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THE TRACE ELEMENT BORON
THE STATE OF RESEARCH IN THE NETHERLANDS [1]

CH. H. HENKENS
Institute for Soil Fertility, Groningen, The Netherlands

Introduction

Warington (1923) was the first to show that boron is essential to the growth of the plant. Owing to the failure of the first attempts at demonstrating the essential nature of boron for the growth of plants other than legumes, many investigators believed that this only obtained in the case of legumes which occupy a special position in the vegetable kingdom. Brenchley and Warington subsequently showed (1927) that boron was essential to numerous other plants. Löhnis (1937) proved that the distinction made by Brenchley and Warington between plants to which boron is essential and plants to which boron is useful was incorrect, and that all plants need boron for normal growth. It was Brandenburg's discovery (1931) that heart rot of beet is caused by boron deficiency that focussed attention on boron.

The physiological importance of boron to the plant

This has been little investigated in the Netherlands. Van Schreven (1935) found that the foliage of boron-deficient potatoes contained an abnormal amount of starch. Hence boron has an effect on the transport of the assimilates.

Löhnis thinks that boron is required for the formation of plant hormones. Eaton succeeded in removing symptoms of boron deficiency by making use of hetero-auxin. E. G. Mulder (1948) showed that peas form no root nodules in aqueous cultures in the absence of boron. Consequently the plants died through lack of nitrogen, while there were no visible symptoms of boron deficiency. When small amounts of boric acid were applied, normal root tubers developed, resulting in nitrogen fixation, but now there were marked symptoms of boron deficiency. It was found that the plants needed somewhat more boron when nitrogen was applied.

Field experiments showed that unlike what had been found in aqueous cultures, no deficiency symptoms occurred in the plant, but the nitrogen fixation was reduced, with the result that the plants ripened earlier and gave smaller yields. Hence in field experiments the boron requirement of the nodules seems to be greater than in aqueous cultures. E. G. Mulder believes it possible that the formation of the nodules in the open begins late, so that most of the boron has already been used up by the plants.

Gerretsen (1954) showed that boron is essential to Azotobacter chroococcum. It was found that the CO_2 production increased as the boron supply improved. It was also found that growth, nitrogen fixation and colour depend on the extent of the boron supply.

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SYMPTOMS OF BORON DEFICIENCY

The general characteristic of boron deficiency is that the growing point dies off. This is followed by the formation of new sideshoots of which the growing point again dies off. Other symptoms are a slight thickening of the foliage and occasional chlorosis. The leaf stalks and foliage are often brittle; often no flowers are formed or when this occurs there is no fruiting. Inhibited growth of the roots is general. However, the said external symptoms of boron deficiency are not common to all plants (for instance, they are absent in swede).

Internal injury is common to all plants. It consists in a degeneration of the meristematic tissues, destruction of the walls of the parenchyma cells, and weak development of the fascicular tissues. The phloem is injured more than the xylem. Before the cells become detached there is hypertrophy and discoloration of the cell walls. Occasionally there is abnormal cell division.

At first only a very advanced stage of boron deficiency (heart rot) was known in beet. VAN SCHREVEN (1939) described the initial stage of boron deficiency in beet, for which he coined the term "vein rot". Recognition of vein rot as the preliminary stage of heart rot is of great importance. Swede suffering from boron deficiency cannot be externally distinguished from healthy plants in any way. The roots are as large as when there is a good supply of boron, and there is no discoloration of the foliage. Discoloration does, however, occur in the interior of the root. The tissue has a glassy appearance and somewhat resembles frost damage. A further peculiarity of swede is that the brown discoloration increases during storage, as was shown by experiments carried out by HUIZINGA and LÖHNIS (1940). The same experiments showed that swede is more sensitive than beet. The diseased plants appear to have a lower boron content than healthy ones, but there is no difference in boron content between older and younger leaves. A peculiar feature is that whereas in other dicotyls the growing point dies off when there is boron deficiency, this is not the case with swede, although patches of "brown" occur in swede in fields in which heart rot never occurs.

