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Effect of organic fertilisers on the zinc and cadmium uptake of soybeans and wheat on an artificially contaminated soil[1]

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Abstract

The objectives of the research reported here was to investigate the effect of organic fertilisers on the Zn and Cd uptake by plants from poluted soils. Soybean and wheat were grown in a greenhouse experiment on soils contaminated with 300 and 3 mg kg^{-1} Zn or Cd respectively. 10 g kg^{-1} dry matter of soybean straw, alfalfa green meal and farmyard manure (1, 4 and 2 % N respecively) were added. The addition of Zn and Cd as nitrates increased their concentrations in both crops, in all growing stages and in all plant parts, but the effect of the organic fertilisers on the Zn and Cd content and uptake were distinctive different. This differences in the effect of the organic fertilisers were attributed to the synergistic effect of nitrogen on the uptake of Zn and Cd.

From the viewpoint as a strategy for improving food quality, it has to be considered that due to a counteracting synergistic effect of nitrogen on the uptake of Zn and Cd only organic sources with low nitrogen content (e.g straw) are suitable. In contrast are aspects of soil protection and soil reclamation where high inputs of high nitrogen containing organic sources not only may increase the efficiency of phytoremediation of contaminated soils via “heavy metal harvesting” through increased biomass production, but also through the synergistic effects of nitrogen on the heavy metal uptake.

Key words: cadmium, food quality, heavy metal harvesting, organic matter, phytoremediation, soybean, synergism, wheat, zinc

Zusammenfassung

Einfluss organischer Düngung auf die Aufnahme von Zink und Cadmium durch Soja und Weizen auf belastetem Boden[4]

Ziel der berichteten Forschungsarbeit war die Untersuchung des Einflusses organischer Düngung auf die Zn und Cd Aufnahme von Soja und Weizen. Der Versuchsboden wurde hierzu mit 300 mg kg^{-1} Zn und 3 mg kg^{-1} Cd in Form löslicher Nitrate kontaminert. Als Behandlung wurden 10 g kg^{-1} (Basis Trockenmasse) Sojastroh, Luzernegrünmehl oder Stallmist (1, 4, 2 % N in der Trockenmasse) verabreicht. Der Zusatz an Schwermetallen erhöhte Gehalte und Aufnahme bei beiden Pflanzenarten, in allen Stadien und in allen Pflanzenteilen. Der Zusatz an organischem Dünger auf Konzentrationen und Aufnahme von Zn und Cd in den Versuchspflanzen war hingegen deutlich von der Art des Düngers abhängig. Unterschiede der Wirkung verschiedener organischer Dünger können mit einem synergistischen Effekt steigender N-Zufuhr auf die Aufnahme an Zn und Cd erklärt werden. Als Konsequenz für die Erzeugung schwermetallarmer Nahrungsmittel ergibt sich, dass auf kontaminierten Böden bevorzugt N arme organische Düngemittel einzusetzen sind.

Aus Sicht der Sanierung belasteter Böden im Zuge einer Phytosanierung können jedoch organische Dünger mit hohen N Gehalten durch Förderung des Schwermetallentzuges durch die Pflanzen vorteilhaft sein.

Schlüsselworte: Bodensanierung, Bodenschutz, Cadmium, Nahrungsqualität, organische Substanz, Phytoremediation, Schwermetalle, Synergismus, Soja, Weizen, Zink

[1] Result from the German/Polish cooperation in agricultural research

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[4] Ergebnis der Deutsch/Polnischen Zusammenarbeit auf dem Gebiet der Agrarforschung

1 Introduction

Environmental contamination with heavy metals is a process, which develops synchronous with civilisation and technical advance. Thus problems associated with trace element retention in soils are becoming increasingly important and measures are needed to prevent their transfer into the food chain (Kabata-Pendias 1992, Stevenson 1986). Treatments recommended at the moment for preventing the uptake of heavy metals are mostly restricted to increasing soil reaction to the level above neutral and, by doing so, creating conditions favourable for the process of binding metals by adsorption or precipitation. Compared to pH less attention has been paid to the possibility of organic matter management to influence the uptake of heavy metals from soils.

