce plants. Plant macronutrients, e.g. phosphorus, have also been found to affect Cd uptake and concentrations in crops, but the relationship is complex.

2.4 *Factors affecting Cd uptake*

a) *Effect of substrate Cd concentration*

Under similar soil conditions (pH, CEC, etc.), amounts of Cd absorbed by plants tend to increase as the concentration of Cd in the soil increases. There may or may not be a linear relation between the increases of Cd concentration in plant tissues and in soil. This relation is influenced by biological and environmental factors.

The greater part of information collected about Cd accumulation in plants are known with soil that has been fertilized with municipal sewage sludges containing Cd. Reviews of Cd absorption by crops grown in sludge-amended soils are numerous and recent[12,42]. They will not be discussed here.

Results obtained in experiments conducted in greenhouses, to evaluate the effect of Cd level in soil on its concentration in plants have to be improved in field trials. Generally the plants grown on Cd enriched soils or in flowing culture solution, containing soluble Cd salts, absorb more Cd than the same plants grown on the same soil amended with identical amounts of Cd in the field.

Root development is different: the roots of the container-grown crops are exposed to contaminated soil or solution exclusively and uniformly, whereas in the field the roots may extend to depths below the Cd contamined layer or to soil volumes not uniformly polluted.

Not only the amount of Cd added, but also its chemical form will influence the amount absorbed by roots. Easily extractable Cd content of a soil is important to predict uptake of the metal by plants.

A growth experiment using corn (maize), rye grass, red clover, turnip and dandelion on a sandy loam soil was carried out in greenhouse by Gupta and Haeni[22]. The Cd doses ranged between 3.6 and 58.1 µg Cd/g soil. There exists a statistically significant relationship between 0.1 M $NaNO_3$ extractable soil Cd, dry matter yield and Cd uptake for all 5 plants.

Pot trials were made on rye grass to see both influences of Cd addition to soil and duration of exposure to soil contamination (fig. 3). There is a progressive enrichment of Cd content in plant tissues. When successive harvests of rye grass are made, the highest tissue concentrations are found at the second harvest[29].

A number of studies suggest that the length of time of soils incubations with Cd also influences the availability of Cd to crops. Bates et al.[5] have followed the Cd concentrations from successive planting of crops grown on soils which were treated with the same amount of Cd prior to each planting; the concentrations of Cd in the first crop of rye grass were approximatively the same as their concentrations in the following 3 crops.

b) *Biological factors affecting Cd uptake*

Plants differ in their tolerance to heavy metals. On old mine spoil tips and on heavy polluted soils, one may find a special calamine-tolerant flora (e.g. *Viola calaminaria* (D.C.) Lej.). Metal tolerance in plants is variable but genetically controlled. Simon[60] has shown that a Cd tolerance occurs within populations of *Agrostis tenuis* Sibth and *Festuca ovina* L. This tolerance is due to the ability of the plant to accumulate the metal in an inert form associated with the cell walls of its roots. When the capacity of absorbing and accumulating sites in the cell walls are exceeded, translocation to stems, leaves and fruits becomes possible with an important hazard of phytotoxicity when Cd concentrations are high.

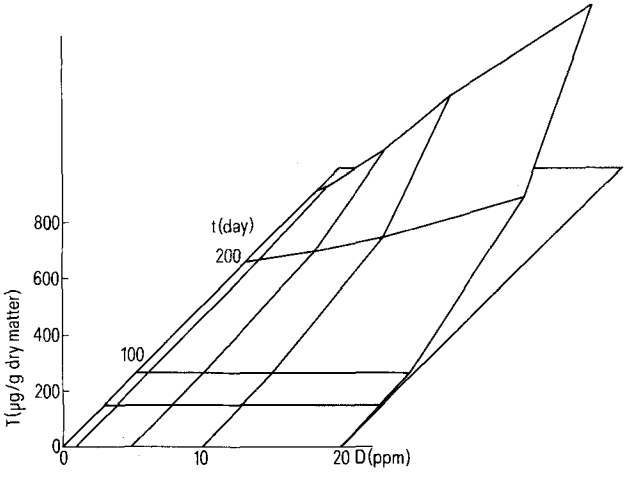

Figure 3. Cd content of rye grass (T) in relation with the concentration of metal in the soil (D), and the time of culture (t)[28].

Many workers have reported that concentrations of Cd in plant parts vary between plant species growing in the same substratum under the same environmental conditions. This reflects the different genetically fixed abilities of the plant roots to restrict the transfer of Cd from roots to epigeal organs[31].

