

Advice Sheet 18: Potentially Toxic Elements in Agriculture Soils

Please note that this advice sheet only applies to agriculture.

What are the potentially toxic elements (PTE's)?

The heavy metals are typically identified as zinc (Zn), copper (Cu), nickel (Ni), cadmium (Cd), lead (Pb), mercury (Hg), chromium (Cr), molybdenum (Mo), selenium (Se), arsenic (As) and fluoride (F).

These elements occur naturally in many soils, in different concentrations but most concern is about the accumulation of these elements in soils by the addition of manures, slurries and waste products.

What problems are they associated with?

Potentially Toxic Element	Problems associated with this Element
Arsenic (As)	The toxicity of arsenic is dependent upon its chemical form - inorganic forms are considered to be carcinogenic to humans but, in small doses, of benefit to some animals.
Cadmium (Cd)	Cadmium, typically inorganic forms, is abundant in the Earth's crust. Acute problems include lung and gastro-tract problems. Cd has a long residency in the body and has been associated with chronic kidney problems, bone damage, respiratory function and reproductive function.
Chromium (Cr)	A metal that is more toxic in its hexavalent form than its trivalent. Humans require a small amount of chromium, but in excess it can cause both acute and chronic problems related to the digestive system, the mouth, blood and major organ damage.
Copper (Cu)	All animals need a certain amount of copper. Copper toxicity is mostly associated with grazing animals, where luxury Cu uptake by grass plant can create toxic swards for grazing animals. In humans it is associated with blood problems and organ dysfunction.

Potentially Toxic Element	Problems associated with this Element
Fluoride (F)	Can cause dental and skeletal problems in humans and other animals.
Mercury (Hg)	Mercury occurs in elemental form, and inorganic and organic compounds in soil. The ingestion of mercury in toxic doses results in death, with central nervous system damage and organ failure.
Molybdenum (Mo)	Has been associated with copper toxicity in animals and increased nitrate toxicity. Has been associated with gout incidence in humans.
Nickel (Ni)	Common metal. Has been associated with reduced organ weight/function and reproductive problems.
Selenium (Se)	A common metalloid used in electronics. In cattle can cause blind staggers and is associated with orientation problems as well as loss of hair and nails etc. Can cause liver and other organ damage.
Zinc (Zn)	Commonly associated with plant toxicity. In humans can cause anaemia and organ damage.

Where do they come from?

As we said above, these elements occur naturally in soils, and often in high levels. In agricultural soils, accumulation is usually caused by the repeated addition of sludges and wastes, but also animal manures (with PTE content reflecting that of the animal diet / vet-med) and from the use of some fertiliser products.

Regulations relating to heavy metals and sludge use

Under the waste to land regulations (Sewage sludge on farmland: code of practice) all applications of sludge and waste to land must be approved by the Environment Agency. For this to happen, the company/person responsible should ensure that there is a soil nutrient demand for the product and that the product will not cause excessive accumulation / toxicity risk – see the calculations at the end of this Advice Sheet. In order to do this a certificate of soil analysis (to prove requirement) and a certificate of sludge material analysis will be required. NRM are specialists in this kind of analysis.

Sampling for PTE's

It is important to note that depth of sampling should be related to the full depth of incorporation/injection – it is not sufficient to just sample the surface.

Samples should be comprehensive and taken by walking a 'W' pattern, sampling through the complete area of concern. You should always wash your hands after handling soil, but this is especially important in this case.

Interpreting results

The following tables are taken from the 'DEFRA Sewage sludge on farmland: code of practice for England, Wales and Northern Ireland (June 2017)'. The table outlines the maximum permissible and advisable concentrations of potentially toxic elements (PTE'S) in soil after application of sewage sludge to agricultural land and maximum annual rates of addition.

The reader is strongly advised to download a copy of this Code: <https://www.gov.uk/government/publications/sewage-sludge-in-agriculture-code-of-practice>

The guide contains vital information on sludge; benefits and hazards along with detailed guidance with regards to spreading.

PTE Limits for Arable Soil

	Maximum permissible concentrations of PTE (mg/kg) for arable soil				Maximum permissible average	
	pH	pH	pH	pH ¹	over a 10-year period	
	5.0-5.5	5.5-6.0	6.0-7.0	> 7.0	(kg/ha) ²	
Zinc	200	200	200	300	15	
Copper	80	100	135	200	7.5	
Nickel	50	60	75	110	3	
	For pH 5.0 and above					
Cadmium	3				0.15	
Lead	300				15	
Mercury	1				0.1	
Chromium	400				15	
Molybdenum ³	4				0.2	
Selenium	3				0.15	
Arsenic	50				0.7	
Fluoride	500				20	

PTE Limits for Grassland

	Maximum permissible concentrations of PTE (mg/kg) for Grassland ^{4,5}					
	pH	pH	pH	pH ¹		
	5.0-5.5	5.5-6.0	6.0-7.0	> 7.0		
Zinc	200	200	200	300		
Copper	130	170	225	330		
Nickel	80	100	125	180		
	For pH 5.0 and above					
Cadmium	3					
Lead	300					
Mercury	1.5					
Chromium	600					
Molybdenum ³	4					
Selenium	5					
Arsenic	50					
Fluoride	500					

1 The increased permissible PTE concentrations in soil of pH greater than 7.0 apply only to soils containing more than 5% calcium carbonate.

