

TRACE NUTRIENT REQUIREMENTS OF SOME PLANT SPECIES ON PEAT SUBSTRATES

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ABSTRACT

In pot experiments responses of lettuce and tomato on pure peat substrates to added lime and trace nutrients were studied. Peat substrates included moss peat (slightly decomposed young *Sphagnum*) and 'black peat' (humified old *Sphagnum* with some *Eriophorum*, *Carex* and *Phragmites*), exposed to frost after cutting. Responses to each minor nutrient were determined in the presence of 'optimum' levels of all other minor nutrients and standard dressings of major nutrients applied to all pots. The main effects were lime, copper, boron and molybdenum. Interactions with lime were positive for copper and boron, and negative for molybdenum. Best all-round results for lettuce were obtained with additions (per 1.2-litre pot) of 3 mg copper sulphate, 1.2 mg borax and 2.4 mg sodium molybdate at pH-H₂O 5.1 (5.0), following application of 5 and 10 g calcium carbonate on moss peat and 'black peat' respectively. Optimum overall treatments for tomato were: 6 mg copper sulphate, 0.6 mg (moss peat) and 2.4 mg borax ('black peat'), 2.4 mg sodium molybdate, and lime additions equal to those for lettuce.

The effectiveness of multi-nutrient fritted (FTE) versus straight trace element fertilizers was tested with chrysanthemum grown on 'black peat'. FTE 32 (1.89% Cu, 0.16% B, 1.26% Mo, 1.0% Mn, 1.86% Zn, 2.66% Fe) proved at least as effective as straight fertilizers in supplying copper, boron and molybdenum, 78 mg per pot (1.2 litre) being optimum. The effects of the other components of FTE were not demonstrated as no responses to these nutrients (given as straight fertilizers) occurred.

INTRODUCTION

Peat is widely used as a growing medium for propagating plants (Roorda van Eysinga, 1965; Woods and Kenny, 1968). It meets the properties required for good growing media: good aeration, good moisture retention, good chemical buffering capacity, few soil-borne diseases and weeds, light weight. In the Netherlands two main types can be distinguished: moss peat (slightly decomposed young *Sphagnum*) and "black peat" (humified old *Sphagnum* with some *Eriophorum*, *Carex* and *Phragmites*) remaining after cutting away the peat moss layer. "Black peat" is less suitable as a substrate because of shrinkage reducing re-absorption of water. However, this can be overcome by exposing the fresh material to frost during the winter (Van Dijk and Boekel, 1965). Both types of peat have been formed under oligotrophic conditions and, therefore, require lime and mineral fertilizers in order to support plants.

The present work, carried out in the period 1968-1970, deals with minor nutrient requirements of lettuce and tomato, i. e. crops commonly raised on peat blocks in the Netherlands, at various pH levels of the pure peat substrate. It was also felt convenient to study the effectiveness of a fritted (multiple) trace element fertilizer (FTE). Fritted trace elements (finely ground glasses, obtained by mixing and smelting silicates and minor element oxides under controlled conditions) are reported to be less phytotoxic than straight salts at high rates (Bunt, 1965). Multiple (low-analysis) fertilizers have also the advantage of being more uniformly distributed in potting substrates than straight (high-analysis) fertilizers that are only needed in small quantities.

EXPERIMENTAL METHODS

The responses of lettuce (cv. Deciso and Noran) and tomato (cv. Eurocross) on pure peat substrates to added trace nutrients and lime were studied in pot experiments in a glasshouse. One week after sowing four plants were planted in each 1,2 litre polythene pot and harvested about four weeks later.

Pots contained 120 g of dry moss peat (maximum water capacity [g water per 100 g dry material] 1250 g) or 220 g of dry 'black peat' (maximum water capacity 660 g) and 60-80% of the water capacity of the substrate was aimed at, depending on the growth stage of the crop. Moss peat (pH-H₂O 3.3) contained (total element in mg/kg dry matter) 3.3 Cu, 7 B, 1 Mo, 18 Mn, 44 Zn, 930 Fe and 94% organic matter; 'black peat' (pH-H₂O 3.0) 4.1 Cu, 6 B, 1 Mo, 6 Mn, 68 Zn, 1130 Fe and 97% organic matter.

The experimental design was 2⁴ factorial, with 3 randomized blocks (replications) and sub-blocks for fertilizer treatments, for each substrate.

Applications of the following (analar) chemicals were standard:

1.0 g NH₄NO₃, 0.76 g KH₂PO₄, 0.19 g K₂SO₄, 0.5 g MgSO₄·7H₂O, 12 mg CuSO₄·5H₂O, 2.4 mg Na₂B₄O₇·10H₂O, 4.8 mg Na₂MoO₄·2H₂O, 3.0 mg MnSO₄·H₂O, 6.0 mg ZnSO₄·7H₂O, 18 mg Fe-EDTA (15% Fe) per pot. Plants were watered with demineralized water. The treatments with trace elements (in mg/pot) were: 0, 3, 6, 12 CuSO₄·5H₂O (standard dressing without Cu); 0, 0.6, 1.2, 2.4 Na₂B₄O₇·10H₂O (standard dressing without B); 0, 1.2, 2.4, 4.8 Na₂MoO₄·2H₂O (standard dressing without Mo); 0, 15, 30, 60 MnSO₄·H₂O (standard dressing without Mn); 0, 30, 60, 120 ZnSO₄·7H₂O (standard dressing without Zn); 0, 9, 18, 36 Fe-EDTA (standard dressing without Fe). The treatments with (analar) calcium carbonate (in g/pot) were: 0, 2.5, 5, 10 on moss peat; 2.5, 5, 10, 20 on 'black peat'. The humified 'black peat', because of its higher specific weight, required about twice as much calcium carbonate for a rise in pH of one unit than the less decomposed moss peat (cf. Olsen, 1968).