A classical experiment comparing these abilities was realized by Jarvis et al.[30]: 23 different species of crops were grown in water culture solution for between 45 and 62 days, during which they were exposed for 3 days to 0.01 mg Cd/l (as $CdCl_2$) in the flowing culture solution. At harvest, Cd concentrations in the shoots ranged from 21.1 mg/kg (fodder beet) to 1.8 mg/kg (radish).

Pot trials using naturally or artificially contamined soils were performed by many authors: e.g. John[31] observed concentrations of Cd in the leaves of plants grown on the soil supplemented with 40 mg Cd/kg ranged from 264.7 mg/kg (radish) to 18.5 mg/kg (cauliflower).

At the Water Research Center (Stevenage, U.K.) 39 crop plants, including representatives of all the major botanical groups, were grown to maturity in a pot trial using contaminated soil. Leaves and edible parts were analyzed. An ornamental cultivar of tobacco showed the highest concentration of Cd in its leaves. Leaves of Chenopodiaceae, and lettuce, tomato, potato and celery also showed comparatively high foliar concentrations of Cd.

Concentrations of metal in the edible roots tubers and grains were usually lower than in the leaves of the same plant and this effect was often very acute, e.g. potato. Concentrations in edible parts ranged from 0.1 mg/Cd in pea seeds to 9.0 mg Cd/kg in lettuce[12].

Some experiments performed in our laboratory have given similar results (fig. 4). There is an important variation amongst cultivars of a single species grown on the same substratum as shown by John and Van Laerhoven[33]. The authors grew 9 cultivars of lettuce in a sand culture experiment, with a range of Cd concentrations from 0.1 to 50 mg Cd/l. After 3 weeks of culture, tissue concentrations in the leaves of the various cultivars receiving 0.1 mg Cd/l in their nutrient solution ranged from 0.4 to 26.6 mg/kg, this kind of variation appears at all treatments.

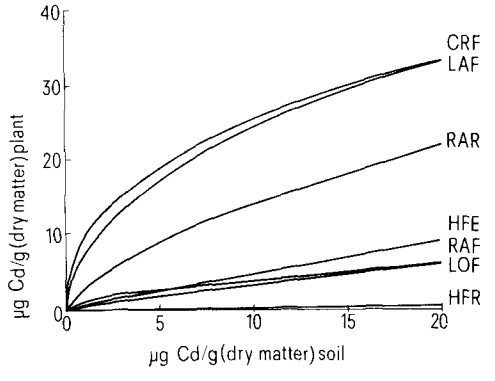

Figure 4. Caption: Evolution of Cd content in plants in relation with Cd addition to soils. CRF, *Lepidium sativum* L. leaves; LAF, *Lactuca sativa* L. leaves; RAR, *Raphanus sativus* L. roots; HFC, *Phaseolus vulgaris* L. leaves; RAF, *Raphanus sativus* L. leaves; LOF, *Lolium multiflorum* L. leaves; HFR, *Phaseolus vulgaris* L. fruits[28].

As leafy vegetables (lettuce, spinach) accumulate the highest concentrations of Cd in their tissues, they may be used, in polluted areas, as indicators to prevent hazards of foodchain contamination[29].

Although much remains to be learned concerning the uptake of Cd by crops, and the accumulation of Cd in edible parts of crops, it should be reasonable to build a model involving the interaction between soil physico-chemical properties, which determine how much Cd is potentially available for root absorption, and biological characteristics (plant genotype) which determine how much Cd is really taken up.

3. *Cadmium in farm animals*

3.1 *Uptake and absorption*

In the environment, farm animals and wild animals can be exposed to cadmium pollution by 2 main routes: inhalation of polluted air and ingestion of polluted food.

Respiratory deposition clearance and respiratory absorption were studied principally in laboratory animals[20]. From these researches it may be concluded that cadmium is absorbed and retained to a considerable degree in the body after inhalation. The respiratory absorption is primarily from the lungs; an absorption between 10 and 40% of inhaled cadmium can be expected as a considerable difference might well exist for different cadmium compounds. Cadmium metabolism has been studied in a variety of mammalian species. Intestinal absorption is low: 0.3% in goat[46,47], 0.035-0.2% in the lactating dairy cow[51,66], 5% in swine[10]. Cadmium absorption is influenced by different dietary factors: calcium, protein and vitamin D deficient diet increase the absorption of cadmium[56,62,71].

