Technical Bulletin 6 February, 1934

NITRIC NITROGEN IN THE SOILS OF THE ARKANSAS VALLEY

By Robert Gardner, Alvin Kezer and J. C. Ward

Colorado Agricultural College
Colorado Experiment Station
Fort Collins

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NITRIC NITROGEN IN THE SOILS OF THE ARKANSAS VALLEY

By Robert Gardner, Alvin Kezer and J. C. Ward[1]

Earlier publications of the Colorado Experiment Station report the finding of abnormal conditions where nitrates were exceedingly high in many areas of Colorado. The publications indicated that the areas of unusually high nitrate content were becoming more extensive. Control measures appeared necessary but the investigations had not gone far enough to make it possible to recommend specific treatments for the soils affected.

The Arkansas Valley was one of the sections from which many soils, high in nitrate content, were reported. A general impression prevailed that the agricultural lands of the Valley, to a large extent, were becoming less productive because of the excessive nitrates.

The apparent seriousness of the problem seemed to justify further investigation with special emphasis on control measures. For this reason an extensive study of the nitrates in the soils in the Arkansas Valley was begun in the spring of 1922 in connection with the Rocky Ford substation. This paper is a report of the work at Rocky Ford from 1922 to 1931, inclusive, and of supplementary work at Fort Collins, in 1932.

Experimental Procedure

The general plan adopted for the study included an intensive soil-sampling program of plats on the experimental farms of the Colorado Experiment Station and the American Beet Sugar Company, at Rocky Ford, and private farms distributed thru the Arkansas Valley. The soil samples were taken from soil under different cropping systems and under various soil treatments. They were analyzed for nitric nitrogen to determine the effects of these various systems and treatments on the nitrate content of the soil. Chloride determinations were also made on the samples to determine the relationship, if any, of the nitrates to the other salts of the soil.

The majority of soil samples were taken from the first 4 inches of soil only. Plats sampled varied in size from 1/200-acre to fields of several acres. Each sample of the larger plats and fields consisted of a composite of from 25 to 50 cores. Four to 10 cores were combined for each sample of the small plats. The samples of the depths below 4 inches were composites of 2 or 3 borings. The samples were run thru a quarter-inch mesh sieve immediately after they were taken.

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[1]J. C. Ward was Assistant Chemist, Colorado Experiment Station, Rocky Ford, at the time he participated in this work, and is now Associate Pharmacologist, Biological Survey, United States Department of Agriculture, Denver, Colorado.

They were spread within a short time over a screen in the laboratory where they dried rapidly. A 1-to-5 soil-to-water extract was made of the air-dried soil for analysis. Analyses were made within 12 to 24 hours after extracting. The Devarda's alloy procedure was used in the nitrate determinations. A modification of Mohr's method was used for chlorides.

Various statistical formulas were used to measure the variability of the data and for the calculation of their significance. Probable and standard errors were calculated by Bessel's formula as modified by Harris (3). Where applicable, "Student's" (2) method of paired comparisons was most commonly used to measure significant differences. Where it was possible, the error of the experiment was calculated by "Student's" (2) generalized formula.

A study of the relative toxicity of nitrates and other salts and of the tolerance of crop plants to these salts was included in the program from 1930 to 1932, inclusive.

The results of the investigations are discussed under the following subdivisions:

1. An extensive survey of the nitrate content normally found under the principal crops grown in the Arkansas Valley.
2. A survey of the seasonal changes which normally occur in the nitrate content of the soil under different crops.
3. A study of the effects of different crop residues on nitrate changes in the soil.
4. A study of the effect of green manures and stable manures on the soil nitrates.
5. A study of the sources of soil nitrates.
6. A study of the influence of excessive quantities of nitrates on crop production.

EXPERIMENTAL RESULTS

1. THE AVERAGE NITRATE CONTENT UNDER DIFFERENT CROPS.—There was no basis for forming an opinion regarding the extent of nitrate excess in the Arkansas Valley previous to the beginning of this project. It was a question as to whether the entire farming area was becoming less productive because of too high nitrate content or whether only very localized areas were affected. Part of the work during the investigations was devoted to a survey of conditions thruout the Valley. A summary of the results of this survey is given in Tables 1 to 9 inclusive. The tables show the number of plats[1] of different crops studied, the average nitrate content[2] of the

[1]The term plat is used in the discussion to refer to both fields and plats.
[2]All nitrate concentrations are expressed in the tables as nitric nitrogen.

Table 1.—The Average Nitric-Nitrogen Content per Season and Average Maximum Reached During the Season under Different Crops from 1922 to 1931 inclusive.

Crop	No. Plats	Season Average*	Season Maximum*
Fallow	147	39.2±1.7	79.8±4.6
Sugar Beets	311	33.4±0.8	59.8±1.6
Vines (Cucurbitaceae)	103	27.0±0.7	50.7±1.9
Corn	112	32.6±1.3	57.1±2.1
Red Clover	14	13.7±0.7	28.4±1.3
Onions	10	29.8±2.2	72.7±5.0
Alfalfa	100	13.9±0.4	24.0±0.8
Small Grains	152	13.0±0.6	25.5±1.3

*Class intervals of 3 p.p.m. were used in calculating the means and probable errors in Tables 1 to 8 inc., except for the smaller populations which were not grouped into frequency classes. Probable errors were calculated by Harris's formula.

Table 2.—Frequency Distribution of Fallow Plats in the Various Nitric-Nitrogen Concentrations.

Nitric Nitrogen	Rocky Ford Substation—137 plats Plat Distribution		A.B.S. Ranch, Rocky Ford—10 plats Plat Distribution		Total—147 plats Plat Distribution	
	Mean Values	Max. Values	Mean Values	Max. Values	Mean Values	Max. Values
p.p.m.	pct.	pct.	pct.	pct.	pct.	pct.
0.0 to 10.0	0.73	....	....	....	0.68	....
10.0 to 20.0	7.30	0.73	....	....	6.80	0.68
20.0 to 30.0	21.90	4.38	20.00	....	21.77	4.09
30.0 to 40.0	20.44	5.11	20.00	10.00	20.41	5.44
40.0 to 50.0	24.81	6.57	10.00	....	23.81	6.12
50.0 to 60.0	16.06	9.49	10.00	10.00	15.65	9.52
60.0 to 70.0	4.38	14.59	40.00	20.00	6.80	15.06
70.0 to 80.0	2.19	16.06	....	10.00	2.04	15.64
80.0 to 90.0	1.46	17.52	....	....	1.36	16.33
90.0 to 100.0	0.73	10.22	....	10.00	0.68	10.20
100.0 or more	....	15.33	....	40.00	....	17.00
Average Mean Nitric Nitrogen per season per plat (p.p.m.)	38.6±0.9		48.1±3.3		39.2±1.7	
Average Maximum Nitric Nitrogen per season per plat (p.p.m.)	78.9±1.6		92.5±9.0		79.8±4.6	

Table 3.—Frequency Distribution of Sugar-Beet Plats and Fields in Various Nitric-Nitrogen Concentrations.

Nitric Nitrogen	Rocky Ford Substation 33 plats		A.B.S. Ranch Rocky Ford 249 plats		Vicinity of Rocky Ford 15 fields		From Pueblo to Lamar 14 fields		Total—311 plats and fields	
	Plat Distribution		Plat Distribution		Field Distribution		Field Distribution		Field and Plat Distribution	
	Mean Values	Max. Values	Mean Values	Max. Values	Mean Values	Max. Values	Mean Values	Max. Values	Mean Values	Max. Values
p.p.m.	pct.	pct.	pct.	pct.	pct.	pct.	pct.	pct.	pct.	pct.
0.0 to 10.0	....	....	1.60	....	....	....	....	....	1.29	....
10.0 to 20.0	48.49	3.03	30.12	6.43	6.67	....	21.44	7.14	30.54	5.79
20.0 to 30.0	51.51	12.12	25.70	12.85	46.67	6.67	21.44	14.29	29.26	12.54
30.0 to 40.0	....	24.24	12.44	14.46	6.67	6.67	21.44	14.29	11.25	15.11
40.0 to 50.0	....	24.24	18.83	17.67	26.67	26.67	14.29	....	9.00	18.01
50.0 to 60.0	....	18.18	6.43	10.84	6.67	20.00	7.14	21.44	5.79	12.54
60.0 to 70.0	....	9.09	5.62	8.03	....	13.33	....	7.14	4.50	8.36
70.0 to 80.0	....	3.03	4.01	5.62	....	13.33	7.14	7.14	3.54	5.79
80.0 to 90.0	....	3.03	1.60	4.82	6.67	6.67	....	....	1.61	4.50
90.0 to 100.0	....	....	1.20	3.21	....	....	....	7.14	0.97	2.90
100.0 or more	....	3.03	2.40	16.07	....	6.66	7.14	21.44	2.25	14.47
Average Mean Nitric Nitrogen per season per plat (p.p.m.)	20.5±0.6		34.5±1.0		36.7±2.8		39.7±1.3		33.4±0.8	
Average Maximum Nitric Nitrogen per season per plat (p.p.m.)	46.8±2.1		61.2±1.8		58.9±3.8		65.7±4.4		59.8±1.6	

Table 4.—Frequency Distribution of Vine (Pincipally Cantaloupe) Plats and Fields in Various Nitric-Nitrogen Concentrations.

