Studies on Manganese Deficiency in a Forest Stand

Studier över manganbrist i ett skogsträdsbestånd

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In 1953 chlorosis was observed in spruce (*Picea Abies*, Karst.) growing on a drained, lime-rich fen at Levide on the isle of Gotland. The chlorosis was restricted to the current needles and vanished gradually during the winter and the second summer. To the author's knowledge this type of chlorosis in conifers has not been described earlier. A colour picture of a spruce twig from this locality has been published (TAMM and INGESTAD, 1955). While chlorosis was observed also in birch (*Betula verrucosa,* Ehrh.) pine (*Pinus silvestris,* L.) seemed relatively healthy.

Since the pH-value of the soil was very high it appeared probable that the chlorosis was a symptom indicating deficiency in some of the micro nutrients (see e.g. TROUG, 1953, p. 41). In the spring of 1954, a preliminary fertilization experiment was carried out. As the symptom disappeared within two months after the addition of manganese it was concluded that the chlorosis was caused by deficiency of this element. No other element applied had any effect. To elucidate further the manganese status of the area new experiments were carried out during the following years.

To the knowledge of the author manganese deficiency in forest trees is a rather unknown and altogether unexplored occurrence. For this reason it was regarded of interest to report the results obtained so far. In addition to the experiments with spruce also some observations on birch and pine will be recorded.

Soil and Vegetation

On three sides the experimental area, about 3,500 m^2 in size, is surrounded by small hills. Westwards it borders on a large tract of drained fens of a somewhat different type. While particularly the spruce trees grow rather slowly within the area, adjacent forest stand is dominated by thriving spruce.

Bare until 1920 the area was drained and used for agricultural purposes during two years. In 1922 birch was planted in mixture with pine that was establishing naturally. However, with the exception of a few trees the birch was subsequently removed. Remaining stand of pine, which was cleaned and pruned in 1943, 1946, and 1951, has now an average height of about 9 meters. Surrounded by an open stand consisting of pine, birch, and some spruce the pine stand with an admixture of some birch now occupies the central part of the area.

Here and there the pine stand has an understory of naturally established

Figure 1. Spruce twigs showing various intensities of chlorosis. The twigs were taken from trees that were sprayed (2 per cent $MnCl_2$, $4H_2O$, 1955 and 1957) left, fertilized (100 kg $MnCl_2$, $4H_2O$ per hectare, 1954) center, and untreated tree, right. (Photo. T.I. 5.9. 1957).

Grankvistar med olika stark kloros. Kvistarna har tagits från besprutade (2 procent $MnCl_2$, $4H_2O$, 1955 och 1957), markgödslade (100 kg $MnCl_2$, $4H_2O$ per hektar, 1954) och obehandlade träd från vänster till höger.

spruce not exceeding a height of one meter. While the vegetation is rich and dominated by grass in the outskirts of the stand it is poor in the central parts.

Beneath a thin layer of litter the following strata was distinguished in a representative soil profile: grey-brown mull rich in sand particles (about 20 cm), light brown sand (about 10 cm), well decomposed black-brown peat (more than 40 cm). Recorded by means of a simple soil gauge, the pH-value of the soil within the area is above 8 in all strata down to a depth of 70 cm. On high places in the adjacent area pH was 4.5—5.0 at a depth of 10 cm.

Deficiency Symptoms

The most striking symptoms were found in spruce. The young needles are highly chlorotic already at the outset. During the following winter and summer the needles turn pale green until autumn the second year when they become dark green. The length and number of needles seem usually to be normal. Figure 1 shows three spruce twigs with various intensities of chlorosis increasing from left to right.

Also birch leaves are chlorotic. While the discoloration is most pronounced in the aged leaves the terminal ones often are fresh green. Leaves with symp-

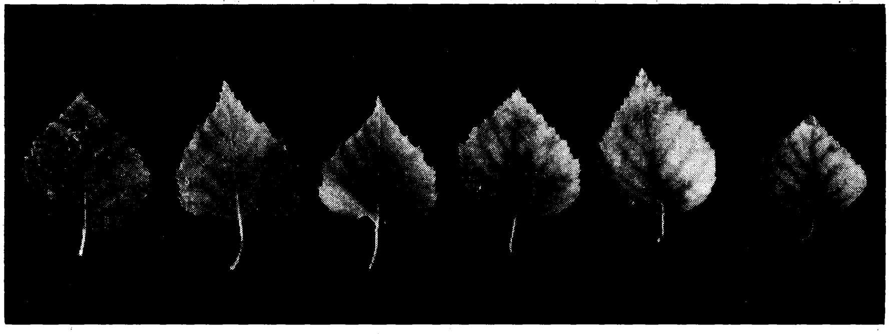

Figure 2. Birch leaves showing increasing chlorosis from left to right. (Photo. T.I. 5.9. 1957).
Björkblad med ökande kloros från vänster till höger.

toms are light green or yellow between the veins. A very acute chlorosis is often associated with a reduction that may be notable but otherwise leaf size is usually indifferent. Figure 2 shows a series of birch leaves with increasing intensity of symptoms from left to right. The two leaves on the far right are green only in a narrow zone along the veins while the remaining leaf surface is bright yellow.

In contrast to spruce and birch pine shows no specific symptoms. Late in the autumn, however, the young needles are occasionally pale green or even yellow.

