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Symptoms of deficiency and excess in crops and the redistribution of nutrients in the plant

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Abstract

Symptoms of deficiency and toxicity in plants are often very specific in the place of appearance and the pattern of yellowing and necrosis. So appear symptoms of deficiency of some elements in the younger parts and others in the older parts. As example of the first group deficiency of calcium can be mentioned where the symptoms (necrosis) can be seen in the plant tips. Symptoms of potassium deficiency become apparent in the leaves of old or moderate age.
The specificity can also be seen in special organs like fruits. Calcium shortage appears especially in fruits (blossomend rot and bitter pit). Boron deficiency becomes at first apparent in the "flower" of broccoli or cauliflower (disorder hollow stem).
The distribution of the nutrient in the plant and differences in the needed quantity in different plant parts explain often the character of the symptoms. The symptoms of calcium and potassium deficiency can be explained by low concentrations in young and old plant parts respectively. For iron and boron the high quantity which is required in dividing or young tissues may give an explanation.
The heterogeneous or homogeneous distribution of certain elements in the plant may be explained by the transport system in the plant. Certain parts of the crop, like young tops and the fruits, receive the nutrient mainly via the phloemvessels, other parts mainly via the xylem vessels. As the phloem sap in contrast with the xylem sap is relatively poor in calcium and manganese and rich in potassium this can explain the symptoms of deficiency of these elements firstly in these parts.
Low concentration of certain elements in the phloem sap may result from its physico-chemical properties. For calcium and some other nutrients are only in low concentrations soluble in the phloem sap. Limitations in solubility are probably associated with high phosphate concentrations. Possibly different active mechanisms for the nutrients in the loading of the phloem may give another explanation for different "mobility" of the nutrients. Further adsorption in certain plantparts can be a third determining factor in limiting further translocation.

Introduction

Symptoms of deficiency and excess for macro- and micronutrients in plants can be very typical (Smilde en Roorda van Eysinga, 1968; Roorda van Eysinga & Smilde 1969, 1971 en 1980). So deficiency of calcium gives necrosis in the plant tops and blossom-end rot of fruits. Boron deficiency also appears as necrosis in tops and induces necrosis of the head in cauliflower and croccoli (Shelp & Shattuck, 1987 ans Shelp, 1988). Boron excess generally produces necrosis of the leafedges in crops.
Some explanations may be offered for the appearance in certain plant parts and not in others. Among these are:
- A difference in the concentration required in different crop tissues, for example between young dividing cells in plant tops and cells in older leaves.
- A heterogeneous distribution of certain elements in the plant. This is caused by differences in nutrient transport system (phloem/xylem). Further more there may be a strong fixation in certain parts of the plants; which

restricts transport to another part. For example the calciumcontent is low in young leaves, while this is not so pronounced for magnesium (Humphries and Devonald, 1977). Calcium is low in fruits (Wiersum, 1967) and in the seeds of bean (Mix & Marschner, 1976).

As mentioned above nutrient distribution in the plant may be explained in terms of mobility. Jacob ans St. Neumann (1987) distinguish for the short distance transport apoplatic and symplastic transport (respectively in cell wall water and in protoplasm). For the long distance transport the two streams are phloem- and xylemtransport.

Especially difference in phloem mobility can be important in determining the distribution in the plant. The mobility in the phloem can be measured in different ways; via ratios of concentrations in younger and older parts, in fruits and leaves, in phloem and xylem exudates, the course of the curve for the uptake-rate into the fruit during fruit growth and mobility of applied isotopes (Bukovac & Wittwer, 1957; van Goor, 1974; van Goor & van Lune, 1980). Literature data indicate that calcium is very immobile, while nitrogen, phosphorus, potassium, chlorine and sulphur are very mobile.

The behaviour of magnesium, zinc, copper, molybdenium, iron, manganese and boron is not clear or intermediate. A possible explanation for the low internal mobility of calcium and, in some cases also manganese may be the low solubility in the phloem sap (van Goor & Wiersma, 1974). Fixation by certain constituents in the tissue can be another cause of low translocation.

