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Management of manganese in soils for arable crops

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Summary

- **Manganese (Mn) deficiency is usually induced by low availability of soil Mn for crop uptake, rather than being due to an absolute shortage of soil Mn.**
- **The field conditions that can induce Mn deficiency are: high soil pH; coarse-textured sandy soils with low organic matter; high soil P; poor root development; poor root-soil contact in under-consolidated (fluffy) seedbeds; low soil temperatures; and below average rainfall.**
- **Where high soil P results in elevated plant P that interferes in the uptake and/or translocation of Mn, fewer high P soils may reduce the incidence of Mn deficiency.**
- **Diagnosis of Mn deficiency is usually made on recognition of visible symptoms and knowledge of the soil characteristics and field history, backed up by plant analysis.**
- **Soil applications of Mn are generally ineffective, as the applied Mn rapidly changes into less available forms.**
- **Foliar treatment options are described involving manganese sulphate, chelated products and inorganic suspensions.**

1. Introduction

Manganese (Mn) deficiency is the most widespread trace element problem in arable crops in the UK and is most seen in cereals. This deficiency has increased in importance over the years because of both the expansion of the cereal area, often onto land which may only be marginally suited for such cropping, and the increased nutrient demand of higher yielding varieties. However, several spring and winter barley trials in the northeast of Scotland showed that high-yielding crops are not necessarily more prone to Mn deficiency than are lower-yielding crops. Substantial increases in the concentration of Mn in soil solution were observed in the rooting regions which were typically larger in higher-yielding crops.

The supply of Mn to plant roots is not merely a function of the total or extractable amount of the nutrient in the soil, but also of the rate of replenishment of the soil solution by the nutrient pool as well as the volume of soil exploited by the root system. Plants obtain nutrients including Mn largely if not exclusively by uptake from solution.

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Soil applications of Mn are generally ineffective, as the applied Mn rapidly changes into less available forms. Deficiencies are best prevented or, where Mn deficiency only occurs infrequently, corrected by foliar sprays with Mn each year. This technical note will concentrate on management of Mn in soils in relation to growth of arable crops.

2. Soil type and field conditions

Manganese is a minor metal element that is essential to plant and animal life. The total Mn content of soils varies widely from a trace to over 7000 mg/kg soil but is mostly within the range 200 – 3000 mg/kg, as compounds of Mn^{2+} and as oxide-Mn and reflects the diverse geology of Scotland. A small proportion is present in the soil solution and thus immediately available to plants. As this soluble Mn is absorbed by plants, it is replaced in the soil solution by exchangeable Mn held by soil colloids. The amount available is strongly influenced by the pH and aeration status of the soil, organic matter content and soil microbial activity. The total Mn content of many soils are larger than the total content of other minor heavy metals often referred to as potentially toxic elements (PTEs) **(https://www.fas.scot/publication/technical-note-tn753-management-of-inputs-of-heavy-metals-to-agricultural-soils-and-crops/)**.

In relation to the soils resource of Scotland it should be remembered that the cropping of our soils has been in progress now for many hundreds of years. Where vegetation is removed by harvesting or grazing, and residues of the above-ground parts are not restored in plant or animal residues, the soils are being progressively mined of such elements. Maximum uptake of Mn in a high-yielding crop is about 400-500 g/ha. Livestock manures are a useful source of Mn with typical wet weight concentrations of 40 g/t in cattle solid manures and 60 g/t in pig solid manures.

Leached sand and podzolic soils are particularly low in Mn as are peaty soils but in most other soils Mn is relatively abundant. Consequently, Mn deficiency is usually induced by low availability of soil Mn for crop uptake, rather than being due to an absolute shortage of soil Mn. The field conditions that can induce Mn deficiency are: high soil pH; coarse-textured sandy soils with low organic matter; high soil P; poor root development; poor root-soil contact in under-consolidated (fluffy) seedbeds; low soil temperatures; and below average rainfall. The overall combination of these factors will dictate the severity of Mn deficiency in crops in any one season. The higher the organic matter content, the lower the soil pH needs to be to prevent deficiency occurring. A temporary shortage of Mn is also often induced under poor soil physical conditions, especially after periods of cold, dry weather that put a poorly rooted crop under stress. Bright sunny weather conditions can also accentuate Mn deficiency, compared with dull, humid conditions.

The capacity of soil surfaces to absorb and retain transition element ions such as Mn is known to be enhanced by the adsorption of P onto oxide surfaces. The use of P fertilisers in arable agriculture has resulted in a build-up of P in some soils. This can result in increasing adsorption of Mn onto oxide surfaces in these soils, thus causing depressed soil solution concentrations and enhanced Mn deficiency in various crops. It is also suggested that Mn uptake is reduced where high soil P results in elevated plant P that interferes in the uptake and/or translocation of Mn, rather than by a direct effect of soil chemistry on Mn availability. Fewer high P soils may reduce the incidence of Mn deficiency.

