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Tolerance of ryegrass to cadmium accumulation

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Summary

New top growth of freshly defoliated ryegrass transplanted into nutrient solution containing cadmium increased in tissue cadmium during successive regrowth periods. Cadmium concentrations of 50-100 mg/kg DM reduced top growth. In media rich in cadmium the tops accumulated 100-500 mg Cd/kg DM during the first few regrowth periods, which resulted in chlorosis, poor subsequent new growth, and ultimately in the death of the plants.

The time course of cadmium accumulation during successive regrowth periods is related to its effects on growth and uptake of the element.

Introduction

The natural cadmium content of vegetation is of the order of 0.1-1 mg/kg DM. Higher contents may result from environmental contamination, but there is a limiting tissue concentration at which Cd is toxic for growth.

John (1972, 1973), and Steiner (1973) grew various plant species in Cd containing media and showed that plant size was not influenced by 1-100 mg Cd/kg DM. Concentration of 100-1000 mg/kg DM reduced growth by 20-80 %.

The relation between Cd concentration in the tissues and yield at the time of harvest differed between the plant species because they varied markedly in rate of growth, uptake, ageing and partitioning of matter between the organs. The general conclusion would be that tissue Cd was toxic for growth when the concentration was higher than 100 mg/kg DM because concentrations higher than 100 mg/kg DM reduced the yield of most of the tested plants.

For radish (John, 1972) results are shown in Fig. 1. Cd was added in increasing amounts to an unlimed soil (pH 4. 1; open symbols) and to the soil limed to pH 5.5 (blackened symbols). Uptake by tops (circles) and whole plants (squares) are plotted as ordinates against DM produced along equal logarithmic scales. The dashed 45 ° lines are for constant concentrations of Cd in the DM, because then uptake is directly proportional to DM production.

Uptake from the limed soil increased Cd in the tops from 10 mg/kg in the control to 200 mg/kg DM in the soil rich in Cd as the external Cd level was raised, but the yield of DM was not reduced.

At the highest Cd treatment, uptakes from the unlimed and the limed soil were the same. But the lower yield on the unlimed soil concentrated the absorbed Cd to the higher level of 400 mg/kg DM in the tops, and its toxicity was manifested by a sudden drop of the yield.

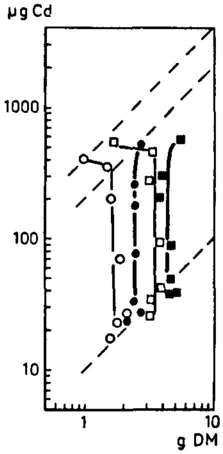

Fig. 1. Cadmium uptake and dry weight of whole plants and tops of radish grown in Cd-enriched soil. Data of John (1972); for explanation see text.

One may question the high figures of 10 mg/kg DM in the control and the high tolerance of growth to 200 mg Cd/kg DM. But it is informative to note that whilst uptake was the same, toxicity of the unlimed soil with a high Cd concentration was neutralized by the better growth on the limed soil. Apparently, tissue Cd, not medium Cd, was toxic for growth at high concentration in the plant, and growth could be restored to normal either by a decrease in uptake, or by an increase in growth.

It is unlikely that there is a well defined critical concentration in the plant which is toxic for growth. Tissues may differ in susceptibility, and the time taken by the metal to kill the tissue or the plant will vary with growth characteristics.

If the growth rate falls off with age and the uptake is accelerated, Cd may concentrate to 1000 mg/kg DM or higher. In this case an acceptable yield is recorded with a Cd content much higher than is toxic for growth. But the leaves are chlorotic, the killing process is in progress, and the growth rate may have dropped to nothing.

Tomato plants with 930 mg Cd/kg DM still yielding 70 % of the maximum growth were grown by Steiner (1973), and may illustrate the case. Seedlings were transplanted into solution culture when 20 days old. On day 70 Cd was added, and on day 130 the plants were harvested.

At the time Cd was added the plants were large, the growth rate had declined, uptake was initiated, and Cd in the plants increased rapidly to a level much higher than is toxic for growth, for a time too short to complete the killing process.

The plants given more Cd were reduced both in size and in Cd concentration. The lower concentration of Cd in the plant was attributed by Steiner to poisoning of the uptake system.

The results show that a progressive increase in tissue Cd leads in the first place to a yield reduction, whilst the uptake is depressed in a later stage of toxicity. Hence plants grown at a high Cd level can have low yields and high concentrations of Cd in the small amount of DM produced.

On the other hand, less than 100 mg tissue Cd/kg DM restricts the growth less severely, and acceptable yields can be grown with Cd contents potentially hazardous to the grazing animal.