Distribution and translocation appeares to be influenced strongly by evaporation of the crop.

Our purpose was to summarize the knowledge present in available literature on this subject. This includes explanation of symptoms from the composition of the plant. Furthermore the explanation of the nutrient distribution from the chemistry of macro- and micronutrients.

Results and discussion

In the following examples of deficiency and some excess symptoms will be given. Moreover, it is tried to explain these symptoms on the basis of plant composition and nutrient transport and mobility in the plant.

Boron

Boron deficiency symptoms appear especially in the youngest parts of the tops, and also in fruits, tubers and roots (Borax cie report, 198. and Smilde and Roorda van Eysinga (1968). In crops like lettuce the growing points and younger leaves die. In the potato tuber necrotic patches appear while in swedes a brown heart develops. In sugar beet heart rot appears in the root, while the growing point dies also. In cauliflower and broccoli the symptoms are necrosis and brown discoloration of head and stem pith and also discoloration of the curd. Tomato fruits become ridged and show corky patches and uneven ripeness in cases of boron shortage.

Uneven distribution of boron explains the symptoms mentioned to some extent as shown in table 1, 2, 3.

Table 1. Nutrient distribution in different parts of spraycarnation Nederpel, 1978

	potassium	calcium	boron	zinc
Older leaf	100%	100%	100%	100%
Younger leaf	75%	87%	60%	108%
Older stem	76%	28%	13%	63%
Younger stem	83%	37%	15%	149%

Older leaf set on 100%

Only with broccoli and cauliflower on the customary solution composition ratios as low as 0.1 - 0.2 (table 2) are reached. Higher ratios are found (in table 2) for the lowest (o) borongift than in the customary gift. An explanation may be that small quantities are still mobile in the phloem.
In general the ratios are less extreme as are found for the very immobile calcium. For calcium fruit leaf ratios for apple can be as low as 0.02 (Van Goor, & Van Lune, 1980) which is much lower than the ratios mentioned for boron in table 3. The ratio between phloemexudate and the content found in leaf of 0.30 is also higher than described.

Table 2. Ratio of boron contents between different parts of broccoli and cauliflower (Shelps, 1988; Shelps and Shattuck, 1987)

	Boron in $mg.l^{-1}$ in the nutrient solution				
	0	0.25*)	1.0	2.5	12.5
Young leaves: Old leaves					
Broccoli	0.74	0.20	0.48	0.81	1.0
Cauliflower	1.37	0.24	0.26	0.45	0.39
"Head" (flower): Old leaves					
Broccoli	0.59	0.12	0.13	0.60	0.07
Cauliflower	0.60	0.11	0.08	0.04	0.05
Phloem exudate: xylemexudate					
Broccoli	2.8	-	-	1.7	1.5

*) Is about the customary content in nutrient solution, Sonneveld and De Krey, 1987

Table 3. Some other data about ratios of boron contents in the plant from different sources (Sonneveld and De Bes, 1984, Van Goor and Van Lune, 1980 and Van Goor, 1974)

ratio fruit/leaf	apple	0.7 - 0.8	ratio young leaf/olf leaf: cucumber 0.5 - 2.4
	tomato	0.3	
	cucumber	0.1 - 0.3	
ratio tuber/leaf	sugar beet	0.45	

for calcium (0.01) and manganese (0.01) (Tammes & Van Die, 1966).
So it is not quite clear if the distribution in the plant gives a good explanation of the symptoms of deficiency in the case of boron. Nor is it clear if the boron mobility in the phloem is low. The assumption is that boron is transported mainly as the uncharged H_3BO_3 compound, which would easily complex with carbohydrate.
This would mean a relatively high mobility of boron in the phloem, because the phloem sap is rich in sugars.

