Technical Information

Advice Sheet 31: Plant Tissue Analysis for Undesirables

Heavy Metals

Plants can accumulate heavy metals in or on their tissues and although these elements occur naturally in the environment, (sometimes at elevated concentration e.g. the teart soils in Somerset) metallic pollution can arise due to over zealous addition of waste disposal products to agricultural land. The presence of some of these elements in plants typically has little effect on plant health but poses potential animal and human health problems when introduced into the food chain. Heavy metal resistance/tolerance in plants is of special concern. The evolution of this metal tolerance is believed to be quite rapid in higher plants and is known to have a genetic basis.

Approximate concentrations of heavy metals, generalised for various plant species are listed at the end of this document.

Cadmium

Cadmium is effectively adsorbed by both root and leaf systems. Cd is considered to be a toxic element to plants and the basic cause of its toxicity lies in its disturbance of enzyme activities. Overt symptoms of Cd toxicity include growth retardation, root damage, chlorosis of leaves, and red-brown discolouration of leaf margins or veins. Cd shows inhibitory effects on photosynthesis, disturbs transpiration and CO_2 fixation and alters the permeability of cell membranes. Cd is also known to interfere with symbiosis between microbes and plants as well as to increase plant predisposition to fungal invasion.

However the greatest concern is the tolerance and adaptation of some plant species to higher Cd levels and this acts as a reservoir through which Cd passes to man and animals, posing a significant health risk, as Cd is a cumulative poison.

Leafy vegetables such as spinach and root vegetables such as turnips should be considered to be the main supply route of Cd to man. A survey of various studies shows that the Cd content of plant foodstuffs and cereal grains reports that levels are fairly low and similar ranging from 0.01-0.22 mg/kg (DM) for cereal grains, 0.07-0.27 mg/kg (DM) for grasses and legumes at 0.08-0.28 mg/kg (DM). However cadmium concentrations rapidly increase in plants grown in polluted areas with lettuce leaves accumulating 22.8 mg/kg (DM) in over-sludged farm land and 3.7 mg/kg (DM) in carrot roots which were grown in the vicinity of a metal processing plant.

Mercury

Mercury seems to be easily absorbed by the root system and is also translocated within the plant, which include from apple leaves to fruit, from potato leaves to tubers, from rice leaves to grains and also from the wheat and pea seed treated with mercurial fungicides into the first generation seed.

The most commonly observed toxic effects of elevated Hg levels are the stunting of seedling growth and root development and inhibition of photosynthesis. Hg accumulated in root tissue inhibits potassium ions uptake by plants. Resistance to Hg compounds in fungi is also a well documented phenomenon. Background levels of Hg in vegetables and fruits vary from 2.6-86 ug/kg (DM) and that natural levels in grasses do not exceed 100ug/kg (DM). The Hg content of cereal grains appear to be similar in a number of studies ranging from 0.9-21 ug/kg (DM). Plants grown in contaminated sites may accumulate much higher than normal amounts of Hg, and certain plant species such as carrots, lettuce and mushrooms in particular are likely to take up more Hg than other plants grown at the same site. Also, some parts of plants such as apple flesh and apple pips have a greater ability to absorb Hg.

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Lead

Lead occurs naturally in all plants but has not been shown to play an essential role in their metabolism. The mode of uptake of Pb by the roots is passive and the rate of uptake is reduced by liming (for some soil types) and low temperatures. The degree to which soil Pb is available to plants is of great environmental concern, although most studies show that Pb from a soil source is not readily located to an edible portion of the plant. However a major source of Pb pollution is airborne and this is also taken up by plants through their leaves. It is at present unclear on how much Pb remains fixed to hairy/waxy cuticles of leaves and how much Pb is absorbed by the foliar cells but there is likely to be a significant translocation of Pb into plant tissues.

Due to interactions of Pb with other elements and many environmental factors, it is not simple to establish Pb concentrations that are toxic to plant processes. Sub-cellular effects of Pb on plant material are related to the inhibition of respiration and photosynthesis due to the disturbance of electron transfer reactions. However Pb poisoning has seldom been observed in plants growing under field conditions probably due to low soil Pb availability.