Experimental

Three methods of application have been used in the fertilization experiments, viz. soil fertilization, foliage spraying, and stem injection. Spraying was carried out by means of a Jena glass bottle that was furnished with a rubber plug penetrated by two glass tubes. By pumping air through one of the tubes a solution was forced through the other tube and transferred by a rubber tubing to a sprayer. The sprayer was made of perspex glass and silver to be chemically indifferent. Stem injection was arranged by boring a hole down into the trunk at 45° angle. The hole was made to reach within about 2 cm from the opposite side. By means of a polyethylene injector and a tube the solution was ejected into the hole.

Table I presents a summary of the various manganese fertilization experiments that were carried out in the years of 1954—1957, and which are described in this paper. In April 1954, some exploratory experiments comprising soil fertilization (phosphorus, manganese, boron, copper, and zinc) and spraying (manganese, copper, and zinc) were carried out. At the soil fertilization 100 kg $MnCl_2$, $4H_2O$, i.e. 28 kg Mn per hectare was added. About 150 ml solution

Table I. Summary of the fertilization experiments with $MnCl_2$, $4H_2O$ carried out at Levide 1954—1957.

Sammanfattning av gödslingsförsöken med $MnCl_2$, $4H_2O$ vid Levide 1954—1957.

Time of fertilization	Number of trees	Species	Average height, meter	Treatment	Amount supplied		
					$MnCl_2$, $4H_2O$ kg/hectare	$MnCl_2$, $4H_2O$ in solution, per cent	Mn g/tree
April, 1954..	—	Spruce	ca 1	Spraying	—	1.0	0.42
	8	»	» 1	Soil fert.	100	—	—
May, 1955...	10	»	» 1	Spraying	—	0.5	0.21
	7	»	» 1	»	—	1.0	0.42
	10	»	» 1	»	—	2.0	0.84
	10	»	» 1	»	—	5.0	2.10
	1	»	5	Injection	—	50	0.70
	4	Pine	ca 9	»	—	50	0.70
June, 1957..	1	Birch	» 1	Spraying	—	2.0	—
						5.0	—
						10.0	—
July, 1957...	Repetition of the spraying experiment of May, 1955						

per tree was used when spraying the needles. This amount was sufficient to wet trees of this size entirely. In this way about 0.4 g Mn per tree was added.

In the autumn of 1954, foliage spraying was the only method that brought about a disappearing of the symptoms, whereas soil fertilization produced no visible effect. On the basis of this result new experiments were carried out in May, 1955. Within four plots, 5×5 meters in size all the small spruce trees were sprayed with solutions containing various amounts of manganese. Every tree received 150 ml solution. The amounts supplied are recorded in Table I. Simultaneously an experiment with stem injection was carried out. To obtain equality, trees were paired and eventually one pair of spruces and four pairs of pines were selected. One tree in each pair was treated with 5 ml of a solution containing 50 per cent $MnCl_2$, $4H_2O$ equivalent to 0.7 g Mn per tree (Table I).

In June 1957, a small birch was sprayed with manganese solutions. On the same tree different twigs were treated with solutions containing 2, 5, and 10 per cent $MnCl_2$, $4H_2O$ until the leaves were wetted to the point of run-off. In July 1957, the spraying experiment with spruce carried out in May 1955, was repeated on the same trees and with the same concentrations.

Analytical Methods and Results

All the samples of leaves and needles were collected in the autumn at a time when the observations recorded were comparable from year to year (TAMM, 1951 and 1955). Thus birch leaves were collected at the end of August or in the beginning of September, needles in October or November. Twigs from equally treated trees constituted one sample. The needle samples were grouped in year series and analysed separately. The pine needles were air-dried separated from the twigs whereas spruce needles and birch leaves were left drying on the twigs. Subsequently the samples were dried in a vacuum oven at about 55° C and ground.

Manganese determinations have been carried out colorimetrically after the wet ashing procedure. Periodate has been applied as oxidizing agent according to SANDELL (1950). Other analytical methods used have been described earlier (INGESTAD, 1957). The standard variations in the analytical values are about 2—5 per cent except when the manganese contents are very low.

The results are summarized in Table II A—D. In some cases a more comprehensive analysis is available (Table II A), in other cases manganese only has been determined. Usually the content of various elements in the needle samples is presented for the last two year series. The content is always expressed in per cent of dry weight.

The manganese content of untreated trees is low and amounts to about one-tenth of the iron content in spite of the fact that the iron content is low rather than high. GLENISTER (1944) who investigated the iron status at manganese overdosages mentioned that the Mn/Fe quotient should be 1 : 2. Thus the analytical values, too, indicate that the manganese content may be in minimum.

The other per cent values as far as comparable ones are available (see INGESTAD, 1957) are not so low or high as to explain the symptoms even if the nitrogen values are relatively low and those of calcium are high.

Table II. Results of the analyses. Element content expressed in per cent of dry weight. Each sample consists of needles from all trees treated equally. The figures are means of duplicate values. The variation is about 2—5 per cent. Birch, spruce, and pine.
Analysresultat. Halterna är uttryckta i procent av torrvikten. Proven består av barr från alla lika behandlade träd. Siffrorna är medeltal av två värden. Felet är c:a 2—5 procent. Björk, gran, tall.