Chromium, Molybdenum, manganese, iron, copper and zinc

A group of micro elements or heavy metals shall be compared now. They can be found in the fourth period of the periodic system with the exception of molybdenzum (figure 1). This means that they differ systematically in complexing behaviour and iondiameter. This will influence their translocation pattern.
In table 4 a. description of deficiency and excess symptoms is given. The most important conclusion from this table is that for manganese the symptoms of deficiency and excess generally appear in the older leaves, where as for iron symptoms can be found both in older and younger parts.
In table 5 data are given on the distribution of the various elements plant manganese cannot be explained from these data. Apparently phloemmobility of manganese is lower than that of iron. Relatively low concentrations of manganese would expected in fruits and young plant parts inducing deficiency symptoms. Indeed manganese concentration in fruits is relatively (table 5), but in the young leaves the difference with iron is not large. Manganese deficiency is more severe in the older leaves and iron deficiency in the younger leaves. Symptoms of manganese excess in the older leaves may be explained by low export from these leaves. Symptoms of copper and zinc deficiency do not appear specificially in young or old leaves. This agrees with the mobility of these elements to younger parts, which is not very low (last column of table 5). Manganese and iron deficiency symptoms may be related to the different roles microelements play in young and old plant tissues and the nutrient concentration needed. All four elements iron, manganese, copper and zinc play a role in photosynthesis, especially iron. Iron is stored in relatively large quantities as ferricphosphoprotein. The quantities needed for the four elements are quite different. This may appear from the large differences in concentrations used in media for plant tissue culture. Jaspars (1963) described concentrations in μmol.l^{-1} in the medium used for cultivation of white and green plant tissues: 890 Fe^{3+};3.5 Mn^{2+};0.17 Zn^{2+} and 0.1 Cu (ratio Fe:Mn:Zn:Cu= 9000:35:2:1). Sonneveld and De Kreij (1987) use the ratio Fe:Mn:Zn:Cu= 50:7:5:1: in recirculation nutrient solution. This would mean that especially the quantities of iron required in dividing plant tissues is relatively high. This may give an explanation for the symptoms of iron deficiency in younger tissues. Another problem is the large difference in manganese reaction of different crops as Sonneveld & Voogt (1975) found.

Periodic System of elements

	Ia	IIa	IIIb	IVb	Vb	VIb	VIIb	VIII	VIIII	VIII	Ib	IIb	IIIa
1	1 H 1.008												
2	3 Li 6.940	4 Be 9.013										5 B 10.82	
3	11 Na 22.991	12 Mg 24.32										13 Al 26.98	
4	19 K 39.100	20 Ca 40.08	21 Sc 44.96	22 Ti 47.90	23 V 50.95	24 Cr 52.01	25 Mn 54.95	26 Fe 55.85	27 Co 58.94	28 Ni 58.71	29 Cu 63.54	30 Zn 65.38	31 Ga 69.72
5	37 Rb 85.48	38 Sr 87.63	39 Y 88.92	40 Zr 91.22	41 Nb 92.91	42 Mo 95.95	43 Tc (99)	44 Ru 101.1	45 Rb 102.91	46 Pd 106.4	47 Ag 107.880	48 Cd 112.41	49 In 114.82

Figure 1. Part of the periodic system with the elements considered.

Table 4. Comparison of symptoms of deficiency and excess in crops for the elements molybdenum, manganese, iron, copper and zinc

	DEFICIENCY					EXCESS					
element	symptoms first or stronger in young leaves	symptoms both in old and ypung leaves	symptoms first or stronger in old leaves	symptoms only in old leaves	symptoms in fruits (fr) or flowers (fl)	symptons only in plant-tips	symptoms only in in young leaves	symptoms first or stronger in young leaves	symptoms both in old and young leaves	symptoms first or stronger in old leaves	symptoms only in old leaves
mobybdenium			II								
manganese			II, III (n), V	I, IV (d)	IV (fl)	V			IV, V(n,ch)	I(n),II (n),III (n)	
iron	II(ch), III(ch), V (ch,n), IV(ch)				III(fr)						
copper	II(cr,n)	II(inh, ch),IV		I(ch,n, cr)	IV(fl)						
zinc		IV(ch,n)	I(n),II (n, inh)	III(ch)			III(ch)	IV(ch)	II(inh)		I(inh, ch)

