Past-Emergence Liquid Nitrogen and Atrazine on Corn 1964

Paul M. Burson, R. D. Curley, and E. G. Bonnell

Three rates of liquid nitrogen (28-0-0) were broadcast as past-emergence when the corn had made about a 2 inch growth. Four lbs. of atrazine per acre was added to the liquid nitrogen to control grassy weeds. This is a practice that is being used in certain areas of the state where liquid N materials are available. Reports indicate there is a burning injury or a partial defoliation from this practice but not sufficient in extent to discourage its use. The rates of the liquid nitrogen were 100, 200 and 300 lbs. per acre plus the atrazine added to each rate. All trial plots received 250 lbs. per acre of 4-12-24 starter fertilizer banded 2 inches to the side and 2 inches below the seed. There was definite injury on the leaves of all corn plants, on all three rates but most serious on the 300 lb. rate. The recovery was much slower on the 300 lb. rate. Ten days later after injury was visible the 100 and 200 lb. rates had recovered but on the 300 lb. rate injury was still visible and the growth had been retarded. The 1964 yield results are as follows:

Fertilizer Treatment	Bu. Yields Per Acre
Check	43.0
Starter	78.0
Starter + Past-emg. Atrazine Broadcast	77.5
" + 250 #dry 33-0-0 (82# N) sidedressed + Atrazine Broadcast	97.0
" + 100 #liquid (28# N) + Atrazine all Broadcast	97.0
" + 200 # " (56# N) + " " "	97.5
" + 300 # " (84# N) + " " "	92.5

Manure, Lime and Starter Fertilizer on Continuous Corn 1964

Paul M. Burson and E. G. Bonnell

Manure, lime and starter fertilizer on 12 years of continuous corn was the best combination of soil treatments under the dry weather conditions in 1964. Lime was applied in December, 1961 at the rate of 3 tons per acre according to soil test. Manure is applied annually at the rate of 10 tons per acre. The started fertilizer, 6-24-12 was placed in a band 2" to the side and 2" below the seed at 175 lbs. per acre according to soil test. The soil types are Judson and Clyde silty clay loams. The 1964 yield results are as follows:

Fertilizer Treatment	Bu. Yield Per Acre	
	No Lime	Lime
Check	68.0	69.5
Manure	74.5	84.5
Manure + Starter	74.5	90.0

Irrigation and Starter Fertilizer for Corn 1964

Paul M. Burson and E. G. Bonnell

An irrigation trial on a small scale was conducted at Rosemount in 1964. The trial was limited in scope because of the lack of sufficient equipment. The soil type was an upland soil of Port Byron silt loam and had been in continuous corn for

9 years. Three different starter fertilizers were banded at planting time; 4-12-24, 5-20-20 and 6-24-12 and the supplemental liquid nitrogen, usually sidedressed, was applied with the starter at planting time. The yield results are as follows:

	Bu. Yield Per Acre	
	check	all fertilizer
No irrigation	11.5	28.8
Irrigation	58.0	85.0

Residual starter Vs Starter Vs Starter and Sidedressing for Corn
1964
Paul M. Burson and E. G. Bonnell

On 9 fields of corn residual starter, starter, and starter + sidedressed nitrogen fertilization were compared in 1964. The starter fertilizer of, 6-12-24 applied at 250 lbs. per acre was banded with 80 lbs. of N sidedressed at the first cultivation. The yield results are as follows for 4 soil types(1):

Fertilizer Treatment	Bu. Per Acre Yield
Check	75.0
Residual starter	79.2
Starter	86.9
Starter + sidedressed N	100.3

(1) Judson and Clyde silty clay laom
Port Bryon silt loam
Ostrander silt loam

Starter Fertilization for Soybeans
1964
Paul M. Burson and E. G. Bonnell

Two fields of soybeans were fertilized with 250 lbs. per acre of 4-12-24 according to soil test. The fertilizer was banded 2" to the side and 2" below the seed. All beans were inoculated. The yield results are as follows:

Fertilizer Treatment	Bu. Yield Per Acre	
Check	22.4	
Starter fertilizer	30.1	
Inc. from fertilizer		+ 7.7

Variety - mint
Soil types - Clyde and Judson silty clay loams.

Continuous Soybean Fertility Study

(Rosemount, 1964)

Dr. A. C. Caldwell, E. C. Seim, G. W. Rehm.

An experiment was begun in 1957 on a Port Byron silt loam at Rosemount, Minnesota, to measure the long term effect of fertilizer applications on the yield and quality of soybeans grown continuously.

In 1964 the experiment was continued. A severe period of drought in mid-summer slowed growth and reduced the final yield of beans.

Drought periods usually cause increased variation in yield due to non-uniform plot conditions. Despite this, differences in growth were observed and recorded when yields were measured. The yields are reported in Table 1. All of the treatments gave an average increase over the control, many of which were statistically significant at the 95% level. Plots which had received heavy application of 0-400-400 and 0-400-400 + 6 T manure 7 years ago increased the 1964 yield by 6.87 and 5.90 bushels per acre respectively.

It is interesting to note that despite the low yields due to drought a more distinct pattern of fertilizer response emerged in this dry year than in several previous years with normal rainfall.

Residual Effect of Fertilizer Treatments on the Yield of Soybeans Grown Continuously. (Rosemount, 1964 - Fertilizer applied in 1957).

Treatment No.	N	P	K	Manure	1964 Yield Bu/acre	Diff.
1	0	0	0		11.39	--
2	0	20	20		11.93	+.55
3	0	40	40		12.88	+1.50
4	0	60	60		14.40	+3.02
5	0	80	80		13.25	+1.87
6	0	400	400		18.25	+6.87
7	0	400	400	+ 6 T man.	17.28	+5.90
8	0	0	0		12.50	+1.12
9	0	20	20		12.65	+1.27
10	0	0	0		14.73	+3.35
11	0	80	80		13.00	+1.62
12	0	0	0		15.30	+3.92
13	0	400	400		14.20	+2.82
14	0	0	0	+ 6 T	15.23	+3.85
15	0	0	0	+ 6 T	13.03	+1.18
	lsd (.95)				3.47	
	hsd (.95)				6.22	

The Effect of Nitrogen Source, Placement and Time of Application on the Yield and Nitrogen Content of Continuous Corn on Webster Clay Loam at Lamberton in 1964.

J. M. MacGregor and W. W. Nelson

The effect urea and ammonium nitrate as sources of nitrogen on the yield and composition of corn is being studied. The nitrogen materials are being plowed down and surface applied. The plowed down treatments are fall applications. The surface treatments were applied in fall, spring and a late sidedressing. This study was started in 1960.

Each experimental plot is 77.5 feet long and six corn rows wide. Each treatment is replicated four times. Sufficient phosphorus and potassium is applied as broadcast and starter applications. A plant population of 18,000 plants per acre is established. The primary objectives of this field project is to investigate:

1) The relative effectiveness of equal amounts of nitrogen as urea or as ammonium when applied to this soil at different rates.
2) The relative efficiency of such nitrogen forms when they are applied in the late fall, in the spring at time of planting, or as late sidedressing in late June or in early July.
3) The relative values of fall plowing down of two sources in comparison to overwintering of the nitrogen fertilizer on the surface of the fall plowed soil.
4) To find if there was any possible fertilizer nitrogen accumulation in the soil, the relative amounts removed by the corn crop and losses sustained through leaching, losses to the air, or losses by soil erosion.

For the first few years, all data was obtained by harvesting and analyzing the corn plants, and computing the nitrogen removal and relative efficiency based on amounts actually present in the corn plants. The plant parts were divided into ears, leaves, upper stalk and lower stalk. Soil samples were collected from some treatments during 1962 and 1963. The depths sampled were 0-6", 6-12" and 12-24" and the results of this study are also reported here.

The 1960, 1961 and 1962 corn yields were somewhat affected by weather, but the area did not seem to drain well, and in 1963, tile drains were laid down along the outer end of each of the plots. Corn yields of 1963 and 1964 have been much more satisfactory than in the three earlier years, although the summer of 1954 was relatively dry during several intervals of the growing season.

The yields of ear corn for each of the five years are shown in Table 1, ranked in order of yield magnitude for 1964. Only the two first treatments (121.4 and 115.7 bushels per acre) were significantly different from the rest by Duncan's multiple rank test.

Table 1. The Effect of Nitrogen Source, Rate and Time of Application on the Yield of Continuous Corn at Lamberton from 1960 through 1964.
(Ranked according to 1964 yield - average of 4 replicates)

Rank	Treatment (lbs. N/A)	Yield of ear corn - bu/A @ 15.5% moisture 1960	1961	1962	1963	1964	Average
1	80 urea - late sidedressing	76.9	86.4	48.2	143.8	121.4	
2	80 urea - at planting	57.7	99.1	40.5	149.3	115.7	
3	80 NH_4NO_3-late sidedressing	50.4	98.4	46.7	140.7	113.0	
4	80 NH_4NO_3- at planting	59.3	90.0	32.7	149.2	112.5	
5	160 urea-plowed under-fall	79.4	112.5	43.5	152.8	112.4	
6	160 NH_4NO_3-late sidedressing	40.7	97.4	77.7	151.7	109.5	
7	80 urea-plowed under-fall	61.7	76.9	36.7	154.5	104.9	
8	40 NH_4NO_3-top of plowing-fall	49.0	96.7	29.6	140.1	101.5	
9	160 NH_4NO_3- plowed under-fall	69.8	97.9	46.7	147.7	100.9	
10	80 NH_4NO_3-plowed under-fall	67.4	97.9	43.6	149.6	100.8	
11	40 urea - at planting	45.4	91.1	31.4	147.6	100.6	
12	40 urea - plowed under-fall	55.1	78.2	29.1	148.8	100.3	
13	40 NH_4NO_3 - at planting	66.2	92.0	45.4	152.2	99.8	
14	40 urea - late sidedressing	57.7	95.6	24.9	142.3	94.1	
15	40 NH_4NO_3- late side-dressing	63.6	92.6	39.5	148.6	90.4	
16	40 NH_4NO_3 - plowed under-fall	42.3	87.5	30.9	148.6	88.3	
17	40 urea - top of plowing-fall	62.3	101.3	37.0	140.7	84.1	
18	check	49.5	88.2	26.1	132.6	72.9	

Total corn yields for the five years of continuous corn have varied considerably, and these are shown in Table 2, along with the pounds of fertilizer nitrogen applied for each bushel of increase obtained. A range of 2.3 to 8.5 pounds of nitrogen was

applied for each additional bushel of corn produced.