Nitric Nitrogen	Rocky Ford Substation 66 plats		Vicinity of Rocky Ford—19 fields		From Pueblo to Lamar—18 fields		Total 103 plats and fields	
	Plat Distribution		Field Distribution		Field Distribution		Field and Plat Distribution	
	Mean Values	Max. Values	Mean Values	Max. Values	Mean Values	Max. Values	Mean Values	Max Values
p.p.m.	pct.	pct.	pct.	pct.	pct.	pct.	pct.	pct.
0.0 to 10.0	1.52	....	....	....	....	....	0.97	....
10.0 to 20.0	42.42	3.03	5.26	....	44.44	....	35.92	1.94
20.0 to 30.0	37.88	9.09	10.52	....	50.00	33.33	34.95	11.65
30.0 to 40.0	10.61	27.27	15.78	10.52	....	38.88	9.71	26.21
40.0 to 50.0	7.56	24.24	36.84	10.52	5.55	22.22	12.62	21.36
50.0 to 60.0	....	12.12	5.26	21.04	....	....	0.97	11.65
60.0 to 70.0	....	12.12	15.78	5.26	....	5.55	2.91	9.71
70.0 to 80.0	....	3.03	10.52	5.26	....	....	1.94	2.91
80.0 to 90.0	....	3.03	....	31.58	....	....	....	7.77
90.0 to 100.0	....	3.03	....	5.26	....	....	....	2.91
100.0 or more	....	3.03	....	10.52	....	....	....	3.88
Average Mean Nitric Nitrogen per season per plat (p.p.m.)	22.7 ± 0.7		45.8 ± 2.5		23.0 ± 1.1		27.0 ± 0.7	
Average Maximum Nitric Nitrogen per season per plat (p.p.m.)	48.8 ± 1.6		73.4 ± 5.2		33.6 ± 1.7		50.7 ± 1.9	

Table 5.—Frequency Distribution of Corn Plats and Fields in Various Nitric-Nitrogen Concentrations.

Nitric Nitrogen	Rocky Ford Substation 41 plats		A.B.S. Ranch Rocky Ford 13 plats		Vicinity of Rocky Ford 15 fields		From Pueblo to Lamar 43 fields		Total—112 plats and fields	
	Plat Distribution		Plat Distribution		Field Distribution		Field Distribution		Field and Plat Distribution	
	Mean Values	Max. Values	Mean Values	Max. Values	Mean Values	Max. Values	Mean Values	Max. Values	Mean Values	Max. Values
p.p.m.	pct.	pct.	pct.	pct.	pct.	pct.	pct.	pct.	pct.	pct.
0.0 to 10.0	....	....	15.38	....	....	....	....	....	1.78	....
10.0 to 20.0	29.27	....	23.08	15.38	6.67	....	6.98	....	16.96	1.78
20.0 to 30.0	51.22	9.76	30.77	23.08	6.67	6.67	44.19	11.63	40.18	11.61
30.0 to 40.0	19.51	24.39	15.38	....	20.00	....	23.26	27.91	20.54	19.64
40.0 to 50.0	....	9.76	....	7.69	20.00	26.67	13.95	27.91	8.04	18.75
50.0 to 60.0	....	24.39	15.38	15.38	20.00	6.67	2.33	9.30	5.36	15.18
60.0 to 70.0	....	7.32	....	15.38	6.67	6.67	....	4.65	0.89	7.14
70.0 to 80.0	....	17.08	....	....	....	....	2.33	2.33	0.89	7.14
80.0 to 90.0	....	....	....	7.69	13.33	26.67	6.98	4.65	4.46	6.25
90.0 to 100.0	....	4.88	....	15.38	....	6.67	....	4.65	....	6.25
100.0 or more	....	2.44	....	....	6.67	20.00	....	6.98	0.89	6.25
Average Mean Nitric Nitrogen per season per plat (p.p.m.)	24.5±0.6		27.2±2.8		52.3±4.2		35.0±1.8		32.6±1.3	
Average Maximum Nitric Nitrogen per season per plat (p.p.m.)	54.2±2.2		51.8±4.9		76.7±5.7		54.6±3.5		57.1±2.1	

Table 6.—Frequency Distribution of Red Clover and Onion Plats in Various Nitric-Nitrogen Concentrations.

Nitric Nitrogen	RED CLOVER — Rocky Ford Substation 14 plats — Plat Distribution		ONION — Rocky Ford Substation 10 plats — Plat Distribution	
	Mean Values	Max. Values	Mean Values	Max. Values
p.p.m.	pct.	pct.	pct.	pct.
0.0 to 10.0	14.28	....	....	....
10.0 to 20.0	78.57	21.43	10.00	....
20.0 to 30.0	7.14	57.14	50.00	....
30.0 to 40.0	....	21.43	30.00	10.00
40.0 to 50.0	....	....	....	10.00
50.0 to 60.0	....	....	10.00	10.00
60.0 to 70.0	....	....	....	10.00
70.0 to 80.0	....	....	....	30.00
80.0 to 90.0	....	....	....	....
90.0 to 100.0	....	....	....	10.00
100.0 or more	....	....	....	20.00
Average Mean Nitric Nitrogen per season per plat (p.p.m.)	13.7±0.7		29.8±2.2	
Average Maximum Nitric Nitrogen per season per plat (p.p.m.)	28.4±1.3		72.7±5.0	

Table 7.—Frequency Distribution of Alfalfa Plats and Fields in Various Nitric-Nitrogen Concentrations.

Nitric Nitrogen	Rocky Ford Substation 25 plats — Plat Distribution		From Pueblo to Lamar 75 fields — Field Distribution		Total—100 plats and fields — Plat and Field Distribution	
	Mean Values	Max. Values	Mean Values	Max. Values	Mean Values	Max. Values
p.p.m.	pct.	pct.	pct.	pct.	pct.	pct.
0.0 to 10.0	16.00	....	25.33	8.00	23.00	6.00
10.0 to 20.0	84.00	44.00	58.67	33.33	65.00	36.00
20.0 to 30.0	....	32.00	14.67	38.67	11.00	37.00
30.0 to 40.0	....	24.00	....	12.00	....	15.00
40.0 to 50.0	....	....	....	5.33	....	4.00
50.0 or more	....	....	1.33	2.67	1.00	2.00
Average Mean Nitric Nitrogen per season per plat (p.p.m.)	12.7±0.4		14.3±0.6		13.9±0.4	
Average Maximum Nitric Nitrogen per season per plat (p.p.m.)	23.9±0.9		24.0±1.2		24.0±0.8	

Table 8.—Frequency Distribution of Grain Plats and Fields in Various Nitric-Nitrogen Concentrations.

Nitric Nitrogen	Rocky Ford Substation 90 plats		A.B.S. Ranch Rocky Ford 28 plats		Vicinity of Rocky Ford 8 fields		From Pueblo to Lamar 26 fields		Total—152 plats and fields	
	Plat Distribution		Plat Distribution		Field Distribution		Field Distribution		Field and Plat Distribution	
	Mean Values	Max. Values	Mean Values	Max. Values	Mean Values	Max. Values	Mean Values	Max. Values	Mean Values	Max. Values
p.p.m.	pct.	pct.	pct.	pct.	pct.	pct.	pct.	pct.	pct.	pct.
0.0 to 10.0	4.44	....	53.57	17.86	37.50	....	30.77	7.69	19.74	4.61
10.0 to 20.0	92.22	17.78	46.43	35.71	37.50	62.50	61.54	57.69	75.66	30.26
20.0 to 30.0	3.33	51.11	....	42.86	12.50	12.50	7.69	26.92	3.95	43.42
30.0 to 40.0	....	17.78	....	3.57	12.50	....	....	3.84	0.66	11.84
40.0 to 50.0	....	5.56	....	....	....	12.50	....	....	....	3.97
50.0 or more	....	7.78	....	....	....	12.50	....	3.84	....	5.92
Average Mean Nitric Nitrogen per season per plat (p.p.m.)	14.2±0.2		9.1±0.6		15.3±2.0		12.4±0.7		13.0±0.6	
Average Maximum Nitric Nitrogen per season per plat (p.p.m.)	28.9±1.0		17.9±1.0		28.7±4.5		21.1±2.4		25.5±1.3	

Table 9.—Decrease in Nitric-Nitrogen Content at Increasing Depths in the Soil Under Different Crops.

Crops	Plats Sampled	Average No. Samples During Season	Sample Depth	Nitric Nitrogen	Decrease from Adjacent Depth	Odds of Significance*
				p.p.m.	pct.	
Fallow	3	6,6	0"— 4"	26.9	.... ..	....
Fallow	3	6.6	4"— 8"	25.5	5.2	2:1
Fallow	3	6.6	8"—12"	21.1	17.3	59:1
Fallow	3	6.6	12"—16"	17.4	17.5	above 100:1
Sugar Beets	2	7	0"— 4"	25.7	.... ..	....
Sugar Beets	2	7	4"— 8"	18.8	26.8	33:1
Sugar Beets	2	7	8"—12"	12.2	35.1	above 100:1
Sugar Beets	2	7	12"—16"	10.7	12.3	10:1
Vines	3	8	0"— 4"	18.7	.... ..	....
Vines	3	8	4"— 8"	15.4	17.6	above 100:1
Vines	3	8	8"—12"	12.6	18.2	above 100:1
Vines	3	8	12"—16"	10.5	16.7	50:1
Corn	2	6	0"— 4"	18.1	.... ..	....
Corn	2	6	4"— 8"	16.0	11.6	7:1
Corn	2	6	8"—12"	14.9	6.9	5:1
Corn	2	6	12"—16"	11.6	22.1	above 100:1
Alfalfa	4	7	0"— 4"	12.2	.... ..	....
Alfalfa	4	7	4"— 8"	11.0	9.8	8:1
Alfalfa	4	7	8"—12"	9.3	15.5	20:1
Alfalfa	4	7	12"—16"	8.1	12.9	20:1
Grain	4	7	0"— 4"	15.1	.... ..	....
Grain	4	7	4"— 8"	13.5	10.6	17:1
Grain	4	7	8"—12"	10.9	19.3	76:1
Grain	4	7	12"—16"	8.2	24.8	above 100:1

*By "Student's" method of paired comparisons.

top 4 inches found during the season, and the average maximum concentration reached during the season. The tables show also the number and percentage of the fields which were found to lie between various limits of concentration. If it were definitely known what nitrate concentrations were optimum for crop production, a glance at these tables would tell what percentages of the fields were optimum and what percentages were too low or too high. There still exists a great uncertainty as to what is the optimum nitrate content and what concentrations are injurious. Many facts have been accumulated which indicate that workers in Colorado previously placed the optimum content and the point at which nitrates become injurious much too low. This will be discussed later.

