THE EFFECT OF CALCIUM CARBONATE ON CERTAIN SOIL CONSTITUENTS AND ON PLANT GROWTH.

by

Robert R. Hudelson, B. S.

SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARTS.

in the

GRADUATE SCHOOL

of the

UNIVERSITY OF MISSOURI

1915

Approved

378.7M71
XH866

HISTORICAL.

Centuries of farm practice have led to the discovery of nearly all of the easily applied natural materials that tend to make soils more productive. Such was the case with manure, bones, the growing of legumes, and just as truly tho perhaps not so extensively, with lime* in the form of marl and chalk. Marl and chalk are not adapted to long distance transportation, however, and it rested with such countries as England, so situated as to have large supplies within easy reach, to develop their use on an extensive scale. We read that as early as 1795 it was the"prevailing practice to sink pits for the purpose of chalking the surrounding land therefrom" and in the same publication, "On the famous Rathamsted Experiment Station it has bben found that the fields that had received liberal applications of this natural limestone a century ago are still moderately productive, while certain fields, remote from the chalk pits, which show no evidence of such applications are extremely unproductive".(1) We are told also that"Marl was used by the ancient Romans". (2)

Naturally, therefore, when chemists began to take an interest in agriculture their attention was attracted to finding the reasons for the use of lime, as well as to the discovery of other forms which might be used where chalk and marl were not available. This led

* For the purposes of this discussion the term lime will often be used to mean calcium carbonate.

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to a very large amount of experimental work covering conditions in many parts of the world. Among the countries from which recent investigations have been reported are Germany, Russia, France, Scotland, England, and Japan, as well as nearly every experiment station in the humid sections of our own land. That there is at present a very real interest in the use of lime not only among investigators but among farmers as well is evidenced by the fact that recent publications from the Deleware (3), Indiana (4), Iowa (5), Massachusetts (6), Michigan (7), Pennsylvania (8), Vermont (2), and Virginia (9) agricultural experiment stations all refer to a popular wave of interest in liming among the farmers of those states.

The determination of the exact function of lime in soils and plants has proved to be very complex and even after this large amount of study many phases of the problem are yet unsolved. The numerous purposes for which lime is applied to soils, such as correcting soil acidity, making better bacterial conditions, improving tilth, acting as a plant food, releasing other plant foods from insoluble compounds, and combatting disease, all add to the complexity of the problems as also does the fact that each soil and each species of plant respond to lime in a different way.

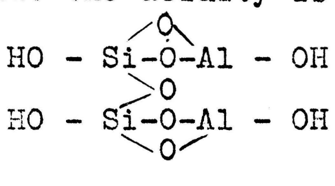
THE PHYSICAL EFFECTS OF LIME IN SOILS.

Lime applied to soils in the form of the oxide, hydroxide, or carbonate readily flocculates the finer clay and colloidal material thus making a more porous, better aerated, and hence a warmer more productive soil. In the amounts ordinarily used in this country this effect is probably slight. Russell of England, however, submits a comparison of two pairs of English soils "similar in constitution and general external conditions, temperature, water supply, etc., but very different in agricultural value because of their different content of calcium carbonate one being readily cultivated while the other is wet and sticky, and only suitable for pasture land". (10)

THE CHEMICAL EFFECTS OF LIME IN SOILS.

It is very important that a soil contain a fair concentration of calcium compounds, particularly of the carbonate and phosphate. Probably all the chlorophyl bearing plants require calcium as a plant food, and without the presence of the carbonate in the soil certain adverse conditions arise, particularly an acid soil reaction. Calcium phosphate is known to be one of the best carriers of phosphorus. Secondary effects of lime such as the displacing of potassium in insoluble compounds are largely matters of theory and have not been well substantiated. That such a reaction takes place with pure feldspar can scarcely be doubted but in the presence of common soil constituents, probably the clay, the displacing of potassium by calcium has not been clearly demonstrated. (11) (12)

The nature of the acidity which develops in soils is not clearly understood tho it has been the object of a great deal of speculation as well as experimentation. Early investigators believed it to be largely if not almost wholly due to organic acids. Probably one of the chief reasons for such a conclusion is the insoluble nature of the soil acids. (13) Later work has shown that much of this acidity is not due to organic compounds but that it is often found in great degree in soils almost free from organic matter. Loew (14) after extensive studies of a certain soil of this nature concludes that the acidity is due to an acid clay and suggests the formula



Harris (13) concludes that the acid reaction of soils is chiefly due to the presence of colloidal matter deficient in basic material, these colloids absorbing the base from indicators or from salts with which they come in contact. According to this theory neutral or alkaline soils have an excess of basic material, and the colloidal matter exists in a flocculated state. It becomes acid thru removal of the basic radical by plants, and by acids formed in the soil solution. This would seem to explain the fact that old soil formations, particularly those subject to rapid leaching are usually acid. Which of these possible sources of acidity is of greatest importance probably depends upon the soil in question. Peaty soils and acid clays probably owe their acid reaction to widely different compounds.

THE BACTERIOLOGICAL EFFECTS OF LIME IN SOILS.

Lime, thru its effect on the soil reaction, has a profound influence on the number and kind of microorganisms in the soil. Brown (15) working at the Iowa Station found that ground limestone at the rate of three tons per acre more than doubled the bacterial count and additional work showed that ammonification, nitrification and nitrogen fixation were all increased. Following this with pot cultures and later with field experiments (16) he found a corresponding increase in crop production. Naturally, increased bacterial activity along these lines tends to break down organic matter more rapidly and numerous experiments have shown the necessity of maintaining the organic matter where lime is used. The influence of the bacterial flora on a soil's fertility is being given more and more attention by investigators.

THE PHYSIOLOGICAL EFFECTS OF LIME.

Numerous experiments have demonstrated that calcium salts are necessary to the growth of all higher plants. Loew (17) observed a greater accumulation of calcium in the green parts of plants, and after studying the higher algae in various solutions with and without calcium, some of them containing closely related compounds such as those of magnesium and strontium, concluded that the nucleus and chlorophyll bodies contain calcium protein compounds. Neither magnesium nor strontium can be substituted for calcium in these compounds, and the poisonous effect of oxalic acid, he concludes, is due to the precipitation of the calcium. It is the belief of other investigators that calcium compounds figure only in the processes of metabolism and that they are not an essential part of plant tissue in its final state.

Calcium is known to be necessary to the normal transportation of starch. This failure to transfer starch in the absence of calcium is thought by Loew to be due to the lack of calcium to form the necessary starch forming plastids.

Calcium is also necessary to the proper formation of the cell wall in cell division.

"It has been shown by Boehm, Von Liebenberg, and Breal that lime is the first constituent extracted from the soil in the function of plant growth. In addition to the neutralizing action of lime by which plant sap acids are removed from the center of activity and returned as dormant constituents or expelled to the surface, it is known that the presence of lime is essential to cellulose formation in the leaves, and that it promotes diffusion of certain forms of albuminoids with which it unites to form soluble crystallizable compounds". (18)

These numerous functions of the calcium compounds, in plant life, are all to be considered, but the present practice of liming soils to increase crop production is based on the supposition that a soil to be most productive should have a neutral or slightly alkaline reaction. Naturally, the amount to be used, the time of application and the effect upon the soil and crop will vary with the soil in question as well as the plants to be grown. This variation of plants in their need for lime has been investigated by Wheeler and Adams (19) and later by Hartwell and Damon (20) at the Rhode Island station, also by Mooers (21) at the Tennessee station.

SCOPE OF PROBLEM.

It is the purpose of this investigation to secure data on the effects of adding calcium carbonate in the form of ground limestone to types of soils of common occurrence in the state of Missouri. These effects were studied in crop yields, in per cent of grain in cereal crops, in inoculation of clover, in the soil reaction, and in amount of nitrates present as well as the easily soluble phosphorus and potassium contained in the soil.

WORK OF OTHER INVESTIGATORS.

Data have been collected at most of the experiment stations of this and other countries on the effect of calcium carbonate on amount of plant growth. The work at the Rhode Island Experiment Station deserves special mention in this connection. The effect on per cent of grain has had little discussion, however. Calcium being found chiefly in the vegetative parts of plants it might be supposed that calcium compounds should increase those parts of the plant more than the grain. Again the well known effect of lime in increasing soil nitrates might be expected to stimulate vegetative growth more than grain production. Data reported by Watson (22) working at the Pennsylvania station show, on the contrary, that for corn and oats, at least, the increase in grain was greater than that in stover or straw.

As to the effects of limestone on factors which contribute to the increase in yield much has been done, but soils are so complex and so varied in nature that results secured under one set of conditions do not necessarily hold under others.

Karraker (28) working at the Missouri Agricultural Experiment Station found that nodules on the roots of clover were smaller but better distributed and more numerous where limestone was applied.

The quantitative effect of additions of lime on the soil reaction has been the subject of much discussion but of little exact record. Gardner and Brown (23) at the Pennsylvania Experiment Station report that, "Of 48 soil samples treated with slaked lime and ground limestone in amounts sufficient to meet the lime requirement as indicated by the Vietch determination, only seven were satisfied when reexamined at the close of the pot test".

"When a ton of limestone in excess of the requirement was applied only three remained acid at the close of the test. One of these was evidently contaminated and the other two were only slightly acid."

"Slaked lime applied in the amounts indicated by the Vietch method reduced the average requirement by 71 per cent as based on the average amount applied. On the same basis limestone reduced the requirement by 72 per cent."

They further conclude that finely ground limestone has been fully as prompt and effective in reducing soil acidity and promoting the growth of clover as equivalents of slaked or caustic lime.

The greater nitrifying power of a limed soil is a matter of easy and frequent demonstration and Brown (16) as well as others has shown that in a fallow pot increasing the lime content increases the amount of nitrates produced. Brown and MacIntire in working with field samples, on which a crop of oats was growing, found, however, that the application of lime did not increase the nitrate content of the soil as shown by periodic determinations.

The effect of liming a soil, on its content of easily soluble phosphorus and potassium compounds, has been studied by a number of investigators. Hartwell and Kellog (24) working at the Rhode Island Agricultural Experiment Station found greater amounts of assimilable phosphorus in limed soils as compared with unlimed ones.

Brown and MacIntire (2) found that lime did not increase the amount of water soluble potassium in field plats on which oats were growing. In fact there was a slight decrease as a general average.

Bradley(25) working at the Oregon Agricultural Experiment Station, found that lime did make a slight increase in the amount of water soluble potassium where soil and fertilizer were mixed in percolators and the leachings analyzed. Working on unfertilized soils, however, he found a decrease in water soluble potassium from the addition of lime. He also found that there was very little effect of lime on the water soluble phosphates.

Morse and Curry (11) working at the New Hampshire Experiment Station found that while lime increased the amount of water soluble potassium in feldspar,it had no such action in soil, altho considerable feldspathic minerals were present. Continuing this study they found that adding clay to the pure feldspar prevented the increase in soluble potassium by lime. They therefore ascribe the failure to secure an increase in soluble potassium of soils to the presence of clay.

PLANS AND METHODS OF INVESTIGATION.

It was planned first to examine the large amount of data already accumulated from the experiment fields of the state on limed and unlimed field plots. These data include yields of grain, straw, stover and hay of the common field crops of this country. They furnish evidence not only as to the effect of lime on the total weight of different crops but on the per cent of grain as well.

This study was followed by an examination of field samples of soil from five of the experiment fields included above. In all 44 samples were taken half of them from limed plots and half from unlimed plots. Careful studies of their nitrate contents and lime requirements were made.

Large amounts of soil from two of the above experiment fields, selecting two of the most acid soils, were secured and pot experiments were conducted to study the effect of different amounts of lime on the growth of clover. The effect of applying lime at long or short intervals before seeding was also studied. The soils in these pots were carefully sampled and studies made of the effect of the ground limestone applications on the nitrate content and the lime requirement. In the case of the series of pots limed at different intervals the easily soluble phosphorus and potassium also were determined.

FIELD EXPERIMENTS WITH GROUND LIMESTONE.

Along with other soil experiments conducted on various soil types, most of them acid, which occur in Missouri, careful records have been kept of the yields of grain, hay, stover, and straw on plots treated exactly alike except that in each case one plot was limed and the other was not. It seemed that these records should furnish an excellent source of information not only as to the effect of lime on the yield of the various crops but as to the effect on the per cent of grain, in case of the cereals. The following tables were computed with this in view. They cover nineteen different localities in the state and a period of years from 1905 to 1913. There are 95 tests showing the effect of lime on corn, 31 tests with oats, 68 tests with wheat, 21 tests with clover, 41 tests with cowpeas, and 4 tests with soybeans. Nearly all of these soils show an acid reaction, the amount varying from none to a lime carbonate requirement of about four tons to neutralize the surface seven inches of an acre. From one to two tons of lime was applied in each case. In most cases this was not enough to neutralize the acid shown by the Vietch method of determination.