Table 2. Total Five Year Corn Yield, Increase and Pounds of Nitrogen Applied per Bushel of Yield Increase as Influenced by Nitrogen Source, Rate and Time of Application at Lamberton.
1960 - 64.

(Ranked according to 5 year total - average of four replicates)

Rank	Treatment (lbs. N/A)	Bu/A.	Bu/A.	Applied 5 yrs.	lbs. N/bu
1	160 urea - plowed under-fall	500.6	131.3	800	6.1
2	160 NH_4NO_3 - late sidedressing	477.0	107.7	800	7.4
3	80 urea - " "	476.7	107.4	400	3.7
4	160 NH_4NO_3 - plowed under-fall	463.0	93.7	800	8.5
5	80 urea - at planting	462.3	93.0	400	4.3
6	80 NH_4NO_3 - plowed under-fall	459.3	90.0	400	4.5
7	40 NH_4NO_3 - at planting	455.6	86.3	200	2.3
8	80 NH_4NO_3 - late sidedressing	499.2	79.9	400	5.0
9	80 NH_4NO_3 - at planting	433.7	74.4	400	5.4
10	80 urea - plowed under - fall	434.7	65.4	400	6.1
11	40 NH_4NO_3 - late sidedressing	434.7	65.4	200	3.1
12	40 urea - top of plowing - fall	425.4	56.1	200	3.6
13	40 NH_4NO_3 - top of plowing-fall	416.9	47.6	200	4.2
14	40 urea - at planting	416.1	46.8	200	4.3
15	40 urea - late sidedressing	414.6	45.3	200	4.4
16	40 urea - plowed under-fall	411.5	42.2	200	4.7
17	40 NH_4NO_3 - plowed under-fall	397.6	28.3	200	7.1
18	check - no nitrogen	369.3	---	---	---

Although the higher total corn yields were obtained with the heavier rates of nitrogen application, these rates were not the most efficient. The lowest rate of 40 pounds of nitrogen per acre was generally the most effective per pound of nitrogen fertilizer used. It should be emphasized that investment for fertilizer nitrogen is

relatively small in comparison to the fixed per acre costs of crop production, which might well justify a heavier rate of nitrogen application to obtain a larger yield increase.

The effect of nitrogen source rate and time of application on the total nitrogen content of 1964 corn from the continuous corn plots is given in Table 3.

Table 3. The Effect of Nitrogen Source, Rate of Application, and Time of Application on the Total Nitrogen Content of 1964 Corn Plants from the Continuous (1960-64) Corn Plots at Lamberton.
(Total above ground plant parts - average of 4 replicates)

Treatment (lbs. N/A)	Leaves	Ears	Upper stalks	Lower stalks	Total	Increase
check	17.7	49.0	2.7	7.8	77.2	---
40 as NH_4NO_3 plowed downfall	22.2	94.9	3.2	15.1	135.4	58.2
40 as urea " " "	29.6	96.8	4.0	7.4	137.8	60.6
40 " NH_4NO_3-left on surface "	24.8	96.9	3.3	9.8	134.8	57.6
40 " urea - " " "-"	28.8	98.5	4.1	13.4	144.8	67.2
80 " NH_4NO_3- plowed downfall	28.8	93.3	5.2	15.1	142.4	65.2
80 " urea - " " -"	28.6	106.4	5.1	17.5	157.6	80.4
160 " NH_4NO_3 - " " -"	30.5	83.1	5.7	16.8	136.1	58.9
160 " urea - " " -"	28.6	121.3	4.5	21.6	175.9	98.7
40 " NH_4NO_3- at planting	24.2	79.8	3.4	8.1	115.5	38.3
40 " urea - " "	20.8	79.4	3.9	8.9	113.0	35.8
80 " NH_4NO_3 -" "	29.1	108.3	4.0	15.4	156.8	79.6
80 " urea - " "	39.3	150.4	5.1	21.4	216.2	139.0
40 " NH_4NO_3- late sidedressing	30.8	90.4	6.0	11.3	138.5	61.3
40 " urea - " "	20.2	83.2	3.6	8.3	115.3	38.1
80 " NH_4NO_3- " "	27.9	97.7	5.0	12.5	143.1	65.9
80 " urea- " "	28.8	113.6	6.1	17.2	165.7	88.5
160 " NH_4NO_3 - " "	38.3	97.3	6.7	20.8	163.1	85.9

Considering the nitrogen present in the corn ears alone, it is evident that the 40 pound per acre rate of nitrogen approximately equalled the amount removed in the grain, whereas with the higher rates more fertilizer nitrogen was applied than was removed in the corn grain. This should be reflected in a build up in the amounts of soil nitrogen on those plots receiving the annual application rates of either 80 or 160 pounds of nitrogen. As will be reported in the following article, soil analyses for total nitrogen indicates no consistent increase in the amounts of nitrogen on the more heavily fertilized plots, but concentrations of soil nitrate nitrogen were much higher under the heavier fertilization treatments.

The Effect of Urea or Ammonium Nitrate Nitrogen on the Nitrate Content of Surface Soil and of Different Parts of the Corn Plant at Lamberton in 1964 (Webster clay loam)

J. M. MacGregor and W. W. Nelson

Many farmers have become concerned with the effect of nitrogen fertilization on the nitrate content of corn plants during the growing season, especially where growth is retarded by dry soil conditions at some period of growth. Research in several mid-western states has shown that drowth conditions result in marked increases in the nitrate content of corn. Olson (1) stated that forages and silages containing less than 0.15% of nitrate nitrogen appear safe to feed, feeds containing 0.15% to 0.40% nitrate nitrogen should be supplemented to supply a ration averaging less than 0.15% nitrate nitrogen, whereas those forages containing over 0.45% nitrate nitrogen are potentially dangerous to feed, even at restricted levels. He concluded that nitrate poisoning of livestock is relatively rare, and that fertilizer practices should be based on Experiment Station recommendations without concern for the possibility of nitrate poisoning.

A long term nitrogen fertilizer experiment has been in progress at the Southwest Experiment Station at Lamberton on a Webster soil planted to continuous corn beginning with the 1960 growing season. Nitrogen has been annually applied at rates of 40, 80 or 160 pounds per acre, either as ammonium nitrate or as urea for five years.

In 1964 corn plants were randomly sampled from two replications on each of five different nitrogen treatments in mid-June, mid-July, mid-August, and finally in mid-September. Soil samples were also taken at the same times at the six-inch depth immediately adjacent to the corn roots. The corn plants were immediately chilled following sampling, and dried in a circulating air oven at 55°C. After drying, the tissues were separated into leaves, upper stalks and lower stalks (with the exception of the mid-June sampling which consisted entirely of leaves). The soil samples were also chilled and all samples were then analysed for nitrate content.

The nitrate values obtained on all samples are shown in the following table. The tissue samples considered to be at toxic levels for uncontrolled animal feeding by Olsons nitrate values are identified with the symbol 't'.

The nitrate content of the soil was directly related to the amounts of fertilizer nitrogen applied over the five year period, with the relatively large amounts present in mid-June rapidly decreasing as the growing season progressed.

Nitrate levels of the corn leaves sampled in mid-June were relatively high, and as the rates of nitrogen applied increased, toxic nitrate levels were consistently present. By mid-July, however, nitrate levels of the leaves were and remained at relatively low levels for the remainder of the growing season.

Upper stalks, which were not available for the June sampling, could be considered relatively safe for feeding during the three months in which these were analyzed.

However, in the lower stalks, these tissues growing on the plots receiving no nitrogen, had relatively low concentrations, but as rate of nitrogen fertilization increased (especially in July with relatively high soil nitrate levels) these tissues consistently contained toxic nitrate concentrations which decreased as the growing season progressed. The nitrate content of lower corn stalks sampled in August and September were relatively safe for feeding where nitrogen was applied annually at the 80 pound per acre rate. However, when this N fertilization rate was doubled to an annual application rate of 160 pounds per acre, the lower corn stalks contained toxic nitrate levels through the entire growing season.

This illustrates that heavy nitrogen fertilization results in abundant soil nitrate and toxic nitrate levels in some corn tissues grown under these conditions in 1964. It is probable that either legume ground or soils receiving heavy applications of barnyard manure would result in similar trends, but of lower magnitude.

