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Comparative Value of Cyanamid in Fertilization of Apple Trees

Soil Changes and Tree Response

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ABSTRACT

Quantitative determinations for nitrate and ammonia nitrogen content were made on soil samples taken at various depths under mature apple trees growing in sod and fertilized with Cyanamid, ammonium sulfate, and sodium nitrate in the fall and spring. With high moisture conditions the decomposition of Cyanamid was rapid and in a few days the ammonia concentration in the soil was almost as high as from fertilization with ammonium sulfate. When no rain fell soon after the Cyanamid was applied, the quantity of available nitrogen in the soil was reduced below that found from the use of the two other materials. This seemed to indicate that a portion of the Cyanamid nitrogen either had been lost or tied up by some biological or physical process.

There was a significant and quite similar soil penetration of ammonia from Cyanamid and ammonium sulfate under optimal weather conditions. Very little variation was observed in rates of nitrification of nitrogen from Cyanamid and sulfate of ammonia, but the rapid absorption of nitrogen by the trees from these materials indicated that this transformation may not be necessary. If the ammonia content resulting from the application of fertilizers is taken as a measure of the residual effect, then greater soil retention of nitrogen results from fertilization with ammonium sulfate than from application of Cyanamid.

The nitrate form of nitrogen was taken up more rapidly by the trees than the ammonia form, but the ammonia continued to be absorbed over a longer period. Sod was a serious competitor for nitrogen applied in the spring. This was in part responsible for the efficient utilization of nitrate of soda in the fall and the good results obtained from the spring application of Cyanamid, which has a temporary caustic effect on grass. Differences in growth and in nitrogen content of the developing parts of the fertilized trees were small but correlated well with variations in the available nitrogen of the soil. Fall applications of all forms of nitrogen fertilizers used gave equally good, if not better, results than spring applications. There was little difference in growth and nitrogen recovery from the three materials under favorable conditions and, with proper use, Cyanamid was as satisfactory as sulfate of ammonia and nitrate of soda for fertilization of apple trees.

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George E. Smith and A. E. Murneek

INTRODUCTION

The recently adopted practice of applying sodium nitrate or ammonium sulfate in the fall rather than in the spring season for apple trees, and the introduction of another nitrogenous fertilizer in the form of Cyanamid has raised the questions as to (a) the proper time of application, and (b) the best source of the nitrogen for this purpose. Cyanamid, as a newer form of fertilizer, has received much attention both in the laboratory and in the orchard. Its unusual properties and desirable residual effects have been called to particular notice. Some experimental work has been done on comparison of these three sources of nitrogen and on the best time for their use in the orchard, but results are not yet conclusive.

The interpretations of fertilizer values and recommendations for their use are often based entirely on plant response, commonly without regard to the soil as a medium through which the nutrients are supplied. Occasionally soil studies alone, without consideration of the plant, have been the experimental source for recommending specific fertilizer treatments. Reasoning on such grounds seems unsafe since the apple tree is a plant that contains large and variable quantities of reserve food materials and its roots cover great soil areas, in which the seasonal nutrient levels may fluctuate widely through competition, for example, with sod crops. Growth differences or changes in the nitrogen content of various parts of the tree may be used as measures of fertilizer value. Unfortunately, growth response is frequently very small even from widely varying treatments. However, if the quantity of nitrogen obtained from the soil by the trees, and the amount of their growth made, can be correlated with nitrogen transformations and movements within the soil zone of the tree roots, then it may be possible to put on a more reliable basis recommendations for fertilizer applications.

REVIEW OF LITERATURE

Because of the importance of nitrogen in plant nutrition and the ease of securing visible and chemical differences from its use, the various forms of nitrogen have been studied extensively both in the laboratory and in the field. Some attention has been given by investigators to the comparative value of different nitrogen carriers for fruits and to the most effective season for their application, but the results from this work are by no means conclusive. The present review will deal only with literature that bears on the use of nitrogen for tree fruits, and of the more recent reports pertaining to the soil transformations and plant utilization of nitrogen from Cyanamid, where this material of uniform composition was employed.

Season of Application

Ever since the early experimental work in Missouri by Hooker (20) (21) (22), who first demonstrated that fall application of nitrogen could be utilized effectively by apple trees, several investigators have supplied evidence as to the relative merits of the various times of application. Weinberger and Cullinan (54) and Aldrich (2) found that nitrogen from fall application is absorbed by the roots in the autumn and held there until growth starts in the spring. The former pointed out that when nitrate was applied in the spring, on soils with high response, results were better than when this fertilizer was put on in the fall, while with Cyanamid and ammonium sulfate the season made little difference. Small variations between fall and spring application of ammonium sulfate and sodium nitrate were obtained by Schrader and Auchter (46) (47), while Gourley (16) reported better results from fall than spring application of Cyanamid.

Comparison of Cyanamid, Nitrate, and Ammonium Nitrogen in Orchards

Collison and Harlan (7) secured greater yields of apples from nitrate than from the ammonium form of nitrogen. They (18) obtained higher yields from nitrate on the light soils, while Cyanamid and ammonium sulfate gave as good or better results on heavy soils. Collison and Anderson (6) working over a six year period on New York soils having a high nitrogen response found that when ammonium sulfate, sodium nitrate, and Cyanamid were applied early in April, there was little difference between yields. However, the nitrate fertilizer produced greater growth than did the ammonia forms. Aldrich (2), Weinberger and Cullinan (54), and

Schrader and Auchter (46) (47), who compared various sources of nitrogen on soils where the response from nitrogen was considerable, found that the nitrate form gave a larger growth and nitrogen recovery. Marsh (28) (29), applied Cyanamid two weeks before bloom to apple trees with results somewhat less satisfactory than those obtained from sodium nitrate and ammonium sulfate. Murneek (39) observed no difference in yields between ammonium sulfate and Cyanamid treatments during the first two years but by the third year the trees receiving Cyanamid produced nearly a bushel more per tree. Gourley (16) believes that Cyanamid should give as good results as the other materials if it is applied at the proper time.

Effects of Ammonium Sulfate and Sodium Nitrate

Sodium nitrate is a fertilizer of basic reaction while ammonium sulfate leaves an acid residue. Obviously they will have varying residual effects when used for long periods and will have different influences on the soil properties. On the Jordan fertility plots at Pennsylvania for example (40), where these fertilizers have been used continuously for fifty years, ammonium sulfate has brought about such an acid condition as to make the soil highly unproductive. During the first twenty-five years there was little difference in crop yield, but since that period there has been a rapid decline in yield on the ammonium sulfate blocks. At Rothamsted (40), on a sandy soil, twenty years elapsed before this condition developed and at Missouri on Sanborn field (33), the break in productivity came after seventeen years.

Crowther and Basu (11) found in their study of the various Rothamsted plots that these materials varied markedly in their cumulative effect on the reaction of different soil types. Continuous use of ammonium sulfate reduced the amounts of the exchangeable bases and increased the total acidity. Sodium nitrate had little effect on the base content of the soil. Although large quantities of sodium have been added, there has been little accumulation of this element in the soil. A conspicuous effect of sodium nitrate has been a destruction of the adsorption complex, with a reduction of the soil's exchange capacity. Apparently a part of the clay was dispersed and filtered down through the soil with it. Studies at Pennsylvania (40), on the Jordan plots and elsewhere have been in close agreement with the above results.

That apple trees are more tolerant of soil acidity and have a lower calcium requirement than many other crops has been advanced as a support for the use of ammonium sulfate in the orchard. Toxicity, due to continuous application of this material, is not clearly understood and this detrimental effect appears to differ from that by naturally developed soil acidity (26), (40), (45). In the light of injuries to grain crops in the case of the long time field trials with ammonium sulfate, it would not be unreasonable to assume that if this salt were used continuously in orchards eventually the soil conditions might exert a deterimental effect on the trees.

Absorption of Nitrate and Ammonia Nitrogen by Plants

In their summary of the literature, Tiedjens and Robbins (53), find the bulk of evidence to indicate that practically all plants can use the ammonium form of nitrogen if applied to soils at the proper pH. The rate of ammonia assimilation increases as the nutrient medium becomes more alkaline. Nitrate is utilized more effectively under more acid conditions. Pirschle (53), found that various seedlings reacted differently to ammonia and nitrate, but nitrates were preferred in an acid medium. He showed that the acidity of the nutrient solution was an important controlling factor in the direct assimilation of ammonia by crop plants. Shive (48), states that seedlings absorb more ammonia than nitrate nitrogen but that the reverse is true for mature plants.

Tiedjens and Robbins (53), demonstrated with various plants that ammonia was no more injurious than nitrates and that plants could grow well and assimilate nitrogen from ammonium hydroxide Tiedjens and Blake (25), found ammonium ions more efficient than nitrates with young apple trees and that the pH of the culture medium limited the assimilation of both nitrate and ammonium ions directly or indirectly. Davidson and Shive (13) obtained almost identical results with peach trees.

From these evidences it would seem that on soils with a pH above 6, fertilizers supplying nitrogen in the ammonia form should be as efficient as nitrates. Theoretically, ammonia would appear to be a better source of nitrogen than nitrates, since the latter must be reduced to ammonia in the process of synthesis of organic nitrogen compounds.

Calcium Cyanamide

Cyanamid is a nitrogen containing fertilizer whose chief constituent is calcium cyanamide.* As manufactured, it contains about 65% calcium cyanamide, 17% calcium hydroxide and 12% free carbon. Its nitrogen content is 21%. Due to peculiar

*In this discussion the commercial product will be referred to as Cyanamid, while the pure salt will be spoken of as calcium cyanamide, and the acid compound (H_2CN_2) as cyanamide.

properties it has received considerable attention. Much of the earlier work was carried on with free cyanamide (H_2CN_2) rather than calcium cyanamide ($CaCN_2$). The difference in behavior of these compounds may account partly for the inconsistent results obtained from field and laboratory studies.

Chemistry and Soil Reactions of Calcium Cyanamide

Crowther and Richardson (12), Cowie (9), McCool (32), and Smock (49) give well summarized accounts of the transformations of calcium cyanamide in the soil. Calcium cyanamide dissolves with decomposition in water to give an acid salt and calcium hydroxide according to the following equation:

$$2CaCN_2 + 2H_2O = Ca(HCN_2)_2 + Ca(OH)_2.$$

This acid salt may be decomposed further to the basic salt and free cyanamide, as follows:

$$2Ca(HCN_2)_2 + H_2O = Ca(OH)_2 + 2H_2CN_2$$

with the basic salt breaking down to free cyanamide (H_2CN_2) and calcium hydroxide.

In acid solutions or at pH values encountered in most soils the free cyanamide is hydrolyzed to urea.

$$H_2CN_2 + H_2O = CO(NH_2)_2$$

In an alkalin medium, such as might result from an uneven distribution of the fertilizer, cyanamide may polymerise in part to dicyandiamide, ($HN = \underset{\displaystyle NH_2}{\overset{|}{C}} — NH — CN$) which is more insoluble than cyanamide.

It is definitely established that the change from calcium cyanamide to urea is chemical rather than biological. Cowie (10) showed that in sterile soils urea was formed and accumulated. Kappen (24) and Ulpani, according to Pranke (42), found these changes were catalyzed by many inorganic compounds, especially salts or oxides of iron and manganese. They believe that the cyanamide molecule is adsorbed on the surface of the soil particle where under the effects of these catalysts it is broken down to urea. Crowther and Richardson (12), found that a large number of minerals could bring about this change. This transformation took place readily in all soils, but is slower in the more sandy types. Within limits, the rate of disappearance was most rapid at high temperatures and with low moisture content. Fink (15) found that soils varied greatly in the rate with which they removed cyanamid from solution.

McCool (32), in summing up numerous observations on dicyandiamide, concludes that under normal conditions, with reasonable care as to time and method of application of calcium cyanamide, the quantity of this more slowly available substance formed is not of practical importance. Under certain conditions, however, it may be significant (3). Moyer (35) has found that plants may utilize nitrogen from dicyandiamide, but it is slowly available and would not be satisfactory for crops that need nitrogen early in their growing season.

The Formation of Ammonia and Nitrate from Cyanamid

Crowther and Richardson (11) (12) (43), and Mukerji (36), report that under moist conditions only a few days are necessary for the ammonia content of Cyanamid-treated soil to be equal to that receiving ammonium sulfate. Fall applications of Cyanamid nitrified slowly while with spring applications, the rate was somewhat slower than with ammonium sulfate. A small dressing of dicyandiamide retarded but did not inhibit nitrification. Though yield differences from the use of ammonium sulfate and Cyanamid were small, Cyanamid gave poorer results when the response to nitrogen was low and better when the response was high. Numerous laboratory studies have been carried out on the nitrification of Cyanamid, most of which show no direct relation to field work. It seems that for most crops the rate of nitrification should not be taken as an index of the value of Cyanamid.

Residual Effect of Cyanamid

Tidmore and Williamson (51) and Pierre (41) found that Cyanamid increased the pH of all soils. Moyer (35) noted that Cyanamid raised the pH of soil higher than an equal weight of hydrated lime. In summing up a number of articles, McCool (32) concluded that when Cyanamid is used over a period of years the soil will be comparable to one receiving ammonium sulfate, and an equal weight of hydrated lime.

By deduction one could reason that Cyanamid, by supplying nitrogen in the ammonia form and making the soil reaction more basic should be more efficient with continuous use, while the reverse condition would be true for ammonium sulfate and sodium nitrate. This theory is supported by the work of investigators (17) (29) (47) who have found an increased response with continuous application of Cyanamid.

MATERIALS AND METHODS

The orchard used for these experiments is on loessal soil in the Missouri river hills, and classified as Memphis silt loam. The soil is not very deep, grading into a heavier texture 24 to 30 inches below the surface, although the tree roots penetrate to a much greater depth. It has a pH of about 6.0 in the surface seven inches. It possesses excellent physical properties, but gives a high response to nitrogen since it contains only about 2000 pounds of N in an acre seven inches.

