METHODS OF APPLICATION OF MANGANESE MATERIALS TO ORGANIC SOILS

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This is to certify that the

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METHODS OF APPLICATION OF MANGANESE MATERIALS TO ORGANIC SOILS

By

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INTRODUCTION

The essential role of manganese in the nutrition of plants is widely recognized. Willis (31) stated that manganese can be considered a true plant nutrient in the sense that it regulates important physiological processes. Further, he postulated that iron is reduced in the organism by the process of photosynthesis and that manganese serves to reoxidize it. That manganese is essential for the normal growth of most plants, especially in organic soils, has been definitely established. In muck and peat soils where applications of minor elements are a necessity for practically all crops, the characteristic chlorotic condition (mottled appearance and accentuated veination) of plants grown in manganese deficient soil is commonly observed.

Various methods have been devised in an attempt to counteract the condition of manganese deficiency in soils. Gilbert (6) found that the deficiency was readily corrected in onions either by spraying the plants with manganese sulphate or by mixing it with fertilizer. However, little research has been conducted in the way of adding manganese materials in the form of a dust-foliar application. No real attempt has been made to determine the extent of manganese intake through the foliage of plants dusted with a material containing the element. The question arises - what counteracting value does a manganese dust display on the deficiency symptoms? In addition, does the dust produce any toxic effects when applied to the foliage, and if so, at what percentage level?

These and other questions which arise prompted an investigation concerning the validity of the use of dusts applied to crops grown in manganese deficient organic soils. Several dust application treatments were set up and compared with the conventional methods of manganese application, to ascertain the differences, if any, in response to the minor element. Laboratory tests for manganese were conducted both on the foliar tissue of the crops grown and on the soil, in an attempt to correlate the quantity of the element present with the type and rate of application.

LITERATURE CITED

Manganese as observed by Vlasyuk (28), improves the assimilation of fertilizers, facilitates the decomposition of organic substances and increases the content of nutritive elements in the soil. Stoklasa (27) reported that manganese is tied up in carbon assimilation processes and promotes rapid photosynthesis in the chlorophyll apparatus. McHargue (17) presented data in agreement with Stoklasa and postulated his theory on the presence of large amounts of manganese in the leaves and lower concentrations in the roots of various plants. Remington and Shiver (22), in examining a number of different vegetables, found from three to eight times as much manganese in the leafy parts as in the roots.

According to Salomone (24), manganese salts stimulated the formation of nitrogenous compounds in the plant. Meyer and Anderson (19) agreed somewhat with Salomone in that they stated that manganese is related in some way to chlorophyll synthesis, and that it plays a part in the oxidation-reduction phenomena of the physiologically active parts of plants.

The first applications of manganese sulfate were made on rice plantations in Japan in 1902 by Aso (1) and in 1903 by Nagoaka (20). The first application of manganese to organic soil probably was made in Sweden by von Feilitzen (29) in 1907.

Russell (23) stated that the soils of England in which manganese deficiency diseases have been found have usually been of the same general type, namely reclaimed peats rich in organic matter and made alkaline by lime.

In Michigan, according to data presented by Harmer (10), manganese deficiency appears on high-lime organic soils which have been burned; on those which are fed by alkaline spring water; on those which have a marl deposit near the surface and on those which originally were acid but have been made alkaline by the application of lime.

According to McGeorge (16), lime-induced chlorosis was not caused by a deficiency of the micro-nutrient elements in the soil but rather was due to a physiological deficiency in which the calcium carbonate content of the soil and its accompanying alkalinity are influencing factors whereby the micro-nutrient elements, especially iron, are rendered inactive in the roots of the plant. Leeper (14), on the other hand, has suggested an hypothesis in which he holds that manganese exists in an equilibrium in the soil as expressed by the following equation: Manganous Mn $\rightleftarrows$ Colloidal Hydrated $MnO_2 \rightleftarrows$ Inert MnO_2. Manganese deficiency is supposedly caused by a reversion of the manganous form of manganese to the inert form of MnO_2. Mellor (18) had substantially the same theory based on experiments in which he showed that hydrated manganous oxide is precipitated in a very fine state of subdivision when a manganous salt is added to neutral or alkaline solutions. Colloidal hydrated manganous oxide is rapidly oxidized to the hydrated dioxide, especially in the presence of alkaline earth hydroxides. This hydrated oxide is easily reduced.

Conner (2) stated that manganese of soils kept under reducing conditions tends to be more soluble than the manganese of soils exposed to oxidizing influences. This follows in line with the thinking of Piper (21) who stated that the availability of manganese is influenced by at least two factors, soil reaction and the oxidation-reduction equilibrium, acting in intimate association. Sherman and Harmer (26) have shown that neutral and alkaline soils possess a great capacity for fixing added soluble manganese. On the other hand, soluble manganese added to strongly acid soils has been found to remain in a very available form. Reducing conditions, however, according to their findings, increase the divalent manganese in the soil.

Cook (3) applied manganese sulfate as a side dressing and spray in early summer to sugar beets at dosages of 100 and 5 pounds per acre respectively. Marked differences in leaf color were noticeable within 10 days. deHaan (5) obtained large increases in yields of sugar beets showing manganese deficiency either by spraying with a 1.9% $MnSO_4$ spray at the rate of 13.5 pounds per acre or by applying $MnSO_4$ mixed with sand at the rate of 54 pounds per acre at planting time. However, results obtained by Gregoire, Hendrick and Carpiaux (8), in experiments with the same crop using sulfate of manganese applied at planting time in quantities varying from 9 to 45 pounds per acre, were not in agreement with deHaan in that the use of the manganese compound slightly lowered the yield of beets but their sugar content was apparently raised in the same proportion. On unproductive alkaline mucks, an annual application of 100 to 200 pounds per acre of manganese sulfate mixed with the fertilizer and added to muck soil crops supplies their need for manganese according to Harmer (9).

Harmer (11) also has shown that manganese sulfate applied in solution as a stream or as a spray on the leaves will produce as good or better results with a much lower rate of application than when the manganese sulfate is applied in the fertilizer. According to Mann (15) the corrective effect of manganese solutions applied to the leaves was evident at dilutions as great as one part of manganese sulfate in one-hundred thousand of water. Davis (4) advocated that four pounds of manganese sulfate per 100 gallons of spray are adequate for crops to show a response to manganese.

Gilbert and McLean (7) found that freedom from chlorosis and increased yields of onions were secured when manganous sulfate was applied especially in the solution form and at a rate of eight pounds per acre. Knott (13), on the other hand, working with the same crop observed striking increases in growth resulting from the addition of 100 pounds of manganese sulfate per acre applied at planting time.

Very little has been done experimentally in this country in the way of adding manganese as a foliar dust. However, according to Klougart (12) a 25% $MnSO_4$ dust has been used as a standard practice for application to any manganese deficient crop in Denmark.

Wilson (32) asserted that the use of the common talcs with dust formulas affords little danger of injury from the diluent fraction.

PROCEDURE

In the fall of 1950, muck was obtained from an unreclaimed area south of the experimental plots at the Michigan State College Muck Experimental Farm. The soil obtained was taken from the upper 12 inches of the profile and later removed to the greenhouse where it was allowed to dry down to apparent optimum moisture conditions for the crops to be grown. Moisture and pH determinations were taken as soon as these conditions prevailed.

One-hundred and twenty-two gallon pots were filled with a uniform weight of soil which had passed through a 1/4 inch screen. To the soil in each pot were added the equivalent of 10 tons per acre of calcium carbonate and 3000 pounds per acre of a 3-9-18 fertilizer mixture, with the exception of 8 pots which were to be used as check pots.

Sixty pots were seeded to sugar beets (Variety 215 x 216) and the remaining sixty to onions (Variety Brigham's Yellow Globe). Approximately 20 sugar beet seeds were planted per pot, and in the case of onions 20-30 seeds per pot were used. The seeds of both crops were treated with Arasan to prevent damage from soil-borne organisms. The sugar beets were thinned to 6, later to 3 and finally to 2 plants per pot. The onions were thinned to 6 plants per pot.