(1) Olson, Oscar: Nitrate Problems in Livestock Feeds. Report of the Fourteenth Annual Soils and Fertilizer Short Course. Leamington Hotel, Mpls, Minn., November 23-24,

Soil Nitrates (ppm) and Percentage Nitrate Nitrogen in Lamberton Fertilizated Corn in 1964
(NH_4NO_3 or urea applied to Webster clay loam)

1st treatment	ppm soil nitrates				Percentage nitrate nitrogen in corn tissues									
					Leaves				Upper stalks			Lower stalks		
	June	July	August	Sept.	June	July	August	Sept.	July	August	Sept.	July	August	Sept.
check	8	2	1	1	0.10									
					0.40									
					0.33	0.03	0.03	0.02	0.07	0.03	0.02	0.01	0.03	0.01
					0.30									
	2	2	1	1		0.02	0.02	0.02	0.05	0.05	0.02	0.04	0.03	0.01
Average	5	2	1	1	0.28	0.03	0.03	0.02	0.06	0.04	0.02	0.03	0.03	0.01
80#/A NH_4NO_3-N (spring)	26	7	3	1	0.35									
					0.41	0.11	0.03	0.03	0.45	0.06	0.02	1.06[t]	0.15	0.03
	11	2	3	2	0.70[t]									
					0.41									
					0.47[t]	0.01	0.04	0.01	0.02	0.08	0.01	0.30	0.17	0.06
Average	19	5	3	2	0.47[t]	0.06	0.04	0.02	0.24	0.07	0.02	0.72[t]	0.16	0.05
80#/A urea-N (spring)	33	4	2	2	0.79[t]									
					0.20									
					0.20	0.01	0.05	0.03	0.05	0.06	0.03	0.18	0.44	0.26
					0.51[t]									
	13	3	5	1	0.48[t]	0.08	0.03	0.02	0.45[t]	0.06	0.03	0.55	0.15	0.08
Average	23	4	4	2	0.44	0.05	0.04	0.03	0.25	0.06	0.03	0.42	0.30	0.17
160 #/A NH_4NO_3-N (fall)	48	45	4	6	0.62[t]									
					0.70[t]	0.12	0.04	0.02	0.37	0.16	0.09	0.87[t]	0.82[t]	0.60[t]
					0.48[t]									
	43	21	8	2	0.58[t]	0.10	0.03	0.01	0.41	0.15	0.07	0.73[t]	0.82[t]	0.45[t]
Average	46	33	6	4	0.60[t]	0.11	0.04	0.02	0.39	0.16	0.08	0.80[t]	0.82[t]	0.53[t]
60#/A urea-N (fall)	36	7	7	2	0.70[t]									
					0.50[t]	0.12	0.07	0.01	0.37	0.13	0.02	0.65[t]	0.83[t]	0.51[t]
					0.57[t]									
	36	5	2	2	0.53[t]	0.16	0.07	0.01	0.48[t]	0.11	0.03	0.68[t]	0.68[t]	0.25
Average	36	6	5	2	0.58[t]	0.14	0.07	0.01	0.43	0.12	0.03	0.67[t]	0.76[t]	0.38

t = toxic to animals, even with limited quantity.

The Effect of Continued NH_4NO_3 and Urea Applications to a Webster Clay Loam on the Nitrate Nitrogen Content of the Soil Under Continuous Corn Cropping at Lamberton.

J. M. MacGregor, R. Munter and W. W. Nelson

A long term nitrogen fertilizer experiment on continuous corn was initiated at the Southwest Experiment Station in the spring of 1960, with annual applications of either ammonium nitrate or urea nitrogen at rates of 40, 80 or 160 pounds per acre. Field corn has been grown each year with a plant population of approximately 18,000 plants per acre. Analyses of the corn have consistently shown that annual nitrogen removal has been at the approximate rate of fifty pounds per acre, and it was thought that the annual fertilizer nitrogen additions should result in the increase in the nitrate nitrogen and in the total soil nitrogen. It was considered that a possible nitrogen increase in the soil would be more amply reflected in the nitrate and in the exchangeable ammonium content of the soil.

Commencing late in April of 1962, soil samples from three soil depths (0"-6", 6"-12", and 12"-24") were sampled on two replicates from ten different nitrogen fertilized plots at monthly intervals until late October. Difficulty was encountered in the analyses and only a portion of the 1962 plot samples were analyzed. The sampling of October, 1963 were analyzed for total nitrogen (Kjeldahl procedure) as well as for nitrate and exchangeable ammonium nitrogen. The ammonium content of the soil showed little variation and since the procedure was detailed and time consuming, ammonium nitrogen content was not determined for the entire 1963 season on the samples from those plots receiving intermediate rates of nitrogen fertilization. Also, since the incomplete analyses of 1962 were much the same as those obtained from the 1963 samples, only the 1962 results are presented in the following tables.

As expected, the average nitrate content of the check (or no nitrogen) plots is considerably lower than in the soils receiving the annual nitrogen treatments. As the rate of nitrogen fertilization increases, the highest nitrate concentrations usually accumulate in the 6"-12" depth, with smaller amounts present in either the surface or in the 12"-24" levels. Nitrates tend to be low in the relatively cool soil of April increase rapidly in May as the soil warms up, and then decrease rapidly during the summer months, even where heavy nitrogen applications have been made. They then increase rapidly in late October as the growing season comes to an end and withdrawal by the corn plants becomes a minimum. As the rate of fertilization was increased, more nitrates (and more total nitrogen in October) seems to accumulate in the 12"-24" soil depth, which may indicate the possibility of nitrate movement to lower soil depths.

If this nitrate movement continues to much lower depths, there is a possibility that some of the nitrogen may be moving down below the reach of the corn roots and thus be lost to crop production. If this does occur, it would at least partially account for the limited nitrogen increase in the upper two feet of the profile with the relatively large amounts of nitrogen fertilizer being applied.

The concentrations of exchangeable ammonium present in the 1963 soil samples under the different treatments are shown in Table 2.

The concentrations of exchangeable ammonium were generally slightly higher in the 6"-12" soil depth, but there was no pattern or definite trend in relation to the kind or rate of fertilization, although there was a slight decrease during the summer months. With the apparent lack of correlation in relation to both fertilization and soil fertility conditions, this type of analysis was soon curtailed to include only the two extremes of fertility treatment.

Table 1. The Nitrate Content of Three Depths of Webster Clay Loam Fertilized with Urea or NH_4NO_3 Nitrogen Under Continuous Corn at Lamberton in 1963.

(Average of two replications).

Soil Depth	Annual Treatment (lbs N/A)	Time of Sampling in 1963 April	May	June	July	August	Sept.	Oct.	Total soil N in ppm October
		Nitrate nitrogen in parts per million							
0"- 6"	check	3.7	15.9	6.3	1.8	1.2	2.2	2.3	2140
6"-12"	"	5.1	9.8	5.5	1.3	1.0	2.1	3.3	2200
12"-24"	"	1.9	2.5	3.5	0.8	1.0	0.4	0.7	990
0"- 6"	80 NH_4NO_3	23.1	27.6	19.9	2.4	2.9	3.0	21.0	2300
6"-12"	plowed down in	12.7	50.7	24.7	2.0	2.1	5.5	13.1	2260
12"-24"	the fall	6.2	15.3	9.1	2.3	2.6	1.8	1.8	1010
0"- 6"	80 urea	16.2	22.9	24.4	2.4	3.4	4.1	13.3	2290
6"-12"	plowed down	24.2	40.7	30.7	1.8	1.5	5.0	11.1	2120
12"-24"	in fall	3.0	3.6	10.5	2.0	1.1	1.1	1.6	950
0"- 6"	160 NH_4NO_3	7.0	16.1	26.8	4.2	4.3	3.7	36.5	2350
6"-12"	plowed down	25.4	48.4	25.0	7.6	11.9	7.8	25.2	2590
12"-24"	in fall	7.5	10.4	9.3	10.2	9.5	13.2	9.6	1100
0"- 6"	160 Urea	22.9	28.4	54.4	4.7	6.2	3.2	30.5	2600
6"-12"	plowed down	42.6	35.3	44.0	6.3	13.1	5.1	17.7	2390
12"-24"	in fall	7.8	18.1	11.7	8.6	8.9	11.3	7.0	960
0"- 6"	80 NH_4NO_3	6.3	70.7	23.6	2.9	3.6	3.2	3.6	2300
6"-12"	broadcast be-	6.6	10.1	19.8	2.0	2.3	1.8	3.5	2290
12"-24"	fore spring planting	1.7	2.1	3.6	2.3	1.1	1.2	1.4	1210
0"- 6"	80 Urea	17.0	28.2	11.2	2.6	1.9	3.2	3.2	2240
6"-12"	broadcast be-	9.4	13.6	8.2	2.2	1.3	2.9	3.5	2310
12"-24"	fore spring planting	1.2	2.9	5.9	4.3	1.3	0.8	1.4	1470
0"- 6"	80 NH_4NO_3	6.3	10.6	9.7	2.6	2.2	4.8	4.2	2040
6"-12"	late sidedress	6.9	7.2	7.8	1.9	1.2	2.6	3.6	2180
12"-24"	June	1.3	3.2	3.5	7.5	0.8	0.9	2.3	1150
0"- 6"	80 Urea	5.2	9.0	4.4	3.6	8.0	4.4	5.3	2220
6"-12"	late sidedress	6.3	7.3	6.8	2.3	4.5	3.4	3.7	2000
12"-24"	June	1.6	2.8	5.1	1.5	2.0	1.6	1.8	2060
0"- 6"	160 NH_4NO_3	7.5	11.2	13.5	12.9	23.1	8.7	9.5	2070
6"-12"	late sidedress	9.0	12.3	16.7	9.7	12.6	4.3	10.4	2170
12"-24"	June	1.5	3.3	10.1	11.8	9.5	7.7	5.4	1090

Table 2. The Exchangeable Ammonium Content of Three Depths of Webster Clay Loam Fertilized with Urea or NH_4NO_3 Nitrogen Under Continuous Corn at Lamberton in 1963.

(Average of two replications).

Soil depth	Annual Treatment (lbs N/A)	Time of Sampling in 1963 April	May	June	July	August	Sept.	Oct.
		Exchangeable NH_4 - N in parts per million						
0"- 6"	check	10.4	15.9	2.8	8.3	7.6	5.2	4.8
6"-12"	"	4.3	17.0	14.5	7.0	7.8	5.8	3.6
12"-24"	"	2.3	5.5	7.4	6.2	5.9	4.3	2.2
0"- 6"	80 NH_4NO_3	12.8	17.9	11.6				
6"-12"	fall plow down	12.3	11.5	4.7				
12"-24"		3.6	2.1	3.8				
0"- 6"	80 urea	21.6	12.2					
6"-12"	fall plow down	14.0	14.8					
12"-24"		1.5	5.5					
0"- 6"	160 NH_4NO_3	6.8	8.6	10.5	10.2	8.4	5.8	16.7
6"-12"	fall plow down	10.0	5.4	12.0	8.4	8.3	5.0	17.7
12"-24"		4.9	4.6	5.6	5.2	5.8	3.7	5.0
0"- 6"	160 urea	28.9	---	17.1	11.6	9.1	3.4	75.6
6"-12"	fall plow down	19.9	10.2	11.8	10.4	7.1	3.1	13.9
12"-24"		3.6	4.5	5.0	4.8	5.1	6.5	6.9
0"- 6"	80 NH_4NO_3	6.3	11.0					
6"-12"	broadcast before	7.4	8.5					
12"-24"	spring planting	4.5	9.1					
0"- 6"	80 urea	5.3	8.7					
6"-12"	broadcast before	3.4	9.4					
12"-24"	spring planting	2.2	2.4					
0"- 6"	80 NH_4NO_3	8.1	9.2					
6"-12"	late sidedress	9.9	4.6					
12"-24"		3.3	1.6					
0"- 6"	80 urea	12.4	13.9					
6"-12"	late sidedress	8.5	3.1					
12"-24"	.	4.9	2.4					
0"- 6"	160 NH_4NO_3	8.8	3.8					
6"-12"	late sidedress	4.7	6.9					
12"-24"		2.0	---					

Comparison of Phosphorus Sources

A. C. Caldwell; E. C. Seim; G. W. Rehm.

A phosphorus source experiment was established at Rosemount in 1951. Twelve treatments of various phosphate materials were replicated four times across a regular rotation of corn, wheat, and two years of alfalfa. In 1959 the rotation was changed to corn, soybeans, wheat, and alfalfa. Potassium has been applied as required according to soil test. Lime was applied to two replicates in the fall of 1961.

