

**THE INFLUENCE OF GROUND LIMESTONE ON
ACID SOILS AND ON THE AVAILABILITY OF
NITROGEN FROM SEVERAL MINERAL
NITROGENOUS FERTILIZERS**

BY

A. NÕMMIK

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Historical ¹⁾.

There are some substances commonly used in agricultural practice which produce beneficial effects upon plant growth even though they do not serve as fertilizers. Such substances act indirectly on the soil, either by rendering it more suitable for cultivation and plant growth or by making available the other plant nutrients stored in the soil.

A substance of this kind is lime, and some authors (Hall, 31) note that "any soil containing less than 1 per cent of calcium will be benefited by liming, and when the percentage falls to 0.2 per cent, lime becomes a necessity to enable the manures to exert their proper action". Though lime contains calcium, one of the elements necessary for plant growth, it is in general not used for this purpose. It is impossible to ascertain the historical period when the value of lime first became known. We find mention of its use by the ancient Romans. Writers of that age (for instance Pliny) refer to the beneficial effects of lime on plant growth. Not all of the reactions involved were understood by the ancients, but the favorable effect of lime upon plant growth was known, and the recognition of this fact in European countries has given rise to the German proverbial expression, "Kalk macht die Väter reich, aber die Söhne arm". We now know that the words quoted do not necessarily express the facts; much depends on how the lime is used, and on the system of cropping employed.

During the last 50 or 60 years numerous articles and papers on the liming of soils have been published in Europe as well as in America. Among the writers in Germany are to be noted Heiden (37), Orth (74), Hoffmann (40), Heinrich (38). In Russia the application of lime was not very usual in the period just referred to, although among the Russian agricultural writers one may find such men as Stebut (85), Engelhardt (23) and

1) Research carried out at the N. Jersey Agricult. Exp. Sta. (U. S. A.), 1926.

others who heartily recommend the use of lime. In recent years series of experiments with lime have been conducted by some Russian agricultural experimental stations (Perm, Moscow), and Samoiloff (80) and other Russian authors give very striking examples of the results of lime deficiency in some Russian soils. Since the beginning of the present century agricultural literature has been very rich in articles about the liming of soils and it is not necessary to list them all.

It is generally recognized that soil acidity has an unfavorable influence upon the fertility of soils. This deleterious result is due to the effects of soil acidity on the chemical, physical, and biological conditions and processes of soils. Whereas formerly the presence of the small sorrel (*Rumex acetosella*), corn marigold (*Chrysanthemum segetum*), spurrey (*Spergula arvensis*), bracken (*Pteris aquilina*) served to indicate the lack of lime in the soil, agricultural chemists are now striving to find an exact chemical method for determining the lime requirement of soils. Some commonly known methods of this character, to which reference is frequently made, have been devised by the following authors: Tacke (88), Hutchinson and McLennan (42), Veitch (94), Truog (92, 93), Daikuhara (20). Although a number of them are in use by various soil workers, these methods are still considered as far from perfect. The difficulties experienced with them may be explained by the fact that we are still ignorant of many of the exact effects of lime in different types and kinds of soils. It is of interest here to note that recent observations by White (101) at the Pennsylvania Agricultural Experiment Station show that sorrel, which is commonly supposed to be a plant avoiding lime, is in reality benefited by lime and usually occurs on acid soils, because there it meets with the least competition from other weeds.

It is generally recognized that lime influences a) the physical, b) the chemical, and c) the biological aspects of the soil. In heavy soils, especially those which have been subjected to strong leaching, there is a tendency of the fine (negative) particles to become too closely aggregated. Such a condition interferes with the air and water movements in the soil and acts unfavorably on plant growth. Lime applications slightly improve matters by keeping the particles flocculated (22), a condition necessary for the desirable granular or crumbly structure.

Chemically lime brings about many complex changes in the soil. Base exchange is forced and probably certain mineral nutrients, for instance phosphorus (21^a, 27, 29, 105) and potassium (2, 77, 89) tend to become more available. Thaer (89) came to the conclusion that "eine Kalimehraufnahme ist eine fast regelmässig beobachtete Folge einer Kalkung. Das bessere Wachstum der Leguminosen nach einer Mergelung ist nicht nur auf die Reaktionsänderung des Bodens und Bakterienwachstums zurückzuführen, sondern bei diesen sehr blattreichen Gewächsen spielt das Kali die wichtigste Rolle". McCool (69) also supposes that "lime performs an additional function when applied to the soil such as liberation or making available certain substances that are utilized by the crops"; McCool found that lime had little, if any, effect on the leaching of potash from the soil, but Lipman and al. (63) with his 15-years' experiment came to the conclusion that the potassium content in limed soil was lower than in unlimed soil. Feilitzen (24) found that the plant food content in drainage water from the limed area of arable and grassland was not higher in comparison with unlimed areas. In a lysimeter experiment Lyon and Bizzel (66) ascertained that the application of lime did not result in an increase in the quantity of potassium contained in drainage water nor in any increase in the amount of potassium removed by the crops, but that the application of lime was accompanied by an increase in the quantity of sulphur in the drainage water. Whittle (102) suggested that lime increases the nitrogen content in the soil when it is applied to legumes, but Mooers and McIntire (71) observed that all forms of lime gave rise to a loss of soil total nitrogen, while increasing the crop yields. There are also indications that lime favors the oxidation of ferrous compounds of iron into ferric compounds (78).

Soil acidity usually favors the accumulation and solubility of toxic organic and inorganic substances. Among these toxic substances soluble aluminium salts have been noted by a number of investigators. Sufficient amounts of these toxic substances may be present to be very harmful to some plants. With the application of lime the acidity of soils as well as the solubility of soluble aluminium is lowered, because aluminium may be forced back into less active compounds (18).

That lime decreases the concentration of hydrogen ions in soils is generally admitted and hence there is no necessity for

discussing this subject at any length. It is sufficient to cite a few examples from the Rhode Island (13) and New Jersey (4) Agricultural Experiment Stations. Their results are of greater value because of the long duration of the experiments.

At the Rhode Island Agricultural Experiment Station one experimental field was under observation from 1909 to 1924. The limed plot received high calcium limestone periodically every 5 year period from 1909 to 1921. The total amount applied was 16,783 pounds of limestone per acre in four applications for the cropped plot. For the last four years the pH values were determined and the average results were as follows:

	1920 pH	1921 pH	1922 pH	1923 pH	1924 pH	Total average pH
No lime	5.2	4.9	4.5	4.5	4.5	4.73
High calcium hydrate	6.6	6.3	5.9	5.8	5.7	6.10

It is seen that the unlimed plot at Rhode Island showed a slight, but decidedly progressive, increase of acidity during the last four years of cropping. The pH value, which was 5.2 in 1920, dropped to 4.5 in 1924. It is only due to cropping in that short period of time.

At the New Jersey Agricultural Experiment Station the nitrogen availability plots were under observation from 1908 to 1920. The rotation was corn, oats, wheat and timothy (two years) without legumes. One series (A) received no lime, and the other (B) received ground limestone at the rate of one ton per acre in 1908, when the work was started, and later at intervals of five years it received two tons per acre (about 0.1 per cent CaO for a depth of 17 cm.). The last application was made in the spring of 1918. A few average pH values for the summer of 1920 for differently treated plots are shown in the following table:

Plot No.	Fertilizer treatment	Series A. Unlimed	Series B. Limed
7	Nothing	5.97	7.01
9	Minerals and 320 lbs. nitrate of soda per acre . .	6.07	7.02
11	Minerals and ammonium sulphate equal to 320 lbs. nitrate of soda per acre	4.70	6.56
13	Minerals and dried blood equal to 320 lbs. nitrate of soda per acre	5.79	6.96
19	Minerals only	5.75	7.13

It will be observed that there has been little change in the pH values throughout the growing period of 1920. A study of the tables reveals a large difference in pH values between limed and unlimed plots. On the limed plots the acidity is much less than on the unlimed ones. Some striking instances of the influence of fertilizers on the soil reaction may be gathered from this experiment: the unlimed and unfertilized plot No. 7 A has a pH value a little less than 6.0, whereas on the corresponding plot No. 11 A, which received minerals and sulphate of ammonia equal to 320 lbs. of nitrate of soda annually, the pH value went down and after 13 years of cropping reached 4.7. Similar results were obtained at the Rhode Island Agricultural Experiment Station as reported by Burgess (9). Here we have a striking example of the human influence on soil reaction. Mention should also be made of the influence of vegetation on the soil reaction. Some investigators, for instance Arrhenius (1) propose to ascertain the soil reaction by vegetative associations.

In recent years considerable attention has been given to the so-called "active" aluminium as a factor inhibiting plant growth in acid soils. It is held by some that the amount of active aluminium salts, rather than the degree of acidity, determines the toxicity of soil to plant growth. Numerous investigations have been made in this direction which indicate a fairly close correlation between the solubility of aluminium, the acidity of the soil, and frequently also plant growth. It was found that lime added to acid soil reduces the solubility of aluminium compounds and also the acidity of the soil. Hartwell (34) supposed that aluminium was the element which was responsible for the different toxic influences on the plants. Equivalent amounts of aluminium sulphate and sulphuric acid, when added to an optimum nutrient solution, produced nearly the same depression in the growth of barley. The nutrient solution, when it contained the acid, was found to have about four times the concentration of hydrogen ions as when it contained aluminium sulphate. Therefore, says the author, the toxic effect of the latter on the barley is attributable largely to the aluminium.

Burgess and Pember (12) have shown the influence of various amounts of lime in rendering the active aluminium of acid soil inactive and reducing the hydrogen ion concentration. A

short extract of the work done with barley by the authors cited will explain their conclusion.

Lime treatment, yields of barley, reaction and soluble aluminium in an acid soil.

Treatment	Average yield of barley per pot	Soil reaction and active aluminium after harvesting of lettuce, barley and onions	
	gm.	Reaction pH	Active Al ₂ O ₃ p. p. m.
None	57	4.47	820
1000 lbs. CaO per acre	69	4.94	645
2000 " " " "	65	5.30	560
3000 " " " "	58	5.60	530
4000 " " " "	59	6.00	450
5000 " " " "	75	6.15	404
6000 " " " "	83	6.30	380

The authors came to the conclusion that lime without acid phosphate greatly reduced the amounts of active aluminium in the soils, but did not produce the largest yield. Combinations of lime and acid phosphate were better than either alone, and the authors recommend it for the correction of acid soil conditions. Heavy lime applications in all cases also greatly reduced the percentages of aluminium absorbed by the plant.