TABLE I

EFFECT OF LIME ON YIELD AND PER CENT OF GRAIN IN CORN

Field	Yield of Grain: With Lime	Yield of Grain: Without Lime	Yield of Corn Stover: With Lime	Yield of Corn Stover: Without Lime	% Grain of total: With Lime	% Grain of total: Without Lime	Increase in Grain Yield	Increase in Stover Yield	Increase in % Grain of total
	bu.	bu.	lbs.	lbs.			bu.	lbs.	
Adrain	28.9	35.7					- 6.8		
"	40.0	40.0					0.0		
"									
Av. Adrain	34.4	37.8					-3.4		
Billings	37.2	39.2	1770	1880	54.0	53.8	-2.0	-110	0.2
"	46.3	41.5	2760	2805	48.4	45.3	4.8	- 45	3.1
"	40.5	31.1	1275	1075	64.0	61.8	9.4	200	2.2
"	31.8	29.3	1610	1500	52.5	52.2	2.5	110	0.3
"	19.2	12.4	2530	2090	29.8	24.9	6.8	440	4.9
"	33.9	27.8	1650	1825	53.5	46.0	6.1	-175	7.5
"	22.5	28.75	1100	1225	53.4	56.4	-6.25	-125	-3.0
"	14.3	9.3	1425	1175	35.9	30.7	5.0	250	5.2
Av. Billings	30.7	27.4	1765	1697	48.9	46.4	3.3	68	2.5
Bowling Green	35.0	34.3					0.7		
" "	27.1	27.1					0.0		
" "	22.9	17.9	1800	1650	41.6	37.8	5.0	150	3.8
" "	49.2	45.7					3.5		
" "	31.4	33.5	1900	1650	48.0	53.0	-2.1	250	-5.0
" "	30.7	34.2	1800	2000	48.9	48.9	-3.5	-200	0.0
" "	3.6	2.9	950	850	17.5	15.9	0.7	100	1.6
Av. Bowling Green	28.5	27.9	1612	1537	39.0	38.9	0.6	75	0.1

TABLE I (continued)

EFFECT OF LIME ON YIELD AND PER CENT OF GRAIN IN CORN

Field	Yield of Grain With Lime	Yield of Grain Without Lime	Yield of Corn Stover With Lime	Yield of Corn Stover Without Lime	% Grain of total With Lime	% Grain of total Without Lime	Increase in Grain Yield	Increase in Stover Yield	Increase in % Grain of total
	Bu.	Bu.	lbs.	lbs.			bu.	lbs.	
Carthage	28.9	28.7	1935	2545	45.5	38.7	0.2	- 610	6.8
"	71.3	67.0	3390	3705	54.1	50.3	4.3	- 315	3.8
"	38.4	37.6	1205	1000	64.9	67.7	0.8	205	-2.8
"	47.1	50.4	1280	1455	67.4	65.9	- 3.3	- 175	1.5
"	43.4	31.8	1436	1460	62.8	54.3	11.6	24	8.5
"	59.9	64.0	2475	2594	57.5	58.0	- 4.1	- 119	-0.5
"	31.2	29.3	1413	1265	55.3	56.4	1.9	148	-1.1
	55.6	52.8	2461	2249	55.9	56.8	2.8	212	-0.9
Av. Carthage	47.0	45.2	1950	2034	57.9	56.0	1.8	- 79	1.9
Dixon	20.0	15.0					5.0		
"	3.8	6.7	1340	1965	13.7	16.0	-2.9	- 625	-2.3
Av. Dixon	11.9	10.9					1.0		
Fulton	37.1	40.5					-3.4		
"	55.0	49.0	3160	3230	49.3	45.9	6.0	- 70	3.4
"	32.2	14.8					17.4		
"	46.0	42.3					3.7		
Av. Fulton	42.5	36.6					5.9		

TABLE I (continued)

EFFECT OF LIME ON YIELD AND PER CENT OF GRAIN IN CORN

Field	Yield of Grain With Lime	Yield of Grain Without Lime	Yield of Corn Stover With Lime	Yield of Corn Stover Without Lime	% Grain of total With Lime	% Grain of total Without Lime	Increase in Grain Yield	Increase in Stover Yield	Increase in % Grain of total
	bu.	bu.	lbs.	lbs.			bu.	lbs.	
High Hill	38.2	36.1					2.1		
" "	44.4	44.7					-0.3		
" "	21.1	25.7	1475	1800	44.5	44.4	-4.6	-325	0.1
" "	19.9	21.2	1390	1485	44.0	44.4	-1.3	- 95	-0.4
" "	34.2	34.5					-0.3		
" "	32.1	31.3					0.8		
" "	60.5	57.9					2.6		
" "	34.9	47.6					-12.7		
" "	22.0	20.2	1455	1435	45.8	44.0	1.8	20	1.8
" "	42.3	40.3	1822	1677	56.5	57.3	2.0	145	-0.8
" "	34.0	33.4					0.6		
" "	42.1	35.1					7.0		
" "	39.1	29.3					9.8		
" "	55.3	39.0					16.3		
" "	26.0	24.4					1.6		
" "	39.0	35.0					4.0		
Av. High Hill	36.5	34.7	1535	1599	47.7	47.5	1.8	- 64	0.2
Hurdland	47.5	36.8					10.7		
"	43.0	32.5					10.5		
"	34.3	29.4	3390	4120	36.1	28.5	4.9	-730	7.6
"	64.0	55.5	2300	4650	60.9	40.0	8.5	-2350	20.9
"	34.6	30.9	2825	2200	40.6	44.0	3.7	625	- 3.4
"	40.0	37.8	1350	1200	62.4	63.8	2.2	150	- 1.4
"	7.1	10.0	2975	3350	11.8	14.3	- 2.9	- 375	- 2.5
Av. Hurdland	38.6	33.3	2568	3104	42.3	38.1	5.3	- 536	4.2

TABLE I (continued)

EFFECT OF LIME ON YIELD AND PER CENT OF GRAIN IN CORN.

Field	Yield of Grain With Lime	Yield of Grain Without Lime	Yield of Corn Stover With Lime	Yield of Corn Stover Without Lime	% Grain of total With Lime	% Grain of total Without Lime	Increase in Grain Yield	Increase in Stover Yield	Increase in % Grain of total
	bu.	bu.	lbs.	lbs.			bu.	lbs.	
Laclede	55.4	52.6	2776	2704	52.8	52.1	2.8	72	0.7
"	42.0	38.5	3100	2800	43.1	43.5	3.5	300	-0.4
"	34.0	26.0	1380	1440	58.0	50.2	8.0	- 60	9.8
"	37.12	33.48	2040	2100	50.4	47.1	3.6	- 60	3.3
"	39.1	37.4	2520	2600	46.4	45.7	1.7	- 80	0.7
"	52.28	46.57					5.7		
Av. Laclede	43.3	39.1	2363	2329	50.1	47.7	4.2	34	2.8
Lamar	51.0	44.0					7.0		
"	45.0	41.3	1905	1905	56.9	54.8	3.7	000	2.1
"	32.9	27.1	1750	1550	51.3	49.4	5.8	200	1.9
"	36.3	44.3	2490	1980	44.9	55.6	-8.0	510	-10.7
"	20.9	23.4	2946	3121	28.4	29.5	-2.5	-175	- 1.1
"	31.7	33.5	1525	1550	53.8	54.7	-1.8	- 25	- 0.9
"	24.3	12.1	1750	1050	43.7	39.2	12.2	700	4.5
Av. Lamar	34.6	32.2	2061	1859	46.5	47.2	2.3	202	- 0.7
Lebanon	13.6	14.3	1850	2000	29.1	28.5	-0.7	-150	0.6
"	35.8	37.4	1875	2000	51.6	51.1	-1.6	-125	0.5
"	18.9	32.0	2330	3420	22.6	34.3	-13.1	-1090	-11.7
Av. Lebanon	22.7	27.9	2018	2473	34.4	37.9	-5.1	- 45[illegible]	- 3.5
Maryville	30.0	29.1	2900	2930	36.7	35.7	.9	- 30	1.0
"	49.9	51.0	3755	3750	42.6	43.2	-1.1	5	-0.6
"	29.4	29.6	3375	3265	30.1	33.6	-0.2	110	-3.5
Av. Maryville	36.4	36.6	3343	3315	36.4	37.5	-0.1	28	-1.0

TABLE I (continued)

EFFECT OF LIME ON YIELD AND PER CENT OF GRAIN IN CORN.

Field	Yield of Grain: With Lime	Yield of Grain: Without Lime	Yield of Corn Stover: With Lime	Yield of Corn Stover: Without Lime	% Grain of total: With Lime	% Grain of total: Without Lime	Increase in Grain Yield	Increase in Stover Yield	Increase in % Grain of total
	bu.	bu.	lbs.	lbs.			bu.	lbs.	
Monroe City	45.6	40.9	2031	2052	55.7	52.8	4.7	- 21	2.9
" "	50.9	38.6	3398	3190	45.6	40.3	12.3	208	5.3
" "	51.0	44.2					6.8		
Av. Monroe City	49.1	41.2	2714	2621	50.6	46.5	7.9	93	4.1
St. James	33.9	32.2	1905	1908	49.9	49.9	1.7	- 3	00.0
" "	40.0	37.4	2000	1600	52.8	56.6	2.6	400	- 3.8
" "	12.9	4.3	1900	1600	27.5	13.0	8.6	300	14.5
Av. St. James	28.9	24.6	1935	1702	43.4	39.8	4.3	232	3.6
Union	8.2	5.0	1090	1045	21.3	21.1	3.2	45	0.2
Unionville	33.5	24.3	2600	3700	41.9	26.8	7.2	-1100	15.1
"	21.3	17.6	1725	1025	30.8	49.0	3.7	700	- 18.2
"	66.4	62.1	3700	3550	50.1	49.4	4.3	150	0.7
"	33.6	26.4	2150	3050	46.6	32.6	7.2	- 900	14.0
"	51.5	56.0	3400	3515	45.9	47.1	-4.5	- 115	- 1.2
"	48.5	34.2	2500	1900	52.0	50.1	14.3	600	1.9
"	37.1	35.7	2850	2800	42.1	42.7	1.4	50	- 0.6
Av. Unionville	41.7	36.6	2703	2791	44.2	42.5	4.8	- 88	1.7
Vandalia D.	38.2	37.1	2220	2315	49.0	47.5	1.1	- 95	1.5
" U.D.	31.0	28.6	2670	1917	39.4	45.6	2.4	753	- 6.2
" D.	47.24	44.49					2.7		
" U.D.	52.55	40.81					11.7		
Av. Vandalia	42.25	37.75	2445	2116	44.2	46.5	4.5	329	- 2.3

TABLE I (continued)

EFFECT OF LIME ON YIELD AND PER CENT OF GRAIN IN CORN.

Field	Yield of Grain		Yield of Corn Stover		% Grain of total		Increase In Grain Yield	Increase in Stover Yield	Increase in % Grain of total
	With Lime	Without Lime	With Lime	Without Lime	With Lime	Without Lime			
	bu.	bu.	lbs.	lbs.			bu.	lbs.	
Victoria	46.3	40.9	2360	2000	52.3	53.3	5.4	360	- 1.0
"	19.1	24.5	1045	1445	50.5	47.9	- 5.4	- 400	2.6
"	20.6	19.0	1325	1000	46.5	51.5	1.6	325	- 5.0
Av. Victoria	28.6	28.1	1577	1482	49.8	50.9	0.5	95	- 1.1
Wittenberg	25.4	20.5					4.9		

TABLE II

EFFECT OF LIME ON YIELD AND PER CENT OF GRAIN IN OATS.

Field	Yield of Grain: With Lime	Yield of Grain: Without Lime	Yield of Straw: With Lime	Yield of Straw: Without Lime	% Grain of total: With Lime	% Grain of total: Without Lime	Increase in Grain Yield	Increase in Straw Yield	Increase in % Grain of total
	bu.	bu.	lbs.	lbs.			bu.	lbs.	
Bowling Green	19.7	16.3	1999	1532	23.8	25.4	3.4	467	- 1.6
" "	58.9	55.8	3560	4065	33.4	30.5	3.1	-505	2.9
" "	45.3	48.1	2767	2994	34.3	33.9	-2.8	-127	0.4
Av. Bowling Green	41.3	40.1	2775	2863	30.5	29.9	1.2	- 87	0.6
Fulton	72.0	67.7	2870	3005	44.5	41.9	4.3	-135	2.6
"	25.5	28.3	1724	1996	32.1	31.2	- 2.8	-272	0.9
Av. Fulton	48.7	48.0	2297	2500	38.3	36.5	0.7	-203	1.7
High Hill	35.7	33.0	2485	2520	31.4	29.5	2.7	- 35	1.9
" "	25.7	29.8	3300	3320	19.9	19.3	- 4.1	- 20	0.6
" "	45.3	45.3					0.0		
" "	17.0	17.0	1134	1089	32.4	33.3	0.0	45	- 0.9
" "	45.3	51.0	3221	3221	31.3	33.6	- 5.7	00	- 2.3
" "	26.6	28.5	2800	2970	23.3	23.5	- 1.9	-170	- 0.2
" "	47.9	41.9	1670	1450	47.8	47.6	6.0	220	0.2
" "	51.0	51.0	2904	2631	35.9	38.3	0.0	273	- 2.4
" "	39.6	28.3					11.3		
" "	24.0	19.8	1361	907	35.9	41.1	4.2	454	- 5.2
Av. High Hill	35.8	34.6	2359	2263	32.2	33.2	1.2	96	- 1.0

TABLE II (continued)

EFFECT OF LIME ON YIELD AND PER CENT OF GRAIN IN OATS.

