Avloppsslam skadar markfloran

Den svenske forskaren, docent Ernst Witter vid markvetenskap SLU, har inom det europeiska samarbetet presenterat forskningsläget när det gäller slammets påverkan på markfloran. Dessa pekar på att det europeiska Direktivets gränsvärden för metallhalter i slam och mark måste sänkas för att hindra en snabb upplagring.

Här följer först hans sammanfattning ur presentationen vid en konferens i Stresa nov 99 (EC DG ENV E3):

- *Resultat av långliggande försök visar att tungmetaller skadar både mångfalden av mikroorganismer och deras funktion i marken.*

- *Förändringar av strukturen hos mikroorganismernas samhälle och mångfald uppträder ofta innan funktionen är påverkad.*

- *De övre gränsvärdena för metallhalter i jord är otillräckliga i dagens Direktiv för att skydda markorganismer och viktiga funktioner, och möter inte kriterier för en uthållig användning av jordbruksmark.*

- *Det finns inte tillräckligt med forskningsresultat för att kunna fastställa gränsvärden för metallhalter i mark, som kan garantera att det inte uppstår allvarliga effekter på markfloran.*

- *Dagens Direktiv medger en snabb upplagring av metaller i mark.*

- *Sådan upplagring är i huvudsak irreversibel.*

- *Ett nytt Direktiv borde utgå ifrån försiktighetsprincipen och lägga stor vikt vid att minimera upplagringen av metaller i marken.*

(Hela presentationen finns i slutet. Där finns också andra undersökningar som visar hur slammet skadar jordbruksmarken.)

Min kommentar:

Detta är kärnan i hela slamfrågan. I och med att vi har att göra med grundämnen blir ökningen av metallhalter i åkern en irreversibel process.
Vi kan inte ta bort metaller därifrån i efterhand. Begreppen kretslopp, uthållighet, ekologi är oförenliga med en sådan fortgående process.
Man kan anföra att de svenska gränsvärdena är lägre än Direktiven, men tillförselns storlek per hektar påverkar endast hastigheten på upplagringen - förr eller senare når man de nivåer där markfloran påverkas. Näringsämnena i slammet måste vara skild från alla avfallsmetaller, som genom avloppsnätets konstruktion idag finns i slammet, för att vi skall kunna nå ett uthålligt kretslopp.

Limit values for heavy metal concentrations in sewage sludge and soil that protect soil microorganisms

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Current Council Directive

One of the aims of the current Council Directive of 12 June 1986 on the Protection of the Environment, and in Particular of the Soil, When Sewage Sludge Is Used in Agriculture is to regulate the use of sewage sludge in agriculture in such a way as to prevent harmful effects on soil, vegetation, animals and man (Commission of the European Communities, 1986). The Directive restricts metal contamination of soils through:

- Limit values for concentrations of heavy metals in soils
- Limit values for heavy metal concentrations in sewage sludge
- Limit values for annual metal loading rates

According to the text in the Directive the main aim of the limit values for soil metal concentrations is to avoid toxicity to plants and man. The purpose of the limit values for sludge and for annual metal loading rates is to ensure that the soil concentrations will not be exceeded as a result of sewage sludge applications (Commission of the European Communities, 1986). In order to fulfil its aims the Directive therefore heavily relies on the existence of maximum soil (threshold) concentrations of potentially toxic heavy metals below which no harmful effects occur.

Since the publication of the Directive a considerable amount of evidence has come to light about the adverse effects of elevated heavy metal concentrations on soil microorganisms. This evidence comes from long-term field experiments where the elevated concentrations have been the result of applications of sewage sludge (sometimes with additional amendments of heavy metals). There is evidence of seriously adverse effects on agronomically important microorganisms such as rhizobia at, for some metals, soil metal concentrations below the upper limit values in the Directive (for review see Giller *et al.*, 1998). The rate of sewage sludge application in these experiments and the concentrations of metals in the sludge were often greater than those allowed under the current Directive. We have, however, no reason to believe that the effects on soil microorganisms seen in these experiments should not occur if soil metal concentrations were allowed to increase to similar levels but at a slower rate as would be the case under the Directive guidelines.