Burgess (11) showed that there does not always exist a relationship between the hydrogen ion concentration of soils of different types and the amounts of "active" aluminium contained therein. For instance, the most acid soil from California, fine sandy loam, with a reaction of pH 4.0 only yielded 53 p. p. m. of aluminium soluble in 0.5 N acetic acid, while the least acid Portsmouth sandy loam from South Carolina with a reaction of pH 5.77 also gave 42 p. p. m. of soluble aluminium. Studying the results obtained, the author comes to the conclusion that the acidity of the different soils may not always be directly correlated with the amounts of active aluminium found and that the group averages follow the correlation of the individual soils of varying reaction within the same soil type. The author also notes that in a great majority of cases, the amounts of active aluminium found corresponded to the heaviness of the rainfall.

Without going into a complete bibliography on the solubility of aluminium compounds, acidity of soil and plant growth, let us note the work of Conner (19), Denison (21), Blair (5), Magistad (67) and McGeorge (70). We shall here concern ourselves only with vegetation tests with barley on acid soils conducted at the New Jersey Agricultural Experiment Station (5). The soils for these experiments were used with the following previous treatments:

- Series I. Soil from nitrogen availability plot 11 A¹)
 Series II. Soil from plot which had previously received a heavy application of sulphur.
 Series III. Soil from acid silt loam which had been without any lime or fertilizer treatment for many years.

The experiments were conducted in pots and some of the results obtained are given here:

Special treatment	Series I		Series II		Series III	
	Yields of barley gm.	Final reaction pH	Yields of barley gm.	Final reaction pH	Yields of barley gm.	Final reaction pH
Nothing	0.0	4.7	0.0	4.4	4.5	5.3
20 gm. ground limestone	9.0	7.5	8.9	7.2	7.4	7.6
10 gm. acid phosphate	5.2	4.5	3.15	4.25	12.8	5.0
1 gm. aluminium nitrate	—	—	—	—	1.6	5.3

The table shows that in the first two series, with an acidity equal to pH 4.7 and lower, the crop failed. Addition of ground limestone or acid phosphate resulted in yields well above those obtained with the untreated soils. With the limestone treatment the acidity was materially reduced, and with acid phosphate treatment the acidity increased slightly. With 1 gm. aluminium nitrate the yield was reduced to even less than the yield with untreated check pots, although the acidity of these pots was lower than the pots treated with acid phosphate.

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1) For treatment of the plot see page 6.

From the biological point of view the great value of lime in the acid soil consists in its power of maintaining the favorable reaction necessary to the development of those microorganisms which transform the organic matter of the soil into plant nutrients. It is well known that organic matter in acid soil, such as crop residues, is converted into plant food more rapidly when the soils are well supplied with lime than when they are without lime. This is explained by the fact that the organisms which cause the breaking down of the organic matter, thus forming available nitrogen compounds, find soils containing lime a more favorable medium for work than acid soils. In the absence of lime, decay of organic matter in the soil gives rise to various acid bodies, and acidity thus produced inhibits the action of many of the valuable groups of microorganisms. Most of the favorable organisms and even some that are unfavorable — such as the producers of potato scab — are assisted by judicious liming.

Numerous investigators have shown that the nitrogen fixing bacteria, either alone or in the nodules of legume plants, are usually benefited by the liming of acid soils. Waksman (100) has established the fact that lime decreases the number of fungi in the soil. Kopeloff (45) investigated the influence of calcium carbonate on the accumulation of ammonia from nitrogenous organic matter by *Penicillium* sp. in soils. He found an increase of ammonium accumulation as the acidity of soil was increased to 2300 lbs. lime requirement. With increase of alkalinity beyond the neutral point there was a decrease of ammonium accumulation. Coleman (17) showed the influence of lime upon the ammonification of dried blood and cottonseed meal in soil. Calcium oxide was added to the soil to neutralize the greater part of the acidity, but leaving an excess present equal to 2000 pounds of lime per acre. All the kinds of soil used were originally acid with a lime requirement (after Veitch) as indicated in the table below.

Organic matter added	Dried blood		Cottonseed meal	
	Wooster silt loam	Carrington loam	Wooster silt loam	Carrington loam
Lime requirement (after Veitch) . .	4300	3700	4300	3700
Ammonia accumulation { Unlimed	82.12	139.40	59.50	80.92
mgm. N. after 6 days' incubation { Limed	104.93	158.35	69.87	90.18

It will be seen from the above table that lime increased the activity of the ammonifying soil microorganisms. Gainey (26) showed that "the presence of *Azotobacter* in soils has frequently been associated with both the presence of calcium carbonate and with the reaction. From available evidence there seems to be no doubt that soils well supplied with calcium carbonate and necessarily alkaline give in cultural solution a more vigorous development of *Azotobacter* than do soils deficient in lime". Christensen (14, 16) also demonstrated the relationship between lime content, acidity and *Azotobacter* development in the soils. It is generally admitted that cultivated soils are able to induce the conversion of organic matter containing nitrogen into nitrates; this fact has been known for a long time and utilized for many years on a commercial scale for the production of nitre. The presence of calcium carbonate, aeration, and moisture are necessary for nitrification.

Mention has been made that lime has a beneficial effect on nitrification. But this process occurs also in rather acid soils as determined by White (101) for Pennsylvania soils. For instance, nitrification took place when the soil showed a lime requirement of 8,373 pounds calcium carbonate per acre. Some other investigators have shown appreciable nitrification in very acid soils, and the presence of nitrates also has been reported in soils with a lime requirement over 10,000 pounds of limestone. Some acid soils may, therefore, be expected to contain the nitrifying organisms and to nitrify to a limited extent at least. Although the nitrifying organisms are quite sensitive to acidity, it is always possible for such organisms to be active in local areas of slight acidity. With liming the nitrification will only proceed more intensively, but the addition of large quantities of lime apparently does not increase the nitrification of the organic matter in the soil as was shown by Stephenson (86). This author also proved that lime considerably increases the nitrification of sulphate of ammonia added to the soil. Three and four tons of calcium carbonate doubled the amount of nitrates produced and there was some increase in the production of nitrate with the increasing amount of lime even up to the 20 ton treatment per acre. For instance, a general average of nitrate nitrogen p. p. m. formed from sulphate of ammonia for the same time incubated was:

Calcium carbonate in tons

per acre	Check	4	8	12	20
Nitrate nitrogen p. p. m.	75.0	157.8	182.1	189.0	193.1

It should be mentioned that this soil originally showed a lime requirement of nearly three tons of lime per acre as tested by the modified Tacke method. Fred and Graul (25) found that organic nitrogenous compounds (casein) were nitrified much more rapidly in acid soils than was sulphate of ammonia. With non-acid soils the reverse is true, sulphate of ammonia nitrifying more rapidly.

Brown and Hitchcock (8) studied the influence of some alkali salts upon the nitrification of sulphate of ammonia in the soils. With reference to calcium carbonate, they found that in small or moderate amounts it is beneficial to nitrification, but when the addition becomes excessive there is a decrease in the activities of the nitrifying microorganisms. The following table of the authors cited demonstrates the influence of calcium carbonate on the nitrification of ammonium sulphate in "normal" and alkali soils.

	CaCO ₃ added per cent	Nitrate nitrogen in mgm. per 100 gm. of soil	
		"Normal" soil	Alkali soil
1	—	3.53	2.02
2	0.189	3.63	2.03
3	0.378	3.89	2.23
4	0.756	4.37	2.45
5	1.512	4.74	2.81
6	6.048	1.10	0.90

In the alkali soil the small amount of the calcium carbonate did not seem to influence nitrification, but when 0.378 per cent was added nitrification increased. Further gain occurred with a larger application up to 1.522 per cent of CaCO₃, but when an application of 6.040 per cent of calcium carbonate was made, a distinct depression in nitrification took place.

Bear (6) among other investigators tested the effect of calcium carbonate on the rate of nitrification. Experiments were carried out with W. Virginia Dekalb silt loam (I) and Wooster silt loam (II). The lime requirement of both soils (after Veitch) was about 3500 pounds of calcium carbonate per 2,000,000 pounds of soil.

The following is an extract from the results obtained:

Calcium carbonate in pounds per 2,000,000 pounds of soil	Nitrogen as nitrate nitrogen, per 100 gm. of soil in mgm.		
	Sources of nitrogen:		
	Ammonium sulphate	Ammonium carbonate	
	Soil II	Soil I	Soil II
0	5.28	7.22	7.50
500	4.00	8.42	8.40
1000	6.15	9.52	8.55
2000	8.50	12.42	11.55
4000	15.74	17.50	15.12
7500	18.18	19.00	16.35
10000	20.98	20.00	16.16
20000	22.87	20.96	16.00

A perusal of the table shows that the addition of calcium carbonate is followed by an increased nitrification which correlates almost directly with the increased application of calcium carbonate. This correlation held fairly well with applications up to 4000 pounds of calcium carbonate per 2,000,000 pounds of soil.

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Numerous observations and experiments have been made in various countries of the world to determine the relative response of different crops to applications of lime and the reason for certain differences in the results obtained. These, as might be expected, show striking disagreements between the different plant families and species. Generally, lime has a beneficial influence on the legume plants. Alfalfa and red and white clover respond markedly to lime, while the response of soybeans and peas is less, but still quite noticeable; vetch and field-beans do not seem to be greatly benefited by lime. Of the cereals generally favored by lime, corn, barley, sorghum and wheat may be mentioned. Rape is little influenced by lime. There are numerous experiments on the relation of lime to soil fertility, crop growth, and nitrogen content of plants, and some complex reasons exist for the promotion of plant-growth by lime. In some cases the calcium may function as a direct plant nutrient; in others the assimilation of plant nutrient elements may be facilitated by the presence of lime. The stimulating influence of

lime on the plant may also play a part. Certain diseases may be retarded or entirely suppressed by lime: a notable example is the slime fungus, *Plasmodiophora brassicae*, which causes "finger-and-toe" in cabbage, turnips, and similar plants. This disease does not seem to occur on soils rich in lime and can be obviated by a thorough liming of soils in which it does prevail.

A great majority of researches have revealed a beneficial effect of lime on crop growth in acid soils, but there are also some investigations showing the harmful effect of lime on acid soils. The reason of the unfavorable influence of lime on acid soils has not yet been established with certainty. Recently Tjulin (91) came to the conclusion that the decrease of yields in leached soils treated with an excessive amount of lime is due to the rapid decomposition of organic matter and the formation of ammonia.