The sixty pots for each crop included 15 treatments, each replicated four times. The following treatments were applied:

1.	$MnSO_4$[1] (spray grade)	100%	dust
2.	" " "	70%	"
3.	" " "	40%	"
4.	" " "	10%	"
5.	Talc check		
6.	Nu-M[2]	100%	dust
7.	"	70%	"
8.	"	40%	"
9.	"	10%	"
10.	No dust		
11.	$MnSO_4$	1.5%	spray

12. $MnSO_4$ mixed with the fertilizer and applied at the rate of 400 pounds per acre at planting time.
13. $MnSO_4$ applied as a side-dressing at the rate of 400 pounds per acre.
14. No lime[3]
15. Nu-M mixed with the fertilizer and applied at the rate of 400 pounds per acre at planting time.

In treatments 1 to 11 inclusive, with the exception of treatment 10, the soils of replications 3 and 4 were covered to prevent dust or spray from coming in contact with their surfaces. These treatments were applied at 2 week intervals.

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[1] Tecmangam, a product of Tennessee Eastman Corporation, was the source of all $MnSO_4$ used in the experiment. It contains 65% soluble $MnSO_4$, other ingredients being ammonium sulphate and magnesium sulphate.

[2] Nu-M, also a product of Tennessee Eastman Corp., is a basic manganese sulfate-carbonate containing 41% metallic manganese.

[3] With the exception of treatment 14, all treatments received the equivalent of 10 tons of lime per acre in order to create a manganese deficiency.

Treatments 1 to 9 inclusive were applied at the rate of 50 pounds per acre for the first three applications to the sugar beets. Subsequent applications for this crop were applied at the rate of 150 pounds per acre. In the case of onions, the same treatments were applied at the rate of 50 pounds per acre for the first application. The next 3 applications were added at the rate of 150 pounds per acre, while the last 3 applications were at the rate of 50 pounds per acre.

All dust treatments were applied by means of a dusting tower (Fig. 1 and 2)*. A known quantity of dust was introduced into the T-tube at the top of the chamber and discharged manually with the aid of an atomizer bulb. The dust descended through a long cylinder and by the time it reached the plant at the bottom it was dispersed evenly over the water-moistened exposed leaf surface. A 1/4 inch wire screen was used to wrap around the plants in order to confine all the leaves within the cylinder.

In treatment 11 the spray was applied to the plants by a hand sprayer until complete leaf coverage was obtained (approximately 200 gals. of spray per acre).

*Dr. G.H.R. Hervey, Dept. of Entomology, New York Agr. Exp. Sta. supplied dusting tower plans which were later modified by Dr. J. F. Davis of the Michigan State College Soil Sci. Department.

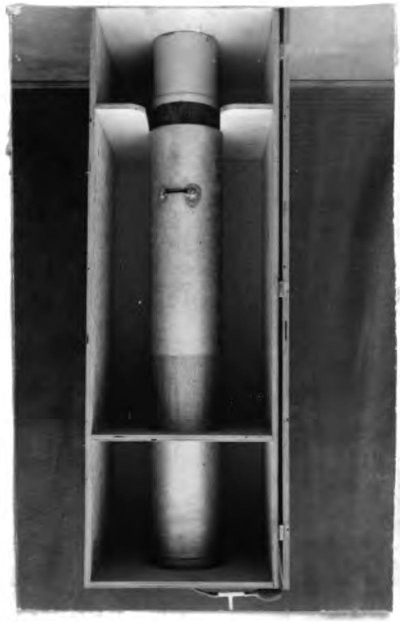

Fig. 1 - Dusting tower showing wire-enclosed plant in position for dust treatment discharged from T-tube at top by means of atomizer bulb. Note movable cylinder in "down" position.

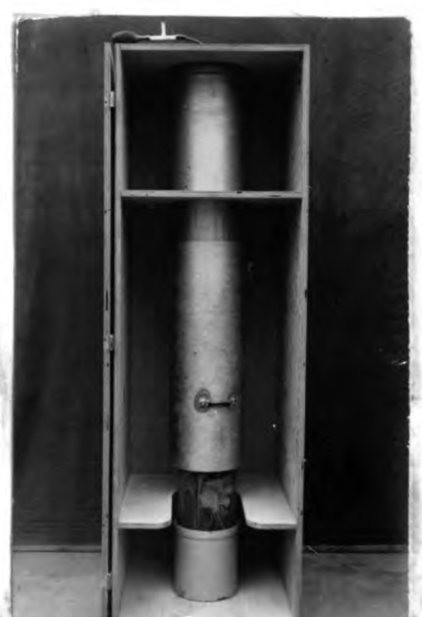

Fig. 2 - Dusting tower showing wire-enclosed plant in position for removal after treatment. Note movable cylinder in "up" position.

The manganese materials used in treatments 12 and 15 were applied at planting time. The specified amounts of $MnSO_4$ or Nu-M were thoroughly incorporated with the soil before seeding.

As regards to treatment 13, the material was sprinkled on the soil surface and incorporated into the top inch of the soil.

During the early growth of the crops, copper was added to all pots at the rate of 100 pounds of $CuSO_4$ per acre. In later stages of growth, a total of 600 pounds per acre of ammonium nitrate were added at different intervals to the sugar beets in an attempt to counteract an apparent nitrogen deficiency.

One week following the application of each dust and spray treatment, notes on the degree of counteraction of the manganese deficiency symptoms were taken for all treatments.

At harvest time, both leaves and roots of the sugar beets, and in the case of onions, tops and bulbs, were analyzed for total manganese. An attempted correlation of these results was made with the yields of the same crops.

Soil samples from limed and unlimed pots were taken and analyzed for exchangeable, easily-reducible, and total manganese.

Leaves from sugar beets in separate field treatments of 1% $MnSO_4$ spray; 50% $MnSO_4$ dust; 50% Nu-M dust, and Check, all grown at the Muck Experimental Farm on a soil to which had been applied 9 tons of limestone per acre, were taken at various intervals during the growing season and analyzed for total manganese. These results were compared with those obtained under greenhouse conditions.

Exchangeable Manganese (25): Exchangeable manganese is the manganese which can be replaced in the soil complex by cation exchange. The exchangeable medium used was a normal neutral ammonium acetate solution adjusted to pH 7.0.

To the 5 gram soil sample from which a moisture sample was taken was added 250 ml. of neutral normal ammonium acetate. The flask was tightly stoppered and then shaken at frequent intervals. At the end of 24 hours it was assumed that equilibrium had been attained. The mixture was filtered through a Büchner funnel, the soil washed with portions of ammonium acetate solution and the soil again returned to the original flask. The filtrate was evaporated to a small volume and it then transferred to crucibles and evaporated to dryness. After the filtrate had reached dryness, the residue was taken up with concentrated HNO_3, after which was added 10 drops of 85% phosphoric acid, 2-3 drops of concentrated sulfuric acid and 0.3 gram of potassium periodate.

The solution was then heated until full color of the permanganate developed. It was then cooled and compared in a colorimeter with previously prepared standards. The manganese content was reported in parts per million.

Easily-Reducible Manganese Dioxide (25): Easily-reducible manganese is the quantity of manganese dioxide that can be reduced by a 0.2 per cent solution of hydroquinone in a buffered solution of neutral, normal ammonium acetate after the water-soluble and exchangeable manganese have been extracted.

To the soil sample from which the exchangeable manganese was extracted was added 250 ml. of normal ammonium acetate solution containing 0.2% hydroquinone and buffered to the pH 7.0. The flask was tightly stoppered and shaken at frequent intervals. At the end of 24 hours the content was filtered through a Büchner funnel and the filtrate treated in the same manner as the filtrate in the exchangeable manganese determination.

Total Manganese (30): A 5 gram sample of air-dry soil or tissue, from which a moisture sample was taken, was weighed into a crucible and ignited over night at 500°-600° C. Three to 5 ml. concentrated nitric acid were added to the ash and boiled for 1 minute. Approximately 25 ml. of distilled water were then added and filtered through a

Büchner funnel. The residue was washed with hot water until the washings came through free of nitrates (test with diphenylamine). The filtrate was evaporated to a volume of 10-40 ml. and treated in the same manner as that for the exchangeable manganese determination.

DISCUSSION OF EXPERIMENTAL RESULTS

Sugar Beets

Fig. 3 - Two sugar beet leaves comparing a healthy leaf on the left with a severely chlorotic one on the right due to a deficiency of manganese.

Fig. 4 - Sugar beets 14 weeks of age. 0 - no lime; 1 - 10 tons lime per acre. Notice the chlorosis of the plants which had received lime.

