The movement of manganese in the plant and the practical consequences

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Summary and conclusions

It was investigated whether manganese applied to the leaves moves from them through the entire plant. The practical consequences of this movement are discussed with reference to the results obtained in trial fields. The following conclusions can be drawn: –

1. Manganese applied to the leaf is transported to the other parts of the plant.
2. The upward movement is much more pronounced than the downward one.
3. Manganese applied to the leaf is drawn off to the root whence it is distributed throughout the plant.
4. Despite this the redistribution of manganese by the plant from the root is insufficient to prevent manganese deficiency in the foliage formed after spraying.
5. In practice this means that if the soil-manganese supply is insufficient throughout the season the plants should be sprayed several times.
6. These conclusions are confirmed by the results obtained in trial fields of wheat, oats, beet and peas.
7. In the case of wheat, oats and beet, the first spraying is best applied as soon as manganese-deficiency symptoms become evident, and the second spraying some four weeks later.

For the control of marsh spot of peas the spray should be applied during flowering. It is best to do this in the middle of the flowering season and to repeat spraying at the end.
The percentage of marsh spot is not reduced by spraying prior to flowering.

1. Introduction

Manganese deficiency is found in soils which have a high pH. In Holland it is very common on sandy clay and calciferous clay soils in which the pH is naturally high and should also be high to ensure optimum growth. It is sporadically found on diluvial sandy soils, rarely over entire fields, but in small patches given excess lime. In such soils manganese deficiency may be prevented by ensuring that the pH-KCl does not exceed 5.4.

The usual method of controlling manganese deficiency in agricultural crops grown on clay soils is to apply a spray of dissolved manganese sulphate. In this connection it is important to know which is the best time to spray and how frequently.

When spraying is employed for the elimination of deficiency diseases it is important to know whether the element concerned moves in the plant from one leaf to another. If there is little or no movement it will be necessary to apply the spray at the time when the plant is in need of the element. The leaves formed subsequently to spraying will not benefit thereby and fresh spraying will be required. For this reason an investigation was made into the movement of manganese in the plant (chapter 3). The results obtained from spraying trial fields of various crops are discussed in chapter 4.

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2. Literature

ROMNEY and TOTH (1954) found that manganese applied to the leaf for control purposes was taken up by the leaf and stem tissue and moved in the plant, there being a tendency for manganese absorbed by the leaf to move upward rather than downward from the point of application. RUCK and GREGORY (1955) concluded that manganese is not moved from the subtending leaf to the bud growing nearby. Magnesium, unlike potassium, is not readily moved. BUKOVAC and WITTWER (1957, 1961) classified the nutrient elements according to their mobility in the bean plant after administration *via* the leaf. They divided the elements into three groups, *viz.* mobile (Rb, Na, K, P, Cl, S), partially mobile (Zn, Cu, Mn, Fe, Mo), and immobile (Mg, Ca, Sr, Ba). In contradistinction to ROMNEY and TOTH, they only noted an upward movement for manganese. BOKEN (1960) found that the manganese concentration in roots of plants sprayed with a 2 % manganese-sulphate solution took only a week to exceed the concentration in the roots of plants that had only been given a basic dressing. The content rose steadily with a decreasing number of days to harvesting, so that the greatest increase was found in plants harvested when ripe. But BOKEN does not state whether the soil was covered during spraying, and moreover manganese sprayed on the leaves might have been washed off by the rain, thus entering the soil from which it could have been taken up by the roots.

3. Movement of manganese in the plant

3.1. Materials and method

Beet and barley were sown in manganese-deficient soil in Mitscherlich pots on 23rd May, 1955. The plants emerged on 2nd June, their number being reduced to four per pot on 1st and 6th July. The beet plants were separated by glass plates and the barley plants by strings to prevent the leaves from touching. On 2nd and 8th July the upper- and underside of one leaf of two beet plants in each pot was wetted with a solution of 1½ % manganese sulphate (with Shell W spreader). A leaf of the two other plants in the same pot was wetted with water (with spreader).

Each barley plant was cut back to two shoots on 4th and 7th July. A leaf of one shoot was wetted with the above manganese-sulphate solution and a leaf of the other shoot with water. In both the beet and the barley the number of leaves above and below the wetted leaf were carefully counted at the commencement of the experiment. The barley was harvested leaf by leaf between 19th and 22nd July, and the beet on 22nd and 23rd July. The leaves of some beet plants were wetted twice and harvested on 28th July. The manganese content of each leaf was determined separately by a microbiological method (with *Lactobacillus arabinosis*). [1]

In other experiments (in 1957, 1958, 1960) use was made of radioactive manganese Mn^{54}. These experiments were performed in water cultures. The seed (sugar beet, *Klein Wanzleben* var. and summer barley, *Agio* var.) was pregerminated in purified glass sand. As soon after germination as the plantlets could be handled to some extent (about 10 days after sowing) they were placed in the nutrient solutions. Use was made of plastic pots with a capacity of 1,200 cc. Demineralised water and salts per analysis were used for making up the nutrient solutions. The salts $Ca(NO_3)_2$, KNO_3,

[1] The manganese content was determined by Dr. F. C. GERRETSEN. He intends to describe this microbiological method in a separate article.