Wagner (95) showed the influence of lime upon the increase in yield over the check when $(\text{NH}_4)_2\text{SO}_4$ was used. For example (yields in kg per ha):

	Barley grain	Oats grain	Winter wheat grain	Sugar beet
Unlimed	229	614	178	2217
Limed ¹⁾	494	886	171	2956
Gain or loss	+265	+272	--7	+739

Patterson (75) reports the influence of lime in crop rotation during a long period of time. Some results of that experiment are cited below:

Yield per acre of limed and unlimed plots:

	Unlimed	Limed
Corn, total for 3 years, bushels . . .	84.8	122.0
Wheat, total for 3 years, bushels . .	50.0	70.0
Hay, total for 5 years, pounds . . .	6311.0	10158.0

Thorne (90) gives the average yield for 10—12 years, with a rotation of corn, oats, wheat, clover and timothy. He found that liming added materially to the yield of corn with or without fertilizer treatment. On the oats liming had a much smaller

1) Burned lime of 300 kg per Morgen.

effect than on the corn crop. With the oats, as with the corn, the greatest increase from liming was found in the low-nitrogen plots — those to which the nitrogen was carried in sulphate of ammonia. Similar results were obtained in the case of wheat. As regards clover, not only did liming produce a great direct increase, but in every instance, excepting only the plots which receive phosphorus in the form of basic slag, the residual increase from the fertilizers applied to the previous crop was materially greater on the limed than on the unlimed plots. The total gain for lime in the timothy crop was greater, and the percentage gain nearly as great as in the case of clover. For example:

Fertilizer treatment	Pounds of hay per acre			
	Clover (average for 11 years)		Timothy (average for 7 years)	
	Unlimed	Limed	Unlimed	Limed
Acid phosphate	1554	2250	2992	3934
Acid phosphate and potassium	2286	3476	2982	4008
Acid phosphate, potassium, and nitrate of soda	2596	3842	3197	4636

Wianko et al. (103) gives the results obtained by the Indiana Agricultural Experiment Station from 1906 to 1921, and shows that lime produced a good increase on all crops in the rotation (corn, wheat and clover), both alone and with stable manure. For example, the average yields per acre from an experiment carried out during 1913—21 (in Jennings county) on a plot located on very acid heavy silt loam were as follows:

Crops	Without manure		6 tons stable manure once every three years	
	No lime	Limed	No lime	Limed
Corn, bushels	44.9	48.1	65.7	73.6
Wheat, bushels	8.9	12.8	13.1	20.1
Clover hay, pounds	2,723	3,317	28,20	35,57

The authors have come to the conclusion that "lime is of great importance in increasing the fertility of the majority of

Indiana soils. Lime is the way to increase legume production". Stewart and Wyatt (87) found that "for the common soil of Southern Illinois (U. S. A.), application of one ton per acre of limestone once every three years is sufficient to keep the soil alkaline".

At the New Jersey Agricultural Exp. Station numerous experiments in pots and on fields have been carried out. The object of the studies was the influence of lime on the yields of crops, total nitrogen, and percentage of nitrogen recovered by the different crops of the rotation. From the numerous experiments we shall quote some of the averages recently obtained. Field experiments were carried out on Sassafras loam soil (61). Prior to the initiation of the experiments, the land had been neglected for a number of years (50, 51). On this soil for the first five year period, in non-legume rotation, the average percentage of nitrogen, total nitrogen and yield of dry matter, was practically the same for the limed and unlimed plots. In the second five year period, the corn crop of 1913 (60) showed an increase after the lime treatment. The other crops showed little or no response to lime. The total yield of dry matter and nitrogen for the single five-year periods and also for three successive five-year periods on the limed plots are only a little in excess of the total for the unlimed plots, as is shown in the table below.

Average of dry matter and nitrogen per acre in crops from limed and unlimed plots.

Periods of cropping	Dry matter		Nitrogen			
	Unlimed lbs.	Limed lbs.	Unlimed		Limed	
			%	lbs.	%	lbs.
First 5-year period, 1908—12 .	3657	3669	1.21	40.66	1.21	40.77
Second 5-year period, 1912—17	2768	2926	1.13	28.31	1.14	31.07
Third 5-year period, 1918—22(61)	2849	3231	—	34.13	—	39.38
Average for 15 years	3091	3275	1.17	34.37	1.18	37.07

The total yield of dry matter for all three 5-year periods was nearly as much on the unlimed plots as on the limed, and the authors point out that the practice of using lime on light to medium heavy soils, when non-leguminous crops

are grown in the rotation, may be questionable. Liming did not greatly affect the percentage of nitrogen in the dry matter of crops.

The authors (58) also carried out a lengthy experiment on the same soil with rotation including legume crops. Different systems of cropping were found, all of which include some legume crop. Calcium and magnesium limestones were used in three different rates, as shown in the table below. An experiment was laid in 1908 for the purpose of testing two sources of lime, applied in different amounts.

For an illustration of nitrogen removed by crops in the second 5-year period; for each rotation, let us give an extract from the results obtained:

Pounds of nitrogen per acre removed by crops
for 5-year period 1913—17.

Treatment	Lbs. lime- stone app- lied per acre	Rotation ¹⁾	Rotation	Rotation	Rotation
		I	II	III	IV
Total nitrogen removed					
Check	—	124.8	165.1	125.1	202.4
Calcium limestone . . .	1000	173.2	192.3	150.6	275.4
	2000	213.4	233.3	167.2	339.4
	4000	226.10	257.4	157.0	416.5
Magnesium limestone . .	1000	195.60	221.2	142.0	349.7
	2000	243.60	242.2	162.3	393.1
	4000	242.3	239.9	157.3	401.7

The authors, in regard to the first ten years, came to the following conclusions: "During the ten years, the limed plots, with only slight exception, yielded distinctly larger crops and more total nitrogen than the unlimed plots. In the majority of cases the percentage of nitrogen was higher in crops from limed than from unlimed plots". For the third 5-year period the authors (59) give their opinions as follows: "With few exceptions, the lime treated plots have shown substantial increases in crop

1) For rotations see Soil Sci. v. 9, p. 91. 1920.

yield over the check plots . . . For the legume crops especially, the limed plots showed a higher percentage of nitrogen in the dry matter than the non-legume crops“.

Fifteen years of observations with manure, fertilizers, and lime, on Sassafras silt loam, at the Delaware Agricultural Experiment Station (Schuster, 82) showed that lime aids in the production of corn and soybeans only where muriate of potash is also applied. Lime does, however, play an important role in the growth of clover and timothy. Lime also improved the quality of corn and increased the percentage of sound grain, when muriate of potash was also used. Lemmermann.(47) found that on a light soil, with 92.21 per cent of sand and 4.13 per cent of clay, liming in amount of 1 per cent calcium carbonate caused a loss of nitrogen in the soil.

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Lime influences not only the yields of dry matter and the total nitrogen in crop yields, but also the availability of soil nitrogen, the percentage of nitrogen in the crop, and the recovery of the nitrogen from fertilizers. Let us here for a moment stop to look into some of the results with barley.

Lipman and his associates (52) carried out pot experiments with barley in the soil. The crop was grown to maturity. The influence of the application of different amounts of lime on the yield of dry matter and the nitrogen content in the barley crop was as follows:

Special treatment	Dry matter in gms.	Per cent of N in dry matter	Total increase of N over check mgm. per pot
1. No limestone	9.85	0.97	—
2. 0.12% CaCO ₃ or 0.67% CaO . .	12.35	0.97	24.83
3. 1.00% CaCO ₃ or 0.56% CaO . .	22.90	1.05	144.95
4. 2.00% CaCO ₃ or 1.12% CaO . .	20.75	1.13	138.06
5. 5.00% CaCO ₃ or 2.80% CaO . .	21.85	1.07	127.71
6. 10.00% CaCO ₃ or 5.60% CaO .	22.70	0.97	114.18
7. No limestone, 2 gm. nitrate of soda	20.09	1.55	229.37

The highest yield of dry matter was obtained with one per cent of limestone or 0.56% CaO, although the yield was

practically as high as with ten per cent of limestone. With 2 gm. of NaNO_3 the yield was nearly as great as with one per cent of limestone. The percentage of nitrogen in dry matter with lime was higher than without lime, except in the pots treated with nitrate of soda. Another experiment was conducted by the same authors (54), emphasizing the importance of CaCO_3 in making available the nitrogen of soil organic matter. The results obtained indicate that the limed pots gave considerably higher yields of dry matter and total nitrogen than the unlimed pots.

In 1915, the above named authors (53) carried out a pot experiment with acid silt loam, with a lime requirement of about five or six thousand pounds per acre. No commercial fertilizers were used and the pots were planted with barley, which grew to maturity. The highest percentage of nitrogen in the dry matter was obtained in the pots with 25 gm. (about 0.43%) of quick lime but without any commercial fertilizers. The yield was even higher than in the pot with the nitrate of soda. From the results of cylinder experiments, the same authors (57) came to the conclusion that lime in the form of carbonate had a pronounced effect upon the yields in general.

To follow the influence of lime upon the nitrogen percentage in the non-legume plants, a good opportunity is offered by the field experiments on the availability of nitrogenous fertilizers at the New Jersey Agricultural Experiment Station. For illustration, let us bring the average results from twenty limed and unlimed plots during the years 1918—1922 for four crops grown on this field (62).

Percentage of nitrogen in the crops 1918—1922.

	Corn — 1918			Oats — 1919		Barley — 1920		Timothy	
	Grain	Stalks	Cobs	Grain	Straw	Grain	Straw	1921	1922
Unlimed (A) plots	1.48	0.86	0.25	2.18	0.72	1.79	0.72	0.98	0.94
Limed (B) plots	1.58	0.95	0.30	2.15	0.72	1.86	0.59	0.98	1.00

The averages for the limed plots, with slight exceptions, show some increase in the percentage of nitrogen, corresponding with the unlimed plots.

Newton (72) found that barley grown in the control nutrient solution, and in solutions deficient in calcium, contained nitrogen as follows:

Barley tops — control, 4.65% N.

Barley tops — low calcium, 5.75% N.

It must be noted that the percentage of nitrogen in plants, particularly in barley, is not constant, but changes greatly during the period of growth. Newton came to the conclusion that the highest nitrogen percent in barley tops and roots was attained after about 48—70 days from the start of the experiment. Bieler and Aso (3) grew barley and other plants in pots. Analyses were made of the plants with reference to nitrogen and phosphoric acid at periods of 2¹/₂ and 4 months after planting. They found that “with wheat and oats the assimilation of plant nutrients was distributed throughout the different periods of growth but with barley it was confined mainly to the earlier stages“. Wilfarth et al. (104) in field experiments with barley (Chevalier) found that at different stages of growth it contained the following total amounts of percentages of nitrogen:

Starting of experiment March 30.	Nitrogen content					
	In plant top, grain and straw together			All plants		
	Nitrogen in dry matter		Highest amount assim. N = 100 %	Nitrogen in dry matter		Highest amount assim. N = 100 %
	%	kgm. per ha.		%	kgm. per ha.	
I. cutting May 29 . . .	2.37	48.09	71.40	2.03	57.26	66.15
II. „ June 17 . . .	1.23	67.52	100.00	1.26	86.56	100.00
III. „ July 3 . . .	0.76	66.62	98.80	0.75	71.26	82.32
IV. „ July 27 . . .	0.70	61.27	90.75	0.70	64.42	74.54

In the above experiment the barley in the last period of its growth lost a part of its total nitrogen. The loss of nitrogen in tops amounted to about 10 per cent and in the entire plant to over 23 per cent. The loss of nitrogen may be explained in part by the translocation of nitrogen to the roots from which it

is absorbed by the soil and in part probably by the fallen dry leaves. The highest yield of dry matter was reached on July 3, but the highest yield of nitrogen in tops, as well as in the entire plant, was found on June 17. At the end of the growth period, the amount of nitrogen assimilated was 90.75 per cent in the tops, and in the plant only 74.54 per cent, as compared with the amount assimilated on July 17.

