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Distribution of mineral nutrients in the plant in relation to physiological disorders

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ABSTRACT

An enumeration of some physiological disorders and their symptoms, deficiency or toxicity, in the plant has been given. It was tried to relate the symptoms described to data on the distribution of inorganic constituents. Furthermore, we tried to find an explanation for the distribution pattern of these constituents from the knowledge of the transport mechanisms within the plant.

Most of the above-mentioned physiological disorders could be explained by the low concentrations of certain elements in a number of plant parts, such as fruits, seeds and the inner part of a head in a crop such as lettuce. This also applies to the very specific symptoms in growing points with insufficient amounts of calcium or boron. The low concentrations of calcium and manganese in fruits, seeds and storage roots could be explained by nutrient supply of these organs mainly taking place through the phloem vessels.

INTRODUCTION

Physiological disorders may occur in many cultivated plants and then decrease yield and quality. We shall confine ourselves in this publication to those disorders which are caused by too low or too high concentrations of *mineral* constituents.

The disorders can be caused in very different ways. Uptake and transport of minerals can be disturbed, which gives rise to a deficiency in the whole plant or in a certain plant organ or tissue. There may even be a deficiency in a very restricted part of a plant organ.

The genetic properties of the plant species play one of the roles in the appearance of physiological disorders. The environmental conditions may also favour the genesis of these disorders. Concentrations and ratios of nutrients in the soil, affecting nutrient uptake, are important in this respect. An unfavourable ratio may cause deficiency symptoms in the whole plant or in a certain part of the plant. Nutrient absorption into and translocation within the plant are strongly influenced by climatic factors, such as atmospheric temperature and humidity. We will try to relate the symptoms of deficiency and toxicity to data about the distribution of the nutrients in the plant or in one organ, i.e. a leaf or a fruit. It will be tried to explain the distribution pattern from the knowledge about transport mechanisms in the plant. Possibly a better insight into these problems may result in a better abatement of the physiological disorders.

DESCRIPTION OF SOME PHYSIOLOGICAL DISORDERS

In the following sections some of the physiological disorders are enumerated with their symptoms (Sorauer, 1969). Most of them are caused by calcium deficiency, one by manganese and one by boron deficiency. They occur especially in fruits, seeds, tubers and the inner parts of a crop, as with lettuce.

Calcium deficiency

In apples one often observes the disorders *bitter pit* and *breakdown*. In apples with bitter pit small brown spots occur immediately under the skin. In apples with breakdown a large part of the tissue is soft and brown. A related disorder is *blossom-end rot* in tomato and sweet pepper. The symptoms are localized in the fruit apex. At first the colour of the apex turns into dark green; this change in colour is probably caused by infiltration of the intercellular spaces by the cell fluid. Subsequently the affected tissue becomes brown and necrotic. In lettuce the physiological disorder *tipburn* is well-known (Smilde and Roorda van Eysinga, 1971), The symptoms of tipburn can vary. One kind of tipburn gives withered edges of older leaves, another consists of a necrosis of the veins near the leaf edges in the head. Furthermore, necrotic spots may develop on the edges of the young leaves, preceded by leaching of latex out of the latex vessels on the leaf surface. It is not probable that all manifestations of tipburn are caused by calcium deficiency. A necrosis of the growing point and the youngest leaves is sometimes found in blanched celery; it is called *black heart*. In Brussels sprouts the disorder *internal browning* occurs, characterized by dead parts in the interior of the sprouts. In tulips, affected by *topple disease*, glassy and water-soaked areas develop on the flower stem. At a later stage the cells shrink and the part above the lesions topples over (Algera, 1968). *Internal brown fleck* occurs in the potato tuber (Combrink and Hammes, 1972).

Manganese deficiency

Marsh spot in peas and beans is characterized by dead spots in the centre of the seeds.

Boron deficiency

Sugar beets with *heart rot* show glassy and necrotic spots, while the younger leaves and growing tips die.

In general one can make the following remarks (Wallace, 1951; Smilde and Roorda van Eysinga, 1968). The deficiency symptoms of nitrogen, potassium, phosphorus, manganese and magnesium occur especially in the older leaves of the plant. On the other hand, iron deficiency is found in the younger leaves. This particularly applies to the deficiencies of calcium and boron, which affect the growing tips.