The trees were fourteen years old in 1934 from date of planting. They are spaced 27′ x 30′ and grow in moderately heavy sod, which is chiefly blue grass. The orchard has received good care and the trees are exceptionally uniform in development. It had received little fertilizer until the spring of 1934 when three pounds of Cyanamid were applied per tree. The trees had been making satisfactory growth and were in a vigorous state.

Four rows of Gano trees adjacent to four rows of Golden Delicious that run the entire length of the orchard were selected for this study. For each fertilizer treatment a block extending across the four rows of each variety and containing eight trees was used. A duplicate set of blocks was selected in a distant part of the orchard. Samples were collected from these 16 trees.

The first fall applications were made from September 20 to October 1 and the second after November 1 when the leaves were usually falling. The first spring treatment was put on from six to eight weeks before, and the second about two weeks before bloom. Each tree received one pound of actual nitrogen (N) spread broadcast beneath the branches.

Composite soil samples were taken at intervals of 12 to 16 days by borings from the surface to a depth of 18 inches. The samples from various depths were kept separately.

A composite sample of the fibrous roots from about 12 trees were collected each time the soil samples were obtained. The roots were washed free from soil, and all over 2 mm. in diameter were discarded. These finer roots were dried in a forced draft oven at 70° C, ground to a fine powder, and bottled for later analyses.

A few whole blue grass plants were taken as samples at the same time from the different blocks, washed, dried and ground similarly to the root samples.

Twig and spur samples were collected starting in the winter and continuing throughout the spring and summer. All of them were taken in early morning, brought to the laboratory and prepared for drying immediately. Uniform bearing spurs from three and four year old wood, with all attached tissues were collected in 1936. In 1936 there was no crop so that the spurs were all non-bearing. From 40 to 50 twigs and spurs composed a sample. Twig samples were divided into old twigs, new twig growth, and twig leaves. Spur samples were divided into spurs, spur leaves, and fruit. The samples were dried at 70° C and the total dry weight determined. They were ground finely and brought to a uniform moisture content before analyses were made. The total quantity of nitrogen present in a given tissue was calculated from the percentage of nitrogen and the dry weight per unit of tissue. This has been found (37) to be desirable since presentation on a percentage basis may not convey a true picture of the total amount of nitrogen absorbed.

In 1935 about two hundred twigs from each plot of the Golden Delicious trees were cut and brought into the laboratory, dried, and length and weight measurements obtained. In 1936, measurements of twig length and diameter (middle of twig between nodes) were made in the field.

Methods of Analyses

The official Kjeldahl-Gunning-Arnold method was used for total nitrogen determinations.

For cyanamide and dicyandiamide determinations, the Caro and Broux method as modified by Crowther and Richardson (12) were used.

In all of the soil analyses made for nitrates and ammonia, where no cyanamide or urea was present, the soil was extracted with a mixture of .2N HCl and N $NaCl$, and the extract from 50 grams distilled into .02N acid.

Matthews aeration method (31) was employed for all ammonia determinations where urea or cyanamide was present.

For urea determinations a few cc. of an extract of Jack Bean Meal was added to the flasks after the ammonia had been removed by aeration. They were allowed to stand three hours to hydrolyze the urea and the resulting ammonia was drawn off into an excess of .02 N acid.

The method of Jacob (23) was used to determine the nitrate nitrogen in cases where cyanamide and urea was present. Where these were no longer evident, the residue from the ammonia distillations was diluted, Devarda's Alloy added and the mixture distilled.

RESULTS

A voluminous quantity of data accumulated during the two seasons in which these measurements were made. The results in general, for related samples, and for the two years, are in close agreement. Only a portion of the evidence, the rest of it being largely duplication, has been included here, with a few notes in the discussion concerning the measurements for which no data are presented.

Fertilizer Applications and Weather Conditions

In the fall of 1934, the first application of fertilizer was made on October 2 to soil that was moist from recent rains. However, as shown in Figure 1, no rain fell for two weeks after the materials

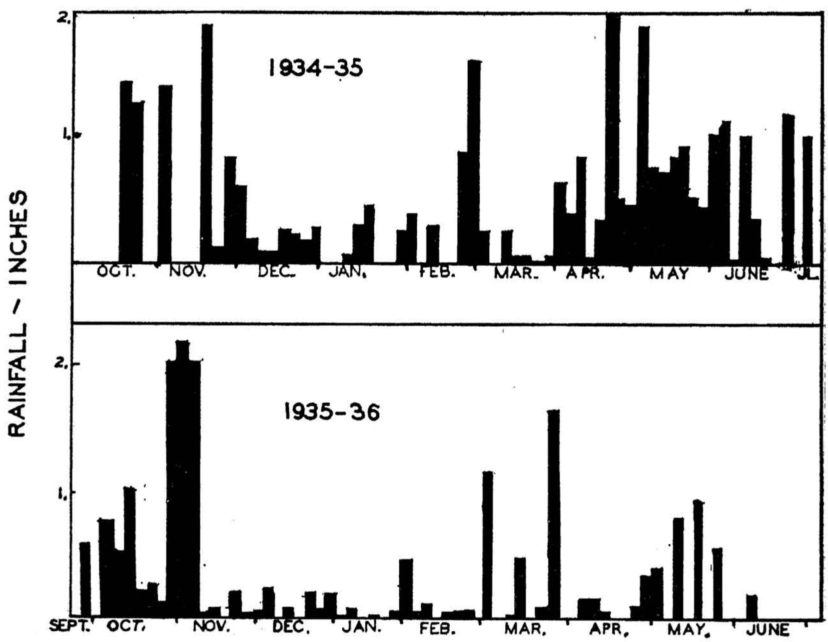

FIGURE 1. RAINFALL IN INCHES/4 DAY INTERVALS.

were applied. In 1935 the corresponding application was made on September 20. The moisture conditions were somewhat similar. All visible remnants of ammonium sulfate and sodium nitrate had disappeared from the ground in a few days, but the granules of Cyanamid, covered by a white crust, remained visible for some time. The late fall applications made on November 6 and 1, in the two years respectively, were each subjected to heavy rainfall and the Cyanamid granules soon disappeared. The fall and winter season of 1934-1935 was about normal in respect to rainfall and temperature, but the winter of 1935-1936 was excessively cold.

The spring of 1935 was wet so that the applications of all three materials made on March 14 and March 30 disappeared quickly. There was much less rain in 1936. Fertilizers of the first application of that year, given on March 4, disappeared rather rapidly, but later there was so little rain that it is doubtful whether the trees received before the blooming period much of the nitrogen from fertilizers applied on April 2. Cyanamid granules were collected from the blocks receiving this application until as late as August. The summer of 1936 was almost rainless and excessively hot. The trees suffered from drouth and made little growth.

Seasonal Changes of Nitrate and Ammonia in Untreated Soil

The records on nitrate and ammonia contents of the check block are in agreement with those from other studies (1) showing that nitrate production closely followed the rainfall curve, reached a peak in late spring and fall following the rains, and were very low during the dry part of the summer and in mid-winter.

The soil was almost saturated with water until June in 1935. The wet condition apparently caused the nitrates to be washed out as fast as formed or else inhibited nitrification. The highest quantity of nitrate found was about 8 p.p.m. In 1936, under drier conditions, the nitrate values were a little higher, reaching 10 to 11 p.p.m. in the surface soil. At no time except in mid-winter, was an appreciable quantity of nitrate found below eight inches, and then the amount was not over 5 or 6 p.p.m. In no case did the ammonia content show any large differences and seldom rose beyond 12 to 15 p.p.m. in the surface soil and occasionally as high as 10 p.p.m. at a depth of 12 to 18 inches below the surface.

Movement of Sodium Nitrate

The records from the fall applications of 1934 indicate the rapidity of downward movement of nitrates, as shown by the data given in Table 1. Nitrogen from the late application, due to heavy rainfall, went to the lower depths at a more rapid rate and in greater quantities than that from the earlier treatment.

Six days after an application was made on November 1, 1935, during which period over three inches of rain fell, there were already 48 p.p.m. nitrate nitrogen at a depth of four to eight inches, while the surface four inches contained only 20 p.p.m. At the same time there were about 25 p.p.m. in the eight to 18 inch depth. The

TABLE 1.—NITRATE CONTENT OF SOIL AT DIFFERENT DEPTHS.
Sodium Nitrate given in the fall of 1934
(as p.p.m. of nitrogen)

Date of Sampling	Depth of Samples, in Inches 0-4	4-8	8-12	12-18	0-4	4-8	8-12	12-18
	Applied October 2				*Applied November 6*			
Oct. 15	129.6	6.3	4.9	2.5				
Oct. 30	56.3	84.0	31.1	21.3				
Nov. 16	14.2	38.5	26.3	8.4				
Nov. 26					45.6	74.3	4.8	3.4
Jan. 5	7.0	20.0	15.3	4.5	3.4	13.3	16.0	13.9
Mar. 16	2.3	2.8	1.2	.6	.2	.1.	1.2	4.2
Apr. 13	.1	.1	.1	.0	.1	.1	.1	.1
May 17	2.3	.1	.1	.0	1.7	1.1	1.1	.6

increase in nitrate below eight inches was quite evident from November to January, but by March in both years and on both fall applications, all indications of sodium nitrate in the soil had disappeared. From the higher nitrate values, obtained from soil at the lower depths, it is suggestive that a considerable quantity from fall applications was lost through leaching.

The downward movement of nitrates was not so pronounced from spring fertilization. The quantity found in the 4-8 inch depth was not over 15 to 18 p.p.m. on any sampling date. That for the 8-18 inch depth was never significantly greater than the corresponding layer on the check blocks. In the wet spring of 1935, when a much heavier sod growth developed, the penetration of nitrate was no greater than in 1936 but its rate of removal from the soil was more rapid. Nitrates from spring applications had disappeared by June in both years.

The quantity of ammonia found in these soil samples was never great. In the spring, from 15 to 18 p.p.m. were found in a few samples from the fall applications. A greater amount was obtained in the dry spring of 1936 than in 1935, but the quantity in the surface soil was never over 20 p.p.m. In the 0-4 and 4-8 inch depths the ammonia content at times was from 5 to 10 p.p.m., which exceeded that on the check blocks. In the lower levels it ran two or three p.p.m. higher, with no consistent variations that could be related to time of application. These rather small differences show that no great amount of nitrate reduction took place and that the disappearance of the nitrate ion was due largely to its absorption as such by the tree roots or blue grass, or to its removal from the soil through leaching.

Movement of Ammonia From Ammonium Sulfate

The slow movement of the ammonium ion and the belief that NH_4^+ must be changed to NO_3^- before absorption, has been responsible for the recommendation of the application of ammonium sulfate for apple trees at least two weeks earlier than sodium nitrate. The quantity of ammonia found at different depths cannot be taken as an index of movement of the ammonium ion, since it may be oxidized to nitrate near the surface then leached to a lower level and reduced to ammonia there. Thus the climatic conditions and nitrate production must be considered when interpreting results.

The figures for the ammonia content at different depths of the soil receiving ammonium sulfate in the fall of 1935 (Table 2) were practically the same as the results of the previous year. On the

TABLE 2.—AMMONIA CONTENT AT DIFFERENT DEPTHS OF SOIL IN P.P.M. OF NITROGEN. AMMONIUM SULFATE GIVEN IN THE FALL OF 1935.

Date of Sampling	Depth of Samples, in Inches							
	0-4	4-8	8-12	12-18	0-4	4-8	8-12	12-18
	Applied September 20				*Applied November 1*			
Oct. 19	93.0	10.1						
Oct. 30	64.6	7.3	3.9		3.9	7.3		
Nov. 7					74.8	23.0	5.0	6.7
Nov. 16	42.6	13.4	7.9	2.2				
Nov. 22					65.2	11.8	12.3	5.0
Dec. 11	31.9	10.6	4.5	2.8	38.7	10.6	3.9	3.4
Jan. 11					33.0	26.4	9.9	9.3
Mar. 3	30.0	9.9	5.5	3.3	23.1	49.1	12.7	8.2
Apr. 2	19.3	6.0	3.3	2.7	23.2	12.1	4.4	5.5
Apr. 17	16.0	6.3	6.6	5.5	20.3	7.7	4.4	6.0
Apr. 30	10.4	6.6			18.2	12.1		
May 16	17.6	7.7			18.7	7.1		
June 19	23.6	7.1			19.8	8.8		

early application, where the fertilizer remained on the surface of the soil for over a week until rain fell, the amount of downward movement was small. On the later application, where rain soon fell, the quantity of ammonia in the lower depths was much greater. This amount was larger in the fall of 1934 since 20 days after the second fall application the soil 8-12 inches below the surface contained 25 p.p.m. and just below this 10 p.p.m. were present. The quantities were four or five times those found in the check blocks. It is also quite noticeable that throughout the winter the lower depths contained more ammonia from the late fall application than from the earlier one.

On the basis of the figures for penetration of the spring applications during the two years, as given in Table 3, it is evident that the quantity of ammonia which reaches the lower depths sampled is much smaller than is the case with fall applications associated with an abundance of moisture. That ammonia can be moved with heavy precipitation is well shown by the samples taken on April 13 and May 17 on both spring applications of 1935. There was a marked decrease in the ammonia content in the surface and a corresponding increase in the 4-8 inch depth.

TABLE 3.—AMMONIA CONTENT AT DIFFERENT DEPTHS OF SOIL IN P.P.M. OF NITROGEN. AMMONIUM SULFATE GIVEN IN THE SPRINGS OF 1935 AND 1936.