Tab, II A. The content of elements (exc. manganese) in samples collected 1955.
Ämneshalterna (utom mangan) i 1955 års prov.

Treatment	Year series	Species	Per cent of dry weight					
			N	P	K	Ca	Mg	Fe
Untreated......	1954	Small spruce	1.07	0.09	0.87	0.84	0.10	0.006
	1955		1.27	0.14	1.27	0.36	0.09	0.004
Untreated......	1954	Large spruce	1.27	0.11	0.79	0.62	0.08	0.004
	1955		1.39	0.17	1.20	0.33	0.08	0.004
Injected........	1954	» »	1.35	0.14	0.91	1.12	0.12	0.004
	1955		1.24	0.14	0.80	0.52	0.08	0.005
Untreated......	1954	Pine	1.53	0.14	0.71	0.51	0.11	0.006
	1955		1.75	0.20	0.96	0.24	0.09	0.005
Injected........	1954	»	1.66	0.16	0.70	0.69	0.13	0.005
	1955		1.70	0.17	0.70	0.32	0.09	0.004
Untreated......	—	Birch	1.81	0.10	0.59	1.30	0.28	0.007

Table II B. Manganese content of spruce needles.

Manganhalt i granbarr.

Treatments	Year series	Manganese content of needles collected various years, per cent of dry weight.		
		1955	1956	1957
Foliage spraying, 1955, 1957				
Control	1954	0.0004		
	1955	0.0004		
	1956		0.0008	0.0020
	1957			0.0012
½ % $MnCl_2$, $4H_2O$	1954	0.0034		
	1955	0.0021		
	1956		0.0020	0.0022
	1957			0.0107
1 % $MnCl_2$, $4H_2O$	1954	0.0085		
	1955	0.0045		
	1956		0.0020	0.0048
	1957			0.0194
2 % $MnCl_2$, $4H_2O$	1954	0.0086		
	1955	0.0053		
	1956		0.0026	0.0030
	1957			0.0181
5 % $MnCl_2$, $4H_2O$	1954	0.0085		
	1955	0.0049		
	1956		0.0031	0.0064
	1957			0.0374
Soil fertilization, 1954				
Control	1954	0.0004		
	1955	0.0004		
	1956		0.0008	0.0020
	1957			0.0012
100 kg $MnCl_2$, $4H_2O$ per hectare	1954	0.0028		
	1955	0.0023		
	1956		0.0027	0.0022
	1957			0.0019
Stem injection, 1955				
Control, high branches	1954	0.0004		
	1955	0.0004	0.0020	
	1956		0.0010	0.0015
	1957			< 0.0003
Control, low branches	1954	0.0016		
	1955	0.0006	0.0016	
	1956		0.0008	0.0015
	1957			< 0.0003
50 % $MnCl_2$, $4H_2O$, branches above injection hole	1954	0.0230		
	1955	0.0100	0.0050	
	1956		0.0026	0.0047
	1957			0.0005
50 % $MnCl_2$, $4H_2O$, branches below injection hole	1954	0.0016		
	1955	0.0012	0.0017	
	1956		0.0015	0.0012
	1957			< 0.0003

Table II C. Manganese contents of birch leaves. In the summer of 1957 leaves on some branches of a small tree were sprayed with variously cencentrated $MnCl_2$, $4H_2O$ solutions. Samples were collected in the autumn the same year.

Manganhalter i björkblad. Sommaren 1957 besprutades bladen på några grenar på ett litet träd med olika koncentrerade lösningar av $MnCl_2$, $4H_2O$. Proven insamlades på hösten samma år.

Treatment	Manganese content of leaves per cent of dry weight
Untreated leaves with acute symptoms	0.0007
” ” ” weak ”	0.0017
Leaves sprayed with 2 % $MnCl_2$, $4H_2O$	0.059
” ” ” 5 % ” ”	0.087
” ” ” 10 % ” ”	0.152

Table II D. Manganese content of pine needles from untreated trees or trees injected in 1955 with a 50 % $MnCl_2$, $4H_2O$ solution. Samples were collected in the autumn the same year.

Manganhalter i tallbarr från obehandlade eller injicerade träd. Injektionen utfördes 1955 med en 50 %-ig $MnCl_2$, $4H_2O$-lösning. Proven insamlades på hösten samma år.

Treatment	Year series	Manganese content of needles per cent of dry weight
Control	1954	0.0006
	1955	0.0007
Injected	1954	0.0078
	1955	0.0160

Results

After manganese fertilization the chlorosis has usually decreased in intensity or disappeared. The effect is less obvious when the manganese has been added to the soil (Figure 1). No effects were visible within the first three years, but in 1957 the chlorosis was less pronounced. For spruce foliage spraying has led to complete recovery of the green colour (Figure 1 and 3). However, after a treatment with ½ per cent $MnCl_2$, $4H_2O$ young needles are somewhat lighter in colour than old ones. In the case of birch all concentrations used have been effective.

Spruce that was treated by injection recovered the green colour above the injection level. Low branches, however, showed no effect. Although young needles on the high branches turned lighter in colour during 1956 and 1957, the effect of the treatment was still obvious.

Figure 3. On the right sprayed spruce trees (2 per cent $MnCl_2$, $4H_2O$, 1955 and 1957). In the foreground spruce trees showing manganese deficiency. (Photo. T.I. 5.9. 1957).