Natural Pb content of the edible portion of plants growing in uncontaminated areas appears to be quite constant in the literature ranging from 0.05-3.0 mg/kg (DM) and averaging at 0.47 mg/kg (DM) for cereals. For grasses the mean was 2.1 mg/kg (DM). The commonly observed increase in Pb amounts in forage plants during the autumn & winter season is not understood.

Several plant species are adapted to grow in high Pb concentrations in the growing media and the highest bioaccumulation of Pb is reported for leafy vegetables (mainly lettuce) grown in surroundings of nonferrous metal smelters where plants exposed to Pb sources of both soil and air. In these locations, highly contaminated lettuce may contain as much as 0.15% Pb (DM).

Arsenic

Although As is a constituent of most plants, little is known about its biochemical role. Several authors report a linear relationship between As concentration of vegetation and concentrations in soil of both soluble and total As, suggesting that plants take up As passively with the water flow. As is translocated in plants since its concentration in grains is linked to levels in soils.

The visual symptoms of As toxicity are leaf wilting, violet colouration of the leaves but most commonly is growth reduction. As toxicity has commonly been noted in plants growing on mine waste and on soils with As added by sewage sludge treatment. The As content of injured fruit trees ranged from 2.1-8.2 mg/kg (DM), but in general the residue tolerance for As in plants is established as 2 mg/kg (DM), but this may be higher in some species. Some plants may accumulate extremely large amounts of As with levels of 6000 mg/kg (DM) being found in tree foliage in the vicinity of a mining operation.

Concentrations of As in food plants grown on uncontaminated soil may vary from 0.009 to 1.5 mg/kg (DM), with leafy vegetables being in the upper range and fruits in the lower range. Mushrooms have been found to be relatively high As accumulators. So these plants that accumulate extremely large amounts of As have the potential to poison animals, and although this is a rare occurrence, detrimental health effects from very high As concentrations in vegetables and forage cannot be precluded.

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Chromium

There is no evidence of an essential role of Cr in plant metabolism and although most soils contain significant amounts of Cr, its availability to plants is highly limited. However, the addition of Cr to soil affected the Cr content of plants, and the rate of uptake by plants is dependent on several soil and plant factors. Typically higher concentrations are observed in roots than in leaves or shoots and lowest in the grains. Several native plants, mainly from areas of serpentine or chromite deposits can accumulate as much as 0.3%. The elevated Cr content of soils in such areas is known to be responsible for the poor growth of forest trees. Symptoms typical of Cr toxicity appear as wilting of tops, root injury, chlorosis in young leaves, chlorotic bands on cereals and brownish-red leaves.

Common levels of Cr found in plants are reported to be in the range of 0.02-0.2 mg/kg (DM), but there appears to be a considerable variation on the Cr content of food plants, with values ranging from 0.02-8 mg/kg (DM) for vegetables, 0.11-3.5 mg/kg (DM) for grasses, 0.014-0.2 mg/kg (DM) for cereals and 0.013-0.074 mg/kg (DM) for fruits.

Human activity can be attributed to the elevated content of Cr in plants today. In polluted cities, grasses have been reported to be as high as 17 mg/kg (DM). There is also evidence of Cr toxicity to livestock grazing grass with an elevated Cr content due to Cr rich sewage sludge additions.

Nickel

There is no evidence of an essential role of Ni in plant metabolism, although some reports indicate that this metal may have some function in plants, due to the beneficial effects of Ni on plant growth. Ni is thought to be an essential component of the enzyme urease, and thus may be required by nodulated legumes that transport N from roots to tops in forms of ureide compounds. N is rapidly and readily taken up by plants from soils and adsorption is positively correlated with the soil Ni concentrations. Many factors affect Ni uptake by plants, but the most pronounced factor is the soil pH. In one study it was shown that increasing the soil pH from 4.5 to 6.5 decreased the Ni of oat grains by a factor of 8.