All of the 1964 crops were adversely affected by a prolonged period of dry weather in early summer. Corn yields were severely damaged by the drought and no treatment yields were recorded. The average yield of the corn was about 15 bushels per acre. The second cutting of alfalfa was also drastically reduced by the drought. Soybeans were adversely affected in that they made very slow growth in the early part of the season.

All of the phosphate sources gave significant increases in alfalfa yield over no phosphate treatment but differences between phosphate sources were too small to be significant at the 5% level. Florida Rock, the highest yielding treatment, gave a higher increase than it has in past years while fused tricalcium phosphate, the second highest yielding treatment was also one of the best treatments in 1963.

No significant differences in the wheat yields were measured by the F test in 1964, although several treatments approached significance when measured by the least significant difference.

As in 1963 and past years, 1964 soybean yields show small increases which are not significant at the 5% level but which are consistently better than the checks.

Effect of various phosphate fertilizers on yield of alfalfa, wheat, and soybeans. (Rosemount, 1964).

Treatments	P_2O_5/A/Yr. lbs.	Alfalfa tons/A.	Wheat Bu./A.	Soybeans Bu./A.
None		1.77	14.9	16.0
Ord. Super	40	2.66	23.1	19.0
Conc Super	40	3.08	23.5	17.6
Cal. Meta	40	2.93	18.0	16.1
Phos. Acid	40	2.89	22.2	18.0
Fused trical phos.				
Fl. rock + Ord. Super	20 + 20	2.92	21.7	18.6
Fl. rock	100	2.76	24.3	17.9
	P_2O_5/A/4 Yr.			
Fl. rock	1000	3.14	22.7	17.7
Western rock	1000	2.39	18.7	18.6
Col. clay rock	1000	2.60	18.3	17.9
Tunis, rock	1000	2.67	19.9	16.2
Std Error ($S_{\bar{x}}$)		.28	2.1	1.6
Lsd (.05)		.81	6.1	4.7
Hsd (.05)		1.40	12.6	8.2

EFFECT OF POTASSIUM FERTILIZATION ON THE YIELD AND POTASSIUM CONTENT OF ALFALFA

H. J. Hopen, A. C. Caldwell and R. S. Grant

Farmers in northeastern Minnesota have had difficulty in establishing and maintaining stands of alfalfa. Soils in the eastern part of Minnesota tend to be acidic and low in native soil potassium. Alfalfa grown on unfertilized soil exhibits the typical yellow or brown deficiency symptoms together with winter killing and uneccnomic yields.

In 1960[1] a study was undertaken at Duluth to determine the effect of 0, 100, 200, 400 and 800 lbs. K_2O/A. on the growth of alfalfa. The fertilizer treatments were broadcast and plowed down in the fall of 1960 and planted to a small grain nurse crop in 1961. In 1963, 200 lbs. was applied as a split-plot topdressing to one half of the 100 lb., 200 lb. and 400 lbs./A. treatments.

The entire experimental area received 125 pounds of phosphorus per acre in 1960 to eliminate this element as a variable. Soil tests in 1963 and 1964 indicated that phosphorus was at medium to high levels in all plots. A unifcrm application of Boron was applied to the entire experimental area in 1962.

The (I) hay yields in 1962, 63, and 64, (II) tissue K content in 1962, 63 and 64 and the (III) soil content of exchangeable K in 1963 and 64 were used to determine the effect of K fertilization on the growth of alfalfa in this study.

1 Appreciation is expressed to Dr. D. G. Baker for assistance during the planning of this study.

I. YIELD OF FORAGE.

Table 1. Yield of forage (2 crops per year) as influenced by single K application.

Lbs. of K_2O Applied per Acre	Tons/Acre				
Fall 1960	1962	1963	1964	Average Annual Yield	Relative* Yield
0	2.71	2.37	1.05	2.04	1.00
100	3.14	3.03	1.67	2.62	1.28
200	3.54	3.69	1.85	3.02	1.48
400	3.42	3.89	2.15	3.16	1.54
800	3.55	4.27	2.45	3.42	1.67

*Yield at treatment level ÷ yield at 0#K_2O/A = Relative Yield

As the amount of fertilizer K was increased the yield was increased. Yield was more than doubled in 1964 in spite of a June and July drought. Admittedly, the yields were low, but the beeficial effect of fertilization are more apparent in an adverse season.

An initial application 200 lbs. K_2O/A. resulted in significantly higher yields than the no K treatment in all three years. As more than 200 lbs. K_2O was applied the yield increase per unit of added K decreased. The 400 lbs. K_2O treatment did not consistently result in higher yields than the 200 lbs. treatment over the three year period; but showed up as an advantage in relative yield in the adverse 1964 growing season. Farmers aiming at yields of four or more tons of forage per acre would be wise to apply 400 lbs. K_2O/A. at seeding and topdress with additional K later in the rotation. The 800 pounds of K_2O/A. appears to be more than is needed as one application.

With Muriate of potash (0-0-60) costing $55 per ton, an 800 lb. K_2O/A. application would be $36. The 400 lb., 200lb. and 100 lb. applications of K_2O would require an investment of $18, $9 and $4.50 per acre respectively.

With alfalfa hay selling at $25 per ton, an increase of only 1/3 ton per acre pays for 200 lbs. K_2O per acre with 0-0-60 retailing at $55 per ton. In this study the smallest yield increase from 200 pounds of K_2O/A. was 1/3 ton per year.

Figure 1. Effect of initial and topdressed K on three cuttings following topdressing.

A potash topdressing in 1963 increased yields above those of the initial application. Topdressing 200 lbs. K_2O/A. after the first harvest in 1963 produced a yield increase in the second harvest in 1963. The 400 lbs. of K_2O applied in 1960 plus 200 lbs. of K_2O in 1963 gave approximately the same yield as the 800 lb. application in both 1963 and 1964. From these data a split application, part as seeding and part as a topdressing, would seem to be the most economical use of K fertilization.

II. TISSUE CONTENT OF POTASSIUM.

Figure 2. Percent K in first and second cutting alfalfa tissue at 0, 100 (+200), 200 (+200), 400 (+200) and 800 lbs. K_2O/A. (1962 tissue data is not included as only the 0, 200 and 800 lb. K_2O/A. were evaluated).

As the level of K applied increased, the amount of K in the alfalfa tissue increased. The K topdressing following the first cutting in 1963 increased the K content of the second cutting of alfalfa. Tissue K levels were greater from topdressed than from non-topdressed areas in both harvests of 1964. The low K content in 1964 was probably due to the dry periods in the fall of 1963 and the mid-season 1964 growing season drought.

Tissue K levels were used in this study to evaluate the uptake and utilization of the soil application of K. If one were to try to keep the tissue K at the desired level of 2.0 to 2.25% in this study, a minimum of 400 lbs. of K_2O/A. would have to be applied at seeding plus an annual topdressing. As higher yields are produced, more K is removed from the soil (Table 2.)

Table 2. Potassium removal as influenced by average annual yield and average tissue K content.

Lbs. K_2O Applied/Acre Fall 1960	Average Annual Yield (Table 1) Tons/Acre	Average % Tissue K (Figure 2)	Average Lbs. of K_2O Removed Each Year/Acre
0	2.04	1.00	49
100	2.62	1.40	88
200	3.02	1.44	104
400	3.16	1.78	136
800	3.42	2.33	191

III. SOIL CONTENT OF EXCHANGEABLE POTASSIUM.

The amount of exchangeable K increased as the application of fertilizer K was increased. In the fall of 1963 and 1964 the check plot (0 pounds of K in 1960), 100 and 200 pound per acre applications contained essentially the same amount of exchangeable K. Therefore, without additional K, within 2 years of seeding, the 200 lbs. of K_2O/A. application was not adequate for forage production on this soil. Exchangeable K in the 400 and 800 lb. K_2O treatments was not depleted to the extent that it had been under lower levels of application.

Table 3. Pounds of exchangeable K at several soil depths in 1963 and 1964.

Lbs. of K_2O Plowed Down in 1960	K_2O* Topdressed in 1963	Exchangeable K - Lb./A.		
		Fall of 1963	Fall of 1964	
Lbs./A.	Lbs./A.	0-6 in.	0-3 in.	3-6 in.
0		70	67	73
100		80	---	---
100	200	140	---	---
200		83	83	77
200	200	147	133	120
400		106	90	83
400	200	246	207	203
800		203	---	---

*After first harvest in 1963.

Topdressing of 200 lbs. of K_2O/A. in the summer of 1963 approximately doubled the exchangeable K levels compared to non-topdressed plots the same fall. The 400 lb. treatment with topdressing contained twice as much exchangeable K as the single 400 lbs./A. K_2O treatment.

In 1963 topdressing of 200 pounds of K_2O per acre showed up in approximately equal amounts in the 0-3 and 3-6 inch levels when sampled in the fall of 1964. This indicates that although it may be more desirable to incorporate the fertilizer elements at time of seeding, there was appreciable downward movement of topdressed K on this loam soil. The fact that the topdressed K was utilized is verified by the increased K content of the tissue together with the yield increases obtained from topdressing.