Field	Yield of Grain: With Lime	Yield of Grain: Without Lime	Yield of Straw: With Lime	Yield of Straw: Without Lime	% Grain of Total: With Lime	% Grain of Total: Without Lime	Increase in Grain Yield	Increase in Straw Yield	Increase in % Grain of total
	bu.	bu.	lbs.	lbs.			bu.	lbs.	
Hurdland	32.8	24.8	2280	1550	31.5	33.8	8.0	730	-2.3
"	34.3	29.4	3390	4120	24.4	18.6	4.9	-730	5.6
"	28.3	31.1	2722	2767	24.9	26.4	-2.8	- 45	-1.5
"	28.3	31.1	1452	1542	38.4	39.2	-2.8	- 90	-0.8
"	59.3	42.5	2000	1665	48.6	44.9	16.8	335	3.7
Av. Hurdland	45.7	39.7	2961	2911	41.9	40.7	6.0	50	1.2
Laclede	38.7	44.3	2800	2856	30.6	33.1	-5.6	- 56	- 2.5
"	58.1	38.2	2949	2178	38.6	35.8	19.8	771	2.8
"	22.6	22.6	1269	1225	36.3	37.1	0.0	44	- 0.8
"	68.0	72.0					-4.0		
"	23.12	20.5	1836	2152	28.7	23.3	2.6	-316	5.4
Av. Laclede	42.1	39.5	2213	2103	33.5	32.4	2.5	110	1.2
Maryville	38.0	37.0	1232	1084	49.6	52.2	1.0	148	-2.6
"	33.9	33.4	2035	1415	34.8	43.0	0.5	620	-8.2
Av. Maryville	35.9	35.2	1633	1249	42.2	47.6	0.7	384	-5.4
Monroe City	15.9	14.5					1.4		
" "	23.3	19.6	1780	1530	29.5	24.4	3.7	250	5.1
Av. Monroe City	19.6	17.0					2.5		
Vandalia	56.2	52.9	2145	2730	45.6	38.3	3.3	-585	7.3
"	51.1	47.6	2720	2220	37.5	40.6	3.5	500	- 3.1
Av. Vandalia	53.6	50.2	2432	2475	41.5	39.4	3.4	- 42	2.1

TABLE III

EFFECT OF LIME ON YIELD AND PER CENT OF GRAIN IN WHEAT.

Field	Yield of Grain: With Lime	Yield of Grain: Without Lime	Yield of Straw: With Lime	Yield of Straw: Without Lime	%Grain of total: With Lime	%Grain of total: Without Lime	Increase in Grain Yield	Increase in Straw Yield	Increase in % Grain of total
	bu.	bu.	lbs.	lbs.			bu.	lbs.	
Adrain	19.6	15.6					4.0		
"	5.7	4.1	2022	1850	14.5	11.7	1.6	172	2.8
Av. Adrain	12.6	9.8					2.8		
Billings	6.2	6.3					- 0.1		
"	4.4	5.1					- 0.7		
"	13.0	12.2	1735	1445	31.0	33.6	0.8	290	- 2.6
"	13.6	12.0	2087	2541	28.1	22.0	1.6	-454	6.1
"	9.0	6.8	1224	4760	30.6	7.9	2.2	-3536	22.7
"	20.0	14.2	1700	1020	41.3	45.5	5.8	680	- 4.2
Av. Billings	11.0	9.4	1686	2441	32.7	27.2	1.6	- 755	5.5
Bland	11.5	13.0	2125	2633	24.5	22.8	- 1.5	- 508	1.7
Bowling Green	25.1	26.5	4230	4655	26.2	25.4	- 1.4	- 425	0.8
" "	24.8	22.7	2320	2520	39.0	35.1	2.1	- 200	3.9
" "	8.1	11.3	869	1739	35.8	28.0	- 3.2	- 870	7.8
" "	18.1	17.3	1996	2132	35.2	32.7	.8	- 136	2.5
" "	23.5	15.8	3234	2074	30.3	31.3	7.7	1160	- 1.0
Av. Bowling Green	19.9	18.7	2530	2624	33.3	30.5	1.2	- 94	2.8

TABLE III (continued)

EFFECT OF LIME ON YIELD AND PER CENT OF GRAIN IN WHEAT

Field	Yield of Grain With Lime	Yield of Grain Without Lime	Yield of Straw With Lime	Yield of Straw Without Lime	% Grain of total With Lime	% Grain of total Without Lime	Increase in Grain Yield	Increase in Straw Yield	Increase in % Grain of total
	bu.	bu.	lbs.	lbs.			bu.	lbs.	
Carthage	18.4	16.4	2030	2400	35.2	29.0	2.0	- 370	6.2
"	19.5	20.0	2205	2265	34.7	34.6	- 0.5	- 60	0.1
"	8.0	5.4					2.6		
"	16.6	18.3					- 1.7		
"	16.4	13.5	1127	1025	46.6	44.1	2.9	102	2.5
"	22.1	27.2	1652	1937	44.5	45.7	- 5.1	- 285	- 1.2
"	23.9	22.2	1950	1870	42.3	41.6	1.7	80	0.7
"	29.0	28.0	2717	2477	39.0	40.4	1.0	240	- 1.4
Av. Carthage	19.2	18.8	1947	1996	40.4	39.2	.4	- 49	1.1
Dixon	10.5	6.2	2157	1325	22.6	21.9	4.3	832	0.7
Fulton	12.6	17.3	2020	2618	27.2	28.3	-4.7	-598	-1.1
"	19.7	24.1	2765	2910	29.9	33.2	-4.4	-145	-3.3
"	6.2	7.5	1170	1057	24.1	29.8	-1.3	113	-5.7
"	11.3	7.6	1919	1460	26.1	23.8	3.7	459	2.3
Av. Fulton	12.4	14.1	1968	2011	26.8	28.8	-1.7	- 43	-1.8
High Hill	25.3	24.2	4002	3952	27.5	26.8	1.1	50	0.7
" "	25.7	29.8	3300	3320	31.8	35.0	-3.9	- 20	-3.2
" "	11.16	10.58	590	535	56.1	54.2	.58	55	1.9
" "	26.8	24.1	3740	3604	30.0	28.6	2.7	36	1.4
" "	27.2	32.3	3405	3165	32.4	37.9	-5.1	240	-5.5
" "	8.0	5.25	1090	735	30.5	30.0	2.75	355	0.5
Av. High Hill	20.7	21.0	2673	2552	34.7	35.4	- .3	119	-0.7

TABLE III (continued)

EFFECT OF LIME ON YIELD AND PER CENT OF GRAIN IN WHEAT.

Field	Yield of Grain: With Lime	Yield of Grain: Without Lime	Yield of Straw: With Lime	Yield of Straw: Without Lime	% Grain of total: With Lime	% Grain of total: Without Lime	Increase in Grain Yield	Increase in Straw Yield	Increase in % Grain of total
	bu.	bu.	lbs.	lbs.			bu.	lbs.	
Hurdland	21.0	22.5	2970	3400	29.8	28.4	-1.5	-430	1.4
"	14.7	17.3	2245	1890	28.2	35.4	-2.6	355	-7.2
""	14.7	11.6	1700	1564	34.1	30.8	3.1	136	3.3
"	32.56	32.16	3143	3473	38.2	35.7	0.4	-330	2.5
Av. Hurdland	20.7	20.9	2514	2582	32.6	32.6	-0.1	- 67	0.0
Laclede	10.9	8.8	1920	1672	25.4	24.0	2.1	248	1.4
"	22.7	27.2	4085	4630	25.0	26.0	-4.5	-545	-1.0
"	9.9	9.9	1665	1690	26.3	26.0	0.0	- 25	0.3
"	15.1	18.8	2391	2221	27.5	33.6	-3.7	170	-6.1
"	14.0	12.0					2.0		
""	28.46	24.76	3055	2882	35.5	34.8	3.7	173	0.7
Av. Laclede	16.8	16.9	2623	2619	27.9	28.8	- .1	4	- .9
Lamar	25.9	21.0					4.9		
"	19.1	15.9	3030	3255	27.4	22.7	3.2	-225	4.7
"	23.2	27.2	2415	3700	36.5	30.6	-4.0	-1285	5.9
"	13.6	17.3	2858	2541	22.2	29.0	-3.7	317	-6.8
"	18.9	18.1	3040	2223	27.1	32.8	.8	817	-5.7
"	17.9	22.5	2580	2925	29.3	31.5	-4.6	-345	-2.2
Av. Lamar	19.8	20.3	2784	2929	28.5	29.3	- .6	-144	- .8
Lebanon	20.2	17.6	3188	3795	27.5	21.7	2.6	-607	5.8
"	18.9	32.0	2330	3420	32.7	45.1	-13.1	-1090	-2.4
Av. Lebanon	19.5	24.8	2759	3607	30.1	33.4	- 5.2	- 848	-3.3

TABLE III (continued)

EFFECT OF LIME ON YIELD AND PER CENT OF GRAIN IN WHEAT

Field	Yield of Grain		Yield of Straw		% Grain of total		Increase in Grain Yield	Increase in Straw Yield	Increase in % Grain of total
	With Lime	Without Lime	With Lime	Without Lime	With Lime	Without Lime			
	bu.	bu.	lbs.	lbs.					
Maryville	38.0	37.0	1232	1084	64.9	67.2	1.0	148	-2.3
"	23.6	20.8	2400	2312	37.1	35.0	2.8	88	2.1
Av. Maryville	30.8	28.9	1816	1698	51.0	51.1	1.9	118	-0.1
Monroe City	10.7	9.3					1.4		
" "	16.7	13.2					3.5		
" "	19.0	13.2	2907	1880	28.1	29.6	5.8	1027	-1.5
Av. Monroe City	15.4	11.9					3.5		
St. James	13.4	12.1	1815	1452	30.7	33.3	1.3	363	-2.6
" "	16.7	13.7	1310	1110	43.3	42.5	3.0	200	0.8
" "	16.6	15.0	1255	1200	44.2	42.8	1.6	55	1.4
Av. St.James	15.6	13.6	1460	1254	39.4	39.5	1.96	206	-0.1
Union	18.7	15.9	3075	3027	26.7	23.9	2.8	44	2.8
Unionville	3.4	2.5					0.9		
"	15.0	10.0					5.0		
"	18.0	13.6	2730	2315	28.3	26.0	4.0	415	2.3
Av. Unionville	12.1	8.7					3.3		
Vandalia	10.2	11.9	3040	3403	16.7	17.3	-1.7	-363	-0.6

TABLE III *(continued)*

EFFECT OF LIME ON YIELD AND PER CENT OF GRAIN IN WHEAT

Field	Yield of Grain: With Lime	Yield of Grain: Without Lime	Yield of Straw: With Lime	Yield of Straw: Without Lime	% Grain of total: With Lime	% Grain of total: Without Lime	Increase in Grain Yield	Increase in Straw Yield	Increase in % Grain of total
	bu.	bu.	lbs.	lbs.			bu.	lbs.	
Victoria	4.7	2.0					2.7		
"	13.7	5.6					8.1		
Av. Victoria	9.2	3.8					5.4		
Wittenberg	12.3	11.9	2320	2364	24.1	23.2	0.4	-44	0.9
"	13.8	9.6	2170	1535	27.6	27.3	4.2	635	0.3
Av. Wittenberg	13.0	10.7	2245	1949	25.8	25.2	2.3	295	0.6

TABLE IV

EFFECT OF LIME ON YIELD OF CLOVER HAY

Field	Yield of Hay With Lime	Yield of Hay Without Lime	Increase in Hay Yield
	lbs.	lbs.	lbs.
Adrain	2800	2750	50
Billings	1435	1450	-15
"	2225	1350	975
"	200	250	-50
Av. Billings	1286	983	303
Bowling Green	5250	3350	1700
" "	1950	1100	850
Av. Bowling Green	3600	2325	1275
Carthage	1340	910	430
"	2925	3775	-850
Av. Carthage	2132	2342	-210
Fulton	860	1400	-450
High Hill	950	000	950
" "	1275	000	1275
Av. High Hill	1112	0000	1112
Hurdland	6975	6250	725
"	3250	3400	-150
Av. Hurdland	5112	4825	287
Laclede	6020	5400	620
"	3280	3608	-328
Av. Laclede	4650	4504	146
Lamar	2500	2500	000
Monroe City	2700	3150	-450
Unionville	1875	1575	300
Victoria	875	750	125
"	3500	2300	1200
Av. Victoria	2187	1525	662
Wittenberg	3364	2840	324

TABLE V

EFFECT OF LIME ON YIELD OF COWPEA HAY

Field	Yield of Hay: With Lime	Yield of Hay: Without Lime	Increase in Hay Yield
	lbs.	lbs.	lbs.
Adrain	4500	5000	-500
Billings	3465	3325	140
"	4675	4100	575
"	1100	1150	-50
"	5025	4525	500
"	2250	1725	525
"	775	1400	-625
Av. Billings	2881	2704	177
Bowling Green	2600	3200	-600
" "	2100	2150	- 50
" "	3050	2800	250
Av. Bowling Green	2583	2716	-133
Carthage	4000	3500	500
"	4380	4350	30
"	4700	4130	570
"	5650	6175	- 525
Av. Carthage	4682	4538	144
Fulton	3240	3060	180
High Hill	1180	1220	- 40
" "	1100	1225	-125
" "	2350	2250	100
" "	2300	2700	-400
" "	1700	2100	-400
Av. High Hill	1726	1899	-173
Hurdland	5850	7150	-1300
Laclede	2616	2448	168
"	3500	3360	140
"	3320	2680	640
Av. Laclede	3145	2829	316

TABLE V (continued)

EFFECT OF LIME ON YIELD OF COWPEA HAY.