Evidence of metal toxicity to soil microorganisms

Early evidence of the toxicity of heavy metals to soil microorganisms dates to the beginning of the 20th century. Much research on this topic since then has concentrated on finding microbial assays for metal toxicity, and on establishing the relative toxicity of a large number of heavy metals. Most of this research has been in the form of relatively short-term laboratory

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studies, where effects are measured at some time interval after the addition of metal salts to soil. A compilation of results from these studies shows a wide disparity as to at which metal concentrations toxic effects occur (Bååth, 1989; Giller *et al.*, 1998). An emphasis on obtaining quantitative relationships between soil metal concentrations and toxicity effects in such studies, appears to have been at the expense of studies aimed at understanding the complex response of the soil microbial community to metal toxicity. Without such an understanding it has proven difficult to interpret the disparity between the different laboratory studies, and moreover we do not know if, or how, we can extrapolate the effects seen in laboratory studies to effects that may occur under field conditions.

It has often been assumed that the addition of relatively large amounts of heavy metals in the form of soluble metal salts in laboratory studies meant that laboratory studies provide a worse-case scenario of metal toxicity, compared to the field situation where soil metal concentrations increase slowly over a time-span of years, and where the metals are often added in less soluble forms, for example adsorbed to organic matter in sewage sludge. Recent evidence, however, has revealed metal toxicity effects under field conditions that may occur even at surprisingly low concentrations (e.g. Dahlin *et al.*, 1997). A possible reason why metal toxicity effects are sometimes observed at such low metal concentrations under field conditions is that elevated soil metal concentrations in the long-term may result in changes in the structure and diversity of the soil microbial community. Such effects will be overlooked in short-term metal toxicity studies. An example that illustrates the long-term effect of metal toxicity on the soil microbial community is the loss of diversity in *Rhizobium* as a result of past sewage sludge applications which resulted in the survival of only one strain of *Rhizobium* in the metal contaminated soil (Giller *et al.*, 1989). This strain happened to be ineffective in N_2-fixation in white clover which was how the effect was noticed in the first place (McGrath, 1994). The loss of N_2-fixation in white clover was therefore not due to a direct toxicity effect on the ability of the legume/*Rhizobium* symbiosis to fix dinitrogen, but due to metal toxicity exerting a stress on the population of rhizobia, which eventually led to the survival of only one strain of *Rhizobium leg.*.

These observations led us to hypothesize that:

- Metal toxicity exerts a selective pressure on soil micro-organisms thus changing the relative competitive advantage between microbial groups
- This results in changes in microbial community structure and in the diversity of soil microorganisms
- These “unseen” effects precede and are the cause of most of the more visible effects seen at the functional level

These hypotheses formed the basis for a recently completed EC-financed study (Giller, 1998) which had as objective to determine the effects of metal contamination as a result of long term sewage sludge application on the diversity and selected functions of the soil microbial community as well as the diversity of specific microbial groups. The study was carried out on soils from the long-term sewage sludge experiment at the Federal Research Centre of Agriculture (FAL) at Braunschweig, Germany. In this experiment either unamended or metal amended sewage sludge had been applied annually between 1980 and 1989 at two different rates, resulting in a gradient of soil heavy metal concentrations across the treatments, with the highest metal concentrations around the upper limit values in the Directive. The results from this study showed that there was a change in the structure and diversity in both broad and narrow subsets of the soil microbial community and an increase in metal tolerance (Figs 1-3).