Date of Sampling	Depth of Samples, in Inches 0-4	4-8	8-12	12-18	0-4	4-8	8-12	12-18
	Applied March 14, 1935				*Applied March 30, 1935*			
Mar. 30	14.9	9.0	8.1	9.5				
Apr. 13	81.3	4.5	5.0	6.2	84.0	9.5	8.4	5.6
May 17	46.6	31.5	10.7	.5	43.1	29.2	8.4	7.2
July 9	34.6	17.2			29.4	16.5		
	Applied March 4, 1936				*Applied April 2, 1936*			
Mar. 3	13.7	6.5	4.9	6.5				
Mar. 19	88.5	26.5	4.9	4.9				
Apr. 2	88.0	6.6	1.6	2.2	9.3	6.6	6.0	4.0
Apr. 16	85.3	4.4	12.7	12.0	184.0	7.7	6.6	7.7
Apr. 30	74.8	8.8			109.0	16.5		
May 16	62.8	13.8			87.4	8.6		
June 9	18.1	12.7			37.9	7.1		

The slower removal of ammonia in 1936 than in 1935 reflects the effect of the drier spring in 1936, the surface soil during 1936 containing roughly twice as much nitrogen from the spring applications as was true for the previous year. At no time in 1936 was there a significant quantity of ammonia below the surface four inches and two months after application (June 9) the surface soil contained nearly 4 p.p.m. ammonia nitrogen, which was more than twice as much as was present in the soil given the fertilizer a month earlier. Since such a small quantity reached the 4-8 inch depth, it is probable that the removal of nitrogen from the soil was due to absorption by the bluegrass, while the roots received little.

The residual effect of the ammonium sulfate for fall and spring applications in both years was evident for a much longer time than was true for sodium nitrate. In June and July there was still present an appreciable quantity of ammonia in the soil of these blocks.

Penetration of Nitrates in Soil Receiving Ammonium Sulfate

There was never any significant quantity of nitrate found in the lower depths of soil receiving ammonium sulfate. On the early fall applications and the spring treatments of 1936 when optimum moisture conditions existed (Table 4) an appreciable quantity was found in the surface four inches. However, on all other applications (as will be shown later) the quantity of nitrate found was relatively small.

TABLE 4.—NITRATE CONTENT AT DIFFERENT DEPTHS OF SOIL RECEIVING AMMONIUM SULFATE (IN P.P.M. OF NITROGEN).

Date of Sampling	Depth of Samples, in Inches							
	0-4	4-8	8-12	12-18	0-4	4-8	8-12	12-18
	Applied October 2, 1934				*Applied March 14, 1935*			
Oct. 16	17.9	2.2	1.9	.1				
Oct. 30	15.7	2.8	4.6	3.9				
Nov. 16	9.8	3.1	3.2	3.6				
Nov. 26	6.3	4.5	3.1	2.0				
Jan. 5	5.0	6.4	5.5	6.3				
Mar. 16	5.5	.2	.1	.1				
Mar. 30	.1	.2	.1	.1				
Apr. 13	4.5	.5	1.7	.0	5.1	.1	2.2	2.0
May 17	5.1	.5	.0	.0	7.3	5.1	2.1	2.1
July 9					13.1	9.3		

Disappearance of Calcium Cyanamide

The difference in behavior of the various Cyanamid applications indicates that rainfall and soil moisture have a pronounced effect on its rate of decomposition and penetration into the soil. Granules of Cyanamid from the early fall treatments were still very numerous and possessed a white coating just before rain fell 2 weeks after application. Analyses of these granules collected two weeks after the application of October 2, 1934, showed 4.9% cyanamide and 2.4% dicyandiamide nitrogen. The data for analyses of soil collected after the application of October 2, 1934, (Table 5) indicate that a significant quantity of cyanamide was yet present after thirteen days. In no case was cyanamide or dicyandiamide detected in the 4-8 inch layer, which indicates that either these materials are not readily moved downward, or if so they are transformed to some other compound. This is further substantiated by the small amount of urea found at this depth.

TABLE 5.—CYANAMIDE, DICYANDIAMIDE, AND UREA CONTENT OF SOIL UNDER TREES IN P.P.M. OF NITROGEN. FERTILIZER APPLIED OCTOBER 2, 1934.

Days after application	Depth in inches	Cyanamide N	Dicyandiamide N	Urea N
7	0-4	20.8	2.0	18.6
	4.8	0.0	0.0	4.4
13	0-4	11.2	5.0	4.8
	4-8	0.0	0.0	2.6
28	0-4	0.0	14.0	2.4
	4-8	0.0	0.0	0.0

The quantity of dicyandiamide formed from this application was significant, since on October 30 the surface four inches contained 14 p.p.m. nitrogen in the dicyandiamide form. When rain soon fell, as was the case of the later fall application in both years and the spring application of 1935, no cyanamide or dicyandiamide could be detected in the surface four inches a week after application. During the very dry spring of 1936, the late application of Cyanamid disappeared rather rapidly, but the still later one persisted so as to permit samples of the granules to be collected throughout the summer until August. Analyses of these granules (Table 6) show that with these dry conditions the removal of nitrogen was slow.

TABLE 6.—ANALYSES OF CYANAMID GRANULES APPLIED ON SOIL SURFACE ON APRIL 2, 1936, AND COLLECTED AT VARIOUS FOLLOWING DATES. (NITROGEN AS PERCENTAGE OF DRY WEIGHT).

Nitrogen as	Date of Sample Collection			
	April 16	May 1	May 14	August 5
Total	11.0	7.7	2.5	1.0
Cyanamide	2.2	Trace	Trace	Trace
Dicyandiamide	8.0	5.8	2.0	.8

The granules collected on April 16, two weeks after application, still contained over half of the original nitrogen, much of which had changed to dicyandiamide, and disappeared very slowly during the dry summer. Such transformations, however, are abnormal. It is probable therefore that under optimum conditions all the cyanamide is transformed within a week, giving an insignificant amount of dicyandiamide.

These results are in accord with those obtained at Rothamsted (12) (43) and elsewhere, in that the rate of transformation to ammonia is rapid when the soil moisture is high or when Cyanamid is cultivated into the soil. Contrariwise, with deficient moisture, especially when the fertilizer is not incorporated into the soil, the rate of transformation to ammonia is much slower, and dicyandiamide may be formed.

The Formation of Ammonia from Cyanamid and its Penetration Into the Soil

The non-leaching properties of Cyanamid have been ascribed partly to the small amount of movement that can take place during the transformation to ammonia. If cyanamide retards nitrification (3) and the ammonia cannot move, then considerable time would be required for the nitrogen to reach the apple roots, and the response from the fertilizer would be slow.

The rates of ammonia production and penetration given in Tables 7 and 8 show that the transformation of Cyanamid was rapid. With the exception of the late spring application of 1936 the soil contained a large quantity of ammonia when samples were taken as early as two weeks after the fertilizer was applied. According to these figures, Cyanamid is much more slowly available than the other common commercial forms of nitrogen only when the conditions under which it is used are unfavorable for decomposition.

TABLE 7.—AMMONIA CONTENT AT DIFFERENT DEPTHS OF SOIL IN P.P.M. NITROGEN. CYANAMID GIVEN IN THE FALL OF 1934 AND SPRING OF 1935.

Date of Sampling	Depth of Samples, in Inches							
	0-4	4-8	8-12	12-18	0-4	4-8	8-12	12-18
	Applied October 2				*Applied November 6*			
Oct. 9	47.4	2.0	.0	.0				
Oct. 16	92.1	18.6	Trace	.0				
Oct. 30	68.3	16.8	16.6	6.6				
Nov. 16	62.7	10.4	3.9	4.5	70.4	Trace	.0	.0
Nov. 26	47.3	24.1	2.5	1.4	31.1	10.8	1.5	1.7
Jan. 5	24.0	7.7	2.2	2.0	30.0	15.0	1.7	Trace
Mar. 16	24.5	10.2	2.8	1.7	25.8	10.2	3.4	1.7
Apr. 13	15.1	6.8	1.2	.6	14.0	2.8	.0	1.2
May 17	16.8	9.0	7.9	4.5	5.1	12.9	7.9	2.8
July 9	14.3	6.9			6.7	14.8		
	Applied March 14				*Applied March 30*			
Mar. 30	81.5	14.5	12.5	6.1				
Apr. 13	88.0	14.0	14.0	.1	97.5	16.8	1.7	1.1
May 17	22.5	10.1	10.1	1.2	33.1	14.0	2.8	.1
July 9	19.4	9.4			13.8	9.8		

TABLE 8.—AMMONIA CONTENT AT DIFFERENT DEPTHS OF SOIL IN P.P.M. OF NITROGEN. CYANAMID GIVEN IN THE FALL OF 1935 AND SPRING OF 1936.

Date of Sampling	Depth of Samples, in Inches							
	0-4	4-8	8-12	12-18	0-4	4-8	8-12	12-18
	Applied September 20				*Applied November 1*			
Oct. 19	49.4	10.1						
Oct. 30	29.3	3.3	3.3		5.0	2.8	2.8	
Nov. 7					66.5	30.2	22.4	3.9
Nov. 16	36.4	16.2	2.8					
Nov. 22					28.0	16.8	9.5	6.8
Dec. 11	33.6	10.1	5.0	2.2	21.3	10.6	5.0	3.4
Jan. 11					17.0	13.2	5.5	6.0
Mar. 3	28.6	18.2	5.5	1.6	25.4	18.2	8.8	11.0
Mar. 27	13.2	6.0	1.1	1.6	11.6	11.0	6.0	6.5
Apr. 17	8.3	6.6	4.9	3.7	4.9	4.9	2.7	3.3
Apr. 30	15.4	8.3			11.5	7.1		
May 16	9.3	5.5			11.6	7.1		
June 9	12.4	7.7			12.7	8.8		
	Applied March 4				*Applied April 2*			
Mar. 3	10.4	7.7	6.0	4.4				
Mar. 19	60.5	12.1	4.9	6.0				
Apr. 2	27.5	14.8	10.4	4.9	7.7	4.4	2.7	1.6
Apr. 16	28.1	10.0	6.0	5.5	44.0	4.4	3.8	3.3
Apr. 30	32.4	11.5			33.0	7.1		
May 16	14.8	6.6			27.2	9.9		
June 9	17.6	7.7			19.8	6.6		

When the figures in Tables 7 and 8 are compared with those in Table 2 for ammonium sulfate, it is noticeable that the penetration of ammonia from Cyanamid was nearly as great as from ammonium sulfate. This is particularly well shown by the samplings on November 7 and 16 after the application of November 1, 1935. Here soil of the 4-8 and 8-12 inch depths on the Cyanamid blocks had a higher ammonia content than that of the ammonium sulfate treatments (Table 2). This relation was also shown by the application of March 4, 1936, when outside of the 0-4 inch depth the 4-8 and 8-12 inch depths of the Cyanamid blocks were as high as the corresponding samples of the soil receiving ammonium sulfate. However, on other applications the penetration of ammonium sulfate was the equal or greater, but differences were small when conditions were favorable for the decomposition of Cyanamid. The residual effect of all the Cyanamid treatments made the previous fall and spring was still evident from samples collected in June or July, and with the dry conditions in the spring of 1936 probably to a much later date the following summer. Although Cyanamid is considered more slowly available than ammonium sulfate, a comparison of the data shows that with the exception of the early fall application of 1934, where it was shown that a large amount of dicyandiamide was formed, the ammonium sulfate blocks contained more ammonium nitrogen in May and June than did the cyanamid blocks. Undoubtedly some factors other than ammonification enter into the utilization of cyanamide but further facts must be secured before a complete explanation can be made of this phenomenon.

Penetration of Nitrate From Cyanamid

The figures given in Table 9 are typical of all applications. In no case was the quantity of nitrate from cyanamid that reached the lower depths significant. It was in some cases slightly greater than the plots given no nitrogen, but there was never any appreciable variation from that soil receiving ammonium sulfate.

TABLE 9.—NITRATE CONTENT AT DIFFERENT DEPTHS OF SOIL RECEIVING CYANAMID. (NITROGEN IN PARTS PER MILLION).

Date of Sampling	Depth of Samples, in Inches							
	0-4	4-8	8-12	12-18	0-4	4-8	8-12	12-18
	Cyanamid app. Oct. 2, 1934				*Cyanamid app. Mar. 4, 1936*			
Oct. 16	13.2	5.6	1.7	.3				
Oct. 30	9.6	12.8	4.2	2.4				
Nov. 16	8.4	4.1	3.2	4.8				
Nov. 26	7.7	3.1	1.7	1.8				
Jan. 5	2.9	2.7	3.4	3.1				
Mar. 3					2.2	1.6	1.1	1.1
Mar. 16	1.2	1.7	3.2	.1				
Mar. 19					18.7	4.9	1.6	3.7
Apr. 2					4.4	4.4	4.4	2.8
Apr. 13	1.7	.1	.0	.0				
Apr. 16					8.8	2.2	1.1	.0
Apr. 30					14.3	6.6		
May 16					24.2	8.2		
May 17	.2	1.1	2.3	.0				
June 8					6.6	3.3		

Nitrification of Cyanamid and Ammonium Sulfate

Since nitrification takes place largely in the surface seven or eight inches of soil, the values obtained for the 0-4 and 4-8 inch depths were averaged to obtain the results given in Figures 2, 3, and 4. The ammonification of Cyanamid was rapid with the exception of the late spring application of 1936. However, the

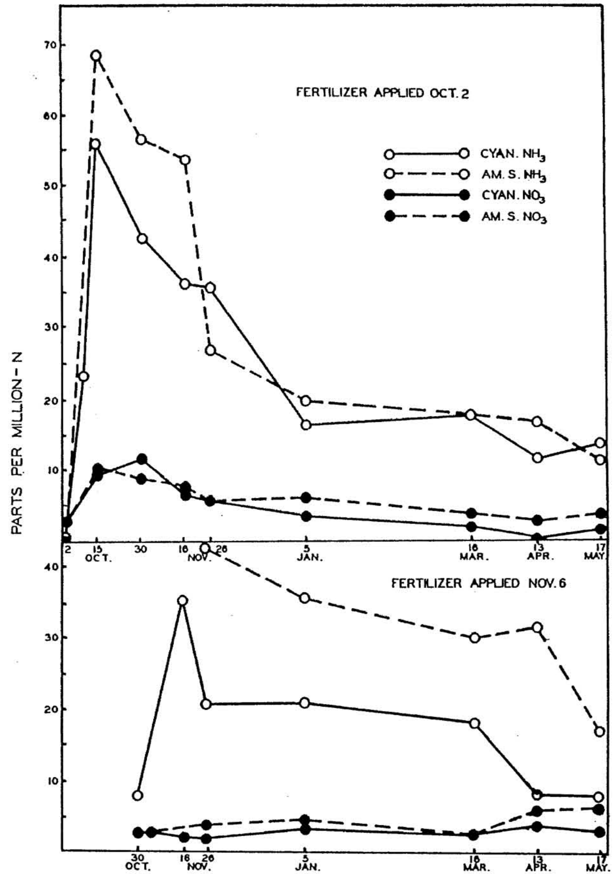

FIGURE 2 - NITRATE AND AMMONIA CONTENT OF SURFACE EIGHT INCHES OF SOIL RECEIVING CYANAMID AND AMMONIUM SULFATE IN THE FALL OF 1934. NITROGEN IN PARTS PER MILLION.