KH_2PO_4 and $MgSO_4$. 7aq were recrystallized several times before use. Iron was supplied in the form of Fe-EDTA.
Per pot of 1,200 cc the complete nutrient solution contained: –
0.984 g $Ca(NO_3)_2$, 0.168 g KNO_3 , 0.168 g KH_2PO_4 , 0.348 g $MgSO_4$. 7aq , 2.016 mg H_3BO_3 , 0.576 mg $ZnSO_4$. 7aq , 0.144 mg $CuSO_4$. 5aq , 0.1 mg Na_2MoO_4 . 2aq and 10 mg Fe.
The nutrient solution was first replenished every fortnight and afterwards every week.
The radioactive manganese was administered in 1957 in three different ways, *viz.*: –

a. *Added to the nutrient solution.* On 5th August an approximately 4-week-old plant was placed in a pot containing the above nutrient solution to which had been added 1.512 mg $MnSO_4$. 4aq marked with 0.2 μC Mn^{54} (pot 554). Another pot (No. 739) was given the same amount of manganese sulphate, but marked with 0.5 μC Mn^{54}. The plants were harvested on 9th and 10th September.
b. *Spraying.* Two beet plants (pots 566 and 572) were sprayed on 10th and 16th August with a 1½ % manganese-sulphate solution to which had been added 0.3 μC Mn^{54} per 2 cc. Plant No. 566 was harvested on 6th September and No. 572 on 22nd August.
c. *Wetting.* One leaf of the beet plant in pot 570 was wetted with the solution specified in b. The fourth leaf from the bottom was wetted, so that three older and two younger leaves were present at the time. The plant was wetted on 5th, 10th, 16th and 19th August and harvested on 4th September.

One leaf of two barley plants (509 and 544) was wetted on 10th August. These plants were harvested on 13th and 12th September respectively.
The plants of all treatments were harvested leaf by leaf and placed in the dryer between filter paper, corrugated paper and two boards. The upper board was weighted with a distributed weight of 6 kilos. The leaves were dried for 2 hours at 90° C and afterwards for a night at 60° C. Any small tubers present during harvesting were either dried whole or cut into pieces. After the drying process autoradiographs were taken.
In 1958 the movement of manganese was studied within a single leaf, and in the case of barley the movement in the direction of the roots. In order to establish the movement within a single leaf, beet plants were cultured in a manganese-free nutrient solution (similar to that used in 1957). For wetting the leaf, use was made of 10 cc of a 1½ % manganese-sulphate solution to which had been added 20 μC Mn^{54} and a few drops of Shell W spreader.
Wetting was performed in three ways, *viz.*: –

aa. the left half of the leaf, upperside, was wetted.
bb. the upper half of the leaf, upperside, was wetted.
cc. the lower half of the leaf, upperside, was wetted.

The two halves of the leaf were separated by a thin coat of vaseline. Four plants were used for each wetting procedure. The leaves concerned were harvested after 6, 9, 13, and 18 days. The leaf parts were wetted twice, the interval being some hours.
The wetting procedures mentioned in aa, bb and cc were also performed by wetting both the upper- and underside of the leaf. These leaves were harvested after 28 days.
During harvesting the two halves were carefully cut off along the vaseline strip and dried in the same way as in 1957. Autoradiographs were then taken, after which the material was ashed and the number of counts a minute calculated with a Geiger-Müller tube.
In the barley experiment the movement towards the root was again studied. Three

plants were so arranged in a plexiglass vessel consisting of six compartments that a part of the roots grew in one compartment and the other part in another (split root). 1.512 mg of manganese sulphate (in 1,200 cc) marked with 5 μC Mn^{54} were added to the nutrient solution in one of these compartments. The same nutrient solution without manganese was placed in the other compartment. After a month the plants were harvested and dried, after which autoradiographs were taken.
The 1958 beet experiments were repeated in 1960, but not only was the upper- and underside of the leaf wetted separately but in some cases both sides. Moreover only a small portion of the petiole was wetted of one plant. Only leaves exhibiting clear symptoms of manganese deficiency were selected for wetting (this procedure was not always followed in the previous experiments). The leaf parts were wetted on 7th and 8th November. On 14th and 17th November the plants were examined for signs of reduced manganese deficiency. On 25th, 26th, 28th November and 1st December the wetted leaves were harvested and treated as in the previous experiments. After these leaves had been harvested the plants were placed for some time in the nutrient solution which was replenished every fortnight. On 6th April 1961 the plants were harvested and divided up into five portions, *viz.* the oldest leaves (dead), intermediate leaves, young leaves, neck of the beet and beet. The samples were dried and ashed, after which the number of counts per minute was estimated.