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Before presenting the experimental data on the availability of the soil nitrogen together with a comparison of mineral nitrogenous fertilizers by barley crop, a short review of the literature on the subject may not be out of place. A comparison of the effects of nitrate of soda and ammonium sulphate during a long period of time, is contained in the Rothamsted Experiments (Hall, 31), where the continuous field experiments with barley were begun in 1852. The arrangement and the manures applied to each plot have remained practically unchanged since that period, and the barley has been grown under the same treatment year after year. Let us make a short extract from these results:

Yield of barley (grain and straw) per acre.
Averages over 51 years (1852—1902).

	Grain bush.	Straw cwt.
Unmanured	15.3	8.8
Complete minerals, no nitrogen	20.4	10.8
Complete minerals, & amm. salts	42.1	24.9
Complete minerals, & nitrate of soda	43.5	27.4

Hall notes that "a little difference is seen in the return for this amount of nitrogen, whether it be applied as ammonium-salts, nitrate of soda, or rape cake. Over the whole period the nitrate of soda gave the highest returns by about 3 per cent, but during the last two decades the plot receiving ammonium salts has been the best of the three".

Wagner with different crops carried out a series of field and pot experiments for the purpose of studying the influence

of various nitrogenous materials on the yields and recovery of nitrogen (95, 96, 97, 98, 99). He found (95) that, in round numbers, of every 100 parts of nitrogen supplied to the common crops (oats, wheat, rye, barley) in the form of nitrate of soda, 71 parts were returned in the crops. Barley particularly recovered 61 (in pots) to 66 (in field) parts of every 100 parts of nitrogen supplied in the form of nitrate of soda, whereas with ammonium from the same 100 parts of nitrogen applied, Wagner found a recovery of about 52 parts. Letting 100 represent the fertilizing value of nitrate of soda, Wagner found the relative value of ammonium sulphate for the barley crop about 80 and on an average 74 for the grain of rye, oats and barley (98, 99). Haselhoff (36) in pot experiments, obtained the following results with barley:

Soils	Nitrogenous materials used	Of every 100 parts nitrogen recovered	If 100 represents nitrogen recovered from nitrate of soda: %
Loam soil	1. Nitrate of soda	88.8	100
	2. Ammonium sulphate	71.6	80
Sandy soil	1. Nitrate of soda	66.7	100
	2. Ammonium sulphate	60.1	90

Lipman and his associates (49) with sand culture in pots found the following effects of nitrate of soda and ammonium sulphate on barley:

Special treatment per pot	Nitrogen recovered per cent	Relative availability per cent
154 mgm. nitrogen in nitrate of soda	53.08	100.0
154 mgm. nitrogen in ammon. sulphate	31.95	60.0
308 mgm. nitrogen in nitrate of soda	51.25	100.0
308 mgm. nitrogen in ammon. sulphate	28.48	55.6

The same authors (52) carried out a sand culture experiment with barley in twenty pound pots. Ammonium sulphate gave the highest average yield of dry matter. The percentage of nitrogen in the dry matter varied very widely. Lipman and Blair (54) have also made some soil culture pot experiments

along these lines in sand and sandy loam soil. A study of the results shows a large difference between the recovery of nitrogen of nitrate of soda in sand (53.1%) and sandy loam (35.0%) soil and closely relative values for sulphate of ammonia (72—74%) in both experiments.

Cylinder experiments relative to the utilization and accumulation of nitrogen were conducted at the New Jersey Agricultural Experiment Station during a long period of time. The results obtained showed that minerals containing calcium carbonate had a slight influence on the recovery of nitrogen in eight kinds of soil. In this experiment it was found that "the average recovery for nitrate for seven years was 39.59%". In another cylinder experiment with Penn loam soil the authors (57) found that the average recoveries for all crops of the third rotation were 62.71 per cent for NaNO_3 and 40.05% for $(\text{NH}_4)_2\text{SO}_4$, or letting 100 represent the average recovery from nitrate of soda, the recovery from ammonium sulphate was 64%.

The majority of experiments show that ammonium sulphate has a lower fertilizing effect than nitrate of soda and the recovery of nitrogen in comparison with nitrate of soda is also lower. Generally it is assumed that the reason for the lower availability in the nitrogen of sulphate of ammonia is that ammonia has to be nitrified to nitrate, before it can be assimilated by the plant. On the other hand, there are frequent indications that during the summers of abundant rainfall, sulphate of ammonia is liable to give better returns than nitrate of soda. For example in the writer's experience (73) during the summer of 1923, with an abundant rainfall, $(\text{NH}_4)_2\text{SO}_4$ gave the higher turnips yield.

A number of research workers attempt to account for the fact that sulphate of ammonia in comparison with NaNO_3 gives lower results. Johnson (43), for instance, suggests that this is due to the $(\text{NH}_4)_2\text{SO}_4$ being fixed in the clay particles of the soil. He assumes that clay matter "fixes ammonia, i. e. converts it into a comparatively insoluble compound, so that the plant may not be able to appropriate it all". Löhnis and Fred (65) supposed that "the assimilation of ammonia by soil organisms is one of the reasons why in fertilizer tests the nitrogen applied as ammonium often does not act as well as does nitrate nitrogen". The possibility is not excluded that the losses of ammonia occur by volatilization from soils treated with heavy

applications, as was shown by Lemmermann (47). Under common field conditions, such volatilization is hardly possible in any appreciable quantity.

The above experiments with nitrogenous fertilizers were carried out on more or less acid soils. Very few experiments of a similar nature have been carried out on arid soils. Here may be noted the experiment with barley by C. B. Lipman (64). The soil used was Oakley blow-sand, 10 pounds per pot. The dry weights of barley with the different nitrogenous treatments were as follows:

	Control	Nitrate of soda	Ammonium sulphate	Cotton-seed meal	Dried blood
Average of dry matter gm. .	12.1	22.3	31.2	29.9	22.7
Assuming dry matter of nitrate of soda equal = 100, we obtain the relative value for the others	—	100.0	140.0	134.0	101.0

Considering the total weight of dry matter produced, the author noted the superiority of sulphate of ammonia and cotton-seed meal to all other fertilizers. The nitrate of soda treatment was distinctly inferior with respect to the total yield of dry matter. The author's results bear out the contention "that the low grade organic nitrogenous fertilizers and sulphate of ammonia are far more available in arid soils like Oakley blow-sand than the high grade nitrogenous fertilizers".

Coleman (17) supposes that the reason for the advantages of $(\text{NH}_4)_2\text{SO}_4$ over equivalent quantities of nitrogen in the form of NaNO_3 may be explained in the following manner: „We may conceive of conditions which militate against the very advantages of sodium nitrate. Its ready solubility, ease of diffusion renders it readily subject to removal in periods of excessive rainfall. Ammonium salts, on the other hand, because of the fact that very valuable portions become temporarily fixed, are less liable to loss by leaching“.

There is also ample evidence that the plants are capable of directly assimilating ammonia nitrogen. Only a few of the many investigations can be referred to in this brief review.

Pitsch (76) conducted an elaborate piece of work along these lines. Maze (68) showed that ammonia may be absorbed and assimilated by higher plants. Kossowitz (46) showed that peas utilized ammonia nitrogen in their growth nearly as well as that of nitrate. Gerlach and Vogel (30), Lemmermann (47) and Hutchinson (41) came to the same conclusions. The latter, for example, concluded that agricultural plants of various kinds may produce normal growth when supplied with nitrogen in the form of ammonium salts under conditions excluding the possibility of nitrification. Recently Shmuk (83) specially emphasized the feeding of plants by ammonia nitrogen, saying: "under natural conditions nitrate cannot serve as the main nitrogenous nutrient source for plants; they are always in an extreme minimum. It is reasonable to suppose that the nitrogenous nutrient sources (for plants) are ammonia into which the nitrates are converted by specific influences of the roots".

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Concerning the influence of sulphate of ammonia upon the percentage of nitrogen in dry matter in comparison with nitrate of soda, the data are inconsistent; however, the majority of the investigators assume that with ammonium salts the percentage of nitrogen in dry matter is higher than in the case of nitrate of soda. This conclusion may have been derived already from the experiments of Pitsch (76) and Wohltmann (106). Hutchinson (41) found in sand and water culture that in those where nitrogen was applied as ammonium salts, the dry matter of the plants contained a higher percentage of nitrogen than when sodium nitrate was employed. In the work of Singleton (84) the percentage of nitrogen changed in either direction. In the above cited work of Lipman (52) with barley, the percentage of nitrogen in dry matter was much higher (3.13%) with an application of nitrate than with an application of sulphate of ammonia (2.59%).

It is also of interest in this connection to note the observations of the Rothamsted Experiment Station extending over a long period of time. Hutchinson (41) reports the percentage of nitrogen in the mixed herbage plots of that station for the long period as follows:

Manuring	Nitrogen per cent in dry matter	
	1856—73	1901—1905
Minerals and nitrate of soda	1.31	1.39
Minerals and sulphate of ammonia	1.55	1.52

Sulphate of ammonia showed a higher percentage of nitrogen than nitrate of soda.

A great number of experiments were also conducted on the comparative value of NaNO_3 and cyanamide. Wagner (96) carried out many experiments along these lines. The results of one of the pot experiments with barley in sandy loam may be cited here. The amount of nitrogen applied was 1 gm. per pot (pots $10'' \times 13''$).

Nitrogenous materials used	Dry matter		Total N in yields mgm.	Nitrogen over check mgm.	Recovery of nitrogen per cent
	Grain gm.	Straw gm.			
Check	6.1	9.2	132	—	—
Nitrate of soda	39.1	56.7	709	577	57.7
Cyanamide	40.0	56.5	691	559	55.9

The author came to the conclusion that with the increase in the amount of cyanamide the fertilizer value falls as compared with NaNO_3 .

Haselhoff (36) assumes that with a spring application of cyanamide on barley the yields were lower as compared with NaNO_3 . On a loam soil the availability of cyanamide was better than on a sandy soil. Hartwell and Pember (33) also carried out pot experiments with different nitrogenous materials. A portion of the pots were seeded to barley. One portion of the pots received 150 mgm., others 300 mgm. of nitrogen per pot. The results shown below illustrate the comparative effects of nitrate of soda and cyanamide on the yield of barley.