Besprutade granar till höger (2 procent $MnCl_2$, $4H_2O$, 1955 och 1957). I förgrunden ses granar med manganbrist.

Table III. Growth data after foliage spraying (1955, 1957) and soil fertilization (1954). The spray solutions contained in the left column mentioned concentrations of $MnCl_2$; $4H_2O$. Spruce.

Tillväxt efter besprutning (1955, 1957) och markgödsling (1954). Besprutningsvätskan höll de i vänstra kolumner angivna koncentrationerna av $MnCl_2$, $4H_2O$. Gran.

Treatment	Number of trees	Total height 1957, cm	Length of terminal leaders, cm				
			1953	1954	1955	1956	1957
Control........	10	89.6 ± 8.6	2.7 ± 0.3	3.8 ± 0.6	4.6 ± 0.7	4.1 ± 0.6	6.3 ± 0.8
Foliage spraying (½ %).......	10	97.2 ± 10.8	4.9 ± 0.7	7.7 ± 1.2	8.5 ± 1.3	9.0 ± 1.3	14.4 ± 1.4
Foliage spraying (1 %)........	7	97.1 ± 17.6	4.0 ± 1.3	5.1 ± 0.9	4.4 ± 0.8	5.7 ± 1.2	10.0 ± 1.9
Foliage spraying (2 %)........	10	86.5 ± 8.6	2.8 ± 0.5	2.2 ± 0.3	2.5 ± 0.3	4.0 ± 0.6	7.5 ± 0.9
Foliage spraying (5 %)........	10	107.8 ± 13.5	5.3 ± 1.2	6.3 ± 1.4	8.3 ± 1.2	8.7 ± 1.4	13.6 ± 2.2
Soil fertilization (100 kg/hectare)	8	80.9 ± 10.8	2.0 ± 0.3	2.6 ± 0.7	6.5 ± 0.6	4.6 ± 0.6	11.6 ± 2.2

Growth data, summarized in Tables III and IV, are based on measurements carried out in the autumn of 1957. Table III shows that the annual height growth variation was great on the various plots at the beginning of the experi-

Table IV. Growth data after stem injection (1955) with 5 ml of a solution containing 50 % $MnCl_2$, $4H_2O$. The figures for the lateral shoots represent means of three twigs. Spruce.

Tillväxt efter staminjektion (1955) med 5 ml 50 %-ig $MnCl_2$, $4H_2O$. Värdena för sidogrenarna utgör medeltal av tre kvistar. Gran.

Treatment		Total height 1957, cm	Length, cm							
			Terminal leader				Lateral shoot			
			1954	1955	1956	1957	1954	1955	1956	1957
Control	high branches	390	28	21	13	10	9.3	7.8	8.5	9.0
	low "						7.3	7.5	6.5	5.3
Injected	above injection hole.	500	20	24	24	24	8.3	9.3	9.5	10.7
	below " "						5.7	5.8	5.7	7.0

ments. Since no foliar analysis was carried out before the treatments it is impossible to draw any conclusions as to the cause of variation. The number of trees, too, in each plot is rather small. For these reasons it is difficult to compare growth data collected from the various plots and to determine whether a raise of the manganese concentration in the spray solution will produce an increase of the growth response. However, the most interesting question is whether the treatments on the whole have led to a growth response. Therefore, the height growth data have been grouped in Figure 4. The group values for foliage spraying are aggregate means that represent all trees treated disconsidering concentration differences of the spraying solutions. In the graph the mean height growth values of the control trees and those of trees growing on fertilized soil are also given. Since but one tree was treated the growth values from injected spruce are not very representative (Table IV). However, the values are interesting because they show the difference in growth response between branches above and below the injection point. Also the influence of manganese supply on the annual growth may be studied.

It is notable in Table III and Figure 4 that trees subjected to foliage spraying in comparison with untreated trees slowly showed a growth increase. With the special exception of 1956, also soil fertilization raised the rate of growth.

Discussion

The paper presents a series of experiments that was started to explore the cause of a chlorosis in spruce. Within the area described the pH-value of the soil is very high (above 8) at least down to 40 cm depth. Since it is a well-known fact that the availability of manganese in the soil is strongly reduced at high pH-values of the soil, as shown by e.g. OLSEN (1934) it was not surprising to find manganese deficiency to be the reason for the symptoms.