Tables 1 to 8, inclusive, show the nitrate content in the first 4 inches of the soil while Table 9 shows the gradient between the surface and the subsoil of a series of plats sampled between 1922 and 1928. The average condition of the subsoil can be estimated by decreasing the values in Tables 1 to 8, inclusive, by the percentage drop indicated in Table 9. The highest concentrations almost invariably lie in the first 4 inches. Thus, if nitrates are present in injurious quantities, an excess should be in the first 4 inches of soil. The subsoil probably gives a better indication as to whether or not the nitrates are present in sufficient quantities for the plants, since the feeding is largely below 4 inches.

The tables indicate that the average nitrate content, under ''cultivated'' crops is about the same for each crop and lies between 27.0 and 34.4 parts per million. The ''uncultivated'' crops were much lower and ranged from 13.0 to 13.9 parts per million. Fallow plats were the highest with 39.2 parts per million. The average maximum reached during the season was between 50.7 and 72.7 parts per million for the ''cultivated'' crops and between 24.0 and 28.4 parts per million for the ''uncultivated'' crops. A maximum of 100 parts per million or more during the season was reached in 17 percent of the fallow plats, 14.52 percent of the sugar-beet plats, 3.88 percent of the vine plats, 6.25 percent of the corn plats and 20 percent of the onion plats. Only 1.94 percent of the beet plats and 0.89 percent of the corn plats had an average of 100 parts per million or more during the season.

2. SEASONAL CHANGE IN NITRATE CONCENTRATION.—Table 10 and Figure 1 show the seasonal distribution of nitrates under different crops. All of the ''cultivated'' crops show a decided peak at some period during the season. No peak is shown for the ''uncultivated'' crops. The nitrate drop from the peak corresponds closely with the period when the crops begin to draw heavily upon the nitrate supply.

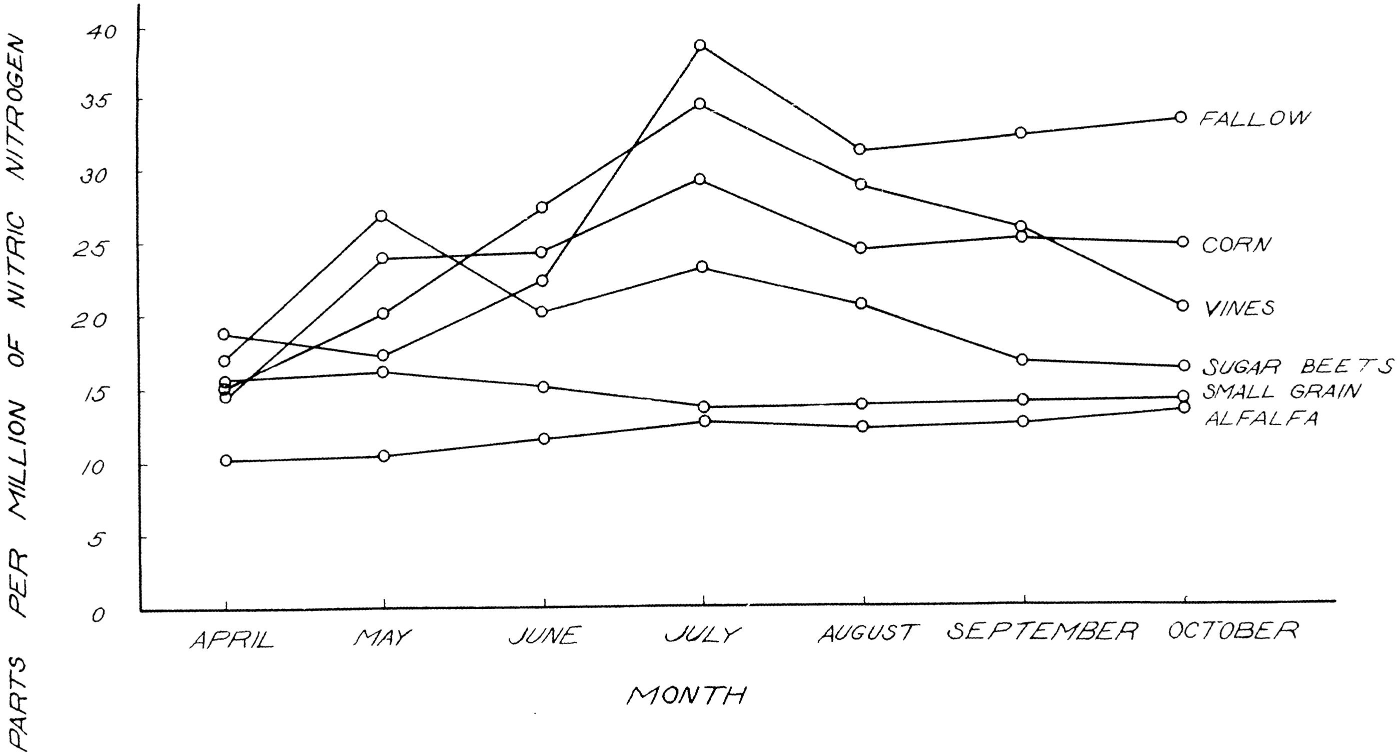

Figure 1.—Mean Seasonal Distribution of Nitric Nitrogen Under Different Crops of the Period 1922 to 1931 inclusive.

Table 10.—Average Nitric Nitrogen per Month in Upper Four Inches of Soil Under Different Crops and Fallow from 1922 to 1928, Inclusive.

Month	Corn	Small Grain	Vines	Sugar Beets	Alfalfa	Onions	Fallow
	p.p.m	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
April	14.3±1.3	15.4±0.8	14.8±0.9	17.2±1.2	10.2±0.7	31.1±7.8	19.1±1.5
May	24.0±1.5	16.1±0.6	20.1±0.4	26.7±1.8	10.3±0.4	28.2±2.5	17.5±1.1
June	24.4±1.4	14.9±0.7	27.6±1.2	20.0±1.8	11.5±0.6	35.4±2.5	22.5±1.1
July	29.3±2.1	13.3±0.4	34.3±1.5	23.4±1.0	12.9±0.6	38.9±6.2	37.2±1.5
August	24.5±2.0	13.7±0.5	28.7±1.3	20.2±1.3	12.0±0.7	40.1±4.4	31.0±1.4
Sept.	24.7±2.2	13.7±0.6	25.6±1.9	16.6±1.2	12.6±0.7	31.0±2.8	32.9±1.6
Oct.	24.4±3.2	13.9±0.7	20.2±1.4	16.0±1.2	15.4±0.7	22.9±2.4	33.2±1.6
No. Plats	23	52	41	29	20	9	52

Table 11.—Treatments Applied to Fertilizer and Crop-Residue Plats in Pounds Per Acre (Crop Residues Contained 36.6 Pounds of Nitrogen Per Acre).

Year	Sulfur	P_2O_5	$NaNO_3$	$(NH_4)_2SO_4$	Blood Meal	Alfalfa	Barley Straw	Corn Stalks	Sawdust
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1925	1000	180	......	......	297	1750	5417	8000	....
1926	1000	180	......	500	290	1616	4386	3338	47,740
1927	1000	180	500	500	290	1360	5556	5100	53,320
1929	1000	180	500	500	360	1560	3960	5560	48,000
1930	1000	......	400	......	264	1580	4025	5650	54,200
1931	1000	180	400	......	264	1580	4025	5650	54,200

3. THE EFFECT OF CROP RESIDUES AND FERTILIZERS.—Studies of the effect of fertilizers and crop residues on the nitrate content of the soil were carried for the duration of the experiment. Table 11 shows the various materials used and rates of application for one series of studies carried from 1925 to 1931. The results of these treatments are shown in Tables 12 and 13. It is very evident that no great difference in either the mean or maximum nitrate content resulted from these treatments, with the exception of the sawdust which gave a significant reduction.

4. THE EFFECT OF GREEN MANURES AND STABLE MANURES ON SOIL NITRATES.—Table 14 shows a comparison of the mean seasonal soil-nitrate content under five different green manures, during 3 years when they were grown continuously and during the following year when the ground was fallowed. Two crops were plowed under each season. The differences resulting from the treatments are small and are not statistically significant. However, the tables do not show a fair comparison between legumes and non-legumes as the alfalfa and clover contained a high percentage of non-leguminous weeds.

Table 12.—Mean Nitric Nitrogen for Each Season in Surface Four Inches of Fertilizer and Crop-Residue Plats.

Year	Sulfur	P_2O_5	$NaNO_3$	$(NH_4)_2SO_4$	Blood Meal	Alfalfa	Barley Straw	Corn Stalks	Sawdust	Check
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
1925	27.5	26.1	....	....	30.4	33.6	28.0	23.9	....	23.8
1926	43.6	45.6	....	67.2	55.6	52.2	43.6	50.8	13.5	50.1
1927	42.7	43.3	40.0	41.2	41.5	37.2	29.0	40.9	21.8	49.3
1929	27.3	23.3	36.3	28.3	29.0	36.6	32.2	32.9	26.6	46.1
1930	11.4	....	16.6	....	11.9	14.2	12.8	12.7	7.9	13.0
1931	23.7	28.5	44.8	....	39.8	27.6	18.7	21.7	12.1	31.8
Average Mean	29.33	33.36	34.42	45.56	34.70	33.56	27.38	30.48	16.38	35.68
Increase over weighted check	–6.35	–6.86	–0.62	–2.93	–0.98	–2.12	–8.30	–5.20	–21.68	....
Percentage Increase	–17.8	–17.5	–1.7	–6.0	–2.7	–5.9	–23.3	–14.5	–56.9	....
*Odds that Increase over check is significant	11:1	5:1	1:1	1:1	1:1	2:1	12:1	11:1	83:1	....

