FACTORS AFFECTING CHLOROSIS IN IRRIGATED WHEAT [1]

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INTRODUCTION

A tendency of Marquis wheat to turn pale when irrigated at germination has been noticed in previous studies, and a similar tendency has been observed in the field when heavy rains occurred soon after the wheat emerged. The pale-green color may last for 3 to 6 weeks before the plants recover their normal green appearance. This mild chlorotic condition has been attributed to the use of cold water for irrigation, but experimental data to support this belief are lacking. Because of this a study was made of the effect on chlorosis of (1) the temperature of the irrigation water at germination and (2) the type of fertilizer used.

EFFECT OF TEMPERATURE OF IRRIGATION WATER ON YIELD OF WHEAT IRRIGATED AT GERMINATION

EXPERIMENTAL METHODS

Studies on the effect of applying irrigation water of different temperatures, to Marquis wheat (*Triticum aestivum* L.) on Fort Collins loam (*7*) [2] were conducted for a 4-year period from 1927 to 1930, inclusive.

The experiment was carried on each year on land which had been summer-fallowed the previous year. This summer fallow was necessary in order to obtain a more uniform moisture content in the soil and also to eliminate volunteer grain and control weeds. In 1928 and 1929, a single series of 10 plots, each one five-hundredths of an acre in size, was used. In 1930, two series of similar plots were employed. Each series was planted to Marquis wheat at the rate of 90 pounds per acre. One drill width of 16 rows was planted in each series.

The wheat was planted on April 8 in 1929 and April 7 in 1930. Canvas covers similar to those described by Robertson et al. (*5*) were used to eliminate the effects of rainfall in 1929 and 1930. Water was applied at the rate of 6 acre-inches [3] to each plot at germination (*5*). The temperatures of the irrigation water applied in 1928 were 41° and 62° F., and in 1929 and 1930 they were 40° and 60°.

The basin method of irrigation was used throughout the investigation. The plots were diked and sufficient water was applied to give the required depth. The amount of water required for a given depth was measured for each plot. The temperatures were controlled by ice or steam, depending on whether the water in the pipe line was higher or lower than the temperature required. The source of the irrigation water is discussed in a previous publication (*5*).

[1] Received for publication Apr. 1, 1937; issued October 1937.
[2] Reference is made by number (italic) to Literature Cited, p. 520.
[3] Inches of irrigation water refer to inches in depth over the area.

The area of each plot harvested was one eight-hundred-and-seventy-firsts of an acre. The 10 center rows were harvested after 3 border rows on each side and 1 foot from each end had been discarded to eliminate possible border effect. The grain was cut 1 inch above the ground with lawn shears, tied in a sheaf, and carefully wrapped in cloth to protect the heads, leafy material, and straw. These sheaves were shocked under cover and allowed to cure for 3 weeks or more. The sheaves were then weighed and the grain threshed. The difference between the cleaned grain weight and the total grain and straw weight was used as the straw yield.

EXPERIMENTAL RESULTS

The studies conducted with irrigation water at temperatures of 40° and 60° F. applied at germination, show a slight difference in grain yield in favor of the plots receiving the water at 40°. However, in 1930 when the number of replications was sufficient to make the application of statistical methods possible, no significant differences were obtained. The straw yield was slightly higher for the plots irrigated with water at 60°, but was not significantly different (table 1).

TABLE 1.—*Yields of grain and of straw from plots irrigated at germination with water at 40° or 60° F.*

Year grown	Plots	Yield per plot when irrigation water at indicated temperature was used			
		40° F.		60° F.	
		Grain	Straw	Grain	Straw
	Number	*Grams*	*Grams*	*Grams*	*Grams*
1929	2	398	820	373	837
1930	4	330±12	617±26	318±12	656±26

Standard error obtained by the analysis of variance (*2*).

An examination of the soil-temperature curves in figure 1, *A* (1928), shows that there was a rise in temperature, in the first foot of soil, of about 4° F. 24 hours after treatment. The second day after irrigation, the temperature dropped to within 1.5° of the low-temperature treatment. After the fourth day the difference between the two treatments did not exceed 2°.

In the second foot (fig. 1, *B*, (1928) there was a difference of 5.5° F. between the two treatments 24 hours after the water was applied. The temperature had become equal after 3 days and fluctuated only slightly thereafter.