3.2. Results

3.2.1. *Beet experiments*

The results of the 1955 experiments are shown in FIG. 1 which illustrates the manganese content of the leaf wetted with manganese sulphate and that of the leaves above and below this leaf and of the leaves formed subsequently to wetting. The manganese content of the heart leaves is also given. It can be seen from this figure that the manganese content of the unwetted leaves of the "manganese" plant does not exceed that of the control ("water") plants, even when two wettings were applied. There is, however, a great difference between the manganese content of leaves wetted twice and those wetted once only.
The leaves of the Mn^{54} experiments in 1957 were placed on the photographic plate for 32—40 days; the results are shown in TABLE 1. When Mn^{54} is added to the nutrient solution it is possible to observe the radioactive manganese in the entire plant. The absence of autoradiographs of leaves 9, 10 and 11 is due to the too short "exposure time" of 14 and 18 days. The autoradiographs of the leaves of plant 739 with the same "exposure time" are often more distinct than those of plant 554, thus reflecting the difference in the amount of Mn^{54} added to the nutrient solution.
All leaves of sprayed plants contained Mn^{54}. It may be deduced from the fact that the Mn^{54} was also contained in the roots that the manganese sprayed on the leaves moved in a downward direction. Although plant 572 was harvested six days after the second spraying the roots were still radioactive; this would indicate rapid transport.
When only one leaf of the plant was wetted (No. 570) the root was also found to contain radioactive manganese. From this it may be deduced that the manganese applied to leaf passes down to the root. The first three leaves above the wetted leaf (5, 6 and 7) and the two leaves (1 and 2) below produced a very weak autoradiograph, only the main vein of these leaves being visible. This may be due to the redistribution of the manganese passed down to the root. The upper leaves produced no autoradiograph after an "exposure time" of as long as 40 days.

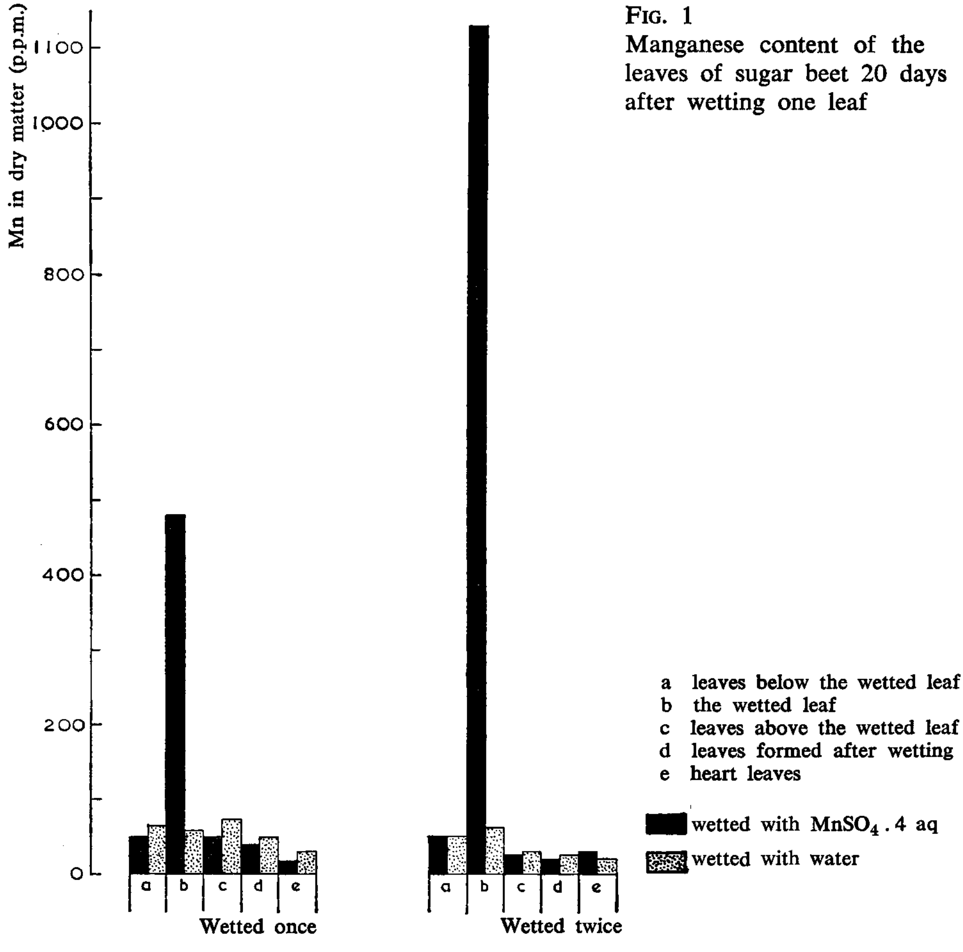

FIG. 1
Manganese content of the leaves of sugar beet 20 days after wetting one leaf

TABLE 2 shows the results of the 1958 autoradiographs, as well as the number of counts a minute measured with a geiger tube in the different leaf-halves. It can be seen that the movement of manganese from the left to the right half of the leaf is negligible, at any rate when the main vein and the underside are not wetted. The average number of counts per minute in the unwetted leaf-half is only slightly over 1 % of that in the wetted part. Except in the case of plant 324, no unwetted leaf-half produced an autoradiograph. Since a strip along the main vein is positive in this case, the possibility of contamination should not be overlooked.
Hardly any radioactive manganese is found in the lower leaf-half either when the upperside of the upper leaf-half is wetted.
On the other hand, when the upperside of the lower leaf-half is wetted the manganese is regularly distributed over the upper leaf-half. In this case the number of counts per minute in the unwetted part averages over 6 % of that in the wetted part, whereas in the two other treatments the average was only 1 % to 2 %.
However, when both the upper- and underside were wetted there was a greater degree