In both, intensive and extensive production systems, stabilisation soil productivity depends to a great extend on the concentration and management of organic matter. This refers to the choice of appropriate rotation systems, intensity of the basic cultivation, mineral fertilisation, etc. These factors can affect, either directly or indirectly, quantities of compounds of plant or animal origin introduced into the soil in a given agronomical system (Campbell 1993, Grzebisz 1987, Oliver 1993).

The common understanding of soil protection involves critical values for heavy metals in order to achieve acceptable concentrations in plants grown on contaminated soils. This concept, however does not take into account that the uptake of heavy metals by plants from soils is not only a function of available concentrations, but is also affected by other factors like for instance organic amendments, which have already been discussed as scavengers (Julia et al. 1998, Kuboi 1986, Lujan et al. 1994, Randall and Hantala 1975, Scott 1992).

Organic substances affect the heavy metal uptake either by supply with other mineral nutrients (e.g. N) or by alternating their mobility by supplying chelating agents.

The objective of this research was to investigate the effect of different organic fertilisers on the uptake of zinc (Zn) and cadmium (Cd) by wheat and soybean.

2 Material and Methods

The experiment was conducted in a greenhouse employing an unpolluted soil from the experimental field of Poznan Agricultural University which is a sandy loam with an initial pH of 6.5 and an average supply with plant available nutrients. Plants belonging to two botanical families, i.e. soybean (*Glicyne max*. L.) - *Papilionaceae* and wheat (*Triticum aestivum*, var. *vulgare*) - *Gramineae* were tested. Three weeks before the beginning of the experiment the soil was subjected to a 3-week incubation in 5 kg pots with 300 mg kg^{-1} Zn and 3 mg kg^{-1} Cd. The metals were added in the form of nitrates. The treatments were the addition of 1 % (by weight) of the following organic fertilisers: soybean straw (1 % N), alfalfa green meal (4 % N) and farmyard manure (2 % N) (FYM). After three weeks of incubation, the artificially contaminated soil was transferred into pots of 250 cm^3 volume and planted with 4 seedlings of soybean or 20 seedlings of wheat. After 18-20 days the plants were harvested. At this time the soybeans had reached the growing stage “V2” and wheat the growing stage “EC13”.

Zn and Cd were determined by means of flame atomic absorption spectroscopy following the digestion of the plant material by aqua regia. The results of the experiment were subjected to a statistical analysis employing multifactorial analysis of variance.

3 Results and Discussion

3.1 Content and uptake of Zn and Cd by soybean and wheat

A measurable consequence of an increased concentration of metals in soil is their accumulation in plant organs. Concentrations of Zn and Cd in plants (both in leaves and roots) growing in the control soil varied and decreased in the order soybean > wheat for Zn and wheat > soybean for Zn. Soybean showed a significant increase in Zn and Cd concentrations both in leaves and roots (Tab. 1). When compared to control soybean seedlings growing in the soil artificially contaminated with Zn showed 3 times higher concentrations in leaves and over 2 times higher concentrations in roots. Also observed was a higher increase of the Zn and Cd concentrations shoots than in roots, which appears to imply a breach of the protective barrier, formed by the root. Nevertheless, the concentration of both elements was considerably higher in roots than in leaves. MacNicol (1985) explains this with the hypothesis that roots act as the first barrier limiting the movement of heavy metals between roots and over ground parts.

Cd concentrations in soybean roots of control plants were 3.6 times higher than in leaves (Tab. 1). Similar results were obtained by Bramley (1994) showing a several times higher concentration of metals in roots in comparison with over ground shoots. Soybean growing in the soil containing only Cd increased its concentration several times; the increment of this metal in roots was sevenfold and eightfold in leaves (Tab. 1).