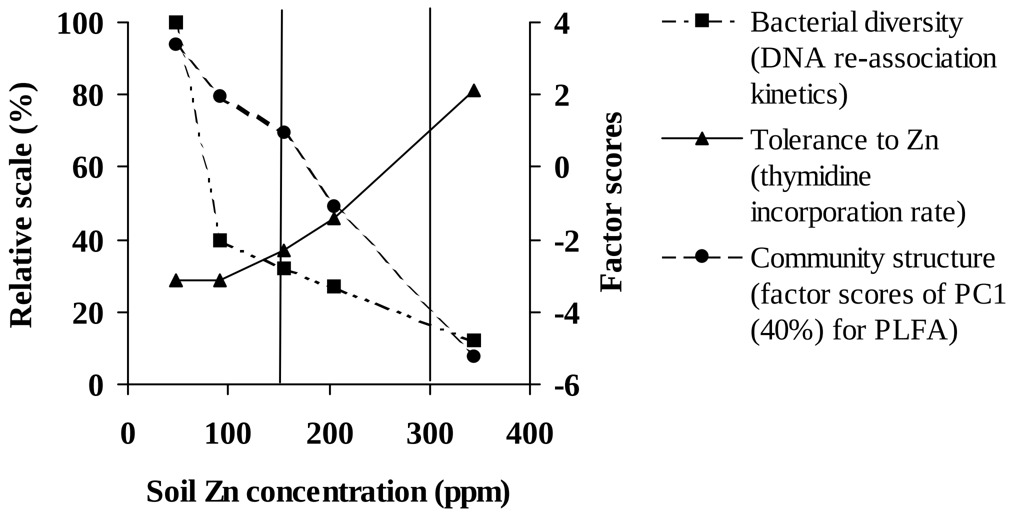

Figure 1. Diversity and tolerance to Zn of the soil bacterial community and structure of the entire soil microbial community in relation to soil metal concentrations (indicated by soil Zn concentrations). Vertical lines indicate the upper and lower limit values for Zn concentrations in soil according to the Directive. The soil with the lowest soil Zn concentration represents the control (N-fertilized) soil, higher Zn concentrations were due to annual applications of unamended or metal amended sewage sludge between 1980 and 1989. Soil samples for determination of soil microbial characteristics were taken between 1994 and 1996. Soil pH ranged from 7.3 to 6.0 and the soil C content from 0.9 to1.6% with increasing rates of sludge application.
Diversity of the soil bacterial community was determined by DNA re-association kinetics, and is here expressed as a % of the bacterial diversity in the control soil. Tolerance to Zn was determined as inhibition of the rate of thymidine incorporation when soil bacteria were challenged with Zn. Analysis of phospholipid fatty acid patterns (PLFA) was used to assess the composition of the soil microbial community and the results shown are the factor scores of the first principal component obtained by principal component analysis of the PLFA data.
Data from Sandaa *et al.* (1999) and Witter *et al.* (2000).