By "Student's" method of paired comparisons.

Table 13.—Maximum Nitric Nitrogen for Each Season in Surface Four Inches of Fertilizer and Crop-Residue Plats.

Year	Sulfur	P_2O_5	$NaNO_3$	$(NH_4)_2SO_4$	Blood Meal	Alfalfa	Barley Straw	Corn Stalks	Sawdust	Check
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
1925	43.4	49.0	.... ..	.... ..	59.5	77.7	44.1	51.0	.... ..	37.8
1926	82.6	59.5	.... ..	168.1	101.5	99.4	77.0	111.3	35.0	84.0
1927	74.2	80.0	77.0	70.7	77.7	75.9	50.7	86.8	37.8	88.9
1929	60.0	53.0	81.0	60.0	57.0	79.0	49.0	56.0	53.0	73.0
1930	24.0	.... ..	41.0	.... ..	25.0	29.0	21.0	23.0	13.0	22.0
1931	46.0	.... ..	83.0	.... ..	78.0	59.0	39.0	42.0	27.0	55.0
Average Maximum	55.03	60.50	70.50	99.60	66.33	70.00	46.80	61.70	33.12	60.11
Increase over weighted check	–5.08	–10.42	10.77	17.63	6.22	9.89	–13.31	–1.59	–31.40	.... ..
Percentage Increase	–9.2	–17.3	18.0	21.5	10.3	16.4	–22.1	–2.6	–48.6	.... ..
*Odds that Increase over check is significant	5:1	2:1	5:1	2:1	2:1	5:1	10:1	1:1	52:1	.... ..

*By "Student's" method of paired comparisons.

Table 14.—Mean Nitric Nitrogen for Each Season in Surface Four Inches of the Green-Manure Plats.

Year	Barley	Cane	Corn	Alfalfa	Red Clover
1927	19.47	17.27	14.07	17.06	18.96
1928	12.48	14.64	14.60	12.94	17.28
1929	25.60	15.91	12.86	13.26	14.91
Average Mean	19.18	15.94	13.84	14.42	17.05
Increase over cane plat	3.24	0.00	-2.10	-1.52	1.11
Percentage increase	20.32	0.00	-13.17	-9.55	6.96
*Odds that Increase is significant over cane	2:1	....	2:1	8:1	1:1
Mean for 1930 (all plats fallow)	25.60	19.97	23.65	23.48	25.62

*By "Student's" method of paired comparisons.

Table 15 shows the mean and maximum nitrate content in a series of plats planted continuously to the same crops from 1922 to 1928. One-half of the land under each crop was given 10 tons of manure each fall. The other half received no treatment. There was a very significant increase in both the mean nitrate content and the maximum nitrate content for the season in the case of every manured plat. The mean increase ranged from 30.1 to 55.8 percent and the maximum increase was from 30.0 to 60.3 percent.

5. THE SOURCE OF THE NITRATES IN THE SOIL.—Any salts carried by the water will be left at, or near, the surface if water is evaporated from the soil. The question arises as to what portion of the nitrates found near the surface has been left there by evaporating water and what portion has been nitrified *in situ*. Chlorine determinations were made of all soil extracts analyzed for nitrates. Any water lost by evaporation should result in an increase in the soil chlorine content at the surface, if the water carried this element. Also, if the water carried nitrates, the nitrates would accumulate along with the chlorides. This principle was recognized by Stewart and Peterson (12).

The relationships of chlorine to nitric-nitrogen accumulations are shown in Figures 2 and 3. Figure 2 shows that the chlorine content remains practically constant until the nitric nitrogen approaches 35 parts per million. From 35 parts per million to 100 parts per million of nitric nitrogen, chlorine increases at approximately the same rate as the nitric nitrogen. It is quite evident that when no surface evaporation is occurring, the nitric nitrogen does not tend to exceed 35 parts per million. The fact that both nitric nitrogen and chlorine increase above this point indicates that they are brought in by the water. However, this can be only partially true as the chlorine content would have been roughly 10 times greater than the nitric-nitrogen content if the water had been the sole source of both elements. It will be shown later that in both the underground and irrigation water the chlorine is approximately 10 times greater than the nitrogen. At least nine-tenths of the nitric nitrogen accumulated in the soil and represented in this portion of the curve, therefore, must have originated in the soil. The accumulation at the surface might

Table 15.—Effect of Ten Tons of Manure Per Acre Per Year on the Nitric-Nitrogen Content of the Upper Four Inches of Soil Under a Continuous Cropping System.

	CORN			
	Unmanured		Manured	
Year	Mean	Maximum	Mean	Maximum
	p.p.m.	p.p.m.	p.p.m.	p.p.m.
1922	12.5	32.4	16.1	36.9
1923	11.8	21.4	14.9	35.5
1924	18.5	55.3	36.6	128.8
1925	14.8	27.0	29.9	63.0
1926	21.0	53.9	27.5	58.8
1927	16.2	35.0	24.0	43.4
1928	13.0	32.9	19.0	47.2
Mean for all Seasons	15.4	36.8	24.0	59.1
Increase of Manured over Unmanured			8.6	22.2
Percentage Increase			55.8	60.3
*Odds that Increase is Significant			Above 100:1	17:1

	BARLEY			
	Unmanured		Manured	
Year	Mean	Maximum	Mean	Maximum
	p.p.m.	p.p.m.	p.p.m.	p.p.m.
1922	8.9	31.4	13.9	39.5
1923	11.7	35.7	15.6	32.9
1924	13.4	21.1	21.9	57.4
1925	14.1	22.7	18.8	42.7
1926	16.9	57.4	19.2	67.2
1927	11.3	13.3	13.6	28.7
1928	12.0	18.9	12.0	21.7
Mean for all Seasons	12.6	28.6	16.4	41.4
Increase of Manured over Unmanured			3.8	12.8
Percentage Increase			30.1	44.7
*Odds that Increase is Significant			Above 100:1	25:1

*By "Student's" method of paired comparisons.

Table 15.—Effect of Ten Tons of Manure Per Acre Per Year on the Nitric-Nitrogen Content of the Upper Four Inches of Soil Under a Continuous Cropping System. (Continued)

	SUGAR BEETS			
	Unmanured		Manured	
Year	Mean	Maximum	Mean	Maximum
	p.p.m.	p.p.m.	p.p.m.	p.p.m.
1922	12.4	37.1	17.5	50.7
1923	12.3	60.1	15.8	45.3
1924	17.7	57.1	26.1	60.2
1925	15.6	32.2	23.2	37.1
1926	16.3	26.3	25.1	56.0
1927	11.7	19.6	17.1	46.9
1928	17.7	36.4	24.5	48.3
Mean for all Seasons	14.8	38.4	21.3	49.2
Increase of Manured over unmanured			6.5	10.8
Percentage Increase			43.9	28.1
*Odds that Increase is Significant			Above 100:1	9:1

	CANTALOUPES			
	Unmanured		Manured	
Year	Mean	Maximum	Mean	Maximum
	p.p.m.	p.p.m.	p.p.m.	p.p.m.
1922	18.8	46.9	23.2	49.5
1923	12.9	34.1	16.7	34.5
1924	17.5	33.2	26.7	57.7
1925	16.5	38.5	24.7	48.3
1926	16.6	28.0	24.4	49.0
1927	16.9	30.6	19.8	46.2
1928	15.1	28.0	19.8	41.3
Mean for all Seasons	16.3	34.2	22.2	46.6
Increase of Manured over Unmanured			5.9	12.4
Percentage Increase			36.1	36.2
*Odds that Increase is Significant			Above 100:1	100:1

*By "Student's" method of paired comparisons.

be the result of the nitrates returning from the subsoil due to a reversal of moisture movement, or of nitrification *in situ*, or both. Very few data are available showing nitric nitrogen in excess of 100 parts per million. For that reason, the upper part of the curve is not plotted, but the few data available show that the curve flattens above this point.

