Minor elements in the nutrition of cereals

by

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In this paper past work on micronutrients in cereal grains in the Netherlands will be briefly reviewed, and more recent results, including some data related to the use of waste materials, will be presented. No attempt is made to review the wealth of literature, relevant data being available in recent reviews on minor elements (BERGMANN, 1968; INRA, 1970; MINISTRY OF AGRICULTURE, FISHERIES AND FOOD, 1971; MORTVEDT et al., 1972).

BORON

Small grains do not require boron dressings for normal growth usually and their tolerance of excess boron is low, especially in barley. Although boron is readily leached from the arable layer of the soil, care should be taken in judiciously administering this nutrient to boron-demanding crops (like sugar beets) preceding small grains in the crop rotation, and fertilizer dressings should not exceed 1.5 kg B per hectare.

As compared with small grains maize is much more exigent in its boron nutrition. Symptoms of boron deficiency reported from arious countries (SHORROCKS and BLAZA, 1973), including short ent cobs with bare tips, irregular kernel distribution and piralling kernel rows, were also observed in The Netherlands, n sandy soils of low boron content. Some pertinent data obained in a pot experiment with various boron-deficient sandy oils are presented in table 1 (SMILDE et al., 1969). Applied oron not only substantially increased cob yield but also improved feeding quality in reducing crude fibre (from 21.3 to 0.5%) and slightly raising crude protein and carbohydrate content. However, these results were not confirmed in concomitant 1965/1966) or later (1975) field experiments on similar soils, ith water-soluble B in the range of 0.18-0.27 and 0.08-0.16 ppm espectively. This may be attributed to either wet and cool veather conditions (1965/1966) or inadvertent land spreading of

ABLE 1. Cob development of maize on boron-deficient sandy soils as affected by applied boron (means of 5 replications = 5 plants, each grown in a 10 litre pot).

il	H_2O sol. B (ppm)	Org. matter (%)	pH-KCl	Cob weight (g)		Cob diam. (mm)		Kernel setting*	
				-B	+B	-B	+B	-B	+B
	0.12	1.7	5.5	69	388	32	54	1.3	9.7
	0.15	2.4	6.3	121	190	38	48	3.7	9.9
	0.14	4.8	5.2	113	273	36	48	2.1	9.5
	0.12	6.1	4.4	40	259	27	47	0	9.3
	0.18	5.7	5.4	143	340	39	48	3.1	9.9

ual score (10 = all kernels set, 0 = no kernels set) pig manure slurry (1975), precluding the occurrence of boron deficiency. SCHERING NEDERLAND Ltd. (1973) claims a positive effect of a "Maneltra-boron" (B_2O_3, 10.7% B) foliar spray, applied at 2 kg per hectare during the very dry 1973 summer, on cob yield and regularity of kernel setting and location. In practice, a fertilizer dressing of 10 kg borax (11% B) per hectare or a foliar spray is recommended as a precaution for soils containing less than 0.30 ppm water-soluble B.

COPPER

Past work in The Netherlands revealed that copper deficiency is likely to occur on heathland soils, reclaimed peat soils and leached (podzolic) sands (MULDER, 1950). Recently the author obtained in a pot experiment a more than forty-fold increase in grain yield of spring wheat on sphagnum moss peat, resulting from applied copper. According to HENKENS (1962a) available (in 0.4 N HNO_3 extractable) soil copper should be at least 3 ppm for oats and 4 ppm for wheat. On copper-deficient soils 25 kg copper sulphate or 400 kg copper slag (1.5% Cu), lasting for at least five years, are recommended (HENKENS et al., 1965).

At present the copper status of sandy soils in certain areas tends to rise, despite the fact that copper fungicides controlling potato blight are no longer being used. This is caused by applying heavy doses of manure slurry from fattening pigs, given a copper-enriched diet, and may give rise to some concern as to copper accumulation in soils in the years to come (cf. JUSTE, 1970).

