NUTRITIONAL DISORDERS

IN

GLASSHOUSE LETTUCE

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The 'Instituut voor Bodemvruchtbaarheid' (Institute for Soil Fertility) is a governmental institution. Research work includes various aspects of soil physics, soil chemistry and soil organic matter, and of plant nutrition and fertilizer application. The 'Proefstation voor de Groenten- en Fruitteelt onder Glas' (Glasshouse Crops Research and Experimental Station) was founded and is now owned by an association of growers and it is subsidized by the Dutch government. The aim of the research work is to increase production and to improve quality of vegetables grown in glasshouses. Consequently, all aspects of cultivation under glass are studied.

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Introduction

Lettuce (*Lactuca sativa* L.), tomatoes and cucumbers are the main crops grown under glass in the Netherlands. The annual sales of lettuce are about 100 million Dutch guilders. Glasshouse lettuce is grown in autumn, winter and spring and, experimentally, in summer. Young plants are normally raised on peat blocks (see references no. 89). In the Netherlands butter head lettuce, characterized by its tender heads under favourable conditions (86), is almost the only type grown.

This publication aims at being a guide in diagnosing nutritional disorders in lettuce. Both toxicity and deficiency symptoms are included, the former being restricted to symptoms resulting from excessive concentrations in soils.

Disorders occur with an absolute or relative deficiency or excess of one or more essential nutrients. For diagnosis, the following methods can be applied:

1 study of visual symptoms
2 plant analysis
3 analysis of the plant's substrate
4 study of the plant's response to nutrients applied to the soil, or to the plant (by spraying or injection).

Correct diagnosis is often only possible by a combination of these methods (109, 120). This publication is based on methods 1 and 2. Colour plates and descriptions are given for nitrogen, phosphorus, potassium, magnesium, calcium, sulphur, boron, copper, manganese, molybdenum, iron and zinc deficiency and nitrogen, boron, manganese, zinc and aluminium toxicity. Mineral disorders are described and analytical data on lettuce foliage given in several papers are reviewed here. The study is mainly based on lettuce of the butter head type. In some trials 'Iceberg' lettuce or cos lettuce were used.

Literature references concern both lettuce grown in the open and under glass or by a combination of these systems. It is not only difficult but also illogical to distinguish between them, especially as symptoms vary so much within one cropping system.

Glasshouse lettuce generally has a higher nutrient concentration than outdoor lettuce. For plant analysis the whole mature head was used, discarding yellow or decaying leaves, or leaves contaminated with soil. If growth were stunted, smaller plants had to be taken.

Causes of the mineral disorders and practical methods of control are

Fig. 1 Normal tipburn in butterhead lettuce from a commercial glasshouse.

Fig. 2 Latex-tipburn in lettuce (cv. Deciso) from a commercial glasshouse.

briefly described. The methods of control are suitable for glasshouse conditions.
Many of the mineral disorders described do not normally occur in commercial glasshouses, so they were induced in lettuce grown on sphagnum peat or in nutrient solution (94, 103).
Malnutrition symptoms in lettuce may vary with substrate, climate and variety (especially presence or absence of anthocyanin). This variation should be remembered when using the plates for diagnosis. Any other causes of disorder must also be excluded, e.g. pests and disease, pesticides, air pollution, drought and excess moisture.
In this context tipburn should be mentioned. Several types of tipburn can be distinguished (39, 111), which are influenced by climate. The growth rate of the crop is decisive in distinguishing between mineral disorders and tipburn. Growth inhibition is a normal characteristic of deficiency, whereas tipburn is found particularly in luxuriously growing crops (112). In our opinion 'tipburn' should be used only for physiogenical and not for nutritional disorders, where indeed tipburn-like symptoms may occur. Normal tipburn is mainly influenced by the salt content of the soil, especially excess nitrate and chloride.
The concentrations of various elements in mature lettuce heads are listed on p. 44. Data for elements we have discussed are derived from our own trials. Other data are quoted from the literature.

Fig. 3 Lettuce (cv. Noran) from an experimental plot in a commercial glasshouse; to the left with, to the right without nitrogen.

Fig. 4 Nitrogen deficiency in commercially grown lettuce (cv. Noran).

Nitrogen deficiency

Symptoms Restricted growth and yellowish-green foliage. With severe deficiency older leaves turn pale and eventually decay. Leaf shape is normal. In severe stunting, in the youngest leaves, no head is formed. Nitrogen-deficient plants often have a dense root system. Descriptions in the literature are similar. The lettuce heads late, if at all (26, 56, 70, 117, 120). A purple flush (117, 130) develops in cultivars with anthocyanin and a brown one in cos lettuce (33). Leaves are sometimes smooth (56, 132) or tough (118).