The legend used for manganese deficiency symptoms of sugar beets is:

h - healthy
v sl - very slightly chlorotic
sl - slightly chlorotic
m - moderately chlorotic
m sev - moderately severely chlorotic
sev - severely chlorotic

Table 1. Manganese deficiency symptoms one week following second application of manganese dusts and spray to sugar beets.

Treatment	Replication 1	2	3	4	Total Mn applied to plants or soil (lb./A)
$MnSO_4$[1] 100% dust	v sl	m sev	m	h	23.4
" 70% "	sl	h	h	v sl	16.4
" 40% "	m	v sl	sl	v sl	9.4
" 10% "	v sl	m sev	sl	m	2.3
Talc check	m sev	sl	m sev	sl	none
Nu-M[2] 100% dust	m sev	sev	m	m sev	40
" 70% "	m	m	sev	m	28
" 40% "	sl	sl	m	v sl	16
" 10% "	m sev	m sev	sev	sev	4
No dust	v sl	sl	m sev	sev	none
$MnSO_4$[3] 1.5% spray	h	sl	v sl	h	12.2
"[4] P.T.	h	sl	h	v sl	93.6
"[5] S.D.	m	v sl	h	h	93.6
No lime	v sl	v sl	h	h	none
Nu-M P.T.	v sl	v sl	v sl	v sl	160

[1]$MnSO_4$ spray grade contains 23.4% Mn.

[2]Nu-M contains approximately 40% Mn.

[3]$MnSO_4$ spray applied at approximately 200 gals. per acre.

[4]$MnSO_4$ P.T. - $MnSO_4$ applied at planting time.

[5]$MnSO_4$ S.D. - $MnSO_4$ side-dressed.

From Table 1 it is observed that the least amount of chlorosis at this stage was present in plants that received soil application of manganese, either at planting time or as a side-dressing. There was no definite correlation between the amount of manganese applied and the symptoms observed in plants receiving dust treatments at this stage although a slight trend could be detected.

Table 2. Manganese deficiency symptoms one week following third application of manganese dusts and spray to sugar beets.

Treatment	Replication 1	2	3	4	Total Mn applied to plants or soil (lb./A)
$MnSO_4$ 100% dust	h	v sl	v sl	sl	35
" 70% "	sl	h	h	sl	24.6
" 40% "	v sl	v sl	m	m	14
" 10% "	m	m sev	m	m	3.5
Talc check	m sev	h	sev	m sev	none
Nu-M 100% dust	sev	sev	m sev	sev	60
" 70% "	m sev	m	sev	sev	42
" 40% "	m	m sev	m sev	m	24
" 10% "	m sev	m	sev	m sev	6
No dust	sev	m sev	sev	sev	none
$MnSO_4$ 1.5% spray	h	h	h	h	18.3
" P.T.	h	v sl	h	v sl	93.6
" S.D.	v sl	h	h	h	93.6
No lime	h	h	h	h	none
Nu-M P.T.	h	v sl	v sl	v sl	160

Table 2 shows the increasing effectiveness of the manganese in those plants growing in pots where it was applied to the soil. Treatments of $MnSO_4$ P.T., $MnSO_4$ S.D. and Nu-M P.T. are rapidly overcoming the manganese deficiencies while the treatments of $MnSO_4$ spray and the unlimed treatment have already resulted in a healthy appearance of the plants. It is interesting to note that plants receiving the spray treatment gave a Mn response as quickly as those to which no lime was applied although no deficiency symptoms were expected in the latter case. The pronounced symptoms displayed by plants treated with the $MnSO_4$ dust could be readily observed where increased amounts of the element were applied. The converse could be noted in the treatments involving the Nu-M dust. Plants receiving the Talc and No Dust treatments responded as expected.

Table 3. Manganese deficiency symptoms one week following fourth application of manganese dusts and spray to sugar beets.

Treatment	Replication 1	2	3	4	Total Mn applied to plants or soil (lb./A)
$MnSO_4$ 100% dust	h	v sl	h	v sl	70.2
" 70% "	v sl	h	h	v sl	49.1
" 40% "	h	h	v sl	h	28
" 10% "	sl	m	sl	m	7
Talc check	m	h	m sev	m	none
Nu-M 100% dust	m sev	m sev	m	m sev	120
" 70% "	m	sl	sev	sev	84
" 40% "	sl	sev	m sev	m sev	48
" 10% "	sev	sev	m	sev	12
No dust	sev	m sev	sev	sev	none
$MnSO_4$ 1.5% spray	h	h	h	h	24.4
" P.T.	h	h	h	h	93.6
" S.D.	h	h	h	h	93.6
No lime	h	h	h	h	none
Nu-M P.T.	h	v sl	v sl	h	160

Table 3 shows that the last five treatments generally resulted in the growth of healthy sugar beet plants. Increasing amounts of $MnSO_4$ dust, with the exception of the 10% treatment, quickly improved the appearance of the plants. The Nu-M dust treatments appeared to be adding little Mn to the plants involved and the chlorotic symptoms of the plants remained practically unchanged. Similarly no changes occurred in the chlorotic condition of the sugar beet plants receiving the Talc or "no dust" treatments.

Table 4. Manganese deficiency symptoms one week following fifth application of manganese dusts and spray to sugar beets.

Treatment	Replication 1	2	3	4	Total Mn applied to plants or soil (lb./A)
$MnSO_4$ 100% dust	h	h	h	h	105.3
" 70% "	h	h	h	h	73.7
" 40% "	h	h	h	h	42.1
" 10% "	h	sl	h	sl	10.5
Talc check	m	h	m sev	m	none
Nu-M 100% dust	h	v sl	sl	m	180
" 70% "	v sl	sl	m	m sev	126
" 40% "	h	m sev	h	m sev	72
" 10% "	sev	m	m	sev	18
No dust	sev	m sev	sev	sev	none
$MnSO_4$ 1.5% spray	h	sl	h	h	30.6
" P.T.	h	h	h	h	93.6
" S.D.	h	h	v sl	h	93.6
No lime	h	h	h	h	none
Nu-M P.T.	h	h	h	h	160

Table 4 shows that the $MnSO_4$ dust treatments, in general, have resulted in the production of healthy plants. Plants receiving the Nu-M dust treatments gradually overcame the severe manganese deficiency symptoms. The effectiveness increased as the amount of manganese applied was increased.

Table 5. Manganese deficiency symptoms one week following the sixth application of manganese dusts and spray, compared with average yields of sugar beets.

Treatment	Replication 1	2	3	4	Total Mn applied to plants or soil (lb./A)	Average yield (gms.)
$MnSO_4$ 100% dust	h	h	h	h	140.4	350
" 70% "	h	h	h	h	98.3	335
" 40% "	h	h	h	h	56.2	289
" 10% "	h	v sl	h	h	14	321
Talc check	v sl	v sl	m	m	none	330
Nu-M 100% dust	h	h	h	h	240	320
" 70% "	h	h	h	h	168	299
" 40% "	h	v sl	h	m	96	328
" 10% "	sl	h	h	v sl	24	282
No dust	sev	m sev	m sev	sev	none	258
$MnSO_4$ 1.5% spray	h	v sl	h	h	36.7	332
" P.T.	h	h	h	h	93.6	328
" S.D.	h	h	h	h	93.6	299
No lime	h	h	h	sl	none	283
Nu-M P.T.	h	h	h	h	160	328

Table 5 shows the rapid disappearance of the manganese deficiency symptoms of the beets receiving the Nu-M dust treatments and their effects on yields. This table may be compared with the detailed yield results shown in Table 6.

From the foregoing tables it is noticed that the plants giving the quickest response to manganese applications were those growing on soil treated with manganese either at planting time, as a side-dressing, or as a foliar spray application. Plants treated with $MnSO_4$ as a foliar dust were slower to respond with the 100% and 70% treatments giving the quicker responses in this case. The slowest response to manganese application was observed in plants on which Nu-M was applied as a foliar dust. None of the foliar applications, regardless of the dilution, caused an injury to the plants thus treated.

Critical levels of manganese are evident in the various methods of application. Chlorosis disappeared when approximately 15 pounds of Mn per acre were added as a spray. With the use of $MnSO_4$ dusts the same results appeared only after 30-40 pounds per acre of Mn had been applied. However, it required about 175 pounds per acre of Mn applied as a Nu-M dust to give the desired healthy condition of the plants. The amount of manganese added in the soil applications evidently was sufficient as normal healthy growth was quickly attained after treatment.