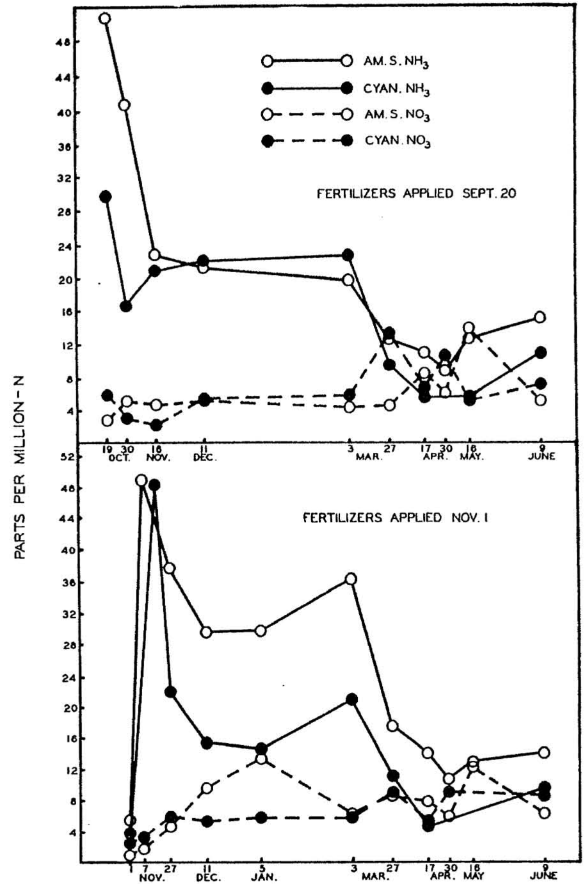

FIGURE 3 - NITRATE AND AMMONIA CONTENT IN SURFACE EIGHT INCHES OF SOIL RECEIVING CYANAMID AND AMMONIUM SULFATE IN THE FALL OF 1935. NITROGEN IN PARTS PER MILLION.

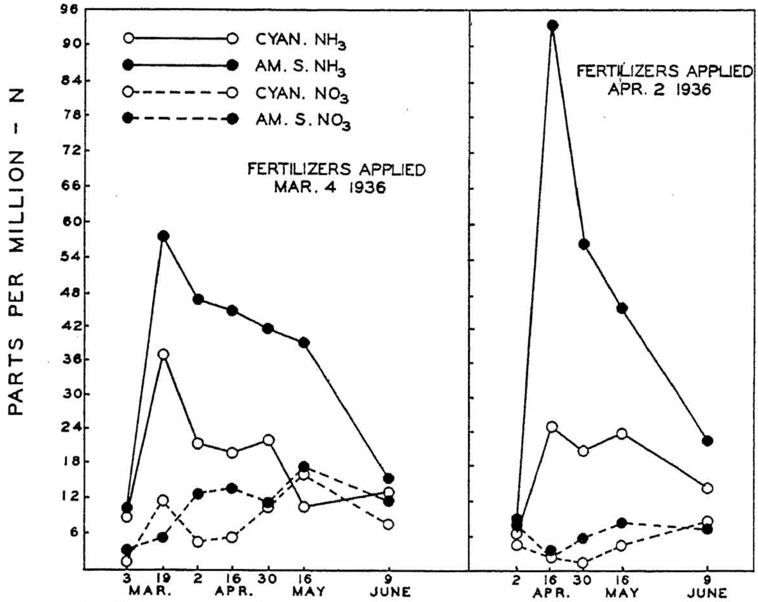

FIGURE 4 - NITRATE AND AMMONIA CONTENT IN SURFACE EIGHT INCHES OF SOIL RECEIVING CYANAMID AND AMMONIUM SULFATE IN SPRING. NITROGEN IN PARTS PER MILLION

ammonia content of the Cyanamid blocks equalled that of those receiving ammonium sulfate only from the second spring application of 1935 and the late fall application of 1936. It is possible that the heavy rains at these times may have moved a larger portion of the ammonium sulfate to a lower depth, and through this favorable condition for the breakdown of Cyanamid, brought about a greater ammonia content in the surface soil.

In all cases, the quantity of ammonia in the Cyanamid blocks diminished at a more rapid rate than in those receiving ammonium sulfate. Even with the two instances where at two weeks after application the ammonia content of the Cyanamid blocks was equal to that of those receiving ammonium sulfate, the quantity dropped rapidly and remained at a lower value than was found for ammonium sulfate throughout the time of measurements. It is evident from the penetration data that ammonia from ammonium sulfate was present in both the surface soil and at lower depths in equal or greater concentrations than in the corresponding Cyanamid blocks. This difference could not be explained by the quantity of nitrate produced.

The nitrification curves are similar to those obtained by Crowther and Richardson (12) with their fall applications to grasslands. A significant amount of nitrate was produced from the first fall applications. The soil was so wet following the second fall applications in both years, and after the spring treatments of 1935, that nitrates could not be found in appreciable quantities. The first spring application of 1936 produced a considerable quantity of nitrate, but soil moisture was entirely too low for much nitrification of the two materials, although the quantity of nitrate produced from ammonium sulfate is perhaps consistently a little larger. No reciprocal relationship seems to exist between the ammonia and nitrate contents, and since no significant leaching occurred, the decrease in ammonia content was due to actual absorption of ammonium or nitrate ions as rapidly as formed by the tree roots or blue grass.

Under conditions of heavy rainfall which were unfavorable for nitrate production, the data indicate that the rate of nitrification was not significantly slower for Cyanamid than for ammonium sulfate.

Total Soluble Nitrogen in Soil

If one assumes that all the soluble nitrogen in the surface 18 inches would be available, the measure of this form of nitrogen should give an indication of the fertilizer still remaining in the soil and available to the trees. The data plotted in Figures 5, 6, and 7 were obtained by adding the nitrate and the ammonia values and averaging the samples taken at the four different depths in the penetration studies.

With the exception of the late spring application of 1935 and late fall application of 1935 in all early samples taken, the quantity of total available nitrogen on the Cyanamid blocks was less than on those receiving ammonium sulfate or sodium nitrate, although in some cases a significant amount of the nitrate from sodium nitrate had been lost. In these two instances, the available nitrogen content was higher for only two weeks as a consequence of the spring application and for about a month from the fall addition. It then dropped below the values for ammonium sulfate. The rates of absorption of nitrogen by roots and bluegrass, presented in the following section, cannot be used to explain this difference. It is possible that the addition of calcium, in the Cyanamid, may have stimulated biological activity resulting in a temporary consumption or transformation of some of the nitrogen into an insoluble form.

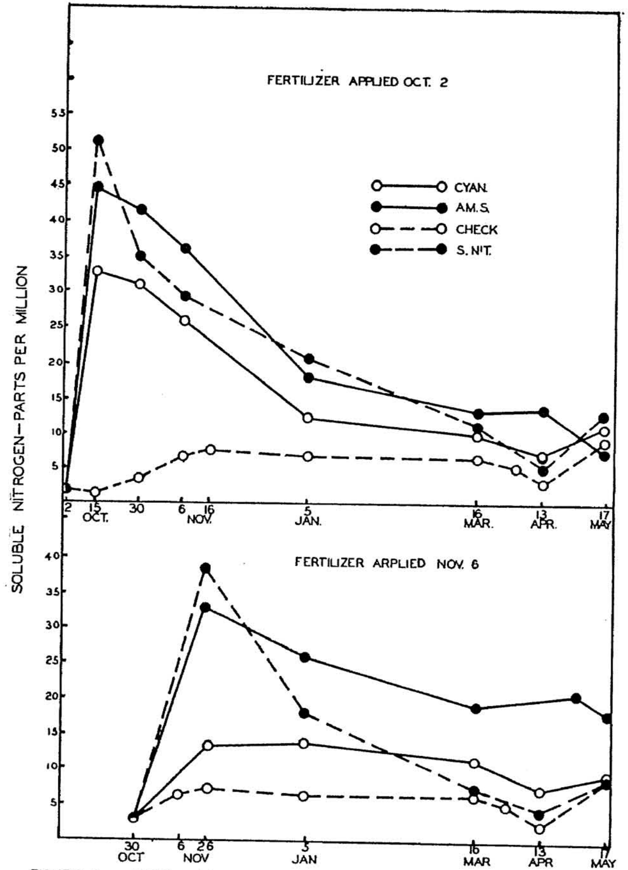

FIGURE 5 - TOTAL SOLUBLE NITROGEN IN SURFACE EIGHTEEN INCHES OF SOIL RECEIVING FERTILIZERS IN FALL OF 1934. NITROGEN IN PARTS PER MILLION.

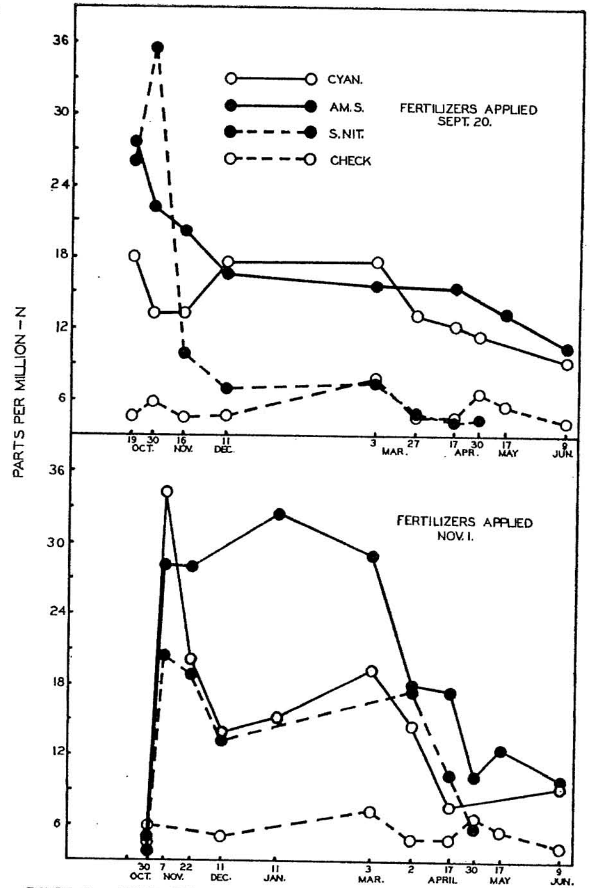

FIGURE 6 - TOTAL SOLUBLE NITROGEN IN SURFACE EIGHTEEN INCHES OF SOIL RECEIVING FERTILIZERS IN FALL 1935. N- IN PARTS PER MILLION.

The above two applications where the amount of available nitrogen dropped, following a high early value, lends support to this theory. According to results from Fink's work (15) it seems possible that the soil might be adsorbing the cyanamide nitrogen and rendering it unavailable for some time. In Beilstein's Handbuch (4a) it is mentioned that the cyanamide radical may react with aldehyde

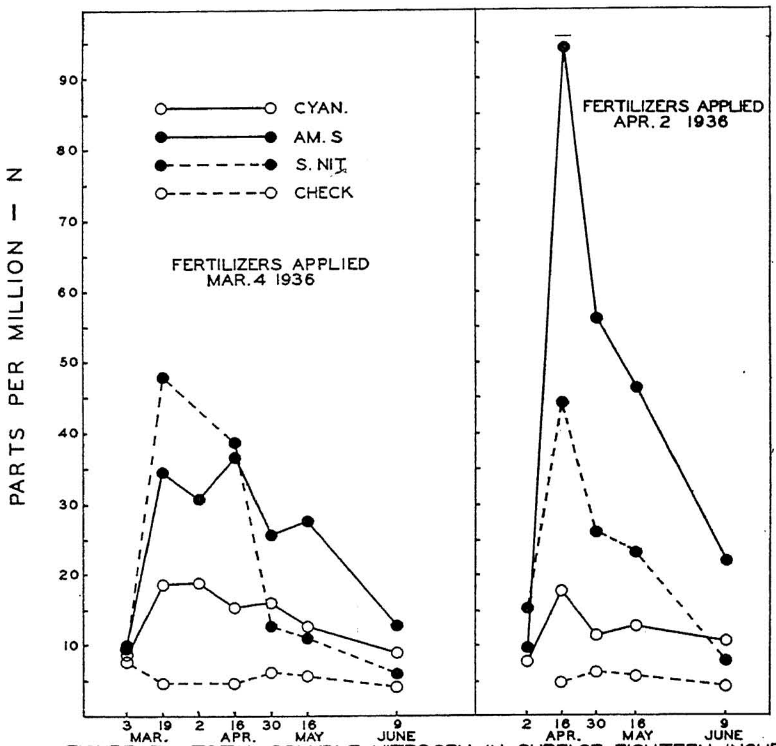

FIGURE 7 - TOTAL SOLUBLE NITROGEN IN SURFACE EIGHTEEN INCHES OF SOIL RECEIVING FETILIZERS IN SPRING. NITROGEN IN PARTS PER MILLION.

groups to form water insoluble compounds. It is possible that the cyanamide reacted with such groups of the soil humus to form insoluble compounds.