In 1929 (fig. 2, *A*,) the temperatures of the soil in the plots came within 0.5° F. of each other 3 days after treatment, and did not fluctuate beyond 1.5° during the 10-day period after irrigation. In the second foot (fig. 2, *B*), there was very little difference.

These results, considered in connection with the yield data, indicate that a difference in temperature in the irrigation water of 20° F., i. e., between 40° and 60°, has no effect on the yield of Marquis wheat irrigated at germination.

The minimum temperature of the air is plotted in figures 1 and 2, along with the soil temperatures. It will be noted that the soil temperature seems to be influenced more by the fluctuation of the air temperature than by the temperature of the irrigation water. This is especially noticeable in the curves for temperature 4 days after the application of the irrigation water. The following theoretical discussion indicates that a rise in temperature of about 10° F. should be the maximum difference expected if outside influences have no effect on the soil complex and the water added is the only contributing factor to the temperature change.

If water and soil of different temperatures are mixed, the final temperature of the complex (assuming no energy changes due to chemical reactions) may be expressed by the equation:

$$\frac{c_1 m_1}{c_2 m_2} = \frac{{}^\circ F_2 - X}{X - {}^\circ F_1} \tag{1}$$

where c_1=specific heat[4], m_1=the mass, and $^\circ F_1$=the temperature of the constituent having the lower temperature, and c_2, m_2, and $^\circ F_2$=the corresponding properties of the constituent of higher temperature, and X=the final temperature.

If water is already present as soil moisture before irrigation, it might be expected that the heat capacity of the soil plus moisture would determine the final temperature. However, when water is added to the soil surface it does not mix intimately with the soil moisture already present, but to a large extent replaces it as the portion already present moves downward. It is a question as to how much exchange of heat there is between moisture in the soil and moisture added under these conditions. Furthermore, the upper layers of soil are changed a little by each succeeding increment of water which enters, so that at the completion of irrigation the surface will approach the temperature of the water added and the extreme depth of penetration will approach the temperature before irrigation. The problem is thus complicated by an unknown degree of mixing with the soil moisture and the development of a temperature gradient. Other complications, of course, are the effects of evaporation and heat radiation during the process.

If we assume that the water added warms or cools the soil only and not the moisture already present and that the evaporation and radiation effects may be neglected, the following example shows the average final temperature and depth of temperature change which should be expected from adding 6 inches of water at 60° F. to a soil at 40°:

Average field capacity of upper 2 feet (estimated)	18.0 percent.
Ratio of weight of soil to weight of water	5.55/1.

Substituting in equation 1—

$$\frac{0.2 \,.\, 5.55}{1} = \frac{60 - X}{X - 40} = 49.47^\circ \text{ F.}$$

Weight of water applied per square foot of surface	31.25 pounds.
Average weight per cubic foot of soil (determined)	88.3 pounds.
Weight of water absorbed per cubic foot (18 percent of soil)	15.89 pounds.
Depth of water penetration and of temperature change (no. 3÷ no. 5)	1.96 feet.

[4] Approximate specific heat of soil obtained from Patten (*4*).

The result is approximately a maximum average rise of 10° F. in soil temperature to a depth of 1.96 feet. The graphs show, as could be expected, that the actual rise in the field was much less than this.

The change in temperature, while appreciable, is small compared with the change which could be expected from a snowstorm. Since the heat of fusion of ice is 79.6 calories, an inch of water as ice would cool an equivalent amount of water nearly 144° F.

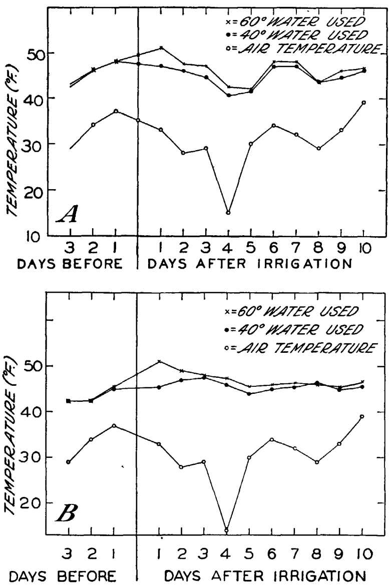

FIGURE 1.—Temperature of the first (*A*) and second (*B*) foot of soil for a 3-day period immediately before and a 10-day period immediately after irrigation with water at 40° and at 60° F., as compared with the air temperature, 1928.