Plantspecies: I lettuce, II tomato, III cucumber, IV chrysanthemum, V carnation

Abbraviations: (n) = necrosis, (ch) = chlorosis, (d) = leaves die, cr = curling of leaves, inh = growth inhibited

Literature: Roorda van Eysinga and Smilde (1971, 1968, 1969, 1980, informatiereeks 89)
Roorda van Eysinga en van der Meys (1982)
Nederpel (1978)

Table 5. Summary of some data in literature about the ratios between the contents in different plantparts for chromium, molybdenum, manganese, iron, copper and zinc (on a dry base)

	ratio "fruit": "leaf"*)	ratio "young leaf": "old leaf"	ratio "phloemexudate": "leaf"
<u>molybdenium</u> MoO_4^{2-}:			
cucumber	0.5		
<u>manganese</u> (Mn^{2+}):			0.01
tomato	0.1		
pepper	0.1 -0.15	0.5-0.8	
cucumber	0.1 -0.3	0.6-0.7	
apple	0.02-0.1		
kiwi	0.02		
<u>iron</u> Fe^{3+}):			0.12
tomato	0.15-0.2		
pepper	0.5	0.8-1.2	
cucumber	0.8-1		
kiwi	0.15		
<u>copper</u> (Cu^{2+});			0.1
tomato	1.2		
cucumber	1 -2		
kiwi	1		
<u>Zinc</u> (Zn^{2+}):			0.3
tomato	0.9		
pepper	0.15-0.2	0.5	
cucumber	0.5 -1		
kiwi	0.5		

chromium bean ratio seed : leaf = 0.01
wheat ratio seed : leaf = 0.015

*) mostly fully grown leaves

Literature:

1) Sonneveld (1981)
2) Sonneveld and De Bes (1984)
3) Sonneveld, De Bes and Voogt (1986)
4) Sonneveld (1982)
5) Huffman and Allaway (1973)
6) Van Goor and Wiersma (1974)
7) Tammes and Van Die (1966)
8) Haag et al (1978)
9) Smith, Buwalda & Clark (1988)

Transport in relation to the distribution

The manganese concentration in phloem exudates is relatively low (table 5) as opposed to that in xylemexudates (table (8 b). In spite of that found Wolterbeem, Willemse and Van Die (1987) that still 78% of the manganese in a tomato fruit came via the phloem vessels, while 100% of the calcium came via the xylemvessels. For copper 93% was translocated by the phloem. The low manganese concentration may be related to the low solubility manganese in phloem exudates (Van Goor & Wiersma (1974)). Biological active systems for "loading" and unloading" can however also play a role. For iron, copper and zinc the ratios between phloem leaf concentration are not so extremely low.

The macroelements potassium, magnesium and calcium

Potassium, calcium and magnesium are elements which differ much in chemical and physico-chemical behaviour. The most important conclusion from table 6 is that calcium deficiency appears in plant tops and younger leaves, and potassium deficiency in the older leaves. In the apex of the fruits local calcium deficiency (blossom end-rot) appears sometimes. Magnesium deficiency appears mostly in the older, but sometimes in the younger leaves. Potassium is found also in the older leaves according to table 6, the idea is however that it appears still more in intermediary leaves than magnesium (Sonneveld 1989, private communication & Sonneveld (1987). This depends also on the plant age, and season.
Calcium excess may induce the disorder "gold speckles" and "green pitting" in tomato and pepper. The yellow spots are located mostly on the calyx part of the fruit (Janse, 1988). It is suggested that high calcium destroys plant cells by the formation of calciumoxalate crystals.
Table 7 shows that the calcium content in the growing points of the plant relative to that in the leaves is very low. Furthermore the ratio for fruit/ leaf is low. This may offer an explanation for the symptoms of calcium deficiency as compared with those of potassium deficiency. Also in the plant sap of leaf laminae compared with that of petioles the differences for tomato were found to be larger for calcium than for potassium (Sonneveld and De Bes, 1988).
The incidence of magnesium deficiency in the older leaves and sometimes the somewhat younger leaves can be accounted of a intermediate mobility. The low mobility of calcium may explain the higher concentration of calcium at the calyx side of the fruit and the symptoms of "gold Speckles".