Adequate fertilizer K should be supplied on soils of northeastern Minnesota to maintain satisfactory yields and tissue K content. One hundred lbs. of K_2O/A. at time of seeding provided a greater yield than the check plot. Typical visual K deficiency symptoms were often evident on the 100 lb. K_2O treatment. Two hundred lbs. of K_2O/A. at seeding consistently provided significantly greater yields than the check plot. No K deficiency symptoms were evident when 200 lbs. of K_2O/A. or more was used.

Winter killing of alfalfa was reduced by the application of 200 lbs. of K_2O or more at least once in the four year rotation.

The effect of lime and molybdenum on the yield of alfalfa, oats, corn, and soybeans.

A. C. Caldwell, E. C. Seim, G. W. Rehm.

The purpose of this experiment, started in the fall of 1951, is to study the long time effects of lime on (1) the yields of some common crops and (2) on the physical and chemical properties of the soil. Treatments were 0, 3, 6, 12, and 24 tons of dolomitic lime per acre, replicated 4 times. A rotation of corn, oats, and 2 years of alfalfa was set up. Each year corn and oats have received 200 pounds of 5-20-20 per acre. The alfalfa has received P and K as needed according to soil tests. Since 1959 soybeans have replaced one year of alfalfa in the rotation. The beans receive 100 pounds of 5-20-20 per acre as a starter fertilizer.

In 1960, molybdenum (as $(NH_4)_2 MoO_4$) was applied at the rate of 8.7 ounces per acre on one of the check plots in each replicate.

The effect of the different treatments on the 1964 yields are shown in the Table. No yields were measured for the corn replicates because of drouth damage. As in past years the most striking response to the lime or molybdenum treatment has been in the yield of alfalfa hay from 2 cuttings. These increases are significantly different at the 1% level. All of the rates of lime application were about equally effective in increasing the alfalfa yield. Molybdenum alone was also significantly effective in increasing the yield of alfalfa but as in 1962 and 1963 the yield increas was not as great as those obtained by liming.

Oat yields were increased by all lime treatments and by molybdenum but these increases were not significant at the 5% level. This has generally been the pattern in past years.

There were no major effects on the yield of soybeans as has been the case in 1963 and previous years.

Effect of lime and molybdenum on yields of alfalfa, oats, and soybeans. (Rosemount, 1964).

Lime Treatment Tons/A.	Alfalfa Tons/A.	Alfalfa Diff.	Oats Bu/A.	Oats Diff.	Soybeans Bu/A.	Soybeans Diff.
0	1.33	---	43.0	---	14.1	
3	3.16	+1.83	53.7	+10.7	16.3	+2.2
6	2.69	+1.36	51.2	+ 8.2	14.6	+ .5
12	2.84	+1.51	54.5	+11.5	18.2	+4.1
24	3.08	+1.75	55.5	+12.5	14.4	+ .3
0 + 8.7 oz. Mo/A.	2.38	+1.05	47.1	+ 4.1	16.8	+2.7
Std. error	.30		4.7			1.8
lsd. (.05)		.89	14.1			5.5
lsd. (.01)		1.23				
hsd. (.05)		1.36	21.5			7.1
hsd. (.01)		1.72				

The effect of lime on the chemical properties of soils 13 years after application.

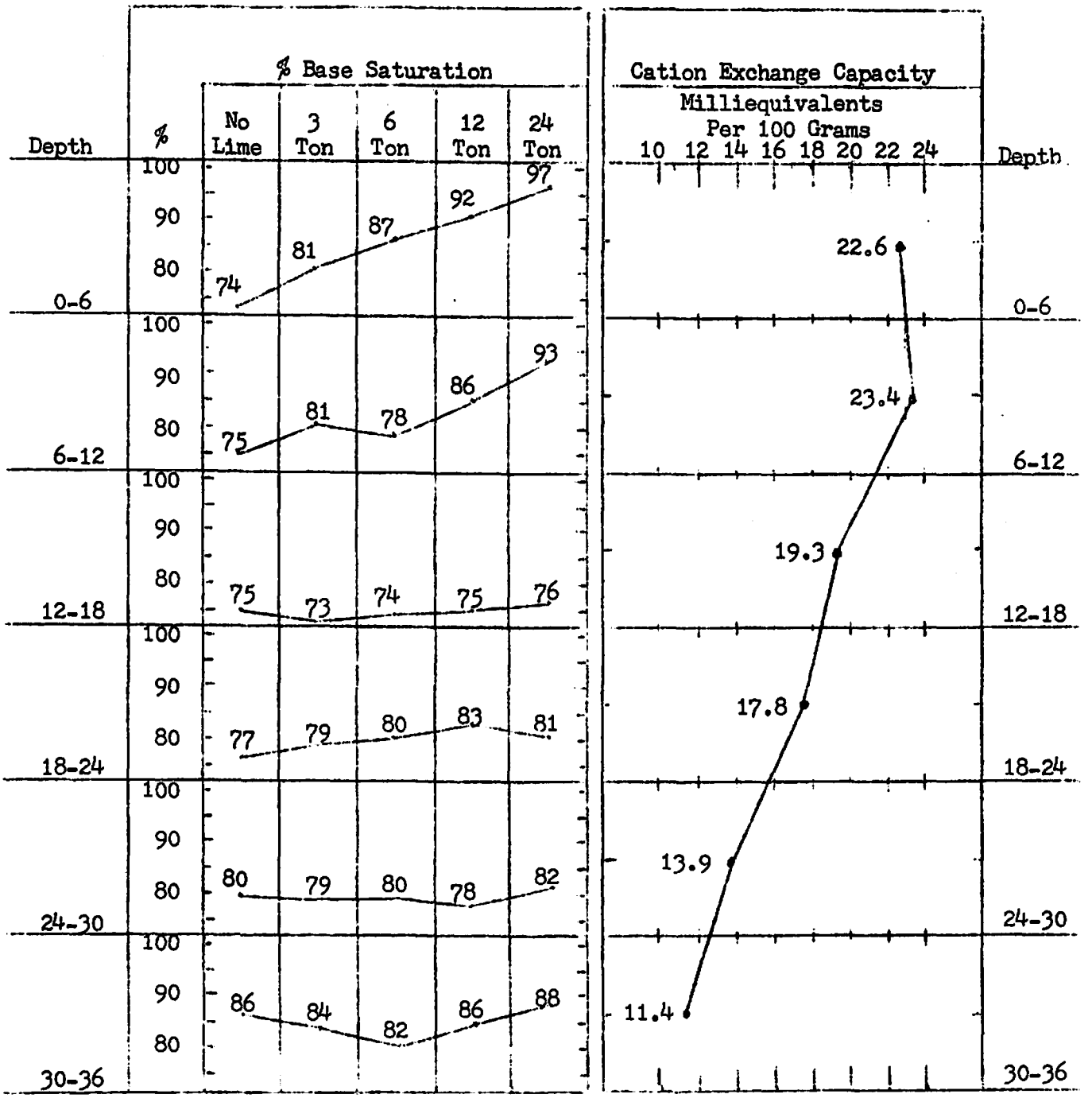
A. C. Caldwell and R. C. Munter

This is one phase of the long time lime study at Rosemount as outlined in the preceding pages of this report. The purpose of this phase of the experiment is to study the effect of various lime treatments on the chemical properties of the soil. The treatments were 0, 3, 6, 12, and 24 tons of dolomitic limestone per acre.

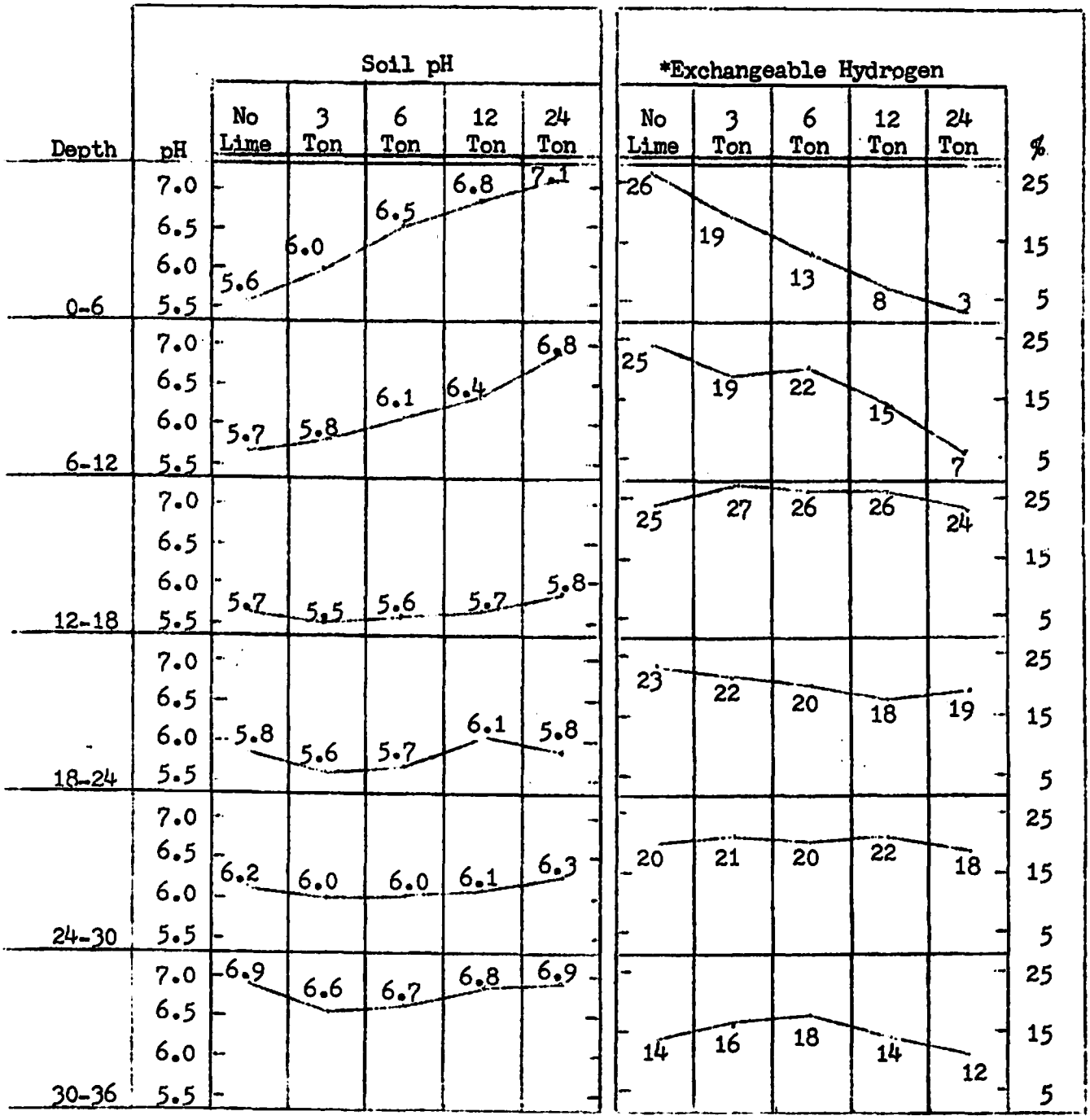
Dolomitic limestone was applied in the fall of 1951. In the fall of 1963, soil samples were obtained in duplicate from all 4 replicates of the various treatments. Soil samples were obtained at 6 depths to a depth of 36 inches. They were then analyzed for exchangeable calcium, magnesium, potassium, hydrogen; pH, phosphorous, organic matter, and total cation-exchange-capacity. The soil type is Port Byron silt loam; a well drained soil having a deep silt loam profile.