Table 6. The effect of methods of application of two manganese materials on the yield of sugar beets grown in the greenhouse.

Grams per pot

Treatment	Treat. No.	Replication 1	2	3	4	Mean
$MnSO_4$ 100% dust	1	340	253	452	362	350
" 70% "	2	318	341	342	341	335
" 40% "	3	269	336	256	295	289
" 10% "	4	295	267	355	267	321
Talc check	5	392	292	313	324	330
Nu-M 100% dust	6	301	332	275	373	320
" 70% "	7	294	283	283	336	299
" 40% "	8	325	380	292	317	328
" 10% "	9	214	266	319	329	282
No dust	10	308	255	250	220	258
$MnSO_4$ 1.5% spray	11	416	290	322	301	332
" P.T.	12	362	267	350	335	329
" S.D.	13	339	296	329	254	300
No lime	14	282	270	314	289	289
Nu-M P.T.	15	353	316	312	330	328

Table 7. Final analysis of variance table of yield data obtained from sugar beets grown in the greenhouse.

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Total	59	118882.98		
Blocks	3	6468.31	2156.10	
Treatments	14	35963.73	2568.84	1.41
Error	42	76450.94	1820.26	

F at 5% level 1.94

Failure of F to reach level of 5% point signifies that no significance existed between treatments.

Although no significance existed between treatments, a definite trend was in evidence. The highest yield was obtained from plants treated with 100% $MnSO_4$ dust and the lowest yield from those receiving no dust treatment. Second and third highest yields were obtained from plants receiving the 70% $MnSO_4$ dust and $MnSO_4$ spray treatments respectively. The average yield of all $MnSO_4$ dusted plants was 324 grams as compared to 337 and 319 grams for those receiving the Nu-M dust treatments and soil application treatments respectively.

With reference to Table 6 it is noticed that the covering of the soil surfaces in replications 3 and 4 of the dust and spray treatments had no influence on yield of beets.

Table 8. Quantities of exchangeable, easily-reducible, and total manganese in limed and unlimed organic soils.

Form of Mn	Limed soil (Mn in p.p.m.)	Unlimed soil (Mn in p.p.m.)
Exchangeable	14	45
Easily Reducible	45	100
Inert	114	32
Total	173	177

Table 8 demonstrates the effect of lime in changing the amounts of manganese present in the various forms. The initial pH of the soil before liming was 6.0 but was raised to a pH of 8.1 after the equivalent of 10 tons of lime per acre had been added. Undoubtedly the high alkalinity influenced the manganese equilibrium within the soil causing a reversion of the more soluble forms to forms which were more highly oxidized and as such were more unavailable to the plant. This unavailability was evidenced by the chlorotic condition of sugar beets and retarded growth in onions on soils treated with lime.

Table 9. The effect of manganese applications on total manganese in sugar beet tissue and on yields.

Treatment	Total Mn in leaves (p.p.m.)	Total Mn in roots (p.p.m.)	Average yield (gms.)
$MnSO_4$ 100% dust	1125	80	350
" 70% "	875	25	335
" 40% "	325	20	289
" 10% "	225	10	321
Talc check	50	5	330
Nu-M 100% dust	163	15	320
" 70% "	150	10	299
" 40% "	100	5	328
" 10% "	113	10	282
No dust	38	5	258
$MnSO_4$ 1.5% spray	1125	10	332
" P.T.	63	15	329
" S.D.	75	15	300
No lime	100	55	289
Nu-M P.T.	100	40	328

Table 9 shows that applications of manganese resulted in an increased manganese content in the plant tissue. It is interesting to note the differences in the amount of manganese absorbed into the leaves by the various foliar applications. The $MnSO_4$ dust was absorbed to a much greater extent than Nu-M dust regardless of the concentration of manganese applied. It should be pointed out that the Nu-M contains 40% Mn as compared to only 23.4% in the spray grade $MnSO_4$. On the other hand, Nu-M was absorbed better through the roots than $MnSO_4$. Noteworthy also is the observation that where high amounts of manganese were applied to the foliage, correspondingly high amounts were found in the roots. Translocation of manganese, then, was definitely in evidence.

There was no correlation between the quantity of manganese found in the leaves and yields. This suggested that other factors along with manganese, and not the latter alone, determined the yields obtained. Although no correlation existed, a trend could be detected. Where the largest amounts of manganese were present in the leaves the yields were also quite high. The lowest yield was obtained where the least amount of manganese was present in the foliage.

Table 10. The total manganese content of sugar beet leaves and the comparative deficiencies of manganese as indicated by leaf symptoms at two growth intervals* at the Michigan State College Muck Experimental Farm.

Treatment	Rate of application per acre	Deficiency symptoms Interval 1	Deficiency symptoms Interval 2	Total Mn in leaves (p.p.m.) Interval 1	Total Mn in leaves (p.p.m.) Interval 2
No manganese	none	severe	moderate	13	35
$MnSO_4$ P.T.	100 pounds	slight	healthy	19	40
$MnSO_4$ S.D.	100 pounds	slight	very slight	31	50
$MnSO_4$ 50% dust	35 pounds	healthy	healthy	31	500
Nu-M 50% dust	35 pounds	very slight	healthy	38	325
$MnSO_4$ 1% spray	200 gallons	healthy	healthy	375	438

*Interval 1 - one week following second spray application and 2 weeks following first dust application; Interval 2 - two days following third dust application and one week following third spray application.

The data in Table 10 illustrate the relative efficiency of the absorption of manganese by plants receiving the various manganese treatments. Manganese sulfate, applied either as a dust or as a spray, was absorbed through the leaves more readily than the Nu-M dust. The table also demonstrates the relatively low amounts of manganese found in leaves of sugar beets grown on soil treated with manganese either at the time of planting or as a side-dressing. The low figures, however, do not necessarily mean that poor growth resulted. The largest beet plants at Interval 2 were growing on plots treated either with manganese at planting time or as a side-dressing. Poorest growth and severest leaf deficiency symptoms were observed in plants on plots which had not received manganese in any form.

In the early stages of growth, plants on plots treated with manganese at planting time were the most advanced of any plants in the experiment. Later, as other treatments were applied, the line of demarcation was not as pronounced. In addition, chlorotic leaf symptoms gradually disappeared from plants in all plots receiving manganese.

<u>Onions</u>

Legend: lime - 10 tons lime per acre; P.T. - planting time; S.D. - side-dressed.

Fig. 5 - Relative height of onions 10 weeks after planting. 3 - lime, 400 pounds per acre $MnSO_4$, P.T.; 5 - lime, 400 pounds per acre $MnSO_4$, S.D.; 0 - no lime; 4 - lime, 400 pounds per acre Nu-M, P.T.

Fig. 6 - Relative height of onions 10 weeks after planting and one week following third application of dusts and spray. 4 - lime, 100% $MnSO_4$ dust; 9 - lime, 100% Nu-M dust; 0 - no lime; 2 - lime, 1.5% $MnSO_4$ spray; 1 - lime.

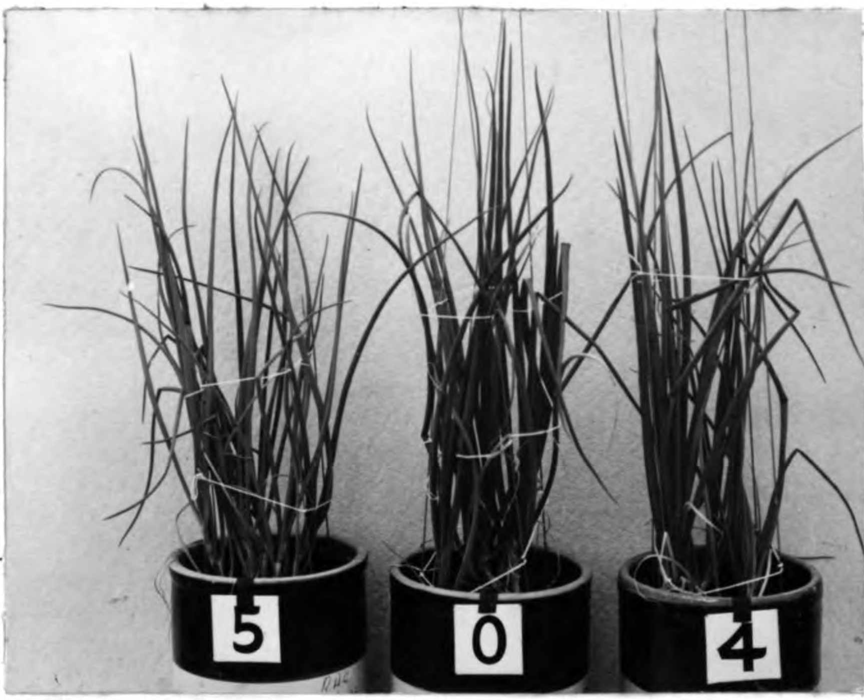

Fig. 7 - Relative height of onions 14 weeks after planting. 5 - lime, 400 pounds per acre $MnSO_4$ S.D.; 0 - no lime; 4 - lime, 400 pounds per acre Nu-M P.T.