The use of sewage sludge has been increasing, and may become a major contributor to Cd pollution of grassland. This raised the interest in the influence of contaminated

Cd environments on the concentration of the element in grass.

The present work concerns the question as to what in fact are the highest possible concentrations in the tops tolerated by growing grass plants during a succession of regrowth periods.

Material and methods

Soil-grown perennial ryegrass plants were taken from a culture in the greenhouse. The roots were washed and trimmed to a length of 2 cm. The plants were placed in 12 litres half-strength Hoagland solution with appropriate micronutrients, and defoliated. After 2 weeks the new top growth was cut back, and the solutions were replaced by similar media with Cd added from a 0.1 *M* $CdSO_4$ containing 2 mol Na_2EDTA/mol Cd, and 3 mol KOH/mol Cd to bring the pH to 6.

The treatments were 0, 0.1, 0.3, 1, 3, 9, 27 and 82 mg Cd per 1 litre nutrient solution. All the EDTA-stabilized Cd remained in solution.

The solutions were renewed weekly. The tops were harvested at intervals of 11 days over a 77-day period, oven-dried, weighed, and analysed for Cd by atomic absorption. Uptake in μg Cd per pot was calculated by multiplying mg Cd/kg DM in the tops by g DM per pot.

Results and discussion

The results are shown by plotting uptakes as ordinates against yields of DM along equal logarithmic scales. At constant concentration of Cd in the DM the uptake is directly proportional to the dry weight of the tops, and the points will lie along a straight line which makes an angle of 45 ° with the axes. If the uptake increases disproportionately, the line is steeper on the upgrade and Cd concentrates in the DM with increase in yield. For each point, the concentration of Cd in the DM can be conveniently assessed by drawing a 45 ° line through the point and reading the ordinate at 1 g DM. In this way the graph shows at a glance changes in uptake, yield, and concentration of Cd.

Fig. 2 shows the cumulative uptake and DM yield at the successive cutting dates. For each treatment, the points are joined by straight lines. From the bottom to the top of the graph the curves follow the order of increase in the external level of Cd.

The curve at the bottom is for the control. Uptake bore a constant relation to gain in DM with Cd more or less constant at 0.5 mg Cd/kg DM. Ideally, there was no Cd other than that in the defoliated transplants, but traces in the medium maintained the small uptake.

With higher Cd concentrations the lines are steeper. Each subsequent new top growth added more Cd relative to DM to the combined yields than the preceding one: Cd concentration in the removed tops increased with the date of cutting. The main contributor to the output of Cd was the growth of Cut 3. At the highest Cd treatment it accumulated about 3000 μg Cd, added only 1 g DM to the yield total, and was followed by the death of the plants.

At the next lower treatments of 27, 9, and 3 mg Cd/litre the curves tend to level off after Cut 3 or 4: uptake was retarded relative to DM production. Over the whole period, these curves acquired more or less the idealized form of a sigmoid curve which

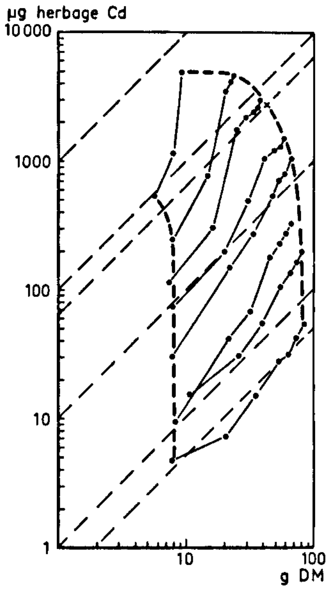

Fig. 2. Cumulative uptake of Cd and production of DM at successive dates of cutting of ryegrass grown in the test solutions of various Cd concentrations.

can be understood in the following sketchy and general terms.

During the first top growth the absorbed Cd was dispersed over a great mass of plant material by retention in the portions of the plant remaining after defoliation, and the new growth received a smaller proportion. After a few cuttings, more of the Cd moved through the Cd enriched stems to the new growth and increased the concentration in the tops. After the removal of subsequent crops the high Cd in stems and roots injured the system of uptake and transfer, less Cd moved to the new growth, the concentration of tissue Cd in the tops declined, and the tops contributed less Cd for each gramme of DM to the cumulative outputs than the preceding regrowth.

The dashed upward curve bordering the points to the left relates Cd uptake and DM production of Cut 1. Uptakes smaller than 300 µg Cd had no effect on yield and raised Cd in the tops to 30 mg/kg DM. The highest Cd treatment reduced growth by 40 % growth with 100 mg Cd/kg DM in the tops.