Field	Yield of Hay With Lime	Yield of Hay Without Lime	Increase in Hay Yield
	lbs.	lbs.	lbs.
Lamar	2900	2950	-50
"	2300	3200	-900
"	3050	3050	000
"	3700	3675	25
"	2050	1750	300
"	2000	1900	100
Av. Lamar	2667	2754	- 87
Maryville	5700	5075	625
Monroe City	3398	3190	208
St. James	2065	1985	80
" "	400	250	150
" "	250	120	130
Av. St. James	905	785	120
Unionville	3750	3800	- 50
"	4100	4900	- 800
Av. Unionville	3925	4350	- 425
Vandalia	2357	2221	136
"	1771	2028	-257
Av. Vandalia	2064	2124	- 60
Victoria	625	1000	- 375
Wittenberg	4250	3150	1100

TABLE VI

EFFECT OF LIME ON YIELD OF SOYBEAN HAY.

Field	Yield of Hay		Increase in Hay Yield
	With Lime	Without Lime	
	lbs.	lbs.	lbs.
Bowling Green	2700	2500	200
St. James	3275	3125	150
" "	3710	3500	210
" "	1460	1080	380
Av. St. James	2815	2568	247

Averaging all the records which show the per cent of grain based on total weight of crop the following results are secured:

TABLE VII

EFFECT OF LIMESTONE ON PER CENT OF GRAIN.

Crop	Treatment	Per cent Grain	Number of crops averaged
Corn	limed	45.7	82
Corn	not limed	44.5	82
Oats	limed	34.3	27
Oats	not limed	34.1	27
Wheat	limed	32.0	55
Wheat	not limed	31.6	55

Apparently the use of ground limestone, on the common soil types found in Missouri, has little effect on the per cent of grain produced. It should be noted, however, that the small effect shown in each case is slightly indicative of an increase in per cent of grain. In view of the facts that most of the calcium in plants is found in the vegetative parts and that one of the chief effects of lime is to increase nitrification in the soil, the opposite might have been expected. Work at the Pennsylvania Agricultural Experiment Station previously noted substantiates these results, however.

TABLE VIII

EFFECT OF LIMESTONE ON CROP YIELDS

AVERAGES OF FIELD EXPERIMENTS (Tables I-VI)

Crop	Av. Yield per Acre		Increase or decrease per acre from liming	Number of tests
	With Lime	Without Lime		
Corn	36.1 bu.	33.4 bu.	2.7 bu.	95
Corn Stover	1717 lbs.	1742 lbs.	- 25 lbs.	82
Oats	38.4 bu.	36.2 bu.	2.2 bu.	31
Oat straw	2311 lbs.	2249 lbs.	62 lbs.	27
Wheat	16.9 bu.	16.1 bu.	0.8 bu.	68
Wheat Straw	2332 lbs.	2381 lbs.	- 48 lbs.	55
Clover Hay	2640 "	2300 "	340 "	21
Cowpea Hay	2929 "	2926 "	3 "	41
Soybean Hay	2786 "	2551 "	235 "	4

As may be seen from the above table, applications of ground limestone have increased the yields of all crops except corn stover and wheat straw. With wheat and cowpeas the increases have been very slight however, and a glance at the yearly records (tables I-VI) will show this effect to have been consistent.

NITRATE CONTENTS AND LIME REQUIREMENTS AS INFLUENCED BY FIELD APPLICATIONS OF LIMESTONE.

During the fall of 1913 samples of surface soil were secured from the limed and unlimed plots on the experiment fields at Bowling Green, Hurdland, and Vandalia in north Missouri and at Carthage and St. James in south Missouri. In all 44 plots were sampled. These were taken to a depth of eight inches by means of a 1½ inch soil auger and each sample consisted of about twenty borings well distributed over the plot. A determination of the nitrate content and lime requirement was made on each sample, and the results are shown in the following tables. Nitrates were determined by the method of Schreiner and Failyer as outlined in Bulletin 31 of the Bureau of Soils, U.S.D.A. Lime requirements were determined by the Veitch method. Because of the prevailing practice of expressing lime requirements in pounds of $CaCO_3$ necessary to neutralize the acid in two million pounds of soil, this being about the weight of the plowed layer (7 inches deep) over an acre, it was thought best to express the NO_3 content as parts per two million of soil.

A study of the nitrate contents, Tables IX to XIII, shows no increase in nitrate from the addition of lime. In fact there seems to be a slight negative correlation since the average nitrate content, in parts per two million, for the unlimed plots is 118 while that for the limed plots is only 111. This difference is probably within the limit of error for the method used. These tables do show consistently, however, that the nitrate content is greatly affected by the plant growth on the land, even tho the samples were taken in late fall. The nitrate content as here shown is highest on the corn land, the corn being in shock in all cases, followed in order by fall wheat, wheat stubble, cowpeas, clover, and soybeans. The results are hardly comparable for clover and soybeans, however, as they represent but one crop in each case. It is significant that the plots carrying most growth have least nitrates. The samples were taken before the fall sown wheat had begun to draw on soil nitrates appreciably and the corn land was practically free from growing plants. The wheat stubble had a considerable amount of weed growth. Cowpeas, soybeans, and clover are late growing crops, which probably accounts for the exhaustion of nitrates. This general arrangement of crops as to their influence on soil nitrates agrees with the findings of Lyon and Bizzell and others(28) who have worked on this problem. This is particularly true with respect to the high nitrate content under corn.

A study of the effect of the limestone added on the lime requirements of these soils shows that the lime requirement was never reduced by as great an amount as the limestone added. In fact the average reduction was only 41.3 per cent of the amount of limestone added when the data from all plots are averaged. This per cent of reduction varies considerably with the soil used, a possible reason being that the acid compounds are different in different soils. In half of the samples studied, however, the per cent ranged from 40 to 50 per cent.

During the progress of this experiment a new method for the determination of soil acidity was suggested by E. Truog of the Wisconsin Agricultural Experiment Station (29) and is described by him as follows. "Ten grams of soil are placed in a 300 cc Erlenmeyer flask and to this is added 1 g. calcium chloride, 0.1 g. zinc sulphide, and 100 cc of water. This is thoroly shaken and then heated over a flame. After the contents have boiled one minute, a strip of moistened lead acetate paper is placed over the mouth of the flask and the boiling continued two minutes more, when the paper is removed. If the soil is acid the paper will be darkened on the under side in proportion to the degree of acidity. If it is non-acid, no darkening will occur." It was found that very small differences in acidity could be detected by this method and for the soils under investigation it seemed the most satisfactory of the several methods tried. The chief difficulty in its use is in the fact that the results must be shown in shades of color and not be expressed in figures. As all methods for determining lime requirements are approximate and are likely to remain so, as long as the exact nature of soil acidity is in doubt, the practice of expressing results in exact figures is more or less misleading.

As the black lead sulphide developed on the test papers is rather easily oxidized to the white sulphate the only exact and permanent method of recording the test seems to be to represent the test papers in permanent color. This was done in the accompanying plates on which water colors were used in copying the original test papers.

TABLE IX

BOWLING GREEN EXPERIMENT FIELD.

Soil samples taken Oct. 25, 1913.

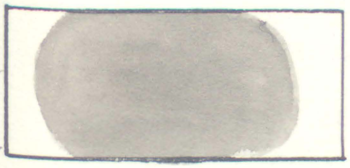
Amount of limestone applied per acre with dates of application	Plot No.	Crop on Field	NO_3 in lbs. per 2 million	Lime requirement in lbs. per 2 million
No Limestone	2	Wheat Stubble	122.5	6690
2000 lbs. 1907	3	Wheat Stubble	85.7	5798
No Limestone	10	Fall Wheat	90.2	7136
2000 lbs. 1907 4000 lbs. fall, 1913	11	Fall Wheat	127.7	4460
No Limestone	18	Cowpeas just recently frosted	93.7	6690
2000 lbs. 1907 4000 lbs. spring, 1913	19	Cowpeas just recently frosted	64.9	4460
No Limestone	26	Corn in shock	100.0	6244
2000 lbs. 1907 4000 lbs. spring, 1913	27	Corn in shock	115.0	4460

PLATE I

BOWLING GREEN EXPERIMENT FIELD

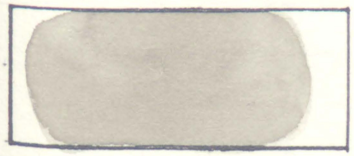
Soil samples taken Oct. 25, 1913.

Amount of limestone applied
with date of application.



PLOT 2

NO LIMESTONE



PLOT 3

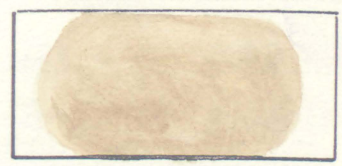
2000 lbs. 1907

PLOT 10

NO LIMESTONE

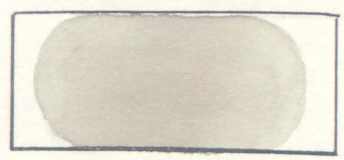
PLOT 11

2000 lbs. 1907
4000 lbs. fall 1913



PLOT 18

NO LIMESTONE

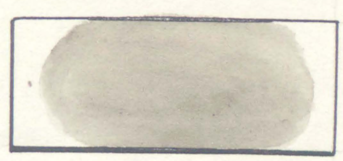


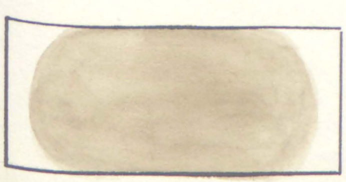
PLOT 19

2000 lbs. 1907
4000 lbs. spring 1913

PLOT 26

NO LIMESTONE





PLOT 27

2000 lbs. 1907
4000 lbs.spring 1913

TABLE X

HURDLAND EXPERIMENT FIELD.

Soil samples taken Nov. 20, 1913.

Amount of limestone applied per acre with dates of application	Plot No.	Crop on Field	NO_3 in lbs. per 2 million	Lime requirement in lbs. per 2 millions
No Limestone	2	Wheat Stubble	117.7	7136
2000 lbs.1907	3	Wheat Stubble	83.3	5798
No Limestone	10	Cowpeas just recently frosted	83.4	6244
2000 lbs.1907	11	Cowpeas just recently frosted	98.3	5352
No Limestone	18	Fall Wheat	116.6	6690
2000 lbs. 1908 8000 lbs. fall,1913	19	Fall Wheat	137.9	5798
No Limestone	26	Corn in shock	175.0	6690
2000 lbs. 1908 8000 lbs. spring 1913	27	Corn in shock	123.7	5798

PLATE II

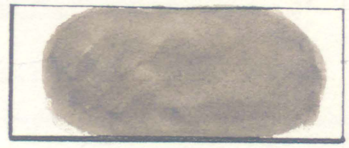
HURDLAND EXPERIMENT FIELD

Soil samples taken Nov. 20, 1913.

Amount of limestone applied
with date of application.

PLOT 2

NO LIMESTONE



PLOT 3

2000 lbs. 1907

PLOT 10

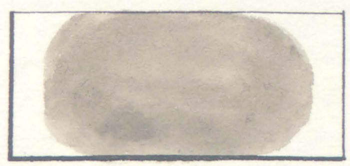
NO LIMESTONE

PLOT 11

2000 lbs. 1907

PLOT 18

NO LIMESTONE



PLOT 19

2000 lbs.1908
8000 lbs. fall
1913

PLOT 26

NO LIMESTONE

PLOT 27

2000 lbs. 1908
8000 lbs.spring
1913

TABLE XI

VANDALIA EXPERIMENT FIELD.