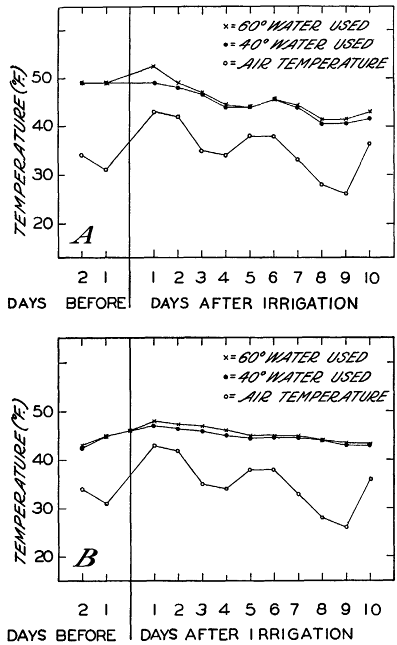

FIGURE 2.—Temperature of the first (*A*) and second (*B*) foot of soil for a 2-day period immediately before and a 10-day period immediately after irrigation with water at 40° and at 60° F., as compared with the air temperature, 1929.

EFFECT OF DIFFERENT FERTILIZER TREATMENTS AT GERMINATION ON THE YIELD OF WHEAT AND ON THE NITROGEN CONTENT OF SOIL, GRAIN, AND STRAW

EXPERIMENTAL METHODS

In 1933 a study was started to determine the effect of different fertilizer treatments at germination on the development of chlorosis and the recovery of Marquis wheat showing chlorosis. Uncovered plots of similar size to those used in the temperature study were employed. The plots were laid out in a 7 by 7 Latin square. The chemical treatments and the amounts used are given in table 2.

TABLE 2.—*Chemical treatments and amounts applied per acre*

Treatment	Salt used	Quantity per acre
		Pounds
Manganese sulphate	$MnSO_4+4H_2O$	318.70
Iron sulphate	$FeSO_4+7H_2O$	297.22
Superphosphate	$CaH_4(PO_4)_2+H_2O$	360.25
Ammonium-acid phosphate	$(NH_4)H_2PO_4$	328.80
Ammonium sulphate	$(NH_4)_2SO_4$	188.77
Calcium nitrate	$Ca(NO_3)_2+4H_2O$	337.35

Marquis wheat was planted on April 3, 1933, April 9, 1934, and April 1, 1935.

Treatment of plots.—In 1933 irrigation water was applied at the rate of 6 inches when the wheat had germinated and was just emerging. The various series were irrigated as follows: April 20, series E; April 24, series F and G; April 25, series H, I and plots 3, 4, 5, and 6 on Series J; April 26, series K and plots 7, 8, and 9 on series J. The chemicals were dissolved in water and sprinkled on the plots within 24 hours after the 6-inch irrigation. After treatment with the chemical, 1 inch of water was applied to each plot.

In 1934 a 6-inch irrigation was applied on April 20 to series A and B; on April 21 to series C; on April 23 to series D and E; and on April 24 to series F and G. The treatments were applied in a manner similar to that used in 1933. On June 20 and 21, an additional 3 inches was applied to each of the plots.

In 1935 a 4-inch irrigation was applied on April 5 to series A, B, and C. A similar irrigation was applied on April 6 to series D, E, and F. On April 8, series G was irrigated with 4 inches of water. This irrigation was necessary because of the dry season of 1934 and of the months of January, February, and March in 1935. On April 20, when the wheat had germinated, an additional 5-inch irrigation was applied to series A and B. On April 22, series C and D were irrigated. Series E, F, and G were irrigated on April 23. The chemicals were applied on all plots in series A to F on April 23 and to series G on April 24. Sufficient rain fell on April 24 and 25 to carry the fertilizers into the soil so no additional irrigation water was applied.

Statistical analysis.—In the interpretation of the data from the crop-and-soils tests, the analysis of variance *(2)* was used. The data were so arranged that the various interactions could be tested. Table 3 presents the analysis of variance for the yield of grain in grams per plot.