The dashed upward curve to the right relates the cumulative uptake and yield of all regrowth periods. High Cd increased the death rate, the highest treatment produced 90 % growth reduction because the new growth was depressed, and restricted to three surviving, harvestable cuts. The cross on the line indicates 50 % growth reduction. The combined new growth then contained 65 mg Cd/kg DM, which is much lower than at 40 % growth reduction in Cut 1 because the plants were exposed longer to the toxic action of tissue Cd.

Fig. 3 shows uptake and yield for each successive regrowth period, with dashed 45 ° lines at various Cd concentrations. Among the plants grown in media lower in Cd, with less than 100 mg Cd/kg DM in the tops, the effects on growth were not very marked. These results are given as uniform dots with an average yield of 10 g DM. Only the higher Cd treatments, which injured the plants more severely, are represented by curves. The lines are drawn thinner and provided with arrows in the direction of later cutting dates.

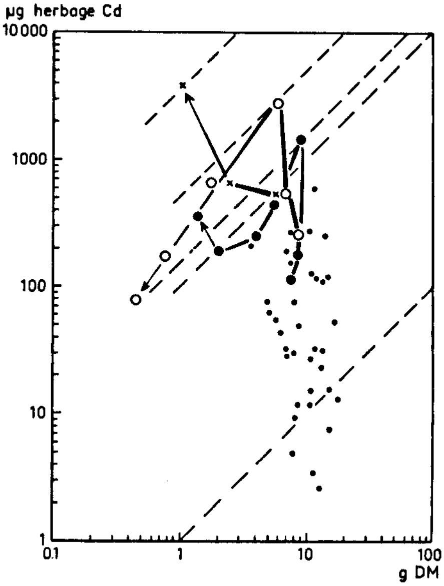

Fig. 3. Uptake of Cd and weight of DM in the successive cuts of ryegrass grown in the test solutions.

At the highest treatment (82 mg Cd/litre; crosses) Cut 1 contained 100 mg Cd/kg DM in 60 % of the maximum DM. Cut 2 had absorbed more Cd, the DM yield was only 25 % of the maximum and had accumulated 300 mg Cd/kg DM. At cutting date 3 the tops were dying and yielded little DM, but uptake had increased considerably with Cd at the exceptionally high level of 3500 mg/kg DM.

At this treatment Cd penetrated rapidly into the new growth during the short time taken by the metal to kill the plants, and concentrated excessively in the small amount of DM produced.

The treatment 27 mg Cd/litre (open circles) is more illustrative of Cd toxicity because it differentiates the time taken by the metal to inhibit growth and uptake. The first 3 cuts absorbed Cd in increasing amounts with little growth depression, and tissue Cd increased from 30 mg Cd/kg DM in Cut 1 to 500 in Cut 3. The leaves were chlorotic, but the high tissue Cd took longer to inhibit growth more drastically, to produce the dramatic growth depression in Cuts 4, 5, and 6, and to kill Cut 7. Where the killing process proceeded to completion, the line joining the points declines steeper than 45 ° on the down-grade to the left: uptake declined relatively faster than the production of DM in subsequent regrowth periods. As a consequence, the Cd concentration decreased from 500 mg/kg DM in Cut 3 to 150 in Cut 6. Cut 7 was killed.

At treatment 9 mg Cd/litre (black circles) the curve is similar with an optimum of 150 mg/kg DM in Cut 3, and a subsequent rapid falling off in activity of uptake and regrowth, except for Cut 7 which absorbed more Cd than the preceding Cuts 6 and 5.

Concluding remarks

The combined evidence shows that once uptake of Cd by grass has been initiated, the first new growth can be tolerant up to 100 mg Cd/kg DM in the tops with a modest reduction in yield.

At high Cd treatments, the element concentrates in the renewed top growth with the number of defoliations because uptake is continued, Cd in the portion of the plant remaining after defoliation increases, and more of it is delivered to each new top growth after the removal of previous regrowth poorer in Cd.

When tissue Cd exceeds the level toxic for growth, subsequent regrowth is strongly reduced, and Cd either concentrates to a very high level in the little DM produced, or is diluted to a lower level because the uptake system is destroyed. At this stage of accumulation the plants are severely injured or dying.

The level of tissue Cd which is toxic for plant performance and survival escapes precise definition because it depends on the particular history of growth and uptake resulting in its concentration in the plant at the time of sampling. But such high levels of tissue Cd will rarely if ever occur in contaminated pastures.

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