TABLE 1. Results of autoradiographs of beet foliage in 1957

Pot No.	Treatment	Date of harvesting	Autoradiograph of positive leaf sample					Negative —	Total No. of leaves
			very dist. ++++	distinct +++	good ++	weak +	very weak ±		
554	0.2 μC Mn^{54} added to nutrient solution on 5th August	9th Sept.				1, 2, 3, 4, 5, 7, 8 ashed beet (32—40 days)[1]	9, 10 (32 days)		10
739	0.2 μC Mn^{54} added to nutrient solution on 5th August	10th Sept.		1, 3, 4, 5, 12, 14 (40 days)		6, 7, 8 ashed beet (32 days)		9, 10, 11 (14—18 days)	14
572	Entire plant sprayed on 10th and 16th Aug.	22nd Aug.	1, 2, 3, 4 (32 days)	6, 8 (32 days)		7, 10 (32 days)	5, 9 ashed beet (32 days)		10
566	Entire plant sprayed on 10th and 16th Aug.	6th Sept.	1, 2, 3, 4 (32 days)	6 (32 days)	7 (32 days)		8, 9, 10, 11, 12, 13 ashed beet (32—40 days)		13
570	1 leaf of plant wetted on 5th, 10th, 16th and 19th Aug.	4th Sept.	wetted leaf (4) (32 days)				1, 2, 5, 6, 7[2] ashed beet (32 days)	8, 9, 10, 11, 12, 13, 14, 15 (40 days)	15

[1] Numbers shown in parentheses indicate the "exposure time".
[2] 1 and 2 below the wetted leaf; the 3rd leaf was lost; 7th and successive leaves newly formed.

TABLE 2. Effect on the Mn^{54} content in the unwetted part of the leaf when a part is wetted with Mn^{54}

Treatment	Pot No.	No. of days between wetting and harvesting	Wetted part		Unwetted part	
			autoradiogr.	counts/min.	autoradiogr.	counts/min.
Left half of upperside wetted	568-1	6	++++ (7 days)	259	— (27 days)	3
	568-2	6	++++ (8 „)	175	— (21 „)	3
	323	9	++++ (8 „)	220	— (10 „)	4
	322	13	++++ (8 „)	380	— (10 „)	4
	324	18	++++ (27 „)	206	± strip (27 days)	3
Upper half of upperside wetted	321	6	++++ (7 „)	186	+ strip (27 „)	3
	320	9	++++ (8 „)	210	+ strip (21 „)	2
	532	13	++++ (8 „)	151	— (21 days)	3
	530	18	++++ (10 „)	136	— (10 „)	6
Lower half of upperside wetted	336	6	++++ (7 „)	375	+++ (27 „)	14
	335	9	++++ (8 „)	163	+++ (21 „)	16
	524	13	++++ (8 „)	212	+++ (21 „)	9
	522	18	++++ (10 „)	94	++ (10 „)	14
Left half of upper- and underside wetted ..	509	28	++++ (35 „)	145	+++ (35 „)	17
Upper half of upper- and underside wetted	521	28	++++ (35 „)	158	+ (35 „)	6
Lower half of upper- and underside wetted	520	28	++++ (35 „)	111	++++ (35 „)	18

of movement in all three cases, but also in this instance there was least movement in the downward direction.

It follows from what has been stated above that the movement of manganese applied to the leaf depends on the point of application. If manganese is only applied to the upperside there is only a distinct movement from the base of the leaf to the apex, but when manganese is applied to both the upper- and underside it is moved in all directions, although in this case there is also least movement from the apex to the base of the leaf.

As was stated above, only leaves exhibiting distinct symptoms of manganese deficiency were wetted in 1960. When the upperside of the *entire* leaf was wetted the phenomenon of manganese deficiency practically disappeared on 14th and 17th November (respectively 7 and 10 days after wetting). The same is true when the upper- and underside are wetted simultaneously. When the underside is wetted there is far less improvement.

When the leaf *parts* are wetted, the wetted part shows about the same response as when the entire leaf is wetted. The response of the unwetted part depends on the point of application of the manganese. When only the left leaf-half is wetted a distinct improvement may be noted in the right leaf-half when both the upper- and underside are wetted. Wetting either the upper- or underside of the left leaf-half only has much less effect on the right leaf-half.

When the lower leaf-half is wetted manganese deficiency first decreases over the entire leaf; a few days later the unwetted upper half of the leaf again shows manganese-deficiency symptoms. Wetting the upper half of the leaf has practically no effect on the manganese-deficiency symptoms in the lower half.

On the whole, wetting the underside has a greater effect, at any rate on manganese-deficiency symptoms, than wetting the upperside.

When a portion of the petiole is wetted there is a marked reduction in manganese deficiency over the entire leaf, beginning at the base. The results of the autoradiographs of the different leaf parts are listed in TABLE 3. The number of days during which the leaves remained on the photographic plate are shown in parentheses. In this case also we notice a distinct movement in an upward direction. There is also a slight downward movement which takes 4 weeks to reveal itself in an autoradiograph.