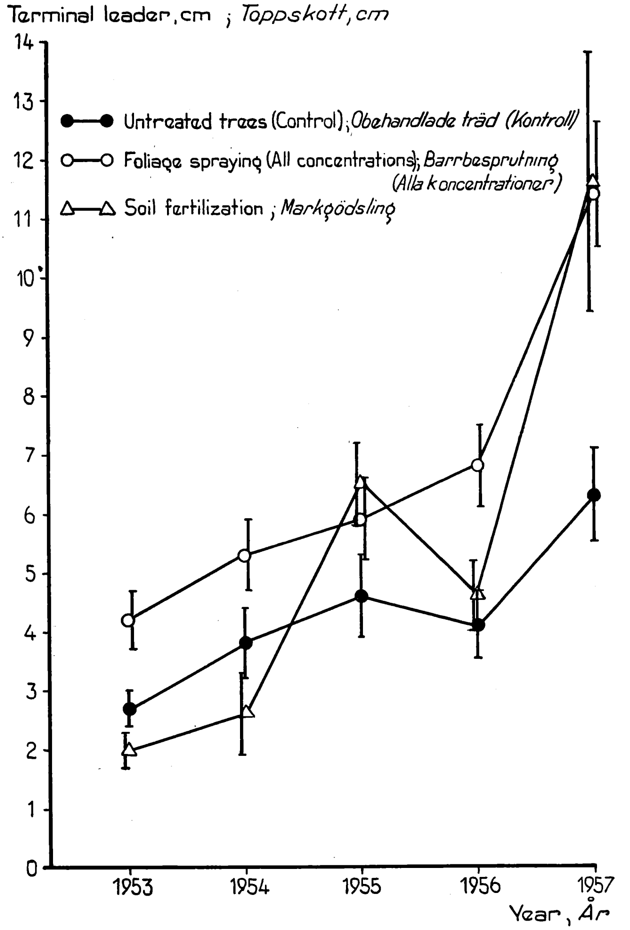

Figure 4. Length of terminal leader with mean errors given. Untreated, foliage spraying and soil fertilization. The values presented for the sprayed trees are aggregate means representing all concentrations of spray solution. Spruce.

Toppskottslängder från obehandlade, barrbesprutade och markgödslade träd med medelfelen angivna. Värdena för de besprutade träden utgör medeltal representerande alla koncentrationer i besprutningsvätskan. Gran.

The fertilization methods used in the experiment have been described. Two methods that deviate from conventional methods of fertilization have been used, viz. stem injection and foliage spraying. Due to its simplicity the latter method has often been used for diagnostic purposes. Although the injection method is rather unusual it has been successfully applied on fruit trees. Thus e.g. BENNET (1931) injected iron salts in solid form. Thorough investigations of the injection method have been carried out by ROACH (1938) and ROACH & ROBERTS (1945) with the salts in solution. In conifers the latter method seems to be preferable. The use of solids is impeded because the injection holes are rather rapidly filled with resins. Table II B shows that the manganese content of needles increased to very high values after injection. The values exceed those obtained after foliage spraying despite the amounts supplied are smaller in relation to the size of the trees. Stem injection has apparently been much more effective than foliage spraying. This may be due to adverse weather after the foliage spraying, but this seems not probable since the weather situation was rather steady at the time for spraying both in 1955 and 1957. Too, the spraying method may be substantially inferior in conifers. A very high manganese content of birch leaves is reached after spraying. Since the foliage was thoroughly wetted on both spruce and birch the effects may be compared. Foliage spraying appears less effective on conifers than on broad-leaved trees. It is also evident that an increase of spray concentration has but a limited effect on the manganese content of the spruce needles. In birch, however, the effect is more definite (Table II C). It must, however, be hold in mind that after spraying manganese may be present on the outside of the leaves and needles that actually are sprayed.

The deficiency symptoms described in this paper are essentially of the same type as those of other plants (see e.g. WALLACE, 1951, and LUNDBLAD, 1955). Thus chlorosis is inherent in both spruce and birch. Chlorosis has been declared a consequence of decreased chlorophyll synthesis due to manganese deficiency (e.g. by BUKATSCH, 1942). In detail, however, the manganese deficiency symptoms vary considerably from one species to another. Thus, the symptoms are sometimes most pronounced in young leaves (potatoes), sometimes in old leaves (fruit trees). In many respects the morphology of long-lasting assimilation organs makes the symptoms rather specific in conifers. Thus, the symptoms are clearly concentrated on tender parts and only current needles are true-yellow. The symptoms in birch, however, are similar to those reported for many fruit trees, e.g. apples.

The results of analyses show that the deficiency symptoms indicate a very low manganese content of the foliage (Table II B and C). In spruce, values of 0.0004—0.0015 per cent are found in young needles that show chlorosis. Chlorosis is lacking at a manganese content of 0.0020 per cent. Untreated birch leaves exhibit chlorosis at a manganese content of 0.0007—0.0017 per cent. The upper limit, 0.0017 is correlated with symptoms that are quite obvious. Thus it may be suggested that chlorosis disappears at a manganese content of about 0.0020 per cent in spruce and above 0.0017 per cent in birch. GOODALL and GREGORY (1947, Table I) report the following per cent values of mangenese content that are correlated with deficiency symptoms: Citrus species 0.0002—0.0010, other fruit trees 0.0005—0.0025, and in some other plant species 0.0005—0.0030. The values reported for spruce and birch are obviously of similar magnitude. In this context attention may be called to the fact that soil fertilization eventually has raised not only the rate of growth (Figure 4) but also the manganese content of the needles to above those correlated with deficiency symptoms (Table II B). The deficiency symptoms, however, remained strong until 1957.

The analytical values also reveal other interesting facts. Especially in the samples of 1955 old needles of untreated spruce have a manganese content that is equal to or barely higher than that of current needles (Table II B). Consequently it does not seem likely that the disappearing of deficiency symptoms in old needles is the result of an increase in manganese content. Yet it is possible that the amount of manganese per unit of living substance is larger in old needles than in young ones. It is also possible that chlorophyll is slowly manufactured by synthesis also at low manganese content of the needles, e.g. at manganese deficiency.