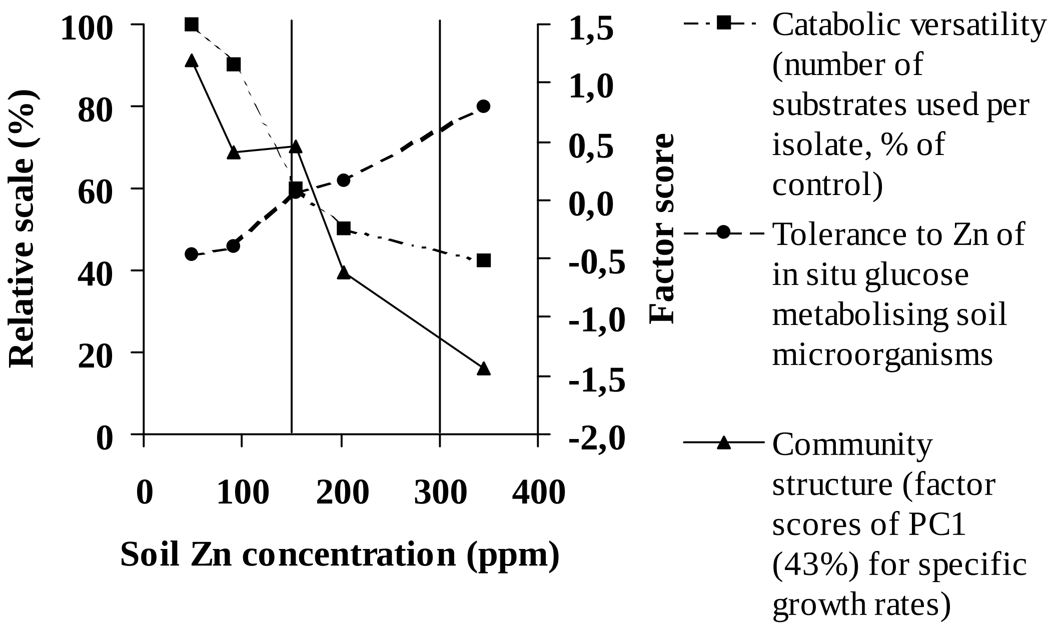

Figure 2. Catabolic versatility of soil bacterial isolates (mainly Gram positive) measured as the number of aromatic substrates that could be used as C and energy source by the isolate. A total of approximately 150 isolates were tested from each soil using 21 different substrates. The results shown are the average number of substrates used by the isolates, expressed as a percentage of the number of substrates used by the isolates obtained from the control soil. Tolerance to Zn was measured *in situ* as the degree of inhibition of the specific microbial growth rate caused by a challenge with Zn added during the exponential growth phase, using glucose as substrate and is expressed as a percentage of microbial tolerance to Zn in the control soil. The “community structure” of the microbial community able to use 15 different C substrates *in situ* was determined by principal component analysis of the specific microbial growth rates for these substrates.
For more details of the soils see the legend for Figure 1.
Data from Wenderoth and Reber (1999) and Witter *et al.* (2000)