Soybean accumulated 3.5 times more Zn on the contaminated soil than in the control (Fig. 3). Most of this Zn was accumulated in leaves, with the exception of the treatment with straw, in which an increase of the uptake by roots was observed. In comparison with Zn, Cd was accumulated more by leaves (Fig. 4). Soybean plants growing in the soil enriched only with Cd contained by up to 60 % more of this metal in their over ground parts.

Table 1
Effect of organic fertilisation on Zn and Cd content (mg kg^{-1}) of soybean (stage V2) and wheat (stage EC13) on an artificially polluted sandy loam

ZN					CD			
	Soybean Stage V_2		Wheat Stage EC13		Soybean Stage V_2		Wheat Stage EC13	
Treatment	plant part roots	leaves	plant part roots	leaves	plant part roots	leaves	plant part leaves	roots
Control	166	629	52	111	0.36	1.3	3.8	4.6
Zn or Cd alone	505	1435	146	867	2.9	9.1	5.4	13.3
Zn or Cd + soya	336	1262	96	259	1.7	5.7	4.8	10.2
Zn or Cd + alfalfa	383	1075	157	595	2.7	3.9	8.5	17.1
Zn or Cd with FYM	310	1123	148	633	1.4	5.3	5.7	11.4
$LSD_{0.05}$	47.8	75.6	31.2	49.3	0.91	1.45	0.92	1.44

In contrast to soybean, wheat roots contained significantly more Zn than over ground organs (Fig.1). In the soil with Zn alone, approximately 80 % of the metal was accumulated in roots. The Cd contamination of the soil caused more a distinctive differentiation in the uptake of this element by leaves and roots than the one by contamination with Zn (Fig. 2). In the treatment with Cd alone, in comparison with the control, the uptake of the metal by wheat leaves increased by 51 %, while in the case of roots it increased up to 2.7 times.

3.2 Organic fertilisation

Plant residues added to the contaminated soil affected the Zn and Cd concentrations in both species and in leaves as well as in roots (Tab. 1) which is in accordance to the results published by Kubol (1986), MacNicol (1985), Singh (1995), Yang (1996).

But also between the different sources distinctive effects were observed. In wheat roots, the addition of any kind of organic fertilisation caused a significant reduction in Zn concentrations. This was particularly apparent in the case of added soybean straw where, in comparison with the treatment "Zn alone", seedling roots contained 3 times less of this element (Tab. 1). The concentration of this element in leaves was somewhat different. It is true that, in comparison with the object with Zn alone, its content also decreased but these changes were statistically non-significant. Wheat seedlings growing in the Cd contaminated soil showed increased concentrations too, but this increase was significant only in the case of roots. Roots of plants growing in the soil with straw showed a significant decrease of the concentration of the metal. Those grown in soil incubated with alfalfa showed a significant increase, while those in the soil with farmyard manure revealed no changes.

Plant residues were found also to exert a significant impact on the uptake of Zn and Cd by the plants. In comparison with the treatment with metals alone, wheat and soybean growing in soil fertilised with organic substances showed a reduced uptake of both Zn and Cd. However, these differences could not be confirmed statistically.

In comparison with the treatments where Zn or Cd were applied alone (100 %), plants grown in the treatments with soybean straw showed a reduced uptake of this elements in the order: wheat (74 %) > soybean (24 %) for Zn and soybean (52 %) > wheat (35 %) for Cd (Fig. 1-4).