About the symptoms in leaves the following characteristics are known. Potassium-deficient leaves show chlorotic and necrotic leaf tips and edges. This applies even more strongly to calcium deficiency. Another uniform symptom in different plants is caused by an excess of manganese. In clover, manganese toxicity produces necrosis of the edges of the leaves. The symptoms can be seen successively in tips, edges and laminae of the leaves (Vogel, 1973). Boron toxicity symptoms occur especially on the leaf edges (Smilde and Roorda van Eysinga, 1968; Vogel, 1973)

RELATION BETWEEN SYMPTOMS AND NUTRIENT CONCENTRATIONS

When trying to explain the symptoms we have to weigh two factors against each other: *concentration in the plant part* and *the need of the tissue for a certain nutrient.* Not all of the content of an element, which is present in a plant part, needs to be available for metabolism.

The substances needed in a tissue are strongly dependent on the physiological status of the tissue. Cells in mitosis differ considerably from elongating cells in this respect. Exact data about the need of different plant tissues are still unknown.

In Table 1 some results of chemical analysis in apple, tomato and sugar beet are given. The low calcium concentration in the fruits compared with the leaves is striking. This may explain the susceptibility of the fruits for disorders like bitter pit and blossom-end rot.

Table 1. Concentration of different elements in some plant parts

Part of the plant		Percentage		mg/kg	
		K	Ca	Mn	B
apple Cox	fruit 17/7[5]	1.50	0.20	7.7	11.5
	leaf 17/8[5]	1.21	1.56	29.1	16.0
	fruit 19/9[5]	0.72	0.035	2.8	5.8
tomato	fruit	0.265[1,2]	0.0042[1,2]	-	14[3]
	leaf	0.512[1,2]	0.277[1,2]		51[3]
sugar beet	tuber[3]	1.7	-	26	15
	leaf[3]	3.2	-	46	25-40
pea	seed	-	-	4-9[4]	-

All values on dry matter, except that under note 2.

[1]Ruhland (1958)
[2]On fresh weight
[3]Sorauer (1969)
[4]Glasscock and Wain (1940)
[5]Sampling date

The concentration of manganese in the seeds of peas is also relatively low, which explains the occurence of marsh spot in these seeds. This also applies to the boron content in the tubers of sugar beets, which might give an explanation for the occurrence of heart rot in sugar beets. The difference between tuber and leaf, however, is rather small and furthermore symptoms also appear in the younger leaves. Another possible explanation may be a difference in boron requirement between the plant tissues.

It is known that the location of the symptoms in the vegetative parts can vary strongly. One can search for an explanation in the results of crop analysis, as given in Table 2. It is evident from the results that calcium and boron concentrations in younger plant parts and especially in the tips of the plants are much lower than in older leaves. This may be an explanation for the deficiency symptoms of these elements.

Table 2. Content of some elements in plant parts of different age
A. Content in gherkin in mg/kg of dry matter[1]

	Leaf				Tip
	old		young		
	edge	lamina	edge	lamina	
boron	1350	460	670	320	130

B. Content in cucumber as percentage of dry matter[2]

	Leaf number (1 = lowest leaf)							
	1	2	3	4	5	6	7	tip
calcium	2.34	1.59	0.74	0.43	0.25	0.12	0.21	0.12
potassium	0.93	0.90	3.35	3.12	3.24	2.88	3.64	4.25
magnesium	1.36	1.12	1.15	0.91	0.87	0.65	0.91	0.86

[1]Alt and Schwarz (1973)
[2]Ward (1973)

Only a restricted amount of research has been done with respect to the distribution of different elements in plant leaves. One of the problems is the determination of very small quantities. It has been found for gherkin (Table 2), soybean and cotton that the boron content of the leaf edges is higher than that of other plant parts (Oertli and Roth, 196? Alt and Schwarz, 1973). This may explain the boron toxicity symptoms in plants. Läuchli (1972) gives data suggesting that leaf calcium has to saturate first the tissues of the vessels before being transported to the mesophyl. This would mean a low content of calcium in the leaf edges for a long period. This could explain the withering of leaf edges and tips in the case of calcium deficiency. The results of Gavalas and Demétriades (1964) are in agreement with this consideration. In their experiments with olive they found withering of the apical parts of the leaves, when calcium or boron were only applied to a slight extent. These symptoms were accompanied by low concentrations of calcium and boron in these parts of the leaves.