FTE fertilizer was tested in pot experiments with *chrysanthemum* on 'black peat'. The pots were placed in a cage of plastified wire netting and protected against rain water. Three cuttings were planted in each 1.2 litre polythene pot and harvested after 10 (cv. Gigiletto) or 15 (cv. Giant Yellow Indianapolis) weeks. The experimental design consisted of 3 randomized blocks (replications) with sub-blocks for lime (if variable) and fertilizer treatments. Standard dressings were similar to those for lettuce and tomato, but in the first experiment (cv. Gigiletto) only half the amounts of Cu, B and Mo were applied. Supplemental liquid dressings with NH₄NO₃ and KH₂PO₄ were given.

In the first experiment application of 3.6 g CaCO₃ was standard (pH-H₂O 3.8). FTE 32 (1.89% Cu, 0.16% B, 1.26% Mo, 1.0% Mn, 1.86% Zn, 2.66% Fe) was applied at rates of 0, 19.5, 39, 78, 156 and 234 mg/pot (no

trace elements in the standard dressing). Treatments with $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$, $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$ and Fe-EDTA were similar to those for lettuce and tomato. The second experiment (cv. Giant Yellow Indianapolis) had variable treatments for FTE 32 and all straight trace nutrient fertilizers (at rates similar to those for lettuce and tomato), at two levels of lime (5 and 10 g CaCO_3 /pot; pH- H_2O 4.3 and 5.3).

Shortly after terminating the experiments the substrates were analysed for pH- H_2O , and sometimes for Cu (0.4 n HNO_3) and B (hot H_2O) in a 1:40 v/w extraction ratio. Plant tops were dried, weighed and analysed for Cu, B, Mo, Mn, Fe (spectrophotometrically) and Zn (by atomic absorption), as far as the plants were treated with these nutrients.

RESULTS

Lettuce

Copper deficiency symptoms (yellowing and wilting leaves with edges curling downward and veins turning pink) occurred in plants on moss peat not given copper fertilizer. Symptoms of molybdenum deficiency (leaves with transparent spots withering from the tip and margins inward and turning brownish-yellow) were observed on either substrate without added molybdenum aggravating with increasing acidity from pH- H_2O 5.1 (5.0) downward. Incidence was more severe on 'black peat' where even plants given 2.4 mg sodium molybdate per pot did not remain healthy at pH- H_2O 3.6.

Dry matter yields of tops for the copper treatments are shown in Figure 1. The response to copper, only occurring at the higher lime levels, was highly significant ($P < 0.01$) on moss peat (pH- H_2O 5.1 or more) but did not reach significance on 'black peat' (pH- H_2O 6.1 or more). Amounts excelling 3 mg copper sulphate gave no further yield increase. Lime had a highly significant effect, pH- H_2O 5.1 (5.0) being optimum. Without applied copper, a further rise in pH significantly ($P < 0.05$) depressed yield on 'black peat'.

Boron had a positive effect on plant growth at the higher lime levels only, as illustrated in Figure 2. The response was only (highly) significant on 'black peat', increasing with lime increments (significant boron x lime interaction). An amount of 1.2 mg borax was adequate for maximum yields. The positive effect of lime was highly significant up to pH- H_2O 4.1, but the

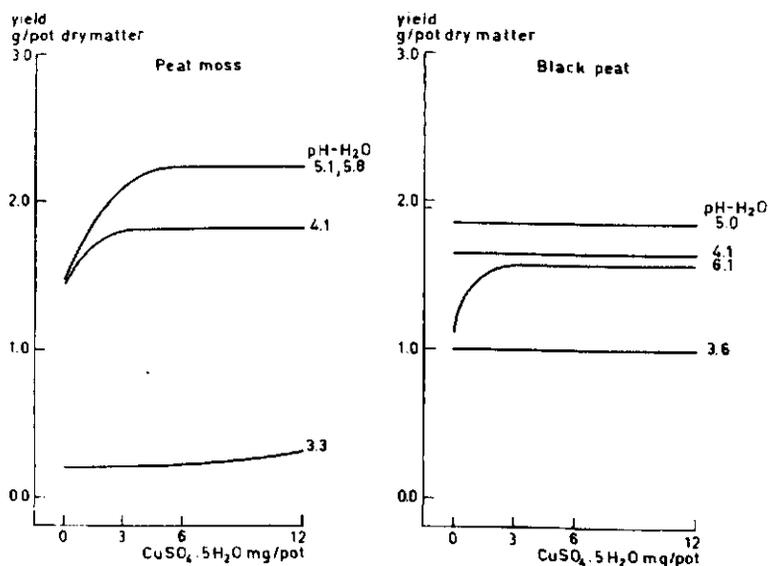


Figure 1. Dry matter yields of lettuce plants (tops) on peat substrates as affected by added copper sulphate and lime (after two-way graphical adjustment).

highest application (pH-H₂O 6.1) depressed yield significantly on 'black peat', particularly so in the absence of applied boron.