Suckling and young animals have higher absorption than adults; milk diet could be an important factor in the increased cadmium absorption in sucklings and youngs since some authors found also a higher cadmium absorption in older animals fed a milk diet[35].

3.2 *Metabolism*

a) *Faecal and urinary excretion*

Faecal excretion is the major excretion pathways for cadmium. After a single oral dose in goats[46,47] and after a single or repeated dose in cows[48,51,66] about 80-90% of the total ingested cadmium is excreted in the faeces within 14 days, after the end of the application.

Faecal excretion of cadmium after an i.v. injection in goats[47] and in cow[66] indicate that metabolized cadmium is principally excreted by the gastro-intestinal tract: after a single injection of $^{109}CdCl_2$ in goats, 5.6% of the cadmium was excreted via feces within 5 days and, in cows, about 5.5% was found in feces within 10 days.

Studies on cadmium metabolism in laboratory animals and ruminants indicated that daily excretion of cadmium in the urine is very low prior to tubular dysfunction. Total urinary excretion observed in goats was 0.031% of the administered dose after oral ingestion and i.v. injection. Authors reported that a contamination with faecal excretion, in the case of oral dosing was not excluded.

In cows a total urinary excretion of 0.05% of dose[51] and as low as 2.5×10^{-3}% of dose was observed after an oral dose of $^{109}CdCl_2$[66]. Experiments on laboratory animals show that once tubular dysfunction has occurred the urinary excretion of cadmium associated to urinary proteins (probably metallothionein) increases markedly[4].

b) *Secretion and distribution in milk*

Cadmium secretion and distribution in cow milk was studied by various authors[48,51,66].

Miller et al.[48] found that after a daily administration of 3 g cadmium as $CdCl_2$, for 2 weeks, the concentration of cadmium in milk samples stayed < 0.1 mg/l of milk and the excretion/day was less than 2.2×10^{-2}% of the daily administered dose. Effectively, cadmium concentration in milk after various single oral doses of ^{109}Cd in lactating cows suggests much lower secretion. Total cadmium secretion in milk either as a single oral dose of cadmium as $^{109}CdCl_2$ in gelatine capsule or as a single oral dose of *Zea mays* leaves, contaminated by $^{109}CdCl_2$ drops, was respectively 1.8×10^{-3}% and 7.0 10^{-4}% of the administered dose[66]. Neathery et al.[51] on the other hand found that the level was below the detection limit: 8×10^{-5}% of dose/day.

The cadmium distribution in milk after "in vitro" incubation of milk with cadmium[48] or after a single oral administration of ^{109}Cd to lactating cows[66] is essentially the same and indicate that cadmium is preferentially bound to the protein fractions with about equal concentrations in casein and albumin. The concentration in lactose is about one half and in mineral-water fraction about one order of magnitude lower than the concentration in proteins, the milkfat does not seem to have any affinity for cadmium (table 3).

c) *Retention and distribution of cadmium in organs of farm animals*

Cadmium retention and distribution in farm animals were reported by several authors: Miller et al.[46,47] presented data obtained from young goats 14 days after an oral or intravenous administration, Neathery et al.[51] from pregnant lactating cows 14 days after an oral application and Van Bruwaene et al.[66] from lactating cows 131 days after an oral application.

Total retention observed in goats was about 0.3–0.4% of administered dose. In cows total retention was estimated to be about 0.75% of the dose, 14 days after an oral dosing; 131 days after dosing, 0.13% of dose was retained after an oral administration of ^{109}Cd solution in gelatine capsules and 0.025% of dose was retained after administration of contaminated *Zea mays* leaves contaminated by externally applied $^{109}CdCl_2$ drops.

At sacrifice of goats and of cows, the highest cadmium concentrations were found in kidneys followed by liver, pancreas and small intestine. In goats a high concentration of cadmium was also found in abomasum. Distribution of cadmium within organs was similar in young goats and in cows sacrificed respectively 14 days and 131 days after dosing; about 50% of the total retained dose was present in the liver and almost 25% in the kidneys. In goats a large part of the remainder was found in the gastrointestinal tract and its contents. In cows, 131 days after dosing, still 4–5% of body burden were found in the following tissues: abomasum, duodenum and jejenum. No differences in distribution was observed after administration of either a $^{109}CdCl_2$ solution or contaminated *Zea mays* leaves. The distribution of cadmium in cows 14 days after dosing was slightly different: 32% was found in liver, 18% in GI contents, 16% in GI tissues and 10% in kidneys.