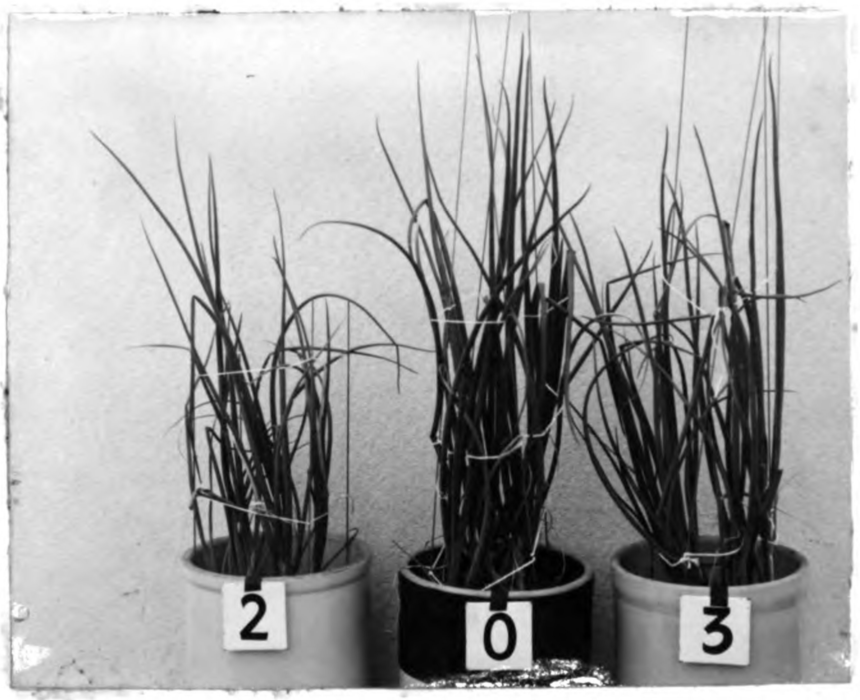

Fig. 8 - Relative height of onions 14 weeks after planting and one week following fifth application of spray 2 - lime, 1.5% $MnSO_4$ spray; 0 - no lime; 3 - lime, 400 pounds per acre $MnSO_4$ P.T.

Fig. 9 - Relative height of onions 14 weeks after planting and one week following fifth application of dusts. 4 - lime, 100% $MnSO_4$ dust; 0 - no lime; 2 - lime, 40% $MnSO_4$ dust.

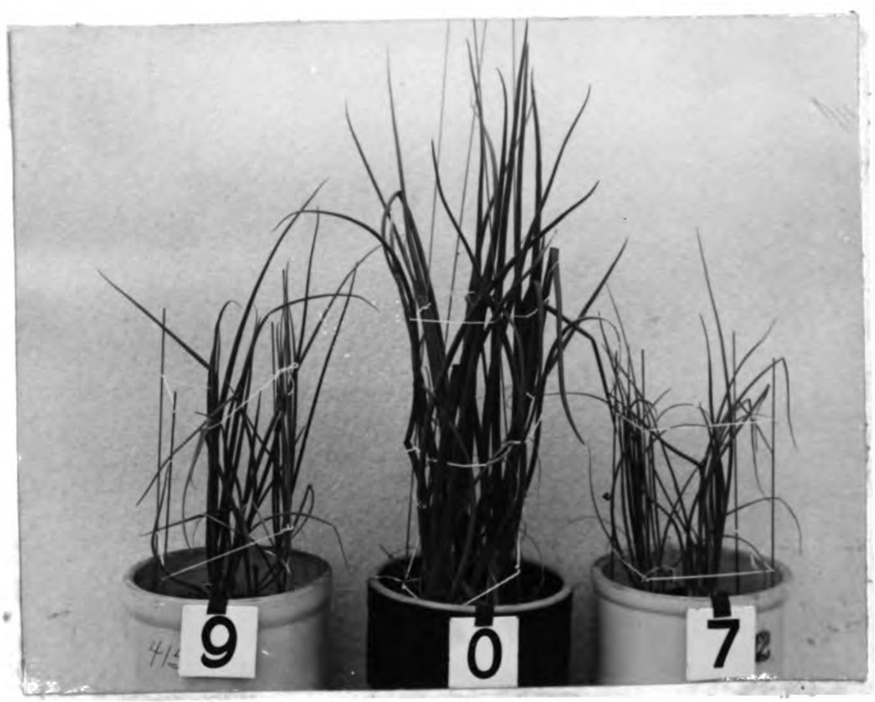

Fig. 10 - Relative height of onions 14 weeks after planting and one week following the fifth application of dusts. 9 - lime, 100% Nu-M dust; 0 - no lime; 7 - lime, 40% Nu-M dust.

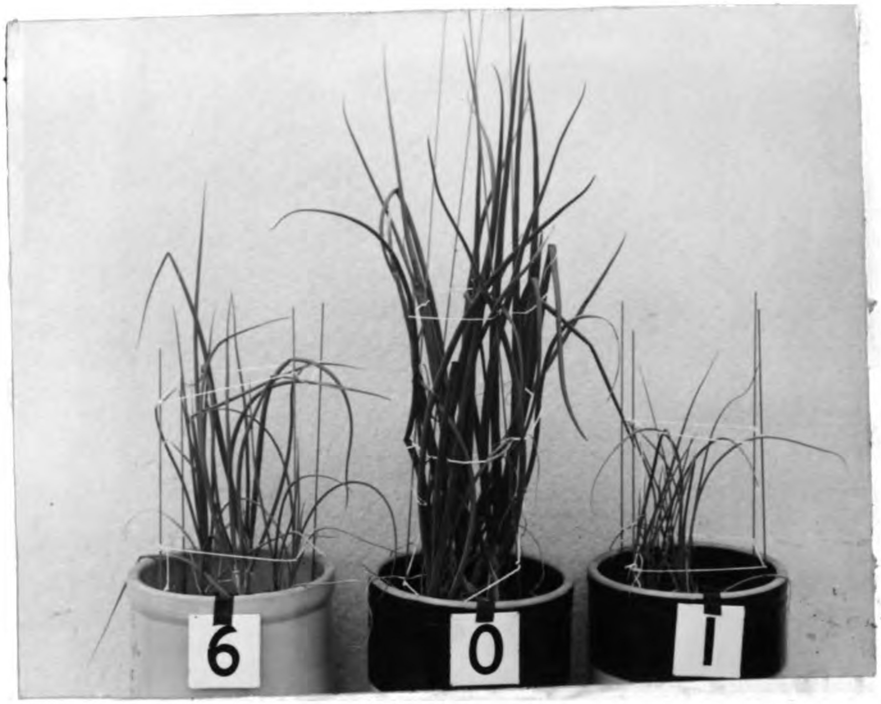

Fig. 11 - Relative height of onions 14 weeks after planting and one week following fifth application of dusts. 6 - lime, 10% Nu-M dust; 0 - no lime; 1 - lime.