Responses to added sodium molybdate and lime were highly significant on either substrate, diminishing with increasing applications of the other material (highly significant molybdenum x lime interaction), see Figure 3. However, the molybdenum effect did not manifest itself in the poorly growing plants on the unlimed moss peat. Molybdenum requirement decreased with rising pH values and did not exceed 2.4 mg sodium molybdate on moss peat. On 'black peat' trends were more extreme, with requirements of 0.0 and more than 4.8 mg sodium molybdate at pH-H₂O 6.1 and 3.6, respectively. With added molybdenum on moss peat maximum yields were obtained at pH-H₂O 5.8, but differences between pH-H₂O 5.1 and 5.8 were not significant without applied molybdenum no pH optimum was reached. On 'black peat' pH optimum was about 5.0 with molybdenum applied, whereas without added molybdenum pH-H₂O 6.1 was still sub-optimum.

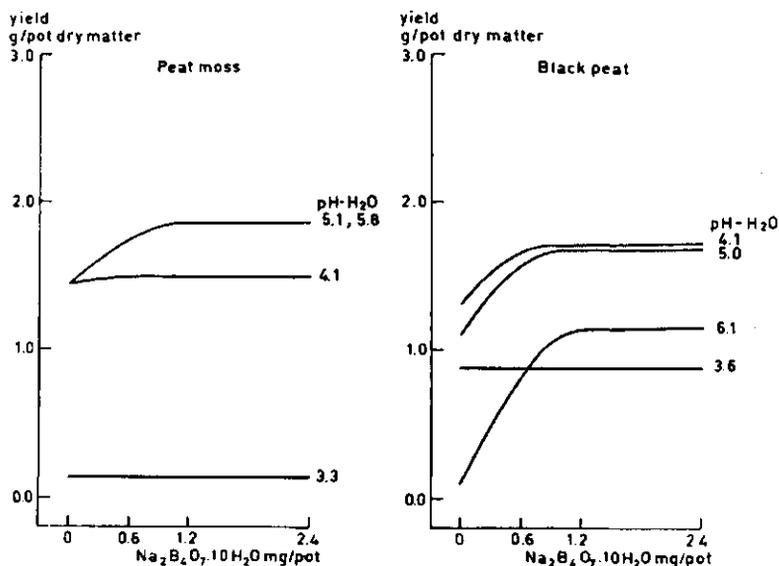


Figure 2. Dry matter yields of lettuce plants (tops) on peat substrates as affected by added borax and lime (after two-way graphical adjustment).

The above results for copper, boron, molybdenum and lime largely confirm those of earlier experiments discussed elsewhere (Smilde and Van Luit, 1972).

Manganese, iron and zinc did not affect growth significantly (data not presented here). Apparently, the high applications of manganese and zinc (see section "Experimental Methods") were still too low to be toxic. In all treatments with these elements lime had a highly significant effect. On moss peat there was no further increase and on 'black peat' even a decrease in yield (especially at the lower levels of iron) beyond pH-H₂O 5.1 (5.0). In earlier experiments manganese had a significant positive, zinc and iron a negative effect at the higher applications of these elements.

Trends for fresh weights were similar to those reported here for dry weights.

Leaf copper, boron and molybdenum clearly reflected treatments with these nutrients (Table I). The same is true for manganese, zinc and iron (data not shown here). Lime depressed leaf boron and, to some extent, copper but raised molybdenum. Manganese, zinc and iron concentrations were maximum at the highest applications of these nutrients and the lower pH values.

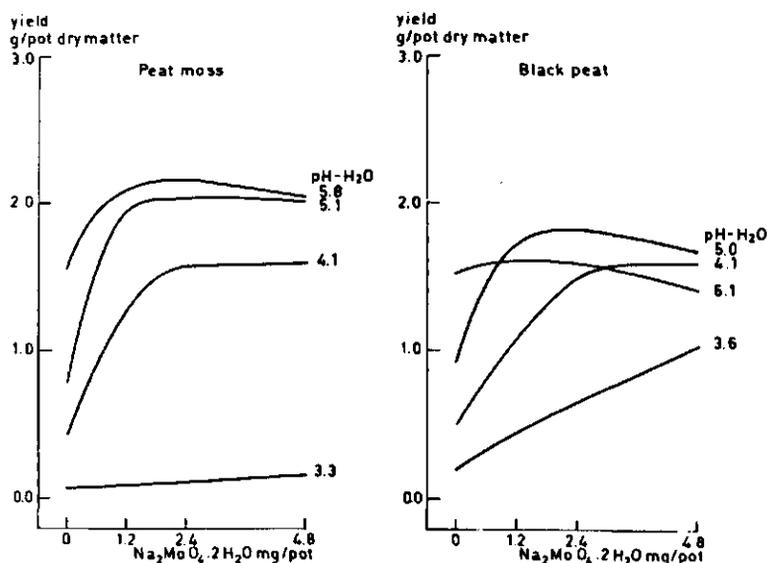


Figure 3. Dry matter yields of lettuce plants (tops) on peat substrates as affected by added sodium molybdate and lime (after two-way graphical adjustment).