High calcium content of the soil is also reflected in the foliage. However, it is interesting to notice the difference between the tree species in calcium uptake (Table II A). While the calcium content of birch leaves may amount to 1.3 per cent, current needles of spruce and pine contain only about 0.6 and 0.3 per cent respectively. In two-year old needles corresponding values are 1.2 and 0.7 respectively. The calcium uptake of spruce and especially pine is apparently slower than that of birch. Similar results have been obtained when studying another lime-rich area where the pH-value of the soil is lower than that stated for this area (TAMM, personal communication).

The growth measurements are not very representative because of the low number of trees. However, it seems reasonable to conclude that all methods of manganese fertilization produced a growth response (Table III and IV, Figure 4). The method of foliage spraying has not clearly increased the growth response when the concentration of manganese in the spray solution was raised (Table III). However, if mean values representing all sprayed trees are calculated, the growth response in relation to that of untreated trees is quite obvious (Figure 4). Although a slump was recorded in 1956, a growth response is clear also in spruce growing on fertilized soil (Figure 4). No definite conclusion can be drawn with respect to injected spruce but there is a tendency of growth increase both in terminal leaders and lateral shoots at least above the level of injection (Table IV).

The growth responses are correlated with the manganese content of the needles. Table II B shows that the foliage spraying in 1955 produced a notable increase of the manganese content and the effect remained also in 1956. Repeated spraying in 1957 has produced rather high values. However, an increase in manganese content is not immediately accompanied by a growth increase. Such a delay of response is a well-known phenomenon in trees. In the control trees there seems to be a spontaneous rise in the manganese uptake especially in 1957. Simultaneously, the growth rate has increased.

It may now be concluded that all the treatments have produced an increase of manganese uptake and growth and that manganese probably is a growth limiting factor at least for spruce on the studied site. It is of interest to notice that the nitrogen status of the area probably is unsatisfactory (Table II A). For this reason it is possible that nitrogen next to manganese has been a limiting factor and that the growth response to manganese supply would have been improved if nitrogen had been added.

The injection method effects the manganese content of the needles also in pine (Table II D). In contrast to what is found in spruce the manganese content of young needles is higher than that of old ones. The physiological condition of pine was poor at the time of injection and impaired after treatment. For this reason the results are hardly conclusive. New experiments with pine have been laid out. The manganese concentrations of the solutions were lower than those used in previous experiments and manganese sulphate was used instead of manganese chloride.

The investigation has shown that manganese deficiency may be of importance for the growth and development of the forest trees under certain conditions. However, unless there is a complete lack of manganese in the soil, manganese deficiency in conifers must be considered unusual. Since high pH-values are rare in Swedish forest soils on account of the properties of needle litter the conditions that cause manganese deficiency may be considered transitory. This is also seen in that often very high manganese contents in forest tree needles and leaves are found (TAMM, 1956 a, Table 5, and 1956 b, Table 2).

Summary

The cause of chlorosis observed in forest trees growing on a drained, lime-rich fen has been investigated by means of soil fertilization, foliage spraying, and stem injection (Table I). The experiments have produced the following results:

1. The chlorosis is caused by manganese deficiency.
2. Foliage spraying and stem injection with solutions containing $MnCl_2$, $4H_2O$ have led to a complete recovery of the green colour of spruce needles and birch leaves. Deficiency symptoms in spruce disappear when the manganese content of the needles amounts to about 0.0020 per cent of dry weight. Corresponding value for birch exceeds 0.0017 per cent. Soil fertilization has within three years not led to a disappearance of the symptoms in spruce in

spite of increased manganese content to above 0.0020 per cent. Subsequently, however, a more greenish tint has been noticed.

3. The manganese content of needles and leaves has increased considerably after foliage spraying, particularly in birch (Table II B and C). In spruce injection has been very effective (Table II B). After soil fertilization the increase in manganese content of spruce needles has been slight but obvious (Table II B). Stem injection has led to high manganese content of needles also in pine (Table II D).

4. Growth responses have been recorded in spruce after all treatments with manganese (Table III and IV).

The author is greatly indebted to Mrs Sigrid Santesson and Miss Britta Alverin for their careful analytical work, to Professor C. O. Tamm for valuable discussions and advice, and to Messrs S. Englund, T. Siltberg and H. Burgtorf for their kind help and assistance in the field work.

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Sammanfattning

Studier över manganbrist i ett skogsträdsbestånd

År 1953 iakttogs kloros hos årsbarren på granar, som växte på en dikad, kalkrik myr vid Levide på Gotland. En färgbild av en kvist från en sådan gran har publicerats av TAMM och INGESTAD (1955). Även björkarna inom området uppvisade kloros medan däremot tallarna föreföll förhållandevis friska. Då markens pH-värde var mycket högt (> 8) föreföll det troligt, att orsaken till klorosen kunde vara brist på något spårämne (jfr t. ex. TROUG 1943, p. 41). Ett preliminärt försök 1954 med markgödsling (fosfor, mangan, bor, koppar och zink) och besprutning (mangan, koppar och zink) visade, att klorosen försvann endast efter manganbesprutningen. Följaktligen lades senare nya försök ut för att bringa större klarhet i områdets mangantillstånd.