The effect of limestone on various chemical properties is represented by figures 1, 2, and 3. Exchangeable Calcium, Hydrogen, and pH show a good relationship to the corresponding lime treatments. There was no change in the amount of exchangeable magnesium. The total cation-exchange-capacity was determined only on the 0 treatment, or check plot. The exchange-capacity decreased with depth. This was because of the loss of organic matter content and the presence of material coarser than silt loams in some profiles below 24 inches.

Total Cation Exchange Capacity From Non-treated Soil, and the Effect of Lime on Percent Base Saturation

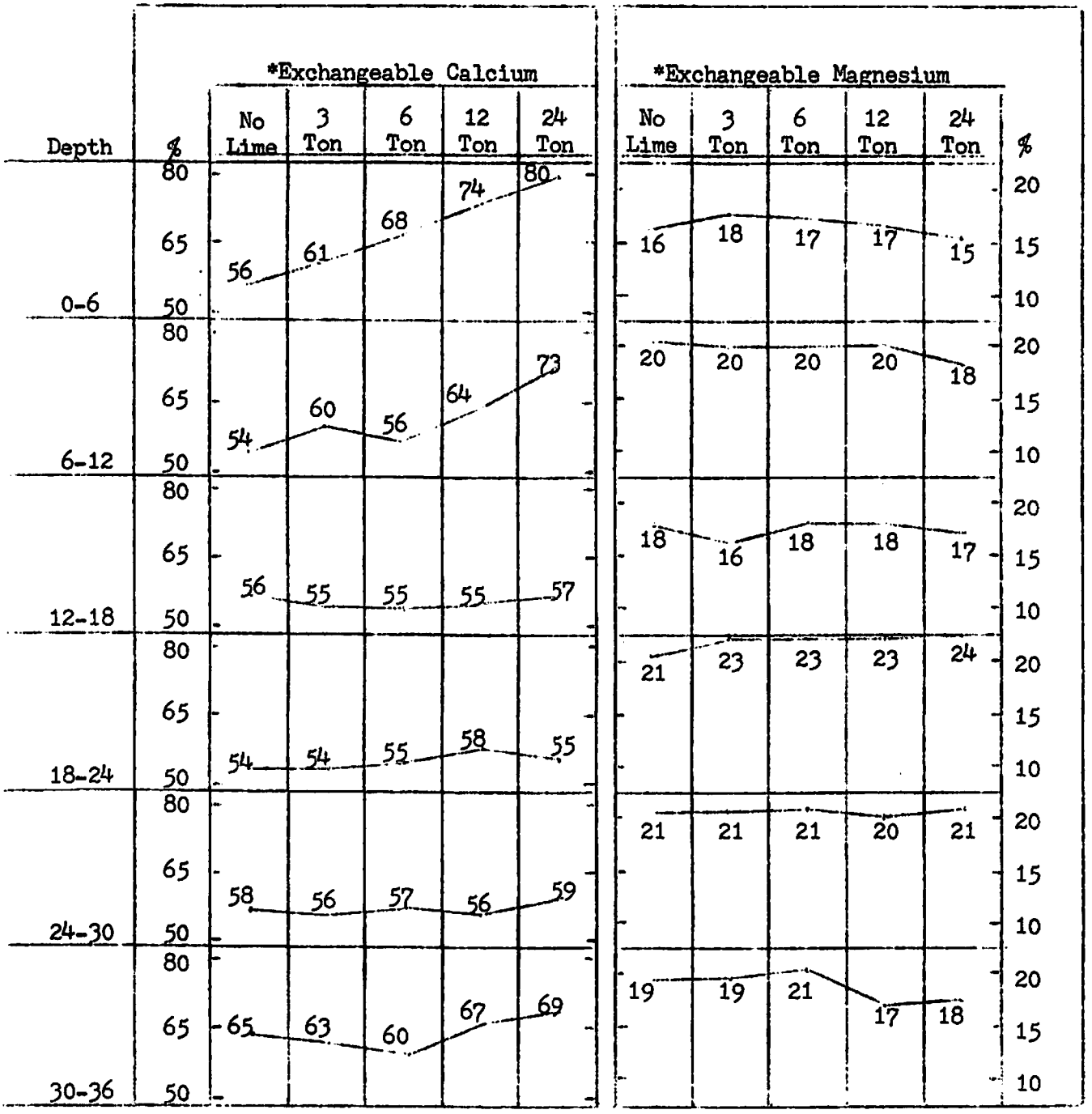


Effect of Lime on Soil pH and Exchangeable Hydrogen
Rosemount



*Percentage of Total Exchangeable Cations (H, K, Ca, Mg)

Effect of Lime on Exchangeable Calcium and Magnesium in Soil
Rosemount



*Percentage of Total Exchangeable Cations (H, K, Ca, Mg)

Field Research

E. C. Seim

In 1964 the alfalfa experiments established in 1962 were continued as were the experiments with corn, soybeans, and alfalfa following corn. New areas were devoted to studies on the effect of sulfur on yield and sulfur content of barley, oats and sunflowers.

Alfalfa

The yields of alfalfa in 1964 and the sulfur content of sulfur in the tissue are reported in Tables 1-4. Yields and sulfur content for the two previous years have been reported in Sulfur Report No. 1, 2, 3, and 4. This experiment compares the effects of annual applications of three rates of elemental sulfur (25, 50, 100 lbs. S/acre), and a 50 lbs. S/acre application of gypsum with a control (0 lbs. S/acre). A similar experiment including a heavy gypsum treatment (1000 lbs. S/acre) was treated only upon initiation of the experiment so that information regarding the residual effec of the various sulfur bearing materials at different rates of application might be obtained. All plots received complete applications of phosphorus and potassium according to soil tests at the start of the experiment. Borax (20 lbs./acre) was applied after the first cutting in 1962. Additional potassium has been topdressed as needed.

Two cuttings of alfalfa were obtained in 1964. A third cutting might have been obtained if the excellent fall growing conditions could have been forecast. The early growth of the alfalfa was stopped by drought. The first cutting was taken at this point. Treated plots consist of almost 100% alfalfa. The checks, however, have such a sparse stand of alfalfa that some grass and weeds have again become established on them.

The effect of the sulfur on the yield of alfalfa is quite striking. Treated plots produce 3 times as much alfalfa hay as the check plots. The increase in yield has been achieved on the residual plots as well as on those receiving annual applications of sulfur materials. On the residual study the heavier applications of elemental sulfur gave somewhat higher yields than the 25 lbs. per acre rate. These increases wer still not statistically different, however. Neither was there any statistical differen in the yield between the two gypsum application rates.

Table 1. Effect of annual applications on sulfur-bearing materials on the yield of Alfalfa

Material	Rate lbs. S/acre	Yield 1st Cut. Tons/acre	Yield 2nd Cut. Tons/acre	Total Tons/acre
None	0	.39	.31	.69
Sulfur	25	1.13	1.26	2.39
Sulfur	50	1.19	1.26	2.45
Sulfur	100	1.15	1.22	2.36
Gypsum	50	1.11	1.16	2.27
lsd (.05)		.27	.26	.49
(.01)		.37	.36	.67
hsd (.05)		.40	.40	.73
(.01)		.50	.50	.91

Table 2. Residual effect of sulfur-bearing materials on the yield of three year old alfalfa.

Material	Rate lbs. S/acre	Yield 1st Cut. Tons/acre	Yield 2nd Cut. Tons/acre	Total Tons/acre
None	0	.32	.44	.75
Sulfur	25	1.09	.96	2.04
Sulfur	50	1.12	1.09	2.21
Sulfur	100	1.26	1.21	2.49
Gypsum	50	1.31	1.19	2.51
Gypsum	1000	1.26	1.13	2.39
lsd (.05)		.28	.24	.50
(.01)		.38	.33	.67
hsd (.05)		.42	.37	.74
(.01)		.51	.45	.91

Table 3. Effect of annual applications of sulfur-bearing materials on the sulfur content of alfalfa.

Material	Rate lbs/S/acre	Sulfur Content of Tissue (%) 1962 Young	1962 Mature	1963 1st Cut.	1963 2nd Cut.	1964 1st Cut.	1964 2nd Cut.
None	0	.192	.133	.220	.236	.167	.192
Sulfur	25	.221	.165	.313	.358	.231	.308
Sulfur	50	.242	.175	.360	.425	.274	.377
Sulfur	100	.283	.192	.403	.444	.336	.423
Gypsum	50	.341	.238	.457	.416	.323	.424
lsd (.05)		.024	.018	.046	.032	.042	.043
(.01)		.032	.024	.063	.043	.058	.058
hsd (.05)		.036	.027	.072	.048	.064	.065
(.01)		.045	.036	.089	.060	.079	.080

Table 4. Residual effect of sulfur-bearing materials on the sulfur content of alfalfa.