In recent years German workers (VETTER and TEICHMANN, 1968) reported responses of cereals to applied copper in field experiments on marine loam and clay soils with 4-8 ppm (HNO_3-extractable) Cu. Moreover, the crops were found to benefit from higher nitrogen dressings only in the presence of applied copper reducing the sensitivity to lodging. The authors also suggested a higher threshold value for copper on loam/clay soils relative to sandy soils (8 versus 4 ppm Cu).

Prompted by this German work the copper nutrition of cereal crops on similar soils in The Netherlands received considerable attention in recent years (VAN LUIT, 1975). Selected data on pot experiments with 15 soils, comprising a wide range in copper (1.6-13.6 ppm), organic matter (1.1-12.6%), particles <16 μm (8.1-70.2%), $CaCO_3$ (0.1-10.1%) and pH-KCl (5.7-7.9), are presented in figure 1. Grain yield losses of up to about 15% were found to occur without (soil) applied copper on soils containing less than 5 ppm Cu. Moreover, an increase in clay and organic matter content aggravated yield reduction.

The above results of pot experiments could not be confirmed in field experiments. Selected data for the latter, on soils with 2.7-3.9 ppm Cu, 2.1-3.2% organic matter, 24-60% particles <16 μm, 0.1-0.5% $CaCO_3$ and pH-KCl 6.1-7.1, are summarized in table 2. Similar discrepancies between the results of pot and field experiments have been reported elsewhere (GUPTA and MACLEOD, 1970). According to table 2 neither a response to ap-

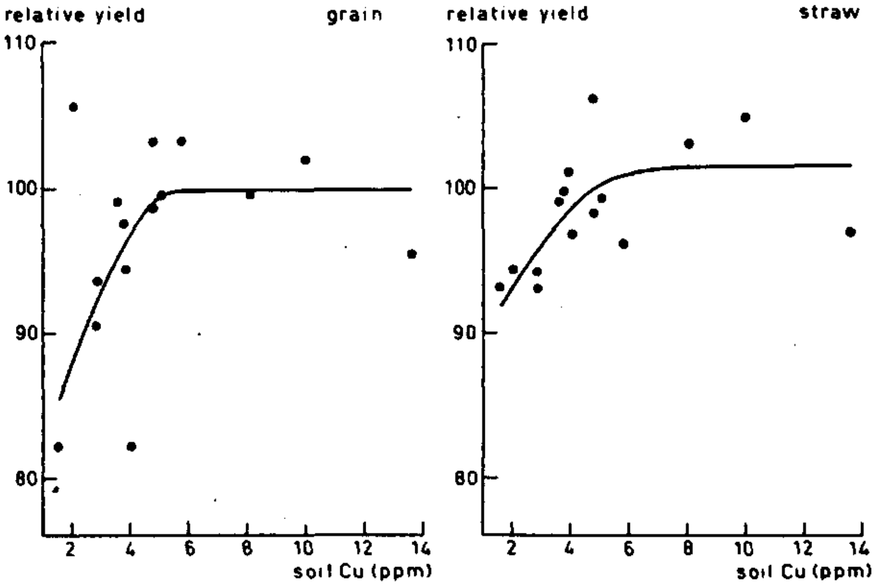

Fig. 1. Relationship between soil copper (0.4 N HNO_3 extraction) and relative spring wheat yields (yields of untreated plants/yields of copper-treated plants × 100%), following correction for equal contents (36%) of particles <16 μm (1968 pot experiment).

plied copper nor a positive copper × nitrogen interaction could be demonstrated. There was some indication of a reduction in lodging resulting from (soil) applied copper.

TABLE 2. Grain and straw yields of spring wheat (in 100 kg/ha) and lodging index (10 = upright, 0 = flat), as affected by nitrogen and copper dressings on marine loam/clay soils (means for 4 field experiments with 3 replications, conducted in 1969).