Crop analysis Nitrogen-deficient lettuce contains 0.04% nitrate-N and 1.58% Kjeldahl-N in dry matter. In the highest-yielding crops, nitrate-N is 1 to 2% (91). Phosphorus-deficient plants have very little (0.20-0.35% nitrate-N; 92). Leaf nitrate decreases with light intensity and therefore depends on date of picking (91, 92).
Outdoor lettuce has 0.18 to 0.42% nitrate-N (10); according to another report 0.2% is normal and 0.02% too low (102).
Most published reports on nitrogen deficiency mention Kjeldahl-N as between 3 and 6% in dry matter. Lower values are sometimes reported for outdoor lettuce. The optimum is 3 to 3.5% N (19). The lowest concentration on record is 0.8% for lettuce in pots under glass (114).

Incidence In various soils with insufficient nitrogen fertilizer, particularly in coarse-textured soils watered excessively, and on peat blocks if the potting mixture has been leached by rain for long.

Control For coarse-textured soils, subject to leaching, topdress once or twice with a 0.2% solution of calcium nitrate. Spraying is possible but less effective. Water young plants in peat blocks with 30-40 mg N per plant in a 2% solution of calcium nitrate and wash residues off plants afterwards.

Fig. 5 Phosphorus deficiency in lettuce (cv. Valore) from an experimental plot in a commercial glasshouse.

Phosphorus deficiency

Symptoms Plants are stunted but show no clear symptoms. They head late, if at all, looking flat and rosette-like. Older leaves die in severe cases. Cultivars with anthocyanin have purple or red tints. The literature gives similar descriptions. According to cultivar, leaves may be dark-green, purple or reddish-bronze (cos lettuce; 33).

Crop analysis Growth is stunted with less than 1.5% P_2O_5 in dry matter; concentrations are not lower than 0.5% P_2O_5. Optimum is 1.9, 2.2 and 2.6% P_2O_5 on acid, calcareous and peaty soils, respectively (87, 92).
Published values for outdoor lettuce are usually lower: 0.9% P_2O_5 when poorly supplied with phosphate and 1.2% P_2O_5 when receiving sufficient phosphate (100). For cos lettuce, values are 0.4 and 0.5-0.6% P_2O_5, respectively (33). Healthy half-grown lettuce contains 0.84% P_2O_5 (27). Glasshouse lettuce usually has more. Published criteria of deficiency (0.6-1.3% P_2O_5) and sufficiency (1.3-2.2% P_2O_5) are close to our standards (14, 128).
American workers (73) found a relation between phosphate in mature leaves (1.5-2.5% P_2O_5) and growth rate but Dutch cultivars showed no such relation.

Incidence In newly-erected glasshouses on poor arable soils, on ploughed grassland unless enough fertilizer is supplied, on soils levelled by excavating or pumping in mud or sand (90), and on peat blocks unless dunged or dressed with inorganic phosphate.

Control Apply phosphate fertilizer, on levelled soils at least 10 kg P_2O_5 per 100 m^2 as triple superphosphate or dicalcium phosphate. For young plants on peat blocks, apply a 2% solution of triple superphosphate or polyphosphate (100-200 mg P_2O_5 per plant). Wash residues off plants afterwards. After planting out, the soil may be watered with phosphate, but base dressing is more efficient.

Fig. 6 Potassium deficiency in lettuce (cv. Noran) from an experimental plot in a commercial glasshouse.

Fig. 7 Potassium deficiency in cos lettuce (cv. Romaine Grise Maraichère) grown on sphagnum peat.

Potassium deficiency

Symptoms No obvious symptoms though moderate lack of potassium reduces growth. Leaves are less crinkled and darker-green than normal. With severe deficiency they become petiolate, more rounded or heart-shaped, (older leaves) and mottled dark-green. Chlorotic spots develop in the tips of older leaves, coalesce later and may become necrotic. Cultivars with anthocyanin have purple leaf margins.
According to the literature symptoms are usually unclear: erect loose growth (45), necrosis without serious decline in growth (131, 132) and an abnormal stem length in cos lettuce (33).

Crop analysis Potassium-deficient lettuce contains 0.9-2.5% K_2O in dry matter; with concentrations below 5% K_2O, growth is reduced. Heavy rates of potash may raise leaf potassium to 11-12% K_2O.
Published values are from 1.6 (97) to 14.1% K_2O (57). Concentrations of 1.5% K_2O for half-grown butter-head lettuce (28) and 4% K_2O for cos lettuce (33) are suboptimal. Optimum levels are 2.1% outdoors (19) and 6-13% K_2O under glass (47).