2 The annual rate of application of PTE to any site shall be determined by averaging over the ten-year period ending with the year of calculation.

3 The accepted safe concentration of molybdenum in agricultural soils is 4 mg/kg. However, there are some areas in UK where, because of local geology, the natural concentration of this element in the soil exceeds this level. In such cases there may be no additional problems as a result of applying sludge, but this should not be done except when in accordance with expert advice. This advice will take account of existing soil molybdenum levels and current arrangements to provide copper supplements to livestock.

4 For grassland you can apply no more than 3 times the average annual limit of PTE in a single year. This is to control how much lead, cadmium and fluoride your livestock ingest.

5 For grassland you must check that PTE additions in the top 7.5cm of grassland soil don't push PTE levels at 15cm and 25cm over the limits set out in this table.

Soil acidity and PTE limits

Acidity levels affect how plants take up elements in soil. In acidic soils, PTEs are more likely to damage crops. Most PTEs become harder for crops to take up as soil pH increases. But selenium and molybdenum are taken up more easily as pH increases. You must not spread sludge on land with a pH below 5.0. If the pH value is less than 5.2, you should seek specialist advice before spreading sludge.

PTE limits in sludge for grassland

You must not spread sludge on the surface of grassland if it contains more than 1200mg/kg dry solids of lead or 1000mg/kg dry solids of fluoride.

There are no set limits on the PTE concentration in sludge you can use on arable soils.

Prediction calculation for determining PTE concentration in soil after application of sewage sludge

The following calculation is used to predict the level of a potentially toxic element in soil after sewage sludge, biosolid or other waste is applied at a known rate.

The PTE level in the soil and applied product prior to application must be known, the application rate, the dry matter/moisture of the product and the usage (i.e. arable or grassland) is also required.

Example calculation for Copper:

1. Firstly we need to know how much copper is in the soil:
 - Total copper in soil = 24.0 mg/kg on a dry matter (DM) basis
2. We then need to know how much is in the sludge:

Contribution from applied sludge = 2.1 kg[Cu]/ha on a fresh (sample as received – SAR) basis

 - This is calculated by multiplying the concentration of Cu in the sludge (in mg/kg) by the application rate (in kg/ha).
3. We then need to calculate the volume of soil to which we are applying the sludge:
 - Assume soil depth of 15 cm (0.15 m) for arable and 7.5 cm (0.075 m) for grassland
 - Our volume of soil is given by depth of soil x area, so for 1 hectare (1 ha = 10 000 m²) of *grassland soil*, the volume is:
 - 0.075 m x 10000 m² = 750 m³ (or 750000 litres!)
4. Now we need to know how much Cu we are going to add to our soil volume:
 - This is given by the application rate, divided by the volume, i.e.
2.1 kg[Cu]/ha/750m³ = 2,100,100mg/750,000 litres = 2.8 mg/l

$$\begin{aligned} Cu [mg/l] &= \frac{\text{Application Rate}}{\text{Volume of soil}} \\ &= \frac{2.1 [kg/ha] \times 1000 \times 1000}{750 [m^3] \times 1000} \\ &= 2.8 [mg/l] \end{aligned}$$

So at this application rate and soil depth, we will be adding 2.8 mg/l to our value. However our value is in mg/kg, not mg/l.

5. We can then convert this to mg/kg if we know the soil dry bulk density. Let us assume the soil density is 1.33 g/cm³:

$$\begin{aligned} Cu [mg/kg] &= \frac{Cu [mg/l]}{\text{Bulk density } [g/cm^3]} \\ &= \frac{2.8}{1.33} = 2.1 [mg/kg] \end{aligned}$$

6. We can now calculate how much we are going to raise our value by:
- New soil Cu value (mg/kg) = Original value (mg/kg) + Additional value (mg/kg)
- i.e. for our grassland soil:

$$\begin{aligned}\text{New Cu [mg/kg]} &= 24.0 + 2.1 \\ &= 26.1 \text{ mg/kg}\end{aligned}$$

A generic version of this equation which can be used for any element (y), sampling depths etc is:

$$N = I + \left(\frac{A \times C}{S \times D \times 100000} \right)$$

Where:	N	= New soil value for element y (mg/kg)
	I	= Initial soil value for element y (mg/kg)
	A	= Application rate of sludge (kg/ha)
	C	= Concentration of element y in sludge (mg/kg)
	S	= Sampling depth (cm)
	D	= Soil bulk density (g/cm ³)

References

Sewage sludge in agriculture: code of practice for England, Wales and Northern Ireland. May 2018

<https://www.gov.uk/government/publications/sewage-sludge-in-agriculture-code-of-practice/sewage-sludge-in-agriculture-code-of-practice-for-england-wales-and-northern-ireland>