	0 kg Cu/ha			5 kg Cu/ha			10 kg Cu/ha		
	grain	straw	lodging*	grain	straw	lodging*	grain	straw	lodging*
70 kg N/ha	27.5	42.5	6.9	26.8	37.9	7.0	27.4	41.4	7.9
105 kg N/ha	28.0	42.2	4.1	28.2	43.2	5.2	28.0	41.5	4.9
140 kg N/ha **	32.0	42.2	9.2	30.4	40.9	9.1	31.7	42.8	9.2

*Visual score
**With CCC spray

MANGANESE

In The Netherlands manganese deficiency in cereal grains frequently occurs on calcareous marine (sandy) loams. Its incidence is either associated with low levels (<60 ppm) of 'easily re-

TABLE 3. Heavy metal concentrations of spring wheat grown on harbour dredge spoils relative to (fluvial clay) reference soils; means for 8 harbour dredge spoils and 2 reference soils in a pot experiment with 6 replications.

	Mn		Zn		Cu		Cd	
	dredge spoils	ref. soils	dredge spoils	ref. soils	dredge spoils	ref. soils	dredge spoils	ref. soils
Soil concn. (ppm)	400-900	500-650	450-1700	60-90	100-250	10-15	5-15	0.8
Plant concn. (ppm)								
grain	1.9-8.2	21-26	60-170	22-24	8.2-12.2	3.5-4.4	0.29-0.84	0.06-0.07
straw	3.5-6.4	13-14	80-210	8- 9	1.7-9.5	0.9	0.52-2.16	0.19
Grain yield (g)	16.6	32.4						
Straw yield (g)	32.0	52.2						

ducible' manganese, i.e. on soils low in organic matter (<2.5%), or with the stage of organic matter decomposition (C/N ratio >11) , i.e. on young, ripening soils ("polders") relatively high in organic matter (DE GROOT, 1963). To control manganese deficiency, usually two foliar sprays of manganese sulphate (10-15 kg/ha) are recommended as from a wide-spread appearance of symptoms in the crop (HENKENS, 1962b). Soil applications of manganese compounds ($MnSO_4$, MnO) are rather inefficient because of the large amounts needed and their poor residual effects (HENKENS and SMILDE, 1967; SMILDE, 1968).

On Pleistocene sandy soils the incidence of manganese deficiency is entirely governed by pH. For prevention, indiscriminate liming allowing pH-KCl to exceed 5.4 should be avoided.

A special case of manganese deficiency worth mentioning occurs on harbour dredge spoils. This material is dumped in nearby polders and left to ripen for some years before cultivation. It has excellent physical properties but its high heavy metal contents (Zn, Cu, Cd in particular), resulting from the deposition of polluted river (Rhine) sediments, may give rise to concern.

In a pot experiment spring wheat when grown on various harbour sludges, containing 10-15% $CaCO_3$, 5-15% organic matter and 20-50% particles <16 µm, was found to accumulate much more zinc, copper and cadmium, and less manganese than on (fluvial clay) reference soils of similar texture.

Table 3 provides strong evidence that manganese deficiency rather than metal (Zn) toxicity is the primary cause of the lower average yields on the dredge spoils. This was substantiated in another pot experiment with the same harbour sludges and soils. On the dredge spoils the test crops, spring wheat and oats, showed slight to severe symptoms of manganese deficiency (grey speck), and two foliar sprays of manganese sulphate were needed generally to control this disorder, resulting in (highly) significant increases in both grain and straw yields. On the reference (fluvial clay) soils neither deficiency symptoms nor responses to foliar applied manganese were observed. Summarized data are shown in table 4.

Recurrent applications of municipal compost (320 tons/ha over 16 years) or equivalent rates of lime (8 tons CaO/ha) on sandy soils, raising pH-KCl to about 6, were found to induce manganese deficiency in small grains, but not in maize. Leaf zinc of the cereals given compost containing about 1500 ppm Zn on dry weight basis, cannot be considered toxic, and manganese deficiency is regarded the main factor affecting yields, if at all (table 5). However, in similarly treated sugar beets the absence of conspicuous manganese deficiency symptoms and high leaf zinc levels (555 ppm) suggest incipient zinc toxicity (data not presented here).