Also for the distribution in the fruits only few data are available. Kohl (1967) found the lowest concentration of calcium immediately under the skin of the apple. The concentration decreases in the direction of the apex of the fruits. This is in agreement with the occurrence of the spots of bitter pit immediately under the skin mostly on the apical side of the fruits. However, it has never been proved with certainty that bitte pit spots develop there because of the low concentration of calcium. Another interesting question, which cannot yet be answered, is the difference between bitter pit and breakdown. Is there only a difference in the distribution pattern for calcium in the two disorders? For tomato it has been found that blossom-end rot develops at the apical side of the fruits, where the calcium concentration was lowest (Van Goor, 1966).

For pea it is evident that the manganese concentration is lowest in the centre of the cotyledons. This is in agreement with the development of marsh spot in these organs (Glasscock and Wain, 1940).

EXPLANATION OF THE DISTRIBUTION PATTERNS FROM KNOWLEDGE ABOUT TRANSPORT IN THE PLANT

In Figure 1 the transport of substances in the plant has been given

schematically. Water, organic substances and minerals are transported. The transport paths are xylem vessels and sieve tubes, and furthermore the substances can move with the water in the cell walls and with the protoplasm. The quantity of different substances, which can be transported in the different ways, can vary widely.

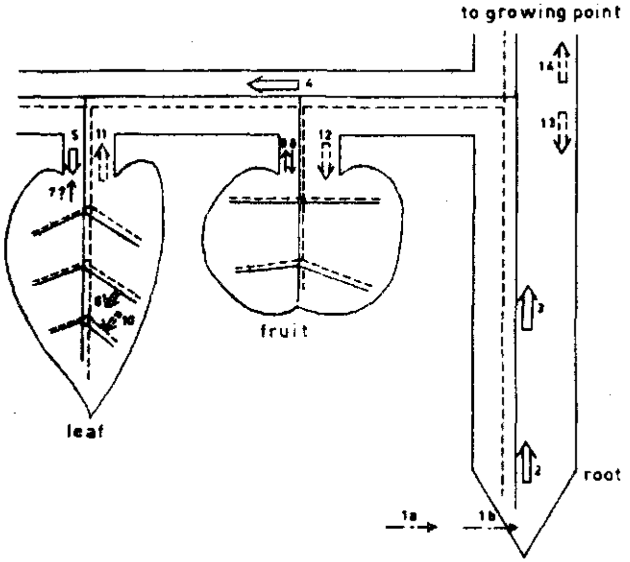

Fig. 1. Schematic view of uptake and transport in a plant with fruits. The arrows indicate the transport streams; the width of the arrow is a rough indication of the quantity of the transport by the relevant flow path:

- ——▶ transport in xylem or cell-wall water.
- – –▶ transport in phloem or protoplasm.
- 1a. Supply of the root surface.
- 1b. Uptake by the root.
- 2, 3 and 4. Transport in the xylem of root, stem and side stem with fruits.
- 5. Supply of the leaf through the xylem.
- 6. Transport from the vessels to the parenchymatic tissue in the leaf (by the cell-wall water?).
- 7. Transport – if any – from leaf through the xylem.
- 8. Transport to the fruit through the xylem.
- 9. Transport from fruit through the xylem.
- 10. Transport from the parenchymatic cells (by the protoplasm?) within the leaf to the sieve tubes.
- 11. Transport from the leaf through the phloem.
- 12. Supply of the fruit through the phloem.
- 13. Transport to the root through the phloem.
- 14. Nutrition of the growing point through the phloem.

Differences in transport of the substances can already occur during transport to the root surface (arrow 1a). We restrict ourselves here to what happens in the plant itself. After the uptake of ions by the plant root, they are transported actively or passively to the xylem vessels. In the roots certain elements are preferentially absorbed, which gives rise to a selection. It is difficult to draw conclusions about this from root analysis, because the concentration in the root depends on three streams: uptake by the root, translocation from root to top and vice versa.

The ions move through the xylem vessels to the plant top. On their way ions move into the surrounding parenchymatic cells. The transport in the xylem vessels is governed by the evaporation process. The large differences in evaporation among the several species of plant parts also cause large differences in the extent of nutrient supply via the xylem to the plant part. A great deal of the transport stream via the xylem moves to the strongly evaporating leaves. Only small amounts move into the fruits, from which only little evaporation takes place. When the fruits are small, a relatively larger supply via the xylem takes place. Taking into account the structure of the growing points inside the head of a crop like lettuce, one also expects little evaporation. The evaporation from organs which grow below the soil surface, such as tubers and pods of groundnut, is still smaller (Wiersum, 1951).