The most common symptom of Ni phytotoxicity is chlorosis, which seems to be Fe induced chlorosis. With plants under Ni stress, the adsorption of nutrients, root development and metabolism are strongly retarded. Before the acute Ni toxicity symptoms are evident, elevated levels of this metal in plant tissues are known to inhibit photosynthesis and transpiration. Also low N_2 fixation by soybean plants was reported to be caused by Ni excess. Generally the range of toxic amounts of Ni in most plant species varies from 10-100 mg/kg (DM). Several species are known for their great tolerance and hyper accumulation of Ni, with some native vegetation growing on acid ferralsols being seen to have accumulated 6542 mg/kg (DM) in their leaves.

Mean levels of Ni in grasses range from around 0.1-1.7 mg/kg (DM), in vegetables levels range from 0.2-3.7 mg/kg (DM) and for wheat grains the levels fall between 0.2-0.6 mg/kg (DM) with oat grains containing higher amounts of Ni, from 0.3-2.8 mg/kg (DM). As Ni is easily mobile in plants, berries and grains are reported to contain elevated Ni concentrations.

Animal and human health can be compromised by elevated exposure to Ni, thus a redistribution of this metal to the environment from the burning of fossil fuel, application of sewage sludge to agricultural lands and by industrial emissions, should be of concern.

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Fluoride

The availability of F to plants is not closely related to the total and soluble F content of a soil. Plants can take up F quite easily from polluted soils, but the bioavailability of soil F is of much less significance than that of airborne compounds. Foliar uptake of gaseous F apparently follows the path of penetration of other gases into the leaf, typically through the stomata. There is no evidence of F phytotoxicity when this element is absorbed by the roots, whereas airborne F is highly toxic. The most emphasised effects of F on plant metabolism are related to:

a) Oxygen uptake decrease
b) Respiratory disorder
c) Assimilation decrease
d) Reduction in chlorophyll content
e) Inhibition of starch synthesis
f) Altered metabolism
g) Injured cell membranes
h) Disturbance of DNA and RNA
i) Synthesis of fluroacetate, a most hazardous F compound
j) Inhibition of pyrophosphatase function

The best documented plant responses to F toxicity are foliar symptoms such as chlorotic and necrotic lesions and the deformation of fruits. However the most significant effect of increased concentrations in plants is toxicity to man and animals.

Plants exhibit a broad range of tolerances to foliar injury by F pollution. Tolerant plants include asparagus, beans, cabbage, carrots and willow; while barley, corn, apricot, pine and larch are classified as susceptible. It can be generalised that susceptible plants would be injured by foliar F concentrations that ranged between 20-150 mg/kg (DM) and highly tolerant plants do not exhibit injury below 500 mg/kg (DM).

The effects of land F on animals is of the greatest concern with toxic threshold values of F in forage being set at 40mg/kg (DM) with more tolerant animals (lamb and turkeys) tolerating a higher F concentration. The F content of plants grown in uncontaminated areas is unlikely to exceed 30mg/kg (DM) and in grasses the F content ranges between 3-6 mg/kg (DM), cereal grains ranging between 0.2-1.7 mg/kg (DM), fruits between 0.2-5.7 mg/kg (DM), vegetables 1.5-7.0 mg/kg (DM), with leafy vegetables in the upper range at 1.3-28.3 mg/kg (DM).

Copper

Cu absorption by the roots is thought to be a mixture of both passive and active mechanisms and there is a definite relationship between the concentration of this metal in the plants and the soil that supports them. There appears to be a strong capability of root tissues to hold Cu against the transport to shoots under both Cu deficiency and Cu excess. This process is not understood but will explain why young organs are usually the first to develop symptoms of Cu deficiency. Generally Cu has a low mobility in the plant relative to other elements, but it is at its highest when there is a 'luxury' supply. Cu plays multifunctional biochemical roles which include photosynthesis, respiration, carbohydrate distribution, N reduction and fixation, protein and cell wall metabolism. Cu influences water permeability of xylem vessels and thus controls water relationships. Cu controls the production of RNA and DNA and its deficiency greatly inhibits the reproduction of plants in the form of reduced seed production and pollen sterility. The deficiency levels of Cu in plants shows enormous differences but it is generally accepted that Cu levels less than 2 mg/kg (DM) is likely to be inadequate for most plants.