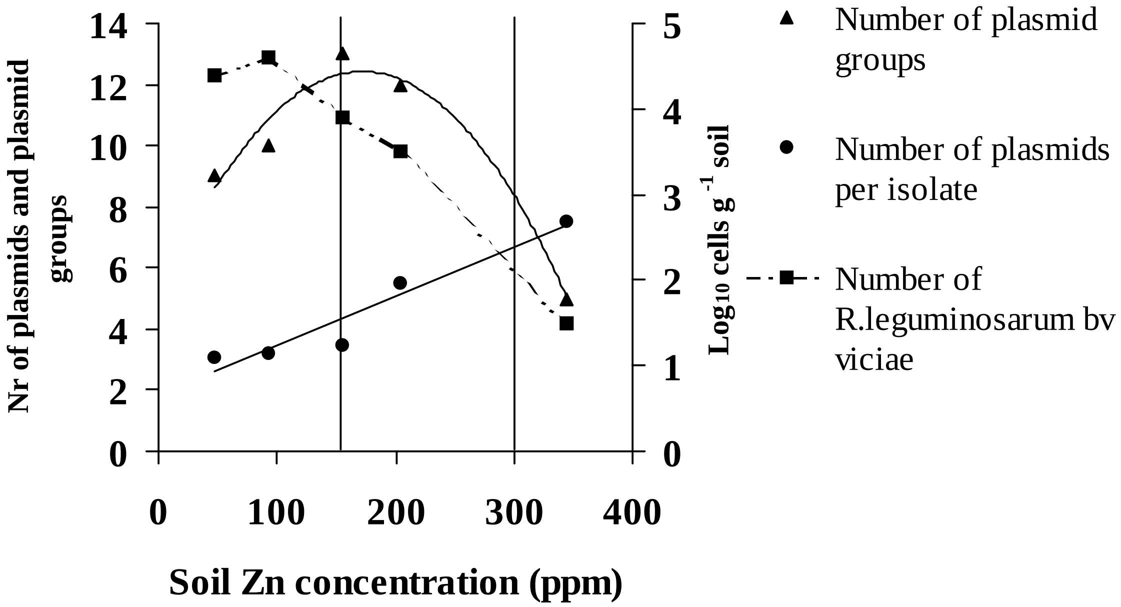

Figure 3. Numbers of *Rhizobium leguminosarum* bv. *viciae*, number of plasmids per isolate and the total number of plasmid groups found in the isolates of *R. leguminosarum*. The number of rhizobia was measured by the most probable number plant infection technique. The number of plasmid groups – based on the number plasmid profiles found - in each population is used as a measure of the diversity in *R. leguminosarum*. The number of plasmids carried by isolates was associated with increased metal tolerance, but there was only a weak tendency of increased tolerance to Zn with increasing soil metal concentrations.
For more details of the soils see the legend for Figure 1.
Data from Lakzian *et al.* (1999).

The results shown in Figures 1-3 show that the change in soil microbial community structure due to increasing soil metal concentrations was associated with a loss of diversity at the highest metal loads, whereas at lower metal loads diversity could either increase or decrease. The increase in metal tolerance with increasing metal load makes it likely that these changes in community structure and diversity was due to a stress exerted by the increased metal concentrations in the soil. Moreover, the tolerance measurements were able to identify that Zn (and possibly Cd) exerted a greater toxicity effect than Cu in these soils (Witter *et al.*, 2000).

It is difficult to assess the consequences of the observed changes in microbial community structure and diversity for functions of the soil microorganisms. There exists no general relationship between microbial community structure, diversity and function. Moreover, whether or not there is functional redundancy in the soil microbial community remains an unresolved issue. In strict Darwinian terms no two species with exactly the same characteristics can co-exist in the same ecosystem, unless physically isolated in time or space. In the case of the metal contaminated soils of the experiment at Braunschweig the loss of catabolic versatility observed in individual isolates did in no instance result in the complete loss of a catabolic capability from the soil microbial community. Clearly, under the experimental conditions under which the catabolic capabilities were assessed there was considerable functional redundancy. In how far there appears to be redundancy for a given function is of course entirely dependent on the function and the conditions under which the function needs to be expressed. The ability to metabolise simple carbohydrates, for example, will have a large degree of functional redundancy, whereas there will only be limited redundancy for the ability to degrade complex organic molecules such as lignin, or PCB's and other difficult to degrade xenobiotics. It is, however, likely that species with partially or even entirely similar catabolic capabilities will differ in some other characteristic that would ensure the survival of all species. For a highly specialised function such a symbiotic dinitrogen fixation the degree of apparent redundancy is likely to be much smaller. Loss of diversity in this group of microorganisms can therefore be expected to more likely result in the loss of a common function, as was shown in the loss of *R. leguminosarum* bv. *trifolii* effective in dinitrogen fixation in white clover in the sludge amended soil from the Woburn experiment due to the survival of only one strain (Giller *et al.*, 1989). In the Braunschweig experiment loss of diversity in the rhizobia bacteria was seen at the higher metal loads, but no loss of dinitrogen fixing ability was found. In contrast, in some of the most contaminated plots (with soil metal concentrations around the upper limit values in the Directive) *R. leguminosarum* bv. *trifolii* was completely absent, with obvious consequences for crop plants relying on this bacterium for symbiotic dinitrogen fixation (although this loss in practice can be overcome by inoculation of seeds).