Nitrogenous materials applied	Total weight of barley per pot — gm.	
	N — 150 mgm.	N — 300 mgm.
	Yields of barley in gm.	
None	26.6	26.6
Nitrate of soda	41.3	52.4
Cyanamide	35.7	33.4
Letting 100 represent the yield of barley with nitrate of soda we find for cyanamide — %	86.5	63.8

The results obtained show, that the effect of cyanamide on the yield of barley was much lower than that of nitrate of soda.

Pot experiments with oats recently carried out by Singleton (84) show that after 64 days of growth, oats recovered nitrogen as follows:

	Nitrate of soda	Ammonium sulphate	Cyanamide
Recovery of nitrogen	67.62%	54.60%	48.86%
Relative values	100.00	80.90	72.10

Generally it must be noted that soil conditions are much more important factors for the action of cyanamide than for that of nitrate of soda or sulphate of ammonia. When bacterial action is deficient, toxic products — possibly dicyanamide — are formed, which are injurious to plant growth. It will also be seen from the above review that the recoveries of nitrogen from the above named nitrogenous fertilizers obtained by the various investigators are anything but constant. Frequently the same experiments, with one and the same plants, lead to different conclusions.

Experimental.

Notwithstanding the fact that numerous experiments dealing with the availability of soil nitrogen as well as of different nitrogenous materials applied to soils have already been conducted, there are many points upon which further light would be helpful. In an attempt to clear up some questions, a series of pot experi-

ments with barley were conducted on an acid soil. The object of the study was to ascertain the influence of different calcium carbonate applications to a very acid soil upon the following factors:

1. The reaction of the soil at the start, during the growing period, and at the end of the experiment.
2. The solubility of aluminium compounds in the soil.
3. The growth of barley.
4. The percentage of nitrogen in the dry matter of the barley.
5. The recovery of nitrogen applied in fertilizers.
6. The formation of nitrate in the soil.

The soil for the experiment was taken from a plot once treated with sulphur for a sulphur oxidation experiment. The soil was screened to remove pebbles, thoroughly mixed and somewhat dried in the greenhouse.

This original Penn loam soil had a pH value of 3.95, a total nitrogen content 0.10%, and a water holding capacity of 32.8% for the portion passed through a 2 mm. sieve. The percentage of such matter was 92.5% of the total particles. At the start, an application of lime in four different amounts was contemplated, but later another increment of lime was added and the experiment was carried out as follows: 1) — No lime, 2) — 0.1%, 3) — 0.2%, 4) — 0.4%, 5) — 0.6% and 6) — 0.8% calculated as calcium oxide on the dry soil. Ground limestone containing about 95.0—95.5 per cent of calcium carbonate served as liming material. The above noted lime treatment was applied in the following five series:

- Series I. Without fertilizers.
- Series II. Only minerals. No nitrogenous fertilizers.
- Series III. Minerals and nitrate of soda.
- Series IV. Minerals and sulphate of ammonia.
- Series V. Minerals and calcium cyanamide.

Each pot of the corresponding series was identically fertilized varying only the amounts of calcium carbonate. The amounts of fertilizer added per pot were:

1. Potash (K_2O) — 0.34 gm as potassium chloride.
2. Phosphoric acid (P_2O_5) — 0.36 gm. as acid phosphate.
3. Nitrogen — 0.32 gm. in forms as noted above.

The limestone, acid phosphate and cyanamide were added in solid form, while the other fertilizers were applied in liquid form, as 1% solutions. All fertilizers, with the exception of the nitrate of soda, were added at the time of compacting the soil in the pots; only one half of the nitrate of soda was added at that time; the other half 30 days later, after taking the soil samples for the determination of pH values in the pots. The ground limestone and fertilizers were thoroughly mixed with the soil. The dryness of the soil favored a uniform distribution of the lime and fertilizers. Small earthenware glazed pots were used. On the bottom of the pots, one pound of gravel was laid and close to one side of the pot a glass tube was placed. This served for aeration and watering. Eight and two-tenths pounds of the soil treated, calculated on the dry basis, were well compacted in the pots over the gravel. Upon compacting, the pots were watered and left standing for 12 days and then on December 8th, 1925, seeded with barley.

Fourteen uniform, well germinated barley (Hanncha) seedlings, of approximately equal size were placed in seven separate holes. The seedlings were placed in such a way that one set of seedlings was in the middle and six sets around it at equal distances. After the planting, each pot was covered with a thin layer of quartz sand to the amount of one half pound. The watering throughout the experiment was done with distilled water, and was maintained at 55—60 per cent of the water holding capacity. The amount of water was periodically checked by weighing the pots.

At the start all treatments were triplicated, one pot being harvested 70 days after seeding, and the other two at the end of the experiment, at the blooming stage of the barley, i. e. 103 days after seeding. The barley came uniformly in all the pots. In the unlimed pots, after about 6 days, the plants showed indications of stunted growth. Eight days after planting the pots were thinned to seven plants in each pot. At first no injurious influences of the cyanamide upon the shoots were noticed, but soon after the first ten days, injury appeared: the tops of the plants became yellow and shrivelled. After 20 days this effect was more pronounced and the plants were retarded in their growth. After 20 days differences were also apparent between the nitrogen fertilized pots and those without such treatment.

Measurement of the height of the plants was made at intervals of each ten days. The following table gives the results after 30 days of growth.

Height of barley sprouts after 30 days of planting in centimeters.

Series	Unlimed	Limed
I	8—10	30—32
II	8—9	30—32
III	9—11	30—34
IV	6—7	30—32
V	6—8	26—28

In the same series, with different amounts of lime, there were no differences in the height of the barley but very notable differences in the height of the barley in limed and unlimed pots.

Besides the pots seeded to barley, there was one series of pots without any plants. For these pots no fertilizers were used,

T a b
Effect of lime on the reaction of th

CaO (Limestone was used)		No plants				B a r l e e							
%	Lbs per acre	No fertilizer								Muriate of potash and acid phosphate			
		Check				Series I				Series II			
		At start- ing	After 30 days	After 70 days	At end (103 days)	At seed- ing	After 30 days	After 70 days	At end (103 days)	At seed- ing	After 30 days	After 70 days	At e (10 day
No lime		pH 3.94	pH 3.92	pH 3.96	pH 3.94	pH 3.96	pH 3.99	pH 3.91	pH 3.93	pH 3.98	pH 4.05	pH 4.02	pH 4.0
0.1	2000	—	—	—	—	4.92	5.00	4.85	4.59	4.92	4.80	4.75	4.5
0.2	4000	6.33	5.88	5.90	5.86	6.32	6.15	5.91	5.73	6.21	6.04	6.12	5.4
0.4	8000	6.96	7.05	7.05	7.10	6.98	7.20	7.10	6.82	6.80	7.16	7.02	6.8
0.6	12000	7.10	7.50	7.45	7.48	7.14	7.35	7.29	7.24	6.90	7.30	7.13	7.2
0.8	16000	7.16	7.55	7.58	7.63	7.14	7.56	7.32	7.36	6.98	7.56	7.42	7.4

but only lime in the amounts indicated above. The object of this series was to determine the influence of lime upon:

- a. the formation of nitrate nitrogen
- b. the pH value
- c. the amount of soluble aluminium in the soil.

*

Before we analyse the results obtained, brief mention must be made of the methods used.

The pH values were determined potentiometrically with Büllmann quinhydrone electrode, as described by Christensen (15). Although Bobko (7) has shown that the soil-water ratio between the limits of 1 : 1½ and 1 : 25 has very light effects upon the pH values in soil extracts, still the determinations of pH value were made under standard conditions, namely with extracts in the ratio of 1 : 5, as recommended by Salter (79). In each determination 50 cc. of water were added to 10 gm. of soil. The soil was in contact

l e 1.
oil during the experimental period.

l a n t s

Muriate of potash, acid phosphate and:

Nitrate of soda Series III				Sulphate of ammonia Series IV				Cyanamide Series V			
At seed- ing	After 30 days	After 70 days	At end (103 days)	At seed- ing	After 30 days	After 70 days	At end (103 days)	At seed- ing	After 30 days	After 70 days	At end (103 days)
pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH
3.96	3.99	4.00	3.96	3.88	4.00	3.89	3.93	3.92	4.25	4.21	4.18
4.85	4.72	4.68	4.72	4.90	4.91	4.82	4.61	5.20	5.12	5.03	4.85
6.10	6.00	5.97	5.60	6.12	5.95	5.36	5.31	6.64	6.26	6.13	5.80
6.94	7.20	6.56	6.87	7.04	7.22	6.81	6.75	7.07	7.15	7.08	7.04
6.98	7.39	7.20	7.25	7.14	7.58	6.92	7.09	7.20	7.46	7.42	7.35
7.17	7.52	7.35	7.42	7.21	7.50	7.20	7.24	7.32	7.60	7.50	7.41

with the water for 15—20 hours before determining the pH value, as is also recommended by Hissink (39). The Kjeldahl method was used in determining the total nitrogen in the soil and in the dry matter of the barley. The colorimetric method as described by Schreiner (81) was used for the nitrate determinations. The “soluble” aluminium was determined by the method described by Burgess (10), with slight modifications: precipitation was made at pH value 5.0—5.2, as recommended by Magistad (67). The reaction was partly checked by potentiometer, but in general the colorimeter method was used with brom cresol green as the indicator. All the nitrogen determinations in the barley, nitrate nitrogen and pH values and a large part of the “soluble” aluminium determinations were made in duplicate. The duplicates of the total nitrogen and pH value determinations checked well. Differences of 20—30 p. p. m. between duplicates were sometimes found in the aluminium determinations.

1. Changes of pH Values in Soils as Affected by Lime and Plant Growth.

In order to obtain definite information on some of the soil reactions during the experimental period, determinations of the pH value in the soil were made:

- a. at seeding,
- b. after 30 days of growth,
- c. after 70 days „ „ ,
- d. at the end, after 103 days of growth.

At seeding and after 30 days' cropping, the soil samples for the determinations were obtained from the pots by means of a small cork borer; the holes were filled with the corresponding soil which had been saved for this purpose. For the determination after 70 and 103 days the samples were taken in the following manner: the entire soil was shaken from the pots, mixed, and a representative sample chosen. The results obtained are summarized in the table no. 1.