Mark och vegetation

Det aktuella området, som är helt litet, låg öppet till 1920, då det dikades och uppodlades. 1922 planterades björk och samtidigt kom en självföryngring av tall. Björken togs sedan bort så när som på några få träd och det resterande tallbeståndet gallrades och kvistrensades 1943, 1946 och 1951. Under beståndet finns nu några smågranar och runt om växer ett glest bestånd av björk, tall och några granar. I detta yttre område är markfloran relativt rik och domineras av gräs. Markprofilen består av ett tunt förnalager, ett sandblandat, gråbrunt mullager (ca 20 cm), ljusbrun sand (ca 10 cm) samt svartbrun torv (> 40 cm). Markens pH är högre än 8 i samtliga lager (kolorimetrisk bestämning).

Bristsymptom

Granens bristsymptom, som är de mest påfallande, består i en stark kloros hos årsbarren. Under den följande vintern och sommaren blir barren gradvis grönare. På hösten, andra året, är barren helt mörkgröna. Barrens längd och antal påverkas däremot inte synbart av bristsjukdomen. I Figur 1 ses tre grankvistar med ökande symptom från vänster till höger. Hos björken är symptomen starkast hos de äldre bladen, som är ljusgröna till gula mellan bladnerverna. Vid stark brist är bladstorleken ofta reducerad. I Figur 2 ses en serie björkblad med ökande symptom från vänster till höger.

Försök

Vid mangantillförseln har tre metoder använts: markgödsling, blad- och barrbesprutning samt staminjektion. Tabell I ger en sammanfattning av de olika försök, som utförts under åren 1954—1957 och som redovisas i denna uppsats. Av tabellen framgår också vilka givor, som använts.

Analysmetodik och analysresultat

Blad- och barrproven insamlades på hösten vid en tidpunkt, som gör det möjligt att jämföra analysresultaten från olika år (TAMM, 1951 och 1955). Sålunda insamlades björkbladen i slutet av augusti eller början av september. Barr insamlades i oktober eller november. Kvistar från lika behandlade träd delades i årgångar, vilka samlades i olika prov för separat analys. Tallbarren torkades avskilda medan

granbarr och björkblad torkades på kvistarna. Proven torkades därefter i vakuumugn och maldes.

Mangananalyserna har utförts enl. SANDELL (1950) efter inaskning på våta vägen. Övrig analysmetodik har beskrivits tidigare (INGESTAD, 1957). Analysfelet uppgår till 2—5 %.

Analysresultaten har samlats i Tabellerna II A—D. I vissa fall har en mera omfattande analys utförts (Tabell II A) men i andra fall har endast manganhalterna bestämts. I de flesta fall har analys utförts på de två sista årgångarna. Halterna är alltid uttryckta i procent av torrvikten.

Så långt jämförbara värden finns tillgängliga (se INGESTAD, 1957), ger analysresultaten ingen förklaring på symptomen, även om kvävehalterna är relativt låga och kalciumhalterna är höga. Manganhalterna är i de obehandlade träden låga och utgör endast en tiondel av järnhalterna, trots att dessa snarare är låga än höga. GLENISTER (1944) har angivit värdet 1 : 2 för kvoten Mn/Fe hos friska växter. Sålunda tyder även analysresultaten på att manganbrist är trolig.

Resultat

Vid mangantillförsel har symptomen minskat eller försvunnit. Detta är mindre påtagligt efter markgödsling än efter besprutning (Figur 1) eller staminjektion. Sålunda synes efter markgödslingen ingen effekt de tre första åren, men 1957 var klorosen mindre intensiv. Efter staminjektionen skedde redan samma år en fullständig återhämtning hos alla grenar över injektionsnivån. De nedre grenarna visade däremot ingen förbättring. Under 1956 och 1957 har färgen på de högt sittande grenarna ljusnat, men ännu är effekten av behandlingen helt påtaglig,

Tillväxtresultaten har samlats i Tabellerna III och IV samt i Figur 4. Tabell III visar, att utgångsläget varit mycket varierande hos de besprutade smågranarna på de olika ytorna. Vidare är antalet försöksträd litet. Det är därför svårt att göra en säker jämförelse mellan tillväxteffekterna efter de olika besprutningarna. Då emellertid frågan om manganbesprutningen över huvud taget medfört ökad tillväxt är av särskilt stort intresse, har medeltal beräknats för alla besprutade granar oberoende av mangankoncentrationen i vätskan. Dessa medeltal är återgivna i Figur 4, där också kurvorna för tillväxten på kontroll- och markgödslingsytorna finns medtagna. Det framgår av Tabell III och IV samt Figur 4, att alla gödslingsmetoderna medfört tillväxtökning. Då emellertid endast ett träd injicerats, är resultaten i Tabell IV mycket osäkra.

Diskussion

En serie försök att fastställa orsaken till en kloros hos gran har redovisats. Inom den aktuella ytan har pH befunnits vara mycket högt i marken. Det är därför icke förvånande, att orsaken till klorosen visat sig vara manganbrist. Bl. a. OLSEN (1934) har nämligen visat, att manganets löslighet i jorden starkt reduceras vid högt pH.