TABLE 3.—*Analysis of variance for yield of grain per plot for the 3-year period, 1933 to 1935, inclusive*

Variance due to—	Degrees of freedom	Sum of squares	Mean square	σ	F[1] *(6)*
Years	2	763,069	381,535		180.65
Rows and columns within years	36	409,889	11,386		5.39
Treatments	6	224,423	37,404		17.71
Treatments x years	12	122,180	10,182		4.82
Error	90	190,127	2,112	45.96	
Total	146	1,709,688			

[1] All higher than 1-percent point.

The *F* test indicates that there is a significant difference in the yields between years, rows, and columns within years, and treatments × years; the last-named difference shows that the treatments reacted differently in different years.

The test further shows that response of Marquis wheat to some of the fertilizer treatments is significant. Similar results were obtained for the straw yields and for the total yield of straw and grain combined.

In 1933 the effect of the various treatments first became noticeable about May 30. The plots treated with calcium nitrate were a much darker green than the other plots. The plots receiving ammonium fertilizer were a shade lighter, but could be distinguished from the other fertilizer and the no-treatment plots, which were light green in color. In 1934 and 1935, a similar condition was noticeable.

EXPERIMENTAL RESULTS

Yield of Grain and Straw

The average yields in grams per plot for the 3-year period are given in table 4.

Table 4.—*The 3-year average yield of grain and of straw from plots irrigated at germination and later treated with different fertilizers*

Treatment	Yield per plot			Treatment	Yield per plot		
	Grain	Straw	Total		Grain	Straw	Total
	Grams	*Grams*	*Grams*		*Grams*	*Grams*	*Grams*
$FeSO_4$	832	1,179	2,011	$(NH_4)_2SO_4$	886	1,319	2,205
$CaH_4(PO_4)_2$	838	1,189	2,027	$NH_4H_2PO_4$	911	1,349	2,260
$MnSO_4$	840	1,191	2,031	$Ca(NO_3)_2$	939	1,492	2,431
No treatment	844	1,202	2,046	Level of significance (2 S.E. (difference)	28	49	77

The grain yields of the plots treated with ammonium sulphate, ammonium phosphate, and calcium nitrate are significantly higher than the yields of the no-treatment plots. The yields of plots treated with iron sulphate, superphosphate, or manganese sulphate do not differ significantly from the check. The straw yields show the same trend. The ammonium- and nitrate-treated plots gave the highest yields. These data indicate that the chlorotic condition of Marquis wheat produced by early irrigations evidently is due to a nitrogen deficiency.

To study further the effect of early irrigations on Marquis wheat, soil samples were taken at intervals throughout the season and analyzed for nitrate nitrogen. Samples were taken in all plots, making, in all, seven samples for each treatment. The samples were taken for the following depths of soil: 0–6, 6–12, 12–24, and 24–36 inches. The nitrate nitrogen was determined by the method described by Gardner and Robertson (*3*), p. 5.

Nitrate Nitrogen Content of Soil

Soil samples were taken in all plots after the irrigation and chemical treatments had been applied. The samples were taken on the following dates: April 29, 1933; April 27, 1934; and May 1, 1935. Different composite samples were drawn for the different tests. The nitrate nitrogen is recorded in parts per million as nitrogen. Table 5 gives the average nitrogen content of the soil for different depths taken in the spring of 1933, 1934, and 1935.

TABLE 5.—*Average quantity of nitrate nitrogen recorded as nitrogen in parts per million for the different depths of soil taken in the spring after irrigation and chemical treatment were applied and in August after the wheat had been harvested on the variously treated plots for the 3-year period 1933 to 1935, inclusive*

SPRING

Treatment	Nitride nitrogen at soil depths indicated (in inches)				
	0–6	6–12	12–24	24–36 [1]	0–36 [1]
	P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
$Ca(NO_3)_2$	9.0	5.0	7.9	12.6	11.2
$(NH_4)_2SO_4$	4.4	4.3	5.1	9.9	8.3
$(NH_4)H_2PO_4$	4.2	3.8	4.4	9.2	7.3
$MnSO_4$	3.2	2.9	4.9	10.3	8.0
$FeSO_4$	2.7	3.6	5.0	9.5	7.1
No treatment	2.6	2.8	5.2	11.3	8.0
$CaH_4(PO_4)_2$	2.5	2.9	6.1	11.2	8.4
Level of significance	[2] 1.3	1.7	1.7	2.8	1.9