Incidence In young plants on sphagnum peat without inorganic potassium fertilizer or dung, in newly built glasshouses on poor soils, in older glasshouses if fertilization is neglected, and especially if planted out with naked roots. In commercial glasshouses, potassium deficiency is rare, as the nutrient is generally applied in liberal amounts in a rotation with crops more responsive than lettuce.

Control Apply dung or 3 kg K_2O per 100 m^2 and double the rate on potassium-fixing clays. To cure deficiency, apply 3 kg K_2O per 100 m^2 by sprinkling with a 0.2% solution of potassium nitrate or, for seedlings in peat blocks, a more concentrated solution, if plants are washed afterwards. Spraying with potassium sulphate (2%) is less effective. Sprays with potassium chloride (1%), twice weekly, are recommended (48).

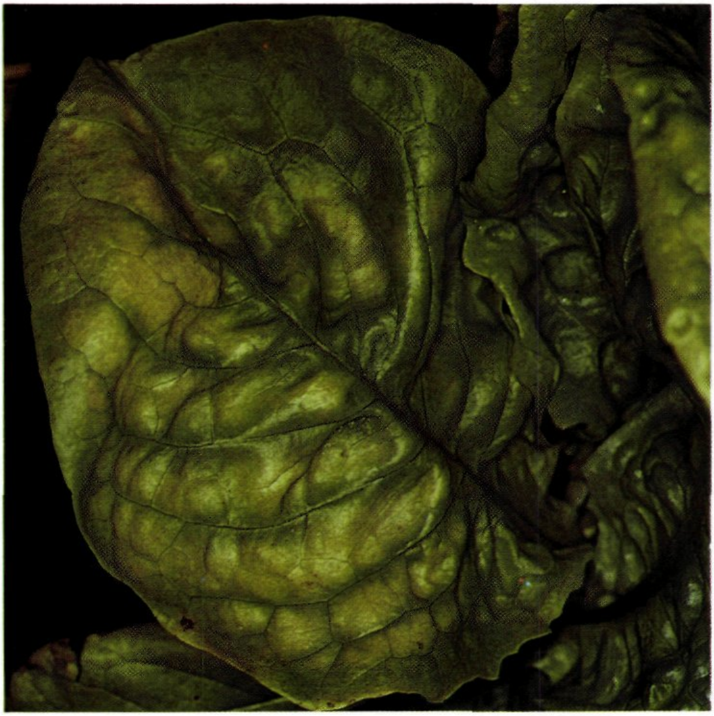

Fig. 8 Magnesium deficiency in lettuce (cv. Rapide) grown in water culture.

Magnesium deficiency

Symptoms Older leaves show a yellow discoloration, which spreads from the leaf edges inward between veins, also including smaller veins. Later the leaf becomes mottled. In water culture, symptoms first developed in younger leaves. Growth is only slightly stunted. In cultivars with anthocyanin, chlorotic areas show a purple flush, especially in older leaves. In acute deficiency, growth becomes severely stunted and the chlorotic areas die.
Published descriptions are similar.

Crop analysis Plants with marked deficiency symptoms and stunted growth contain 0.08-0.17% MgO in dry matter. Malnutrition symptoms may occur with less than 0.6% MgO, but with this content there is generally no distinct dwarfing. In healthy heads the concentration is 0.4-0.8% MgO.
The published data supply similar or somewhat higher values (1-1.5% MgO). Starved cos lettuce contains 0.2-0.4% MgO and a healthy crop 0.5-1.5% MgO (33). The highest value on record is 5.4% MgO (34).

Incidence In practice, magnesium deficiency is mainly ascribed to poor root development in cold and wet soils. The cultivar 'Proeftuins Blackpool' seems susceptible (16).

Control Cultivation methods should be designed to promote root growth. For prevention, apply dolomite when liming, or kieserite. In acute deficiency, apply up to 10 kg Epsom salt per 100 m^2, preferably sprinkled as a 1% solution. As with other crops, a good supply of nitrate is essential. High or low volume spraying with a 2% and 10% solution of Epsom salt respectively, is also possible. This treatment should be repeated a few times.

Fig. 9 Calcium deficiency in lettuce (cv. Rapide) grown in water culture.