Since our experimental results were consistent for all applications, the condition which they indicate may be fundamental in the soil transformations of calcium cyanamide. A detailed study of the decomposition of granular Cyanamid as applied in orchards has been started and will be reported in a later publication.

Changes in Soil Reaction and Base Content

The chief objection to the use of ammonium sulfate as a source of nitrogen is its effect on increasing the soil acidity. Sodium nitrate has no seriously undesirable properties in this respect but the sodium has no value in plant nutrition, and if large quantities are continuously used, it may bring about a poor physical condition of the soil. Cyanamide having calcium as the cation does not bring about either of the above effects, and this property has been emphasized by its manufacturers. In order to ascertain what residual effect these materials have when used in the orchard, the 0-4, 4-8, and 8-12 inch depths of soil from the early fall applications of the samples collected June 9, 1936 were analyzed for total bases, exchangeable hydrogen, exchangeable calcium and determinations made for pH.

The pH data in Table 10 were obtained with a quinhydrone electrode. Exchangeable bases were determined by treating the soil with an excess of a standard acid, and after filtering, titrating the excess acid with standard sodium hydroxide. From another aliquot of this solution shaken with the soil, the exchangeable calcium was precipitated as calcium oxalate and determined by titration with standard permanganate. For exchangeable hydrogen, a 10 gram sample of soil was leached with neutral normal

TABLE 10.—THE EXCHANGEABLE CALCIUM, HYDROGEN AND BASES, AND pH OF SOIL BENEATH APPLE TREES GIVEN APPLICATIONS OF FERTILIZER EARLY IN THE FALL FOR TWO YEARS. EXPRESSED AS MILLIEQUIVALENTS PER 100 GRAMS OF SOIL.

	Depth in inches	pH	Exc. Bases	Exc. Hydrogen	Exc. Calcium
	0-4	6.05	7.85	2.57	5.87
Check	4-8	5.90	7.50	2.76	5.77
	8-12	6.20	9.85	2.59	6.40
	0-4	5.45	7.42	4.28	3.85
Ammonium	4-8	5.85	7.28	3.72	5.90
Sulfate	8-12	5.95	11.58	2.67	9.20
	0-4	6.10	10.73	2.48	9.85
Cyanamid	4-8	6.00	8.00	2.85	7.50
	8-12	5.90	10.86	2.48	9.75
	0-4	6.05	8.85	2.29	4.80
Sodium	4-8	6.48	7.28	2.85	4.35
Nitrate	8-12	6.00	10.44	2.28	5.87

barium acetate and an aliquot of the leachate titrated with standard base to phenolphthalein end-point, and the amount of hydrogen ions removed was calculated.

It is unfortunate that a sample of soil was not secured from each individual block before any fertilizer was applied, since there is considerable variation in the field and a comparison of the fertilized blocks after two years with the check is not entirely satisfactory. However, disregarding these irregularities, the residual effects of these three different materials were quite pronounced.

It is evident from Table 10 that ammonium sulfate decreased the pH of the surface soil more than half a pH unit, with smaller decreases in the two other depths sampled. Cyanamid increased the pH only slightly, while sodium nitrate had little effect on the surface four inches. The latter caused a .4 of a pH unit rise in the 4-8 inch depth, which indicates a rapid movement of the sodium ion, and is in agreement with other work (34) (40). It appears from these figures that ammonium sulfate had little effect on exchangeable bases, which seems hardly logical in light of the decrease in pH and exchangeable calcium from its use. Both Cyanamid and sodium nitrate increased the exchangeable bases in the surface four inches but the effect on the two lower depths was not great.

The increase in exchangeable hydrogen from the use of ammonium sulfate is quite evident since there was a much greater quantity in both the 0-4 and 4-8 inch depths than was present in the untreated soil. Cyanamid and sodium nitrate did not bring about much change in the quantity of exchangeable hydrogen but in all three depths both caused some reduction, with the greater decrease from sodium nitrate, especially in the 8-12 inch soil layer.

Ammonium sulfate greatly reduced the exchangeable calcium in the surface soil while sodium nitrate reduced it somewhat but not so much as did ammonium sulfate. The large quantity of calcium found in the 8-12 inch depth on the ammonium sulfate block may be an error or it may be the true condition as a result of its displacement by the hydrogen ions above and leaching down to this depth. Further support for this view is obtained from the large quantity of exchangeable bases found at this depth. The reduction in quantity of calcium in the surface soil both from ammonium sulfate and sodium nitrate could be due to the utilization of large quantities by the sod plants when the nitrogen causes decided stimulation of growth. The Cyanamid applications have, as would be expected, greatly increased the calcium in the surface soil. A substantial increase also appeared over the untreated soil in the 8-12 inch depth, but this figure appears doubtful since the 4-8 inch depth did not show such a difference.

Absorption of Nitrogen by the Tree Roots

Changes in the nitrogen content of the the fine roots of apple trees is a fair index of absorption, since it has been shown that nitrogen is taken up by the fine roots in the fall and winter and rapidly moved to the larger ones. Although some of the larger roots analysed (under 2mm.) might permit some storage of nitrogen, fluctuations in the percentages found at any one time should be markedly influence by the nitrogen recently absorbed.

Nitrogen from Cyanamid was taken up as rapidly as that from the two other fertilizers in the fall of 1934 and spring of 1935, with the exception of the early fall application (Figures 8, 9, and 10). However, in late spring the roots of trees in this block had by far the highest nitrogen content of the three materials applied at this time. This slow intake of the first fall application in 1934 was probably due to the complications resulting from the deficiency of moisture. It is possible that the dicyandiamide formed and the ammonia fixed by the soil did not become available to the roots until this time. Although the first fall application in 1935 was subjected to similar weather conditions as the corresponding one in 1934, the lag in absorption was not evident. In fact, the quantity of nitrogen in the roots of Cyanamid treated trees was greater than in trees receiving the two other materials. It is probable that there was sufficient residual effect of Cyanamid from the preceding year to give this increase. In this connection it is interesting that the following spring, in the case of the early fall application in 1935, the roots of Cyanamid treated trees had a higher percentage of nitrogen in late spring than those receiving ammonium sulfate. The differences between the two fertilizers is perhaps not large enough to be significant with the late fall application. The nitrogen content of roots receiving sodium nitrate in the fall was much lower during the winter and spring than that found for those roots given Cyanamid and ammonium sulfate.

There was no great difference in the nitrogen content of the roots from the different spring applications of 1935, but it appears that a greater amount was taken up by trees receiving Cyanamid and ammonium sulfate. The same relation existed for the early application in the spring of 1936, but moisture was so low with the later one that none of the materials were taken up in large quantities though sodium nitrate seemed to be absorbed most readily.

The roots of trees receiving fertilizer in the fall possessed a higher percentage of nitrogen in the following spring than did the corresponding spring treatments immediately following the

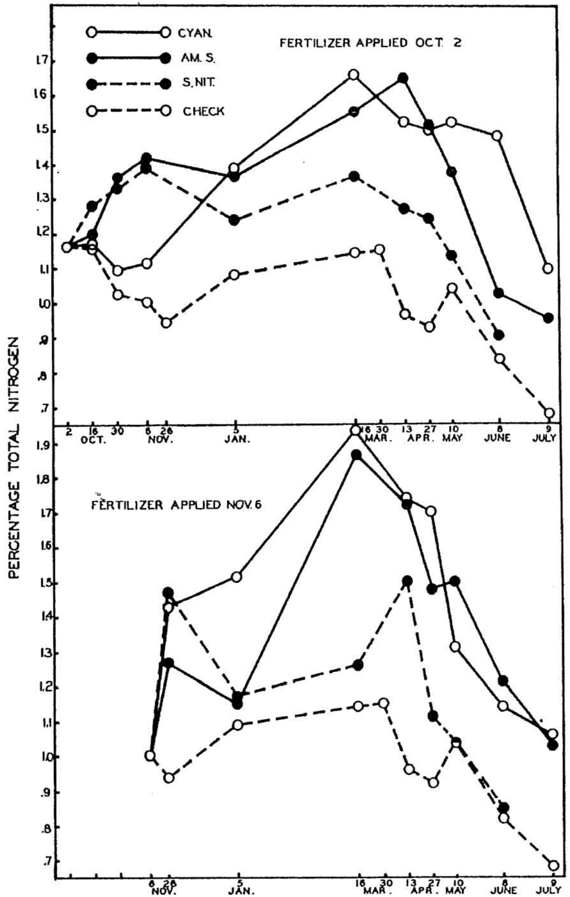

FIGURE 8 - TOTAL NITROGEN IN FIBROUS ROOTS OF APPLE TREES RECEIVING FERTILIZER IN FALL OF 1934 NITROGEN IN PERCENTAGE DRY WEIGHT

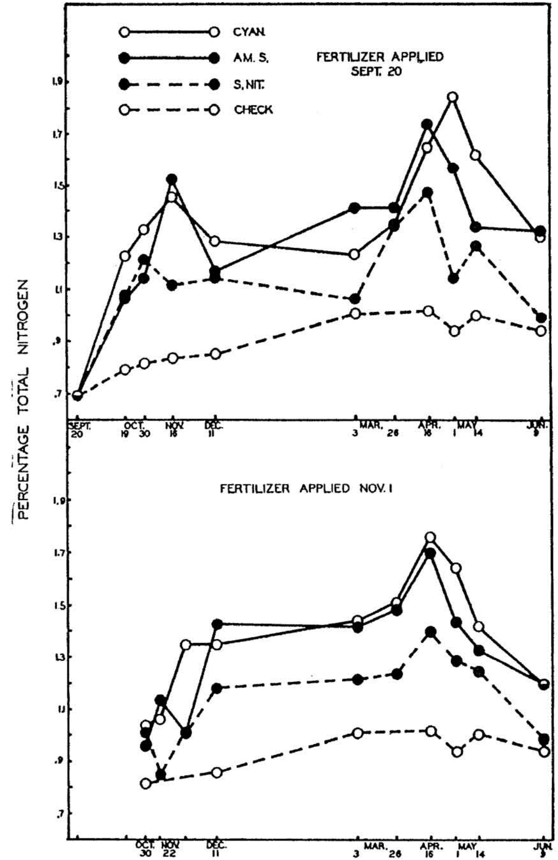

FIGURE 9 - TOTAL NITROGEN IN FIBROUS ROOTS OF APPLE TREES RECEIVING FERTILIZER IN FALL OF 1935. NITROGEN IN PERCENTAGE DRY WEIGHT.

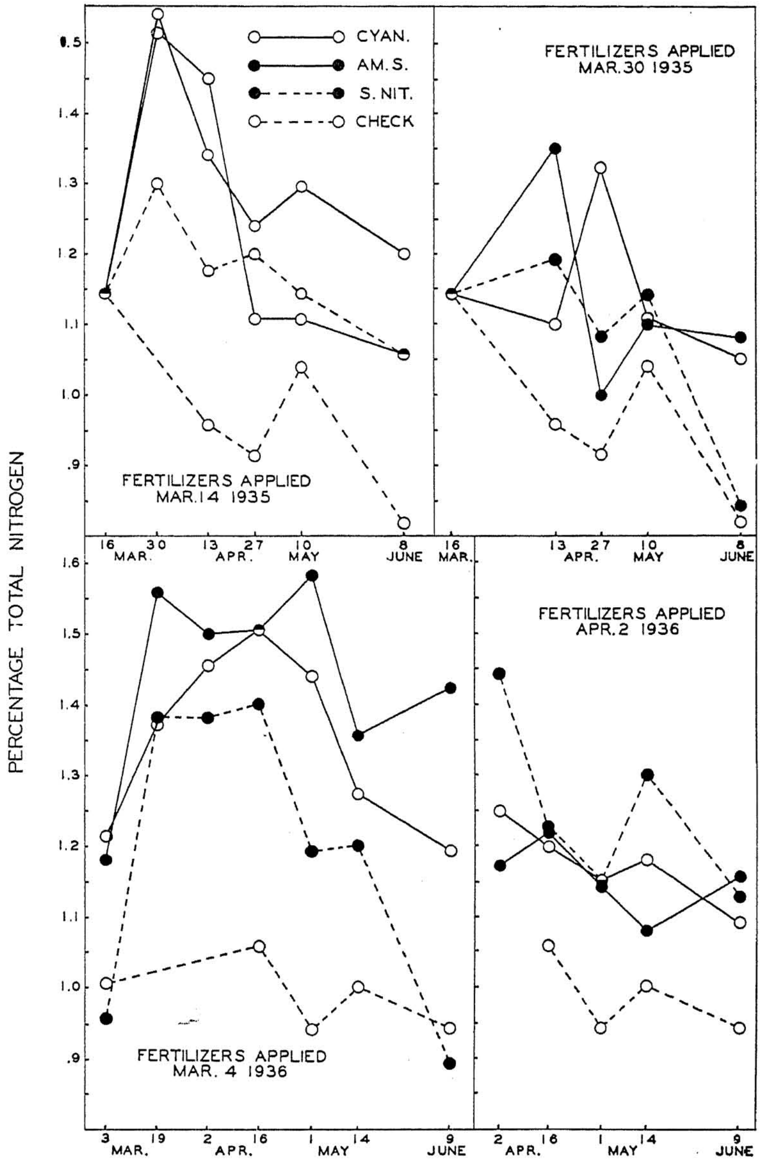

FIGURE 10 - TOTAL NITROGEN IN FIBROUS ROOTS OF APPLE TREES RECEIVING FERTILIZER IN SPRING. NITROGEN IN PERCENTAGE DRY WEIGHT.

spring application of fertilizer. This condition has been observed by Aldrich (2) and Weinberger and Cullinan (54). This would suggest that some of the nitrogen absorbed in the fall may be stored in the roots in an insoluble form that is moved out slowly in the spring while that from the spring applications would go to the aerial portions soon after absorption.