Comparison of Figures 1-3 and Table I shows that responses to copper, boron and molybdenum are normally associated with leaf concentrations of less than 3.6 ppm Cu, 16 ppm B and 0.12-0.19 ppm Mo, respectively.

Substrates containing less than 0.5-0.6 mg/litre 0.4 N nitric-acid-extractable Cu were found to be copper-deficient and those with less than 0.13-0.20 mg/litre hot-water-extractable B boron-deficient. These figures are tentative being based on few plant tests. More experience with the extraction procedure is clearly needed.

Tomato

On 'black peat' symptoms of copper deficiency (bluish-green leaves with margins curling into a tube towards the midribs) were observed in plants not given copper fertilizer. Boron-deficient plants (smallest leaflets curling, turning brown and dying; petioles very brittle and fracturing on touching)

TABLE I. Cu, B and Mo concentrations (ppm in dry matter) of lettuce tops (cv. Noran) on peat substrates as affected by applications of copper sulphate, borax, sodium molybdate and lime

| CaCO ₃ , g/pot | CuSO ₄ ·5H ₂ O, mg/pot | | | Na ₂ B ₄ O ₇ ·10H ₂ O, mg/pot | | | Na ₂ MoO ₄ ·2H ₂ O, mg/pot | | | | | |
|------------------------------|--|-----|-----|---|----|-----|---|-----|------|------|------|-------|
| | 0 | 3 | 6 | 12 | 0 | 0.6 | 1.2 | 2.4 | 0 | 1.2 | 2.4 | 4.8 |
| Moss peat ⁺ | | | | | | | | | | | | |
| 0 | 3.3 | 3.3 | 8.0 | 9.4 | - | +++ | - | - | - | - | - | - |
| 2.5 | 2.9 | 4.0 | 6.6 | 6.4 | 21 | - | 20 | - | 0.02 | 0.26 | 0.28 | 0.61 |
| 5 | 3.6 | - | 5.9 | 7.7 | 14 | 22 | 25 | 28 | 0.06 | 0.68 | 2.24 | 5.08 |
| 10 | 1.6 | 3.3 | 4.5 | 6.4 | 8 | 14 | 17 | 24 | 0.06 | 2.42 | 2.74 | 10.03 |
| Black peat ⁺⁺ | | | | | | | | | | | | |
| 2.5 | 1.9 | 3.1 | 2.3 | - | 20 | 31 | 28 | 30 | - | 0.09 | 0.03 | 0.03 |
| 5 | 1.8 | 3.8 | 3.0 | 4.6 | 16 | 19 | 22 | 24 | 0.01 | 0.04 | 0.07 | 0.12 |
| 10 | 2.3 | 4.1 | - | 3.8 | 9 | 12 | 16 | 21 | 0.01 | 0.07 | 0.19 | 0.68 |
| 20 | 2.9 | 2.5 | 3.1 | 3.7 | - | 10 | 13 | 16 | 0.02 | 0.31 | 0.71 | 1.67 |

⁺ pH-H₂O: 3.3, 4.1, 5.1, 5.8, respectively.

⁺⁺ pH-H₂O: 3.6, 4.1, 5.0, 6.1, respectively.

⁺⁺⁺ Too little material or lost.

were found at the highest rate of lime (pH-H₂O 6.3) and borax applications not exceeding 0.6 mg per pot. The lower the rates of applied lime and sodium molybdate, the more severe the incidence of molybdenum deficiency (leaves showing pale-green interveinal mottling and margins curling upward). At pH-H₂O 6.3 symptoms developed temporarily, in plants not given molybdenum fertilizer only. By contrast, at pH-H₂O 3.9 even plants receiving 4.8 mg sodium molybdate per pot were (slightly) affected. Iron deficiency (fine pattern of interveinal chlorosis in terminal leaves) only occurred at pH-H₂O 6.3, in the absence of applied iron.

On moss peat molybdenum deficiency symptoms were less serious than on 'black peat', only appearing in plants not given sodium molybdate; no symptoms occurred at pH-H₂O 6.2 (highest lime rate) and 3.2 (no lime applied). Interestingly, iron deficiency symptoms developed in the poorly growing plants on unlimed moss peat without iron-EDTA added.

Dry matter yields of plant tops in the treatments with copper sulphate are shown in Figure 4. Responses to copper were highly significant on either substrate, increasing with lime increments (highly significant copper x lime

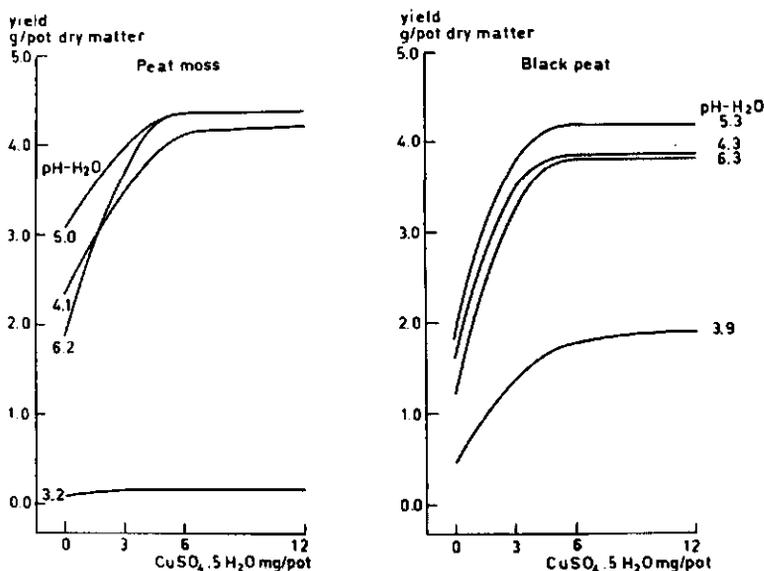


Figure 4. Dry matter yields of tomato plants (tops) on peat substrates as affected by added copper sulphate and lime (after two-way graphical adjustment).