Transport of potassium, magnesium and calcium

So far the results described above showed a very heterogeneous distribution for calcium in, but a very homogeneous distribution for potassium. The position of magnesium is in between that for potassium and calcium (Cmelik et al, 1986). This is in concurrence with the nutrition of the young plant parts and the fruits predominantly via the phloem. The phloem sap is low in calcium, rich in potassium and medium for magnesium (table 8a). This means that calcium is translocated very slowly from one place in the plant to the other, for example from old to yound leaves, and within the fruit (local deficiency).
The composition of the xylem sap, which controls the flux of nutrients to the older leaves is quite different. Calcium and magnesium content differ less with potassium than in the phloem sap (table 8a and 8b) especially in the kiwi vines.

Explanation of the low concentration of calcium may be from active selectivity in the process of loading of the sievetubes, but also purely from a limitation of the loaded quantities by the very restricted solubility (Van Goor and Wiersma, 1974). In table 9 the solubility of some potassium, magnesium and calcium salts is given. The very low solubility of calcium salts and the position of magnesium between potassium and calcium is shown. From table 10 it is apparent that the ionic product of calciumphosphate equals the solubility product; the phloem exudates are saturated with calcium. Part of the phosphorus can however be organic, which means that the real differences are different from this simplified calculation.
The behaviour of magnesium varies in the different crop experiments. An explanation can be that the solubility is sometimes limiting for magnesium and sometimes it is not. It is possible that better control of the magnesium nutrition is obtained by manipulating the composition of the phloem sap or changing the chemical form of magnesium therein artificially.

Table 6. Comparison of symptoms of deficiency and excess in crops for the elements potassium, magnesium and calcium

	DEFICIENCY					EXCESS
element	symptoms in plant-tips	symptoms first or mainly in young leaves	symptoms both in old and young leaves	symptoms first or mainly in old leaves	symptoms in fruits (fr) or flowers (fl)	symptoms in fruits (fr) or flowers (fl)
potassium				I(ch,n,inh) II(ch,n,cr, inh),III(ch, n,e), IV(n, e),V (tl,inh)	II(co,fr), IV(inh,fl)	
magnesium			IV(ch)	I(ch,inh), II(ch,n), III(ch), V(ch)		1)
calcium	II(ch,n), IV(n)	I(n),II (ch,n), III(n,e, ch),IV(n, cr)	V(n,tl)		II(n,ap), IV(fl,inh)	II(gold spickles

Plant species: 1 lettuce, II tomato, III cucumber, IV chrysanthenum, V carnation

1) roots necrosis

Abbreviations:
(n) = necrosis
(ch)= chlorosis
(d) = leaves die
(co)= colour defect in fruit
(ap)= symptoms in apex fruit
(cr) = curling of leaves
(e) = necrosis of leafedges
(tl) = necrosis of leaftips
(inh)= growth inhibited

Literatuur: Roorda van Eysinga and Smilde (1971, 1968, 1969, 1980, "informatiereeks "89) Roorda van Eysinga en Van der Meys (1982) Nederpel (1978)