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In spite of the general Cu tolerance of plants, this metal is considered also to be highly toxic. Copper induced chlorosis and root malformations are the most common visual characteristic indicative of this toxicity. Processes induced by this toxicity include tissue damage and elongation of root cells, alteration of membrane permeability and inhibition of photosynthetic electron transport.

Prediction of the Cu content of the soil that results in these toxic effects on plants is difficult. Before toxic symptoms and yield reductions are evident, it will be the health risk to both man and animals due to the crop containing elevated Cu levels that needs to be the primary concern. Thus supplying the appropriate content of Cu is essential. Cu content of whole plant shoots do not often exceed 20 mg/kg (DM) and thus this value is often considered to be the threshold value. The range of Cu in grasses varied between 2-20 mg/kg (DM), in fruits between 1.9-8.8 mg/kg (DM), in vegetables between 1.5-8.1 mg/kg (DM) and in cereal grains from 2.8-6.7 mg/kg (DM).

Zinc

Soluble forms of Zn are readily available to plants and its uptake has been reported to be linear with the soil concentration. Evidence suggests that Zn uptake is mostly metabolically controlled and is considered to be highly mobile within the plant.

Zn plays essential metabolic roles in plants of which the most significant is its activity as a component of a variety of enzymes and is related to the metabolism of carbohydrates and proteins. There is some evidence that Zn influences the permeability of membranes.

Plant species differ widely in their susceptibility to Zn deficiencies which are relatively common but recently special concern has focused on the Zn toxicity and the Zn tolerance exhibited by most plant species, because of the prolonged use of Zn fertilisers and as well as the input from the modern day industrial pollution. Plants grown in Zn contaminated soils have reached the magnitude of 0.x % (DM) and are a very real health risk. Chlorosis and depressed plant growth are common symptoms of Zn toxicity.

Natural Zn content of grasses range from 12-47 mg/kg (DM) and for cereals the values ranged from 22-33 mg/kg (DM), for fruits the values were 1-26 mg/kg (DM), for vegetables the range was 14-38 mg/kg (DM) and lettuce was at 73 mg/kg (DM).

Selenium

The physiological role of Se has not been established. More interest in plant Se is due to the importance of this element in nutrition, particularly for domestic animals, since Se can act as a micronutrient and as a toxin. When present in soluble forms Se is readily absorbed by plants and some plants can act as Se accumulators. Seleniferous plants can concentrate Se to extremely high levels (up to 1000 mg/kg (DM). Available data concerning Se content of plants shows that for grasses the range is between 17-174 ppb (DM), for cereals grains the range was 1-250 ppb (DM) in Europe but US levels were higher at 10-2030 ppb (DM). Fruits having a range of 26-36 ppb (DM), vegetables ranging from 11-150 ppb (DM) and lettuce at 57 ppb (DM).

The levels of Se in crops that are adequate and safe for animals are believed to be about 100 ppb (DM). Disorders in livestock may be expected when Se concentrations in forage plants are below 10 ppb (DM). Other threshold values, such as a toxic level of 3000 ppb (DM) and a minimum requirement of 100 ppb (DM) have been proposed for grasslands.

Molybdenum

Mo is an essential micronutrient and the evidence suggests that plants actively take up Mo and Mo is moderately mobile in the soil. Normally there is 1 mg/kg (DM) in leaf tissues but nodulated roots contain several times these concentrations. Most of this Mo apparently is in the nitrate reductase of root and shoots and in the nitrogenase of the nodule bactericides. Thus the requirement of plants for Mo appears to be related to the N supply, plants supplied with NH_4-N have less need of Mo than those utilising NO_3-N. Since the most important function of Mo in plants in NO_3 reduction, a deficiency of Mo causes symptoms similar to those of N deficiency, although some plants also exhibit Mo deficiency symptoms such as whiptail in cauliflower.