interaction). Application of 6 mg copper sulphate per pot met the crop's requirements. Lime had a highly significant effect, increasing yields up to pH-H₂O 5.0 (moss peat) or 5.3 ('black peat') and subsequently depressing them at higher rates (effect significant in the absence of added copper).

The effect of boron was highly significant on either substrate, increasing with increasing additions of lime (highly significant boron x lime interaction), see Figure 5. At pH-H₂O 4.3 (4.1) or less there was no (significant) response. Application of 0.6 mg borax was sufficient on moss peat,

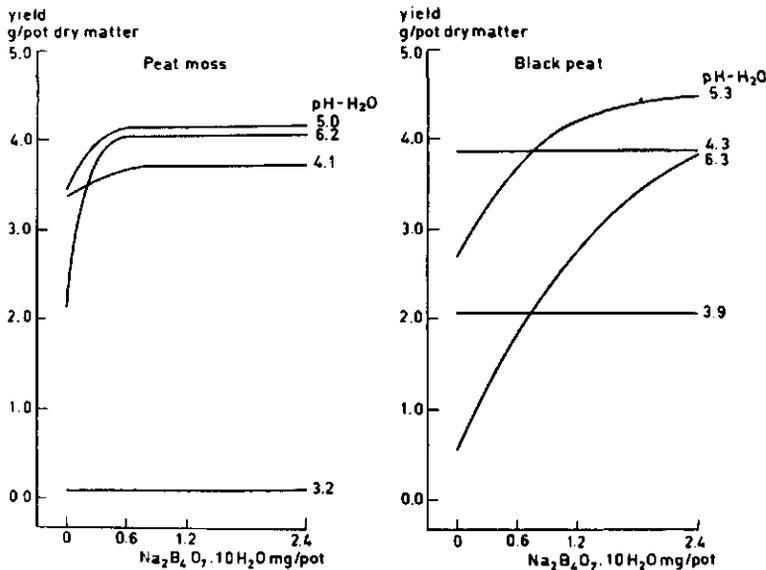


Figure 5. Dry matter yields of tomato plants (tops) on peat substrates as affected by added borax and lime (after two-way graphical adjustment).

but 'black peat' needed at least 2.4 mg for maximum yields. The lower rates of lime had a (highly significant) positive effect, but the higher rates depressed yield significantly, the more so as less boron was applied. Trends were most pronounced on 'black peat'. On this medium distinct pH optima were found, shifting from 5.3 to 4.3 with borax diminishing from 2.4 to 0 mg. On moss peat pH-H₂O 5.0 was optimum at all levels of applied borax and a significant depression at the higher pH occurred with no borax added only.

The (highly significant) responses to molybdenum diminished with increasing lime applications and were nil at pH-H₂O 6.2 (6.3), see Figure 6. Molybdenum x lime interaction was highly significant. On unlimed moss peat plant growth was too poor to reveal any effect. For moss peat addition of 2.4 mg sodium molybdate was enough, but the crops requirements on

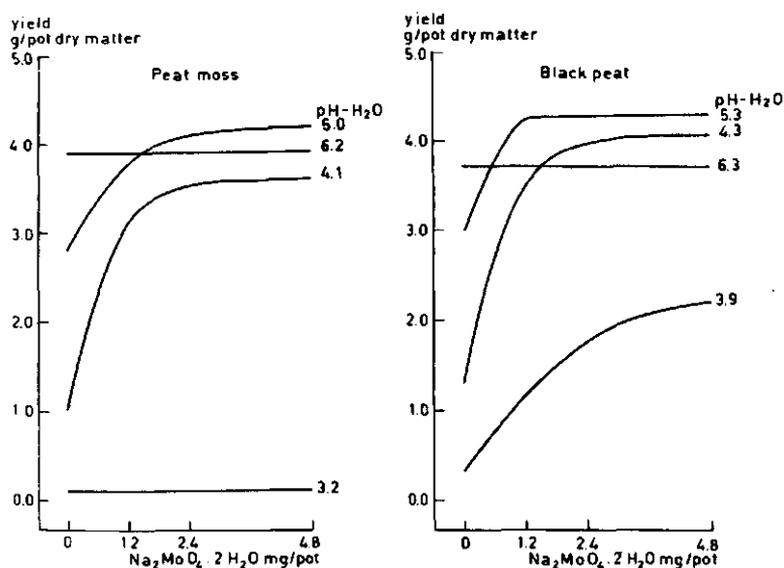


Figure 6. Dry matter yields of tomato plants (tops) on peat substrates as affected by added sodium molybdate and lime (after two-way graphical adjustment).