Table 7. Summary of literature data on the ratios between the contents in different plant parts for potassium, magnesium and calcium (on a dry weight basis)

	ratio "fruit": "leaf"	ratio "young leaf": "old leaf"	ratio "growing tip": "old leaf"	ratio "phloem exudate": "leaf Yucca
potassium:				0.9
tomato	1-2;1.5	0.7-0.9		
cucumber	4-5			
apple	0.7			
kiwi	1.2			
magnesium				0.03
tomato	0.3-0.4;1;0.4	0.4-0.8		
cucumber			0.5	
apple	0.2-0.25			
kiwi	0.2			
calcium				0.01
tomato	0.05;0.07 0.1-0.2	0.3-0.6		
cucumber			0.05	
kiwi	0.07			

calcium content leaf edge for lettuce 1-2 mg/g dry weight
leaf centre 4 mg/g dry weight

Literature:
1) Voogt 1981)
2) Humphreys and Denvalo (1977)
3) Adams (1966)
4) Collier and Huntington (1983)
5) Van Goor and Wiersma (1974)
6) Fernandez et al (1975)
7) Ward (1973)
8) Tammes and Van Die (1966)
9) Sonneveld & Welles (1988)
10) Smith, Buwalda & Clark (1988)

Table 8a. Comparison of the potassium, magnesium and calcium contents of phloem exudates of different plant

	SIEVE TUBE SAP							XYLEM SAP	LEAF
	Yucca				Dahlia	Ricinus	Quercus	Quercus	Yucca
	bleeding sap		with Aphis fabae	with Aphis sambuci	with Aphis fabae	bleeding sap	bleeding sap		
	1)	2)	2)	2)	2)	3)	4)	4)	4)
potassium	0.93(100%)	0.84(100%)	1.68(100%)	1.63(100%)	1.8(100%)	2-4(100%)	9.5(100%)	12.7(100%)	1.04(100%)
magnesium	0.028(3%)	0.055(6.5%)	0.19(11.3%)	0.14(8.6%)	0.2(10%)	0.1(3%)	0.035(0.3%)	0.82(6.5%)	1.04(100%)
calcium	0.0078(0.8%)	0.007(0.8%)	0.05(3.1%)	0.023(1.4%)	0.02(1.1%)	0.02-0.09 (0.6-3%)	0.022(0.23%)	1.3(10.2%)	0.67(64%)

All data calculated as % of dry matter. pH Ricinus sap is 8 Between ( ) % of potassium

Literature 1) Tammes and Van Die (1966)
2) Tammes and Van Die (1976)
3) Hall and Baker (1972)
4) Van Die and Willemse (1975)

Table 8b. Content of macro- and microelements in the bleeding xylem sap from kiwifruit vines

MACROELEMENTS			MICROELEMENTS		
Element	Content mM	% of K	Element	Content μM	% of Mn
Phosphorus	7.9	11	Iron	17	14
Potassium	6.7	100	Manganese	126	100
Calcium	13.8	206	Copper	11	9
Magnesium	5.2	78	Zinc	18	14
Sulphur	1.8	27	Boron	45	36

Clark, Holland & Smith (1986)

Table 9. Solubility of some salts of potassium, magnesium and calcium in water ($mol.l^{-1}$)

	chloride	nitrate	suphate	phosphate (HPO_4^{2-})	citrate
potassium	4.6	3.2	0.65	9.6	5.6
magnesium	5.7	4.7	2.9	0.01	0.7
calcium	6.7	7.6	0.02	0.001	0.0002

Table 10. Solubility of calcium phosphate in phloem exudate. Concentration in $mol.l^{-1}$

	Yucca flaccida Tammes and Van Die (1966)	(1976)	Ricimus communis Hall & Baker (1972)
Estimated P concentration	10×10^{-3}	5.7×10^{-3}	4×10^{-3} - 6×10^{-3}
Estimated Ca concentration	0.35×10^{-3}	3.2×10^{-3}	0.5×10^{-3} - 2.5×10^{-3}
Ionic product $(Ca^{2+}) \times (HPO_4^{2-})$	3.5×10^{-6}	18.2×10^{-6}	1.9×10^{-6}-14×10^{-6}
Solubility product $(Ca^{2+}) \times HPO_4^{2-}) = 1.96 \times 10^{-6}$			

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