As stated under 3.1 (materials and method) the wholly or partially treated leaves were harvested between 25th and 28th November. The nutrient solutions were then regularly replenished and the remainder of the plant was able to continue growing up to 6th April. This enabled us to establish to what extent manganese already transported from the treated leaf to the root had been redistributed over the plant. For this purpose the plant was ashed, after which the number of counts per minute was calculated. The results are shown in TABLE 4.

It was found that manganese transported to the root is distributed over the entire plant. Since the total activity was calculated, and not the activity per gram of ash, it is impossible to state whether the distribution is regular. The maximum total activity is reached when both the upper- and underside of the leaf is wetted.

3.2.2. *Barley experiments*

The results of the 1955 experiment are listed in FIG. 2, which shows the manganese content of the leaf wetted with manganese sulphate and water, as well as that of the leaves above this leaf and that of the leaves formed subsequent to wetting. The

TABLE 3. Results of autoradiographs of beet foliage in 1960

Treatment	Part of plant	Result of autoradiograph	
		14 days	28 days [1]
Left half of leaf			
Upperside wetted	*Left half of leaf*	++++	
	Right „ „ „	—	—
	Petiole	—	±
Underside wetted	*Left half of leaf*	++++	
	Right „ „ „	—	—
	Petiole	—	—
Upper- and underside wetted	*Left half of leaf*	++++	
	Right „ „ „	±	+
	Petiole	—	—
Lower half of leaf			
Upperside wetted	*Lower half of leaf*	++++	
	Upper „ „ „	+	+
	Petiole	—	+
Underside wetted	*Lower half of leaf*	++++	
	Upper „ „ „	+	+
	Petiole	—	±
Upper- and underside wetted	*Lower half of leaf*	++++	
	Upper „ „ „	+	++
	Petiole	—	±
Upper half of leaf			
Upperside wetted	Lower half of leaf	—	—
	Upper „ „ „	++++	
	Petiole	—	±
Underside wetted	Lower half of leaf	—	—
	Upper „ „ „	++++	
	Petiole	—	±
Upper- and underside wetted	Lower half of leaf	—	—
	Upper „ „ „	++++	
	Petiole	—	±
Portion of petiole wetted	Leaf	—	± main vein
	Wetted portion of petiole	++++	
	Petiole below wetted part	—	±
Entire leaf wetted			
Upperside wetted	*Leaf*	++++	
	Petiole	—	±
Underside wetted	*Leaf*	++++	
	Petiole	—	±
Upper- and underside wetted	*Leaf*	++++	
	Petiole	++	++++

[1] The wetted parts of the leaf were not exposed for 28 days.

++++ very distinct. + weak. — negative.
++ distinct. ± very weak.

manganese content of the ears is also given. The leaves below the wetted leaf are not taken into account as part of them had been lying on the ground. The manganese content of the leaves wetted with manganese sulphate is very high, but there is no difference between the unwetted leaves of the "manganese" plants and the control ("water") plants.

TABLE 4. Radioactivity in counts/min of beet plants over 4 months after harvesting the part of the plant treated with Mn^{54}

Part of plant wetted	Part of plant	No. of leaves	Activity in counts/min	Total counts/min
Entire leaf, upperside	Old leaf	15	22.0	
	Middle-aged leaf	25	3.9	
	Young leaf	25	17.0	
	Neck of beet	—	4.8	
	Beet	—	34.5	82.2
Entire leaf, underside	Old leaf	17	8.7	
	Middle-aged leaf	35	22.6	
	Young leaf	27	22.9	
	Neck of beet	—	7.7	
	Beet	—	27.4	89.3
Entire leaf, upper- and underside	Old leaf	17	36.0	
	Middle-aged leaf	27	25.5	
	Young leaf	27	21.4	
	Neck of beet	—	16.7	
	Beet	—	30.9	130.5
Left half of leaf, upperside	Old leaf	21	24.6	
	Middle-aged leaf	18	21.2	
	Young leaf	16	7.1	
	Neck of beet	—	12.8	
	Beet	—	18.3	84.0
Upper half of leaf, upperside	Old leaf	15	26.2	
	Middle-aged leaf	25	21.0	
	Young leaf	25	32.4	
	Neck of beet	—	8.9	
	Beet	—	11.9	100.4
Lower half of leaf, underside	Old leaf	14	27.6	
	Middle-aged leaf	31	19.3	
	Young leaf	30	10.6	
	Neck of beet	—	7.5	
	Beet	—	28.4	93.4
Lower half of leaf, upperside	Old leaf	14	22.0	
	Middle-aged leaf	16	23.2	
	Young leaf	25	10.3	55.5
Lower half of leaf, upper- and underside	Old leaf	7	22.8	
	Middle-aged leaf	22	32.1	
	Young leaf	23	17.1	
	Neck of beet	—	12.4	
	Beet	—	38.7	123.1
Portion of petiole	Old leaf	17	24.0	
	Middle-aged leaf	18	26.4	
	Young leaf	25	15.7	66.1

The leaves of the experiments conducted with Mn^{54} in 1957 were placed on the photographic plate for 30 days. The wetted leaf produces a distinct autoradiograph, but the remainder of the plant produces none at all, except the petiole of plant 509 (very weak).