Soil samples taken Sept.26,1913.

Amount of limestone applied per acre with dates of application	Plot No.	Crop on Field	NO_3 in lbs. per 2 million	Lime requirement in lbs. per 2 million
No Limestone	*5U. D.	Being sown to Wheat	116.1	8028
2000 lbs. 1908 4000 lbs. fall,1913	* 7 U. D.	"	98.0	6690
No Limestone	* 5 D.	"	154.6	8920
2000 lbs. 1908 4000 lbs. fall, 1913	* 7.D.	"	152.9	5798

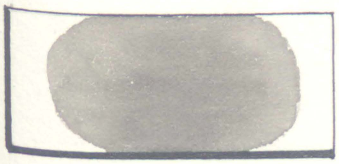
* First two plots poorly drained, second two plots tile drained.

PLATE III

VANDALIA EXPERIMENT FIELD

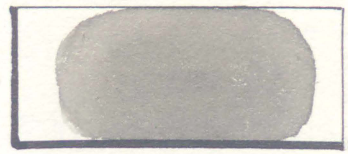
Soil samples taken Sept. 26, 1913.

Amount of limestone applied
with date of application.



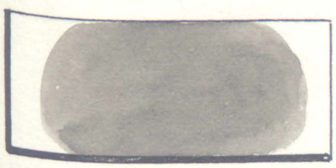
PLOT 5 D*

NO LIMESTONE



PLOT 7 D

2000 lbs. 1908
4000 lbs. fall 1913



PLOT 5 U.D.

NO LIMESTONE

PLOT 7 U.D.

2000 lbs. 1908
4000 lbs. fall 1913

* Plots marked D are tile drained and plots marked U.D. are flat and poorly drained.

TABLE XII

ST JAMES EXPERIMENT FIELD

Soil samples taken Oct. 8, 1913.

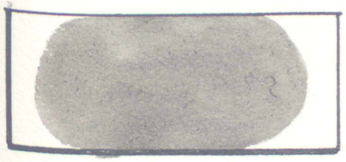
Amount of limestone applied per acre with dates of applications	Plot No.	Crop on Field	NO_3 in lbs. per 2 million	Lime requirement in lbs. per 2 million
No Limestone	1	Soybeans in shock	50.0	4460
4000 lbs, 1909	2	Soybeans in shock	50.0	3122
No Limestone	8	Corn in shock	87.0	5352
4000 lbs., 1910	9	Corn in shock	93.1	3568
No Limestone	15	Wheat Stubble	48.4	6244
4000 lbs., 1911	16	Wheat Stubble	56.6	4460
No Limestone	22	Cowpeas off ready for wheat	68.4	6244
4000 lbs., 1912	23	Cowpeas off ready for wheat	57.9	4460

PLATE IV

ST. JAMES EXPERIMENT FIELD.

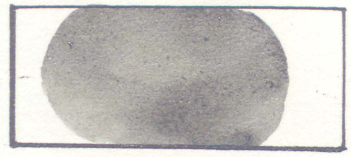
Soil samples taken Oct. 8, 1913.

Amount of limestone applied with
date of application.



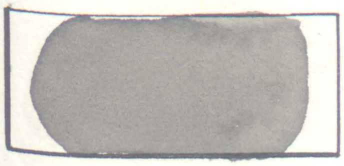
PLOT 1

NO LIMESTONE



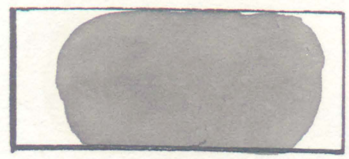
PLOT 2

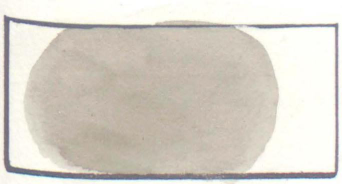
4000 lbs. 1909



PLOT 8

NO LIMESTONE



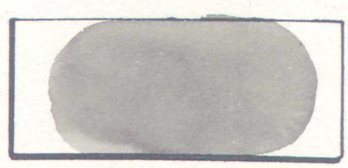


PLOT 9

4000 lbs. 1910

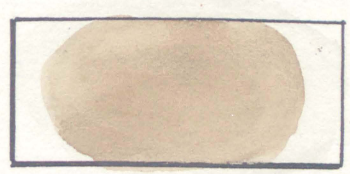
PLOT 15

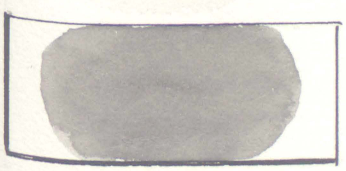
NO LIMESTONE



PLOT 16

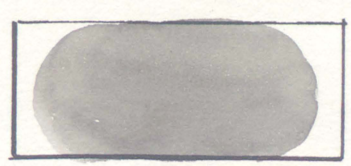
4000 lbs. 1911

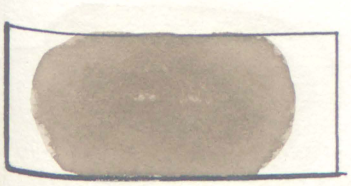




PLOT 22

NO LIMESTONE





PLOT 23

4000 lbs. 1912

TABLE XIII

CARTHAGE EXPERIMENT FIELD.

Soil samples taken Oct. 4, 1913.

Amount of limestone applied per acre, with dates of application	Plot No.	Crop on Field	NO_3 in lbs. per 2 million	Lime requirements in lbs. per 2 million
No Limestone	1	Corn in shock		3857
4000 lbs., 1909	2	"	85.7	924
No Limestone	7	"	223.0	4621
4000 lbs., 1909	8	"	226.5	2773
No Limestone	9	Ready to sow wheat	162.2	4621
4000 lbs., 1909	10	"	193.7	2773
No Limestone	15	"	218.0	4621
4000 lbs., 1909	16	"	215.5	2773
No Limestone	17	Wheat Stubble	214.2	4014
4000 lbs., 1911	18	"	125.2	2230
No Limestone	23	"	102.9	2310
4000 lbs., 1911	24	"	63.1	924
No Limestone	25	Clover	48.4	3857
4000 lbs., 1910	26	"	37.0	1848
No Limestone	31	"	87.1	2773
4000 lbs., 1910	32	"	54.5	924

PLATE V

CARTHAGE EXPERIMENT FIELD

Soil samples taken Oct. 4, 1913.

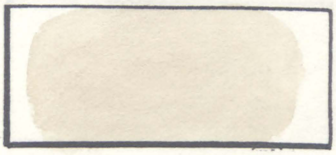
Amount of limestone applied
with date of application.

PLOT 1

NO LIMESTONE

PLOT 2

4000 lbs. 1909

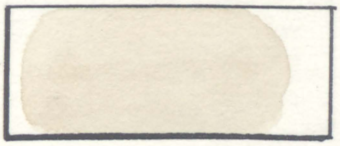


PLOT 7

NO LIMESTONE

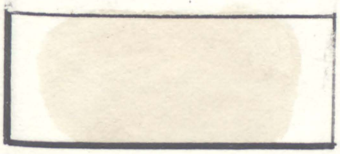
PLOT 8

4000 lbs. 1909



PLOT 9

NO LIMESTONE



PLOT 10

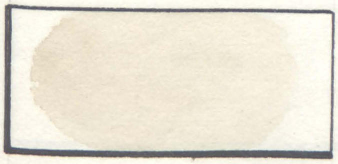
4000 lbs. 1909

Sample lost

PLOT 15

NO LIMESTONE

Sample lost



PLOT 16

4000 lbs. 1909

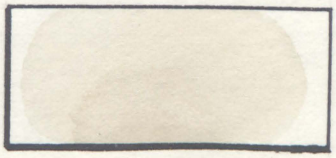


PLATE V

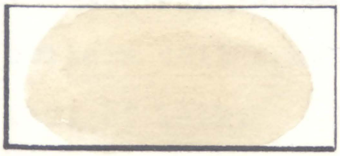
CARTHAGE EXPERIMENT FIELD (continued)

Soil samples taken Oct. 4, 1913.

Amount of limestone applied
with date of application.

PLOT 17

NO LIMESTONE

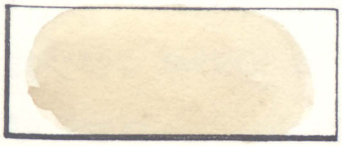


PLOT 18

4000 lbs.1911

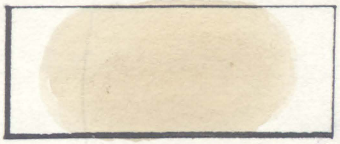
PLOT 23

NO LIMESTONE



PLOT 24

4000 lbs.1911



PLOT 25

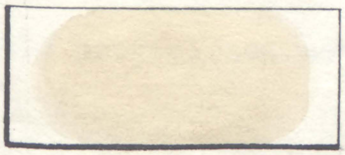
NO LIMESTONE

PLOT 26

4000 lbs. 1910

PLOT 31

NO LIMESTONE



PLOT 32

4000 lbs.1910

POT EXPERIMENT WITH DIFFERENT AMOUNTS OF LIMESTONE.

In order that a closer study might be made of the effect of different amounts of limestone both on plant growth and certain soil constituents, a pot experiment was begun in the fall of 1913. Soil was secured from the Bowling Green and Hurdland Experiment fields, the first being typical Putnam silt loam and the second Grundy silt loam. Putnam silt loam is a gray prairie type of level topography underlaid by a very plastic clay layer at fifteen to twenty inches beneath the surface. The Grundy is a similar type not quite so level in topography, darker in color and with a clay layer which is not quite so heavy. Both have a high degree of acidity. Only the surface soil to a depth of eight inches was used.

The soil was air dried and sifted through a sieve having a quarter inch mesh. It was then weighed into three gallon glazed pots, 12000 grams of air dry soil per pot. This was equivalent to 11558 grams of water free soil in case of the Putnam silt loam and 11443 grams of the Grundy silt loam. Each pot was then emptied on a rubber cloth and the proper amount of limestone thoroly mixed with the soil. The limestone used was a very pure non magnesian variety and was passed thru a 100 mesh sieve. The pots were watered from the bottom and no drainage was provided. Lime requirements were determined by both the Veitch method and the provisional method of the Association of Official Agricultural Chemists as described in Bureau of Chem. Bul. 107. The Bowling Green soil was found to have a requirement, by the Veitch method, of 3528 pounds and by the provisional method of 850 pounds, both being the number of pounds of calcium carbonate necessary to neutralize two million pounds of soil. The Hurdland soil gave requirements of 5512 and 1042 pounds respectively, by the two methods. Determinations at the close of the experiment seem to indicate that these amounts may be somewhat low, tho the determinations were repeated and were found to check closely.

Duplicate series of pots were provided for each soil making in all four series of eight pots each. The first two were left unlimed, one to be cropped and the other left fallow. Number three in each series received lime enough to reduce the requirement shown by the Veitch method to 2000 pounds. Number four had enough lime to make the requirement 1000 pounds and number five to make it neutral. Number six had just enough limestone to neutralize the acid shown by the provisional method and hence had the lightest application of any limed pot in the series. Pots, seven and eight, were given excesses of one and two tons per acre respectively as based on the Veitch determination. All of these applications were calculated on the supposition that the lime requirement would be reduced by an amount equal to the amount of limestone added, which in the progress of this experiment was found to be untrue. The general plan of this work is shown in the following tables.