In order to determine if this difference was due to soluble or insoluble forms, a few contrasting samples of apple tree roots were selected and determinations made for soluble and insoluble nitrogen. Those used were from trees given the early fall application of Cyanamid in 1934 and early spring applications of Cyanamid in 1935 and collected from March 16 to June 8, 1935. The results are given in Table 11.

TABLE 11.—TOTAL, SOLUBLE, AND INSOLUBLE NITROGEN CONTENT OF FIBROUS TREE ROOTS. IN PERCENTAGES ON DRY WEIGHT BASIS.

Time of application	Sampling date	Total N	Soluble N	Insoluble N
Oct. 2, 1934	March 16	1.66	.57	1.09
	April 13	1.52	.55	.97
	April 27	1.50	.58	.92
	May 10	1.52	.60	.92
	June 8	1.48	.58	.90
Mar. 14, 1935	March 30	1.52	.57	.95
	April 13	1.45	.56	.89
	April 27	1.11	.46	.65
	May 10	1.11	.44	.67
	June 8	1.06	.38	.68

These figures show clearly that the higher nitrogen content of tree roots fertilized in the fall was due to nitrogen held as insoluble compounds. In the later samples, there was a marked decrease in soluble nitrogen in the spring fertilized roots, while it remained practically constant for those receiving fertilizer in the fall. Since the rate of removal of both fractions was greater for the spring fertilized roots, this lends further support to the possibility that the nitrogen from fall applications is built into complex compounds during the winter. Some investigators (8) (25) have shown that apple tree roots remain fairly active throughout the winter. Succulent roots were observed until late December, when samples were taken in the field, although the number fell off greatly during the cold weather in 1936. Potted trees, with windows in the side, were set up in the hope of measuring seasonal root activity. In the winter of 1935-36 all visible growth ceased in late December, but the winter was so severe that it is doubtful whether the insulation was sufficient to keep the roots near their normal temperature. In the much milder winter of 1936-37 succulent roots could be observed at a much later date. With this root activity during the winter it is possible that the nitrogen applied in the fall may have stimulated new root growth and have been utilized in the production of new root tissues. This would have raised the percentage of nitrogen on a dry weight basis, yet the nitrogen may have been stored in such a form that it could not readily move in the spring, while nitrogen applied in the spring may be more readily available.

Absorption of Nitrogen by Bluegrass

The small response from sodium nitrate and ammonium sulfate in some cases when applied to trees growing in grass sod, has been attributed to the absorption of the nitrogen by the grass. Since Cyanamid has a retarding effect on growth of grass immediately after application, it is possible that greater quantities of nitrogen might penetrate to the region where most of the apple tree roots are concentrated.

No toxic effect on grass could be observed from any of the fall applications of Cyanamid. In the wet spring of 1935, the grass in the treated area was burned considerably. There was also burning from the two other materials, but it was not so pronounced. Late in the spring the grass on the Cyanamid and ammonium sulfate blocks was noticeably greener than that receiving sodium nitrate, with no evidence of early burning. With the dry conditions of 1936, no toxic effect on sod was observed on any of the spring applications.

The changes in nitrogen content of the entire bluegrass plants were essentially the same for the two fall applications of 1934 and late spring application of 1935 (Figures 11, 12, and 13). From three to four weeks after application, the percentage of total nitrogen in grass from the sodium nitrate blocks was greatest, then it fell off, while that from the ammonium sulfate and Cyanamid in the fall of 1934 and spring of 1935 continued to remain high and showed little contrast. These figures for total nitrogen, however, do not give a true picture of the total amount of nitrogen held, since as the volume of early growth from ammonium sulfate and sodium nitrate was many times greater than from Cyanamid, because of the latter's toxic effect.

There is a contrast between the fall sodium nitrate applications in 1935 and those of the previous fall (Figure 12). Ammonium sulfate and Cyanamid from the 1935 application gave the greatest nitrogen percentages in the grass while in 1934 the relation was reversed. Cyanamid showed the greatest residual effect in the following spring, whereas in the previous spring it was in this respect the same as ammonium sulfate. It is possible that the residual effect of the previous year may have been sufficient to bring about this increase by the two other fertilizers over sodium nitrate. Almost identical results were secured from the applications in the

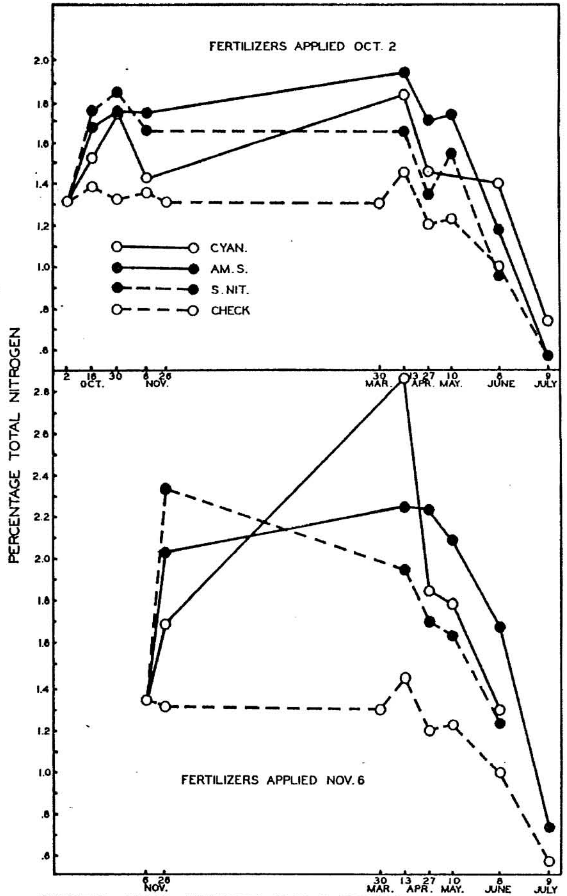

FIGURE 11 - TOTAL NITROGEN IN BLUE GRASS PLANTS UNDER TREES RECEIVING FERTILIZER IN FALL OF 1934. NITROGEN IN PERCENTAGE DRY WEIGHT.

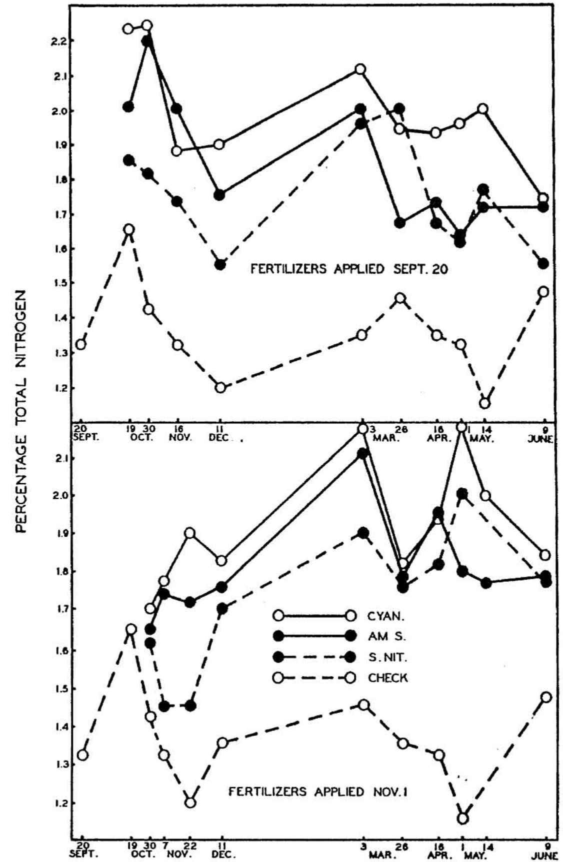

FIGURE 12 - TOTAL NITROGEN IN BLUE GRASS UNDER TREES RECEIVING FERTILIZER IN FALL OF 1935. NITROGEN IN PERCENTAGE DRY WEIGHT.

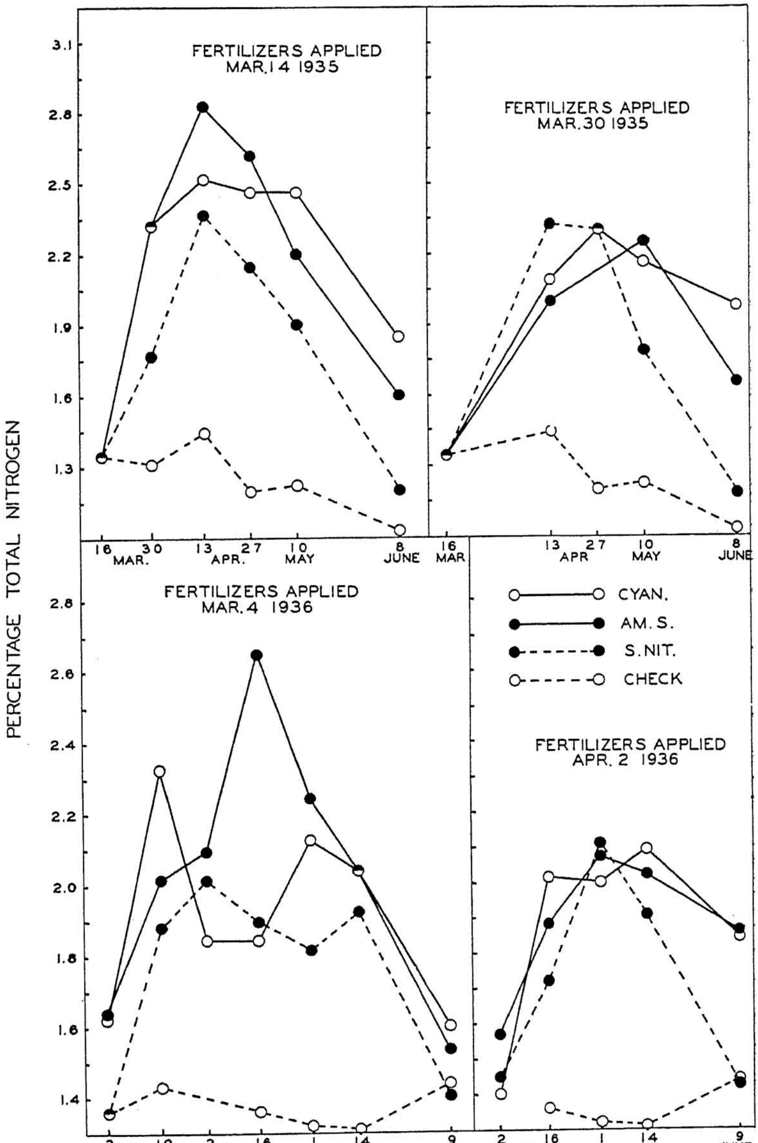

FIGURE 13 — TOTAL NITROGEN IN BLUE GRASS BENEATH TREES RECEIVING FERTILIZERS IN SPRING NITROGEN IN PERCENTAGE DRY WEIGHT.

spring of 1936, except that there was little difference between ammonium sulfate and Cyanamid.

Immediate Effect of Fall Fertilization on Nitrogen Content of Twigs and Spurs

Neither the time of application nor the source of nitrogen had any visible effect on the quantity or color of the leaves. The fertilized trees had noticeably greener and denser foliage than the checks and held their leaves later in the fall, but in this respect no difference could be observed between the blocks given different fertilizers. The figures for the percentage of nitrogen in the twigs collected in the winter of 1935 showed no significant increase in nitrogen content in those trees fertilized in the fall, over those receiving no nitrogen. On November 15, 1934, a sample of twigs from trees given fertilizers on October 2 had .81% nitrogen from sodium nitrate, .80% from Cyanamid, .82% from ammonium sulfate, and .80% from the check blocks. Four months later on March 16, 1935 (just as buds were breaking), twigs from the fertilized blocks contained about 1.0% nitrogen and from the check about .90%. As soon as the leaves began to develop, the nitrogen content in the twigs from the fertilized blocks increased for a time at a more rapid rate than was true in the case of the checks, but by May this difference was slight.

The nitrogen content of the spurs from the fertilized trees was no higher during the winter than in those of the check trees, but in 1936 the early spring spur samples gave substantially higher values for the samples from fertilized trees.

These results are in agreement with those of other investigators (2) (54) who found no increase in nitrogen content of the twigs until the following spring from trees receiving fertilizer in the fall.

The analyses of the growing tissues gave more consistent results than did the twigs, which indicated that they would be a more suitable material on which to base conclusions. Just what portion of the tree is the best indicator of fertilizer value cannot be said, but it would seem that the nitrogen content of the twig leaves would be most indicative, since it has been found (39) that they contain in spring and early summer, a very large proportion of the tree's nitrogen.

Comparison of Fall and Spring Applications of Sodium Nitrate

Although penetration data indicated that a considerable quantity of the fall applied nitrate was lost, evidence from the tree analyses shows that recovery was greater from fall than from spring applications. Some of the data for the sodium nitrate blocks, plotted in

Figure 14, show clearly that a greater quantity of nitrogen was obtained by the tree from autumnal fertilizations.