LÖHNIS (1941) succeeded in obtaining boron deficiency in swede in aqueous cultures. The youngest leaves were curled and crumpled, the others being in a horizontal position, while the leaf tops were bent double. VAN SCHREVEN (1935 and 1938) described the characteristic symptoms of boron deficiency in potatoes. In potatoes suffering from boron deficiency the growing point dies off, the foliage becomes thick and brittle, and the leaf margin curls upward. The plant has a squat appearance. The leaf stalks break off easily, especially in the older leaves. The tubers usually have a rough and cracked surface and are smaller than usual. The most characteristic symptom in the tuber is local or universal brown discoloration of the ring of vascular bundles. This discoloration is generally greatest at the navel end of the tubers. In severely affected tubers the part inside the ring of vascular bundles often has a glassy appearance, and when cut through there is something of a crackling sound. Experiments conducted by VAN SCHREVEN showed that a dressing of 20 kg of borax per hectare can give a 16.6% increase in yield. At the same time it was found that 63% of the tubers on the check plots had internal symptoms of disease, whereas this percentage was reduced to 16% by dressing with 20 kg of borax per hectare, and in addition the plants were found to be less severely affected.

QUANJER found in pot culture experiments that the skin of the tubers is cracked when there is boron deficiency (communicated by VAN SCHREVEN, 1938). This raises the question whether the increased scab injury thought to be found when there is boron deficiency can be explained in this way.

The monocotyls differ from the dicotyls in the external symptoms of boron deficiency. OVERBEEK (1934) found in maize translucent stripes in the longitudinal direction of the leaf. In sugar cane VAN DEN HONERT (1932) observed small transparent spots on the leaves and severe growth inhibition. According to LÖHNIS (1936) barley forms no ears when deficient in boron; rye forms an ear, but it withers at the top and does not grow; wheat forms a normal ear externally which fails to flower, and in oats the pollen grains are empty.

Up to 1954 practically no cases were recorded in Holland of boron deficiency in plants other than potato, beet and swede. In 1954 HARMSEN found boron deficiency in lucerne in the province of Limburg. When deficient in boron, lucerne remains small and thick-set because the internodes do not continue to grow, so that the plants show a great similarity to box shrubs. The entire development is retarded, so that flowering begins later or is even completely absent. The foliage has a faded brown or greyish-yellow discoloration beginning from the top and margins of the leaflets. The leaf veins retain their green colour longer than the mesophyll between them. The yellow discoloration is frequently followed by anthocyane-red discolorations of the leaf margin. This red discoloration can always be observed on the denticulations of diseased leaflets. The top leaflets are rounder and wider than is the case in healthy plants. It is also noticeable that in the same plant certain shoots will continue to grow at a reasonable rate and have a practically normal appearance, whereas others are greatly foreshortened and stubby.

In cauliflower boron deficiency is shown by rust-brown discoloration of the head, and the leaf margins are also discoloured with yellow and red margins. Watery discolorations later passing over into necrosis occur on the midribs, particularly of the young leaves (VAN DEN ENDE, 1954).

In fruit trees suffering from boron deficiency the new shoot dies, beginning at the top, after which side-shoots appear which also wither in turn. The result is a witches' broom. Not only do the growing points die, but necrosis also occurs in the cambium layer. The surrounding tissue reacts to this by forming a cork film of dead cells. When it is cut, brown spots can be seen in the bast. These brown spots consist in dead tissues surrounded by a layer of cork cells. In apples, fairly well-defined, round, and originally rather green spots are formed, which can be recognised from the outside as dark, glassy patches when they lie close to the surface. Afterwards the patches become brown and dry to a spongy, tough consistency.

D. MULDER (1953) says that the earlier this suberisation occurs, the more it is situated towards the interior and grouped around the core. According to BRANDENBURG (1939) suberisation does not increase after harvesting, unlike the brown discoloration in swede. Externally boron deficiency in apples may be recognised by the occurrence of malformations and splits in the fruit, particularly when the deficiency occurs early.

In stone fruit the symptoms in the fruit are of an entirely different character. Plum, cherry and peach react to very harmful effects by forming gum. This is also the case when there is boron deficiency. In plums and peaches cavities are formed in the fruit, which are filled with gum. Sometimes the fruit tears and the gum runs out. Cherries tear without forming gum. In Holland gum formation occurs in plums in certain years. No one has yet ventured to state as a fact that this is due to boron deficiency, as gum formation is so dependent on weather conditions.