Cadmium distribution in goats after intravenous and oral dosing[47] indicated that the pathway of dosing has affected the metabolism. Accordingly it seems reasonable to suspect that cadmium absorbed from the GI tract is probably in association with some types of protein compounds.

Feeding a level of cadmium which approaches the upper limits which could be fed without developing noticeable toxicity symptoms does not greatly influence the percentage of radiocadmium absorbed or the rate at which it is lost[46]. Thus it seems evident that goats do not have homeostatic control mechanism which would be dependent on dietary or tissue cadmium levels for changing amounts of cadmium absorbed and reexcreted.

In conclusion, the liver and the kidneys appear to be the 2 organs of greatest interest with regard to cadmium storage, however cadmium is found in the most compartments of the body. Since relatively little cadmium is transferred to muscle or to milk it is apparent that the main food products (other than liver and kidneys) from ruminants are quite well protected from cadmium accumulation.

3.3 *Transfer in animal products*

a) *Transfer coefficients*

Transfer coefficients are expressed as the fraction of daily nuclide intake present in 1 l of milk or 1 kg of organ.

Table 3. Distribution of cadmium (in percent of total activity in milk) in the principal organic constituents of milk collected 2 days after a single oral dose of $^{109}CdCl_2$ (Van Bruwaene et al.[66])

Administration mode of Cd	Casein	Albumin	Lactose	Fat
In gelatine capsules	28.8 ± 0.08	5.5 ± 0.04	3.0 ± 0.34	Not detectable
In maize leaves	17.7 ± 0.40	4.0 ± 0.13	3.3 ± 0.26	Not detectable

Table 4. Cadmium concentrations in beef muscle, liver and kidneys (expressed as mg/kg fresh weight) observed in various countries

Muscle	n*	Liver	n*	Kidneys	n*	Countries	Years	References
0.047–0.183	4	0.108–1.16	4	0.220–39.88	4	FRG	1968	39
0.011 ± 0.079 (0.041 ± 0.022)	30	–	–	–	–	FRG	1972	24
< 0.005	141	0.005–0.3 (0.06 ± 0.05)	141	0.04–1.66 (0.3 ± 0.3)	141	FRG	1972/74	38
< 0.005	280	0.005–1.658 (0.05)	280	0.005–1.95 (0.23)	283	FRG	1972/75	37
< 0.04	8	0.1–0.38 (0.23)	8	0.4–2.0 (1.1)	8	Belgium	1980	65
0.01–1.00	1947	** 0.01–3.17	2316	** 0.01–7.82	2.553	USA	1971/74	53
0.035 ± 0.034	71	(0.183 ± 0.228)	71			USA	1974	53
0.001–0.04	13	0.071–0.3	13	0.12–1.2	13	The Netherlands	1977	67
				0.18–5.69 (1.11)	150	Denmark	1975	32

* n = number of animals; ** with measurable concentration.

In the case dealing with the transfer of cadmium in milk, a broad range of values of transfer coefficient are proposed. A transfer coefficient value of about 1.10^{-3} day/l is reported by Ng et al.[52], based on the concentrations of cadmium in forage and milk. A survey on transfer of cadmium in cow milk conducted in Belgium[65] suggests a value of $< 1.10^{-6}$ day/l.

From some experimental works, daily administration for 14 days of 3 g of cadmium chloride in a cow[48] and of 9 mg $CdCl_2$/kg body weight[43] values of transfer coefficients of respectively $< 3.3\ 10^{-5}$ day/l and 5.9×10^{-8} day/l are suggested. After a single oral dose the transfer coefficient can be calculated indirectly taking into account that the activity time integral/kg in milk or organ equals the concentration at equilibrium reached under continuous dosage. For example, after a single oral dose of ^{109}Cd chloride in cow, transfer coefficients of 1.10^{-4} day/l[15] and $< 2.7\ 10^{-6}$ day/l[51] were obtained.

The transfer coefficients estimated by Van Bruwaene et al.[66] for liver and meat, were 0.02–0.2 day/kg (liver) and 1×10^{-4} to 1×10^{-3} day/kg (muscle), the values of the transfer coefficient for meat being in the same order of magnitude as the value reported in the NRC[54] (5.3×10^{-4} day/kg).

b) *Cadmium concentrations observed in farm animals*

It is generally recognized that ruminant and especially cattle are more exposed to local pollution situation than pigs or other intensive breeded domestic animals for human consumption. Ruminants are depending for 90% and even more on their daily ration of local produced forage and feeds.