AUGUST

Treatment	0–6	6–12	12–24	24–36 [1]	0–36 [1]
$Ca(NO_3)_2$	3.0	1.6	1.9	4.9	2.7
$(NH_4)_2SO_4$	2.9	1.5	2.6	3.5	2.4
$(NH_4)H_2PO_4$	3.1	1.8	1.7	3.2	2.4
$MnSO_4$	2.8	1.6	1.9	3.0	2.0
$FeSO_4$	2.9	1.6	2.0	2.9	2.0
No treatment	3.0	1.5	1.8	1.9	1.7
$CaH_4(PO_4)_2$	3.0	1.4	1.9	2.4	1.9
Level of significance	.55	.53	.54	2.1	.8

[1] 2-year average 1933 and 1935.
[2] Each depth was set up as a separate experiment and the standard error obtained by the analysis of variance. A test for homogeneity was applied to a complex experimental set-up for all of the data for nitrogen in the 4 depths of soil. The test in this case is designed to determine whether the observed variances can be considered as having been drawn from the same population. 3 of the depths showed homogeneity but the fourth depth (24–36 inches) indicated lack of homogeneity. All of the data were then analyzed by separate depths. The writers are indebted to Dr. F. R. Immer of the Minnesota Agricultural Experiment Station for the method of testing the data and to Dr. A. E. Brandt of the statistical laboratory, Iowa State College, for developing the method and permitting its use.

The nitrate nitrogen content of the first and second 6 inches is important since the roots of the young seedlings evidently have not penetrated below this depth at this early stage of growth. Weaver (*8, pp. 133–134*) described a month-old Marquis wheat plant as follows:

> On May 1, a month after planting and when the second leaf was half grown, a typical root system was drawn. The number of roots varied from three to eight. Lateral roots were fairly abundant but entirely unbranched. The greatest lateral spread was 5 inches and the working depth or working level (*i. e.* a depth to which many roots penetrate and to which depth considerable absorption must take place) 6.5 inches.

The nitrate nitrogen content of the soil in the calcium nitrate plot was significantly higher than that of any of the other plots. The two sets of plots receiving nitrogen as ammonia were significantly higher than the no-treatment plot, but were not significantly higher than the plots receiving manganese sulphate. In the second 6 inches the amount of nitrate nitrogen in the calcium nitrate plots, while still significantly higher than that of the other plots, was lower than that in the first 6 inches. While the ammonium sulphate plot was somewhat higher than the no-treatment plot, it did not differ significantly from the other treatments. The nitrate nitrogen content of the soil in the second foot was, in all cases, higher than that of the second 6 inches. The calcium nitrate plot was significantly higher than the other plots. In the third foot a noticeable increase of nitrogen is apparent. Tests made in 1934 before and after irrigation indicated that the nitrates were washed below the third foot. The first 6 inches; second 6 inches, and second foot were almost depleted as far as the nitrate tests showed. A slight loss was indicated in the third foot.

No significant differences were noted in the first 6 inches or in the second 6 inches of soil taken from the different plots in August (table 5). In the second foot, however, the plot receiving ammonium sulplate differed significantly from the other plots in parts per million of nitrogen. In the 0–36-inch column a significant difference between the no-treatment and the calcium nitrate plots was found. None of the other plots showed a significant difference.

The yield data indicate that the nitrate added as calcium nitrate increased the yield over the other treatments. The soil-analysis data show that the nitrate nitrogen in the calcium nitrate plots was considerably higher in the first 6 inches. Evidently, a lack of nitrogen at this stage affects the normal development of the young seedlings. The calcium nitrate plots were a much darker green than the other plots.

The plots receiving nitrogen as ammonium acid phosphate outyielded the plots receiving no nitrogen. The nitrate content of the first 6 inches of soil, however, was not significantly different from that of some of the plots receiving no nitrogen. A similar condition was found in the second 6 inches.

The ammonium sulphate-treated plots which differed significantly in yield from the plots receiving no nitrogen showed the same condition in the nitrate content of the soil. Since the nitrate was more effective in correcting the chlorotic condition, it would appeor that nitrogen is more readily absorbed by wheat plants as the NO_3 ion than as the NH_4 ion. The benefits received from the ammonium salts could have been due either to nitrification of these salts or to the direct absorption of ammonia. Nitrification could have been appreciable and still not have been detected in the analyses.