Material	Rate lbs/S/acre	Sulfur Content of Tissue (%) 1962 Young	1962 Mature	1963 1st Cut.	1963 2nd Cut.	1964 1st. Cut.	1964 2nd Cut.
None	0	.194	.139	.221	.304	.167	.178
Sulfur	25	.228	.164	.236	.285	.188	.209
Sulfur	50	.256	.181	.308	.381	.226	.250
Sulfur	100	.285	.191	.319	.377	.278	.292
Gypsum	50	.337	.220	.332	.358	.243	.224
Gypsum	1000	.392	.275	.489	.466	.378	.414
lsd (.05)		.027	.018	.048	.089	.023	.037
(.01)		.037	.025	.065	.120	.045	.051
hsd (.05)		.039	.028	.073	.132	.050	.056
(.01)		.048	.034	.089	.162	.061	.069

The tables on the sulfur content of the alfalfa show greater differences between the rates and types of sulfur materials than is reflected in the yields. For annual applications 25 lbs. of sulfur per acre in the elemental form raised the sulfur content of the alfalfa significantly. Each increasing rate of application increased the sulfur content of the tissue. The 100 lbs./acre elemental sulfur application now produces alfalfa with the same sulfur content as alfalfa supplied with 50 lbs. of sulfur annually as gypsum.

The data for the residual study seems to indicate that all of the sulfur materials and rates produced a peak sulfur supply in 1963 (the year after application). The levels of sulfur in the 1964 cuttings has dropped below the 1963 levels in all treatments. Although gypsum (50 lbs. S/acre) produced forage with a higher sulfur content than elemental sulfur in the year of application, in 1964 the 50 lbs. per acre rate of elemental sulfur has been equally as effective as 50 lbs. of sulfur as gypsum in supplying sulfur to the alfalfa. The 100 lbs. per acre rate of elemental sulfur is now superior to 50 lbs. of sulfur as gypsum in supplying sulfur to the plants. In 1964 only the heavy gypsum application continued to supply sulfur at levels which produced forage with sulfur contents greater than .3%.

In 1963 the area which had been used in 1962 to check the effect of various sulfur bearing materials on corn was planted to alfalfa. No further sulfur applications were made to those plots which had received elemental sulfur, 16-20-0-S, or K_2SO_4. The plots which had initially received 10 lbs. S/acre as gypsum were treated with an additional 50 lbs. S/acre as gypsum. In August of 1963 a trace element mixture containing Zn, Cu, Mn, Mo, and Fe was applied to those plots which initially had received the Cominco product containing Zn, Mn, N, and S. Sulfur applied as part of the trace element salts was 15 lbs. per acre. No harvest was taken of the young alfalfa in 1963. In 1964 the early growth was severely hit by drought. Consequently, no yields were recorded. The field was clipped and sprayed with Dalapon to control quack grass. Treatment differences began to appear almost immediately in the new growth. By the time of the second cutting the checks were easily visible in every replication. In the plots which had originally received 10 lbs. S/acre as K_2SO_4 in the corn row the

position of these old corn rows were clearly outlined by improved growth of the alfalfa. As all of the plots had received 300 lbs. of K_2O per acre before planting the alfalfa, it seems unlikely that this effect could be due to the additional potassium. Best growth was recorded on those plots which had received the trace element sulfur-treatment.

Yields of this second cutting and the percent sulfur in the tissue are reported in Table 5. The residual effect of the sulfur applied on the corn has significantly increased the second cutting yield of alfalfa. Those plots which received additional sulfur treatments have not produced more alfalfa than the residual treatments. The additional treatments have, however, increased the percent sulfur in the alfalfa tissue.

Barley-Oats

Trials were again conducted in 1964 to study the effects of sulfur-bearing materials on barley and oats. Earlier barley and oat trials were reported in reports 1, 2, and 4. In 1964 the sulfur treatments used were 10 lbs. of sulfur per acre as elemental sulfur, sodium sulfate, and gypsum. Treatments were applied in the row with a sulfur-free starter fertilizer.

The gypsum and elemental sulfur treatments were duplicated on the barley experiment using radioactive gypsum and elemental sulfur (tagged with S^{35}). Plants grown on these plots were used to measure "A" values and the percentage of sulfur in the tissue which came from the fertilizer treatment. The methods and results of this part of the barley study are reported elsewhere in this paper.

The barley yields in 1964 averaged about 40 bushels per acre, (Table No. 6). Only the non-radioactive gypsum treatment gave a significant yield increase. Although the sodium sulfate and radioactive gypsum treatments did not produce yield increases, they increased the sulfur content of the whole plant and of the grain on the same order as the gypsum treatment. The fact that elemental sulfur did not

increase the yield of barley nor the percentage of sulfur in the plants or grain seems to indicate that this material which needs to undergo oxidation to sulfate before it is readily available to the plant is not as effective as gypsum and sodium sulfate for short cool season crops such as barley. This disadvantage could perhaps be overcome by applying the sulfur to the previous crop so that sufficient oxidation will have occurred by the following spring.

The oats showed no significant yield response to any of the sulfur materials (Table No. 7). Gypsum and sodium sulfate significantly increased the percent sulfur in the whole plant but only the sodium sulfate treatment significantly altered the percent sulfur in the oat grain.

The grain from the barley trial was checked for kernel size and crude protein to determine if the sulfur treatments had any effect on quality. The data is inconclusive but interesting (Table No. 8). Gypsum and elemental sulfur slightly decreased the percent of thin kernels and increased the percent of plump kernels. Sodium sulfate, on the contrary, seems to have had an adverse effect upon kernel size, as this treatment produced 2.7% fewer plump kernels than the untreated plots. The slight decrease in the quality of the grain from the plots which had received radioactive treatments may indicate that these treatments were not free of harmful effects despite the low level of radioactivity with which these materials were tagged. Crude protein of the barley grain as measured by total Kjeldahl nitrogen showed a slight but consistent increase with sulfur application.

Corn and Soybeans

In 1964 corn and soybeans were replanted on the same plots which were in corn and beans in 1963. No additional applications of sulfur were made. Treatments on the corn trial consisted of four levels of sulfur (0, 5, 15, 25 lbs.S/acre) applied as sodium sulfate in 1963. The soybean treatments applied in 1963 were (1) no sulfur, (2) 25 lbs. of sulfur per acre as elemental sulfur, (3) 50 lbs. of sulfur per acre as elemental sulfur, and (4) 50 lbs. of sulfur per acre as gypsum.

Table 5. Effect of sulfur-bearing materials on the yield and sulfur content of alfalfa following corn.

Material	Rate lbs/S/acre	Date of Application	Yield (2nd Cutting) tons/A	S in Tissue %
Check	0		.38	.198
Sulfur	25	1962	.65	.215
Sulfur	50	1962	.67	.275
Sulfur	100	1962	.65	.306
Gypsum	60	10 lbs. S in 1962 50 lbs. S in 1963	.64	.345
K_2SO_4	10	1962	.64	.233
16-20-0-S	10	1962	.53	.2222
Trace-S	25	10 lbs./A Zn-Mn-N-S in 1963 15 lbs. S in Trace El. mix. 1963	.68	.305
lsd. (.05)			.20	.043
(.01)				.058
hsd. (.05)			.32	.068
(.01)				.082

Table 6. Effect of sulfur-bearing materials on the yield and sulfur content of barley.

Material	Rate lbs.S/acre	Yield bu./acre	Sulfur whole plant %	Content grain %
None	0	39.0	.103	.138
Gypsum	10	44.7	.124	.150
Elem. Sulfur	10	39.8	.109	.142
Na_2SO_4	10	40.6	.131	.155
Gypsum-S^{35}	10	41.0	.119	.155
Elem. Sulfur-S^{35}	10	37.8	.105	.139
lsd. (.05)		4.2	.010	.007
(.01)			.013	.009
hsd. (.05)		6.3	.015	.010
(.01)			.018	.012

Table 7. Effect of sulfur-bearing materials on the yield and sulfur content of oats.

Material	Rate lbs.S/acre	Yield bu./acre	Sulfur whole plant %	Content grain %
None	0	53.5	.124	.173
Gypsum	10	51.6	.142	.177
Elem. Sulfur	10	51.5	.126	.175
Na_2SO_4	10	55.5	.154	.194
lsd. (.05)		N.S.	.011	.007
(.01)			.015	.009
hsd. (.05)			.015	.009
(.01)			.019	.012

The corn yields for 1964 and the percent sulfur in the tissue and grain are reported in Table 9. There were no significant differences in the yields from the several levels of sulfur application. It may be noteworthy that the plant population in 1964 was double that of 1963 (19,400 plants per acre). This population was contingent upon the availability of irrigation facilities in 1964. Irrigation was not available to the 1964 crop because of numerous unavoidable delays and although the corn plants never suffered serious physiological damage there were indications that plant nutrient uptake and ear development were impaired by moisture deficiency.

No significant differences were found in the percent sulfur in the 6th leaf tissue samples or in the grain. The constancy of the sulfur level in both tissue and grain is of interest because it poses the problem of how the plant regulates sulfur uptake and why alfalfa differs in this respect from corn.

Soybean yields are reported in Table 10. As with the corn, the yields were curtailed by the effects of drought. No significant increases were obtained by sulfur fertilization. The percent sulfur in the soybean grain indicate that soybeans like corn may possess a mechanism to regulate the uptake of sulfur. Soybeans, however, contain a much higher amount of sulfur than corn.

Sunflowers

Sunflowers treated with 50 lbs. of sulfur per acre as gypsum were compared with untreated plants. The variety of sunflowers was Mingren. Treatments were replicated six times. In 1964 the yield of sunflower seed (Table 11) was not altered by the sulfur treatment.

Table 8. Effect of sulfur-bearing materials on the kernel size and protein content of barley.