A review of cadmium concentrations observed in beef muscle, liver and kidneys in different countries is presented in table 4.

Although less interest has been devoted to the measurements of the cadmium concentration in pig tissues, some data are available in the literature: Table 5 reports cadmium concentration in pig muscle, liver and kidneys observed in Federal Republic of Germany. The data presented in tables 4 and 5 demonstrate that meat contained the lowest cadmium level and kidneys the highest, the cadmium concentration observed in kidneys being 2–5 times more important than the cadmium concentration in liver. A large variation around the mean values is observed.

Table 5. Cadmium concentrations in pork muscle, kidneys and liver observed in Federal Republic of Germany[24]

	Number of samples	$\bar{X}$	S	Range of concentration
Muscle (in µg/kg fresh wt)	82	12.3	11.6	1.46–72.1
Kidneys (in mg/kg fresh wt)	72	0.54	0.277	0.1–1.67
Liver (in mg/kg fresh wt)	82	0.19	0.061	0.086–0.4

Some authors[37] observed in cattle a relationship between the age of the animals and the cadmium content in kidneys; the cadmium content in kidneys and in livers are also closely correlated. These authors observed no indication that breed or sex had any effect on Cd content of kidney and liver.

3.4 *Cadmium toxicity in domestic animals*

Cadmium toxicity has been demonstrated experimentally in numerous animal species[16,17]. Manifestations of toxicity include loss of weight, reduced food intake, anemia, hypertension, proteinuria, poor bone mineralization, testicular necrosis, aborted fetuses, neonatal death and youngs with birth defects.

a) *Cadmium toxicity in ruminant* (cattle and sheep)

A plant fungicide (cadmiate) was given in doses of 50, 100, 200, 300 and 500 mg/kg food to adult cows for maximum 49 weeks of less and to mature ewes for 41 weeks[72]. A dose of 50 mg Cd/kg food caused only a slight reduced food intake and wight loss but above a dose of 200 mg Cd/kg food, anemia was observed. In sheep, levels of 100 mg Cd/kg food decreased RBC (erythrocyte), PCV (packed cell volume) and Hb (hemoglobin) values. A dietary concentration greater than 200 mg Cd/kg food for both cattle and sheep had BUN (blood urea nitrogen) levels that increased later on during the experimental period. The BUN levels increased gradually in the blood of cattle but increased sharply in blood of sheep.

In pregnant cows and sheep for all doses (50–500 mg Cd/kg food) aborted fetuses, neonatal death and youngs with birth defects were observed. In sheep

infertility was also observed. Placenta which acts as a barrier to low doses of cadmium can be overcome at high doses; residues of cadmium appeared in the tissues of fetuses.

Lactating cows, given 3 g of cadmium daily, lost considerable weight and milk production declined sharply for several days and then increased appreciably but stayed substantially lower than for control cows. When cadmium treatment was stopped milk production increased within 10 days to normal production[48]. Powell et al.[59] studied cadmium toxicity in calves. Calves were given: 40, 160, 640 and 2560 mg Cd/kg food with and without supplementation of 100 mg Zn/kg food. It seems that calves can tolerate considerable Cd concentrations in food. There was immediate reduction in feed consumption with weight loss for all groups fed as much as 160 mg Cd/kg food. For the lowest dose (40 mg Cd/kg) these effects were annulated by the addition of 109 mg Zn/kg food. Calves fed 640 or 2560 mg Cd/kg food exhibited unthrifty appearance, rough hair coat, severe body dehydration, dry and scally skin, loss of hair from legs, thighs, chest floor and brisket mouth lesions, oedematous shrunken and scaly scrotum, sore and enlarged points, impaired sight, extreme emaciation.

With 160 mg Cd/kg food, the testicle growth was decreased; whereas at 640 mg Cd/kg good there was very little testicle growth. The results of this study indicate that a very severe and extended Cd toxicity may cause serious damage to the testicle development in the bovine.

After stopping the Cd treatment, improvement in appearance feed consumption, growth were quite rapid, also sperm-producing tubules were not completely destroyed as suggested by other studies.

Sheep appear to be very sensitive to cadmium, even concentrations of 5 mg Cd/kg food ($CdCl_2$) during 163 days result in a slight reduced body weight[19]. Interactions of cadmium with copper, iron, zinc and manganese were studied in sheep by different authors[18,49].