A study of the table shows that with an increase of the amount of lime used, the hydrogen ion concentration decreased markedly in all series. With light applications of lime (0.1%—0.4%) the changes of the pH values are fairly correlated

with the amount of lime used; with heavy applications of lime the pH values change only a little — applications of lime from 0.4% to 0.8% only changed the pH value from 6.8 to 7.5. The changes of the pH values were considerable during the first three 10-day periods and after that time became approximately constant as found in the unplanted pots, which served as the standard. It may be noted also that with a lower application of lime — from 0.1% to 0.4% — the hydrogen ion concentration in the planted pots, with few exceptions, decreased gradually during the growth of the barley, beginning from the time of seeding. In the unplanted pots, these changes were not so marked. With the heavy application of lime — from 0.4 upwards — the pH values changed very little after 30 days. A study of the same table shows that potassium chloride and acid phosphate in equally small amounts (0.54 gm. of KCl and 2 gm. of acid phosphate) had an influence on the pH values. This phenomenon is clearly recognizable during the early stages of the experiment; at the end it was not noticeable. For instance:

pH values of series I and II after 30 days' growth.

Special treatment	Amounts of calcium oxide					
	0.0%	0.1%	0.2%	0.4%	0.6%	0.8%
	pH	pH	pH	pH	pH	pH
No fertilizers	3.99	5.00	6.15	7.20	7.35	7.56
KCl and acid phosphate . . .	4.05	4.80	6.04	7.16	7.30	7.56

It is possible that the influence noted was due to the potassium chloride, as is the opinion of Christensen (15) and Hissink (39). It is of interest to note that with KCl and acid phosphate there was a slight increase of the hydrogen ion concentration as compared with the unfertilized section, but only in the limed pots up to the neutral point; in the unlimed and heavily limed pots it was not noticed. It must also be remarked that an application of 2.71 gm. of cyanamide per pot considerably decreased the acidity of acid soil in comparison with other nitrogenous fertilizers.

It is well known that the continuous use of sulphate of ammonia, a physiologically acid salt, produces an acid condition

in the soil, whereas nitrate of soda, a physiologically alkaline salt, tends to the production of alkaline conditions. Studying table no. 1, it will be seen that this influence came to light already during the first cropping of barley and even in heavily limed pots.

For example, let us take a summary of the pH values from table no. 1 for the end of the experiment.

PH values of the soils at the end of experiment with nitrate of soda and sulphate of ammonia.

Special treatment	Amount of calcium oxide as limestone					
	0.0%	0.1%	0.2%	0.4%	0.6%	0.8%
	pH	pH	pH	pH	pH	pH
Nitrogen as nitrate of soda	3.96	4.72	5.60	6.87	7.25	7.42
Nitrogen as sulphate of ammonia . . .	3.93	4.61	5.31	6.75	7.09	7.24

2. Influence of lime upon the solubility of aluminium compounds in the soil.

Table no. 2 shows the influence of liming upon the solubility of aluminium compounds of the soil in 0.5 normal acetic acid. In general it may be said that with increasing amounts of

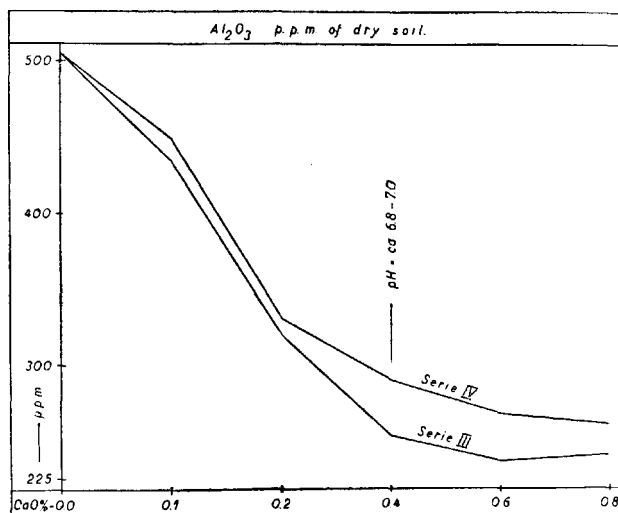


Diagram no. 1. Influence of lime upon the solubility of aluminium compounds. Series III. Minerals and nitrate of soda. Series IV. Minerals and sulphate of ammonia.

lime added, the amount of aluminium soluble in 0.5 normal acetic acid decreases. The correlations between the amount of lime used and the amount of soluble aluminium up to about the neutral point come out more clearly. Above the neutral point, as will be seen, ground limestone is comparatively less influential in retarding the solubility of aluminium compounds as indicated in diagr. no. 1 for the series IV and V. There seem to be differences in the amount of soluble aluminium with the different fertilizers used, but too much emphasis cannot be placed on this, since the precipitation of aluminium was effected by a method which may also give some traces of iron in the precipitate.

Table 2.

Effect of lime applications on the solubility of aluminium compounds in the soil. Al_2O_3 parts per million of air dry soil.

CaO (Limestone was used)		No plants		Barley plants		
		No fertilizers		Muriate of potash, acid phosphate and:		
Per cent	Lbs. per acre	Series I		—	NaNO_3	$(\text{NH}_4)_2\text{SO}_4$
				Series II	Series III	Series IV
0.0	—	510	520	495	504	505
0.1	2000	—	456	442	434	450
0.2	4000	256	290	310	320	330
0.4	8000	230	236	262	253	290
0.6	12000	230	234	232	237	268
0.8	16000	221	215	208	240	260

3. Influence of Lime upon the Growth of Barley.

Generally it may be stated that practically all the *unlimed* pots have failed to produce growth and that the plants died prematurely. All the pots with 0.1% calcium oxide treatment in some series produced a fairly good growth of barley, but generally the plants were stunted and duplicates in the majority of cases gave large disagreements. At the end of December a remarkable influence of the fertilizer applications became noticeable; in the unfertilized pots the sprouts were thin and more stunted. About the middle of January, the differences were more pronounced; some tips of barley in the pots with minerals but without any nitrogenous fertilizers and in the cyanamide

pots became yellowish and dried up. On March 5 the first head came in the second series (without nitrogen). In the middle of March the plants were generally heading and on March 20, i. e. after 103 days of growth, the barley was harvested. The samples were slowly dried in the oven and left at room temperature to attain a constant weight; they were then ground and analysed in the usual manner. In a similar fashion the first harvesting was prepared. Tables 3—7 give the results obtained for all the series. On the basis of these results some calculations have been made, which are included in the tables noted. These tables contain:

- a. yields of dry matter for both harvestings,
- b. nitrogen percentage in dry matter,
- c. total nitrogen in mgms per pot,
- d. nitrogen percentage recovered from the pots where nitrogen in fertilizer was added.

Table 3.

Series I. (No fertilizers). Influence of different amounts of lime on the yield of dry matter, total nitrogen assimilated and percentage of nitrogen in dry matter.

Lime-stone as CaO	Lbs per acre	Num- ber of shoots per pot	Nitrogen assimilat- ed after 70 days of growth	Time of harvesting:						
				After 70 days			After 103 days			
				Dry matter per pot	Nitrogen		Dry matter		Nitrogen	
					In dry matter	Total per pot	per pot	average of two	In dry matter	Total per pot
%			%	gm.	%	mgm.	gm.	gm.	%	mgm.
0.0	—	7.0	—	0.20	—	—	0.17 0.15 12.7	0.16	—	—
0.1	2000	7.0	—	—	—	—	7.5 14.8	10.1	1.31	132
0.2	4000	20.0	29.6	4.8	2.09	100	14.6 19.8	14.7	0.96	142
0.4	8000	23.0	22.4	6.8	2.60	177	20.2 20.5	20.0	1.14	228
0.6	12000	22.0	21.3	6.5	2.62	170	22.6 17.3	21.5	1.05	216
0.8	16000	22.0	loss	6.2	2.90	180	17.5	17.4	1.05	175

In the tables is also given the number of shoots at the time of first harvesting, showing the force of tillering of plants. At the last harvesting, the tillering was about the same, and is therefore not indicated in the tables. The study of the tables shows that the yields from duplicate pots with lime over 0.1% of calcium oxide are generally in fair agreement; only in series V, with cyanamide, the divergences were at times too large.

Table no. 3 represents the results of the unfertilized series. As to the yields of dry matter at the end of the experiment, it will be seen that the yield of dry matter gradually increases with the increase of the amount of lime applied up to 12,000 pounds per acre. After this point the yield goes back. The same appears in the yield of the first harvesting, but there the differences are less marked. The percentage of nitrogen in the dry matter of the first harvesting also increases with the increase

Table 4.

Series II. (Minerals only, no nitrogen). Influence of different amounts of lime upon the yield of dry matter, total nitrogen assimilated and percentage of nitrogen in dry matter.

Lime-stone as CaO	Lbs. per acre	Number of shoots per pot	Nitrogen assimilated after 70 days of growth	Time of harvesting						
				After 70 days			After 103 days			
				Dry matter per pot	Nitrogen		Dry matter		Nitrogen	
					In dry matter	Total per pot	per pot	average of two	In dry matter	Total per pot
%			%	gm.	%	mgm.	gm.	gm.	%	mgm.
0.0	—	7.0	—	0.18	—	—	0.18	0.19	—	—
0.1	2000	9.0	—	—	—	—	12.8	11.8	1.40	165
0.2	4000	21.0	18.4	6.5	2.05	133	19.7	19.7	0.83	163
0.4	8000	22.0	21.6	7.6	2.25	171	24.9	24.8	0.88	218
0.6	12000	24.0	17.9	8.4	2.18	183	25.7	25.9	0.87	223
0.8	16000	24.0	21.7	8.4	2.33	195	28.4	28.3	0.88	249
							28.2			

of lime. It may be pointed out that the latter is a general phenomenon also in other series, with the exception of the cyanamide series. Attention may also be called to the high percentage of nitrogen in the pots with 0.1% of calcium oxide in the final harvesting. This phenomenon is apparent in all the series and seems to be in fair agreement with the results obtained by Lipman and Blair (55) who note that "starved plants store up more nitrogen in proportion than the healthy plants". The differences in the percentages of nitrogen in the final harvesting are slight and it is not possible to draw any conclusion in regard to the influence of lime upon the percentage of nitrogen in the dry matter of the barley at that stage of growth. The total

Table 5.

Series III. (Minerals and nitrate of soda). Influence of different amounts of lime on the yield of dry matter, total nitrogen assimilated, percentage nitrogen recovered and percentage nitrogen in dry matter.