Boron richness of Dutch soils

Lehr states (1940) that on the basis of Goldschmidt and Peters' (1932) spark spectrograph analyses it may be assumed that Netherlands marine clay soils have a boron content of 0.01% and the river clay soils one of 0.002%. In the clay soils boron occurs in the soil in a fairly homogeneously divided form; this would make it all the more readily available. The chief supply of boron in sandy soils is stored as a mineral reserve in the form of borosilicates and only becomes slowly available to the plant by means of hydrolysis. In addition to this reserve a small part is present in the organic material, but this part is more mobile and hence more readily available to the plant.

The sandy soils in the Netherlands have a boron content between 0.005 and 0.0025% in tourmaline, and between 0.001 and 0.002% in organic material. The heart rot map of the Netherlands compiled by Lehr from practical data shows that these differences in the boron content of Dutch soils are also reflected in farming practice.

According to Lehr, the fact that in the northern provinces less heart rot occurs on sandy soil than in the southern provinces is due to a large extent to the higher organic matter content in the northern provinces. Another reason he adduces is the greater use of Chilean nitrate. Edelman pointed out (1939) that a considerable amount of boron is added to the soil by rain (cyclical salt) as well as by fertilisation.

Factors affecting the occurrence of boron deficiency

1 *Drought*

In farming practice dry weather is found to favour the occurrence of boron deficiency. Whether this is due to fixation of boron in the soil or to the plant's inability to absorb nutriment without moisture has not been studied in the Netherlands. The latter explanation is quite feasible when we remember that most of the boron available to the plant is found in the organic material on the surface. Foreign investigations show that drying of the soil causes an increase in the fixation of boron, and it also appears that fixation increases with rising temperature. Lehr attempted (1940) to ascertain the effect of drying of the soil on the availability of boron. The yield figures show that pretreatment of the soil is reflected in an improvement of the yield progressing from dust-dry via air-dry soil to soil kept moist. The total amount of boron absorbed also shows, albeit not so clearly as the increase in yield, that the boron uptake was better in the samples which had been kept moist. According to Lehr this may just as well be due to the good effect of keeping the soil moist on the plant development, resulting in a higher total amount of boron in the plant, as that, vice versa, a better supply of boron results in a better yield.

2 *Acidity*

Acid soils are not greatly affected by boron deficiency, although the same soils produce boron-deficient plants when the pH is increased. Owing to this it was long thought that the high pH was the cause of heart rot. LEHR found (1940) that the uptake of boron, at any rate below a pH of 7, is independent of the pH. Hence this shows that the pH has no direct effect on the boron uptake. The effect of the pH on the availability of boron has not yet been adequately studied in the Netherlands and the results obtained by foreign research workers are conflicting.

3 *Fertilisation*

Liming the soil leads to an increase in the boron deficiency. Whether this is due to a change in the availability of boron in the soil, or whether changes occur in the plant, has not been investigated in the Netherlands. HUDIG and LEHR found (1938), as did also WARINGTON (1934), that calcium and boron had a mutual effect on each other. Their experiments with mustard showed that the development of mustard without calcium improved with increasing doses of boron. In pots without boron the mutual effect was even more in evidence, since the crop showed transition stages from very diseased to completely healthy plants as the Ca additions increased. A good growth was observed and the highest yield was obtained on the pots with the greatest $CaCl_2$ addition. LEHR also found (1940) that boron deficiency symptoms with mustard could be eliminated by the addition of more calcium. Is was found that there was no change in the boron content itself when the $CaCl_2$ application was varied. The problem is whether in these experiments there was any interchange between the symptoms of boron deficiency and those of calcium deficiency. Several research workers have pointed out that the two types of symptoms are very similar. In fact, in the experiments conducted by the above-mentioned authors it was found that the plant was also sensitive to an increase in the calcium concentration when the boron concentration was raised.

Many investigators believe that boron is fixed by liming. LEHR states (1940) that the theory according to which boron is said to be fixed as calcium borate is untenable. He believes that the fixation of boron as a result of liming is to be regarded as a deflocculation of the organic boric acid complexes. The fact that the extra addition of boron is not fixed would be due to the much slower process of complex formation with the organic material already deflocculated.