TABLE XIV

AMOUNT OF LIMESTONE EXPERIMENT

BOWLING GREEN SOIL

Pot Number	Soil Treatment	Grams of limestone per pot	Equivalent application in lbs. per acre
BA1 & BB1	Fallow, no limestone	0.0	0000
BA2 & BB2	Clover, no limestone	0.0	0000
BA3 & BB3	Clover, lime requirement reduced to 2000 lbs.	9.7	1528
BA4 & BB4	Clover, lime requirement reduced to 1000 lbs.	15.45	2528
BA5 & BB5	Clover, limed to neutralize by Vietch method	21.2	3528
BA6 & BB6	Clover, limed to neutralize by provisional method	5.1	850
BA7 & BB7	Clover, limed with 1 ton in excess of Vietch requirement	32.7	5528
BA8 & BB8	Clover, limed with 2 tons in excess of Vietch requirement	44.2	7528

TABLE XV

AMOUNT OF LIMESTONE EXPERIMENT

HURDLAND SOIL

Pot Number	Soil Treatment	Grams of limestone per pot	Equivalent application in lbs. per acre
HA1 & HB1	Fallow, no limestone	0.0	0000
HA2 & HB2	Clover, no limestone	0.0	0000
HA3 & HB3	Clover, lime requirement reduced to 2000 lbs.	20.0	3512
HA4 & HB4	Clover, lime requirement reduced to 1000 lbs.	25.75	4512
HA5 & HB5	Clover, limed to neutralize by Veitch method	31.5	5512
HA6 & HB6	Clover, limed to neutralize by provisional method	6.0	1045
HA7 & HB7	Clover, limed with 1 ton in excess of Veitch requirement	43.0	7512
HA8 & HB8	Clover, limed with 2 tons in excess of Veitch requirement	54.5	9512

All pots were inoculated by means of liquid culture from the Bureau of Plant Industry of the U.S. Dept. of Agr., and all except the number one pots in each series were sown with red clover Jan. 20, 1914. Water was added to the amount of 3,000 cubic centimeters or 25 per cent of the air dry weight of soil. This amount was maintained by weekly additions until growth became so rapid that semi weekly watering was necessary. On March 1st, it was observed that Pots HA2, HB2, HA6, and HB6 were much the best of the Hurdland series. The plants were taller and more vigorous. Next in order were HA3 and HB3. Those in the Bowling Green series stood in the same relative order, showing a uniform and consistent depression in growth, from liming. The chief difference between the two series on different soils was in the fact that more seeds germinated and the plants started off more vigorously on the Hurdland than on the Bowling Green soil. This was probably due to the fact that the latter contained less organic matter and less nitrates as shown by analysis.

On May 11th the following observations were made. During the seedling and earlier stages of growth there was a distinct and consistent depression in growth from liming. There seemed to be a little less depression on those pots having enough lime to neutralize by the Vietch method with another downward tendency with increasing excess of lime. After about the first of April there was a tendency of the heavier limed pots to overtake the unlimed ones and on May 11th, when the clover was being attacked, by the red greenhouse spiders the heaviest limed pots seemed to withstand their attacks best tho the spiders seemed about equally thick on all pots.

On May 16th the clover was harvested from all pots, and the weights are shown in tables XVI and XVII. It should be noted that there was very little variation in amount of growth at that time. The reason for harvesting so soon was that the red spiders became very bad and resisted all efforts to eradicate them. The plan of cutting proved to be a good one as the clover was not bothered again thruout the season.

The clover was permitted to send up new tops and growth came on very rapidly. This time, however, the limed clover grew somewhat more rapidly than the unlimed on the Bowling Green soil, and there was little effect of liming on the Hurdland soil. No depression from liming was to be noticed. Not only did the limestone increase growth on the Bowling Green soil, but the clover growing on the limed pots was a much darker green. Pots BA2,BB2,BA6, and BB6 were decidedly yellowish, altho the remaining pots showed little difference among themselves. Plate VI was made from representative leaves taken from the unlimed and limed pots. This darker color of the plants on the limed pots together with the fact that they were later in maturing than those receiving no lime indicated that the available nitrogen was increased by liming. The limed clover was stockier and denser in growth, however. The

PLATE VI

Unlimed Limed

unlimed plants grew rather spindling. It is probable that the slight effect of lime on the Hurdland soil may have been due to the fact that this soil, being better supplied with organic matter had sufficient nitrates to more than balance its supply of other available plant foods.

On July 17th, two months after the first cutting was made, the clover had blossomed and most of the blossoms were drying up. A second cutting was made at this time, and notes were taken as to the number of mature and immature blossoms with a view to getting some data regarding the effect of limestone on maturity. These are shown in tables XVI and XVII and only indicate a slight delay in maturity due to liming. The general appearance of the plants indicated a greater difference. The effect of the limestone on the amount of growth during this second period was very marked on the Bowling Green soil as is shown in table XVI and in plates VII and VIII. It should be noted, also, that there was a gradual increase in effect as the amount of limestone was increased. With the second cutting, just as with the first, the Hurdland soil showed little effect of liming. Some increase was produced by the light applications of limestone but amounts over 20 grams per pot or 3500 pounds per acre seemed to be no more effective than the smaller amounts. The determinations of acidity both before and after the experiment show that these small amounts are far from being enough to make the soil neutral.

Immediately after the second cutting the pots were allowed to dry out rapidly; in fact they were dried down almost to the wilting point before harvesting, in order to prevent new leaves from starting. When dry the soil was slipped out of the jars and the mass of roots and soil thoroly loosened up. The soil was then sifted thru a $\frac{1}{4}$ inch mesh sieve and the roots carefully picked out. In this way the soil was saved for reseeding and all except the very small roots secured. After being thoroly washed and dried the roots were weighed, and the weights are shown in tables XVI and XVII. In general the amount of roots grown in the Bowling Green soil varied directly with the amount of tops from the second cutting and showed marked benefit from liming. With the Hurdland soil there was even less effect of the limestone on weight of roots than on the weight of tops.

The difference in the response of these two soils to applications of limestone is difficult to interpret with assurance. Some of the difference in effect on plant growth might easily be due to a difference in chemical composition of the two soils, and their analyses are given, below (p54), for comparison.

TABLE XVI

AMOUNT OF LIMING EXPERIMENT

BOWLING GREEN SOIL

Pot Number	Grams limestone added per pot	1st cutting tops dry wt. in grams	2nd cutting tops dry wt. in grams	Roots dry wt. in grams	Number mature heads	Total number of heads
BA1	0.0	FALLOW				
BB1	0.0	FALLOW				
BA2	0.0	14.05	14.95	5.35	4	5
BB2	0.0	13.60	12.15	6.55	4	4
BA6	5.1	13.20	12.00	7.02	2	6
BB6	5.1	14.40	21.30	9.45	8	12
BA3	9.7	13.85	22.60	9.00	13	21
BB3	9.7	13.80	20.95	9.10	9	14
BA4	15.45	13.80	22.60	7.60	16	22
BB4	15.45	13.50	23.85	9.35	15	19
BA5	21.2	13.75	19.60	8.01	10	14
BB5	21.2	12.02	20.30	8.15	8	8
BA7	32.7	13.85	22.20	10.40	11	16
BB7	32.7	14.20	24.00	10.22	9	15
BA8	44.2	13.10	25.00	9.37	13	24
BB8	44.2	14.20	25.25	9.65	9	14

TABLE XVII

AMOUNT OF LIMING EXPERIMENT

HURDLAND SOIL

Pot Number	Grams limestone added per pot	1st cutting tops dry wt. in grams	2nd cutting tops dry wt. in grams	Roots dry wt. in grams	Number mature heads	Total number of heads
HA1	0.0	FALLOW				
HB1	0.0	FALLOW				
HA2	0.0	15.70	22.80	9.40	11	15
HB2	0.0	14.65	21.60	9.70	10	13
HA6	6.0	14.20	23.40	8.22	13	18
HB6	6.0	15.35	23.55	8.65	14	23
HA3	20.0	15.40	25.85	9.30	16	22
HB3	20.0	15.90	24.35	8.90	15	21
HA4	25.75	14.25	24.30	8.75	13	18
HB4	25.75	13.65	25.10	9.12	11	22
HA5	31.5	13.80	23.00	7.20	16	20
HB5	31.5	13.50	24.40	8.35	14	22
HA7	43.0	14.70	26.40	9.02	14	21
HB7	43.0	15.75	24.95	9.98	5	16
HA8	54.5	15.00	26.40	9.80	9	19
HB8	54.5	15.75	24.50	8.90	11	16

PLATE VII.


NO LIME
FALLOW
BA1
NO LIME
BA2
LIME REQUIREMENT
REDUCED TO 2000 LBS
VIETCH METHOD
BA3
LIME REQUIREMENT
REDUCED TO 1000 LBS
VIETCH METHOD
BA4
NEUTRAL BY
VIETCH METHOD
3528 LBS C.CO.
BA5
NEUTRAL BY
HOPKINS METHOD
850 LBS C.CO.
BA6
2000 LBS C.CO.
IN EXCESS
VIETCH METHOD
BA7
4000 LBS C.CO.
IN EXCESS
VIETCH METHOD
BA8

PLATE VIII


NO LIME
FALLOW
BB1
NO LIME
BB2
LIME REQUIREMENT
REDUCED TO 2000 LBS
VIETCH METHOD
BB3
LIME REQUIREMENT
REDUCED TO 1000 LBS
VIETCH METHOD
BB4
NEUTRAL BY
VIETCH METHOD
3528 LBS C.CO.
BB5
NEUTRAL BY
HOPKINS METHOD
650 LBS C.CO.
BB6
2000 LBS C.CO.
IN EXCESS
VIETCH METHOD
BB7
4000 LBS C.CO.
IN EXCESS
VIETCH METHOD
BB8

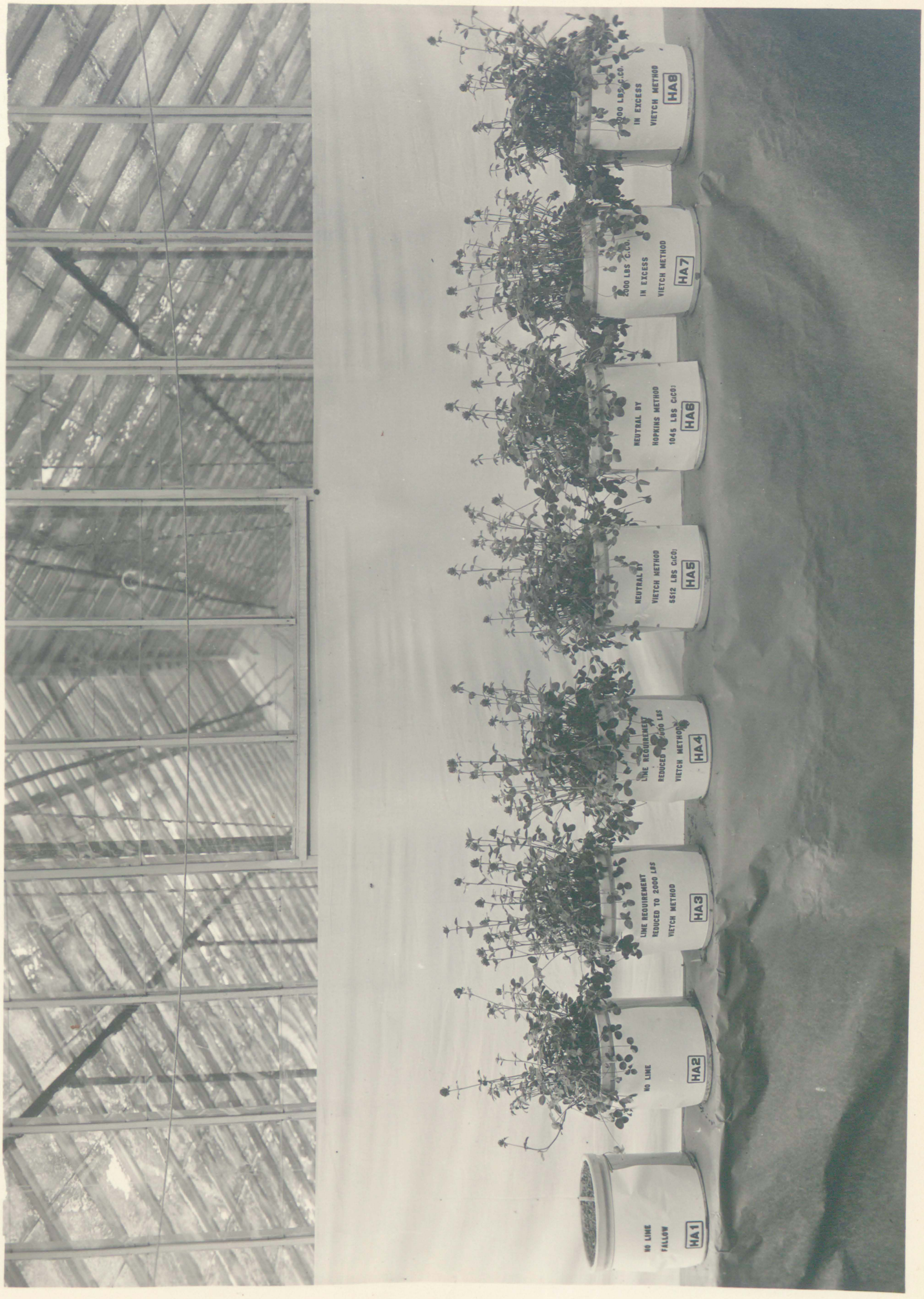
ANALYSIS OF SURFACE SOILS FROM BOWLING GREEN AND HURDLAND EXPERIMENT FIELDS.

Expressed in terms of pounds of the element in 2 million pounds of soil.