'black peat' varied distinctly with applied lime from 1.2 to over 4.8 mg sodium molybdate (pH-H₂O 5.3 and 3.9 respectively). Lime affected growth highly significantly. In the presence of applied molybdenum pH-H₂O 5.0 (5.3) gave best results and higher values were detrimental (only significantly so on 'black peat'). Without added molybdenum optimum pH was reached on neither substrate.

Iron raised yields significantly on 'black peat' at the highest rate of lime (pH-H₂O 6.3), but had no effect at lower pH values nor on moss peat (data not presented here). The (positive) manganese effect just reached significance on 'black peat'. Trends for zinc were not marked, in general best results were obtained with the lower applications. In the treatments

with these nutrients the lime effect was highly significant, pH-H₂O 5.0 (5.3) being optimum and higher values depressing yields on 'black peat', specially at the lower additions of iron.

The results recorded here support those of previous experiments. Trends for fresh and dry weights were similar.

Trends in leaf composition (Table II) are similar to those for lettuce and need no further comment. From Figures 4-6 and Table II the following minimum sufficiency levels are derived: 6.9 ppm Cu, 25 ppm B, 0.27 ppm Mo.

Substrates containing, on an average, more than 1.0 mg/litre 0.4 N nitric-acid-extractable Cu and 0.15 mg/litre hot-water-extractable B supplied sufficient copper and boron respectively. The data have the same limitations as in the case of lettuce.

Chrysanthemum

The chrysanthemum experiments were intended to analyse the effects of the various components of FTE 32, deriving the responses to separate trace nutrients from parallel treatments with straight fertilizers.

In the first experiment (cv. Gigoletta) responses to copper, boron, molybdenum and iron were determined in the presence of medium levels of the non-variable minor nutrients (in the standard dressing). As distinct from the treatments with straight fertilizers, the treatment with FTE included no minor nutrients in the standard dressing. At the rate of 78 mg FTE per pot and equivalent rates of straight fertilizers (6 mg copper sulphate, 1.2 mg borax, 2.4 mg sodium molybdate, 18 mg iron-EDTA) all treatments received equal quantities of the various trace elements.

Deficiencies of copper, boron and molybdenum occurred in plants given insufficient amounts of these nutrients. Copper and boron deficiency symptoms included stunting and chlorosis, and boron deficiency sometimes death of the growing point. Molybdenum deficiency was characterized by chlorotic and wilting leaves. Symptoms were controlled with medium rates of straight fertilizers and FTE.

Copper (as copper sulphate) and boron (as borax) increased yield significantly, molybdenum (as sodium molybdate) did so almost significantly, but iron (as iron-EDTA) had no effect (Table III). There were responses to borax and sodium molybdate up to the highest rates applied. Therefore, the low yield maxima in the treatments with copper sulphate and iron-EDTA

TABLE II. Cu, B and Mo concentrations (ppm in dry matter) of tomato tops (cv. Eurocross) on peat substrates as affected by applications of copper sulphate, borax, sodium molybdate and lime

| CaCO ₃ , g/pot | CuSO ₄ ·5H ₂ O, mg/pot | | | Na ₂ B ₄ O ₇ ·10H ₂ O, mg/pot | | | Na ₂ MoO ₄ ·2H ₂ O, mg/pot | | | | | |
|------------------------------|--|-----|-----|---|----|-----|---|-----|------|------|-------|-------|
| | 0 | 3 | 6 | 12 | 0 | 0.6 | 1.2 | 2.4 | 0 | 1.2 | 2.4 | 4.8 |
| Moss peat ⁺ | | | | | | | | | | | | |
| 0 | - | 1.7 | 3.9 | 6.0 | - | - | - | - | - | - | - | - |
| 2.5 | 1.9 | 5.2 | 8.4 | 12.8 | 21 | 30 | 34 | 43 | 0.07 | 0.97 | 2.02 | 3.75 |
| 5 | 2.6 | 6.0 | 8.5 | 13.1 | 12 | 20 | 26 | 34 | 0.06 | 2.41 | 5.24 | 9.75 |
| 10 | 2.0 | 5.2 | 6.9 | 9.3 | 9 | 10 | 15 | 24 | 0.15 | 5.59 | 12.90 | 19.60 |
| Black peat ⁺⁺ | | | | | | | | | | | | |
| 2.5 | 1.3 | 2.0 | 2.0 | 3.1 | 24 | 31 | 34 | 40 | - | 0.14 | 0.21 | 0.25 |
| 5 | 2.2 | 2.5 | 4.4 | 6.7 | 20 | 25 | 31 | 38 | 0.03 | 0.20 | 0.22 | 0.60 |
| 10 | 1.3 | 2.7 | 4.8 | 7.0 | 11 | 14 | 17 | 25 | 0.04 | 0.27 | 1.51 | 2.53 |
| 20 | 2.5 | 2.7 | 3.1 | 6.4 | 5 | 6 | 8 | 12 | 0.09 | 1.11 | 3.30 | 7.78 |

⁺ pH-H₂O: 3.2, 4.1, 5.0, 6.2, respectively.
⁺⁺ pH-H₂O: 3.9, 4.3, 5.3, 6.3, respectively.
⁺⁺⁺ Too little material or lost.