Although soluble soil Mo is readily taken up by plants and some species are known to accumulate much Mo, its toxicity symptoms in plants under field conditions are rare indeed, whereas toxicities to animals feeding on forage high in Mo are well documented e.g. cattle grazing on 'teart' pasture will within a few days develop a starey coat and scour. So while correcting Mo deficiencies may be accomplished by Mo application as soil, foliar or seed treatments, care must be exercised in its use as Mo may be very toxic, at quite low concentrations in fodder plants, thus the preferable control of Mo deficiency is liming the soil to a pH of around 6.5.

The Mo concentration in plants closely reflects the soluble Mo in the soil and the uptake of Mo by plants is a function of soil pH. Some native plants, especially leguminous species are known to accumulate as much as 350 mg/kg (DM) without showing toxicity symptoms. However the Mo content of forages is of special concern so most available data focuses on the Mo status of grasses and legumes. Mean Mo levels range from 0.33 mg.kg (DM) and from 0.73-2.3 mg/kg (DM) in legumes. In areas where toxicity was observed in grazing animals, the Mo content of grasses ranged from 5.00-20.00 mg/kg (DM) and in legumes from 5.2-26.6 mg/kg (DM). In pasture Mo is known to vary with different stages of plant development and with periods of the growing season. The Mo levels have been reported to be higher in Spring and the Autumn seasons.

Plant foodstuffs contain variable amounts of Mo within the range of 0.07-1.75 mg/kg (DM) with legume vegetables being in the upper range and fruits in the lower range and cereal grains around 0.49 mg/kg (DM) and in contaminated sites the ready availability of Mo causes a huge increase in uptake, and levels as high as 1000 mg/kg (DM) have been found in cabbages grown on Mo polluted soil near a Mo processing plant.

Bromide

The natural Br content of plants seems not to exceed 40 mg/kg (DM) but marine plants generally contain more Br than do land plants and may concentrate this element up to a range of x000 mg/kg (DM). Higher values found in land plants should apparently be related to pollution. Plants take up Br readily from Br enriched soils but the method of transportation is not clear. Methyl Bromide and other Br organic compounds such as fumigants for soils, grains and fruits may be a serious source of Br contamination in human diets.

Br can substitute for part of the Chloride requirement of plants, therefore in excess it is toxic to plants. Plant species differ in their tolerance to soil Br but several vegetables and flowers are known to be sensitive (potato, spinach, sugar beet, onion, carnations and chrysanthemums). Symptoms of Br toxicity resemble excess salt effects, so chlorosis followed by leaf tip necrosis is the common feature. Plants resistant to Br toxicity (carrots, tobacco, tomatoes, celery, melons) can accumulate more than 2000 mg/kg (DM) Br without showing any effects. Available data lists that mean Br levels in grasses range from 17-119 mg/kg (DM), for vegetables the range is between 0.37-26 mg/kg (DM), for fruits the values fell between 0.2-10 mg/kg (DM), with cereal grains between 21-33 mg/kg (DM) and lettuce at 22 mg/kg (DM).

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Approximate Concentrations of Potentially Toxic Elements in Mature Leaf Tissue, generalised for Various Species (mg/kg DM)		
Potentially Toxic Element	**Normal Concentrations (mg/kg DM)**	**Excessive Concentrations (mg/kg DM)**
Copper (Cu)	5 – 30	20 – 100
Zinc (Zn)	27 – 150	100 – 400
Arsenic (As)	1 – 1.7	5 – 20
Cadmium (Cd)	0.05 – 0.2	5 – 30
Chromium (Cr)	0.1 – 0.5	5 – 30
Fluoride (F-)	5 – 30	50 – 100
Mercury (Hg)	N/A	1 – 3
Molybdenum (Mo)	0.2 – 1	10 – 50
Nickel (Ni)	0.1 – 5	10 – 100
Lead (Pb)	5 – 10	30 – 300
Selenium (Se)	0.01 – 2	5 – 30

References

Kabata-Pendias, A. and Pendias H. (2000) Trace Elements in Plants and Soils

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