Limestone as CaO		Number of shoots per pot	Nitrogen assimilated after 70 days of growth	Time of harvesting						Recovery of N		
%	Lbs. per acre			After 70 days			After 103 days			per pot over check	In %	
				Dry matter per pot	Nitrogen in dry matter	Total Nitrogen per pot	Dry matter per pot	Nitrogen average of two	Total Nitrogen per pot			
			%	gm.	%	mgm.	gm.	gm.	%	mgm.	mgm.	%
0.0	--	7.0	--	0.20	--	--	0.19	0.20	--	--	--	--
0.1	2000	17.0	--	?	2.52	--	18.5	19.2	1.48 ¹⁾	288	123	38.5
0.2	4000	27.0	13.2	9.7	3.68	356	39.6	39.9	1.03	410	247	77.2
0.4	8000	27.0	20.7	9.9	3.80	376	40.2	42.3	1.10	474	256	80.0
0.6	12000	28.0	17.0	10.2	4.02	410	43.2	43.9	1.14	494	271	84.7
0.8	16000	28.0	24.7	10.4	3.98	414	41.3	46.6	1.20	550	301	94.1
							44.9	45.8				

1) The last half of nitrate nitrogen by mistake added after 47 (instead of 30) days.

amount of nitrogen increases with the application of lime up to about 0.4—0.6% of calcium oxide and then falls back considerably.

In table no. 4, similar results are given for series II, i. e. with minerals, but without nitrogenous fertilizers. Here the yields of dry matter and total nitrogen increase continuously with the increase of the amount of lime applied. The total yields of dry matter are considerably higher than in the unfertilized series, but the total amount of nitrogen assimilated is only slightly higher than in the first series: the percentage of nitrogen in the dry matter of the final harvest is considerably less than in the first series at the same time, as summarized in table nr. 8 below. Apparently in series II the nitrogen was the limiting factor, thereby influencing the yield of dry matter and the nitrogen percentage.

Table 6.

Series IV. (Minerals and sulphate of ammonia). Influence of different amounts of lime on yield of dry matter, total nitrogen assimilated, percentage of nitrogen recovered and percentage of nitrogen in dry matter.

Limestone as CaO		Number of shoots per pot	Nitrogen assimilated after 70 days of growth	Time of harvesting						Recovery of N		
%	Lbs. per acre			After 70 days			After 103 days			per pot over check	In % %	
				Dry matter per pot	Nitrogen in dry matter per pot		Dry matter per pot	Nitrogen average of two per pot	Total Nitrogen in dry matter per pot			
			%	gm.	%	mgm.	gm.	gm.	%	mgm.	mgm.	%
0.0	—	7.0	—	0.15	—	—	0.16	0.18	—	—	—	—
0.1	2000	17.0	—	—	—	—	11.8	11.8	2.20	260	95	29.7
0.2	4000	27.0	9.5	8.6	3.88	352	33.7	33.0	1.18	389	226	70.6
0.4	8000	32.0	17.4	8.7	4.25	370	32.3	32.0	1.40	448	230	71.9
0.6	12000	31.0	17.2	8.4	4.35	365	32.1	32.7	1.35	441	218	68.2
0.8	16000	26.0	13.8	7.4	4.37	349	31.8	29.5	1.37	405	156	48.8
							32.9	28.2				

In tables 5—7 the results of the series with nitrogenous fertilizers (Series III—V) are represented. A very clear effect was noticed in the increase of dry matter and in the higher percentage of nitrogen in dry matter at the end of the harvest, as compared with series I and II. The percentage of nitrogen in dry matter at the time of the first harvest is also considerably higher. With nitrate of soda the yield of dry matter in

Table 7.

Series V. (Minerals and cyanamide). Influence of different amounts of lime applied on yield of dry matter, total nitrogen assimilated, percentage of nitrogen recovered and percentage of nitrogen in dry matter.

Limestone as CaO		Num-ber of shoots per pot	Nitrogen assimilat-ed after 70 days of growth	Time of harvesting						Recovery of N		
%	Lbs. per acre			After 70 days			After 103 days			per pot over check	In % %	
				Dry matter per pot	Nitrogen in dry matter	Total Nitrogen per pot	Dry matter per pot	average of two	Nitrogen in dry matter per pot			
			%	gm.	%	mgm.	gm.	gm.	%	mgm.	mgm.	%
0.0	—	7.0	—	0.20	—	—	0.17	0.18	—	—	—	—
							0.20					
0.1	2000	16.0	—	?	2.90	—	14.8	14.3	2.09	299	134	41.9
							13.8					
0.2	4000	20.0	18.7	5.4	4.50	243	17.9	16.8	1.78	299	136	42.5
							15.6					
0.4	8000	27.0	26.3	6.6	4.62	320	20.7	20.6	2.05	422	204	63.8
							20.6					
0.6	12000	26.0	32.2	6.4	4.50	288	24.3	23.9	1.72	411	188	58.8
							23.5					
0.8	16000	29.0	22.0	7.8	4.35	339	25.6	25.3	1.80	455	206	64.4
							25.0					

both harvests, the total nitrogen assimilated and the increase of nitrogen over the check¹⁾ gradually increases with the increase of lime used.

Taking as a basis the pH value of the soil at 30 days after seeding [the reaction having attained apparent equilibrium

1) Series II being assumed as check.

conditions (table no. 1)] it will be seen that below 6.0 of the pH value the increase in the amount of lime caused a striking increase in the yield of dry matter and total nitrogen. Above this point up to pH 7.5, the increases of dry matter and total nitrogen are much lower, as may be seen in diagram 2.

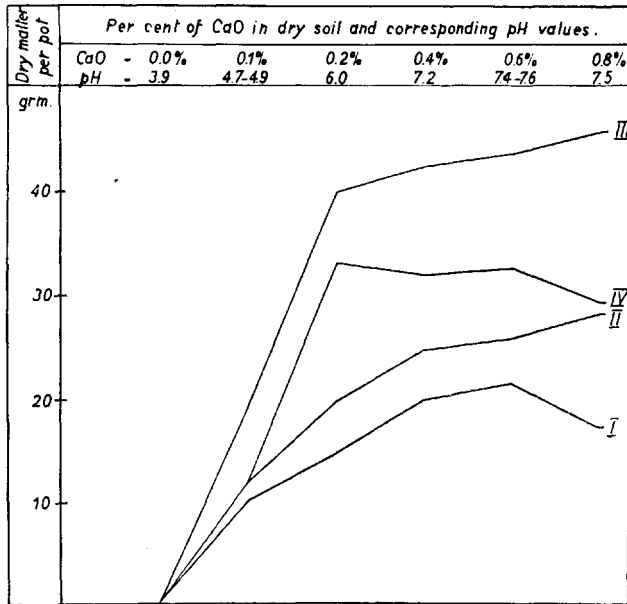


Diagram 2. Influence of different amounts of lime and reaction of the soil upon the yield of dry matter in Series I—IV.

- Series I. Without fertilizer.
- Series II. Minerals only.
- Series III. Minerals and nitrate of soda.
- Series IV. Minerals and sulphate of ammonia.

It is of interest to note that at the time of the first harvesting the percentage of nitrogen in Series III and IV at a lower pH value was lower than in the less acid pots (table no. 9, diagr. 3). At the time of the final harvest the reverse was the case (table no. 8).

Table no. 6 shows the results of series IV with sulphate of ammonia as the source of nitrogen. It seems that the yield of dry matter reached its highest point at pH value 6.0, and then commenced to decrease; but the decrease is not too striking, as is shown in diagram 2. The highest yield of the total nitrogen

assimilated takes place at pH value 7.2—7.4 (diagr. 4 and table 6), then it goes down considerably. Comparing diagrams 2 and 4 one may conclude that in general the yields of dry matter and total nitrogen coincide, but that in the highest yields they disagree in some cases.

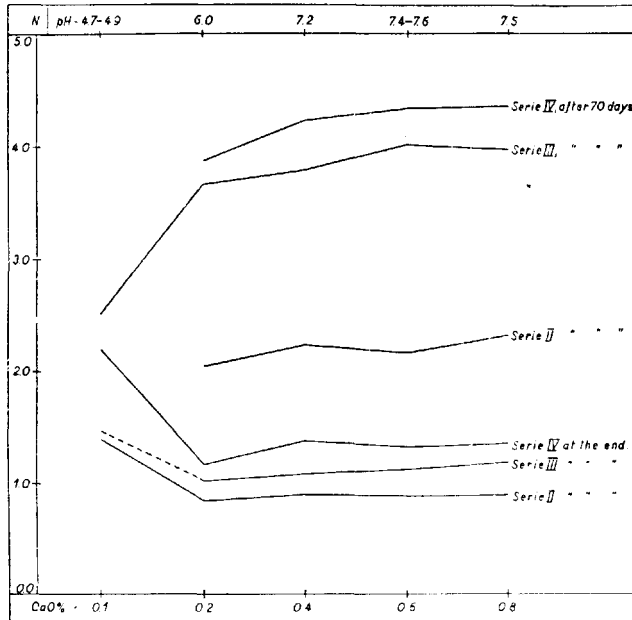


Diagram 3. Influence of lime upon the percentage of nitrogen in dry matter of barley (in two stages of growing period).

Serie II. Only minerals. No nitrogenous fertilizers.

Serie III. Minerals and nitrate of soda.

Serie IV. Minerals and sulphate of ammonia.

4. Influence of Lime upon the Percentage of Nitrogen in Dry Matter.

Here it is of interest to point out that the percentage of nitrogen in dry matter is higher with an application of sulphate of ammonia than with applications of an equivalent amount of nitrate of soda. (Diagr. 3). This phenomenon is in fair agreement with the results obtained by Pitsch (76), Maze (68), Hutchinson and Miller (41), and some other experimentors referred to above. It may be added that Gericke (28) has recently investigated the differences produced in the protein content

of the grain of several cereals by applications of nitrogen made at different growing periods and has come to the conclusion that the results from the sets of pots with ammonium sulphate "are essentially similar to the results obtained from the sets treated with nitrate of soda".

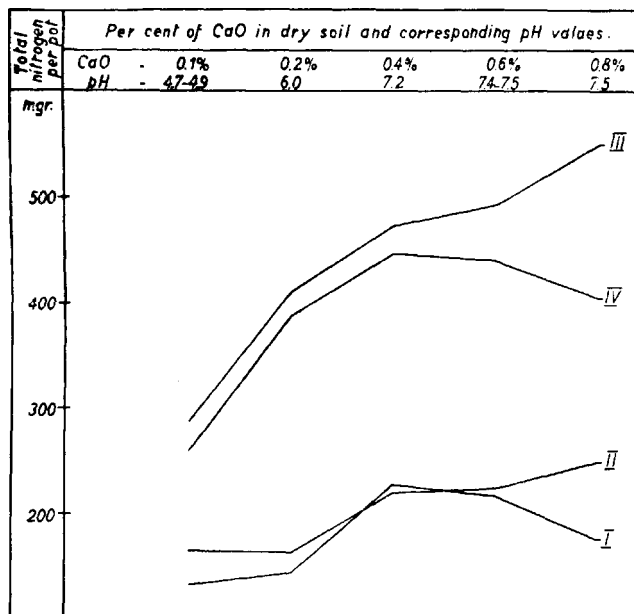


Diagram 4. The influence of different amounts of lime and reaction of the soil on the total nitrogen assimilated per pot in Series I—IV.