Calcium deficiency

Symptoms Growth is severely stunted, the plant looking flat and the leaves having an open rosette growth. Growth restriction is severest in the youngest leaves that are somewhat darker and more crinkled than normal. Irregularly shaped brown to grey lesions develop in the margins of the youngest leaves and spread to older ones. They coalesce, causing leaves to die from the tips and margins inward. The dead leaf tissue is greyish green in colour. A light purple discoloration was sometimes observed in the middle leaves of cultivars with anthocyanin.
One author (110) gives a similar description, others (115, 120, 132) mention no distinct symptoms. Brown lesions and curling of the leaf edges are sometimes reported (56, 122). Starvation symptoms mentioned for cos lettuce are somewhat different (33). One author (46) ascribes tipburn to calcium deficiency. Calcium-deficient lettuce is very susceptible to *Botrytis* (35, 120, 122, 127).

Crop analysis Lettuce with abnormally stunted growth contains 0.3-0.9% CaO in dry matter. Plants restricted in growth, but with no further symptoms, contain 1.3-1.8% CaO and normal ones 1.5-2.5% CaO.
Lower values are reported for lettuce grown outdoors. In cos lettuce, concentrations of less than 0.8% CaO are considered deficient, those of 0.8-2.2% CaO sufficient (33, 115).

Incidence Calcium deficiency is unknown in practice, but may occur in young plants raised on sphagnum peat if no lime is added. Bad patches occurring in crops growing on lime-deficient soils may be caused by manganese and aluminium toxicity, or molybdenum deficiency.

Control For prevention, apply about 4 kg lime per m^3 oligotrophic peat. In glasshouse soils a minimum reserve of 0.2% calcium carbonate is favourable. Curing the deficiency is not considered feasible. If large acid patches occur it is better to discard the old crop and, after liming the soil, replant.

Fig. 10 Sulphur deficiency in lettuce (cv. Vitesse) grown in water culture.

Sulphur deficiency

Symptoms The whole plant, particularly the heart, turns greenish-yellow and growth is restricted. Leaves are less crinkled, thicker and stiffer than normal, and the older leaves have a dull appearance. Cultivars containing anthocyanin sometimes show a pale purple flush in the leaf edge and the tissue surrounding the smaller veins. Growth of 'Iceberg' lettuce is stunted and the entire plant is slightly chlorotic, which is not observed in cos lettuce.

Crop analysis Lettuce with deficiency symptoms has 0.03-0.11% sulphate-S and 0.14-0.26% total-S in dry matter. Healthy plants contain 0.15% sulphate-S and 0.4% total-S.
The concentrations reported in literature vary from 0.25-0.39% total-S. One publication (20) mentions an increase in total-S from 0.17 to 0.35% as a result of air pollution.

Incidence Sulphur deficiency is unknown in commercial glasshouses. It may be found in areas far from industrial pollution if only sulphur-free fertilizers are used (109).

Control Apply sulphur-containing fertilizers.

Fig. 11 Boron deficiency in lettuce (cv. Vitesse) grown in water culture.

Fig. 12 Boron deficiency in cos lettuce (cv. Romaine Grise Maraichère) grown in water culture (older leaves removed).

Boron deficiency

Symptoms Plants are darker than normal and severely stunted. Butterhead lettuce is rosette like. Leaves, especially the youngest ones, are stiff and rounded with chlorotic mottling at the edges and between the veins. Cultivars with anthocyanin are discoloured purplish-brown. Brown spots develop at the growing point and in the youngest folded leaves. In acute deficiency the growing point dies. Roots develop extremely poorly. Dwarfing and a dark colour are characteristic of boron-deficient 'Iceberg' and cos lettuce.
Various authors give similar descriptions and in one reference (65) diversity of boron deficiency symptoms is specially mentioned. The exudation of latex, causing the brown spots (112), may be influenced by climate. We observed brown spots especially in spring. Boron deficiency may be mistaken for tipburn, especially latex-tipburn (9, 29, 66, 112).

Crop analysis Boron-deficient lettuce heads contain 6-10 ppm and normal ones 32-37 ppm B in dry matter.
According to published data, the minimum sufficiency level is 20-23 ppm B (55, 61), whereas healthy plants contain normally 25-50 ppm B. Some authors give lower concentrations, with 6 ppm B as a minimum (6) without mentioning growth abnormalities. Higher values have been reported (up to 177 ppm B) for plants affected by manganese toxicity and other disorders (31).

Incidence In the Netherlands boron deficiency in lettuce is unknown in commercial glasshouses. It may occur in glasshouses after excessive liming of sandy soils dressed with much oligotrophic peat and little or no dung. Boron deficiency may occur in young plants raised on sphagnum peat, but this has not yet been observed.