Implications for limit values for soil and sewage sludge

Despite the difficulties in establishing relationships between microbial diversity and function, the loss of diversity must in general be seen as an undesirable effect, because of the potential loss of microbial functions that this implies. When assessing the gravity of a given effect on soil microorganisms, the extent of the effect must be put in relation to the reversibility and duration of the effect. Soil cultivation, choice of crops, and numerous other standard agronomic practices can have effects on soil microorganisms that may be even more severe than some of the effects we have seen at moderate levels of metal contamination in the Braunschweig experiment. These effects are, however, by and large entirely reversible and of short duration. This is in stark contrast to the effects caused by the toxicity effect exerted by heavy metals in soil. Heavy metals have a persistency in agricultural soils in the order of many thousands of years (McGrath, 1987), which is a compelling argument for adopting a precautionary approach in regulations concerning metal contamination of agricultural soils (Witter, 1996). In terms of the EU Directive on the agricultural use of sewage sludge, a precautionary approach would be reflected in the annual metal loading limits (i.e. limit values that regulate the rate at which heavy metals are allowed to accumulate in the soil) and in the limit values for heavy metal concentrations in soil. In the current Directive the former limits are set extremely high, and are essentially redundant as for most metals the average metal concentrations in municipal sewage sludge in EU member states are considerably below the limit values (Commission of the European Communities, 2000). A precautionary approach to limit values for annual metal loading rates would try to set these limits as low as practically possible with a view to successively reduce loading rates until a situation of near "zero-accumulation" of metals in soils is achieved, at least for the potentially most toxic metals. A precautionary approach to limit values for soil metal concentrations might want to set limit values as low as practically possible, and at least below concentrations known to result in adverse effects. In practice this is, however, difficult to achieve. There is a large natural variation in soil metal concentrations making it difficult to establish metal concentrations that will identify metal polluted soils. The evidence for soil metal concentrations that can be associated with no adverse effects on soil microorganisms is incomplete, and there is also some doubt whether there are clear threshold soil metal concentrations below which there are no adverse effects. The evidence from the Braunschweig experiment on the effects of elevated soil metal concentrations on the number of rhizobia suggest that there may be a threshold value, which for Zn would be in the range of 150-250 mg kg^{-1} (Chaudri *et al.*, 1993). Some of the evidence from the Braunschweig experiment reviewed here (Figs 1-3), however, suggests that soil microorganisms may already become affected at low metal loading rates, with no evidence of threshold concentrations. This issue will remain difficult to resolve, not least because of the difficulties in establishing statistically significant effects on biological parameters with a large inherent variability.

Conclusions

- Evidence from long-term field experiments show that heavy metals impair both microbial diversity and function in soils
- Changes in microbial community structure and diversity often occur before functions are affected
- The upper limit values for soil metal concentrations in the current Directive insufficiently protect soil micro-organisms and important functions, and do not meet criteria for a sustainable management of agricultural soils
- There is insufficient evidence to set limits for soil metal concentrations that can guarantee to avoid adverse effects on soil microorganisms
- The current Directive allows a rapid accumulation of metals in soils
- Such accumulation is essentially irreversible
- A new Directive should encompass a precautionary approach and put more emphasis on minimising metal accumulation in soils

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Andra rapporter som visar att slammet skadar åkermarken.

I flera fall har man genom att sprida slam i större givor påskyndat upplagringen, dvs man ligger före i "förstörelsens tidtabell". Då har man funnit flera exempel på hur förstörelsen går till och vad som redan äger rum eller väntar oss:

1. **Naturvårdsverket och Lantbruksuniversitetet** har undersökt åkrar som tagit emot stora givor med förorenat slam. Man ser en kraftig ökning av metallhalterna i matjordslagret:
" I tre av försöken har halten av en eller flera av metallerna bly, koppar, zink och kadmium i matjorden fördubblats eller tredubblats. Sådana höjningar är vad vi kan vänta oss om 100 - 200 år om de anvisningar som finns för spridning av slam på jordbruksmark följs."
"Vi känner inte till vilka effekter som uppstår i mark-växtsystemet då slam används som gödselmedel under en mycket lång period."
(Ur "Fakta om miljövårdsforskning", SNV mars 1984)