TABLE III. Dry matter yields (g) of chrysanthemum tops (cv. Gigoletta) on 'black peat' following application of copper sulphate, borax, sodium molybdate, iron-EDTA and FTE 32 (means of 3 pots)

| Rate | $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ | $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ | $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$ | Fe-EDTA | FTE 32 |
|----------------|---|--|---|---------|--------|
| 0 | 2.0 | 2.2 | 4.8 | 6.0 | 2.6 |
| 0.5 | | | | | 2.4 |
| 1 | 3.0 | 3.0 | 5.6 | 5.6 | 1.7 |
| 2 [†] | 5.9 | 5.9 | 5.9 | 5.9 | 10.2 |
| 4 | 5.5 | 8.4 | 7.2 | 5.1 | 9.0 |
| 6 | | | | | 10.6 |
| F-test | * | * | approx. * | N.S. | * |

[†]Rate 2 = 6 mg $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, 1.2 mg $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$, 2.4 mg $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$, 18 mg Fe-EDTA, equivalent to 78 mg FTE 32 per pot.

are largely attributed to a shortage of boron and molybdenum in the standard dressings (1.2 mg borax and 2.4 mg sodium molybdate). Similarly, boron may well be a limiting factor in the sodium molybdate treatment. Plants responded significantly to FTE at the medium and higher, but not at the lower rates. At equivalent rates of FTE (78 mg) and straight fertilizers FTE was the more effective source of trace nutrients. In none of the treatments with straight fertilizers the yield maximum of FTE was attained.

From the responses to single nutrients it is concluded that the FTE effect was caused by its copper, boron and molybdenum components. As the crop did not respond to iron an effect of this constituent was not revealed.

The second experiment (cv. Giant Yellow Indianapolis) was more comprehensive than the first in also varying manganese, zinc and lime applications. Standard dressings of copper sulphate, borax and sodium molybdate (in the treatments with straight fertilizers) were higher to prevent any shortages.

Plants with insufficient copper showed distinct symptoms: yellowing of all leaves and appearance of necrotic patches in the middle leaves, often desiccating entirely but remaining attached to the petioles in a drooping position. Symptoms were controlled with 3 mg copper sulphate or 78 mg FTE 32 per pot. No other deficiency symptoms were observed.

TABLE IV. Dry matter yields (g) of chrysanthemum tops (cv. Giant Yellow Indianapolis) on 'black peat' following applications of copper sulphate, borax, sodium molybdate, manganese sulphate, zinc sulphate, iron-EDTA, FTE 32 and lime (means of 3 pots)

| Rate | $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ | $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ | $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$ | $\text{MnSO}_4 \cdot \text{H}_2\text{O}$ | $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ | Fe-EDTA | FTE 32 |
|----------------------------|---|--|---|--|---|---------|--------|
| 5 g/pot CaCO_3 † | | | | | | | |
| 0 | 4.7 | 11.4 | 11.2 | 11.4 | 12.0 | 11.0 | 3.9 |
| 0.5 | | | | | | | 4.8 |
| 1 | 8.9 | 11.5 | 10.5 | 11.5 | 11.5 | 11.6 | 8.4 |
| 2 | 10.7 | 12.2 | 11.5 | 11.9 | 12.1 | 12.0 | 10.8 |
| 4 †† | 11.8 | 11.4 | 11.5 | 11.7 | 11.7 | 11.7 | 12.1 |
| 6 | | | | | | | 12.3 |
| F-test ** | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | ** |
| 10 g/pot CaCO_3 † | | | | | | | |
| 0 | 11.6 | 40.9 | 39.7 | 36.1 | 38.0 | 40.5 | 10.3 |
| 0.5 | | | | | | | 20.8 |
| 1 | 31.7 | 38.0 | 37.0 | 37.9 | 39.0 | 37.4 | 23.0 |
| 2 | 35.4 | 40.2 | 42.3 | 38.3 | 37.6 | 38.4 | 43.2 |
| 4 †† | 37.2 | 41.4 | 38.3 | 36.2 | 38.4 | 39.5 | 37.1 |
| 6 | | | | | | | 40.8 |
| F-test ** | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | ** |

† pH-H₂O 4, 3 and 5, 3 respectively; F-test **.

†† Rate 4 = 12 mg $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, 2, 4 mg $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$, 4, 8 mg $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$, 6 mg $\text{MnSO}_4 \cdot \text{H}_2\text{O}$, 12 mg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, 36 mg Fe-EDTA, equivalent to 156 mg FTE 32 per pot.

The crop responded highly significantly to lime in all treatments (Table IV). Copper had a highly significant effect, 6 mg copper sulphate being about optimum. The (positive) copper x lime interaction also proved highly significant. Surprisingly, none of the other trace elements affected growth. There was also found to be a highly significant response to FTE, specially so at the higher pH (positive interaction), 78 mg per pot being near-optimum.

Apparently, in this experiment the active agent of FTE was copper. The optimum application, in terms of copper, was equal for FTE and copper sulphate. However, at the higher pH the yield maximum was significantly higher for FTE. It is noteworthy that in all other treatments with straight fertilizers the yield maximum of FTE was about equalled, showing that the standard dressings contained sufficient copper.