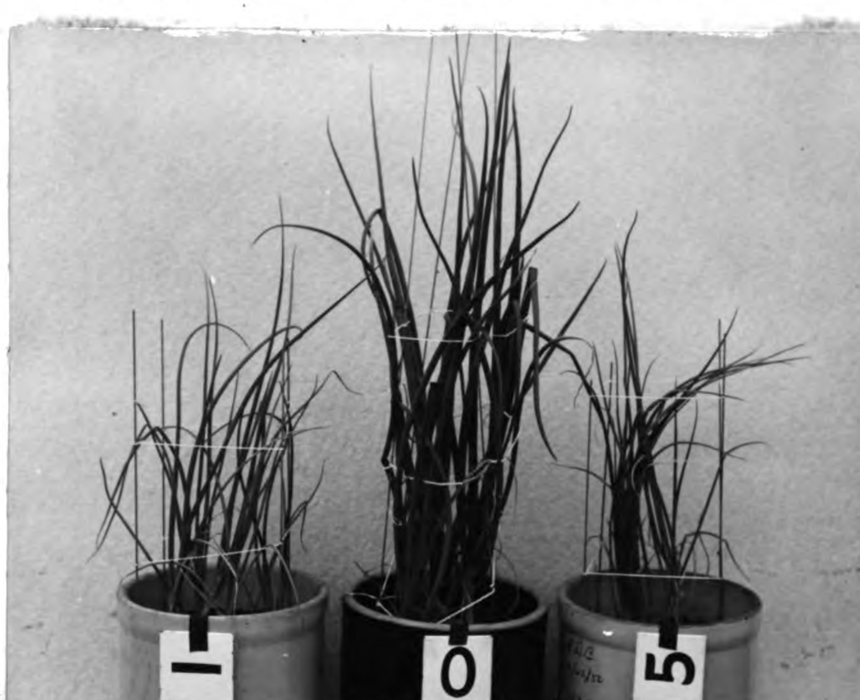

Fig. 12 - Relative height of onions 14 weeks after planting and one week following fifth application of dusts. 1 - lime, 10% $MnSO_4$ dust; 0 - no lime; 5 - lime, talc dust.

Fig. 13 - Relative height of onions 14 weeks after planting and one week following fifth application of dusts and spray. 5 - lime, 400 pounds per acre S.D. ($MnSO_4$); 0 - no lime; 4 - lime, 400 pounds per acre Nu-M P.T.; 4 - lime, 100% $MnSO_4$ dust; 1 - lime; 6 - lime, 10% Nu-M dust; 2 - lime, 1.5% $MnSO_4$ spray.

The accompanying figures (5-13 inclusive) illustrate the relative height of onions under various treatments at 10 and 14 weeks after planting.

In the early stages of the experiment the onions in pots that had not been limed made the best growth. As the season progressed, onions on soils treated with manganese at planting time or as a side-dressing showed a marked growth response to manganese. The final yields, however, for the three treatments were in the following order of decreasing magnitude: no lime, manganese at planting time and side-dressed (Fig. 14). Manganese sulfate applied as a dust increased the growth of onions in order of the strength applied. The Nu-M, even though containing a higher percentage of Mn, was not as effective as the manganese sulfate in increasing the growth and when applied without a diluent resulted in a reduction in yield as compared to yield from plants receiving a 70% dust application. Manganese sulfate applied as a 1.5% spray was very effective in supplying manganese to the onion crop. Poorest growth was obtained in onions dusted with talc and in those which received no manganese treatment.

The most prominent manganese deficiency symptom in the onions during the first 14 weeks after planting was retarded growth. Some dying-back of the tips was observed but this was not of major consequence. Neither of the above symptoms was exhibited by the onions growing on the unlimed soil.

The comparative yields of onions at harvest time obtained from pots of the various treatments are illustrated by the accompanying figures (14-18 inclusive).

Fig. 14 - 4 - lime, 400 pounds per acre Nu-M, P.T.; 0 - no lime; 5 - lime, 400 pounds per acre $MnSO_4$, S.D.; 3 - lime, 400 pounds per acre $MnSO_4$, P.T.; 2 - lime, 1.5% $MnSO_4$ spray.

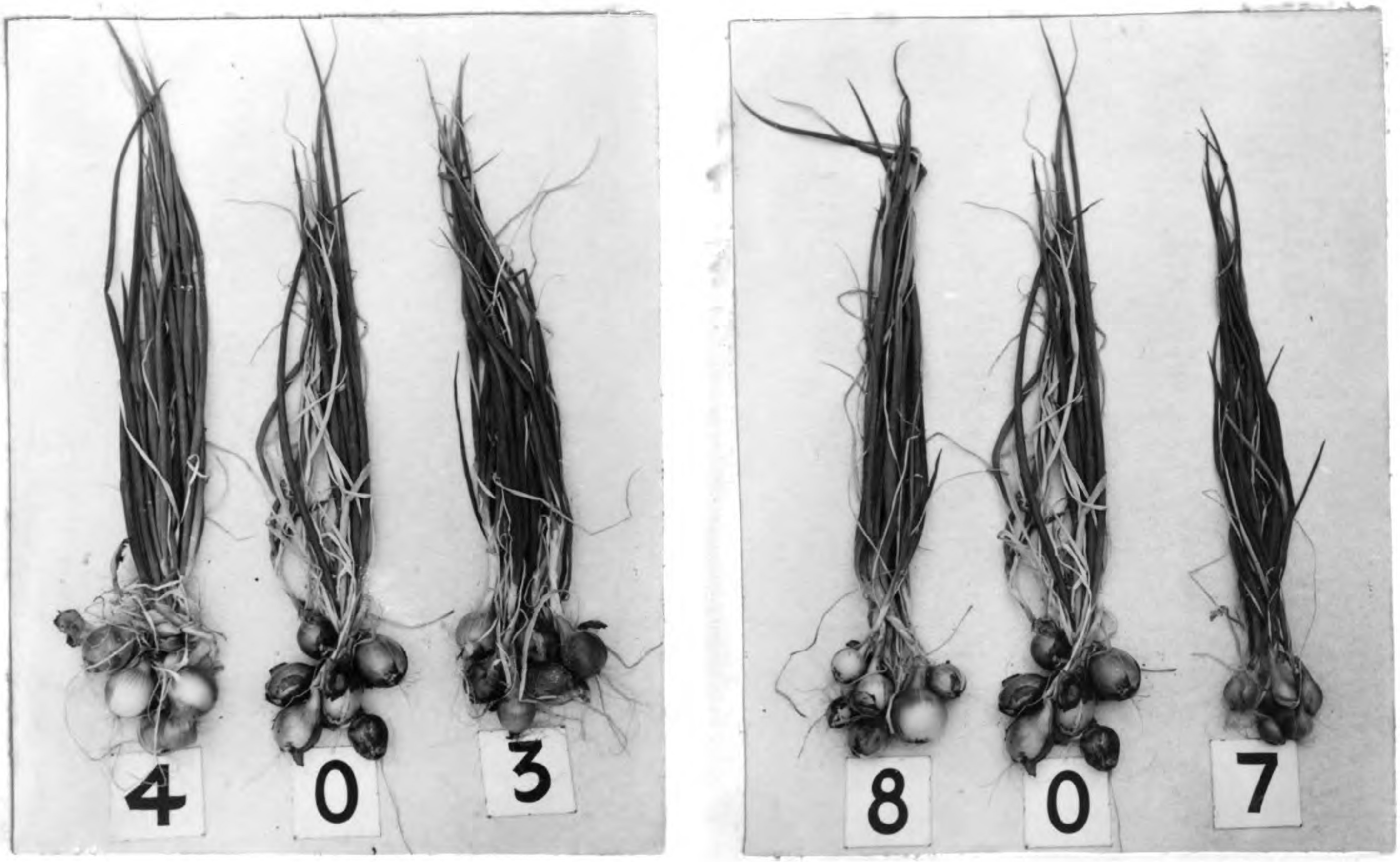

Fig. 15 - 4 - lime, 400 pounds per acre Nu-M, P.T.; 0 - no lime; 3 - lime, 400 pounds per acre $MnSO_4$, P.T.; 8 - lime, 70% Nu-M dust; 7 - lime, 40% Nu-M dust.