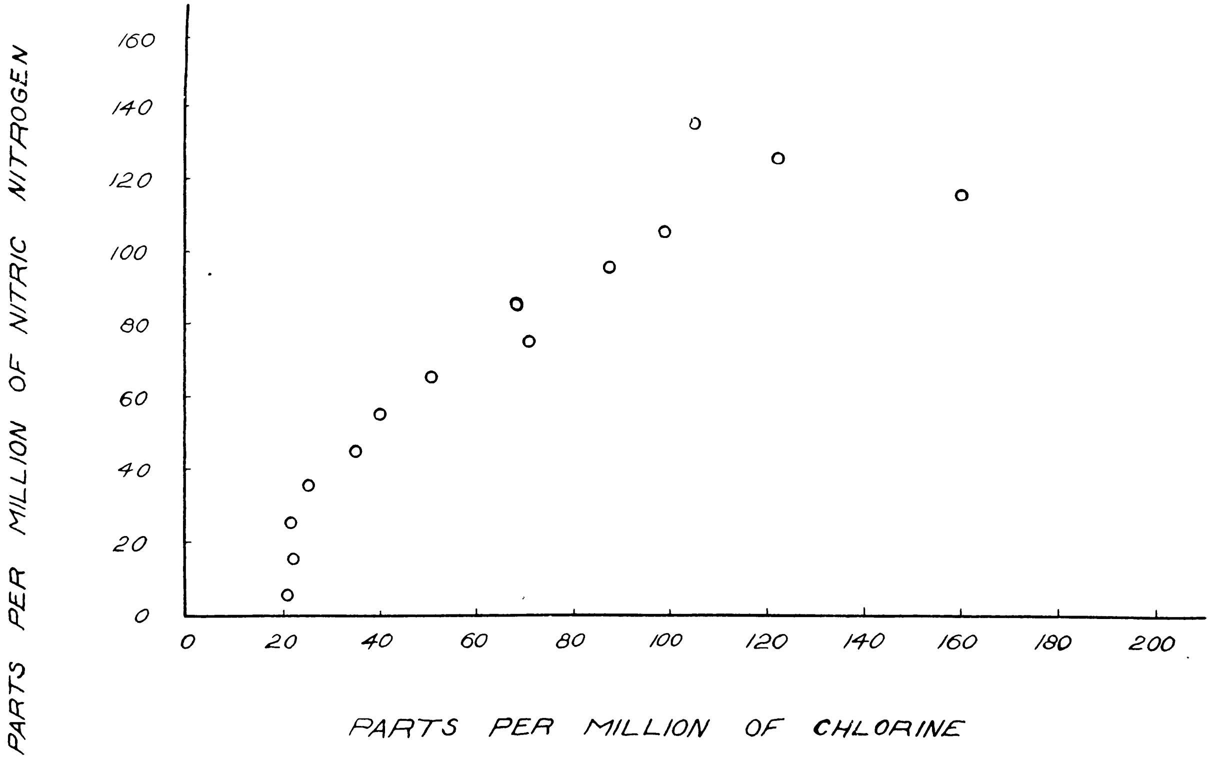

Figure 2.—Mean Ratio of Nitric Nitrogen to Chlorine During the Season in the First Four Inches of Soil for the Period 1922 to 1931 Inclusive.

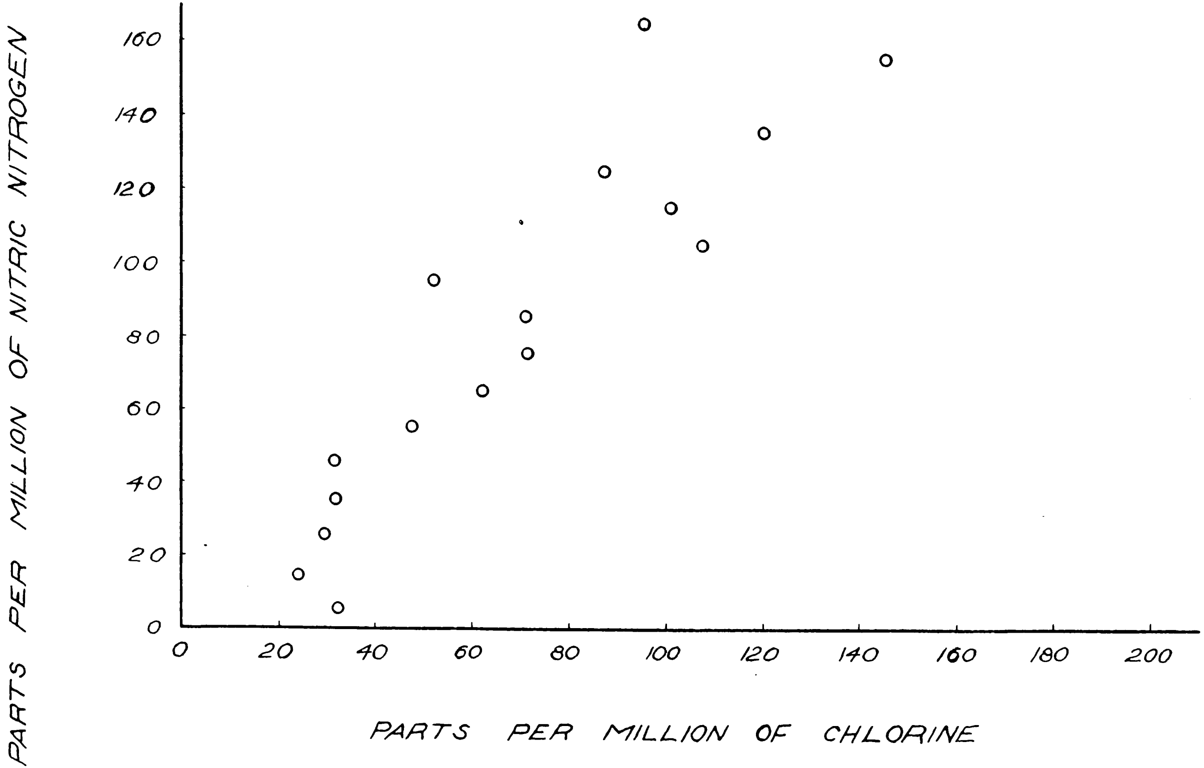

Figure 3.—Ratio of Nitric Nitrogen to Chlorine at the Maximum Nitric Nitrogen Content for the Season in the First Four Inches of Soil for the Period 1922 to 1931 inclusive.

Table 16 shows the chlorine and nitric-nitrogen content in a miscellaneous group of samples collected from "nitre spots" in various parts of the Valley. These show definitely that the ratio of nitrogen to chlorine in the "nitre spots" approaches the ratio found in the irrigation and drainage water. The lower part of the curve should be quite accurate, as this portion of the curve shown in the graph includes 850 plats sampled during 10 seasons, or approximately 10,000 samples. Each point, especially in the lower part of the curve, is the composite of a large number of samples. The points plotted are the class centers of group intervals of 10 parts per million.

In 1931, an attempt was made to measure the actual amounts of nitrogen fixed and nitrified per acre, per season under field conditions. This study was undertaken with the hope of relieving some of the uncertainty in regard to the amounts of nitrates lost thru the soil in the percolating water and thus permit the estimation of the probable effects of poor drainage on nitrate accumulation.

The data reported were obtained from 4 plats in an 8-year rotation. Two plats were in onions, one of them following cantaloupes and the other a new seeding of alfalfa plowed under in the fall for green manures. The other two plats were newly seeded alfalfa, with barley as a nurse crop, and both followed sugar beets.

Table 16.—Rates of Nitric Nitrogen to Chlorine in Areas of High Nitric-Nitrogen Content, Commonly Called "Nitre Spots."

	Nitric Nitrogen	Chlorine	Ratio N:Cl
	p.p.m.	p.p.m.	
	952	15,393	0.062
	445	2,736	0.162
	1,226	9.953	0.123
	1,667	11,348	0.147
	2,561	30,812	0.083
	395	2,800	0.141
	752	932	0.806
	755	1,472	0.051
Mean	1,094	9,430	0.196

Average ratio of nitrogen to chlorine is 1 part nitrogen to 8.6 parts chlorine.

*The first five samples were collected in 1925 and the last three in 1929.

The four plats were sampled weekly to a depth of 6 feet by foot sections, except that the upper foot was divided into the first 4 inches and the next 8 inches. The surface sample was the composite of 25 cores and the others were composed of two borings. All samples were analyzed for nitric nitrogen and chlorine, and the surface 4 inches for total nitrogen.

All irrigation water was measured. The chlorine content of the water was estimated from daily analyses made of water from the same ditch in 1929 (See Table 17). The mean chlorine content,

Table 17.—Chlorine and Nitrogen Added per Acre in Irrigation Water.

Onions After Green Manure

Date	Acre-Feet of Water	Lbs. N. per Acre	Lbs. Cl. per Acre
4/15	0.252	2.0	24.2
4/27	0.190	1.5	18.2
5/16	0.222	1.1	16.4
6/18	0.201	0.7	7.1
7/3	0.111	0.5	5.2
8/1	0.217	1.2	11.4
8/11	0.350	2.0	18.3
8/20	0.143	0.8	6.3
8/29	0.092	0.5	4.8
11/13	0.360	2.6	27.3
Total	2.138	12.9	139.2
Amt. per acre-foot water		6.0	65.1
Ratio N : Cl in water		.092	

Onions After Cantaloupes

Date	Acre-Feet of Water	Lbs. N. per Acre	Lbs. Cl. per Acre
4/15	0.277	2.2	26.6
4/27	0.209	1.6	20.1
5/16	0.244	1.2	18.0
6/18	0.221	0.7	7.7
7/3	0.122	0.6	5.6
8/1	0.239	1.3	12.5
8/11	0.518	2.9	27.2
8/20	0.186	1.1	9.7
8/29	0.148	0.8	7.7
11/13	0.428	3.1	32.4
Total	2.592	15.5	167.5
Amt. per acre-foot water		5.9	64.6
Ratio N : Cl in water		.092	

Barley After Sugar Beets

Date	Acre-Feet of Water	Lbs. N. per Acre	Lbs. Cl. per Acre
4/15	0.319	2.5	30.7
4/27	0.212	1.7	20.3
5/18	0.357	1.8	26.5
6/13	0.390	1.3	13.7
6/30	0.465	1.5	16.3
7/23	0.562	2.8	26.2
8/21	0.500	2.8	26.2
11/14	0.368	2.7	27.9
Total	3.173	17.1	187.8
Amt. per acre-foot water		5.3	59.1

Barley After Sugar Beets

Date	Acre-Feet of Water	Lbs. N. per Acre	Lbs. Cl. per Acre
4/17	0.279	2.2	26.9
4/27	0.370	2.9	35.5
5/18	0.782	3.8	57.8
6/13	0.995	3.3	34.9
6/30	0.447	1.5	15.6
7/23	0.183	0.9	8.5
8/21	0.349	2.0	18.3
Total	3.405	16.6	197.5
Amt. per acre-foot water		4.9	58.0

for each month in 1929, was used in calculating the chlorine content during the corresponding month in 1931.

Three possible sources of the introduction of nitrogen were recognized: The atmosphere, the irrigation water and seepage water. Three means of escape were also considered: Escape into the subsoil in drainage water, into the atmosphere and removal in the crops. Direct measurement of the amounts entering and escaping from the soil by all of these sources involved almost insurmountable difficulties, but an indirect procedure was adopted which seemed feasible for getting results which are a close approximation.