Control For prevention, apply borax, but only on the basis of soil analysis. To cure deficiency, distribute evenly 200 g borax per 100 m^2 and spray a 0.1% solution.
In published reports (1, 2, 29, 81) 90 to 330 g borax per 100 m^2 are recommended. Oligotrophic peat should receive 10 g borax per m^3.

Fig. 13 Copper deficiency in lettuce (cv. Deci-Minor) grown in water culture.

Fig. 14 Leaves of a copper-deficient lettuce plant (cv. Deci-Minor) grown on sphagnum peat.

Copper deficiency

Symptoms The plant lacks firmness and growth is reduced. Leaves are narrow and cupped, and as chlorosis develops along the edges, they curl downward. Later, the leaves yellow and wilt from the outer edge and tip inward to the base, the veins turning pink. Symptoms progress from older to younger leaves. No heads are formed.
This description agrees with published data.

Crop analysis Copper-deficient plants contain less than 2 ppm and normal plants 7-17 ppm Cu in dry matter.
Concentrations between 1 and 60 ppm Cu are mentioned in literature with 7-10 ppm Cu as the optimum level (54, 67).

Incidence Copper deficiency is unknown in glasshouses. In trials it was noticed in young plants growing on sphagnum peat with no copper added.

Control Add 10 g copper sulphate or 150 g copper slag (1.5% Cu) per m^3 oligotrophic peat as a precaution. Copper sulphate may be sprayed at concentrations up to 0.1%.

Fig. 15 Manganese deficiency in lettuce (cv. Noran) grown in water culture.

Manganese deficiency

Symptoms The entire plant turns greenish-yellow but growth is only slightly stunted. Leaves are smoother than normal. 'Iceberg' and cos lettuce are yellowish-green in colour. With acute deficiency the older leaves especially become chlorotic, but the veins, including the smallest ones, remain green. Cultivars with anthocyanin show no red discoloration.

These symptoms agree fairly well with the scarce data in literature. One author (56) mentions asymmetrical leaves with necrotic spots in the margins and hollow midribs. However, the latter symptom also occurs in older leaves of normally growing plants.

Crop analysis Plants with manganese deficiency symptoms contain 6-14 ppm Mn in dry matter, whereas healthy heads have 16-150 ppm. Concentrations reported are of the same order as those presented here, ranging from 1-169 ppm Mn, but no attention is paid to symptoms (6). Old leaves have a much higher manganese content than young ones (31, 116). Steaming the soil may considerably raise plant manganese (42), see also p 39.

Incidence Manganese deficiency may occur on calcareous loam and clay soils and on excessively limed sand or peat soils. In practice the extent of the disorder is unknown.

Control High volume spraying with a 0.1% or low volume spraying with a 1% solution of manganese sulphate will cure the deficiency. A dressing of 2 × 2½ kg manganese sulphate per 100 m^2, with or without sulphate of ammonia, may be applied using a sprinkler irrigation system.

Fig. 16 Molybdenum-deficient lettuce plant (cv. Deciso) grown in a peat block.

Fig. 17 Leaves of a molybdenum-deficient lettuce plant showing necrotic spots.

Molybdenum deficiency

Symptoms Young plants turn pale green, the cotyledons remaining somewhat darker. Leaves wither from the tip and margins inward, the dying tissue assuming a brownish-yellow colour. Transparant spots which later become necrotic and coalesce may appear in older plants. These symptoms progress from the older to the younger leaves which stay alive longest. Growth of both foliage and roots is severely stunted and plants may collapse entirely.
Similar descriptions are given in literature.

Crop analysis Young plants with distinct starvation symptoms contain 0.3 ppm and healthy plants 2.3-3.7 ppm Mo in dry matter. In literature the sufficient or optimum levels given vary widely, i.e. from 0.03 to 3.2 ppm Mo (54, 77, 78). A concentration of about 70 ppm Mo is considered toxic (122). However, another author (54) found 280 ppm Mo in lettuce showing only a slight decline in yield. Young plants contain considerably more molybdenum than mature ones (84).

Incidence In the Netherlands and other countries in Western Europe molybdenum deficiency was not recognized until 1968, although the symptoms had often been described. In the autumn of 1968 there was a wide-spread occurrence of 'wilting leaves' in young plants raised on blocks of oligotrophic peat (cf. 13, 113). We found molybdenum shortage to be the cause of this problem. The disorder is promoted by a low pH and a high sulphate content of the growth medium (69). As the pH effect is very strong, molybdenum deficiency is sometimes mistaken for calcium deficiency. Growth restriction is reported to be more serious in winter than in autumn or spring, probably as a result of a difference in light intensity (84).