Significant numbers of lambs fed low levels of dietary Cd had markedly depressed blood and liver Cu concentrations and ceruloplasmin levels indicating a significant derangement of Cu metabolism; the data also indicate significant disruption of Fe, Zn and Mn metabolism in various parts of the body. Low Cu and Fe levels in liver are associated with anemia, whereas decreased Mn concentrations in body tissues are associated with skeletal defects[41].

b) *Cadmium toxicity in swine*

Cadmium toxicity was studied in 8-week-old swine at levels of 0, 50, 150, 450 and 1350 mg Cd/kg feed during a 6-week comparison period[10]. There was no mortality during the comparison period. Animals receiving 450 and 1350 ppm cadmium exhibited signs of toxicity. The skin covering the inner portion of the hindlegs and the ears were red and scaly and in these areas small leasions similar to those found in the early stages of parakeratosis were observed. Growth rate was decreased as a function of Cd level and was inhibited in the 1350 ppm group. Hematocrit values were the most sensitive criteria of toxicity, they decreased in all Cd fed animals. Bone ash content was decreased as a function of Cd intake. The addition of Zn (52 mg Zn/kg) had little influence on the toxicity symptoms of Cd in young pigs[58].

c) *Cadmium toxicity in poultry*

Effects of cadmium administration were studied in chickens by Krampitz[36]. LD_{50} in chikens is observed at levels of 165-188 mg Cd/kg b.wt and the lethal dose is about 216 mg Cd/kg b.wt. Toxicity was already observed at Cd concentrations of 60-90 mg Cd/kg feed, but toxicity can be reversed by addition of zinc, manganese, copper and cobalt to the ration[63].

Broiler and laying rations containing 20 and 40 mg Cd/kg reduced the body weight respectively by 8 and 24% and reduced the feed conversion efficiency by 3 and 11%[69]. By addition of 20-200 mg of zinc, no difference with control animals was observed[61].

Bone decalcification was observed in consumption chickens fed rations with 5 mg Cd/kg[69]. Enteritis and nephritis in chickens was observed after feeding ration with 3 mg Cd/kg[36].

Contraceptive effect was observed in laying hens, when fed 7-10 days a ration containing 50 mg Cd/kg a total stop of laying was observed[27].

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Full Papers

An analysis of the effects of urethane on cardiovascular responsiveness to catecholamines in terms of its interference with Ca^{++} mobilization from both intra and extracellular pools

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Summary. Urethane (1×10^{-2}-1×10^{-1} M) reduced, in a concentration-dependent manner, both intra and extracellular Ca^{++} dependent noradrenaline-induced contractions of perfused rabbit ear artery as well as the tonic contractions produced by perfusion with high K^+ solution. However, a quantitative analysis of the data indicated that for urethane concentrations similar to those found in plasma during anesthesia urethane antagonism is confined to noradrenaline-induced contractions which depend upon the mobilization of Ca^{++} from intracellular storage sites. In KCl-contracted arteries, urethane enhanced the relaxant effects of isoprenaline. - Urethane reduced the amplitude of contractions of spontaneously beating guinea-pig right atrium at concentrations which have only a limited effect on frequency. In addition, it decreased in a concentration-dependent manner the amplitude of isoprenaline-activated electrically driven, and K^+ depolarized guinea-pig right ventricular strips. Urethane had no effect on the chrono and inotropic actions of isoprenaline on cardiac preparations. In in vivo experiments the chronotropic response to low doses of isoprenaline was significantly higher in urethane-treated as compared to unanesthetized rats. The higher dose of isoprenaline tested produced a significant fall in systolic blood pressure in urethane-anesthetized rats. A significant correlation exists between the chronotropic response to isoprenaline and resting heart rate values in urethane-anesthetized rats.
These results indicate that urethane, at concentrations similar to those found in plasma during anesthesia selectively interferes with mobilization of Ca^{++} from intracellular storage sites. In addition, the interference of urethane anesthesia with the isoprenaline chronotropic effect 'in vivo' cannot be explained by a direct interference of urethane with β-adrenoceptors at cardiac level.

Introduction

Urethane is a widely used anesthetic in animal experimentation mainly because of its long duration of action and skeletal muscle relaxant properties[35,38]. Its use is widespread although it is known to lower blood pressure in intact animals[11,16] and to decrease the contractile response of vascular smooth muscle to noradrenaline[10,11,29,30] to angiotensin[11,40] and in a somehow specific manner to α_2-adrenoreceptor agonists[3,4].

Both the hypotensive action of urethane and its antagonism toward vasoactive agents 'in vivo' have