The nitric nitrogen introduced into the soil by the irrigation water and removed by the crops was calculated from water and crop[1] analyses. The nitric nitrogen found in the soil in the spring and fall was calculated from the mean of weekly determinations during April and October. Total nitrogen (except nitric) changes from spring to fall also were calculated from the mean of weekly determinations in April and October of the surface 4 inches. The nitric-nitrogen loss by leaching was estimated from the chlorine loss. The nitrogen loss into the atmosphere and the nitrogen loss by leaching other than as nitrates were not measured.

The four following equations show the method used in arriving at the chlorine loss by leaching, the nitrogen loss by leaching, the nitrogen nitrified, and the nitrogen fixed:

$$Cl_d-(Cl_b-Cl_a)-Cl_c=Cl_e \qquad (1)$$

$$(N_f/Cl_f)Cl_e=N_e \qquad (2)$$

$$(N_b-N_a)+N_e+N_c-N_d=N_g \qquad (3)$$

$$(N_j-N_i)+(N_b-N_a)+N_e+N_c-N_d=N_h \qquad (4)$$

in which N_a = Nitric nitrogen in profile in spring
N_b = Nitric nitrogen in profile in fall
N_c = Nitrogen removed by crop
N_d = Nitric nitrogen in irrigation water
N_e = Nitric nitrogen loss by leaching
N_f = Mean nitric nitrogen in sixth foot during season
N_g = Nitrogen nitrified during season
N_h = Nitrogen fixed during season
N_i = Total nitrogen minus nitric nitrogen in profile in spring
N_j = Total nitrogen minus nitric nitrogen in profile in fall
Cl_a = Chlorine found in profile in spring
Cl_b = Chlorine found in profile in fall
Cl_c = Chlorine removed by the crop
Cl_d = Chlorine added in irrigation water
Cl_e = Chlorine loss by leaching
Cl_f = Mean chlorine found in sixth foot during season

As an example of the calculation, the values in the first column of Table 18 are calculated below by substituting figures for symbols in the equations:

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[1]Since there was no means of determining what portion of the nitrogen in the crops was taken from the soil as nitric nitrogen, the assumption was made in the calculations that it all came from this source.

139.2—(-9.2)—1.5=Chlorine leached=146.9 .... (1)
(.90)146.9=Nitrogen leached=132.2 .... (2)
47.5+132.2+35.0—12.9=Nitrogen nitrified=201.8 .... (3)
-89.5+47.5+132.2+35.0—12.9=Nitrogen fixed=112.3 .... (4)

The results are summarized in Table 18. They show that the nitrogen introduced by the water was relatively small compared with the amount fixed, nitrified, or the amount utilized by the crops. They answer definitely the question as to the approximate relative proportion of the nitrogen resulting from fixation and nitrogen brought into the soil by the water where seepage is not a factor. The nitric nitrogen introduced by the water is much less than the amount needed for crop production.

In the cases of the onion crop and combined barley and alfalfa crops, the nitrogen fixed was found to be in excess of the amount utilized by the crops. This was particularly true of the onion crops, where the amount fixed was several times the amount utilized. It is evident that an excess would soon build up in the soil, if drainage were stopped and the rate of fixation continued. However, it should be noted that the chlorine, if drainage were stopped, would increase at approximately the same rate as the nitrogen, and all the soluble salts would increase accordingly.

Table 19 shows the ratio of the excess nitric nitrogen for the season to the total salts introduced by the irrigation water. This table shows that with the amount of irrigation water applied, the total salts would increase from 3.8 to 326 times as rapidly as the nitrates. Less water would be applied under poor drainage, but since in poorly drained land there is usually seepage from below, salts would be introduced with the underground solution, which is much more concentrated than the irrigation water. It would be impossible with rates of nitrification approaching those observed for the concentration of nitrates ever to approach the concentration of the other salts under any circumstances where sufficient water to produce a crop is applied, whether from the surface or seepage. This reasoning should be applicable to the Valley as a whole, as the principal source of irrigation water is the same. Therefore, it seems probable that nitrates can never become the first to limit crop production in the Arkansas Valley unless we assume that nitrates are several times as toxic as the other salts present in the water. The salts included in Table 19 are exclusive of calcium sulphate and are principally sodium and magnesium sulphates. The relative toxicities of nitrates and the other salts are discussed later.

Table 18 shows the amount of nitrogen which can be expected to be introduced by the irrigation water, but does not show the amount that might be introduced in seepage water. An average of 13 samples of water, taken from a shallow well near the experimental plats

Table 18.—Rate for Season of Nitrogen Fixation and Nitrification.

		Onions after Green Manure	Onions after Cantaloupes	Barley and Alfalfa after Sugar Beets	Barley and Alfalfa after Sugar Beets
		lbs. per acre	lbs. per acre	lbs. per acre	lbs. per acre
Chlorine in Irrigation Water	(Cl_d)	139.2	165.0	187.8	197.5
Chlorine in Crop	(Cl_c)	1.5	1.3	5.8	5.7
Chlorine Gained in Soil Profile	$(Cl_b - Cl_a)$	− 9.2	− 2.9	25.6	−10.6
Chlorine Leached from Soil	(Cl_e)	146.9	166.6	156.4	202.4
Nitric Nitrogen Leached from Soil	(N_e)	132.2	154.9	76.6	87.0
Nitric Nitrogen Gained in Soil	$(N_b - N_a)$	47.5	1.8	−56.6	− 8.6
Nitrogen in Crop	(N_c)	35.0	37.0	137.0	115.0
Nitric Nitrogen in Irrigation Water	(N_d)	12.9	15.5	17.1	16.6
Total Nitrogen Minus Nitric Nitrogen Gained in Soil	$(N_j - N_i)$	−89.5	− 0.5	45.5	7.5
Nitrogen: Chlorine Ratio in Sixth Foot of Profile	$(N_f)/(Cl_f)$	0.9	0.93	0.49	0.43
Nitrogen Nitrified		201.8	178.2	139.9	176.8
Nitrogen Fixed		112.3	177.7	185.4	184.3

in 1929, showed a chlorine-nitrogen ratio of 8.9 parts of chlorine to 1 part of nitrogen. This ratio naturally would be approached in the soil if much seepage occurred. It should be noted that this is approximately the chlorine-to-nitrogen ratio observed for the samples in Table 16.

So far as these plats are concerned, there appears to be no consistent difference between the rates of nitrification and fixation under the "cultivated" and "uncultivated" crops.

Table 20 shows the comparative amounts of nitric nitrogen in the first foot under the two specific crops during the season. The "cultivated" crops are significantly higher than the "uncultivated" crops in this respect. The difference between these two types of crops is general as is shown in Tables 1 to 9. This behavior previously has been attributed to higher rates of fixation and nitrification under cultivated crops, but Table 18 shows that the difference in this particular case can be explained by the higher rates of utilization by the uncultivated crops. The same explanation seems adequate for the generally greater nitrate content in the surface 4 inches under "cultivated" crops for even tho the "cultivated" crops were heavy nitrogen feeders, cultivation reduces the feeding roots near the surface.

6. A STUDY OF THE INFLUENCE OF EXCESSIVE QUANTITIES OF NITRATES ON CROP PRODUCTION.—A knowledge of the quantities of nitrates in the soil which are injurious to crops is naturally of fundamental importance before any attempt should be made to control nitrate excesses. The practically universal deficiency of nitric nitrogen in agricultural soils has given little impetus to research workers to study the effects of excessive quantities. Headden (7) held to the opinion that nitrates were very much more toxic than other salts commonly found in the soil. Harris, Thomas and Pittman (3) present evidences that the toxic limits of chlorides and nitrates are not materially different. The uncertainty regarding the quantities of nitrates required to produce crop injury made it necessary to study further this phase of the subject. The work accomplished to date is preliminary but it is of value in estimating the probability of crop reduction from nitrate concentrations found in the Arkansas Valley.

Three series of experimental results are presented:

1. Results obtained from water cultures.
2. Results obtained from flower-pot studies.
3. Results obtained from field plats.

THE EFFECT OF SALTS ON THE GROWTH OF SUGAR-BEET AND BARLEY SEEDLINGS IN WATER CULTURES.—Crone's nutrient solution (1) was used for the water cultures. The salt solutions all contained the nutrients of Crone's solution in addition to the salt concentrations given in the tables. The seeds were placed on absorbent cotton

Table 19.—Ratio of Nitrogen Fixed and Nitrified in Excess of Crop Use to Total Sodium and Magnesium Salts Added in the Irrigation Water.

	Onions after Green Manure	Onions after Cantaloupes	Barley and Alfalfa after Sugar Beets	Barley and Alfalfa after Sugar Beets
	lbs. per acre	lbs. per acre	lbs. per acre	lbs. per acre
Nitrogen Fixed in Excess of Nitrogen Used by Crops	77.3	140.7	48.4	69.3
Nitrogen Fixed in Excess of Crop Use Calculated as $NaNO_3$	469.2	845.6	290.8	420.6
Nitrogen Nitrified in Excess of Nitrogen Used by Crops	166.8	141.2	2.9	61.8
Nitrogen Nitrified in Excess of Crop Use Calculated as $NaNO_3$	1,012.4	848.6	17.4	375.1
Salts in Irrigation Water	3,823.0	4,635.0	5,676.0	6,090.0
Ratio of Salts in Water to Nitrogen Fixed in Excess of Crop Use (Calculated as $NaNO_3$)	8.1	5.4	19.5	14.5
Ratio of Salts in Water to Nitrogen Nitrified in Excess of Crop Use (Calculated as $NaNO_3$)	3.8	5.4	326.2	16.2

Table 20.—Nitric Nitrogen Under Different Crops During 1931.