Liming is not the only factor influencing boron deficiency. VAN DER PAAUW found (1953) that a potash dressing may favour the occurrence of boron deficiency. The Netherlands Agricultural Lime Bureau found on a recent heath reclamation area in the province of Limburg that a potash dressing without the addition of boron had a harmful effect on potatoes. When boron was also applied the yield was higher with increasing dressings of potash (STRUIJS, 1956), REEVE and SHIVE (1944) found the same in pot culture experiments, although in the same experiments they observed that a potash application may also favour boron excess when there is an ample supply of boron; hence the greater the amount of potassium absorbed by the plant, the greater is the uptake of boron.

Boron content of diseased and healthy plants

Lehr's investigation (1940) shows that there is no correlation between the boron content of the beet and its state of health, but there is a correlation between the boron content of the leaves and the state of health. Among the various varieties of beet he finds no widely divergent figures in the healthy specimens. Without exception the content of the beet fluctuates around 20 p.p.m., whereas the leaf content varies from 20 to 30 p.p.m. Whereas in healthy beets the leaf content is about twice that of the beet, in diseased beets the leaf content may fall below the beet content. Hence this shows that the leaf needs most boron, and that it is the first to suffer if insufficient boron is available. Little is known in Holland regarding the boron content of other plants, although it seems that in potatoes, as in beet, the boron content of the tuber varies very little (8 to 10 p.p.m.) and the content in the leaf appears to be higher and to react more strongly to fertilisation.

Boron fertilisation

It has been concluded from practical experiments that a dressing of 25–30 kg of borax per hectare is sufficient to prevent heart rot of beet. The boron dressing is best applied in the spring. Both the crop and the sugar content increase as a result of a boron dressing on soils where there is a danger of heart rot. De Haan (1935) obtained an increase in yield of 8000 kg in beet by applying borax, and the sugar content rose by 1.5 %.

Brandenburg (1939) found that on soils where heart rot only occurs under extreme conditions, a borax dressing in the absence of the disease neither results in any appreciable increase in yield nor in an increase of the sugar content.

Wind (1951) believes that the precautionary policy should be adopted of giving a small amount of borax to beet on sand and river clay soils.

An average beet harvest removes 350–400 grammes of boron from the soil (equivalent to 3–3.5 kg of borax), so that when it is dressed with 20–30 kg of borax 85–90 % of the boron remains behind. There is insufficient information about the after-effect of a boron dressing. Brandenburg (1935) found an after-effect lasting twelve months.

Another method of supplying boron is to spray the plant with a boron solution. The reader is referred to Van Alphen's review of the literature (1956).

According to Brandenburg (1939), most of the boron absorbed by the plant is fixed in the leaf and can only be rendered mobile again with difficulty. This theory is supported by the fact that when the boron supply is interrupted boron deficiency very soon occurs and the symptoms are first exhibited in the top .

Boron toxicity

In Holland this has hitherto only been noticed in bulbs (Pijls and Den Dulk, 1951). Dutch agricultural crops most sensitive to boron deficiency are practically insensitive to boron excess. An investigation made by Winsor (1950) shows that the occurrence of boron toxicity depends not only on the sensitivity of the crop but on the type of soil and the form of fertilisation too. On light soils there is a great risk of boron toxicity in sensitive crops. Experiments conducted by VAN SCHREVEN (1935) showed that the beet is not very sensitive to boron excess. At a concentration of 100 mg of boric acid per litre certain anomalies occur in the foliage. The leaves assume a more horizontal position and the leaf margins of the outer leaves arch upward locally. In these leaves chlorotic patches are formed between the veins. At 50 mg per litre the symptoms are still absent, but the leaves still tend to assume a horizontal position. Compared to the pea, the lupin tolerates a fairly high concentration of boron (VAN GENNEP 40 mg/litre).

The amount of precipitation may have a great influence on the occurrence of boron excess.

SOIL RESEARCH

LEHR has developed a chemical extraction method for determining boron in the soil. The soil is extracted with hot water, and the boron is then colorimetrically determined after colouring with a curcuma solution. The significance of the soil boron content obtained by this method is being studied by the Institute for Soil Fertility in co-operation with LEHR. GERRETSEN is engaged in developing methods of microbiological determination.

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