	Bowling Green lbs..	Hurdland lbs.
Nitrogen, total	3500	3760
Phosphorus, sol. in strong acid	2030	1978
Potassium, " " " "	4835	6009
Calcium, " " " "	4964	6702
Organic matter, wet combustion method	5.77%	6.54%

The greater effect of limestone on the Bowling Green soil as compared with that from Hurdland might partly be due to increase in nitrates or in easily soluble potassium, or to a direct addition of calcium, if these analyses be taken as evidence. The increase in calcium is unlikely to cause an apprecable effect, however. A greater neutralizing effect of limestone when applied to the Bowling Green soil is shown in the acidity determinations on the field samples as well as those on the soils of the pot experiment. This seems to indicate a difference in the nature or at least in the effect of the acids of the two soils. This variation may be associated in some way with the difference in the content or character of the organic matter. Probably too little attention has been given to this factor in studies of soil acidity.

PLATE IX


NO LIME
FALLOW
HA1
NO LIME
HA2
LIME REQUIREMENT
REDUCED TO 2000 LBS
VIETCH METHOD
HA3
LIME REQUIREMENT
VIETCH METHOD
HA4
NEUTRAL BY
VIETCH METHOD
5512 LBS CaCO3
HA5
NEUTRAL BY
HOPKINS METHOD
1045 LBS CaCO3
HA6
2000 LBS CaCO3
IN EXCESS
VIETCH METHOD
HA7
IN EXCESS
VIETCH METHOD
HA8

EFFECT OF LIMESTONE ON INOCULATION OF CLOVER.

A careful examination of the clover roots for the effects of lime on inoculation revealed the following conditions. The clover on the unlimed pots and those having the smallest application in each series had relatively few nodules but they were large and were borne in (palmately branched) clusters. Pots three, four, and five in each series had well distributed and very numerous nodules, very few of them in clusters. The one exception was pot BB5 with an enormous cluster of nodules which, when flattened out, was about the size of a silver dollar. Pots with an excess of lime, particularly those having an excess of two tons above the Vietch lime requirement, seemed to have the nodule formation depressed. They had very few nodules but unlike the unlimed pots these were well distributed with little tendency to form in clusters. They were very small, also.

All pots had been well inoculated with the liquid culture used. It is impossible to determine from the data at hand whether the difference in nodule formation was due to greater nitrate production in the heavier limed pots or to the direct effect of a difference in degree of acidity on the growth of the nodule forming organisms. The nitrate content of the soil in the heavier limed pots was no greater than in the unlimed pots at the close of the experiment. In fact the nitrates decreased as the lime increased on the Bowling Green soil but the later maturity and deeper green color,as well as the larger growth of the limed clover,indicated that the extra amount of nitrate produced was being taken up.

The following tables give the results of determinations of nitrate content and acidity at the close of the pot test.

TABLE XVIII

EFFECT OF AMOUNT OF LIMESTONE ON NITRATE CONTENT AND ON LIME REQUIREMENT

BOWLING GREEN SOIL

Pot Number	Soil Treatment	Grams limestone per pot	Parts NO_3 in 2 million of soil	$CaCO_3$ requirement at close of experiment
BA1	Fallow, no limestone	0.0	261.5	6469
BB1	" " "	0.0	494.8	6931
BA2	Clover, no limestone	0.0	17.0	5083
BB2	" " "	0.0	21.2	6007
BA6	Clover, limed to neutralize by provisional method	5.1	8.1	5545
BB6	" " " "	5.1	15.5	5083
BA3	Clover limed to reduce Veitch requirement to 2000 lbs.	9.7	10.9	4159
BB3	" " " "	9.7	14.0	5083
BA4	Clover, limed to reduce Veitch requirement to 1000 lbs.	15.45	11.6	3235
BB4	" " " "	15.45	14.5	4621
BA5	Clover, limed to neutralise by Veitch method	21.2	6.4	3235
BB5	" " " "	21.2	15.0	4621
BA7	Clover, limed with 1 ton excess	32.7	6.3	4621
BB7	" " " " " "	32.7	9.6	4159
BA8	Clover, limed with 2 tons excess	44.2	6.4	2310
BB8	" " " " " "	44.2	8.6	2773

TABLE XIX

EFFECT OF AMOUNT OF LIMESTONE ON

NITRATE CONTENT AND LIME REQUIREMENT

HURDLAND SOIL

Pot Number	Soil Treatment	Grams limestone per pot	Parts NO_3 in 2 million of soil	$CaCO_3$ requirement at close of experiment
HA1	Fallow, no limestone	0.0	552.6	7856
HB1	" " "	0.0	685.6	8318
HA2	Clover, no limestone	0.0	11.9	7856
HB2	" " "	0.0	21.3	7856
HA6	Clover, limed to neutralize by provisional method	6.0	16.4	5083
HB6	" " " "	6.0	11.2	5545
HA3	Clover, limed to reduce Vietch requirement to 2000 lbs.	20.0	7.6	6007
HB3	" " " " "	20.0	12.6	5545
HA4	Clover, limed to reduce Vietch requirement to 1000 lbs.	25.75	10.1	4621
HB4	" " " "	25.75	11.4	4159
HA5	Clover, limed to neutralize by Vietch method	31.5	11.6	4621
HB5	" " "	31.5	12.9	4159
HA7	Clover, limed with 1 ton excess	43.0	10.6	4621
HB7	" " " " " "	43.0	10.6	4621
HA8	Clover, limed with 2 tons excess	54.5	7.1	4621
HB8	" " " " " "	54.5	10.9	4621

The nitrate content of the Bowling Green soil as shown in these tables, is closely correlated with the amount of growth and to a somewhat less extent with the maturity of the clover. It varies inversely with the amount of growth and directly with degree of maturity. This would seem to indicate that the nitrate content in the cropped soil is no measure of the nitrifying efficiency of the soil unless accompanied by determinations of the nitrogen in the crop. A larger growth takes up any increase in nitrates and, as the plants begin to mature, nitrates are no longer used in such quantities and some accumulation begins. As the heavily limed pots were delayed in maturity, this accumulation had not begun when the crop was harvested. There was little consistent variation in nitrates in the Hurdland soil just as there was little consistent variation in amount and character of growth.

In this connection it is interesting to note the nitrate content of these soils at the beginning of the experiment. The Hurdland soil used contained 139.6 parts NO_3 in two million of soil while that from Bowling Green contained but 40 parts in two million. The more rapid early growth of clover on the Hurdland soil was probably due largely to its greater nitrate content since the two soils were found to contain practically equal amounts of easily soluble phosphorus and potassium. The Bowling Green soil gave an analysis of 36 parts fifth normal acid soluble phosphorus and 22 parts water soluble potassium in two million of soil.

The analysis of the Hurdland soil gave corresponding amounts of 37 parts phosphorus and 21 parts potassium.

The lime requirements shown in these tables are all surprisingly high, and they do not show a reduction from liming as great as the amount of lime applied. The general tendency toward higher requirements than at the beginning of the experiment is probably due to some slight difference in handling the determination, tho an effort was made to handle it in exactly the same way.

The following plates, XI and XII, show the results of Truog acidity tests on the soils of this experiment. They should be compared with the Veitch lime requirements shown in tables XVIII and XIX. The steady reduction in degree of acidity is striking altho it is naturally to be expected. The Truog method indicates a somewhat greater reducing power of the limestone applied than does the Veitch method.

PLATE XI

LIME REQUIREMENTS - TRUOG METHOD

11558 grams W.F. soil per pot with amount of ground limestone indicated, added 6 months before sampling.

Bowling Green Soil.

BA1

NO LIMESTONE
FALLOW

BB1

BA2

NO LIMESTONE
CLOVER

BB2

BA6

5.1 g LIMESTONE
CLOVER

BB6

BA3

9.7 g LIMESTONE
CLOVER

BB3

BA4

15.45 g LIMESTONE
CLOVER

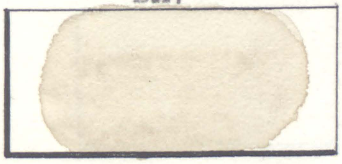
BB4

BA5

21.2 g LIMESTONE
CLOVER

BB5

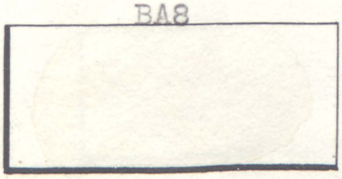
BA7



32.7 g LIMESTONE
CLOVER

BB7

BA8



44.2 g LIMESTONE
CLOVER

BB8

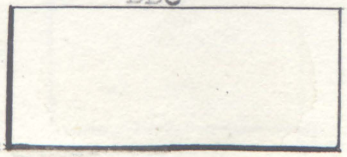


PLATE XII

LIME REQUIREMENTS - TRUOG METHOD

11443 grams W.F. soil per pot with amount of ground limestone indicated, added 6 months before sampling.

Hurdland Soil.

HA1

NO LIMESTONE

FALLOW

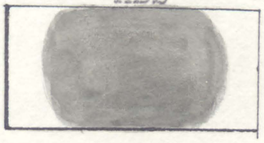
HB1

HA2

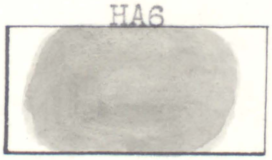
NO LIMESTONE

CLOVER

HB2



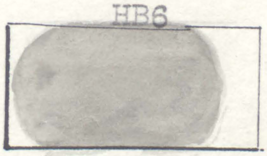
HA6



6.0g LIMESTONE

CLOVER

HB6

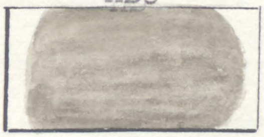


HA3

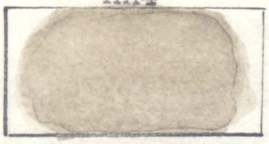
20.0g. LIMESTONE

CLOVER

HB3



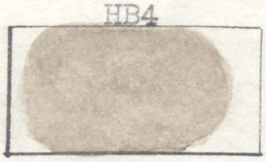
HA4



25.7g LIMESTONE

CLOVER

HB4

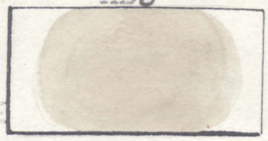


HA5

31.5g LIMESTONE

CLOVER

HB5

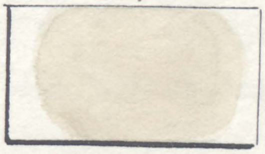


HA7

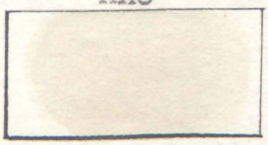
43.0g LIMESTONE

CLOVER

HB7



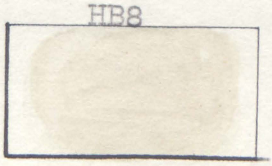
HA8



54.5g LIMESTONE

CLOVER

HB8



TIME OF LIMING EXPERIMENT.

At the time of starting the pot experiment with different amounts of lime, another experiment was begun with a view to finding the effects of liming at long or short intervals before sowing clover. Sixteen pots were used, all being filled with the same amount of soil and in the same way as described for the Hurdland soil series in the amount of liming experiment. The selection of the Hurdland soil proved to be unfortunate as it was found to be less responsive to liming than was the Bowling Green soil, but this was not known at the beginning of these experiments. All pots were watered with an amount equal to twenty-five per cent of the air dry weight of soil, and kept at approximately this content by setting them on a balance and adding water to the desired weight. They were thus kept in optimum conditions for plant growth for one year beginning Jan. 20th, 1914. They were not seeded however, until Jan. 20th, 1915 when all pots were turned out on rubber cloths and sampled after thoro mixing. Any difference in compactness of the soil in the various pots was thus equalized.

Each pot received an addition of 43 grams of ground limestone, passed thru a 100 mesh sieve, applications being made by turning the soil out on a rubber cloth and thoroly mixing. These additions were made at intervals as shown in the following table. This amount of limestone is equivalent to a field application of 7500 pounds per acre or a ton in excess of the Veitch requirement determined at the beginning of the experiment.

TABLE XX

TIME OF LIMING EXPERIMENT

Soil Treatment	Date of Liming	Pot Numbers
Fallow, no limestone		TA1 & TB1
Clover, no limestone		TA2 & TB2
Limed just before seeding	Jan. 20, 1915	TA3 & TB3
Limed 1 month before seeding	Dec. 20, 1914	TA4 & TB4
Limed 2 months before seeding	Nov. 20, 1914	TA5 & TB5
Limed 4 months before seeding	Sept. 20, 1914	TA6 & TB6
Limed, 8 months before seeding	May 20, 1914	TA7 & TB7
Limed 12 months before seeding	Jan. 20, 1914	TA8 & TB8

The pots were not seeded to clover until the end of the first year and no weights have been secured, but soil studies have been made of the lime requirements, the nitrate content, and the easily soluble phosphorus and potassium. The methods for determining nitrates and lime requirement have been discussed. Phosphorus was determined by dissolving out with fifth normal hydrochloric acid as described in Bureau of Chem. Bul. 107. Water soluble potassium was determined by the colorimetric method No. 1 of Schreiner and Failyer as given in Bureau of Soils Bul. 31.

TABLE XXI

EFFECT OF TIME OF LIMING ON THE AMOUNT OF PHOSPHORUS SOLUBLE IN $N/_5$-HCL.