2. Slamförsök vid **Lantbruksuniversitetet** har visat att de blågröna algerna är känsliga och är kraftigt påverkade. Förmågan att fixera kväve är bara 20% av normala blågröna alger. Blågröna alger från slambehandlad jord växer också mycket långsammare än alger från annan jord. Inte heller frilevande kvävefixerande bakterier trivs i jord som gödslats med slam. Deras förmåga att binda kväve blir starkt nedsatt. Rhizobium-bakterier lever tillsammans med ärtväxternas rötter och är viktiga kvävefixerare. Bakterier i den mark som fått slam var sämre på att knyta an till växtrötterna och bilda knölar. Mängden biomassa i jorden var reducerad.
(Ur "Fakta från Lantbruksuniversitetet, Mark/Växter" Nr 11 1990)

3. I ett **slamodlingsförsök i Dalarna** ser man förhöjda halter av tungmetaller i spannmålskärnan och säger "Förhöjningen kan ligga inom felmarginalen men när det gäller koppar- och zinkupptaget i spannmålskärnan är den klart högre vid odling med den höga slamgivan."
(Ur "Näring i cirkulation - Ett Dala-projekt", 1993)

4. I ett **slamodlingsförsök i Igelösa och Petersborg i Skåne** ser man förhöjda halter av tungmetaller i både mark och gröda samt effekter av detta.
Koppar i marken: "Kraftigt förhöjda värden vid ökad slamgiva i båda försöken."
Kvicksilver i marken: "Höjda värden vid ökad slamtillförsel på Igelösa. På Petersborg endast vid högsta slamgivan."
Zink i marken: "På Igelösa kan man konstatera en ökad koncentration med ökad slamtillförsel."
Bly i marken: "På Igelösa finns en tendens vid senaste provtagningstillfället till ett samband mellan slamtillförsel och koncentrationen i jorden."
Kadmium i marken: Här pekar man på ett försök på Igelösa "som har förhöjda värden".
När det gäller tungmetaller i grödan säger man om nickel att "upptaget klart ökar med ökad slamgiva". I försök med både slam och konstgödsel "då får man ökat upptag av koppar och kadmium vid slamtillförsel."
När det gäller markbiologiska tester ser man negativ påverkan när det gäller "heterotrof kvävefixering. Denna process har i andra tester visat sig vara speciellt känslig för koppar."
(Ur "Slamspridning på åkermark", Malmöhus läns Hushållningssällskap m fl 1994).

5. **Amerikanska naturvårdsverket EPA** har pekat ut koppar som en mycket riskabel metall eftersom den blir giftig för växter (fytotoxisk) i litet förhöjda halter i marken.
Naturvårdsverket har i sin SNV rapport 3623 angivit att man når denna toxiska nivå i svensk åkermark efter endast 75 års slamspridning.

Koppar är troligen en av de mest kritiska metallen i slam, eftersom stora mängder koppar från vattenledningarna i alla kommuner nu flyttas ut på åkrarna, samtidigt som metallen är så farlig för marken. I Holland har man satt koppar till grisarnas kraftfoder för att de ska växa bättre. Men samtidigt har man genom tanklöshet förgiftat åkermark genom att sprida denna kopparförorenade gödsel. Det finns nu där åkrar som det inte går att odla på. I Sverige har Uppsala och Malmö extremt höga metallhalter som överskrider gränsvärdena, men som ändå sprids.

Andra tungmetaller som visat sig vara toxisk för åkermarken är zink och silver, det senare ämnet mäts inte ens upp i svenska slam som godkänts för spridning. Även den giftiga metallen platina från katalytiska avgasrenare och sällsynta jordartsmetaller från elektronik är inte undersökta, trots att de också finns i slammet.

Observera att dessa skador nås förr eller senare vid användning av slam. Slamgivans storlek eller halterna i slammet påverkar inte detta faktum, så länge slammets metaller inte kommer från urin och avföring. Så gott som inga metaller försvinner från den svenska åkermarken. Därför ökar mängden oavbrutet med slam. Det är som att gå mot ett klippstup. Vare sig man tar stora steg eller små steg kommer man förr eller senare fram till stupet.