Control For prevention, lime the soil and apply 5 g ammonium or sodium molybdate per m^3 potting soil (89); other authors (75, 84) recommend 2-3 g of these fertilizers. In acute deficiency, apply 15 g ammonium or sodium molybdate per 100 m^2 in ample water. Spraying a 0.05% solution of these fertilizers is also possible.

Fig. 18 Iron deficiency in lettuce (cv. Noran) grown in water culture.

Fig. 19 Iron deficiency in lettuce (cv. Magiola) grown in water culture.

Iron deficiency

Symptoms The whole plant turns pale green and growth is stunted. Older leaves are mottled as the veins, especially the larger ones, are less chlorotic than the interveinal tissue. In more advanced stages the youngest leaves particularly turn pale yellow and the veins become chlorotic too. Growth stops completely and the oldest leaves die. Usually, leaves are less crinkled than normal, which also occurs in 'Iceberg' lettuce. In cultivars with anthocyanin a purple flush was noticed in the youngest leaves affected by acute iron deficiency.
These symptoms agree with the scarce data in literature (33). One report mentions a crinkled foliage (56).

Crop analysis Lettuce plants with distinct iron deficiency symptoms have 93-604 ppm and healthy plants 130-1468 ppm Fe in dry matter. According to published data (67) 36-82 ppm Fe in dry matter is optimum. The lowest value reported is 9 ppm (6) and the highest 632 ppm Fe (67), but no mention is made of malnutrition symptoms. Iron concentration increases with leaf age (31).

Incidence Deficiency may occur on calcarous soils of bad structure. There are no known quantitative data as to its occurrence in practice.

Control For curing the deficiency, apply (experimentally) chelates: 5-10 g Fe-EDDHA or 12-20 g Fe-DTPA per m^2.

Fig. 20 Zinc deficiency in lettuce (cv. Deci-Minor) grown in water culture.

Fig. 21 Lettuce leaf showing zinc deficiency (Bottom part and right hand top of the leaf were shaded by other leaves during growth).

Zinc deficiency

Symptoms Affected plants have a rosette appearance and growth is restricted. At first no chlorosis develops. Later, large papery necrotic spots with a dark margin appear along leaf edges, especially in the inverveinal tissue. As leaf areas not exposed to light remain green and fresh, the plant looks typically 'scorched'. The symptoms commence in older leaves and progress to the younger ones.
According to the only report in literature (56) known to us, zinc deficiency delays growth but noticeable symptoms are lacking.

Crop analysis Zinc-deficient plants contain 12 ppm and healthy plants 30-330 ppm Zn in dry matter.
According to American data (101, 133) zinc concentrations lie normally between 60 and 120 ppm; in Israel (83) values from 14 to 32 ppm Zn have been found.

Incidence Zinc deficiency in crops grown outdoors is only known in some parts of the world. Glasshouse lettuce is unlikely to show deficiency symptoms.

Control To cure the deficiency, spray a 0.05% solution of zinc sulphate.
Published data (56) recommend zinc sulphate sprays (0.09% solution) or soil application (1 kg per 100 m^2).

Fig. 22 Excess nitrogen in lettuce (cv. Rapide) grown on sphagnum peat (for comparison, part of a normal plant to the right).

Excess nitrogen

Symptoms Plants are dark or greyish green and have a rosette appearance. Growth is inhibited. Leaves are small, rounded and more crinkled than normal, and resemble spinach leaves. In cultivars with anthocyanin, the margins of younger leaves may turn red. The symptoms are like those caused by excess (sodium) chloride. In trials, tipburn is sometimes associated with higher nitrogen dressings. However, crops with growth reduced by excess nitrogen are less susceptible to tipburn (107).
There are few literature references, but one mentions a dark leaf colour (93).

Crop analysis Plants showing symptoms of nitrogen excess only had nitrate and Kjeldahl-N concentrations a little higher than plants with optimum nitrogen supply. Nitrogen contents are influenced by date of picking.
Kjeldahl-N may be lowered by applying excessive nitrogen (93).

Incidence Symptoms occur on soils rich in readily soluble nitrogen, especially if insufficiently watered.

Control For curing the toxicity, apply ample water.

Fig. 23 Boron toxicity in lettuce, grown in sand culture.

Fig. 24 Detail of a leaf showing boron toxicity.

Excess boron

Symptoms Along the edges of older leaves brownish-grey sunken spots develop into a ring-shaped pattern, with dark brown veins (perceptible when holding the leaf against a beam of light). As the toxicity becomes more severe, the spots coalesce and desiccate, making the tissue of the entire leaf tip papery to touch. Symptoms start in older and progress to younger leaves, the youngest ones continuing to grow more or less normally.
The brief description in literature agrees with these symptoms. However, chlorosis in older leaves (56) was not observed.