Vid försöken har två metoder använts, som avviker från gängse gödslingsmetodik, nämligen bladbesprutning och staminjektion. Båda har tidigare använts med framgång. Den förra utgör en enkel och ofta använd diagnostisk metod för fastställande av orsakerna till bristsymptom. Staminjektion med såväl fasta salter som lösningar har beskrivits av t. ex. BENNETT (1931), ROACH (1938) och ROACH & ROBERTS (1945). Hos barrträd synes det vara fördelaktigare att använda lösningar än fasta salter, då hartsutsöndring kan försvåra utnyttjandet av de senare. Barr-analysresultaten (Tabell II B och D) visar, att injektionsmetoden lett till de högsta manganhalterna trots att den tillförda mängden varit mindre i förhållande till trädens storlek. Att barrbesprutningen ej varit så effektiv kan bero på otjänlig väderlek. Detta är emellertid mindre troligt, då vädret varit stadigt vid besprutningarna både 1955 och 1957. Hos björk har besprutningen lett till höga halter (Tabell II C) och det är möjligt, att besprutning kan vara relativt ineffektivt hos barrträd.

Bristsymptomen är i stort sett av samma typ som hos andra växter (se t. ex. WALLACE, 1951, och LUNDBLAD, 1955). Sålunda ingår kloros i symptombilden hos såväl gran som björk. Kloros vid manganbrist anses bero på minskad klorofyllsyntes (t. ex. BUKATSCH, 1942). En minskad klorofyllsyntes kan också ha andra orsaker, t. ex. genetiska. Klorosen är ibland koncentrerad till de unga bladen (gran och t. ex. potatis), ibland till de äldre (björk och t. ex. fruktträd).

Hos gran motsvarar bristsymptomen halter på 0,0004—0,0015 procent mangan av torrvikten. Vid 0,0020 procent saknas däremot symptom. Hos björk finner man symptom vid halter på 0,0007—0,0017 procent. I det senare fallet är symptomen relativt svaga. Det synes sålunda troligt, att manganklorosen försvinner hos gran vid ca 0,0020 procents halt i barren och hos björk vid halter över 0,0017 procent i bladen. En jämförelse med motsvarande värden angivna av GOODALL och GREGORY (1947, Table I) för en rad olika växter ger vid handen, att gran och björk icke avviker i någon större utsträckning. I detta sammanhang bör påpekas, att markgödslingen lett till såväl tillväxtökning (Figur 4) som höjning av manganhalten i barren till värden, vilka överstiger dem, som motsvarar bristsymptom (Tabell II B). Bristsymptomen har trots detta varit starka ända till 1957.

Analysvärdena ger också andra intressanta upplysningar. Det framgår sålunda av Tabell II B, att manganhalten icke ökar med ökad ålder hos barren, men att klorosen trots detta försvinner andra året. Det är emellertid möjligt, att mängden mangan per mängd levande substans är större hos de tvååriga än de ettåriga barren. Det är också möjligt, att klorofyllsyntesen sker även vid låg manganhalt, men då betydligt långsammare.

Markens höga kalkhalt återspeglas i bladens och barrens kalciumhalter, dock i mindre utsträckning hos gran och speciellt tall än vad man skulle vänta. Sålunda framgår det av Tabell II A, att kalciumhalten i årsbarr från gran och tall är 0,6 resp. 0,3 procent, men däremot 1,3 procent hos björk. Det förefaller sålunda som om kalciumupptagningen hos gran och tall sker långsammare än hos björk.

Det förefaller möjligt att fastslå, att, även om tillväxtvärdena är ganska osäkra, alla mangangödslingsmetoder lett till tillväxtökning (Tabell III och IV, Figur 4). Det är emellertid svårt att avgöra om ökad mangankoncentration i besprutningsvätskan har givit ökad tillväxt (Tabell III). Om däremot medeltal beräknas motsvarande alla besprutade träd oberoende av mangankoncentrationen, finner man en klar tendens till tillväxtökning (Figur 4). Tillväxtökningarna är korrelerade med ökningar i manganhalterna i barren (Tabell II B). Det är möjligt, att tillväxtökningen varit mera markant, om kvävetillståndet hade varit bättre (Tabell II A).

Undersökningen har sålunda visat, att manganbrist under vissa omständigheter kan vara av betydelse för skogsträdens tillväxt och utveckling. Då emellertid höga pH-värden är ovanliga i svenska skogsmarker på grund av barrförnans egenskaper, torde manganbrist vara en sällsynt företeelse i skogen. Detta antydes också av att manganhalterna i blad och barr kan vara mycket höga hos skogsträden (se TAMM, 1956 a, Tabell 5 och 1956 b, Tabell 2).

Sammanfattning

Orsaken till en kloros hos skogsträd på en dikad, kalkrik myr har undersökts genom markgödsling, bladbesprutning och staminjektion. Följande resultat har framkommit:

1. Klorosen beror på manganbrist.
2. Klorosen försvinner hos gran när manganhalten uppnår ca 0,0020 procent av barrtorrvikten. Motsvarande värde för björk ligger högre än 0,0017 procent. Markgödsling har endast mycket långsamt påverkat bristsymptomen trots att manganhalterna ökat till över 0,0020 procent hos gran.
3. Manganhalterna i barr och blad har starkt ökat efter besprutning och staminjektion, men mindre efter markgödsling.
4. Tillväxten hos gran har ökat efter mangantillförsel genom såväl markgödsling som besprutning och staminjektion.

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