FIG. 3 illustrates the experimental design followed in 1958. The results of the autoradiograph and the number of counts per minute are shown in the diagram. The exposure time was 27 days. As was anticipated, the Mn^{54} in the Mn^{54} compartment

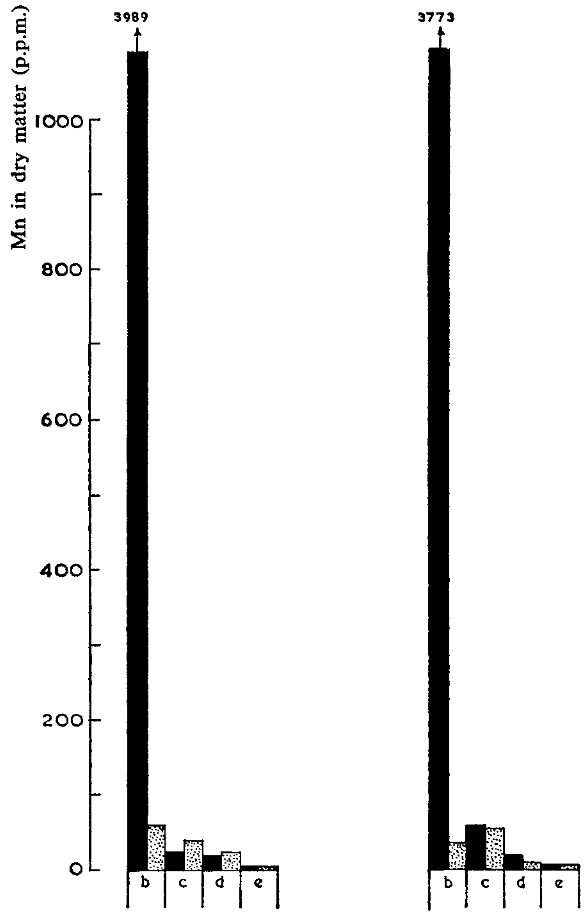

FIG. 2
Manganese content of the leaves of barley 20 days after wetting one leaf

b the wetted leaf
c leaves above the wetted leaf
d leaves formed after wetting
e ear

wetted with $MnSO_4 . 4$ aq
wetted with water

was uniformly distributed over the above-ground parts by the roots. Movement in the direction of the roots was very slight. In the large plant it proved to be quite considerable, this being due to the presence of Mn^{54} in the upper part of the root, possibly resulting from contamination. Hence this experiment shows that manganese is rapidly taken up by the plant and that there is some slight transport of manganese from the above-ground parts to the root.

3.3. Conclusion

It may be inferred from the above experiments that when manganese is applied to the leaf it is transported to the other parts of the plant, but that the movement depends on the site of application of the manganese. Treatment of parts of the leaf clearly demonstrated that there is more pronounced upward than downward movement of manganese. This is in agreement with the above-mentioned results obtained by ROMNEY and TOTH. When the upper- and underside are treated simultaneously, more manganese is found in the unwetted parts than when the upperside only is