Nitrogen Content of Grain and Straw

The nitrogen content of the grain and straw was determined by the Gunning method (*1*).

The average percentage of nitrogen in the grain is given in table 6. The nitrogen content of the threshed grain varied slightly for the different treatments. The calcium nitrate plots gave the lowest content in every case, except in 1935. The average content for the 3-year period indicates a significant difference over the no-treatment plots for the plots receiving manganese sulphate and ammonium phosphate.

The nitrogen in the straw was considerably lower than in the grain (table 6).

The nitrogen in the straw was low in the ammonium-treated plots. No significant difference was noticed between the other treatments. All of the other plots were significantly higher than the ammonium acid phosphate and ammonium sulphate plots.

TABLE 6.—*Average yearly nitrogen content of grain and of straw from the differently treated plots for 1933 to 1935, inclusive*

GRAIN

Treatment	1933	1934	1935	3-year average
	Percent	*Percent*	*Percent*	*Percent*
$MnSO_4$	2.80	2.74	2.58	2.71
$(NH_4)H_2PO_4$	2.79	2.76	2.58	2.71
$FeSO_4$	2.79	2.74	2.58	2.70
$(NH_4)_2SO_4$	2.79	2.73	2.54	2.68
$CaH_4(PO_4)_2$	2.76	2.73	2.54	2.68
No treatment	2.76	2.73	2.52	2.67
$Ca(NO_3)_2$	2.63	2.73	2.61	2.66
Level of significance	.071	.056	.066	.037

STRAW

Treatment	1933	1934	1935	3-year average
No treatment	0.49	0.43	0.52	0.48
$Ca(NO_3)_2$	.45	.46	.56	.48
$CaH_4(PO_4)_2$	.48	.41	.56	.48
$MnSO_4$	.48	.41	.51	.47
$FeSO_4$	.47	.40	.51	.47
$(NH_4)H_2PO_4$	.47	.42	.47	.45
$(NH_4)_2SO_4$	.45	.43	.46	.44
Level of significance	.028	.035	.035	.019

EFFECT OF TEMPERATURE OF IRRIGATION WATER AND FERTILIZER TREATMENTS ON THE DEVELOPMENT OF CHLOROSIS

As previously stated, the mild chlorotic condition often found in small grains after heavy rains or applications of irrigation water to the plants in the earlier stages of growth has been attributed to various causes, one of the commonest being the temperature of the irrigation water. From the tests described above, there is no indication that water at a temperature as low as 40° F. has any more detrimental effect on the plants than water at 60°. The temperature of the soil was affected more by the temperature of the surrounding air than by the temperature of the irrigation water between the range of 40° to 60°.

An application of calcium nitrate immediately after irrigation prevented the occurrence of chlorosis. A similar but less pronounced effect was obtained when ammonium sulphate or ammonium acid phosphate was applied. No difference in the color or type of growth was noticed in the plants receiving manganese sulphate, iron sulphate, and superphosphate. These results indicate that the chlorotic condition resulted from a shortage of nitrogen rather than from any other elemental deficiency. Nitrate proved more effective than ammonium salts in controlling the chlorotic condition, indicating a greater availability of the nitrate ion.

When the nitrate nitrogen content of the soil in the first 6 inches was low, chlorosis resulted. When the content was high, as in the plot treated with calcium nitrate, no chlorosis occurred. Ammonium nitrogen had a similar effect, but to a less degree.

SUMMARY

Tests conducted with Marquis wheat irrigated at germination with 6 inches of water have shown that:

(1) The temperature of irrigation water ranging from 40° to 60° F. has no effect on the yield of grain or straw.

(2) The addition of nitrogen fertilizer to the crop immediately after irrigation prevents the chlorotic condition often observed in young wheat plants after heavy rains or the application of irrigation water and increases the yield of grain.

(3) The irrigation water washes the soluble nitrate nitrogen below the 3-foot level.

(4) Yields both of straw and grain are increased by applications of calcium nitrate, ammonium acid phosphate, and ammonium sulphate in the order named.

(5) In plots treated with calcium nitrate, the nitrate nitrogen content was high in the first 6 inches of soil. In plots receiving no nitrogen the nitrate nitrogen content was significantly lower.

(6) Applications of manganese sulphate, iron sulphate, and superphosphate did not alter the chlorotic condition or increase the yield over the no-treatment plots.

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