Data in Table V show that the response to copper was accompanied by a decrease in leaf copper at the lower and an increase at the higher applications of copper sulphate. This is the well-known 'Steenbjerg phenomenon' occurring at extreme (trace) nutrient deficiencies (Steenbjerg, 1954). In the other treatments with straight fertilizers no such yield responses occurred and increasing rates of (non-deficient) nutrients generally produced rises in leaf concentrations of the nutrients in question (except iron at the higher pH).

Leaf concentrations in the FTE treatments are more difficult to interpret. Copper showed a pattern similar to that for copper sulphate. In general, concentrations of the other elements decreased with an increase in dry-matter production ('dilution'), particularly so at the lower applications of FTE (except molybdenum at the higher pH). Actually, the total amounts of trace nutrients (copper included) contained in the foliage increased with increasing rates of FTE. At equivalent rates of FTE and straight fertilizers the minor element concentrations were largely of the same order, but leaf manganese was lower for FTE. A rise in pH increased leaf molybdenum, lowered boron, manganese and zinc, and had no clear effect on copper and iron.

DISCUSSION

Penningsfeld's (1960; Penningsfeld and Heussler, 1965; Penningsfeld and Forchthammer, 1968) trace element recommendations for young vegetable and flower crops raised on peat substrates are rather similar to those given here, but lower than the amounts suggested by Woods and Kenny (1968). Apparently, plants cultivated on peat substrates (with a high chemical buffering

TABLE V. Cu, B, Mo, Mn, Zn, Fe concentrations (ppm in dry matter) of chrysanthemum foliage (cv. Giant Yellow Indianapolis) as affected by applications of straight trace element fertilizers, FTE 32 and lime

| Rate | Leaf Cu | | Leaf B | | Leaf Mo | | Leaf Mn | | Leaf Zn | | Leaf Fe | |
|---|-------------------|-----|---|-----|----------------------------------|------|-------------------|-----|-------------------|-----|---------|-----|
| | CuSO ₄ | FTE | Na ₂ B ₄ O ₇ | FTE | Na ₂ MoO ₄ | FTE | MnSO ₄ | FTE | ZnSO ₄ | FTE | Fe-EDTA | FTE |
| 5 g/pot CaCO ₃ ⁺ | | | | | | | | | | | | |
| 0 | 2.9 | 3.5 | 10 | - | 0.09 | - | 53 | - | 82 | 303 | 166 | 327 |
| 0.5 | | 3.0 | | - | | - | | - | | 370 | | 273 |
| 1 | 2.2 | 2.6 | 15 | 28 | 0.12 | 0.19 | 131 | - | 111 | 306 | 205 | 231 |
| 2 | 2.5 | 3.0 | 22 | 20 | 0.10 | 0.11 | 186 | 116 | 119 | 259 | 280 | 192 |
| 4 ⁺⁺ | 3.0 | 3.0 | 26 | 27 | 0.12 | 0.14 | 281 | 132 | 180 | 264 | 193 | 181 |
| 6 | | 3.8 | | 28 | | 0.11 | | 135 | | 264 | | 170 |
| 10 g/pot CaCO ₃ ⁺ | | | | | | | | | | | | |
| 0 | 2.6 | 2.8 | 6 | 36 | 0.09 | 0.25 | 45 | 177 | 76 | 330 | 189 | 304 |
| 0.5 | | 2.3 | | 27 | | 0.27 | | 113 | | 224 | | 256 |
| 1 | 2.2 | 2.7 | 9 | 22 | 0.18 | 0.39 | 121 | 92 | 86 | 190 | 183 | 234 |
| 2 | 5.8 | 5.3 | 14 | 26 | 0.28 | 0.69 | 186 | 86 | 114 | 164 | 192 | - |
| 4 ⁺⁺ | 3.6 | 2.8 | 15 | 18 | 0.31 | 0.48 | 241 | 110 | 150 | 154 | 186 | 208 |
| 6 | | 2.9 | | 26 | | 0.51 | | 107 | | 110 | | 174 |

⁺ pH-H₂O: 4.3 and 5.3, respectively.

⁺⁺ Rate 4 = 12 mg CuSO₄·5H₂O, 2.4 mg Na₂B₄O₇·10H₂O, 4.8 mg Na₂MoO₄·2H₂O, 6 mg MnSO₄·H₂O, 12 mg ZnSO₄·7H₂O, 36 mg Fe-EDTA, equivalent to 156 mg FTE 32 per pot.

⁺⁺⁺ Too little material or lost.

capacity) are tolerant of a wide range in trace nutrient applications, with the possible exception of boron (Bunt, 1965). As shown in the present study, amounts up to 60 mg of manganese and zinc sulphate did not affect growth adversely. It should be emphasized, however, that yields may decline without visual symptoms of deficiency or excess occurring.

Experiments with chrysanthemum were performed under long-day conditions inhibiting flowering largely (cv. Gigoletta) or completely (cv. Giant Yellow Indianapolis). Effects like a delay in flowering in copper-deficient plants (Bunt, 1971) and quilling of petals in boron-deficient plants (Adams et al., 1971) were not demonstrated therefore. Studies on the effects of added minor nutrients on number, size and quality of chrysanthemum flowers grown on peat substrates are in progress now. The results presented here support the few published data (Bunt 1965, 1970; Roll-Hansen, 1967; Adams et al., 1970) that FTE's are good sources of trace nutrients, the effectiveness of the iron constituent requiring further study though.

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