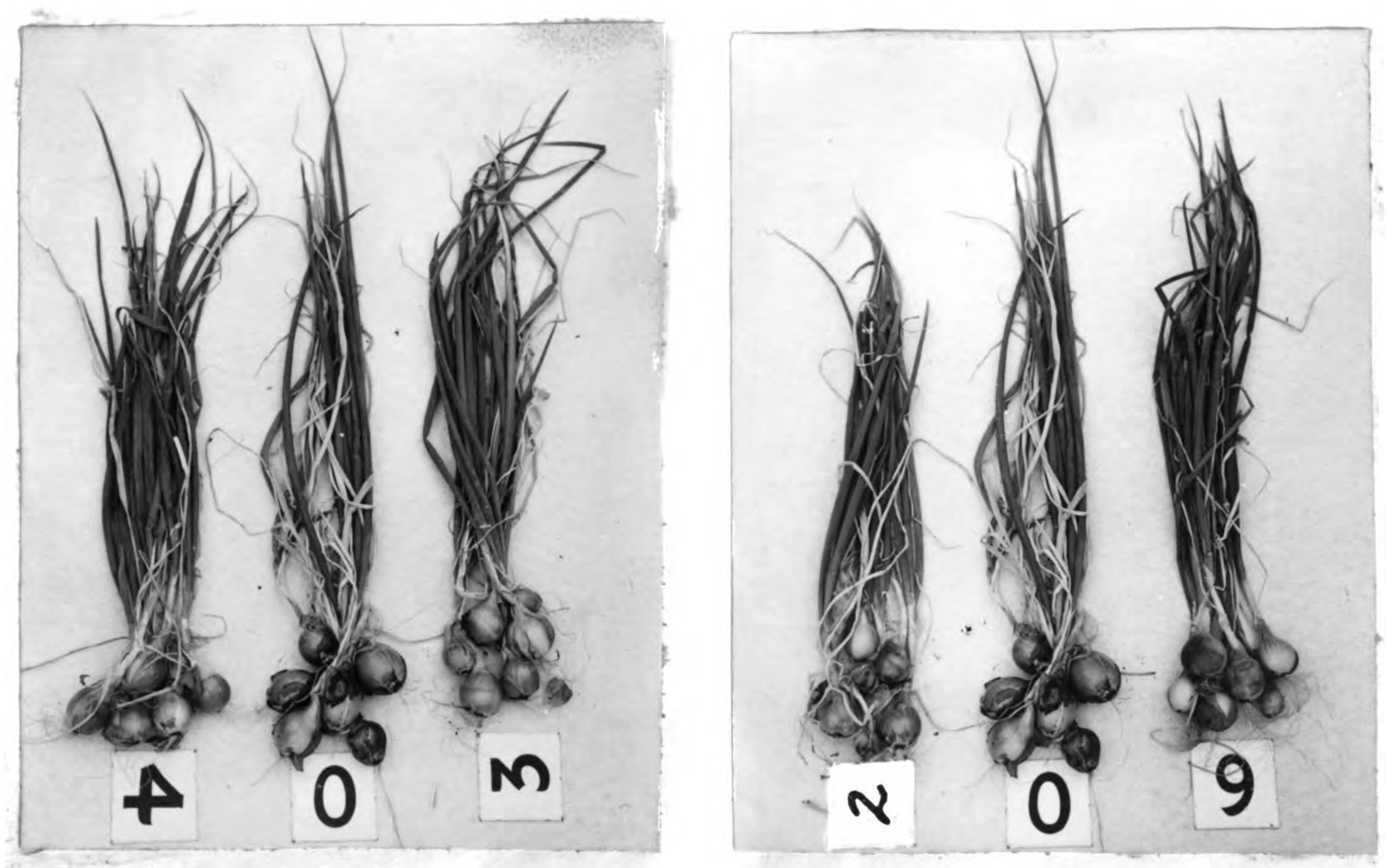

Fig. 16 - 4 - lime, 100% $MnSO_4$ dust; 0 - no lime; 3 - lime, 70% $MnSO_4$ dust; 2 - lime, 40% $MnSO_4$ dust; 9 - lime, 100% Nu-M dust.

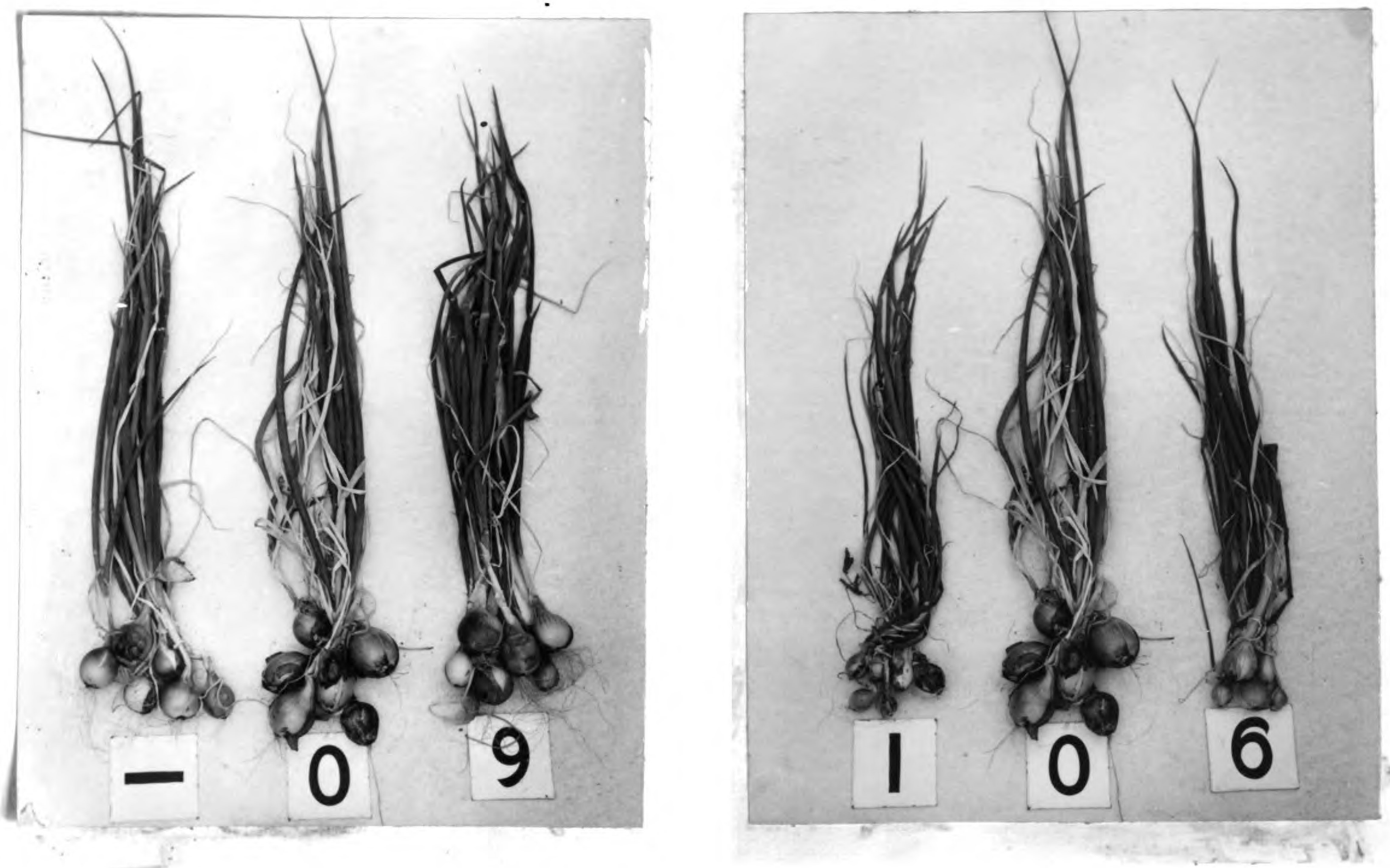

Fig. 17 - 1 - lime, 10% $MnSO_4$ dust; 0 - no lime; 9 - lime, 100% Nu-M dust; 1 - lime; 6 - lime, 10% Nu-M dust.

Fig. 18 - 1 - lime; 0 - no lime; 5 - lime, talc dust.

Table 11. The effect of methods of application of two manganese materials on the yield of onion bulbs and tops grown in the greenhouse.