Date	Onions After Alfalfa		Onions After Cantaloupes		Grain and Alfalfa		Grain and Alfalfa	
	0″–4″	4″–12″	0″–4″	4″–12″	0″–4″	4″–12″	0″–4″	4″–12″
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
5/23	24	7	29	21	13	32	11	5
6/1	31	13	20	13	9	8	17	12
6/6	17	9	17	16	3	2	13	8
6/12	23	7	13	6	13	9	3	5
6/19	50	19	8	5	3	2	8	4
6/26	49	21	8	5	5	4	6	2
7/3	87	23	43	12	7	7	5	3
7/10	58	20	21	13	4	2	4	4
7/17	73	23	46	24	6	8	8	6
7/24	47	22	20	13	8	2	7	3
7/31	46	7	28	14	6	1	1	1
8/7	70	22	42	15	7	4	3	4
8/14	49	20	50	15	15	3	5	3
8/21	106	36	72	19	6	9	5	3
8/28	35	15	72	16	3	6	6	5
9/4	91	26	34	14	6	4	5	3
9/11	49	22	20	13	3	3	5	3
9/18	81	15	111	21	5	1	5	3
9/25	138	15	72	10	7	2	9	1
10/2	89	15	47	12	1	4	2	2
10/9	12	19	38	7	4	1	3	2
10/17	17	17	7	8	6	4	4	4
10/23	13	18	30	12	6	4	6	4
10/30	18	20	16	18	6	4	4	3
11/6	17	15	8	6	5	4	3	1
11/13	23	16	14	19	4	5	3	4
11/20	11	8	13	10	7	6	6	4
Average*	49.0±4.3	17.4±0.8	33.3±3.3	13.2±2.5	6.2±0.4	5.2±0.7	5.8±0.4	3.8±0.6

*Probable errors were calculated by Bessel's formula.

pads in the bottom of pint milk bottles and 50 cc. of solution was pipetted into each of the bottles. The bottles were kept capped to retard evaporation and transpiration losses. Small pin holes in the caps provided some aeration. Twenty seed balls were used in each of the sugar-beet cultures and 20 barley seeds in each of the barley cultures. The beet seeds were of good quality but the barley seeds were very low in viability. The beet seedlings were harvested and weighed the sixteenth day after planting. The weights are given as green weights of the whole plants.

Table 21.—Effect of Salts on Sugar-Beet Germination

Concentration of Salt Solution	Germination on Eighth Day Based on Check as 100 Percent							
	$NaNO_3$	$NaCl$	$Ca(NO_3)_2$	$CaCl_2$	$NaNO_3+$ $Ca(NO_3)_2$	$NaCl+$ $CaCl_2$	$NaCl+$ $Ca(NO_3)_2$	$NaCl+$ $Ca(NO_3)_2$ $+CaSO_4$
normality	pct.	pct.	pct.	pct.	pct.	pct.	pct.	pct.
3750	12.2	4.9	4.9	0.0	4.9	0.0	2.4	2.4
.2140	48.9	34.2	48.9	68.4	24.5	39.1	22.0	41.6
.1430	78.2	51.3	75.8	107.5	75.8	63.6	41.6	51.3
.0715	75.8	92.9	95.4	97.8	90.5	95.4	97.8	102.7
.0286	85.6	83.1	90.5	112.5	70.9	102.7	78.2	114.9
Check	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 22.—Effect of Salts on Sugar-Beet Seedling Growth in Water.

Concentration of Salt Solution	Average Green Weight of Seedlings on Sixteenth Day							
	$NaNO_3$	$NaCl$	$Ca(NO_3)_2$	$CaCl_2$	$NaNO_3+$ $Ca(NO_3)_2$	$NaCl+$ $CaCl_2$	$NaCl+$ $Ca(NO_3)_2$	$NaCl+$ $Ca(NO_3)_2$ $+CaSO_4$
normality	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.
.3750	13	20	10	10	11	10	13	10
.2140	38	32	17	23	21	25	24	23
.1430	29	40	25	36	29	38	35	29
.0715	37	36	35	42	50	40	43	38
.0286	51	39	57	38	33	55	45	40
Check	41	42	44	40	30	36	38	38

The results of the sugar-beet experment are recorded in Tables 21 and 22. The treatments were not replicated in this experiment and consequently the significance of small differences can not be estimated. However, the tables show very clearly that the differences between the effects of individual salts of equal concentrations are not great. A concentration of approximately 0.2 normal is approached in each case before marked injury occurs, and even when the concentration approaches 0.4 normal, growth equals about 30 percent of that in the nutrient solution alone. There is no indication that the nitrates are more toxic than the chlorides. If the curves for the effects of nitrates and chlorides are plotted with growth against salt concentration, the nitrate curve would be slightly above the chloride curve. Harris, Thomas and Pittman (3) showed the same fact to hold with wheat seedlings in soil cultures.

Table 23 gives the comparative effects of sodium chloride, sodium sulphate and calcium nitrate on barley germination, weight of seedlings and height of seedlings. The seedlings were harvested on the twenty-eighth day after planting. The weights recorded are the green weights of the whole plants. The treatments were replicated five times. The calcium-nitrate treatment showed the least injurious effect of any of the treatments on germination, weight and height of plants. The sodium chloride resulted in greatest injury. The table indicated that, except for the highest concentration, the differences between the three salt effects are more nearly proportional to the osmotic concentration of the solutions than to the normality and are not greatly affected by the nature of the ions.

THE EFFECT OF SALTS ON GROWTH OF BARLEY AND SUGAR BEETS IN FLOWER POTS.—Table 24 shows the effects of nitrogen and phosphorus, alone and in combination, on barley plants in a series of flower pots. The nitrogen was applied as calcium nitrate and the phosphorus as mono-calcium phosphate. The soil used was Cass fine sandy loam, from near Fort Collins, which was deficient in available phosphorus. Six-inch pots containing 1500 grams of soil each were used. The treatments were in duplicate. Ten seeds were planted in each pot and the plants thinned to three. The experiment was carried out-of-doors with the pots set into the ground level with the surface in order to cut down temperature changes and evaporation. Sufficient rain fell on two or three occasions during the season to cause some leaching of the pots. The greatly reduced concentration at the end of the season may have been partly due to the leaching loss. The first 28 days of growth was in the higher concentration as no appreciable amount of rain fell during that period.

The results in Table 24 show that the growth of the plants was not materially affected by the nitrate treatments alone below 500 parts per million nitrogen. The nitrate with the phosphate gave better growth up to this point than phosphate alone. Nitrate and phosphate together gave approximately the same grain yield up to 200 parts per million nitrogen. Phosphate alone gave best results above this point. Nitrate alone gave practically no grain yield.

Table 25 gives a record of the yield of sugar-beet seedlings in the same-sized pots used for the barley plants. The same fertilizer treatments also were used but the soil was a sandy loam from the Arkansas Valley. This experiment was carried in the greenhouse. The pots were paraffined to prevent absorption of the fertilizer and no leaching was permitted to take place. However, the concentrations of nitrate were greatly reduced at the end of the experiment,

Table 23.—Effect of Salts on Germination of Barley and Growth of Barley Seedlings in Water.

Concentration of Salt Solution	Germination			Average Green Weight of Green Seedlings			Average Height of Plants			Difference over Standard Error of Difference		
	NaCl	Na_2SO_4	$Ca(NO_3)_2$	NaCl	Na_2SO_4	$Ca(NO_3)_2$	NaCl	Na_2SO_4	$Ca(NO_3)_2$	$Ca(NO_3)_2$ & NaCl	Na_2SO_4 & NaCl	$Ca(NO_3)_2$ & Na_2SO_4
normality	pct.	pct.	pct.	mg.	mg.	mg.	cm.	cm.	cm.			
.375	6.6	10.0	7.2	0	9	19	1.7	2.7	2.8	0.8	0.7	0.1
.214	11.6	13.8	13.3	8	19	44	2.4	3.4	6.1	2.7	0.7	1.9
.143	17.2	30.0	28.3	25	41	64	3.6	7.2	13.5	7.2	2.6	4.6
.0715	33.8	36.1	32.2	49	83	109	8.4	13.4	18.9	7.9	3.6	3.9
.0286	31.1	36.6	39.4	91	108	143	17.1	20.6	22.7	4.3	2.5	1.5

*Standard errors were calculated by "Student's" generalized formula.

Table 24.—Effect of Excessive Amounts of Nitrates and Phosphorus on the Growth of Colsess Barley in Flower Pots.

Amount Applied to Soil	NITROGEN				PHOSPHORUS				NITROGEN AND PHOSPHORUS			
	Nitric Nitrogen Residue at Harvest	Green Weight of			Nitric Nitrogen Residue at Harvest	Green Weight of			Nitric Nitrogen Residue at Harvest	Green Weight of		
		Straw	Roots	Grain		Straw	Roots	Grain		Straw	Roots	Grain
p.p.m.	p.p.m.	g.	g.	g.	p.p.m.	g.	g.	g.	p.p.m.	g.	g.	g.
0.0	16	.627	.482	.070	16	.627	.482	.070	16	.627	.482	.070
10.0	20	.747	.722	.140	18	.950	1.185	.262	14	.942	.670	.000
50.0	24	.747	.712	.000	26	1.610	1.477	1.620	31	1.867	1.437	1.597
100.0	24	.612	.695	.000	14	1.715	1.547	1.767	16	2.292	1.647	1.447
200.0	52	.572	.545	.000	18	1.937	1.550	1.487	30	2.689	1.722	1.497
500.0	49	.807	.580	.000	28	1.832	1.350	1.880	75	2.300	1.525	.640
1000.0	64	.317	.500	.000	18	1.615	1.675	1.375	135	2.257	1.672	.230
2000.0	100	.177	.405	.000	8	1.762	1.365	1.477	160	2.095	1.590	.170

altho leaching was prevented. The table shows the concentrations at the end of the period, as well as the rates of application.

Ten seed balls were planted in each pot and the plants thinned on the twenty-sixth day to the six largest plants. The beets were harvested 61 days after planting. The tops and roots of each of the plants were weighed separately and the standard errors were calculated from the deviation from the means of the separate treatments.