Pot Number	Time of Liming	Per cent of phosphorus water free basis	Lbs. phosphorus in 2000000 lbs. of soil
TA1	Not limed	.00284	56.8
TB1		.00245	49.0
TA2	Not limed	.00277	55.4
TB2		.00271	54.2
TA3	Immediately before sampling	.00357	71.4
TB3		.00280	56.0
TA4	1 month before sampling	.00312	62.4
TB4		.00333	66.6
TA5	2 months before sampling	.00323	64.6
TB5		.00294	58.8
TA6	4 months before sampling	.00276	55.2
TB6		.00309	61.8
TA7	8 months before sampling	.00302	60.4
TB7		.00302	60.4
TA8	12 months before sampling	.00306	61.2
TB8		.00312	62.4

THE EFFECT OF LIMESTONE ON THE EASILY SOLUBLE PHOSPHORUS IN SOILS.

These tables indicate that liming has slightly increased the amount of easily soluble phosphorus, but there is no indication that the process is gradual. The pots limed immediately before sampling seem to be affected about as much as those limed earlier. It was expected that this study might reveal a reason for the depressing effect of lime which was observed in the first seeding of the amount of liming experiment. As previously noted this effect was not noticeable after the pots had been limed for three months. In this time of liming experiment, however, there was no depression of growth due to liming even when the lime was applied immediately before seeding. As the same soil was used which gave a distinct depression in the other experiment this is difficult to explain. Evidently the cause for the depression did not operate in this experiment. The large amount of phosphorus dissolved by fifth normal acid seems to indicate that it was probably not a limiting factor. Doubtless keeping the soil under favorable bacterial conditions for a year had much to do with making large amounts of plant food available. It should be noted that this soil contained, at the beginning of the experiment, only 37 parts of soluble phosphorus in two million of soil. The very rapid growth of clover on these pots when they were seeded, Jan. 20, 1915 is another indication that there was much available plant food present. This would seem to indicate that the depression in growth, due to liming immediately before seeding, is caused by the lime reacting with compounds containing available plant foods, particularly phosphorus, and thus making them less soluble. With so much soluble phosphates present in this soil after a year of fallow the portion reacting with the lime added seems not to have affected plant growth.

TABLE XXII

EFFECT OF TIME OF LIMING ON THE AMOUNT OF POTASSIUM SOLUBLE IN DISTILLED WATER

Pot Number	Time of Liming	Per cent of potassium water free basis	lbs. potassium in 2000000 lbs. of soil
TA1	Not limed	.00293	58.6
TB1		.00291	58.2
TA2	Not limed	.00292	58.4
TB2		.00313	62.6
TA3	Immediately. fbefore sampling	.00417	83.4
TB3		.00313	62.6
TA4	1 month before sampling	.00351	70.2
TB4		.00336	67.2
TA5	2 months before sampling	.00303	60.6
TB5		.00302	60.4
TA6	4 months before sampling	.00295	59.0
TB6		.00307	61.4
TA7	8 months before sampling	.00303	60.6
TB7		.00320	64.0
TA8	12 months before sampling	.00308	61.6
TB8		.00291	58.2

THE EFFECT OF LIMESTONE ON THE WATER SOLUBLE POTASSIUM IN A SOIL.

From table XXII it may be noted that the average per cent of water soluble potassium of the four unlimed pots is .00297 while the twelve limed ones average .00320 per cent. In this as in the work of other investigators previously noted there is but slight evidence of an increase in water soluble potassium from the application of limestone. This was true when the limestone was added immediately before the determination was made as well as when it was added at longer periods up to one year before making the determination. The large amount of water soluble potassium found in these samples is probably due to the same factors which caused a high per cent of easily soluble phosphorus. An analysis of this soil before putting it in the pots gave 21 parts of water soluble potassium in two million of soil which is equal to .0011 per cent.

Following this pot experiment, water soluble potassium was determined on soil from four limed and four unlimed plots on the St. James experiment field. As an average of these no effect of lime on soluble potassium could be detected.

THE EFFECT OF TIME OF LIMING ON THE AMOUNT OF NITRATES IN A SOIL.

The colorimetric method of Schreiner and Failyer is not very well adapted to the determination of such large quantities of nitrates as found in this experiment, and considerable variation is noticeable in the records. Each record in the table is an average of four determinations, however, and the general tendency toward a larger nitrate content ,where the lime has been on longer,can hardly be questioned. The fact that the soil was kept fallow and at summer temperature thru an entire year accounts for the very large accumulation of nitrates. The absence of any drainage would prevent their being leached away. Naturally liming immediately before sampling had no effect on the nitrate content, and there is little evidence of an increase in one month. There is little difference shown between the two, four, and eight months periods, tho during the period from eight months to one year a marked increase resulted. The nitrate content of pots limed for one year was practically double that of the unlimed pots. It was expected that this would make a difference in the way the clover started when the pots were seeded Jan. 20, 1915, but apparently all pots had nitrates enough since all the clover started very rapidly and with little difference. It is possible that the nitrates may become exhausted earlier in the unlimed pots, however.

TABLE XXIII

EFFECT OF TIME OF LIMING ON THE AMOUNT OF NITRATES

Pot Number		Lbs. NO_3 in 2000000 lbs. of soil	Average of duplicate pots. Lbs. NO_3 in 2000000 lbs. of soil lbs. NO_3
TA1	Not limed	485	576
TB1		667	
TA2	Not limed	769	749
TB2		728	
TA3	Immediately before sampling	601	599
TB3		596	
TA4	1 month before sampling	684	707
TB4		730	
TA5	2 months before sampling	1009	1001
TB5		993	
TA6	4 months before sampling	976	988
TB6		1000	
TA7	8 months before sampling	1008	982
TB7		957	
TA8	12 months before sampling	1226	1225
TB8		1224	

The following plate shows the record of lime requirements at the end of one year in this time of liming experiment. According to this Truog test the reaction of the limestone with the soil was very gradual after the first main effect, and it took eight months if not the entire year to bring it to completion. The greater part of the neutralization seemed to take place almost immediately, however. The thoro mixing both at the time the limestone was added and at the time of sampling may have had much to do with this. Naturally the limestone was taken in with the soil sample and the reaction was hastened in the processes of making the acidity determinations.

The Veitch method does not indicate any difference in the effect of the limestone when put on at long or short intervals before testing. In fact if the results in table XIV be taken as evidence there is a slight indication that the immediate liming is most effective.

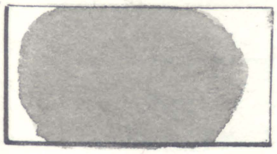
PLATE XIII

LIME REQUIREMENTS - TRUOG METHOD

POT EXPERIMENT

11000 grams of soil per pot limed with 43 grams of ground limestone at different intervals, as indicated. All pots at optimum growing conditions for 1 year before samples were taken.

TA1



NO LIME

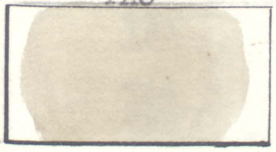
TB1

TA2

NO LIME

TB2

TA3

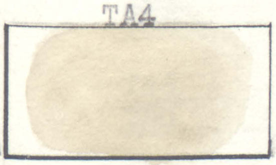


LIMED IMMEDIATELY

BEFORE SAMPLING

TB3

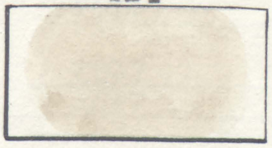
TA4



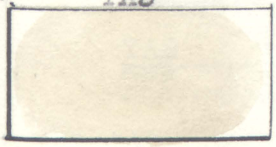
LIMED 1 MONTH

BEFORE SAMPLING

TB4



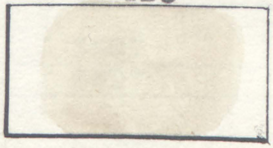
TA5



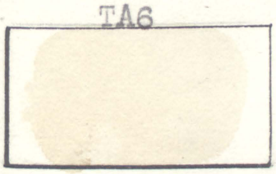
LIMED 2 MONTHS

BEFORE SAMPLING

TB5



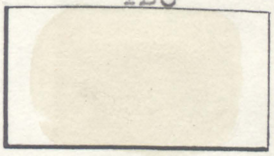
TA6



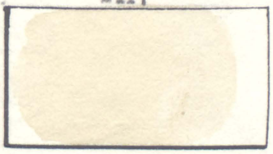
LIMED 4 MONTHS

BEFORE SAMPLING

TB6



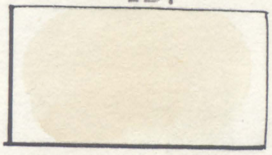
TA7



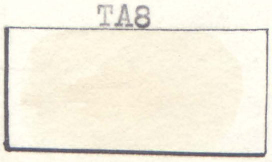
LIMED 8 MONTHS

BEFORE SAMPLING

TB7



TA8



LIMED 1 YEAR

BEFORE SAMPLING

TB8

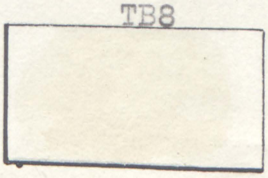


TABLE XXIV

EFFECT OF TIME OF LIMING ON LIME REQUIREMENT

AS SHOWN BY THE VEITCH METHOD.

Pot Number	Time of Liming	Lbs. of $CaCO_3$ necessary to neutralize 2000000 lbs. of soil
TA1	Not limed	8318
TB1		7856
TA2		7856
TB2	Not limed	7856
TA3	Immediately before sampling	2773
TB3		2773
TA4	1 month before sampling	3235
TB4		3235
TA5	2 months before sampling	2773
TB5		2773
TA6	4 months before sampling	3697
TB6		3697
TA7	8 months before sampling	3235
TB7		3697
TA8	12 months before sampling	3697
TB8		3697

SUMMARY .

1. The use of ground limestone has increased the yield of all the more common crops of the state except corn stover and wheat straw, when tried on experiment fields situated in nineteen different localities in Missouri. The increases in cowpea hay and wheat were very slight, however.

2. Under field conditions limestone has little effect on the per cent of grain in cereal crops. Slight differences indicated a tendency toward an increase in per cent of grain.

3. Studies of 44 field samples of soil, half of them limed and half unlimed, indicated that the amount and character of growth on the soil had much more influence on the nitrate content than did the application of limestone. In fact the limestone applications were found to make no increase in the amount of nitrate present in the soil under these conditions.

4. Determinations of the lime requirements of these same field samples showed an average reduction in the lime requirement equal to 41.3 per cent of the amount of lime applied.

5. Truog acidity tests on these samples indicate that the neutralizing effect of limestone is comparatively quick when added to soils in the field, also that it has greater neutraliz-

ing effect on some soils than on others.

6. In pot experiments it was found that the growth of clover was depressed by additions of limestone, the depression increasing with the amount of limestone but that this effect disappeared after the clover had been growing about three months, and at the end of six months one soil showed a marked increase in growth of clover due to liming. The amount of increase in both tops and roots depended upon the amount of lime up to an excess of two tons above the Veitch requirement.

7. There is a marked difference in the response of different soils to limestone, even when they are about equally acid.

8. Applications of limestone caused the nodules on clover roots to be better distributed with less tendency to grow in clusters. They were also reduced in size particularly when an excess of limestone was added.

9. The amount of limestone was found to have no effect in increasing the soil nitrates under clover in pot experiments. On the other hand, because of the larger growth and later maturity of the clover, the heavier limed soils had less nitrates than the unlimed soils.

10. With pots limed at different intervals before seeding and when these were kept for a year under optimum conditions of

temperature and moisture for plant growth , it was found that soils limed for two, four, or eight months had more nitrates than those unlimed or limed for any shorter period of time before seeding. Soils limed for one year had about 20 per cent more nitrates than those limed for eight months and nearly twice as much as the unlimed soils.

11. The time of liming had no effect on the amount of phosphorus soluble in fifth normal hydrochloric acid. Liming at any interval, however, seemed to increase this easily soluble phosphorus to some extent.

12. Liming had little if any effect on the water soluble potassium in the soil either when the application was made immediately before sampling or when made at intervals up to one year before sampling.

13. Very high per cents of nitrates, of phosphorus soluble in fifth normal acid, and of water soluble potassium were found in soils that had been kept under favorable conditions for plant growth for one year. The very rapid growth of clover when these pots were seeded was a further indication of the abundance of available plant food in these soils.

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COLUMBIA

DEPARTMENT OF AGRICULTURAL CHEMISTRY

May 22, 1915.

Dean Walter Miller,

Chairman Graduate Committee.

My dear Dean Miller:

I have looked over the thesis of Mr. R. R. Hudelson and I wish to compliment him upon the excellency of his dissertation both in respect to the subject matter and the way in which he handled his subject. This thesis certainly meets the general standard which has been established in the University for the Master's dissertation.

Yours sincerely,

C Robert Moulton

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