Grams per pot

Treatment	Treat. No.	Bulbs Rep.1	Rep.2	Rep.3	Rep.4	Mean	Tops Rep.1	Rep.2	Rep.3	Rep.4	Mean
$MnSO_4$ 100% dust	1	153	158	151	124	147	81	86	63	106	84
" 70% "	2	118	147	114	130	127	106	68	59	77	78
" 40% "	3	93	122	132	108	114	75	61	70	63	67
" 10% "	4	68	50	124	140	96	45	44	49	65	51
Talc check	5	36	83	44	137	75	36	41	40	61	45
Nu-M 100% dust	6	138	84	80	77	95	78	94	50	38	65
" 70% "	7	148	120	157	59	121	79	72	76	79	77
" 40% "	8	57	40	60	52	65	56	63	60	32	53
" 10% "	9	71	40	138	36	71	47	52	56	31	47
No dust	10	15	86	14	45	40	17	62	26	50	39
$MnSO_4$ 1.5% spray	11	128	131	115	120	124	87	85	61	108	85
$MnSO_4$ P.T.	12	181	207	153	142	171	117	115	88	74	99
$MnSO_4$ S.D.	13	125	133	160	126	136	99	105	108	78	98
No lime	14	242	204	244	218	227	106	92	142	65	101
Nu-M P.T.	15	200	214	218	211	211	108	86	90	79	91

Table 12. Analysis of variance of yield data of onion tops and bulbs.

Source of variance	Deg. of free.	Bulbs Sum of squares	Bulbs Mean square	Bulbs F	Tops Sum of squares	Tops Mean square	Tops F
Total	59	192028.98			39092.18		
Blocks	3	1378.05			837.51		
Treatments	14	153576.73	10969.77	12.43**	25338.93	1809.92	5.29**
Error	42	37074.20	882.72		12915.74	307.52	

Least significant difference:

Bulbs	5% level	42.4 grams
	1% level	56.7 grams
Tops	5% level	25.0 grams
	1% level	33.5 grams

**Significant at 1% level.

As indicated by the data in Table 11 the decreasing order of magnitude of yields of bulbs by treatments was as follows: 14, 15, 12, 1, 13, 2, 11, 7, 3, 4, 6, 5, 9, 8 and 10. In general the soil applications were more effective than the foliar treatments. Of the foliar treatments the higher percentage levels of the $MnSO_4$ dust gave highest yields followed by yields obtained from plants treated with the $MnSO_4$ spray and finally those treated with the Nu-M dust. The talc dust treatment gave yields comparable to those obtained from plants treated with the lower percentage levels of the Nu-M dust. All treatments, with the exception of

Treatments 5, 8 and 9 produced significantly better yields than Treatment 10.

The decreasing order of magnitude of yields of tops by treatments was as follows: 14, 12, 13, 15, 11, 1, 2, 7, 3, 6, 8, 4, 9, 5 and 10. Here again the soil applications of manganese were generally more effective than the foliar treatments. The trend for yields of tops produced by the manganese foliar treatments generally followed the same pattern as that for yields of bulbs. Plants growing in the unlimed soil gave the highest yields of tops whereas lowest yields of tops were obtained from plants which had received no manganese treatment.

Table 13. Total manganese in onion tissue compared with quantity of manganese applied and average yields of tops and bulbs.

Treatment	Treat. No.	Total Mn applied to plants or soil (lb./A)	Total Mn in tops (p.p.m.)	Total Mn in bulbs (p.p.m.)	Average yield	
					Tops	Bulbs
$MnSO_4$ 100% dust	1	152	400	90	84	147
" 70% "	2	106.5	400	50	78	127
" 40% "	3	60.8	325	25	67	114
" 10% "	4	15.2	175	15	51	96
Talc check	5	none	75	10	45	75
Nu-M 100% dust	6	260	163	25	65	95
" 70% "	7	182	238	25	77	121
" 40% "	8	104	288	25	53	65
" 10% "	9	26	138	20	47	71
No dust	10	none	50	13	39	40
$MnSO_4$ 1.5% spray	11	28.14	300	50	85	124
" P.T.	12	93.6	25	15	99	171
" S.D.	13	93.6	13	15	98	136
No lime	14	none	63	15	101	227
Nu-M P.T.	15	160	50	20	91	211

Several trends are exhibited in Table 13. In the first place, it is apparent that where large amounts of manganese were applied as a $MnSO_4$ foliar dust, correspondingly large amounts were found in the tissue of both tops and bulbs of onions. This would suggest efficient absorption of the micro-nutrient element on the part of the plant and also the capacity to translocate it to the bulb. Increased percentages of manganese applied in this form gave correspondingly increased yields of both tops and bulbs.

Although the 100% $MnSO_4$ dust produced the highest yield of all foliar treatments without apparent injury to the plants, the author suggests that a diluent fraction be added whenever a manganese sulfate - sulfur mixture is used,to prevent fire hazard.

The application of Nu-M as a foliar dust gave somewhat varied results in that where high amounts of manganese were applied, correspondingly high amounts were not necessarily found in the tissue of the onions. Yields of tops and bulbs were highest in plants treated with the 70% dust, demonstrating that a diluent was necessary to give maximum results.

The $MnSO_4$ spray treatment, as in the sugar beets, showed extremely high efficiency in the absorption of the element. This good response was borne out at harvest time also in that reasonably high yields were obtained from the treated plants.

Manganese added to the soil produced results that differed a great deal from those obtained from the foliar applications of the element. Plants treated with $MnSO_4$ at planting time and those receiving the side-dressing treatment both received the same total amount of the element, however, it is obvious that those plants obtaining manganese at the outset of their growth gave higher yields of bulbs. Although plants from both treatments contained the same amount of manganese in the bulbs, those receiving Mn at planting time contained more in the tops which reflects the length of time they had to absorb the element. Nu-M applied at planting time gave better results than when used as a dust. Although plants treated with the Nu-M received much more Mn than those in the other soil treatments, higher yields were obtained in the bulbs and larger amounts of Mn were detected in the tissue.

Onions growing in the unlimed soil produced highest yields in both tops and bulbs. Although no manganese was applied to either the soil or foliage, the amount of manganese found in the tissue was about the same as in the plants of the other soil treatments.

Treatments 5 and 10 produced the lowest yields of onions, although the amount of manganese detected in the tissue of plants thus treated did not differ greatly from the quantity found in the tissue of plants growing in soil treated with manganese. The author cannot explain the circumstances influencing these results.

A correlation study was made between quantity of manganese in the tops versus yield, with unsatisfactory results. Evidently one cannot "pin-point" manganese as the individual factor influencing the yields obtained although it no doubt played a major role.

SUMMARY

Two manganese materials, commercial grade manganese sulfate (Tecmangam), 23.4 per cent Mn, and Nu-M, 40 per cent Mn, were applied in the form of foliar dusts (10, 40, 70 and 100 per cent), as a soil application at planting time, as a side-dressing and as a 1.5 per cent manganese sulfate spray to Brigham's Yellow Globe onions and 215 x 216 sugar beets growing in the greenhouse on a virgin organic soil obtained from the Michigan State College Muck Experimental Farm.

Ten tons of lime (C.P. calcium carbonate) per acre were added to the pots for the purpose of inducing manganese deficiency.

Data were obtained on the effect of the various treatments on the yield and manganese content of tops and bulbs of onions and leaves and roots of sugar beets grown in the greenhouse and the manganese content of sugar beet leaves from plants produced at the Muck Experimental Farm.

The following results were noted:

1. The addition of ten tons of lime per acre to the organic soil investigated increased the pH from 6.0 to 8.1 and induced a chlorotic leaf condition that could be corrected with manganese supplements.

2. The amount of exchangeable and easily-reducible manganese in unlimed soils was much greater than that found in soils treated with 10 tons of lime per acre.

3. The most effective method of treatment for the onions and sugar beets was the application of manganese to the soil at planting time, the side-dressing method being next most effective.

4. Manganese applied in the form of a 1.5 per cent manganese sulfate spray was comparatively more effective in correcting manganese deficiency symptoms in sugar beets than in onions.

5. Manganese sulfate applied as a dust was more effective in correcting manganese deficiency symptoms than was the Nu-M form with both onions and sugar beets. Manganese sulfate applied without a diluent caused no noticeable adverse effects on plant development whereas the application of Nu-M without a diluent resulted in a yield reduction of onions.

6. The amounts of manganese found in the tissue of sugar beets and onions generally increased with the percentage of the material contained in the dust mixtures with the highest amount associated with the manganese sulfate dusts. Lowest amounts of manganese were found in the tissue of plants receiving no manganese treatment.

7. Highly significant differences were observed between yields of onions with the highest yield being obtained from plants growing on the unlimed soil followed by yields obtained from plants growing on soil to which had been applied manganese at planting time. No significant differences between yields of sugar beets were noted although the highest yield was obtained from the 100 per cent manganese sulfate dust.

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