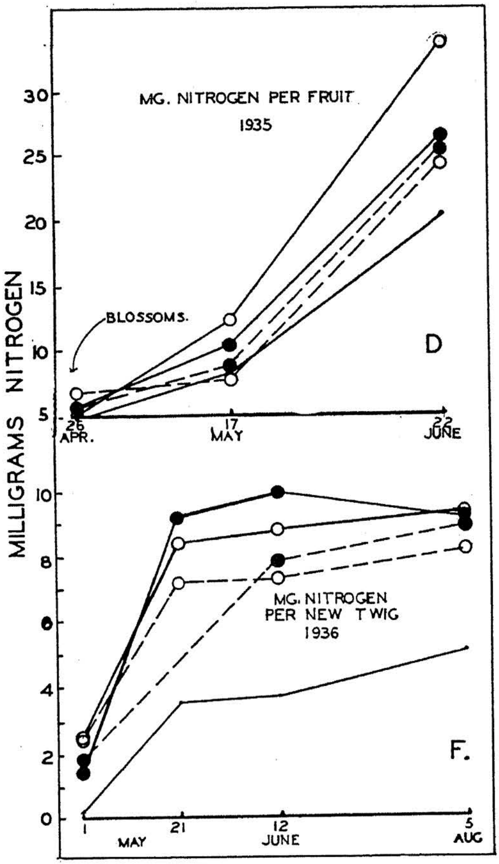

FIGURE 14 - NITROGEN CONTENT AND GROWTH RESPONSE OF TREES RECEIVING SODIUM NITRATE IN FALL AND SPRING

There is some evidence, on the contrary, for better utilization of the sodium nitrate put on in the spring. Most of the data, however, do not show consistent superiority of either spring or fall applications. The bulk of the evidence indicates that more nitrogen was taken up by the trees from fall than spring fertilizer treatments. Despite the rapid downward movement of the nitrate ion, shown by penetration studies, which suggested a serious loss from leaching, it is quite probable that the greater competition of the sod with the tree for nutrients in the spring may have been sufficient to offset this loss. A pronounced leaching would then have a decided advantage.

Comparison of Fall and Spring Fertilizations of Ammonium Sulfate

From the applications of ammonium sulfate made in the fall of 1934 and in the spring of 1935 the greatest growth and nitrogen recovery was secured from spring fertilization. During the following year, with a dry spring, the fall application gave markedly higher values. In all of the samples studied differences in nitrogen content of the various samples were small and in many cases the quantity of nitrogen found in a particular tissue at successive dates would not show the same trend as another portion of the tree top. In this respect there does not appear any significant difference in response between fall and spring applications of ammonium sulfate if spring weather conditions are conducive to its penetration into the soil. However, when dry conditions prevailed the fall treatments were decidedly better utilized.

Comparison of Fall and Spring Applications of Cyanamid

From a gross consideration of the results from all Cyanamid fertilized blocks, it seems that fall applications have been superior, although, under favorable conditions, Cyanamid used in the spring has given quite comparable results. There are only a few exceptions in which the spring fertilization has given higher values. The differences between spring applications of 1935 and those of fall 1934 were not great and the fertilization with Cyanamid made two weeks before bloom was quite efficiently utilized. This indicates that Cyanamid may be safely used in the spring if weather conditions are favorable. On the other hand, the spring applications of 1936, especially the late one, were much inferior to those made the previous fall. They show that trouble may arise from spring treatments when there is a deficiency of moisture.

Almost all the data given in Figure 15 bear out the statement made earlier, namely that the rainfall immediately following the application of Cyanamid has a marked effect on its decomposition and absorption by tree roots. In all of these results from both years the late fall applications, when rain fell soon after the Cyanamid was spread on the ground, have given values for growth and nitrogen recovery that are significantly greater than when the fertilizer was applied earlier and drier conditions prevailed. The same difference also exists when the Cyanamid applications made in the spring of 1935 are compared with those in the spring of

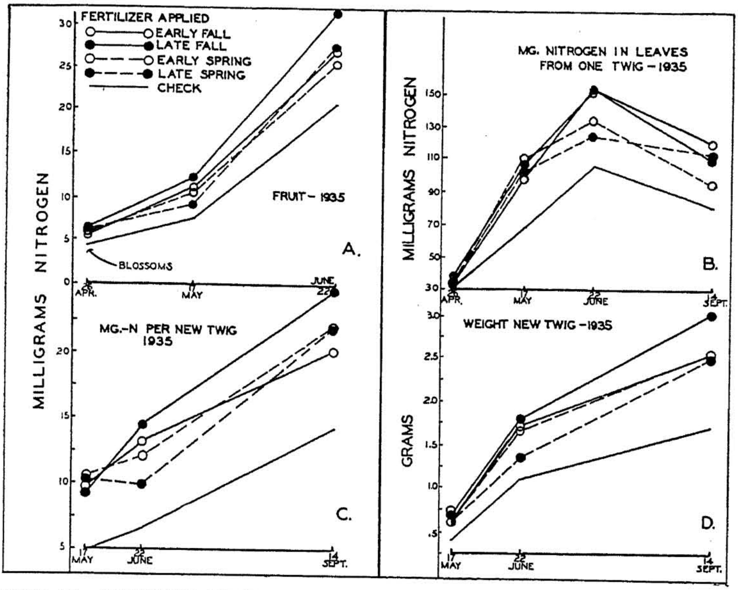

FIGURE 15 - NITROGEN CONTENT AND GROWTH RESPONSE OF TREES RECEIVING CYANAMID IN FALL AND SPRING.

1936. In 1935 the fertilization made two weeks before bloom was well utilized, and with effects not much inferior to those from the earlier application or to those made in the fall. Those made in the spring of 1936, especially the late one, were much less efficient than the other applications. If the records for sodium nitrate and ammonium sulfate (Figures 14 and 15) are considered, this difference between the two fall applications of ammonium sulfate and sodium nitrate does not exist, thus disposing of any explanation based on time of application.

Comparison of the Three Nitrogen Carriers

As was true for the various applications of one fertilizer, so likewise the differences in nitrogen content and quantity of growth resulting from these three nitrogen carriers was small, with considerable variation found between parts of the tree on which measurements were made.

Analyses of nitrogen content of the samples collected in 1935 show that there are some cases where sodium nitrate was inferior to the two other materials and other cases with evidence for its superiority. Graphs B and C in Figure 16 are of particular interest since in these cases it appears that Cyanamid applied in the spring

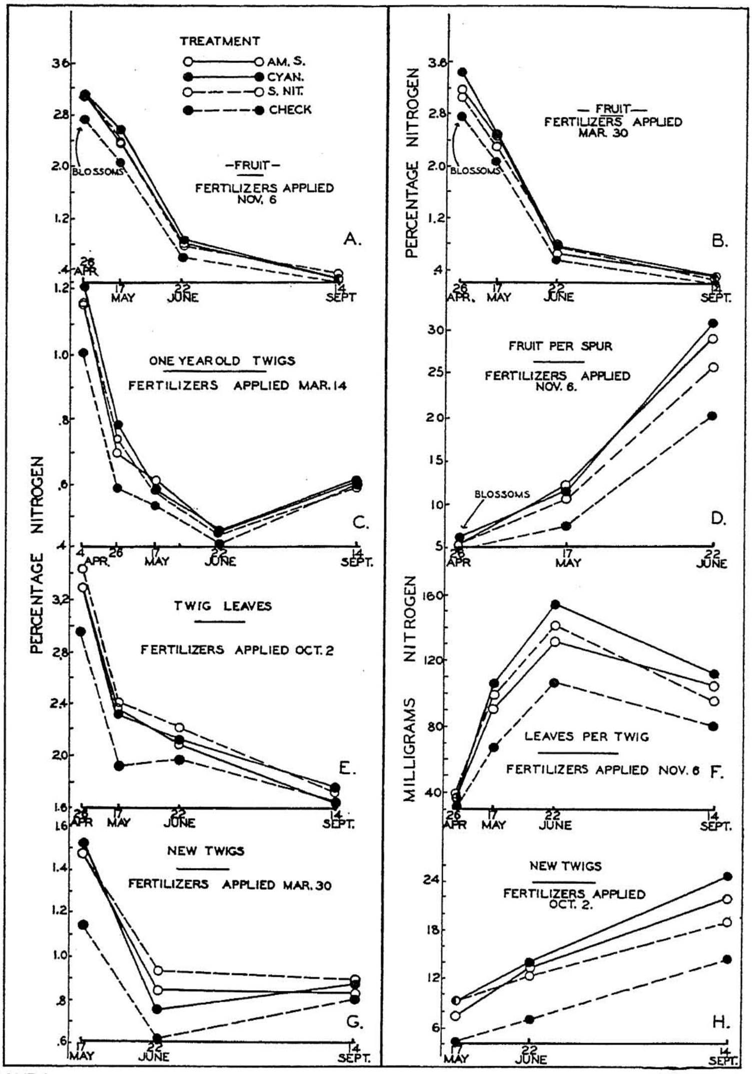

FIGURE 16 - NITROGEN CONTENT OF TREES IN 1935 - FERTILIZERS APPLIED IN FALL OF 1934 AND SPRING OF 1935.

was as efficiently utilized as were the two other fertilizers. The data shown by Graph F in Figure 16 deserve special attention since they give evidence of a distinct superiority of Cyanamid. The twig leaves of trees given this fertilizer contained a large proportion of the tree's nitrogen. This lends further support to the belief in the better utilization of Cyanamid when applied under favorable moisture conditions since most of the other times of application do not show such an advantage.

Neither clear cut advantages nor disadvantages of ammonium sulfate can be found for any particular season. In no case did it give an inferior response nor show any decided advantages, but the results seemed to be quite satisfactory for all applications when compared with the other materials. The results secured in the dry spring and summer of 1936 from spring applications and those made the previous fall demonstrate the smaller amount of recovery that would be expected from the more slowly available materials under dry conditions. Nitrogen from sodium nitrate was taken up in larger quantities than from the two other fertilizers. The amount obtained from ammonium sulfate was somewhat greater than that from Cyanamid, but this difference was not as large as between sodium nitrate and ammonium sulfate. Contrariwise, some of the data from the early spring application in 1936, show that Cyanamid applied in early April gave values comparable with those obtained from the other materials.

The quantity of nitrogen obtained in 1936 from the previous fall applications of the different fertilizers is interesting in that many parts of the tree show a larger quantity of nitrogen recovered from sodium nitrate than from ammonium sulfate or Cyanamid. In general a comparison of the quantity of nitrogen obtained by the trees from these three materials indicates that the application of sodium nitrate made in the fall gave comparatively greater response the second year it was used. It is probable that the dry spring prevented the normal absorption of the more slowly available fertilizers during winter and early spring while the quickly available nitrate was not influenced greatly.

Weight, Length, and Diameter of Terminal Growth

In late fall, after growth had ceased, 25 to 30 twigs were removed from each of the eight Golden Delicious trees on each block. They were brought into the laboratory, dried, and measurements made of their lengths and weights. In 1936 the lengths and diameters (middle of twig between nodes) were measured in the orchard on the same number of twigs. As shown in Table 12 there was a close correlation between length and weight or diameter, but the percentage difference between weights is greater than the difference between length measurements.

In 1935, despite a very heavy crop, average of 19 bushels per tree, the terminal growth was greater than in the dry season of

TABLE 12.—AVERAGE LENGTH, WEIGHT, AND DIAMETER OF TWIGS FROM GOLDEN DELICIOUS TREES RECEIVING FERTILIZER IN FALL OF 1934 AND 1935, AND SPRING OF 1935 AND 1936.

Time of application		Av. length centimeters 1935	Av. length centimeters 1936	Av. weight grams 1935	Av. Diameter mm. 1936
	Check	21.3±.29	12.5±.20	1.38	2.92±.009
Early fall	Am. Sul.	29.8±.29	19.6±.21	2.47	3.14±.007
	Cyanamid	29.1±.27	17.2±.15	2.17	3.18±.008
	Sod. Nit.	26.8±.26	19.4±.23	1.94	3.20±.008
Late fall	Am. Sul.	28.0±.34	17.2±.25	2.22	3.06±.008
	Cyanamid	30.5±.30	19.6±.22	2.24	3.22±.008
	Sod. Nit.	26.5±.22	20.6±.17	1.90	3.21±.009
Early spring	Am. Sul.	21.3±.31	17.7±.28	1.18	3.12±.009
	Cyanamid	26.8±.35	18.7±.40	1.86	3.18±.007
	Sod. Nit.	25.7±.43	19.1±.24	1.81	3.20±.009
Late spring	Am. Sul.	27.8±.33	15.6±.23	2.14	3.11±.008
	Cyanamid	28.4±.44	16.2±.36	2.20	3.08±.007
	Sod. Nit.	25.1±.31	16.1±.34	1.65	3.12±.009

1936 with almost no crop. In the case of the late spring application of 1936, when the trees secured little of the given nitrogen, the length of growth was greatly reduced and in almost the same relation for all materials. However, the diameters of twigs from the Cyanamid blocks were smaller, indicating less growth after the terminal bud had formed.

From a consideration of all the length measurements, it appears that fall applications of all three materials have given as good, if not greater, growth than when the fertilizers were applied in the spring. In 1935, Cyanamid applied late in the spring gave equally as good, if not greater twig growth than the two other materials, which is in agreement with the nitrogen recovery data. The superior growth obtained from fall applications of sodium nitrate over spring is striking and is in agreement with conclusions drawn from the nitrogen and growth analyses.