Crop analysis Lettuce affected by boron toxicity has 40-200 ppm B in dry matter depending on the severity of the symptoms.
In literature references (15, 61) a critical level of 60 ppm B is stated.

Incidence Toxicity is easily caused by applying too much boron fertilizer and, therefore, great care should be taken in using these materials.

Control Slight toxicity symptoms may be suppressed by watering heavily. In severe cases, discard the crop and leach the soil. Additional measures are liming or applying large quantities of (limed) oligotrophic peat.

Fig. 25 Manganese toxicity in lettuce (cv. Noran) of an (unsteamed) experimental plot with low pH in a commercial glasshouse.

Fig. 26 Manganese toxicity in lettuce (cv. Deci-Minor) grown in water culture.

Excess manganese

Symptoms The veins, particularly the smaller ones, of older leaves turn brown. Leaves may show severe marginal chlorosis and very small necrotic spots develop, especially in the leaf tip and the margins of the leaf base. The spots coalesce into larger ones, causing leaves to desiccate from the margins inward. As older leaves die and younger leaves are stunted the developing head is loose and tulip-shaped.
These symptoms are supported by literature findings, although necrotic spots and, sometimes, chlorosis (106) are more emphasized than brown veins. Symptoms and susceptibility vary with cultivar. Yellowing of leaf margins is reported for cos lettuce (34).

Crop analysis Manganese toxicity is found in lettuce containing more than 200 ppm Mn in dry matter, but distinct symptoms occur with more than 300 ppm Mn.
The above concentrations are in accordance with published data. One publication (31) reports 180 and 550 ppm Mn, another (116) 730 and 2375 ppm Mn, for young and old leaves respectively. It is possible that toxicity symptoms in cos lettuce do not appear until leaf manganese is in the 600-1600 ppm range (34).

Incidence Steaming of clay and loamy soils releases much plant-available manganese which may induce toxicity, especially at low pH. On very acid soils the disorder may also occur without steaming. Crops grown in summer and autumn are more susceptible than those grown in winter.

Control For prevention, lime the soil. Possibly, steam-air mixtures of lower temperatures will be used in the future.

Fig. 27 Zinc toxicity in lettuce (cv. Deci-Minor) grown in water culture.

Fig. 28 Zinc toxicity in 'Iceberg' lettuce (cv. Great Lakes) grown in water culture.

Excess zinc

Symptoms The plant shows a brownish-yellow flush and growth is stunted. Sometimes red-brown spots develop on the main veins and the surrounding leaf tissue, especially in middle leaves. With acute toxicity, leaves are cupped and erect and no head is formed. The oldest leaves are affected most, whole leaves yellowing, wilting and dying. Chlorosis and wilting of older leaves are also mentioned in the only publication (56), known to us.

Crop analysis Plants affected by zinc toxicity contain 520-639 ppm Zn in dry matter.

Incidence Zinc toxicity has not been observed in practice.
Soil-borne zinc toxicity may occur near zinc and metallurgic factories (32). In literature (82) zinc toxicity in crops grown in pots in galvanized cages is reported. Similarly, the disorder might occur in glasshouses with galvanized frames.

Control Apply lime and phosphate to reduce availability of soil zinc.

Fig. 29 Aluminium toxicity in lettuce (cv. Deci-Minor) grown in water culture.

Fig. 30 Aluminium toxicity in cos lettuce (cv. Romaine Frise Maraichère) grown in water culture.

Excess aluminium

Symptoms Plants have a rosette appearance and growth is severely restricted. Leaves are erect and more crinkled and oval than normal. Younger leaves are dark green, but may become chlorotic later. Older leaves show intensive yellowing and eventually die.
The few references mention similar symptoms, one author (104) describing leaves standing upright like tulip petals ('tulip disease').

Crop analysis Normal heads contain 32-105 ppm Al, whereas plants with toxicity symptoms have 160-240 ppm Al in dry matter.
One publication (40) states 7 ppm Al for normal plants. Another report (31) mentions 66 ppm in older leaves of a healthy crop and 354 ppm Al in the case of aluminium toxicity. In cos lettuce concentrations ranging from 39-120 ppm Al are found, and liming the soil has no effect (34).

Incidence In the Netherlands aluminium toxicity is not known in practice.
In may be one of causes of the 'soil acidity complex' (36, 116). In Belgium it is supposed to be the cause of 'tulip disease' (104).

Control For prevention, lime the soil. Applying extra phosphate may also be favourable (56).

Chemical composition of healthy lettuce heads, grown under glass.