3. Manganese function, plant uptake and deficiency symptoms

3.1 Function

Manganese has a role in many biochemical processes in plants and resembles magnesium in its biochemical function. It is required for photosynthesis and is both a constituent and activator of enzymes involved in protein synthesis and lipid metabolism. However, unlike some other essential trace elements which are usually integral components of enzymes, Mn can often be replaced by other metal ions in its role as an activator of enzymes. A shortage of Mn often results in impaired activity of the nitrate-reductase enzyme with consequent accumulation of nitrate in plant tissue. A good supply of Mn helps better crop establishment and reduces plant losses over winter.

3.2 Plant uptake

Manganese is absorbed by plant roots from the soil solution in divalent (Mn^{2+}) form. Manganese availability depends on the chemical reduction of Mn oxides by organic matter, and on some biological processes involving microbial or root products, and the rate of reduction increases at more acid pH values. Applications of acidifying fertilisers such as ammonium sulphate increase Mn uptake by crops. Phosphate fertiliser applications may also increase Mn uptake through soil acidification, but the effect on Mn utilisation within the plant may depend on the relative uptake of P and calcium.

Although Mn is more available in poor drainage conditions, shallow and restricted rooting in these conditions may reduce Mn uptake, especially if the topsoil becomes dry at some stage during the summer. Crops require a continuous supply of Mn since remobilisation within the plant is limited, particularly at low levels of supply. Transient deficiencies can thus occur, due to changing weather and soil conditions. The Mn content of plants varies greatly, usually from a trace up to 500 mg/kg in the dry matter, depending on soil Mn availability. Much larger, toxic concentrations can occur in plants growing on very acid soils. Plant Mn concentrations decrease significantly with increasing pH value. Maximum uptake of Mn in a winter wheat crop yielding 8 t/ha is about 400-500 g/ha. Typical Mn offtakes in cereal grain and straw at harvest are 26 g and 40 g per tonne (fresh material) respectively.

3.3 Deficiency symptoms

When comparing the growth and Mn absorption by seedlings of different cereal cultivars under both deficient and adequate Mn supply conditions, the amount of absorption was more closely related with the extent of lateral root growth than with efficiency of Mn uptake per unit of root. Spring varieties are more susceptible than winter varieties of cereals, presumably because of their quicker growth habit and different pattern of root development. Cereals also exhibit varietal tolerance to Mn deficiency.

The most characteristic symptom of Mn deficiency is leaf interveinal chlorosis, which can quickly develop in affected crops. The deficiency also shows as a general paling of leaves which can go unnoticed or be confused with other agronomic problems such as poor drainage conditions. In cereals, deficiency symptoms usually first appear in spring as patches of pale green, limp growth which, if left untreated, leads to general plant stunting and species-specific leaf spotting. All leaves are affected, starting with the oldest leaves. Symptoms can appear at any time from about the third leaf stage until flag leaf emergence, depending on the season. Unconsolidated areas show the most pronounced symptoms, with wheel marks standing out as green lines within the field. On more extreme soil types, it is common to find Mn deficiency in winter cereals starting to develop in late autumn. Initial symptoms are like a spring Mn deficiency except that, if left untreated, the crop suffers tiller death or even death of whole plants.

In oats, interveinal yellowing develops together with grey-or buff-coloured specks or streaks, in the basal halves of the leaves. The streaks mainly may coalesce so that the leaf tissue above the affected area may remain green but hang limply. Severely affected leaves will eventually turn completely brown and wither. In barley, small brown or black spots and streaks or flecks develop along the interveinal tissue. In wheat, the older leaves usually show faint chlorotic streaking, changing to interveinal white and eventually brown necrotic streaks in severely affected leaves. In Scotland, Mn deficiency is more common in barley than in wheat, perhaps because barley is often grown on lighter, coarse-textured soil.

Figure 1. Better growth where soil has been compacted by tractor and implement wheels.

Figure 2. Small brown spots and streaks develop along the interveinal tissue in pale green leaf.

In oilseed rape Mn deficiency occurs initially on the younger leaves. Chlorosis develops between the veins, while a narrow area on each side of the veins remains green. As the small veins remain green as well, a mosaic-shaped pattern appears.

Manganese deficiency can occur on many horticultural crops, though it is most seen as “Marsh spot” on peas (symptoms of brown centres in peas and chlorotic leaves). Manganese deficiency symptoms are often transient but usually seen at high soil pH, especially on dry sandy soils, soft seedbeds and/or immediately after liming.

4. Diagnostic methods

Diagnosis of Mn deficiency is usually made on recognition of visible symptoms and knowledge of the soil characteristics and field history, backed up by plant analysis.