Material	Rate lbs.S/acre	Kernel % thins	Size T plump.	Protein %
None	0	34.3	18.3	11.4
Gypsum	10	33.7	19.1	11.6
Elem. Sulfur	10	31.3	19.8	11.6
Na_2SO_4	10	34.8	15.5	11.5
Gypsum-S^{35}	10	36.5	15.8	
Elem. Sulfur-S^{35}	10	35.7	16.2	

Table 9. Effect of sulfur on the yield and sulfur content of 2nd year corn.

Material	Rate lbs.S/acre	Yield bu./acre	Sulfur in Tissue 6th leaf	grain
None	0	79.2	.188	.135
Na_2SO_4	5	78.4	.196	.136
Na_2SO_4	15	79.9	.190	.136
Na_2SO_4	25	75.5	.192	.138
		N.S.	N.S.	N.S.

Table 10. Effect of sulfur-bearing materials on the yield and sulfur content of soybeans.

Material	Rate lbs.S/acre	Yield bu./acre	% S in Grain %
None	0	19.8	.322
Sulfur	25	20.2	.321
Sulfur	50	19.1	.325
Gypsum	50	19.4	.327
		N.S.	N.S.

Table 11. Effect of sulfur on the yield of sunflower seed.

	Gypsum (50 lbs.S/acre) lbs./acre	Check lbs./acre
	1443	1226
	1438	1199
	1150	1263
	1042	1047
	1115	1216
	1111	1424
Total	7299	7375
Ave.	1217	1229

Sulfur "A" Values

For the past three years several experiments have been conducted to compare the effectiveness of various sulfur-bearing fertilizers. In these experiments yield increases and the percentage of total sulfur in the plant tissue at various stages of growth were the criteria used to measure effectiveness.

Another measure of the efficiency of a fertilizer material is the availability of the nutrient element in the fertilizer relative to the availability of the total amount of the nutrient present in the soil mass. This may be expressed as the percent of the nutrient in the plant which came from the fertilizer or by the "A" value as defined by Fried and Dean[1].

In 1964 gypsum and elemental sulfur tagged with radioactive S-35 were used to determine "A" values for the Todd sandy loam. Gypsum and elemental sulfur were tagged with sulfur-35 in the laboratory according to the method of Jordan and Baker[2]. The radioactive materials were applied in the row with a starter fertilizer application of 100 lbs. of 12-32-16 at the time of seeding the barley. Samples of the whole plants and of the grain were taken at maturity and analyzed for total sulfur. Yields of grain were also recorded at this time. The samples were digested by the nitric-perchloric acid method. Sulfur was precipitated as barium sulfate, plancheted on fritted stainless steel discs and counted in a proportional flow counter. Samples were counted for a period of time necessary to reduce the counting error to 2% or less.

The percentages of sulfur in the mature barley samples which came from the tagged gypsum or elemental sulfur are recorded in Table 12. The "A" values are recorded in Table 13. The average percentage of the total sulfur in the barley grain which came from the gypsum was 31.4%. When elemental sulfur was used the per cent was 8.9%. These results are not surprising as it is well known that the

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1. Fried, M. and Dean, L. A. A concept concerning the measurement of available soil nutrients. Soil Sci. 73: 263-271, 1962.
2. Jordan, J. V. and Baker, G. O. Studies in N. Idaho soils using radiosulfur. Soil Sci. 88: 1-6, 1959.

Table 12. Percentage of plant sulfur from applied fertilizer

Plot	Gypsum 10# S/acre		Elemental Sulfur 10# S/acre	
	Whole plant %	Grain %	Whole plant %	Grain %
1	37.2	28.0	13.9	7.6
	34.5	31.3	13.9	9.0
2	25.7	30.7	9.3	7.6
	35.4	28.2	11.1	5.5
3	30.4	19.3	6.8	9.6
	33.6	35.3	7.8	10.4
4	32.3	35.4	9.3	6.7
	25.4	33.5	13.9	8.1
5	27.5	35.4	15.0	12.1
	31.7	28.5	16.0	10.7
6	38.9	35.3	8.6	8.4
	42.5	35.3	9.5	10.5
Average	32.9	31.4	11.3	8.9

Table 13. Sulfur "A" values for mature barley grown in the field on a Todd sandy loam

Plot	"A" value equivalent to 10# S/acre as Gypsum		"A" value equivalent to 10# S/acre as El. S.	
	Whole plant lbs. S/acre	Grain lbs. S/acre	Whole plant lbs. S/acre	Grain lbs. S/acre
1	16.88	25.71	61.94	121.58
	18.98	21.95	61.94	101.11
2	28.91	22.57	97.53	121.58
	18.25	25.46	80.09	171.82
3	22.89	41.81	137.06	94.17
	19.76	18.33	118.20	86.15
4	20.10	18.25	97.53	139.25
	29.37	19.85	61.94	113.46
5	26.36	18.25	56.67	72.64
	21.55	25.09	52.50	83.46
6	15.71	18.33	106.28	109.05
	13.53	18.33	95.26	85.24
Average	21.02	22.83	85.58	108.29

sulfate ion is the primary form of sulfur taken up by the plant. In gypsum the sulfur is in the sulfate form and no transformation need occur before the fertilizer can be utilized by the plants. Elemental sulfur however needs to undergo oxidation to the sulfate form before it is readily available to the plants. Although the utilization of the elemental form of sulfur was much less than the utilization of the gypsum form of sulfur the plants did not suffer from visible signs of sulfur deficiency nor was there any significant decrease in grain yield. It is interesting to note however, that with elemental sulfur the difference between the percent of sulfur in the grain and in the whole plants approached significance. If the plants were functioning at a minimum level of sulfur nutrition, we could expect most of the sulfur to be immediately incorporated into organic compounds including protein. Very little or none would be mobile if an actual sulfur deficiency occurred. Later, at the time of grain development the large root system could be expected to take up a larger percentage of soil sulfur relative to uptake from the fertilizer band. The answer may also lie in the effect of moisture on the oxidation rate of the elemental sulfur.

The Todd sandy loam has an "A" value of 22.8 lbs. of sulfur per acre equivalent in biological availability to barley as 10 lbs. of sulfur as gypsum. There are 108.3 lbs. of sulfur per acre equivalent in biological availability to 10 lbs. of elemental sulfur per acre. Neither of these figures can be considered low as is evidenced by the normal check yields obtained. Part of this available sulfur present in each "A" value may have been contributed to the soil by atmospheric fallout in rain, snow, and dust or by direct adsorption of SO_2 by the soil and plants. The greater variation among the elemental sulfur "A" values is probably a reflection of different localized conditions such as temperature, moisture, and microbical spectrum which could affect the oxidation of the sulfur to the sulfate.

If the "A" value for gypsum is assigned a value of 100% availability, then for a 10 lb. application of elemental sulfur only 2.03 lbs. will be equally as available as the sulfur in a 10 lb. application of gypsum. Therefore, in this

experiment elemental sulfur was only 20.3% as available as the sulfur in gypsum.

Leaching of SO_4-S

A new leaching study was established in the spring of 1964. Sulfur treated plots received 200 lbs. of sulfur per acre as gypsum. Sweet corn was grown on both treated and untreated plots. An analysis of soil samples taken from these plots at 6 inch intervals to a depth of 36 inches on September 26th is now in progress.

Sulfur in the Atmosphere

The collection and analysis of rainwater and snowfall for sulfur and the measurement of the SO_2 content of the atmosphere by the lead peroxide "candle" method has continued. At the end of September, 1964, 24 consecutive months of measurements were completed for each of the four locations where samples are taken. The data recorded for the months May to October, 1964 are reported in Tables 14 and 15. Previous monthly data has been reported in reports 1, 2, 3, and 4. Table 16 reports the sulfur in precipitation totals for the two year period beginning October 1st, 1962. Table 17 presents the atmospheric sulfur totals for the same period.

For the two year period the average annual amount of sulfur brought to earth in rain and snow was about four times as great at St. Paul as at Park Rapids. Amounts recorded for Lamberton and Duluth were about 1.8-2.2 times as great as Park Rapids respectively.

The amount of sulfur absorbed annually by the lead peroxide coated surface averaged over six times greater at St. Paul than at Park Rapids. The average amount absorbed at Duluth was almost twice as great as Park Rapids. The average amount absorbed annually at Lamberton, Minnesota was similar to the amount absorbed at Park Rapids.

Table 14. Sulfur in the atmosphere and sulfur in precipitation at Park Rapids and Lamberton, Minnesota from May 1964 to October 1964.

	Park Rapids			Lamberton		
Period	Rainfall (inches)	S in Rainfall (lbs S/A)	SO_2 in atmosphere (lbs S/A)	Rainfall (inches)	S in Rainfall (lbs S/A)	SO_2 in atmosphere (lbs S/A)
May	1.28	0.31	0.40	3.14	0.76	0.25
June	8.06	0.66	0.29	1.65	0.49	0.22
July	3.20	0.22	0.21	3.17	0.82	0.20
August	4.52	0.52	0.22	3.80	0.77	0.22
Sept.	3.42	0.34	1.38	3.89	0.73	0.36
Oct.	0.26	0.46	0.22	0.50	0.32	0.31
TOTAL	20.74	2.51	2.72	16.15	3.89	1.56

Table 15. Sulfur in the atmosphere and sulfur in precipitation at St. Paul and Duluth, Minnesota from May 1964 to October 1964.

	St. Paul			Lamberton		
Period	Rainfall (inches)	S in Rainfall (lbs S/A)	SO_2 in atmosphere (lbs S/A)	Rainfall (inches)	S in Rainfall (lbs S/A)	SO_2 in atmosphere (lbs S/A)
May	2.56	1.25	1.39	5.61	1.03	0.54
June	2.03	0.46	1.78	3.51	2.12	0.29
July	2.00	1.38	1.70	2.26	.58	0.38
August	6.28	2.56	0.89	7.16	1.89	0.33
September	4.47	1.81	1.38	7.83	0.54	0.44
October	0.60	0.69	2.29	0.54	0.26	0.47
TOTAL	17.94	8.15	9.43	26.91	6.42	2.45