MOLYBDENUM

Molybdenum deficiency in cereal crops is uncommon in The Netherlands, sometimes occurring though on (acid) loamy sands with iron concretions and/or a low available phosphate status.

TABLE 4. Grain and straw yields of spring wheat and oats on harbour dredge spoils and (fluvial clay) reference soils as affected by foliar applied manganese; means for 8 harbour dredge spoils and 2 reference soils in a pot experiment with 6 replications.

	Spring wheat						Oats					
	dredge spoils			reference soils			dredge spoils			reference soils		
	grain (g)	straw (g)	def. index*	grain (g)	straw (g)	def. index*	grain (g)	straw (g)	def. index*	grain (g)	straw (g)	def. index.*
- Mn	211	330	7.9	322	536	10.0	270	298	6.8	384	409	10.0
+ Mn	346	488	10.0	313	521	10.0	425	388	9.6	374	401	10.0

*Visual score (10 = no deficiency symptoms, 0 = very severe symptoms)

TABLE 5. Yields and leaf Zn contents of cereals as affected by applied municipal compost or an equivalent amount of lime in field experiments on sandy soils.

	Silo maize			Spring barley			Oats		
	yield (kg/are)	leaf Zn* (ppm)	Mn def. symptoms	yield grains (kg/are)	leaf Zn (ppm)	Mn def. symptoms	yield grains (kg/are)	leaf Zn (ppm)	Mn def. symptoms
No compost	138	155	-	32	89	-	18	103	-
320 ton/ha compost	147	288	-	21	187	+	20	206	+
8 ton/ha CaO	158	n.d.	-	24	60	+	15	80	+

*Sampled in June.

If liming is impracticable or costly, soil application (2-4 kg/ha) or a foliar spray (0.25-0.50 kg/ha) of sodium molybdate are recommended for control.

BRANDENBURG (1961) reports an iron-molybdenum deficiency syndrome in winter rye and oats, characterized by chlorotic striping in the leaves, on unreclaimed sphagnum peat at pH 4.0 or lower, molybdenum deficiency predominating above, and iron deficiency below pH 3.5. The disorder was controlled by joint application of 4 kg sodium molybdate and 100-400 kg iron-EDTA per hectare. In a pot experiment with spring wheat on sphagnum peat moss (cf. section COPPER) several foliar sprays of sodium molybdate and iron-EDTA were needed to suppress chlorotic striping (unpublished data by the author), supporting Brandenburg's findings.

ZINC

Zinc deficiency in cereals has not been observed as yet in The Netherlands. However, the most sensitive cereal grain, maize, the acreage of which is rapidly expanding in the last decade, has not been extensively studied so far in this respect. In France zinc deficiency occurs on (loamy) sand soils with less than 3.3 ppm 0.2 M HCl-extractable Zn and pH-KCl exceeding 5.6, its incidence being favoured by cool and wet weather in early summer (DARTIGUES and LUBET, 1967).

Zinc toxicity in oats on fields subject to inundation by zinc-polluted streams was reported by HENKENS (1961). Affected plants were stunted; leaves, containing up to 3100 ppm Zn, had pink tips and necrotic spots resembling manganese deficiency. The disorder could be controlled by soil amendment with high rates of lime (up to 16 tons $CaCO_3$/ha) considerably reducing leaf Zn (360 ppm), but also inducing manganese deficiency. As strict regulations prohibiting discharges of (industrial) waste materials into open water courses have been issued, a more definite control is achieved now by deep ploughing, substituting virgin sub-soil for the polluted arable layer.

More recently the incidence of zinc toxicity resulting from atmospheric pollution by zinc smelters in the Belgian-Dutch frontier area (Lommel-Budel) received considerable attention (SMILDE et al., 1974). In maize and other crops studied zinc toxicity was found to be associated with a physiological) Zn/P imbalance inducing phosphorus deficiency. Conversely, an upset Zn/P balance caused by excess phosphate is known to aggravate zinc deficiency (TROCMÉ, 1974).