4.1 Plant analysis

A critical leaf Mn content of 20 ppm (100% DM) is used to diagnose deficiency in all crops, including cereals, oilseed rape and horticultural crops:

Plant Mn concentration (ppm)	Soil Status	Yield Response
<20	deficiency	yield response likely
20-30	low	yield response possible
30-40	satisfactory	yield response unlikely
>40	well supplied	no yield response

Some general guidelines on the use of plant analysis, and interpretation of results, are:

- **The interpretation of plant analysis is not an exact science. The concentration of any specific nutrient depends on the plant species, age of the plant, part of plant analysed, variety and even the level of the other nutrients present. Plant analysis will indicate those nutrients that are clearly adequate or deficient. In those cases where the values are borderline or several nutrients appear deficient, expert advice must be taken.**

- **For most nutrients, values decline with maturity. Plant analysis ideally should be carried out early in the growing season when the plants are young. Interpretation of the results is easier, and this also allows sufficient time for foliar nutrient sprays to be applied to overcome any deficiency.**

- **All samples submitted for analysis must be clean and free from dust or soil and ideally should not have been recently sprayed with any nutrient-containing spray. The presence of soil can lead to falsely elevated values, making interpretation impossible. Analysis of both affected (i.e., showing apparent deficiency symptoms) and, for comparison, unaffected plant samples is often helpful for interpreting the results.**

4.2 Soil extraction

Soil analysis for Mn (exchangeable and easily reducible) has not proved to be of any value in the diagnosis or prediction of the deficiency in the UK, and most laboratories indicated that Mn analysis from soil was unreliable.

5. Treatments

5.1 Soil application

Soil application of manganese sulphate is never recommended for the control and treatment of Mn deficiency. Although high rates of manganese sulphate, either broadcast or combine drilled, have been shown to give some control of the symptoms, this treatment is much more expensive than foliar spraying and unreliable because the applied Mn may rapidly become unavailable to the crop.

Combine drilling with ammonium-N compound fertilisers can reduce the severity of Mn deficiency in spring barley but this technique, with its slower drilling rate, may only be worthwhile where severe Mn deficiency is otherwise likely to occur.

5.2 Foliar application

Foliar spraying with Mn is the recommended method for effective control or treatment of Mn deficiency. Foliar Mn sprays should be applied in the spring when deficiency symptoms are first identified, provided there is sufficient leaf cover for Mn uptake at that stage, otherwise routinely during late tillering to early stem extension (GS24-31) on fields with a known history of moderate to severe Mn deficiency problems in most years. A Mn spray application is not, however, normally considered worthwhile beyond ear emergence stage, where a deficiency is identified late in the season. Where severe Mn deficiency occurs, 2 or 3 sprays may be necessary. Autumn, as well as spring Mn sprays are, however, required on winter cereals if deficiency symptoms develop during the autumn, as deficient crops will be prone to frost damage and winter kill. Autumn Mn sprays should be applied when there is sufficient leaf cover, generally after the start of tillering (GS21). Applications of Mn as a foliar spray once symptoms have appeared will allow the crop to recover quickly and make normal growth.

The three main forms of Mn spray are:

- **manganese sulphate, at 4.5-9.0 kg/ha in 250 litres water plus wetter. An application rate of 5 kg/ha should be used for autumn treatment unless a frost is expected, when a lower application rate e.g., 2.5 kg/ha is advisable to reduce scorch risk to stressed crops. However, manganese sulphate can be difficult to dissolve, is not compatible with many other agrochemicals for tank mixing and can cause leaf scorch, especially on a stressed crop.**

- **chelated products (mainly based on EDTA, but also phenolic acid or lignosulphate chelates); they have advantages of much greater compatibility with other agrochemicals, better solubility and no risk of crop scorch but supply less Mn and are more expensive. Chelated products are equally effective as manganese sulphate, if supplied in sufficient quantity.**

- **inorganic suspensions: these proprietary products are based on manganese sulphate as a flowable suspension, together with stickers and wetters in a tank mixable formulation. Some of these products also contain a proportion of chelated Mn.**

5.3 Seed treatments

Field trials testing manganese oxide or sulphate as a seed-pellet additive for controlling Mn deficiency have been trialled.

Manganese deficiency was not completely cured by the pelleting treatment, but the treatment was useful as a starter in helping to control Mn deficiency early in the growing season, particularly when the seedlings were too small to be sprayed effectively.

Where ammonium nitrate-based NPK fertiliser was combine-drilled with the Mn-treated spring barley seed a soil pH drop of 0.6 units in the root zone was reported. This acidification resulted in substantial mobilisation of Mn into the soil solution, enhancing the effectiveness of the Mn seed treatment by causing increased uptake of Mn and better early growth with increased tillering.

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