- Series I. No fertilizers.
- Series II. Minerals only.
- Series III. Minerals and nitrate of soda.
- Series IV. Minerals and sulphate of ammonia.

In the series with cyanamide (table no. 7) it will be generally observed that the injurious effects of the cyanamide have brought about certain abnormalities in the life of the barley, therefore the results must be taken with precaution. First of all, it is of interest to note the extraordinarily high percentage of nitrogen in the dry matter of the second harvest. This is not to be explained on the basis of the retarded growth of the plants, since the barley was in head in this series and had reached the same stage of development as in the other series. And besides,

the leaves were more dry than in the other series. The nitrogen increase may perhaps be explained by some specific influence of the cyanamide. We shall give a summary of the nitrogen content in the dry matter of the second and first harvest.

Table 8.

Nitrogen percentage in dry matter in different series at the final harvest.

Calcium oxide used %	Percentage of nitrogen in dry matter				
	Series I	Series II	Series III	Series IV	Series V
	%	%	%	%	%
0.1	1.31	1.40	1.48	2.20	2.09
0.2	0.96	0.83	1.03	1.18	1.78
0.4	1.14	0.88	1.10	1.40	2.05
0.6	1.05	0.87	1.14	1.35	1.72
0.8	1.05	0.88	1.20	1.37	1.80

Table 9.

Nitrogen percentage in dry matter in different series at the first harvest.

Calcium oxide used %	Percentage of nitrogen in dry matter				
	Series I	Series II	Series III	Series IV	Series V
	%	%	%	%	%
0.1	—	—	2.52	—	2.90
0.2	2.09	2.05	3.68	3.88	4.50
0.4	2.00	2.25	3.00	4.25	4.62
0.6	2.62	2.18	4.02	4.35	4.50
0.8	2.90	2.33	3.98	4.37	4.35

From the table no. 8 and diagram 3 it will be seen that at the final harvest in series II—IV the lowest percentage of nitrogen resulted from an application of lime to the amount of 0.2% CaO in the soil, which gave a pH value of 6.1—6.3. From that point a slight increase begins in the percentage of nitrogen which reaches about constant nitrogen content for every series at a pH value of ca 7.0. In the series without any nitrogenous fertilizers (series I and II) an increase of lime changed the pH

value of the soil and did not markedly increase the percentage of nitrogen in the dry matter after the neutral reaction in the soils had been reached. In the series with nitrate of soda, an increased lime application was followed by an increase of the nitrogen content in the dry matter. At the time of the first harvest, the increase of lime was followed by an increase of the nitrogen content up to pH value 7.4—7.5.

5. Influence of Lime upon the Recovery of Nitrogen Applied in Fertilizers.

In tables no. 5—7 (the last columns) are shown the percentages of nitrogen recovered by barley at the last heading stage from the nitrogenous fertilizers applied. The percentages of nitrogen recovered are obtained by subtracting from the total recovery in the nitrogen fertilized pots of a given series, the amount recovered in the corresponding minerals pots (Series II, without nitrogen fertilizers) for that series, dividing the remainder by the amount of nitrogen applied per pot and pointing off for the percentage. The first result apparent from these data

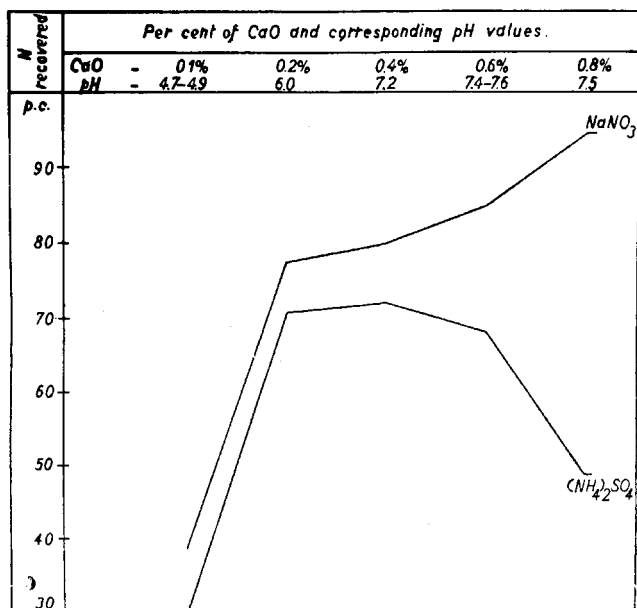


Diagram 5. Influence of different amounts of lime and reaction of the soil upon the recovery of nitrogen from nitrate of soda and sulphate of ammonia.

is that at pH values below 6.0, lime has had a striking effect upon the recovery of nitrogen from nitrate of soda and sulphate of ammonia. For the cyanamide this stage is reached later. Diagram 5 confirms the above statement concerning the recovery of nitrogen from nitrate of soda and sulphate of ammonia.

At the pH value 6.0 the increase in the recovery of nitrogen with nitrate of soda is reduced, but the recovery continues to increase gradually and reaches the highest point in our experiment at the pH value 7.5. With sulphate of ammonia below the pH value 7.2, we have almost the same amount of nitrogen recovered as at 6.0, but after this point, the per cent recovery of nitrogen from sulphate of ammonia goes down and after the pH value 7.6, it takes a sudden drop.

In tables no. 3—7 are also given the percentages of the total nitrogen assimilated after 70 days of growth. This percentage generally fluctuates between plus 20—30 and cannot be correlated with the amounts of lime. It is of interest to note that in the unmanured series the increase of lime is followed by a decrease of the percentage of nitrogen assimilated after 70 days, and that at pH value 7.5 some loss of nitrogen is indicated after 70 days.

Table 10.

Nitrate nitrogen in the soil during the period of growth. P. P. M. on air dry soil.

Time of sampling	Limestone as CaO		No plants		Barley plants			
	Per cent	Lbs. per acre	No fertilizers		Muriate of potash, acid phosphate and			
			Series I	Series II	— Series III	Nitrate of soda Series IV	Sulphate of ammonia Series IV	Cyanamide Series V
After 70 days	0.0	—	—	0.8	0.7	37.0	1.1	0.9
	0.2	4000	—	0.2	0.2	2.3	0.4	0.2
	0.4	8000	—	0.3	0.3	3.2	2.5	0.2
	0.6	12000	—	0.4	0.2	3.1	0.9	0.3
	0.8	16000	—	0.2	0.2	2.8	0.8	0.2
	0.0	—	0.9	0.4	1.0	24.3	2.8	0.7
After 103 days (at end of experiment)	0.1	2000	—	0.4	0.3	6.4	0.4	0.4
	0.2	4000	4.1	0.3	0.4	0.4	0.3	0.5
	0.4	8000	16.0	0.6	0.5	0.5	0.6	0.5
	0.6	12000	27.4	0.5	0.6	0.7	0.6	0.5
	0.8	16000	25.8	0.5	0.5	0.6	0.7	0.6

6. Influence of Lime upon the Formation of Nitrate in the Soil.

In order to obtain some information on the influence of lime upon the formation of nitrate in the soil, determinations were made at the start, at certain intervals, and at the end of the experiment. The results are summarized in table no. 10. The original soil had 0.9 p. p. m. nitrate nitrogen on a dry basis.

In the unplanted and unfertilized series, it will be seen that the increase of lime is followed by an increase of nitrates, the highest amounts of nitrate found during the 103 days being at pH values 7.5—7.6. In the unlimed pots with a pH value of 3.93, no nitrates were formed in the course of 103 days. With a lime application of 4000 pounds per acre and a pH value about 5.9 only an insignificant amount — about 3 p. p. m. — of nitrate nitrogen was formed during the same period. In all planted and limed pots, with the exception of the series with NaNO_3 , the amount of nitrate nitrogen was less in the majority of cases than one p. p. m. In the series with nitrate of soda at the first harvest, the nitrate content was considerable with nitrate of soda. At the second harvest no differences comparable with the other series are apparent. Only with a lime application of 0.1% higher nitrate nitrogen content was found; this may be explained by the fact that a later application of nitrate of soda was made (see table 5). It is also worth noting that in the series with nitrate of soda the amount of nitrate nitrogen in the unlimed pots, which produced practically no growth, gradually diminished. At the start of the experiment and also after 30 days a 43 p. p. m. nitrate nitrogen was added. In the unlimed pots 37 p. p. m. was found, after 70 days, and after 103 days, 24.3 p. p. m. Apparently the nitrates were utilized by the microbial flora capable of surviving in such an acid soil.

It may be added that the experiment was conducted during the winter from December 8 to March 20, in the greenhouse. The greenhouse temperature, during the experimental period, varied considerably from day to night. It must also be stated that there was comparatively little sunshine during the day. These conditions influenced the length of the growth period and perhaps also some of the results as regards the percentage of nitrogen recovered.

Conclusions.

From the experiment with barley described above the following conclusions may be drawn:

1. Ground limestone decreases the hydrogen ion concentration in the soil and in very acid soils changes in the pH values up to the neutral point may be correlated with the amounts of lime used. Above the neutral point the changes in the pH values, were much less marked when ground limestone was applied.
2. Ground limestone considerably decreases the solubility of aluminium compounds in the acid loam soil.
3. Ground limestone at first considerably increases the yield of dry matter in very acid loam soil. Above the neutral point the applications of lime cause either a small increase or even a decrease in the yields of dry matter. It is noteworthy that a heavy application of ground limestone caused a considerable decrease in the yield with sulphate of ammonia.
4. At an early stage of growth (up to 70 days in the experiment) an increase of lime applied is followed by an increase of the nitrogen percentage in the dry matter. An increase of lime applied at pH values 6.0—7.5 has only an insignificant influence upon the percentage of the nitrogen content in the barley crop at the heading stage. In general, the percentage of nitrogen in dry matter is considerably higher with an application of nitrogenous fertilizers.
5. The recovery of the nitrogen of nitrate of soda and sulphate of ammonia at pH values below 6.0 is strikingly benefited by lime. After this point the recovery of nitrogen of nitrate of soda increases only gradually and reaches the highest percentage at pH value 7.5. With sulphate of ammonia the highest percentage of recovery is reached at a pH value of about 7.2, and from this point the percentage of nitrogen recovered goes down, at first slowly, then rapidly; and at the value 7.5 it drops to 48.8%.
6. Lime considerably increases the formation of nitrates in unplanted pots. At a pH value below 4.0 no nitrate in unplanted pots was formed. At the pH value about 5.9 only

an insignificant amount — about 3 p. p. m. — of nitrate nitrogen in course of 103 days in unplanted pots was formed.

7. The application of sulphate of ammonia during the first part of the growth of the barley, decreases the pH value by about 0.1—0.2, as compared with nitrate of soda.

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