From the xylem the ions in the leaf can be transported further to the parenchymatic tissue by means of the cell-wall water (arrow 6). From these transport paths ions can be absorbed by the content of the cell. Subsequently the ions can move from cell to cell by the protoplasm. The quantity absorbed in the cell depends on the function of the element in the cell metabolism. Loss of ions from the transport stream with the protoplasm also occurs in consequence of immobilization processes within the protoplasm (i.e. absorption in certain cell particles).

From the leaves, assimilates and ions are transported by the phloem to other plant parts, such as fruits and roots (arrow 12, 13). Perhaps there is a direct connection between the transport stream in the protoplasm and the sieve tube content. Slightly or non-photosynthesizing organs like fruits, seeds, and tubers get all or most of their nutrient supply by the sieve tubes. The entry into the phloem system or at an earlier stage into the protoplasm (through a membrane) means again a possibility for selection of the ions.

The quantities of the various elements transported in the sieve tubes can differ considerably. This quantity will be indicated below as mobility. In Table 3 some analyses are given for two plant species, which allow tapping of the phloem exudate. The ratio of the concentrations of the ions in exudate and leaf can be used as a measure of their mobility. It is evident from Table 3 that the mobility values are especially low for calcium and manganese. Rather low are the values for magnesium. The low mobility of calcium and manganese might be explained by their low solubility in the sieve tube sap (Van Goor and Wiersma, 1974).

Table 3. Content of different elements in phloem exudate of some plants, compared with leaf contents

	Yucca[1]			Ricinus[2], exudate, μg/1
	exudate[3], μg/g	leaf[3], μg/g	cont. in exudate/ cont. in leaf	
potassium	9324	10489	0.889	2300-4400
sodium	23	198	0.116	46- 276
calcium	78	6665	0.012	20- 92
magnesium	283	10395	0.027	109- 122
manganese	3	239	0.012	-
iron	8	66	0.121	-
boron	10	34	0.294	-
zinc	12	44	0.273	-
phosphorus	1720	2110	0.815	113- 178

[1]Tammes and Van Die (1966).
[2]Hall and Baker (1972).
[3]Figures on dry weight basis.

Another possibility for determining the mobility is to follow the transport of isotopes within the plant tissue. It may also be worthwhile to determine the transport from older to younger leaves, which occurs probably mainly through the sieve tubes. The results are largely the same, although there are some differences in the way in which the different authors rank the elements. Mengel (1965) ranks manganese as a moderately mobile element. Price (1970), on the other hand, regards it as an immobile element. The mobility of borate would be low (Price, 1970).

Only a slight transport via the phloem of elements like calcium can explain the low concentrations of calcium and manganese in organs like fruits (Wiersum, 1966). It is also possible to explain the low concentrations of calcium in inner parts of certain crops, like Brussels sprouts. The evaporation of the more interior parts of the sprouts is small, which means that the nutrient supply mainly occurs via the phloem and that consequently only a slight transport of calcium to these parts takes place. The results of experiments on mobility are less clear for boron; an explanation for the boron deficiency in sugar beet therefore cannot be given.

It is still difficult to explain the results of distribution in the leaves. The ions enter the leaves by the veins. The concentration at a certain site is determined by means of the supply and the redistribution. The redistribution of calcium is very restricted. With the help of these considerations it is possible to explain the low concentrations of calcium in leaf edges and leaf tips in the gradient from vein to edge. It is not clear why one cannot reason in the same way for boron. Perhaps absorption during the transport is smaller than for calcium. This would mean that an element like boron would accumulate more in leaf edges. It is also possible that high concentrations in leaf edges would especially occur in cases of excess. This would give an explanation for the observations of Vogel (1973) for manganese and boron excess.

The coupling of the distribution of an element over the relevant organs (i.e. fruit and leaf) on the one hand, and the ratio between xylem and phloem supply on the other, gives a possibility for decreasing the incidence of the physiological disorder. One can do this by manipulation of the relative evaporation of the different plant parts.

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