The average of probable errors for length of growth on all fall fertilized blocks is ± .28 cm. while for the spring applications it is ± .33 cm. This would indicate that the nitrogen absorbed in the fall is more evenly distributed to the aerial portion of the tree in the spring, resulting in a greater uniformity of growth.

Effect of Nitrogen Fertilizers on Yield of Fruit

The number of trees used in these trials was not great enough to give any reliable yield data, but since the trees had developed such a strong alternate bearing habit, yield records were taken to see if any effect on alternate bearing could be found. In 1935, the yields from the Golden Delicious trees varied from 16 to 22 bushels with an average of 19 per tree. The Gano trees varied from 6 to 10 bushels. No consistent differences resulting from any of the treatments could be found from either variety. In 1936, none of the Golden Delicious trees had more than a dozen fruits and the Gano trees averaged less than half a bushel.

DISCUSSION AND APPLICATION

The results of this investigation make it clear that applications of nitrogen to apple trees during the fall in Missouri can be expected to give equally as good results as spring fertilization. These experiments and those of others indicate that when nitrogen is put on the soil in the fall it is rapidly absorbed, held in the roots during the winter, and does not move to the twigs until growth starts in the spring. There should then be no different physiological effect resulting from time of application of nitrogen fertilizers, as long as they are put on while the trees are dormant. Nitrogen from fall applications would reach twigs no sooner than that applied in the spring.

There is no doubt that response from the use of Cyanamid in the fall has been superior to spring applications of this fertilizer. However, when conditions were favorable for its decomposition, applications made even two weeks before blooming gave results comparable to those obtained with sodium nitrate and ammonium sulfate. Although spring applications have in some instances been satisfactory, the dry conditions that frequently exist in Missouri are not conducive to its best utilization and whenever possible it should be applied in the fall.

It is evident that soil moisture and the rainfall immediately following a Cyanamid application have a marked effect on its rate of decomposition. The granules become covered with a white crust when they are not immediately dissolved, and remain on the surface of the soil for some time. With high moisture, ammonia production is rapid and the soil will contain as much of this form of nitrogen a week after application as where an equivalent amount of ammonium sulfate is used. When dry weather prevails, this accumulation is retarded and the quantity produced never reaches a high value. Even when conditions are favorable for ammonia to be formed it does not remain in the soil long.

On practically all of the applications, the total quantity of soluble nitrogen (nitrate plus ammonia) present in the surface 18 inches of soil was less throughout the period of taking of samples than in the ammonium sulfate blocks, and also less for some time than on those receiving nitrate of soda. In mid-winter when there was evidence for much of the nitrate from sodium nitrate being moved below 18 inches, and no indication of a significant movement of nitrogen from Cyanamid, the surface 18 inches of soil receiving sodium nitrate contained much more available nitrogen. This difference was more pronounced when dry weather followed immediately the fertilizer applications. Undoubtedly this condition is fundamental in the decomposition and utilization of Cyanamid, as a comparison of the percentage nitrogen in the trees and the amount of growth made gives an excellent correlation. In every instance the response was greater on the treatments where the decomposition of Cyanamid was rapid. From other investigations (3) (5) (12) it is suggestive that dry conditions may bring about the formation of dicyandiamide. When the nitrogen is not immediately taken up by the trees, the increased bacterial action (probably due to additions of very active calcium) may tie up a considerable quantity in biological forms, or the Cyanamid might be adsorbed as such by the soil complex. It is also possible that insoluble condensation products may be formed with the soil humus (4a). All of these suggestions are only theories. Further study is necessary before a definite explanation can be had.

This investigation has failed to show any marked difference in the leaching properties of the nitrogen from Cyanamid as compared to ammonium sulfate, or to difference in length of time that the nitrogen remains available in the soil. The downward movement of ammonia from Cyanamid was almost as great as from ammonium sulfate. Although the Cyanamid treated soil seldom contained as much ammonia as that receiving ammonium sulfate, had the quantities found in the lower depths sampled been computed on a percentage basis of the total amount present in the surface 18 inches the values would probably have been about equal for the two materials. On all applications, except one, the soil receiving ammonium sulfate had more available (water soluble) nitrogen during May and June than did that receiving Cyanamid. Unless some of the nitrogen from Cyanamid is tied up in some biological or insoluble form, then the so-called "lasting effect" of nitrogen from Cyanamid has no foundation.

Under field conditions the amount of nitrification taking place from ammonium sulfate and Cyanamid was small and there was little difference between the two materials. This is in agreement with results obtained at Rothamsted (45) with pasture fertilizations. In no case was it possible to find any significant lag on the Cyanamid blocks as has been reported when larger quantities were used

(3) (12) (44). In the dry summer of 1936, no accumulation of nitrates was observed, as Marsh (30) had found previously. Apparently in this soil, possessing a heavy sod and having a low nitrogen content, no accumulation occurred and the quantities of nitrate present on both the check and the fertilized blocks was so low it was difficult to measure. Had the orchard been cultivated and the soil contained a greater quantity of nitrogen and organic matter, the nitrate level might have been higher and some accumulation would have been noted. However, on soils of this type it would not seem that the accumulation of nitrates in a dry year would ever be sufficient to take the place of an application of commercial fertilizer.

The nitrate form of nitrogen moves more rapidly in the soil than the ammonia form, and under the sod conditions of this experiment a greater quantity from the fall applications of sodium nitrate penetrated to the lower depths than from that put on in the spring. When only the soil data are considered this rapid movement in the fall would suggest a serious loss from leaching. However, the quantity of growth made and the nitrogen found in the trees receiving sodium nitrate in the fall indicated that this was not true and that this movement has a decided advantage. In agreement with other work (4) it was evident here that the blue grass tied up a much larger quantity of nitrate from the spring applications. A greater amount of this fertilizer applied in the fall reached the tree roots.

The favorable results from the late applications of Cyanamid were undoubtedly due to the reduced competition by the bluegrass as a result of the temporary injury from the Cyanamid, whereas the nitrogen from sodium nitrate and ammonium sulfate was rapidly taken up by the grass.

These results, pointing to a better utilization of nitrate from fall applications, are contrary to findings of others (2) (47) (54). It seems logical to think, however, that on an open and deep soil of this type, although much of the nitrate went down, there would be sufficient tree roots at the lower depth to absorb most of it. However, if clean culture is used (50) or if the soil is very sandy or possesses an open subsoil, much of the material applied in the fall might be lost and spring applications would be more satisfactory.

Where rain soon falls after ammonium sulfate is applied, there is a rapid penetration of ammonia. A greater movement occurred from the fall than spring applications and it is probable that the greater growth of the blue grass in the spring was the explanation. However, the difference in the response was not as significant as between the spring and fall applications of sodium nitrate.

From the data on tree response it seems that, when moisture conditions are ideal in the spring, ammonium sulfate applied at this time gave as good, if not slightly better, results than when applied in the fall, which differs from the results obtained with sodium nitrate, where the fall applications would seem to be the better. This is contrary to expectation, since recommendations (38) have always called for earlier applications of ammonium sulfate than of sodium nitrate in order to insure sufficient time for the more slowly moving ammonium ion to get into the tree. However, the advantage shown for spring applications is slight. Fall applications should be safer as a means of avoiding the possibility of dry conditions, such as existed after the late spring application in 1936.

Judging from the results obtained during the relatively short time that this investigation has been in progress it appears that these three nitrogen carriers have different residual effects on the soil. A continued use of Cyanamid should be most desirable, since it conserves soil bases and reduces exchangeable hydrogen.

These figures are in good agreement with those which have been reported on pot experiments (35). In the two years that these applications were made the ammonium sulfate reduced the exchangeable alcium 2 M. E. per 100 grams of soil or about 40% in the surface 4 inches, while Cyanamid increased it about 4 M. E., or 80%. This figure is too large since the increase in the surface soil would account for more calcium than was applied. In the two years, calcium had been added to the area beneath the trees to the extent of about 500 pounds to the acre while 4 M. E. in the surface four inches would amount to a gain of nearly 900 pounds. Despite this discrepancy the data serve to illustrate the difference between the two materials.

If these two fertilizers were used continuously the difference would be quite significant and might in time have a pronounced effect on tree growth. If the orchard were cultivated and a legume grown as green manure, the difference in calcium content resulting from these two materials might have an even more marked effect on the tree, indirectly through cover crop stimulation.

Analyses of the tree roots after the first year's fertilization indicated that the nitrogen from sodium nitrate was taken up the most rapidly of the three materials, with Cyanamid being slightly slower than ammonium sulfate. The nitrogen from the two latter materials continued to be absorbed from fall applications throughout the winter and into late spring with little if any difference in this respect between the two. The following year the relation between Cyanamid and ammonium sulfate was about the same, but the carry-over effect probably accounted for the greater rate of absorption of nitrogen in the fall from these fertilizers than from sodium nitrate. The evidence shows that as long as the soil is not frozen, the roots remain active and may absorb nitrogen throughout the winter.

The rapidity with which nitrogen was absorbed from Cyanamid and ammonium sulfate and the small amounts of nitrates that were produced, indicate that apple trees growing in this soil of pH 6 can use the ammonium form of nitrogen and nitrification is not necessary. This is in agreement with the work of Tiedjens and Blake (52) and Tiedjens and Robbins (53), who found that ammonia is utilized best at the higher pH values. It does not agree with Davis' work (14) who failed to take the reaction of the medium into account. This evidence indicates that on soils of this kind the nitrification rates are not necessarily a measure of a nitrogen fertilizer value.

Extreme care in taking samples and making analyses was necessary to obtain consistent differences in the nitrogen content of leaves and twigs and the amounts of growth made. It is but natural to expect variations of the tissues used and only a general trend seems of value in interpreting the results. The expression of data on a quantity as well as on a percentage basis is desirable, as frequently the "diluting effect" of increased growth on the quantity of nitrogen present in a given tissue seems to mask existing differences. Results from the analyses of various parts of the tops have been quite valuable in interpreting results. It has been possible to correlate the tissue analyses with the transformation of the fertilizers in the soil and their absorption by the roots. It appears that when any of the three fertilizers are applied under favorable weather conditions either in spring or fall the results will be satisfactory.

In general, the nitrogen taken up and the growth made by the trees does not agree in all instances with the findings of others (2) (47) (54). The results indicate that fall applications of sodium nitrate have been superior to spring, and the difference between sodium nitrate and ammonium sulfate has been small. Cyanamid has given quite satisfactory results, with the greatest response from this material being secured from fall applications, when conditions were favorable for its decomposition.

The value of a source of nitrogen or the best time for its application would seem to be influenced greatly by the soil type on which it is used or the kind of orchard management that is practiced. This has been shown by numerous studies of sod and clean culture management. It is obvious that many factors enter into the utilization of the various forms of nitrogen by apple trees, and practically every locality will present a different problem. Undoubtedly the soil type, climatic conditions or some other factor was responsible for the difference in response reported here, of which the climate probably was of the greatest importance.

There seems to be no property of Cyanamid or characteristic of its behavior to disfavor its use as an orchard fertilizer. It is by no means as safe in the hands of the inexperienced, as sodium nitrate and ammonium sulfate, and some precautions must be exercised in its use. It is evident that if care is taken to make Cyanamid applications when there is present an abundance of soil moisture, better results will be secured. Under these conditions, fall applications of nitrogen have been highly satisfactory.

SUMMARY

1. Determinations of ammonia and nitrate nitrogen at different soil depths were made as a means of following the transformations and movement of nitrogen from sodium nitrate, ammonium sulfate and Cyanamid, when broadcast under apple trees growing in sod, at two times each in the fall and spring seasons. Rates of absorption of nitrogen by the roots, the amount taken up by the bluegrass and the quantity present in branches and leaves were determined on samples taken at specific intervals.

2. Downward movement of nitrogen from sodium nitrate was more rapid in the fall than in the spring. This penetration enabled the trees to secure more nitrogen from the fall applied nitrate, and consequently to make greater growth.

3. Under high moisture conditions, the decomposition of Cyanamid and accumulation of ammonia was rapid. There was little penetration of the cyanamide ion, since it was changed to urea and ammonia in the surface soil and the nitrogen which moved downward was in the ammonia or in the nitrate form.

4. A significant soil penetration of ammonia from Cyanamid and ammonium sulfate took place when there was an abundance of moisture after the fertilizers were applied. Only a slight differ-

ence in the rate of movement of ammonia from these two sources was observed.

5. There was little difference in the rates of nitrification of Cyanamid and ammonium sulfate, but the rapid absorption of nitrogen by the trees from these materials indicates that this transformation may not be necessary.

6. The total amount of soluble nitrogen remaining in the soil receiving Cyanamid decreased more rapidly than where nitrate or sulfate was applied.

7. The quantity of ammonia present in the soil during May and June from fertilizer applications of the previous fall was greater from ammonium sulfate than from Cyanamid. There is the possibility that nitrogen from Cyanamid has been made temporarily insoluble, from which condition it may be released.

8. Cyanamid and ammonium sulfate nitrogen were not taken up by apple trees as rapidly as the nitrate form, but the absorption continued for a much longer period. There was no great difference in this respect between Cyanamid and sulfate of ammonia.

9. Sod was a serious competitor for nitrogen applied in the spring. This was in part responsible for the efficient utilization of nitrate of soda applied in the fall, and the good results obtained from spring applications of Cyanamid, which has a temporary caustic effect on grass.

10. Differences in growth and nitrogen present in the developing parts of the fertilized trees were small, but a correlation of the general trends in this direction with soil changes was found valuable in interpreting results.

11. Fall applications of all three sources of nitrogen gave equally good, if not better, results than spring applications.

12. Cyanamid was fully as efficient in supplying nitrogen as were sulfate of ammonia and nitrate of soda when applied under favorable climatic and soil moisture conditions. It should be used preferably in the fall, and care should be taken to make applications when there is an abundance of moisture.

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