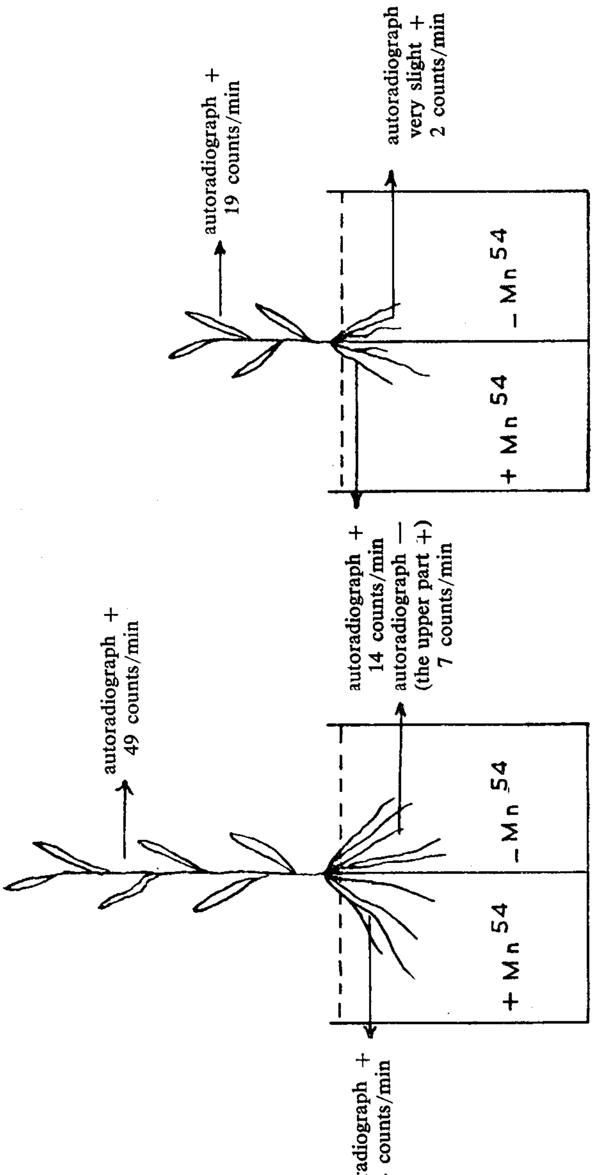

FIG. 3. Results of the split-root experiment with barley in 1958

wetted. Although in this case the total surface wetted is greater, as is also the total amount of manganese, it seems likely that the underside absorbs manganese more readily than the upperside.
Manganese applied to the leaf is transported in the direction of the root and thence redistributed over the plant. But this movement and redistribution is not considerable, so that it is a question whether in practice, when spraying mainly affects the upperside, such movement can make any substantial contribution towards the manganese supply of the leaves formed after spraying. If not, this would have a practical bearing on the spraying time and the number of sprayings required.

4. Results of spraying trial fields

The work described in chapter 3 showed that manganese applied to the leaves is readily transported in an upward direction, but only with difficulty in the opposite direction. Although there is some movement in the direction of the root, it is a question whether the redistribution of manganese transported to the root is sufficient to prevent manganese deficiency in the newly formed leaves.
This query is answered by the results of the field experiments conducted since 1954, the object of which was to ascertain the best spraying time and the optimum number of sprayings.

4.1. Field experiments with cereals

A number of trial fields of *winter wheat* were laid down in the Wieringermeer polder in 1954 and the various spraying times and combinations thereof compared. Severe manganese deficiency occurred on one of these trial fields and the results of this field are given below.
The first spraying (S_1) was on 13th April and the following at weekly intervals. The plants were sprayed with a solution of 1½ % manganese sulphate with added spreader (1,000 litres per ha). During the spraying on 6th May (S_4) the deficiency symptoms were marked and widespread. As TABLE 5 shows, spraying had the best effect on this date. When the plants were sprayed a week later (S_5) the yield was 400 kilos lower than after S_4. Some plots received a second spraying on 9th June, resulting in an additional increased yield of 400 kilos. There was an overall increase in yield of 1,450 kg per ha as a result of spraying on the appearance of the deficiency symptoms and repeating the spraying about four weeks afterwards.

TABLE 5. Effect on the grain yield of winter wheat of spraying with a solution of 1½ % manganese sulphate (1,000 l/ha)

Treatment	Grain yield in kg/ha av. of 4 replicates	Relative yield
No spraying	2930	100
S_1 „ on 13th April	3640	124
S_2 „ „ 20th „	3740	128
S_3 „ „ 26th „	3930	134
S_4 „ „ 6th May (severe and widespread deficiency symptoms)	3940	134
S_5 spraying on 14th May	3560	122
S_{26} „ „ 20th April and 9th June	4220	144
S_{46} „ „ 6th May and 9th June	4380	149
S_{56} „ „ 14th May and 9th June	3750	128

A trial field of *oats* was laid down in 1961 with a view to ascertaining the effect of different concentrations and amounts. On the first occasion the crop was sprayed when the deficiency symptoms appeared (24th May) and the spraying repeated on 27th June. The results obtained from this trial field are shown in TABLE 6.

TABLE 6. Effect on grain yield of oats of spraying with manganese-sulphate solution

Treatment				Grain yield in kg/ha, av. of 4 replicates	Relative yield
No.	spraying date	manganese-sulphate solution			
		amount in l/ha	%		
0	No spraying	—	—	2860	100
S_1	24th May	1000	1.5	3630	127
S_{12}	„ and 27th June	1000	1.5	3980	139
S_3	„	800	1.5	4090	143
S_{32}	„ and „	800	1.5	4060	142
S_4	„	600	1.5	3800	133
S_{42}	„ and „	600	1.5	4010	140
S_5	„	800	1.875	3820	134
S_{52}	„ and „	800	1.875	4220	148
S_6	„	600	2.5	3840	134
S_{62}	„ and „	600	2.5	4220	148

According to this table, the second spraying led to an additional increase in yield in four cases. There was only one exception. In this connection it should be noted that this treatment (S_3) was already producing a high yield, so that we are justified in asking whether the soil-manganese supply in these plots might not have improved. Although small differences occurred between the various treatments that were simultaneously sprayed, these differences cannot be reliably demonstrated. So we can conclude that both the concentration and amount of spray liquid may vary within wide limits provided there is no burning, which is a drawback of spraying cereals. The yield may be *radically reduced as a result of burning.* [1]

4.2. Field experiments with beet

The trial fields of beet clearly showed that the leaves formed after a spraying derive little benefit from the manganese dressing. This was found after a count made on different dates of the number of plants suffering from manganese deficiency. The first spraying was administered to a trial field of beet on 25th May and the second on 22nd June. The number of plants affected by manganese deficiency was counted on 20th June, nearly a month after the first spraying. TABLE 7 shows that 50 % of the plants on the untreated plots were suffering from manganese deficiency on that date, but only 11 % of the plots sprayed once on the same date. The number of diseased plants was again counted on 20th July, a month after the second spraying. The

1 Burning depends on the rate of uptake and the weather conditions. Uptake is most rapid when there is only slight evaporation on the leaf, *i.e.* when the sprayed surface remains wet for a long period. Care should be taken to ensure uniform distribution (large drops should be avoided). But the risk of burning increases when the leaves remain wet for a long time after spraying. According to CALDWELL (N.A.A.S. Quarterly Review (1955) 241—252) it is desirable for the leaf to be dry after about 15 minutes, so that spraying should not be carried out in poor drying weather. The best time for spraying on hot and sunny days is in the early morning or late afternoon. The rate of uptake can also be reduced by adding sugar, lime and magnesium sulphate.