This Zn-P antagonism could not be explained satisfactorily on the basis of chemical reactions in the soil involving mutual immobilisation. Indeed, precipitations of water-soluble ("plant-available") phosphate by zinc in zinc-enriched soils was found to play only a minor part. Moreover, applied phosphate had no depressive effect on total zinc absorption in plant tops, but did reduce their zinc concentration as a result of "dilution", effected by drastic growth responses. As distinct from phosphate, added lime reduced both total zinc content and zinc concentration of plant tops, suggesting a direct inhibitive effect on zinc uptake or translocation. On the unamended soil, leaf Zn in maize did not exceed values of about 1000 ppm and the crop responded vigorously to phosphate also in the absence of applied lime. By contrast, leaf Zn of crops like beans, lettuces and tomatoes reached levels of 2000-3000 ppm on the unamended soil, and both lime and phoshate were needed to alleviate zinc toxicity in reducing zinc concentrations to non-toxic levels.

With a view to the utilization of zinc containing waste materials, such as sewage sludge, harbour dredge spoils and municipal compost, attempts have been made in our institute to establish critical doses of applied zinc in various soils, using oats as an indicator crop. On six soils of rather similar pH (pH-KCl 4.6-5.6), but ranging in texture from sand to heavy clay the minimum dose of zinc injurious to oats was found to vary from 100 (sandy loam) to well over 800 (clay, peaty sand) ppm of Zn added as zinc sulphate. On (sandy) loam soils excess zinc induced symptoms typical of manganese deficiency, on sands symptoms like stunting and bluish-green discoloration were more suggestive of phosphorus deficiency (DE HAAN and VAN DRIEL, unpublished results).

NICKEL AND CADMIUM

Of the heavy metals commonly encountered in sewage sludge etc., viz. zinc, copper, lead, chromium, nickel and cadmium, the latter two are the most toxic for cultivated crops. In work similar to that for zinc mentioned above, the minimum toxic dose of nickel was found to vary from 12.5 to well over 100 ppm Ni (added as sulphate) for sands, rising with an increase in organic matter content, and to amount to 25 ppm Ni for loam/clay soils, irrespective of clay content (DE HAAN and VAN DRIEL, unpublished results). Characteristic symptoms of nickel toxicity, as described in the literature (ANDERSON et al., 1973), were observed in the oat crop on all soils, viz. a rather regular pattern of alternate bands of different chlorosis intensity, the more chlorotic sections in several cases being totally devoid of chlorophyll.

Doses of cadmium toxic to plant growth were of a rather similar order as those reported above for nickel. No characteristic toxicity symptoms other than stunting were observed. Much lower additions of cadmium may already result in Cd concentrations in grains considered unacceptable in human foodstuffs (>0.1 ppm).

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SUMMARY

The paper is a review of minor nutrient deficiencies (boron, copper, manganese, molybdenum) in cereals grown in The Netherlands. Soil micronutrient levels and other characteristics favouring their incidence, and control measures are reported. The occurrence of manganese and/or phosphorus deficiency in high-zinc media, like harbour dredge spoils, zinc-polluted soils or soil given large amounts of municipal compost, is discussed. Toxic doses for soil-applied inorganic zinc, nickel and cadmium are mentioned.

RESUME

La communication traite les carences en oligoéléments (bore, cuivre, manganèse, molybdène) chez les céréales cultivées aux Pays-Bas. Les teneurs en oligoéléments dans le sol et d'autres caractéristiques favorables à leur apparition, et les méthodes de lutte sont rapportées. L'apparition d'une carence en manganèse

et/ou en phosphore dans des milieux enrichis en zinc, comme les boues de port, les sols exposés aux pollutions de zinc ou les sols recevant de grands apports de compost d'ordures ménagères, est discutée. Les apports toxiques pour le zinc, le nickel et le cadmium, appliqués au sol sous forme des sols inorganiques, sont mentionnés.