		References
% of fresh weight		
dry matter	3.5 - 5.5	
% of dry matter		
N	4.5 - 6.0	
nitrate-N	0.8 - 2.4	
P_2O_5	1.8 - 3.0	
K_2O	5.0 - 12.0	
MgO	0.6 - 1.5	
CaO	1.5 - 3.0	
S	0.2 - 0.4	
sulphate-S	0.1 - 0.2	
Na_2O	0.1 - 1.5	
Cl	1.0 - 3.5	
SiO_2	0.1 - 18.5	(59)
ppm of dry matter		
B	25 - 40	
Cu	7 - 17	
Mn	20 -200	
Mo	1 - 4	
Fe	100 -600	
Zn	30 -300	
Al	30 -100	
Co	0 - 6	(6, 11)
As	0.12- 3.9	(11)
Pb	3.9 - 4.6	(11)
Ba	70	(11)
I	1.6 - 6.7	(56)
F	1 - 5	

Key to references

Nitrogen deficiency
Symptoms 26, 33, 45, 56, 70, 117, 118, 120, 130, 132.
Crop analysis 3, 10, 14, 19, 21, 22, 25, 33, 51, 53, 57, 59, 76, 87, 88, 91, 92, 96, 97, 98, 100, 101, 102, 107, 114, 124, 133, 134.

Phosphorus deficiency
Symptoms 14, 24, 26, 33, 45, 56, 70, 117, 118, 120, 131, 132.
Crop analysis 3, 6, 7, 14, 21, 22, 23, 24, 25, 27, 30, 31, 33, 34, 40, 51, 53, 57, 59, 73, 74, 76, 85, 87, 88, 91, 92, 96, 97, 98, 100, 101, 107, 114, 124, 128, 133, 134.

Potassium deficiency
Symptoms 26, 33, 44, 45, 48, 56, 70, 117, 118, 120, 127, 129, 132.
Crop analysis 3, 6, 7, 14, 19, 21, 22, 25, 28, 31, 33, 34, 40, 47, 51, 53, 57, 59, 74, 76, 85, 87, 88, 91, 92, 96, 97, 98, 100, 101, 107, 114, 115, 124, 127, 133, 134.

Magnesium deficiency
Symptoms 5, 33, 41, 45, 56, 70, 120, 132.
Crop analysis 3, 6, 7, 14, 21, 22, 31, 33, 34, 40, 47, 57, 59, 76, 87, 88, 91, 92, 97, 98, 100, 101, 107, 115, 124, 133, 134.

Calcium deficiency
Symptoms 33, 35, 46, 56, 110, 115, 120, 122, 132.
Crop analysis 3, 6, 7, 14, 21, 22, 23, 24, 25, 30, 31, 33, 34, 40, 46, 47, 51, 53, 57, 59, 76, 87, 88, 91, 92, 97, 98, 100, 101, 107, 114, 115, 124, 133, 134.

Sulphur deficiency
Crop analysis 7, 20, 100, 107.

Boron deficiency
Symptoms 1, 2, 9, 12, 29, 49, 56, 60, 61, 65, 66, 81, 109, 110, 121.
Crop analysis 6, 15, 31, 40, 49, 55, 61, 62, 124.

Copper deficiency
Symptoms 2, 17, 56, 75, 109.
Crop analysis 6, 31, 40, 54, 67, 101.

Manganese deficiency
Symptoms 56, 70, 120.
Crop analysis 6, 31, 34, 40, 42, 52, 71, 95, 101, 106, 116, 124.

Molybdenum deficiency
Symptoms 2, 8, 37, 38, 56, 68, 70, 72, 75, 77, 78, 80, 84, 119, 121, 122, 126.
Crop analysis 6, 18, 42, 43, 54, 77, 78, 79, 80, 84, 99, 108, 122, 124.

Iron deficiency
Symptoms 33, 56.
Crop analysis 6, 31, 34, 40, 50, 67, 71, 85, 101, 124.

Zinc deficiency
Symptoms 56.
Crop analysis 83, 101, 133.

Excess nitrogen
Symptoms 56, 93.
Crop analysis 93.

Excess boron
Symptoms 4, 15, 56, 61, 66, 125.
Crop analysis 15, 61.

Excess manganese
Symptoms 8, 34, 36, 56, 64, 80, 105, 116, 123, 125.
Crop analysis 31, 34, 42, 58, 63, 64, 80, 105, 106, 116, 123.

Excess zinc
Symptoms 56.

Excess aluminium
Symptoms 36, 56, 104, 116.
Crop analysis 31, 34, 40.

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