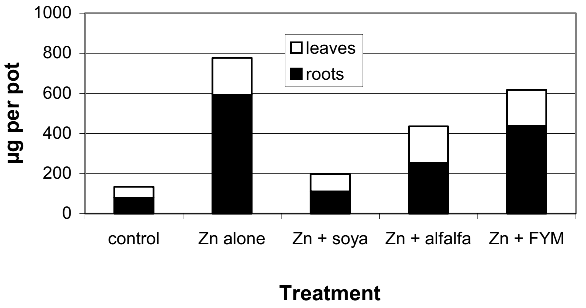

Fig. 1
Effect of organic fertilisation on the Zn uptake of wheat (stage EC13) on an artificially polluted sandy loam (statistical significances are communicated in the text)

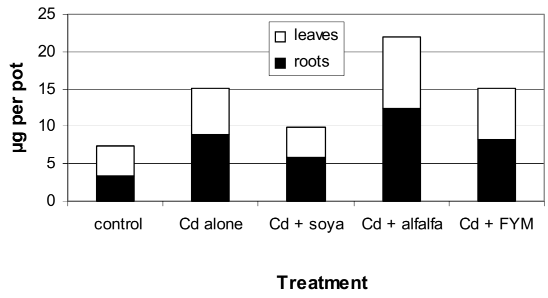

Fig. 2
Effect of organic fertilisation on the Cd uptake of wheat (stage EC13) on an artificially polluted sandy loam (statistical significances are communicated in the text)

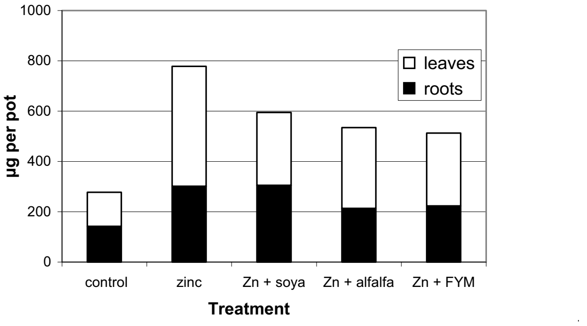

Fig. 3
Effect of organic fertilisation on the Zn uptake of soybean (stage V2) on an artificially polluted sandy loam (statistical significances are communicated in the text)

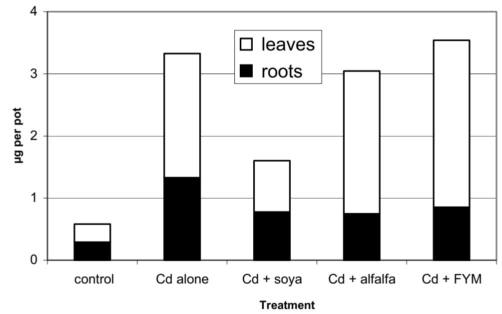

Fig. 4
Effect of organic fertilisation on the Cd uptake of soybean (stage V2) on an artificially polluted sandy loam (statistical significances are communicated in the text)

The effect of alfalfa was not so clear, because in the treatments with Cd an increase in the accumulation of this metal was recorded in over ground organs (19 % in soybean and 56 % in wheat). A similar effect is reported by Oliver (1993) who observed a considerably higher content of this metal in wheat grown after the addition of pulses than when the same crop plant was grown after cereals. This may indicate an effect of the nitrogen applied with the organic fertilisers by a synergistic effect of nitrogen on heavy metal uptake which has been described by Schnug (1984). This may also explain the differences between the organic fertilisers which show a considerable range of their nitrogen content from 1-4 %.

Conclusions

The addition of organic matter to Zn and Cd polluted soils can reduce the uptake of this heavy metals in plants and thus prevent them from entering the food chain.

From the viewpoint as a strategy for improving food quality it has, however, to be considered that due to a counteracting synergistic effect of nitrogen on the uptake of Zn and Cd only organic sources with low nitrogen content (e.g straw) are suitable.

Quite in contrast to this are aspects of soil protection and soil reclamation: high inputs of high nitrogen containing organic sources may not only increase the efficiency of phytoremediation of contaminated soils via “heavy metal harvesting” through increased biomass production, but also through the synergistic effects of nitrogen on the heavy metal uptake.

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