The highest yield, with nitrogen applied alone, was obtained with the 100-parts-per-million treatment. The highest yield was obtained when nitrogen and phosphorus were applied each at the rate of 200 parts per million. No increase occurred with phosphate alone.

Table 25.—Effect of Excessive Amounts of Nitrates and Phosphorus on the Growth of Sugar-Beet Seedlings in Flower Pots.

		TOPS			ROOTS		
Nitric N or P Applied	Nitric N At End	Weight	Increase Over Check	D/S.E.*	Weight	Increase Over Check	D/S.E.
			NITROGEN				
p.p.m.	p.p.m.	mg.	pct.		mg.	pct.	
0.0	7	359	....	.... ..	128	.... ..	.. ..
50.0	52	1065	196.6	22.0	227	77.3	3.7
100.0	85	1467	308.6	7.0	235	83.5	2.5
200.0	220	1027	186.6	6.3	187	46.0	2.3
500.0	340	701	95.2	3.3	88	31.2	1.5
1000.0	600	580	61.5	.... ..**	36	71.8	.. ..
2000.0	1490	0	....	.... ..	0	.... ..	.. ..
			PHOSPHORUS AND NITROGEN				
50.0	90	1517	322.5	8.2	356	171.8	6.4
100.0	105	1850	415.0	14.2	355	177.3	6.6
200.0	130	2343	552.6	19.3	308	140.6	4.7
500.0	210	1630	354.0	3.5	161	15.7	0.9
1000.0	660	0	....	.... ..	0	.... ..	.. ..
2000.0	580	0	....	.... ..	0	.... ..	.. ..
			PHOSPHORUS				
50.0	8	300	–16.4	1.5	126	–1.5	0.1
100.0	9	256	–28.6	3.3	181	41.4	1.5
200.0	7	295	–17.8	1.5	120	–6.2	0.4
500.0	6	250	–30.3	2.7	100	–21.8	1.2
1000.0	6	315	–12.2	0.8	121	–5.4	0.2
2000.0	4	311	– 7.7	1.1	115	10.1	0.6

*Calculated on individual weights of 12 plants.

**Too few plants to calculate errors.

THE INFLUENCE OF EXCESSIVE NITRATE CONCENTRATIONS ON CROP YIELDS IN FIELD PLATS.—A few comparisons of crop yields with nitric-nitrogen content of the soil are shown in Table 26. The data presented, except for sugar beets, are not sufficient to show more than the fact that within the range of nitrate change shown in Table 26 there does not seem to be any marked relationship between yield and nitrate content of the soil. However, in the case of sugar beets there appears to be a definite, positive correlation which is shown by a significant correlation coefficient of 0.5.

Yield data from 1925 to 1928, inclusive, for the "continuous cropping" sugar-beet plats for which nitrate data are given in Table 15, show a much higher yield on the manured plats where nitrates were significantly higher. The average increase in yield of the manured plats over the unmanured plats for the period was 75.1 percent. The average sugar contents for 1927 and 1928, the only years for which sugar-content data were available, were 12.7 for the unmanured and 13.7 for the manured plats. The difference in sugar content may have no significance, but the difference in yield is highly significant by "Student's" method of paired comparisons. The evident correlation between yield and nitrate content for sugar beets does not, of course, prove that the increased yield was due to the higher nitrate content of the soil. However, if the higher yield is not due to nitrates, there must be an association between nitrates and the factor or factors responsible for the increase.

Table 26.—Correlation Between Crop Yields and Mean Nitric-Nitrogen Content in First Four Inches of Soil for the Season.

SUGAR BEETS		ALFALFA		CANTALOUPE SEED		COLSESS BARLEY	
Yield	Nitric Nitrogen	Yield	Nitric Nitrogen	Yield	Nitric Nitrogen	Yield	Nitric Nitrogen
tons	p.p.m.	tons	p.p.m.	lbs.	p.p.m.	bu.	p.p.m.
7.0	17.7	4.0	11.1	184	26.1	17.8	13.6
11.2	20.0	4.0	13.1	194	21.8	24.8	10.5
11.4	15.1	5.5	13.9	200	16.3	27.5	14.4
11.5	15.6	5.7	13.5	202	24.5	31.5	16.9
12.7	17.9	5.7	13.3	250	20.4	33.1	14.2
12.8	11.7	6.3	10.4	250	25.2	40.3	11.3
13.0	17.6	6.5	12.3	260	16.7	44.1	11.1
13.9	15.8	6.5	13.5	275	23.7	44.2	19.2
14.1	16.3	7.0	14.5	300	20.2	47.8	17.9
14.6	21.9	7.2	14.4	......	......	50.4	12.8
15.0	18.0	7.2	12.9	......	......	......	......
16.8	19.6	7.4	11.5	......	......	......	......
17.1	20.2	....	......	......	......	......	......
17.1	24.5	....	......	......	......	......	......
17.3	26.8	....	......	......	......	......	......
18.5	25.3	....	......	......	......	......	......
19.3	17.1	....	......	......	......	......	......
21.4	23.4	....	......	......	......	......	......

Coefficient of Correlation 0.53

P* = 0.02. Since the probability is low the correlation may be regarded as significant

*Fisher, R. A., Statistical Methods for Research Workers, third edition.

Table 27 gives the results of a field experiment with sugar beets where very high fertilizer applications were applied. The beets were thinned to approximately 12 inches in each row and plats of single rows of 10 beets each were used as units. Treatments were made to alternate fertilized and unfertilized rows. The treatments were replicated five times and placed at random in each replication. Individual applications of fertilizers were made in trenches around the beets. Fertilizer treatments were made three times during the season, one-third of the total being applied each time in a quart of water. The first treatment was made June 19, the second June 28 and the third July 26. The beets were harvested September 16. The early harvest and a severe epidemic of "leaf spot" contributed to the low sugar content.

The outstanding fact shown in this table is that 2900 pounds per acre of sodium nitrate did not decrease the yield, sugar content, or purity of the beets, when applied alone or with the phosphate or potash. It is also worthy of note that the only significant increase in top growth was produced on the phosphated plats. This behavior does not support the general belief that excessive nitrates are entirely responsible for the excessive top growth often observed in the Valley. Only the highest phosphate application gave a significant increase in root growth. The high phosphate application was accompanied by a high nitrate application which makes it impossible to determine the part each had in increasing the yield.

Table 27.—Effect of Heavy Fertilizer Treatments on the Yield and Quality of Sugar Beets.

Treatment	BEET ROOTS			BEET TOPS			SUCROSE		PURITY	
	Average Weight	Increase Over Check	D/S.E.*	Average Weight	Increase Over Check	D/S.E.*	Average	Increase Over Check	Average	Increase Over Check
	g.	pct.		g.	pct.		pct.	pct.		
Check—No Treatment	748.2	.. ..	.. ..	799.5	.... ..	.. ..	7.98	.. ....	.704	.....
4230 lbs. $MgSO_4$. $7H_2O$	758.6	1.4	0.1	796.1	0.4	0.0	8.24	0.26	.715	.011
2923 lbs. $NaNO_3$	736.0	-1.6	0.1	826.1	3.3	0.3	7.68	-0.30	.714	.010
1908 lbs. NaCl	762.6	1.9	0.2	791.5	1.0	0.1	8.51	0.53	.719	.015
2923 lbs. $NaNO_3$, 610 lbs. Treble Superphosphate	819.9	9.6	0.7	1002.8	25.4	1.8	7.69	-0.29	.678	-.026
2923 lbs. $NaNO_3$, 610 lbs. Treble Superphosphate, 306 lbs. K_2SO_4	802.5	7.2	0.5	1036.0	29.5	2.5	7.93	-0.05	.696	-.008
292 lbs. $NaNO_3$, 6104 lbs. Treble Superphosphate	1019.5	36.2	2.4	1068.2	37.3	2.5	8.50	0.52	.709	.005
2923 lbs. $NaNO_3$, 306 lbs. K_2SO_4	720.7	-3.7	0.3	891.6	11.5	1.0	8.36	0.38	.712	.008

*Standard errors were calculated by "Student's" generalized formula.

SUMMARY

Results are given of a survey of the nitrate content of soils of the Arkansas Valley covering a period of 10 years. The average amount of nitric nitrogen in the upper 4 inches of soil during the season was found to vary with the type of crop grown and to range from 12.7 to 39.2 parts per million. The average maximum reached during the season ranged from 24.0 to 78.8 parts per million.

The addition of crop residues sufficient to add 36.6 pounds of nitrogen per acre had only a slight effect on the nitrate content of the soil. No significant differences in the effect of various green manures were observed. Barnyard manure greatly increased the soil nitrate content.

A study of the rates of accumulation of nitrates and other salts in the soil showed that the other salts accumulated much more rapidly than the nitrates under any farming conditions which would allow salt accumulation.

A study of the source of nitrates in the soil showed that most of the nitrates under normal conditions were from nitrogen fixed *in situ* but the study indicated that a large percentage, if not all, of the nitrates in very poorly drained soil was introduced by the water.

A series of experiments with water cultures, pot cultures and field plats indicated that the tolerance of the field crops studied is approximately the same for nitrates as for the other common "alkali" salts normally found in the soil.

A comparison of crop yields under different nitrate concentrations in the field indicates that within the range of nitrate concentrations studied, which is assumed to be approximately the normal range, the yield increases with the nitrate content, if any relationship exists.

From the quantities of nitrates usually found in the soil and the study of the quantities to which crops appear tolerant, the conclusion has been drawn that excessive nitrates in the Arkansas Valley are not normally a cause of reduced yields and are possibly not always sufficient for maximum yields.

Extremely high nitrate concentrations have been shown to be limited to areas of poor drainage and are accompanied with concentrations of other salts sufficiently high to be more toxic than the nitrates.

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