TABLE 7. Manganese-deficiency symptoms in beet a month after spraying with a 1.5 % manganese-sulphate solution

Treatment		% of plants exhibiting manganese deficiency	
No.	spraying date	on 20th June	on 20th July
0	No spraying	50	38
S_1	25th May	11	26
S_{12}	„ and 22nd June	11	1.5
S_{123}	„ 22nd June and 20th July	11	1

number of diseased plants on plots sprayed once (S_1) was substantially equal to that on the untreated plots, whereas plots treated twice (S_{12}) only contained a small number of diseased plants. Here the newly formed leaves had not greatly benefited from the first spraying, with the result that manganese-deficiency symptoms reappeared. The yields from this trial field corresponded to these results. A single spraying scarcely increased the yield. Two sprayings increased it by 4.4 tons or over 9 %, and the sugar yield increased 767 kilos or over 10 %.

4.3. Field experiments with peas

The results obtained from the trial fields of peas also indicate that the movement of manganese applied to the leaf is too slight for the unsprayed parts of the plant to derive any benefit. Manganese deficiency of peas gives rise to marsh spot. In the 1958 experiments sprayings prior to and during flowering were compared. During threshing a sample was taken from each plot and 100 peas were examined for marsh spot.

It was found that on all three trial fields spraying prior to flowering causes no reduction in the percentage of marsh spot. The results obtained from one of the trial fields are listed in TABLE 8.

The untreated plots had an average of 78 % marsh spot. In plants sprayed prior to flowering (S_1) the percentage was the same as that of the untreated plots. The mean percentage of marsh spot in S_1 treatments (S_1, S_{12}, S_{13}, S_{14}, S_{123}, S_{134}, S_{1234}) was 32. The average of treatments without S_1 (0, S_2, S_3, S_4, S_{23}, S_{24}, S_{34} and S_{234}) was 29 %. This shows that spraying prior to flowering had no effect.

The best results were obtained by spraying the plants when in full bloom. The average infestation in S_3 treatments (S_3, S_{13}, S_{23}, S_{123}, S_{34}, S_{234} and S_{1234}) was only 16.5 %, whereas in treatments not sprayed on 19th June (S_1, S_2, S_{12}, S_4, S_{14}, S_{24}, S_{124}) it was 40 %.

Comparison of the various combinations of S_3 shows that S_{34} (spraying in full bloom combined with spraying at the end of flowering) was the best combination. The average infestation in the S_{34} treatments (S_{34}, S_{134}, S_{234} and S_{1234}) was 9.5 %, compared to 23.5 % in treatments in which S_3 was not combined with S_4 (S_3, S_{13}, S_{23} and S_{123}).

The results obtained from the other trial fields were in agreement with those given above. In this case, however, a single spraying in full bloom was sufficient. But in these experiments the percentage of marsh spot was much lower.

The results obtained with the trial fields of cereals, beet and peas are entirely in agreement with what was expected from the study of the movement of manganese applied to the leaf. The results of all field trials show that the plant should be sprayed

TABLE 8. Effect on the incidence of marsh spot in marrowfat peas (*Zelka* var.) of spraying with a 1½ % manganese-sulphate solution (1,000 l/ha)

Treatment		Percentage of marsh spot			
No.	spraying date	1	2	3	average
0	No spraying	75	83	76	78
S_1	28th May	84	90	76	83
S_2	11th June (a few flowers open)	49	49	37	45
S_{12}	Combination of S_1 and S_2	18	67	46	44
S_3	19th June (in full bloom)	26	28	16	23
S_{13}	Combination of S_1 and S_3	41	39	26	35
S_{23}	,, ,, S_2 ,, S_3	17	23	17	19
S_{123}	,, ,, S_1, S_2 and S_3	7	14	31	17
S_4	9th July (a few flowers still open)	42	6	44	31
S_{14}	Combination of S_1 and S_4	53	39	41	44
S_{24}	,, ,, S_2 ,, S_4	19	15	17	17
S_{124}	,, ,, S_1, S_2 and S_4	6	26	17	16
S_{34}	,, ,, S_3 and S_4	3	7	0	3
S_{134}	,, ,, S_1, S_3 and S_4	7	4	21	11
S_{234}	,, ,, S_2, S_3 and S_4	38	5	12	18
S_{1234}	,, ,, S_1, S_2, S_3 and S_4	9	7	3	6

when it requires manganese. Although it was demonstrated that manganese moves in the direction of the root, redistribution from the root is too slight to prevent manganese deficiency in the newly formed leaves. This is clearly illustrated by the good effect of a second spraying.

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